ECE Illinois

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

Measurements of phase differences between temperature and vertical wind perturbations associated with gravity waves in the mesopause region

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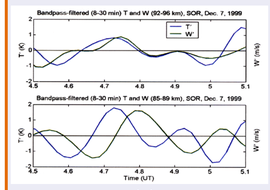
ABSTRACT:

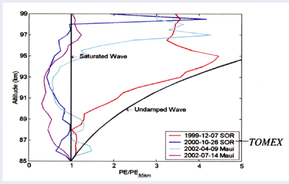
The study of the phasing of atmospheric gravity wave (AGW) temperature and vertical wind perturbations (T' and w') in the mesopause region as illustrated by Swenson et al. (2003) used correlative measurements of temperature and vertical wind from Na lidar and airglow brightness (OH and O_2). The data shows the phase relation between T' and w' parameters and heat flux as described by Guo et al. (2017) for damped gravity waves. The measurements enable studies of wave state, i.e. freely propagating or damped. Data from the Andes Lidar Observatory (ALO) on Cerro Pachón, Chile (30.25° S, 70.74° W) Na wind/temperature lidar are sufficient to resolve gravity wave T' vs w' phase differences with altitude. Phase data from two nights are presented along with T', w', and convective/dynamical instability data (where available) for each night to provide a more comprehensive picture of the gravity wave effects.

WAVE DAMPING



(a)

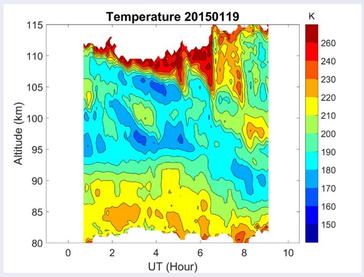
Swenson et al. (2003) showed that the relative phase between T' and w' affects wave potential energy. If T' and w' are in phase, the wave is "saturated" and the potential energy remains approximately constant with increasing altitude. If T' and w' are in quadrature, however, the wave is freely propagating and the potential energy will increase accordingly. A damped wave (phase between 0 and quadrature) thus dissipates some of its energy to the surrounding atmosphere. Figure (a) shows the approximate phase progression from lower altitudes (bottom) to higher altitudes (top) of a wave measured on December 7, 1999 at Starfire Optical Range in Albuquerque, NM. The wave is freely propagating at lower altitudes, as can be seen in the increasing red potential energy line of Figure (b). Around 92-96km, T' and w' are in phase, and the potential energy becomes constant.

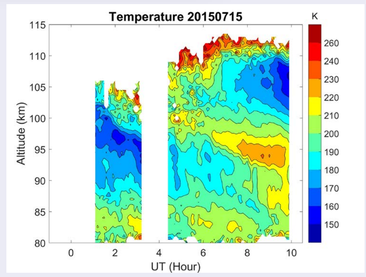


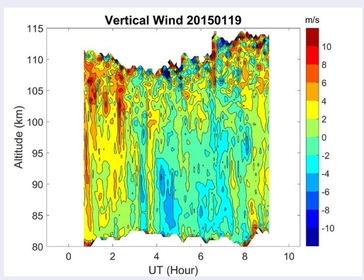
(b)

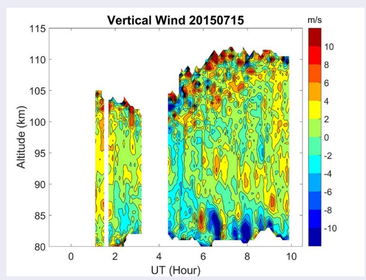
Citation: Swenson, G. R., Liu, A. Z., Li, F., & Tang, J. (2003). High Frequency Atmospheric Gravity Wave Damping in the Mesosphere., *Advances in Space Research, Vol. 32, Issue 5,* doi:10.1016/S0273-1177(03)00399-5

