Space Traffic Management Conference | 2016 Emerging Dynamics

Nov 16th, 5:30 PM

Observational and Modeling Study of Gravity Wave Propagation Through Reflection and Critical Layers

Bing Cao
Department of Physical Sciences, Embry-Riddle Aeronautical University

Christopher J. Heale
Department of Physical Sciences, Embry-Riddle Aeronautical University

Alan Z. Liu
Department of Physical Sciences, Embry-Riddle Aeronautical University

Jonathan B. Snively
Department of Physical Sciences, Embry-Riddle Aeronautical University

Fabia A. Vargas
Department of Electrical and Computer Sciences, University of Illinois at Urbana-Champaign

See next page for additional authors

Presenter Information

Bing Cao, Christopher J. Heale, Alan Z. Liu, Jonathan B. Snively, Fabia A. Vargas, Gary R. Swenson, and Anthony D. Mangognia

Observational and Modeling Study of Gravity Wave Propagation Through Reflection and Critical Layers

MLTG-04

Bing Cao[1], Christopher J. Heale[1], Alan Z. Liu[1], Jonathan B. Snively[1]

1. Department of Physical Sciences, Embry-Riddle Aeronautical University

Fabio A. Vargas[2], Gary R. Swenson[2], Anthony Dominic Mangognia[2]

2. Department of Electrical and Computer Sciences, University of Illinois at Urbana-Champaign

1. Introduction

✧ Complete dispersion relation of gravity waves is written as (Nappo. 2013, Page 29)

$$m^2 = \frac{N^2}{(c-u)^2} + \frac{1}{c-u}\frac{d^2u}{dz^2} - \frac{1}{H(c-u)}\frac{du}{dz} - \frac{1}{4H^2} - k^2$$

✧ When $m^2 > 0$, gravity waves can be characterized by corresponding k and c, and are able to propagate. While $m^2 < 0$ indicates evanescence for gravity waves.

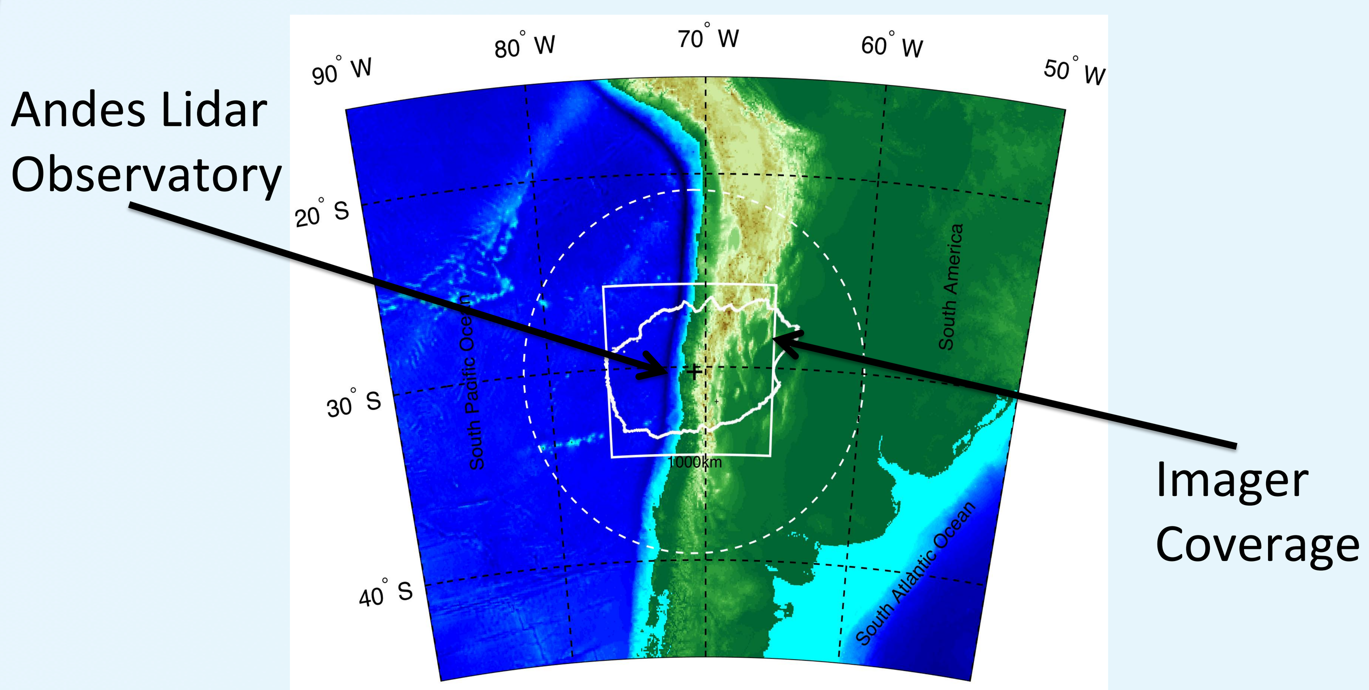
✧ When upward-propagating gravity waves encounter evanescence area, partial or total reflection can occur.

