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Seasonal Variability and Dynamics of Mesospheric Gravity Waves Over the Andes

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Introduction

The ALO is a new facility developed for atmospheric research, located at the foot of the Andes mountain range in Cerro Pachon, Chile (30.2°S, 70.7°W). As part of a collaborative program, Utah State has a Mesospheric Temperature Mapper (MTM) on site, which is used to study short period gravity wave dynamics and temperature variations in the mesosphere-lower thermosphere region. The MTM began taking measurements of the OH(6,2) and O_2(0,1) spectral bands in August 2009 and a complete profile of seasonal variation in gravity wave characteristics has been created for August 2009 through August 2010 using the OH(6,2) Band. The primary goal of this program is to

❖Quantify seasonal variability of gravity wave structures.

❖Compare and contrast seasonal directionality and characteristic variability with results from the Maui-MALT oceanic site.

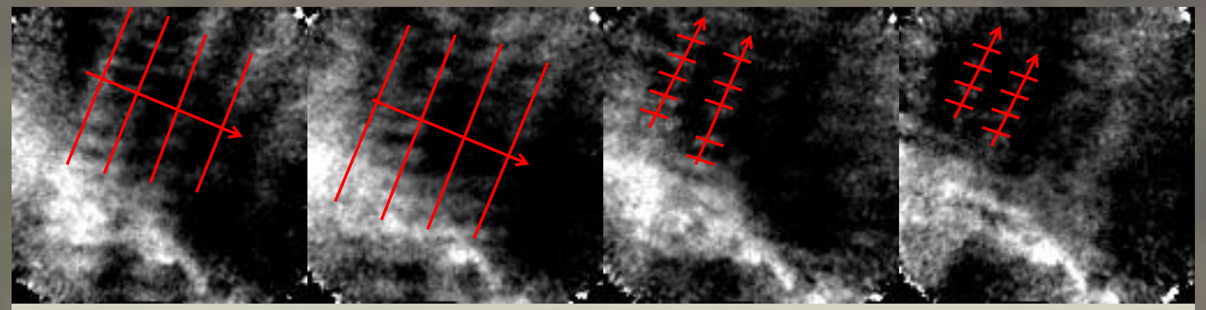
❖Quantify mountain wave observations, their frequency, images, characteristics and seasonal variability.

Seasonal variability for gravity wave structures at this site is shown. New evidence for a number of mountain wave events has been observed during the winter months. Future work includes investigating yearly repeatability, which is seen at other sites, and continued investigation of unique events occurring over the Andes mountain range.

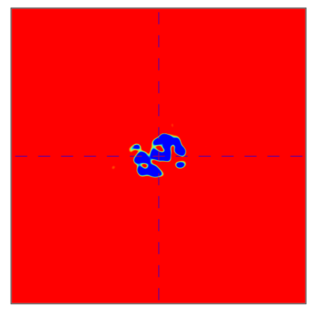
Instrumentation

The USU Mesospheric Temperature Mapper is a high quality bare CCD imager which images the OH and O_2 layers at 87km and 94km, respectively. The camera cycles through five filters, two each for the OH and O_2 layers as well as a background filter and a dark image for calibration. The gravity waves shown here were imaged in the OH rotational lines $P_1(2)$ and $P_1(4)$ of the (6,2) band. The 1024 by 1024 pixel array is binned into 8 by 8 blocks resulting in a 128 by 128 pixel image for high signal to noise temperature mapping. Cycle time for OH and O2 sequence is 6 minutes. The resulting images are then further processed for the measurement of gravity waves, as described below.

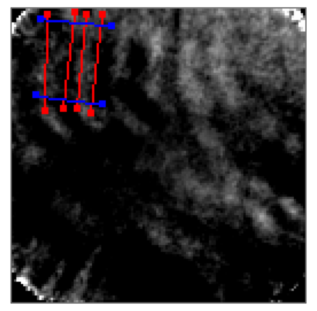
Example Data and Analysis



Two simultaneous events imaged in the OH layer in February, 2010. In all four images small scale ripples can be seen propagating along the length of the bands. Bands are highlighted in the left two images, while ripples are highlighted in the right two. The Milky Way can be seen in the lower left of the image.