LIDAR OBSERVATIONS



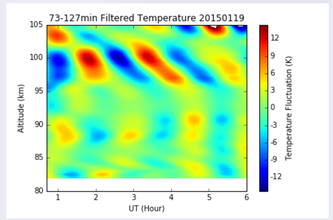


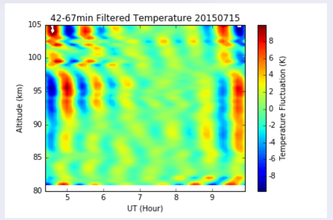




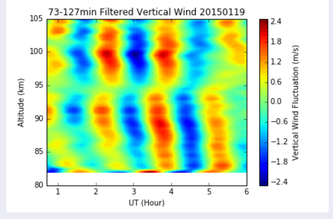
Lidar measurements of temperature and vertical wind speed for the nights of January 19, 2015 (left) and July 15, 2015 (right). Zonal and meridional (3-D) winds were also measured for 20150715. These data were collected by the Na Doppler lidar system located at Cerro Pachón, Chile (30.25° S, 70.74° W).

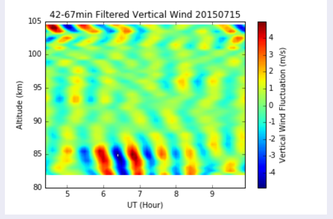
GRAVITY WAVE PERTURBATIONS



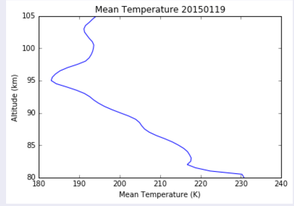


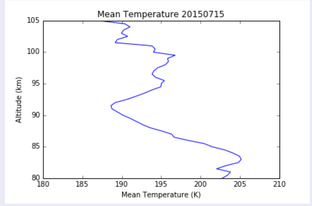
T'





w'

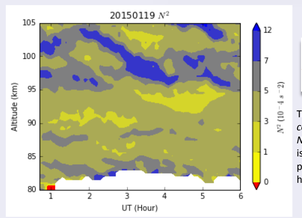




Mean T

Bandpass-filtered temperature and vertical wind data (T' and w') for 20150119 (left) and 20150715 (right). The bandpass centers (approx. 100 minutes and 54 minutes, respectively) were determined by corroborating high-frequency spectral peak data from both airglow intensity (OH and O(^{1}S)) and the lidar observations at the approximate altitudes of the peaks of the OH and O(^{1}S) layers (87 km and 96 km, respectively). Note that the time windows for T' and w' presented here show only a portion of each full night.

INSTABILITIES



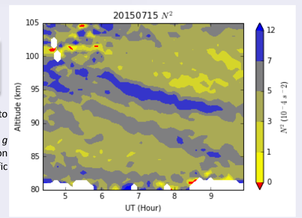
$$N^2 = \frac{g}{T}\left(\frac{dT}{dz} + \frac{g}{c_p}\right)$$

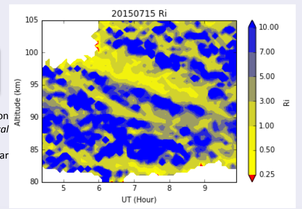
The N^2 parameter is related to *convective* stability. N is the Brunt-Väisälä frequency, g is the gravitational acceleration parameter, and c_p is the specific heat at constant pressure.

$$Ri = \frac{N^2}{S^2}$$

$$S = \sqrt{\left(\frac{du}{dz}\right)^2 + \left(\frac{dv}{dz}\right)^2}$$

The R_i parameter (Richardson number) is related to *dynamical* stability. S represents the vertical wind shear in the horizontal (u and v) winds.



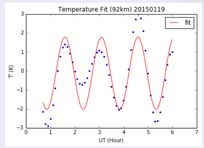


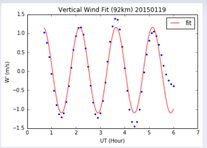
If N^2 < 0, the (negative) vertical temperature gradient is larger than the dry adiabatic lapse rate g/c_p (which is approximately 10 K km^{-1}). This condition is a good indicator of convective instability. A large value of N^2 thus indicates a convectively stable portion of the atmosphere.