✧ When a gravity wave reaches a level at which the horizontal wave phase speed equals the background wind speed. Thus the wave meets a critical level, which leads to the wave breaking and momentum deposition in the background flow.

✧ Waves with high frequencies and small horizontal wavelengths are more likely to be reflected in the atmospheric wind field.

Co-located Temperature/Wind Lidar and Airglow Imager at Andes Lidar Observatory observed a gravity wave event undergoes both reflection and critical layer. A non-linear numerical model perfectly reproduce the wave event.

2. Data and Method



✧ An sodium Temperature/Wind Lidar was deployed in Andes Lidar Observatory (ALO) at Cerro Pachón (30°S,70°W), Chile from September 2009.

✧ All-sky airglow imaging system is installed at the same site to measure the mesospheric hydroxyl (OH) airglow emission at nighttime.

Basic Information of Lidar and Imager systems:

Equipment	Temporal Reso.	Spatial Reso.	Spatial Coverage	Available Time	Measurements
Lidar	90 s	0.5 km(v)	85-105 km	03:00-08:00UT	Temperature/ Wind Speed
Imager	2.5 min	~0.5 km(h)	OH@~87 km O5@~96 km	02:00-08:00UT	Airglow Emission Intensity

✧ Spectral methods are used to extract the wave packet.

✧ Chebvshev-II band pass filter with cutoff period [20min,35min].

✧ Median filter used to smooth image noise and small structures.

Important wave parameters:

Date	Period	Horizontal Wavelength	Wave Speed	Propagation Direction	Amplitudes
Jan 16, 2015	20-35 min	~45 km	~30 m/s	188° (almost Southward)	~15 K @T' ~10 m/s @w'

