Lidar observations of fine-scale atmospheric gravity waves in the nocturnal boundary layer above an orchard canopy

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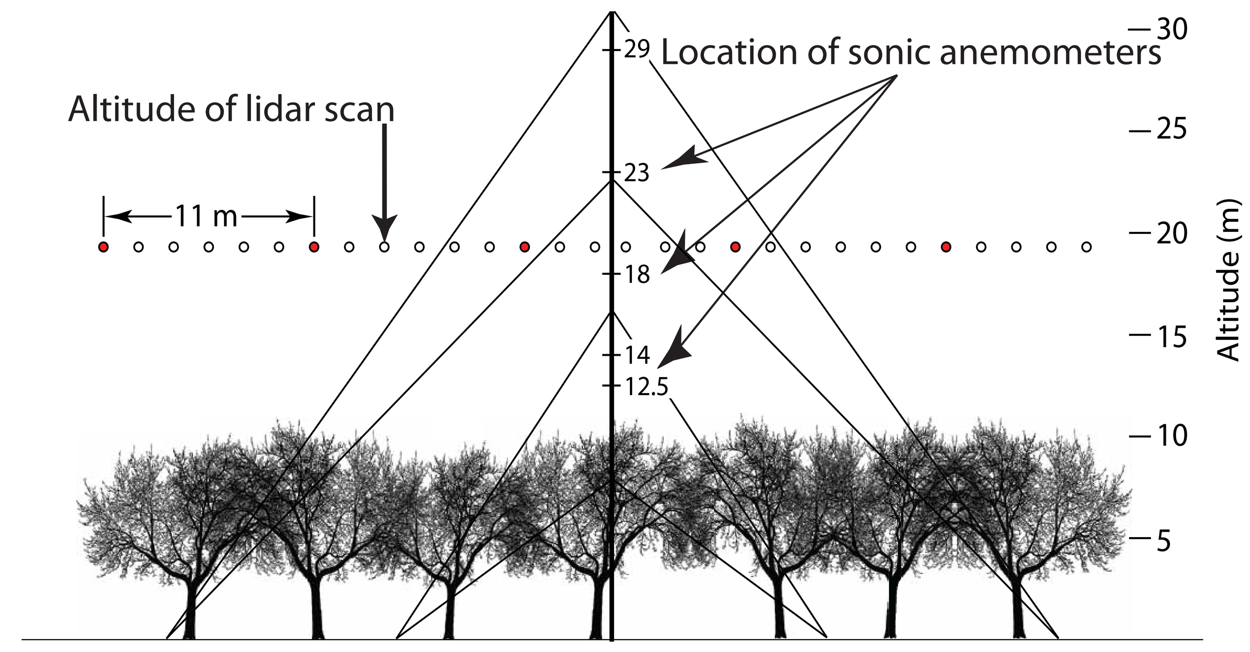
Experiment: Canopy Horizontal Array Turbulence Study (CHATS)