Unambiguous fast Fourier transform



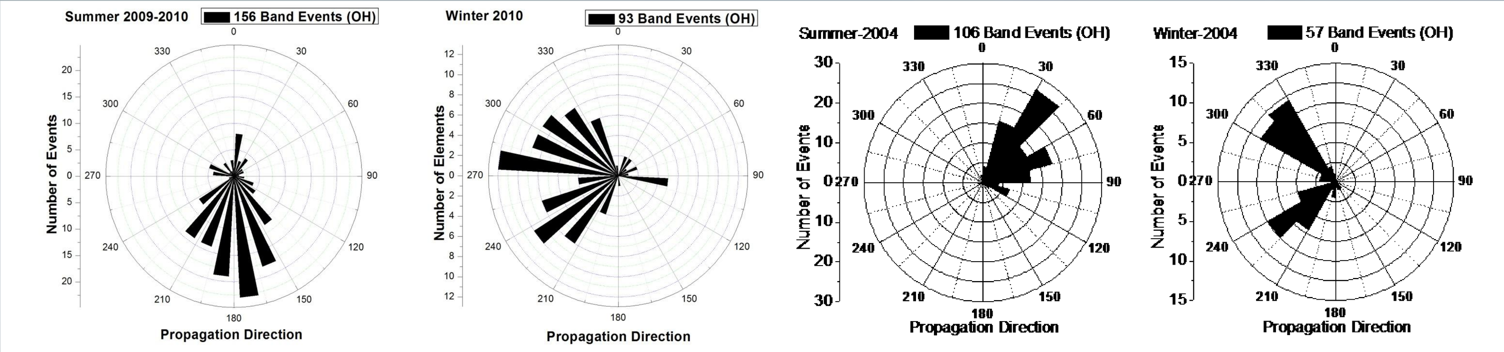
Measuring horizontal phase speed

Raw images from the MTM imager must be processed before measurements can be taken (Garcia et. al. 1997).

- ❖ Stars and hot pixels are removed
- ❖ The set of nightly airglow images and dark images are both averaged.
- ❖ Average images are used to flat-field each image in the set, Using the dark average as an intensity baseline and dividing out the average airglow intensity, allowing events near the edge of the image to be seen and measured.
- ❖ Images are calibrated to align the top edge of the image to due north
- ❖ Images are un-warped, mapping points imaged on the surface of a sphere to a rectilinear coordinate system, allowing for accurate measurement of wavelengths and velocities.
- ❖ An unambiguous fast Fourier transform method is used to find the wavelength and direction of propagation (top)
- ❖ Average horizontal phase velocities for four images are measured. A total of six measurements are taken for each event and the standard deviation of the mean is found.

The Andes Lidar Observatory is located on Cerro Pachon in the Coquimbo region of Chile. Above is a view of the ALO amongst the mountains of the Andes range. To the right is a map of Chile with Cerro Pachon marked for reference.