3.1 Band-pass Filtered T'/w' from Lidar

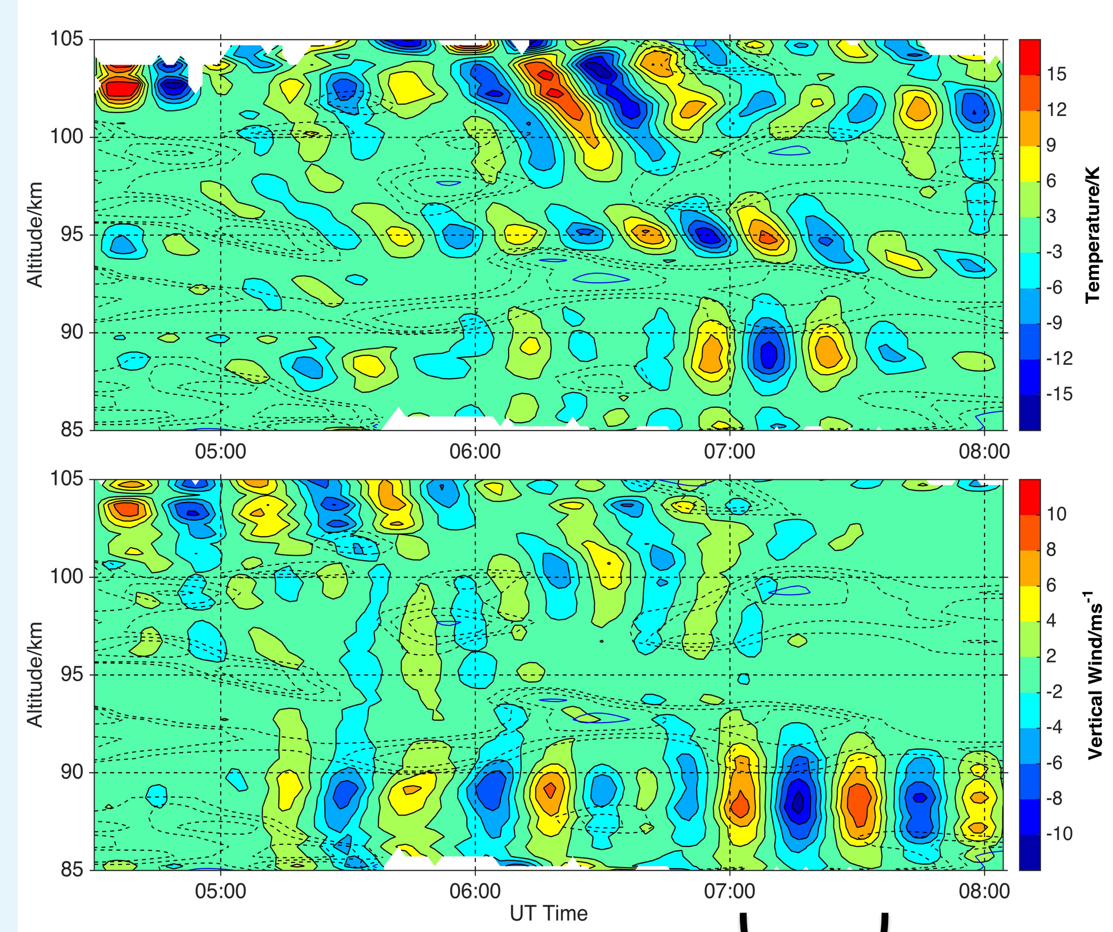
◆ Band-pass filtered temperature and vertical wind are obtained between 04:30-08:00UT.

◆ T' and w' are shown in contours with color. Buoyance frequency squared (N^2) smaller than 10^{-4} rad²/s² is shown in contours with dashed lines.

◆ Strong wave pattern with layered structure are identified in both T' and w', with amplitudes up to ~15 K and ~10 m/s.

◆ The magnitudes of T' (top) are found to be related to N^2.

◆ There is a 90° phase lag of w' to T', and T' is in phase with emission perturbation.

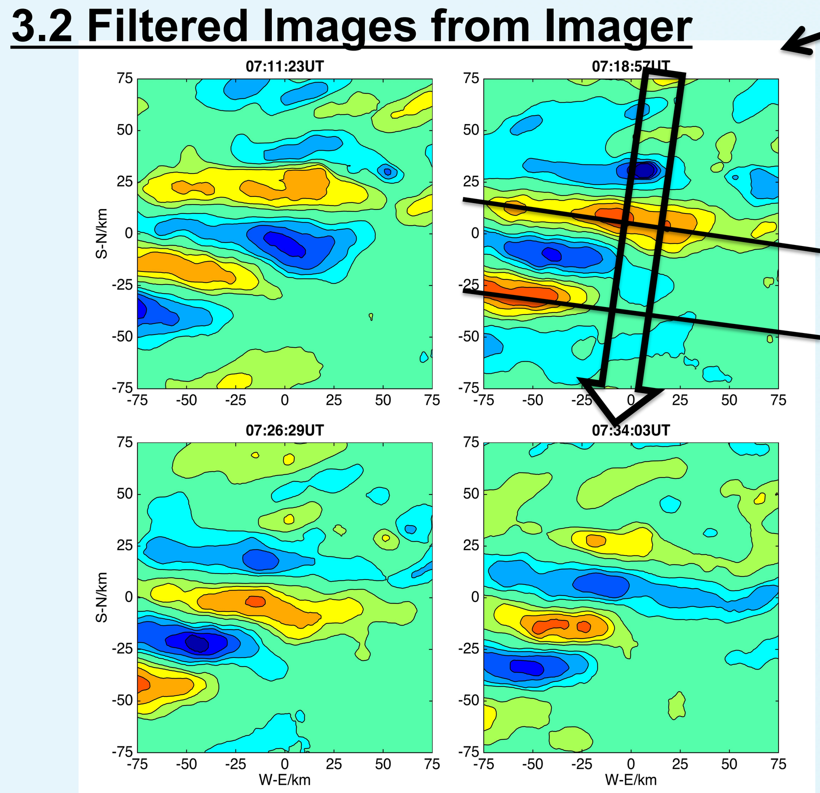


◆ Linear gravity wave theory predicts a proportionality for the temperature variance,

