ECE ILLINOIS

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

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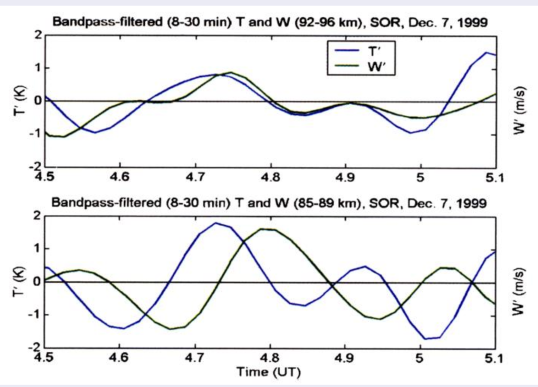
ABSTRACT:

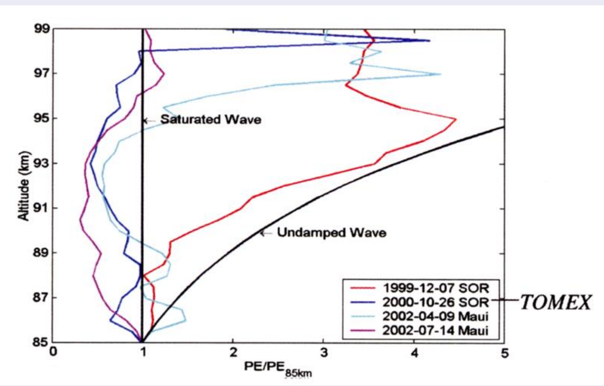
The study of the phasing of atmospheric gravity wave (AGW) temperature and vertical wind perturbations (T' and w') in the mesopause region as illustrated by Swenson et al. (2003) used correlative measurements of temperature and vertical wind speed from Na lidar and airglow brightness (OH and O^1S). The data show 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. T' vs w' phase differences for short-period (1-6 hours) gravity waves are obtained for two nights of data. Similar analysis on many more nights should provide insight into the climatology of gravity wave propagation state in the mesosphere.

WAVE DAMPING



(a)

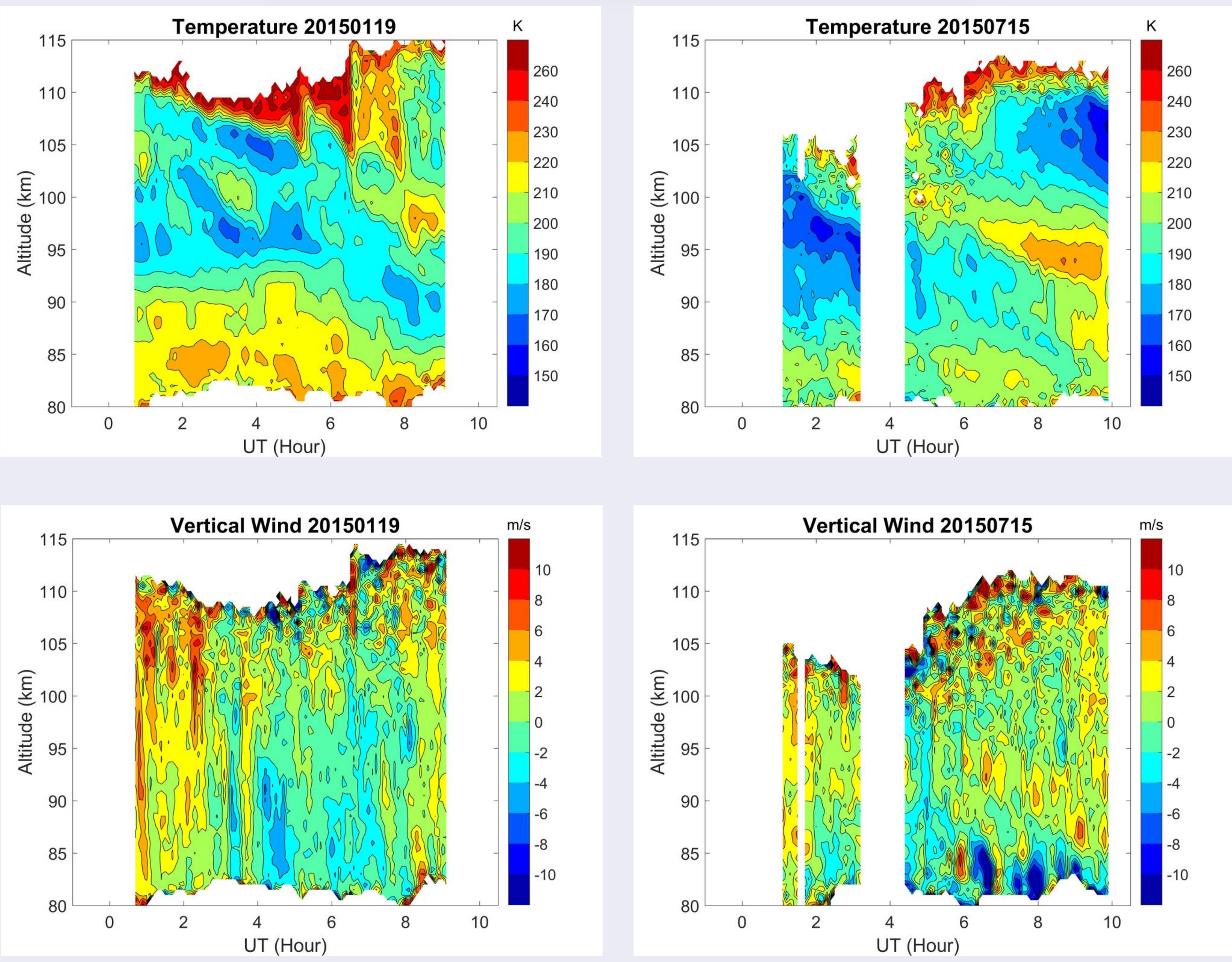
Swenson et al. (2003) showed that the relative phase between T' and w' affects wave potential energy. If T' and w' are in phase, the wave is "saturated" and the potential energy remains approximately constant with increasing altitude. If T' and w' are in quadrature, however, the wave is freely propagating 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)