Wave Propagation Profiles

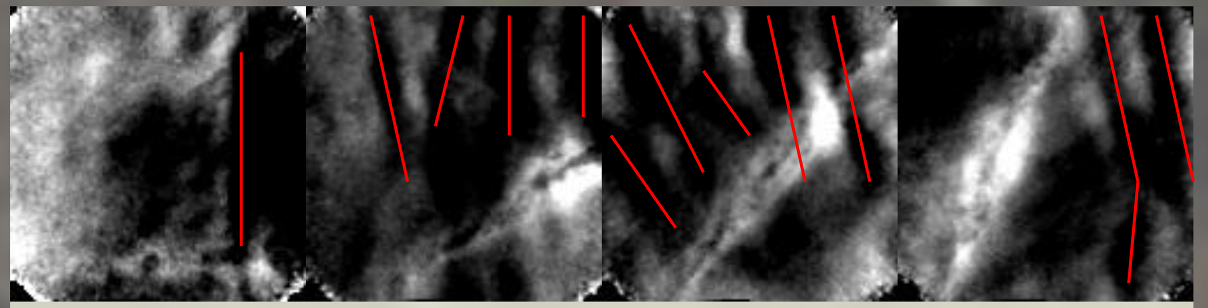


Directional profiles for regular band structures in summer (left) and winter (center left) for the Cerro Pachon mountain site. Bands in the summer season (November through February) show a clear preference for propagation to the south. The winter season (May through August) shows a clear preference for propagation to the west. Gravity wave events with low velocities (mountain wave candidates) have been removed. Transitional months in the spring (September, October) and the fall (March, April) show no clear preference in direction.

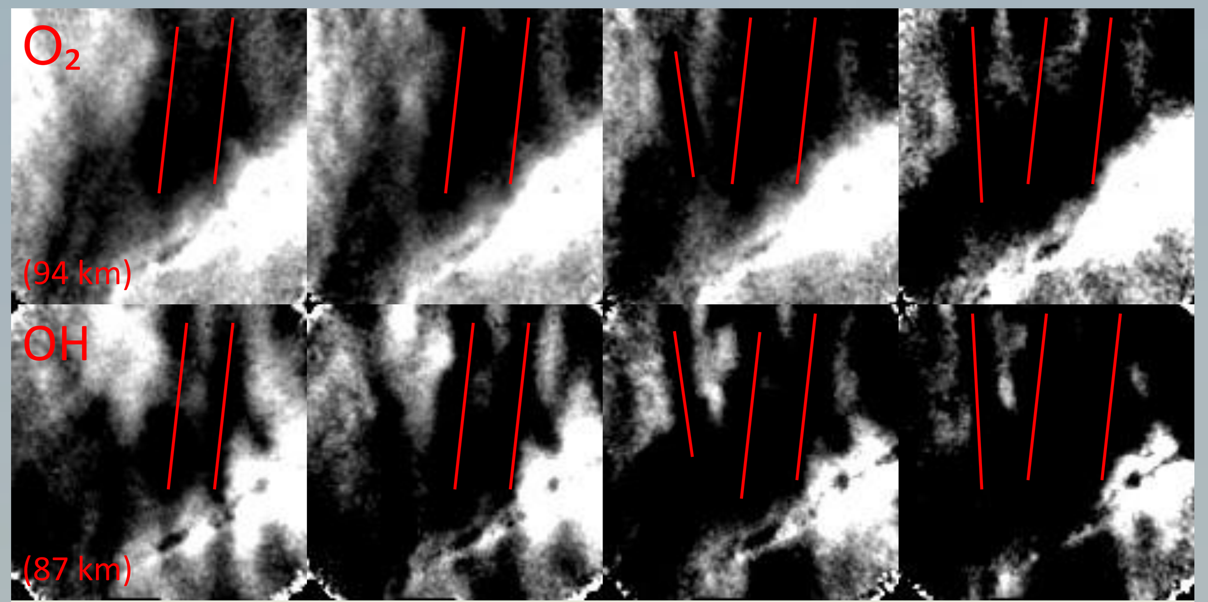
Prior to being located in Cerro Pachon, the CEDAR USU Mesosphere Temperature Mapper operated at the Maui-MALT site in Hawaii. Band events for the summer (center right) and winter (right) seasons in 2004 are shown. During the Maui-Malt campaign seasonal band directionality was regularly northeast during the summer season and bi-modally west during the winter (northwest, southwest). Both data sets show evidence of east-west wind filtering as the seasons change. As more data is collected at the Cerro Pachon site, it is expected that yearly regularity will be observed as it was at the Maui-MALT site.