$$\overline{(T'/T_0)} = (N^3/N_0)(\rho_0/\rho)$$

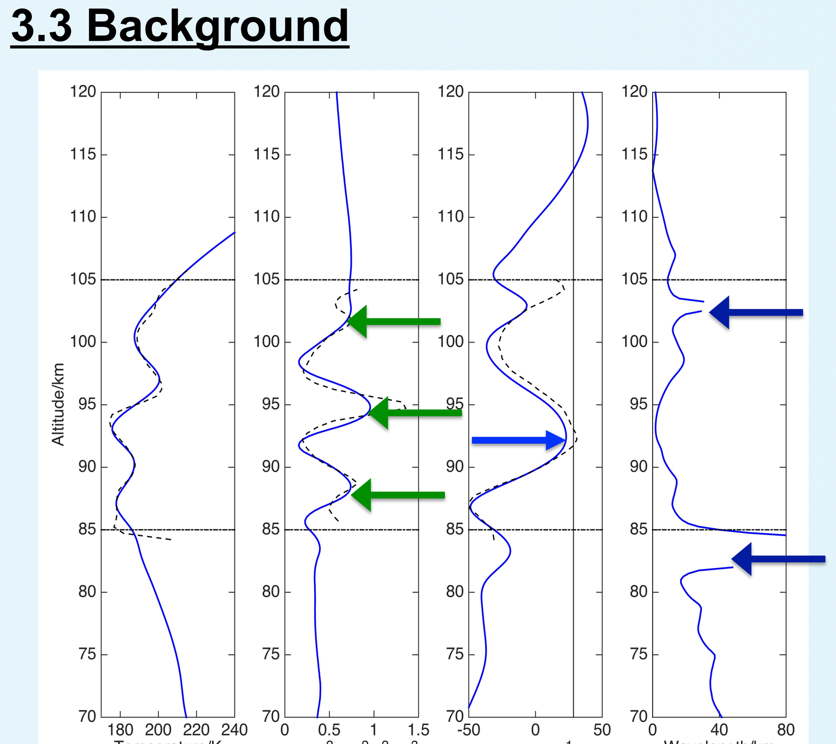
Airglow images during this period are shown below.