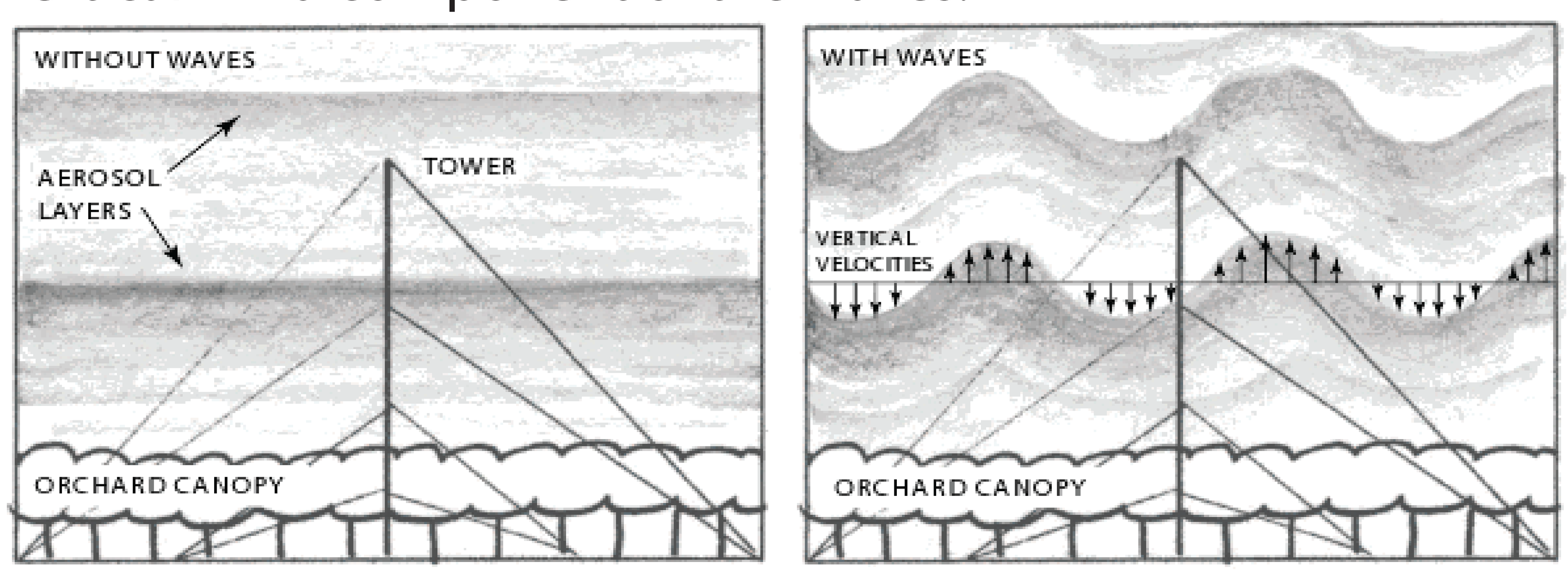
REAL System Specifications:
Wavelength: 1.543 µm
Pulse energy: 170 mJ
Pulse rate: 10 Hz
Pulse length: 6 ns
Beam diameter at lidar: 66 mm ($1/e^2$ points)
Beam divergence: 0.24 mrad (full angle)
Telescope diameter: 40 cm
Receiver field of view: 0.54 mrad (full angle)
Digitizer speed: 100 MSPS
Digitizer range: 14 bits
Detector type: 200-µm InGaAs APD



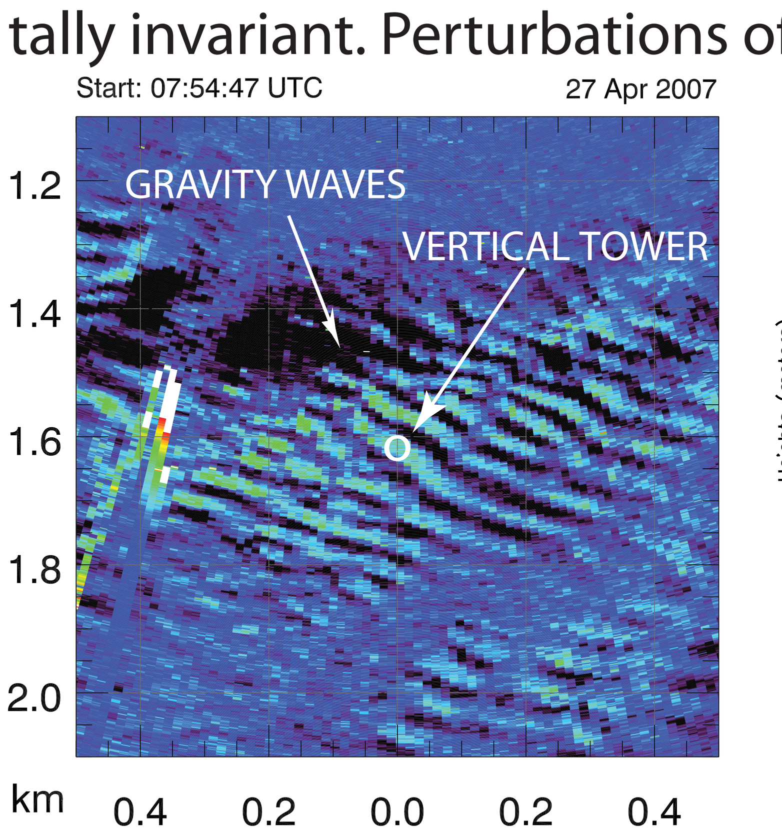
CHATS took place in Dixon, California from 15 March through 11 June 2007. A 30 m vertical tower equipped with 13 sonic anemometers was installed in the orchard. The Raman-shifted Eye-safe Aerosol Lidar (REAL) was located 1.61 km north of the tower and collected data nearly continuously in the area surrounding the tower and orchard. The REAL provides two-dimensional spatial images of aerosol backscatter intensity often revealing coherent structures such as plumes and waves. During the three months of data collection, the lidar observed 52 episodes of fine-scale gravity waves above the canopy in the stable nocturnal boundary layer.