Mountain Waves

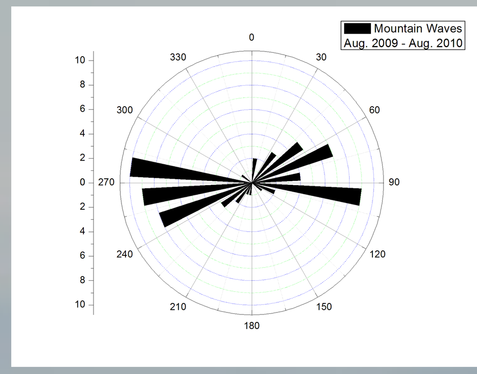
Mountain waves are standing gravity waves caused by orographic forcing. They occur when a strong wind flows over a large geographic uplift such as a mountain range (sketch, top left). Mountain waves are commonly observed in the troposphere and are known to reach as high as the stratosphere. Under the right conditions mountain waves could reach higher altitudes, and have recently been observed for the first time at altitudes as high as 90 km (Smith et. al. 2009). An aerial photo of a tropospheric mountain wave is shown (center left). Below is a candidate for a mountain wave in the OH layer at 87km altitude.

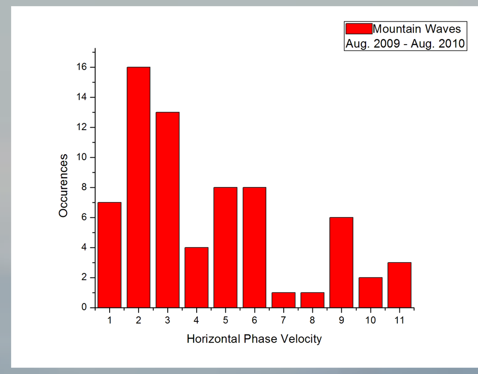


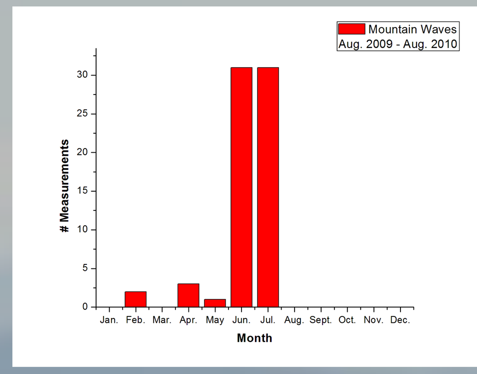
Images of a candidate mountain wave event taken in July 2010 with a duration of nearly 6 hours. During this event bands moved back and forth along an axis perpendicular to their wave-fronts. For clarity, wave troughs are depicted by red lines. Measurements taken yielded an average horizontal phase speed for these structures below 5m/s.



Sequential images of gravity waves in the OH layer and O_2 layers. Images show similar slow moving, nearly north-south aligned structures in the same positions, which suggests orographic forcing as their cause. Contrast has been enhanced and troughs are marked for clarity.