Likewise, the value of the Richardson number R_i can also give an indication of atmospheric stability: a value of R_i < 0.25 traditionally indicates the onset of turbulence, and a large value of R_i indicates a dynamically stable portion of the atmosphere. Note: R_i data for 20150119 is unavailable because horizontal winds were not measured.

Citation: Li, F., A. Z. Liu, and G. R. Swenson (2005), Characteristics of instabilities in the mesopause region over Maui, Hawaii, *J. Geophys. Res., 110*, D09S12, doi:10.1029/2004JD005097.

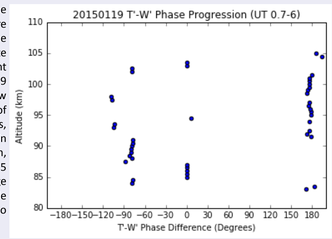
T' VS w' PHASE MEASUREMENTS

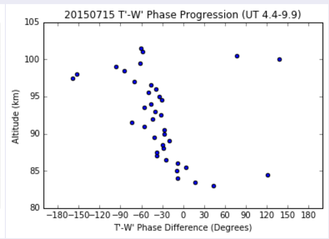




To extract phase information from the ALO T' and w' data, a sinusoid was fit to both T' and w' at each altitude in 0.5 km steps. The fit period was kept the same for T' and w' so that their phase angles could then be subtracted from each other. The figures to the left show example fits for the night of 20150119 at 92 km, the approximate altitude of maximum signal. The T'/w' perturbations are the blue dots, and the fit is shown by the red curve.

The results of the sinusoidal fits are shown to the right. The two nights demonstrate two seemingly different cases: the 20150119 wave is in phase at low altitudes, 180° out of phase at high altitudes, and approximately in quadrature in between, while the 20150715 wave appears to change gradually with altitude from being in phase to being in quadrature.





The data provides insight into the effects of the background atmosphere on AGWs in the mesopause region. These effects influence the degree of saturation, damping, and the heat flux associated with quasi-monochromatic AGWs.

Citation: Guo, Y., A. Z. Liu, and C. S. Gardner (2017), First Na lidar measurements of turbulence heat flux, thermal diffusivity, and energy dissipation rate in the mesopause region, *Geophys. Res. Lett., 44*, doi:10.1002/2017GL073807.

SUMMARY:

-Two nights of lidar measurements of temperature and vertical wind from Andes Lidar Observatory on Cerro Pachón, Chile (30.25° S, 70.74° W) are presented

-The temperature and vertical wind data were bandpass filtered to produce T' and w' perturbations; the bandpass centers were determined by corroborating spectral peak data from the lidar measurements and OH/O(^{1}S) airglow intensity

-Convective (and dynamical, where available) instability data for the two nights is provided to characterize the background atmosphere

-The relative phase of T' and w' is related to wave state, i.e. freely propagating or damped

-The T' and w' perturbations were fit to a sinusoid in altitude steps of 0.5 km to obtain phase information. The phase angles were then subtracted to obtain the progression of phase difference with altitude. On 20150119, the wave is in phase at low altitudes, 180° out of phase at high altitudes, and in quadrature in between. On 20150715, the wave changes gradually with altitude from being in phase to being in quadrature.

-The data provides insight into the effects of the background atmosphere, which influence the degree of saturation, damping, and heat flux associated with quasi-monochromatic AGWs.

ACKNOWLEDGEMENTS:

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Also, thank you to Alan Liu for creating the T and w plots on the ALO website (http://lidar.erau.edu/data/nalidar/index.php).

REFERENCES:

-Swenson, G. R., Liu, A. Z., Li, F., & Tang, J. (2003). High Frequency Atmospheric Gravity Wave Damping in the Mesosphere., *Advances in Space Research*, *Vol. 32*, *Issue 5*, doi:10.1016/S0273-1177(03)00399-5

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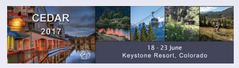

MLT Gravity Waves