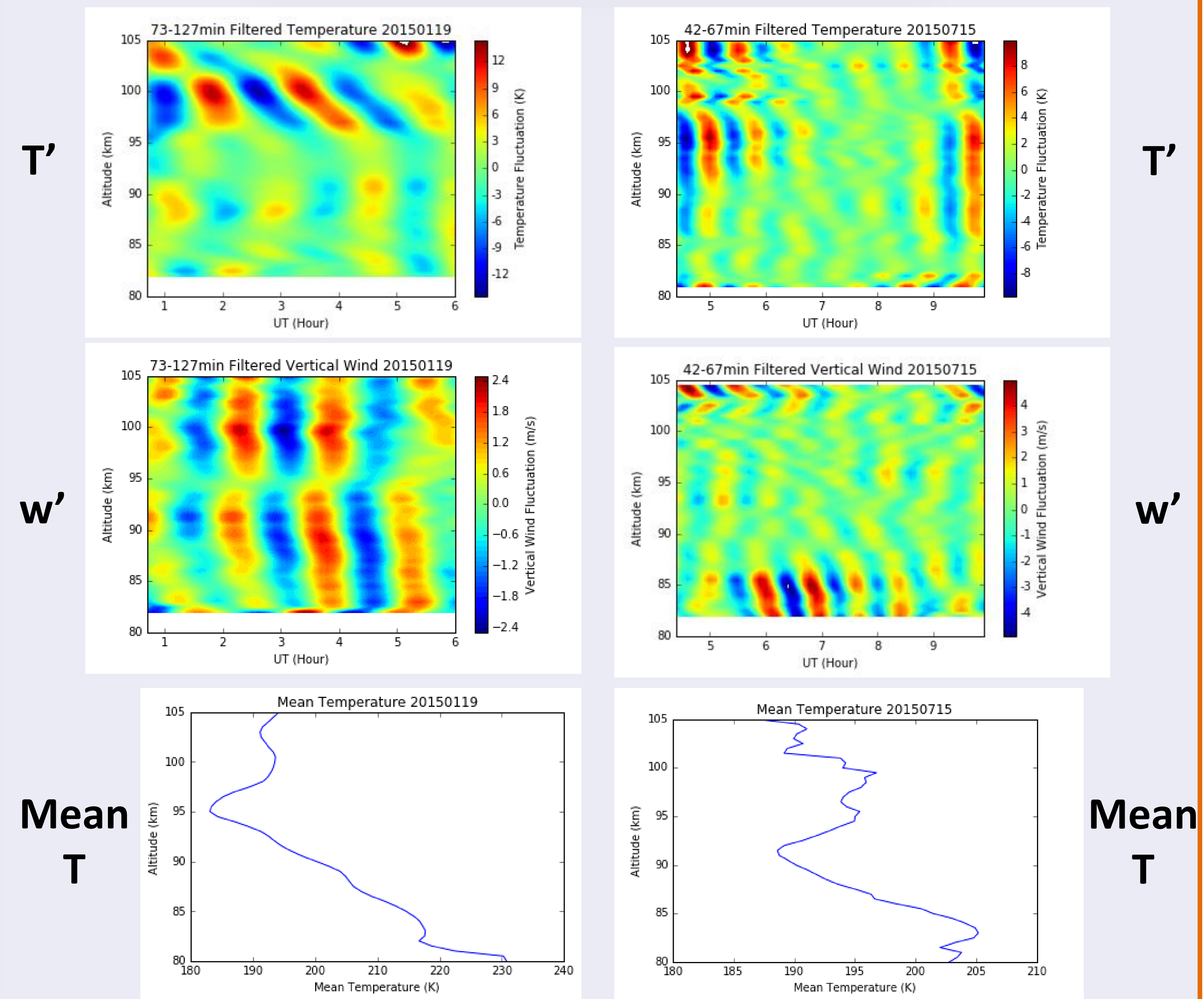
Citation: Swenson, G. R., Liu, A. Z., Li, F., & Tang, J. (2003). High Frequency Atmospheric Gravity Wave Damping in the Mesosphere., *Advances in Space Research*, *Vol. 32*, *Issue 5*, doi:10.1016/S0273-1177(03)00399-5