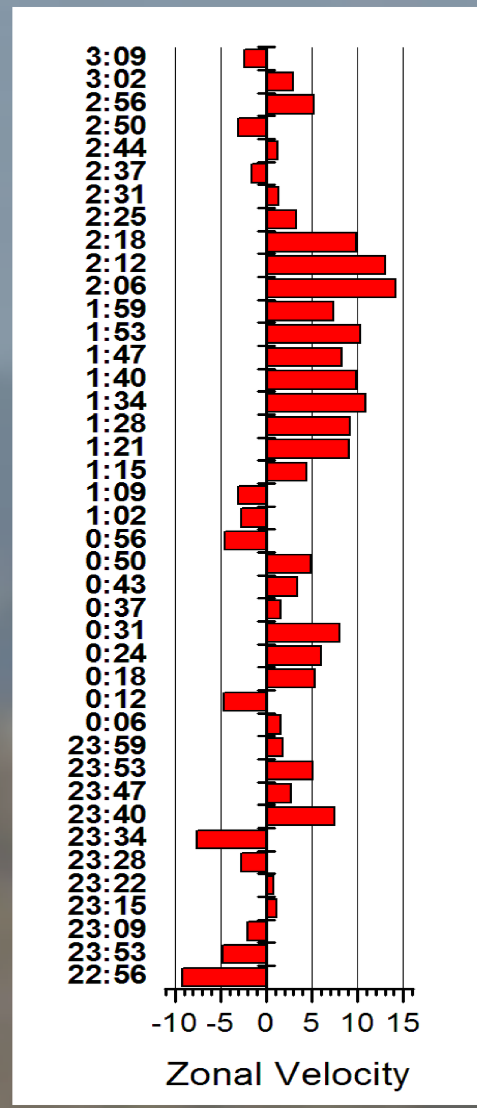
Mountain waves are commonly seen in the troposphere and stratosphere, but have only recently been observed in the mesosphere, with the first sighting by Smith et. al. in 2008. For the year 2009-2010 a total of 68 low velocity (<5m/s) events (plotted above) were recorded. The majority of these took place in June and July of 2010, when strong eastward winds prevail. It is thought that mountain waves result, and the unique conditions at Cerro Pachon allows them to propagate up into the MLT region.

Above Left: Propagation direction profile for mountain wave events above Cerro Pachon Chile for the year 2009 – 2010. Propagation direction has a strong East-West preference, which is expected from mountain waves aligned parallel to the Andes mountain range.

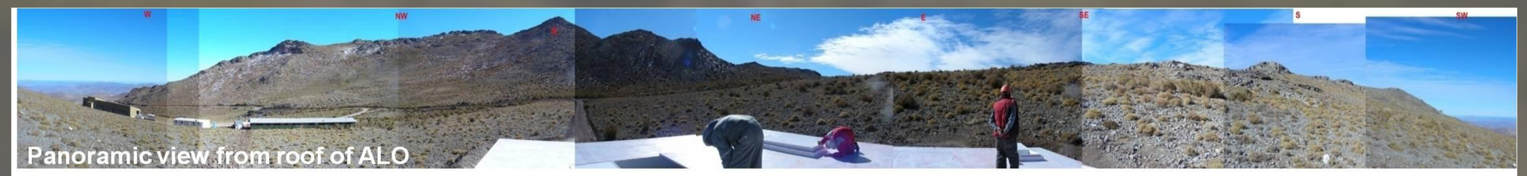
Above Center: Mountain wave velocities for the year 2009-2010. A theoretical stationary wave like a mountain wave is in reality expected to be characterized by low and variable horizontal phase speeds.

Above Right: Low velocity wave events appear almost exclusively in June and July.

Right: Running average of zonal velocities for a low velocity wave event in June 2010. The entire event lasted for 3.25 hr with no interruptions. This variation may be typical for mountain waves. Average zonal velocity for the event was 3m/s eastward.



Summary



One year of analysis of gravity wave events over Cerro Pachon shows strong seasonal preference to the west during the winter months and south during the summer. At other sites preferential headings repeat annually corresponding with the seasons and it is expected that this will be the case in Cerro Pachon. New evidence for mountain wave events in the mesosphere have been observed in the winter months of June and July. These events have low horizontal phase velocities of 5 m/s or less on average. These events have a clear east west directional preference, aligned with the Andes. Zonal directions for select events frequently change back and forth from eastward to westward, exhibiting behaviors expected of "stationary" mountain waves.

Future work: will include profiles for subsequent years to investigate the seasonal regularity of gravity waves at this site. Additional investigations of mountain wave events in the mesosphere, uniquely observed at the Andes mountain range, will be continued to better quantify and identify their characteristics. Tropospheric wind measurements for the area will be used to investigate and understand the causes for the seasonal variations observed. Ducted wave events will be analyzed in a similar way.