3.2 Filtered Images from Imager



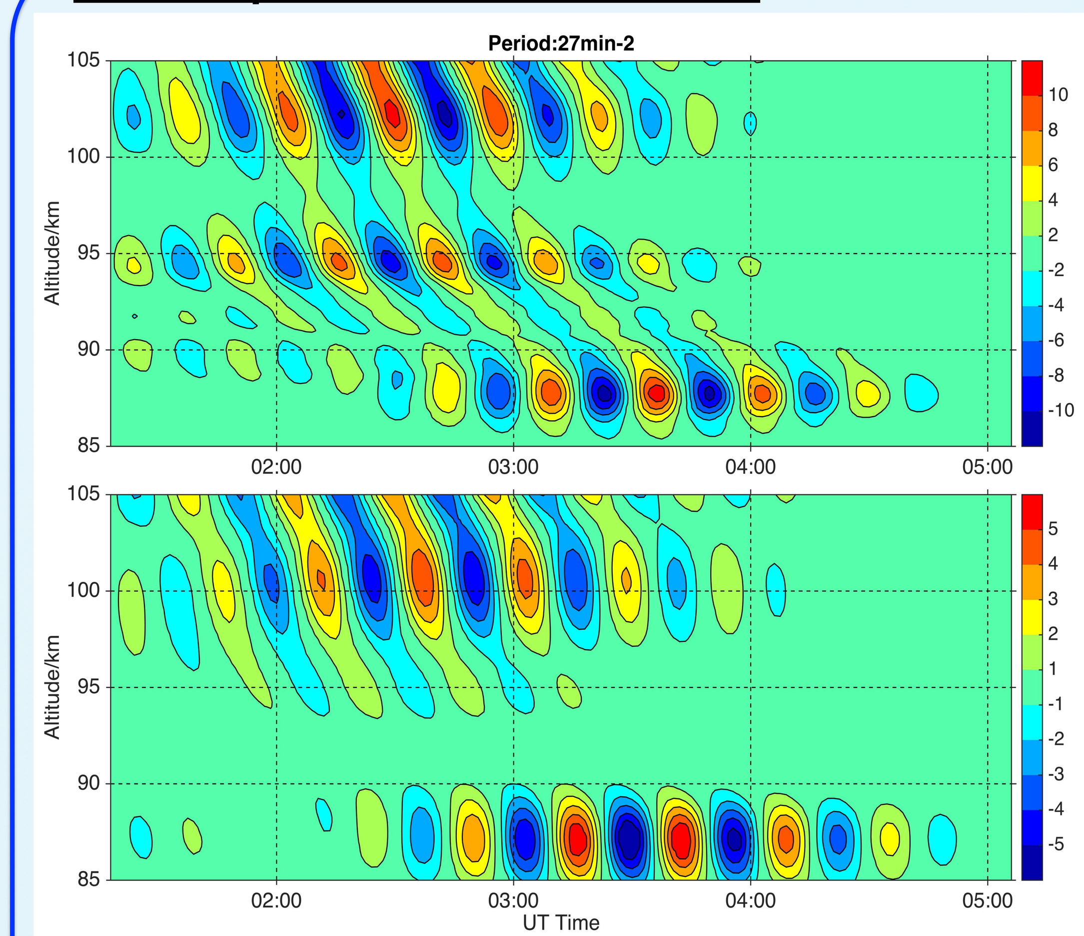
◆ Horizontal wavelength and wave propagation direction are determined as ~45 km and ~188°

3.3 Background



◆ 3 peaks in N^2, 1 critical layer, 2 reflection layers are marked with colored arrows.

3.4 Comparison with Simulation



◆ Simulated T' and w' amplitudes are slight smaller than observational because simulation only covers narrow spectrum.

◆ A fully-nonlinear model was used to simulate this event and was able to reproduce most of the observed features.

◆ Wave parameters and background information are provided by observational data merged with model data.

◆ Note that horizontal winds used here are from measurements of the same lidar but ~10 days later.

◆ Spatial resolution is 0.25 km and 2 km in vertical and horizontal direction and temporal resolution is 90 s, these are similar to lidar measurements.

◆ Gaussian modulated cosine as initial body forcing at x=200 km, z=65 km.