LIDAR OBSERVATIONS



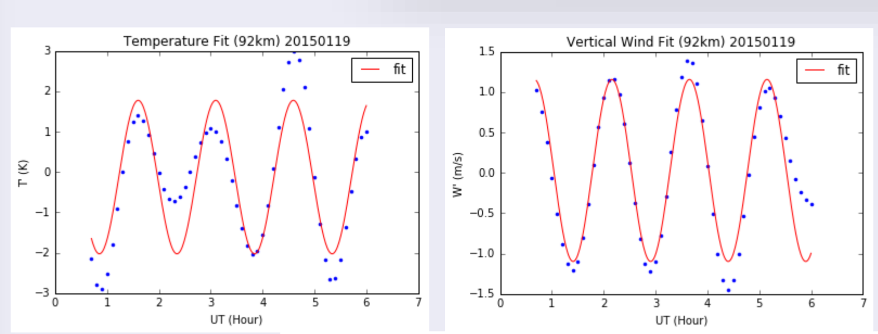
Lidar measurements of temperature and vertical wind speed for the nights of January 19, 2015 (left) and July 15, 2015 (right). Zonal and meridional (3-D) winds were also measured for 20150715. These data were collected by the Na Doppler lidar system located at Cerro Pachón, Chile (30.25° S, 70.74° W).

GRAVITY WAVE PERTURBATIONS



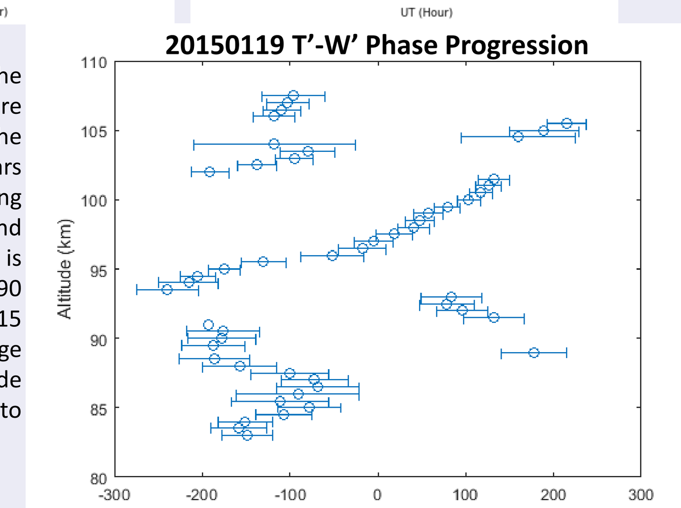
Bandpass-filtered temperature and vertical wind data (T' and w') for 20150119 (left) and 20150715 (right). The bandpass centers (approx. 100 minutes and 54 minutes, respectively) were determined by corroborating high-frequency spectral peak data from both airglow intensity (OH and $O(^1S)$) and the lidar observations at the approximate altitudes of the peaks of the OH and $O(^1S)$ 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.