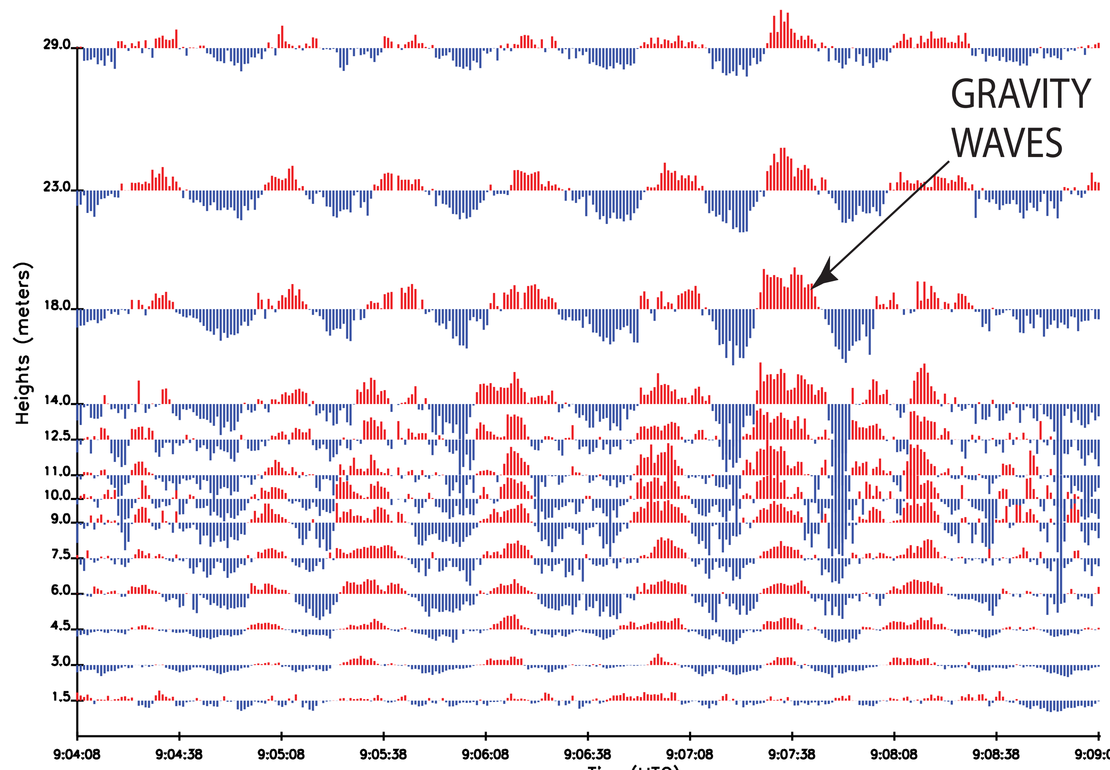
Q: Why can the REAL detect these waves?

A: We hypothesize that aerosol strata are displaced by the vertical wind component of the waves.



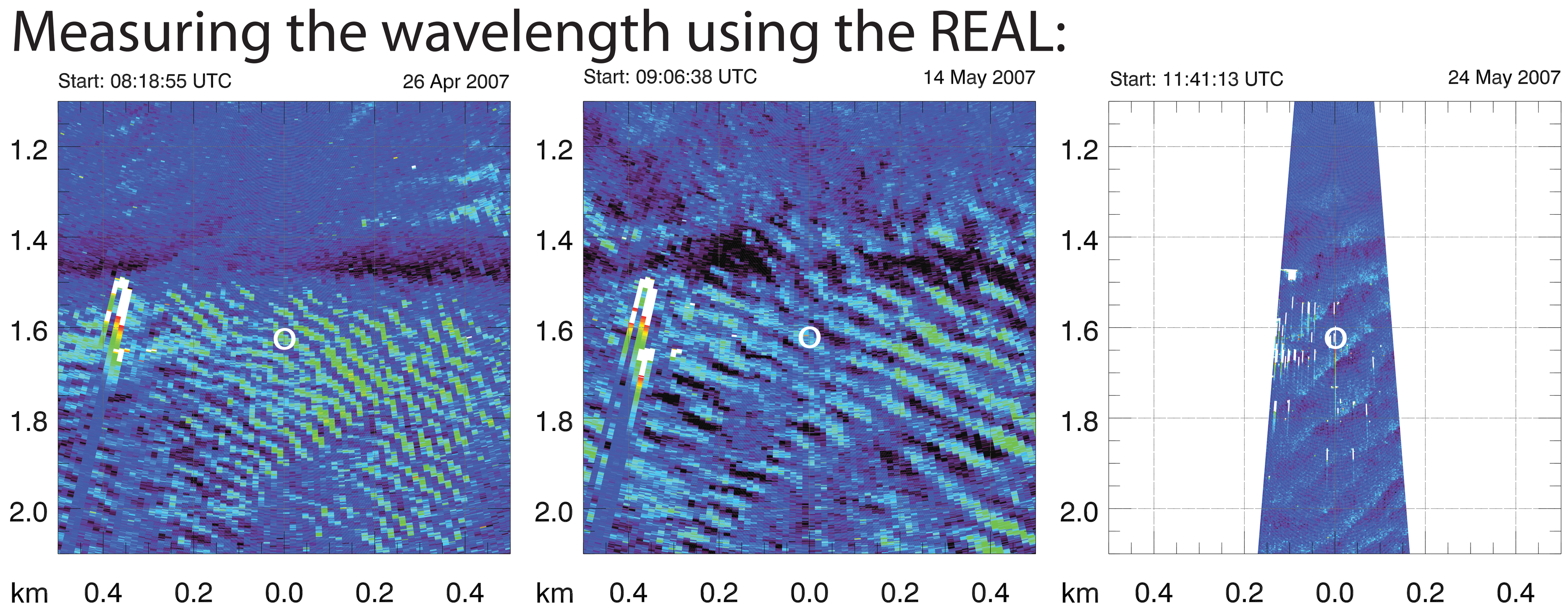
Vertical cross section of the lower atmosphere that may occur at night during quiescent conditions. Stable stratification and weak flow result in the formation of vertical gradients of aerosol backscatter that are horizontally invariant. Perturbations of these strata can form waves.