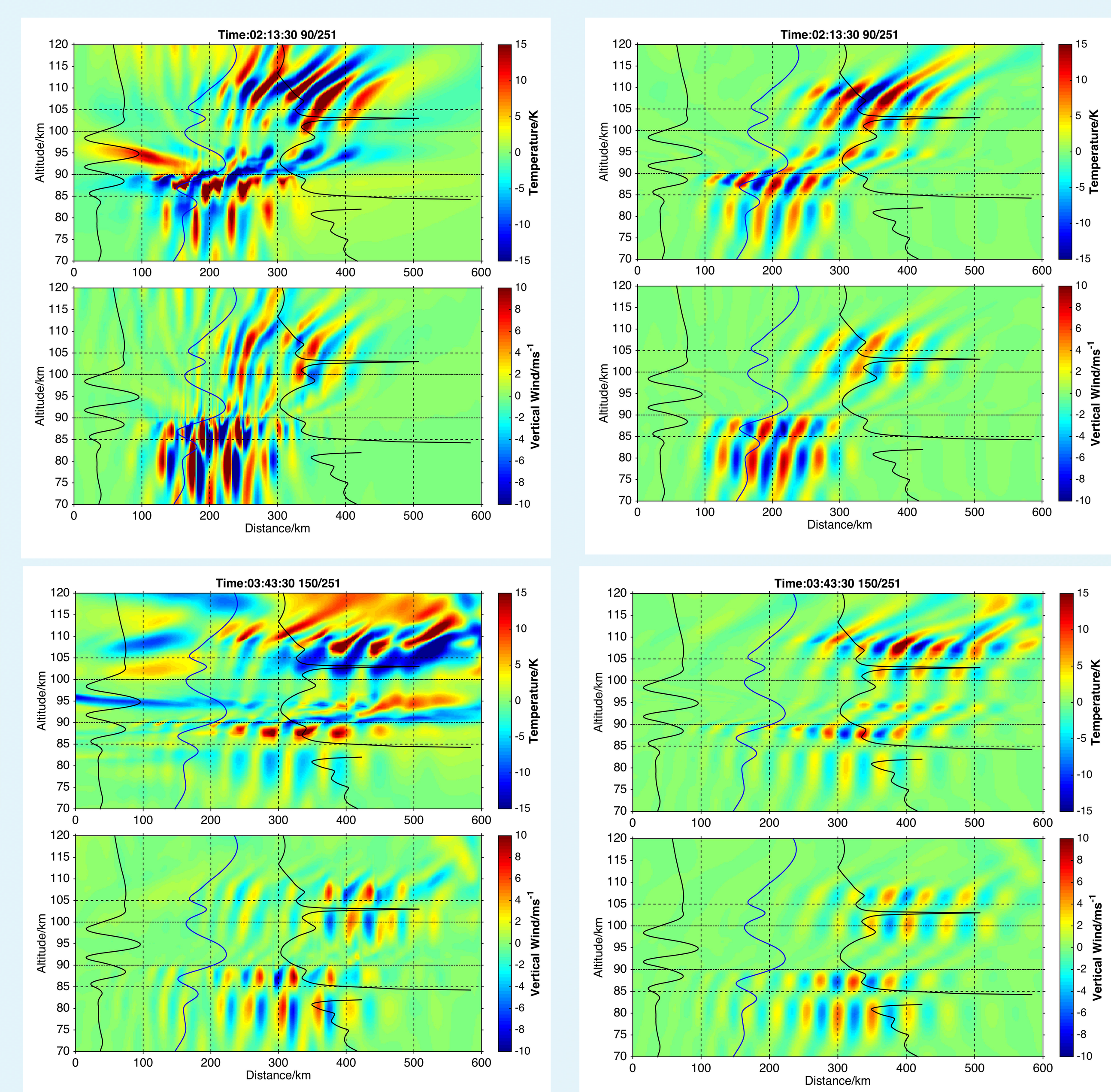
3.5 How do waves propagate and get reflected

◆ As indicated by the gaps in the vertical wavelength profile, there exists two reflection layers. One is below 85 km and another is between 100 and 105 km.

◆ Waves are partially reflected at the reflection layers. Faster (higher frequency) waves with more vertically-oriented phase are more likely reflected. Slower waves with less vertically-oriented phase penetrate to higher altitudes.

◆ Near 93 km, wave speed almost equals to background wind speed and the vertical wavelength approaches zero. Wave breaking can be found in original temperature and wind data. Relative slower waves could be blocked by the critical layer.

◆ Enhancement of vertical wind is found near reflection layers.



4 Summary and Conclusion

◆ A first time observation of a complex gravity waves reflection/critical level event, which was also successfully modeled.

◆ The success of modeling of such complex event will provide important insights into gravity wave propagation and dissipating processes.

◆ The observations of co-located high resolution lidar and imager provide a complete picture of gravity waves.

◆ When gravity waves encounter reflection layer, vertical wavelength increases and the phase lines are oriented more vertically. This explains the enhancement of vertical winds(~10 m/s) near reflection layers.

◆ When gravity waves approach critical layers, vertical wavelength goes to zero. Wave phase lines are oriented near horizontally. Waves will break into smaller scale structures.

◆ This kind of large wave events have strong impact to the variability of the atmosphere, and are also likely to cause perturbations in the ionosphere through neutral-ion coupling.

Acknowledgements

- This work is supported by NSF grants AGS-1229085, AGS-1110199 and AGS-1136278.

caob@my.erau.edu Bing Cao

CEDAR 2015 Seattle,WA, June 23 2015