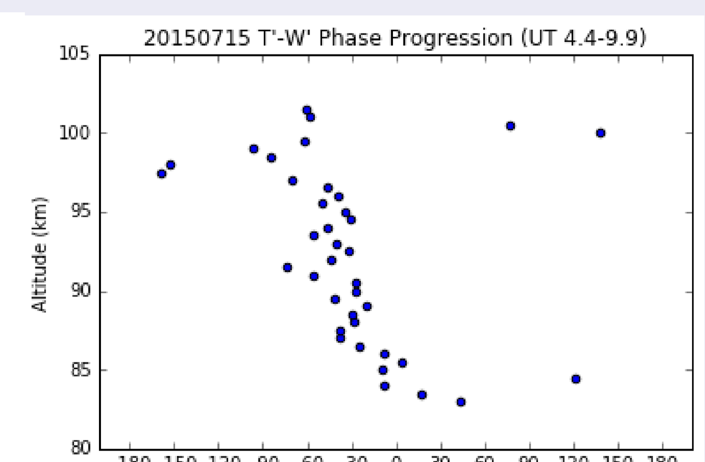
T' VS w' PHASE MEASUREMENTS



To extract phase information from the T' and w' perturbations, 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 altitude of maximum SNR. The T' or 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 20150119 wave appears to be freely propagating around 85-90 km and 97-100 km and is saturated around 90 km, while the 20150715 wave appears to change gradually with altitude from being in phase to being in quadrature.





The data provide 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.

FUTURE WORK

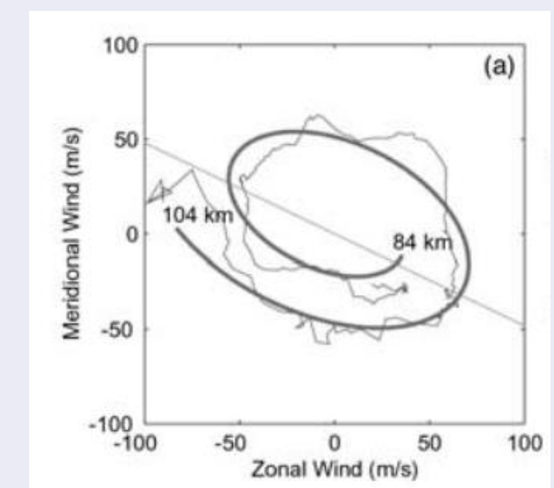
Since the goal of this research is ultimately to investigate AGW propagation state climatologically, many more waves and therefore nights of data must be analyzed. Since airglow data is not available for every night of lidar data, another method of AGW parameter extraction must be used. Fortunately, for nights with horizontal {zonal (U) and meridional (V)} wind data, there exists such a method using hodographs [Hu et al, 2002]. The model for quasi-monochromatic gravity waves is described to the right.

$$U'_m = Ue^{\beta(z-z_0)}\cos[m(z-z_0)+\theta_u],$$

$$V'_m = Ve^{\beta(z-z_0)}\cos[m(z-z_0)+\theta_v],$$

$$T'_m = Te^{\beta(z-z_0)}\cos[m(z-z_0)+\theta_T],$$

The gravity wave model used by Hu et al (2002) for the hodograph method. U' and V' are the perturbations in the zonal and meridional winds. ß is the exponential growth factor.



An example hodograph fit of zonal vs meridional wind at 3:30 UT on 19990908 from Hu et al (2002). The thick spiral is the fitted curve, and the slanted line indicates the direction of wave propagation (295.7°).

Most of the ALO lidar data from 2015 onwards has horizontal winds, so the hodograph method can be used for AGW parameter extraction. Furthermore, upgrades to be implemented to the ALO transmitting and receiving optics will ensure that high spatial and temporal resolution horizontal wind data continues to be available in the future. These upgrades include the addition of an extra 40" zenith mirror to the receiving optics and a beam splitting platform which will allow the system to make zenith and off-zenith measurements simultaneously.

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 analyzed.

-The temperature and vertical wind data were bandpass filtered to obtain T' and w' perturbations.

-The wave periods were determined by corroborating spectral peak data from the lidar measurements and OH/$O(^1S)$ airglow intensity; in the future, a hodograph method described by [Hu et al, 2002] will be used to identify and extract the AGW parameters from lidar data only.

-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 T' and w' phase angles were then subtracted to obtain the progression of phase difference with altitude. On 20150119, the wave freely propagates at lower and higher altitudes and appears to be damped in between. On 20150715, the wave appears to become gradually less saturated with altitude.

-The analysis of many more nights of data will provide insight into the effects of the background atmosphere on AGW propagation, including the degree of saturation, damping, and heat flux associated with quasi-monochromatic AGWs.

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