Time series of the vertical wind component show how gravity waves (as observed in the figure above right) can vertically displace the horizontal aerosol strata and enable the elastic backscatter lidar to observe the wave structure in a near-horizontal plane. Coherent oscillations of the vertical component of air motion in the anemometer data support our hypothesis that aerosol strata are displaced by the vertical wind component.

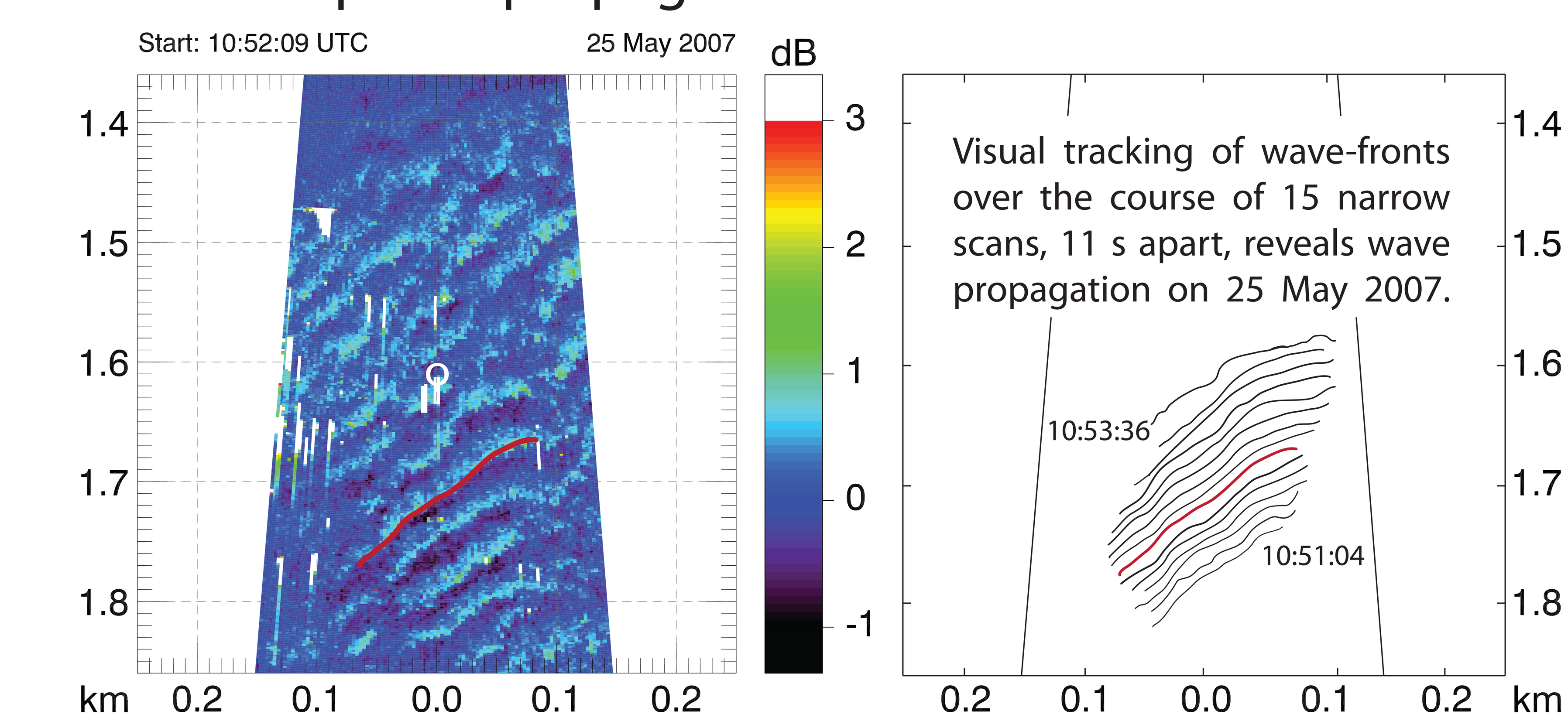
Measuring the wavelength using the REAL:



The REAL has the unique capability to measure the spatial extent of these waves. The wavelength is a measurable quantity that can be identified for all 52 cases. The wavelengths range between 40 m (above left) and 100 m (above right).

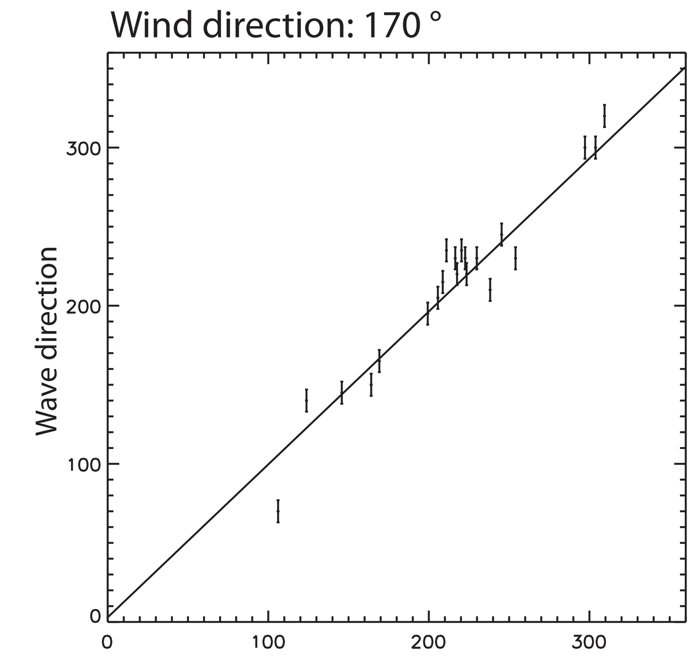
Q: What controls the phase propagation direction of the waves?

A: We hypothesize that the mean horizontal wind direction controls the phase propagation direction of the waves.



In each case, we can identify the wave-fronts from the lidar scans (above left). Using the visual tracking technique, we can identify the wave phase speed and propagation direction (above right). We can compare these values with values collected from the anemometers on the tower.

Lidar-derived wave properties
Wavelength: 40 m
Phase speed: 0.92 m/s
Propagation direction: 165 °
Sonic anemometer measurements
Period: 50 s
Wind speed: 1.58 m/s
Wind direction: 170 °



There are 22 cases where the time between scans is fast enough to accurately determine the wave phase direction. The graph (below left) shows the relationship between the propagation direction of the waves versus the wind direction in degrees for these 22 cases. The strong correlation between the wave propagation direction and wind direction supports our hypothesis that the waves are carried by the wind. Similarly, we expect the mean wind speed to control the wave phase speed. Comparison of wind speed and wave propagation speed is ongoing.

Future Research:

This poster presents our first examination of the characteristics of waves in the CHATS data set. We plan to continue this work to determine the linkage between temperature and wind profiles and characteristics of the waves such as wavelength and wave propagation speed. We plan to use the observations to verify theoretical explanations of the cause of the waves.

More information can be found on our website: www.phys.csuchico.edu/lidar

References:

Mayor, S. D., et al., 2007: Polarization lidar at 1.54-microns and observations of plumes from aerosol generators, *Opt. Eng.*, **46**, DOI: 20.1117/12.781902.

Lee, X., 1997: Gravity waves in a forest: a linear analysis, *J. Atmos. Sci.*, **54**, pp. 2574-2585.

Patton, E. G., et al., 2011: The Canopy Horizontal Array Turbulence Study (CHATS), *Bull. Meterol. Soc.*, **92**, pp. 593-611.

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