June 2012

Upgraded ALO Rayleigh Lidar System and Its Improved Gravity Wave Measurements

Leda Sox
Utah State University

Vincent B. Wickwar
Utah State University

Joshua P. Herron
Space Dynamics Lab

Marcus J. Bingham
Utah State University

Recommended Citation

Sox, Leda; Wickwar, Vincent B.; Herron, Joshua P.; and Bingham, Marcus J., "Upgraded ALO Rayleigh Lidar System and Its Improved Gravity Wave Measurements" (2012). CEDAR Workshop. *Graduate Student Posters.* Paper 2.
https://digitalcommons.usu.edu/graduate_posters/2

Upgraded ALO Rayleigh Lidar System and Its Improved Gravity Wave Measurements

Leda Sox[1], Vincent B. Wickwar[1], Joshua P. Herron[2], Marcus J. Bingham[1]
([1]Physics and CASS; [2]Space Dynamics Lab; Utah State University, Logan, UT)

Introduction

We have recently made the first measurements with the new, very large Rayleigh-scatter lidar system at the Atmospheric Lidar Observatory (ALO) at Utah State University in Logan, Utah. The new system is an upgraded version of the original Rayleigh lidar that operated at ALO from 1993 to 2004. With the new system the observational altitude upper limit has increased and the resolutions in the reduced data have become finer. These improvements to the data will have significant impacts on the study of atmospheric gravity waves and other middle-atmosphere phenomena.

System Background

Figure 1. Two 532 nm laser beams in parallel shooting up through the steel cage that holds the four receiving mirrors.

The much larger ALO Rayleigh-scatter lidar combines two Nd:YAG lasers to achieve a total laser power output of 42 W at 532 nm. The lasers are pulsed at 30 Hz and frequency-doubled from a wavelength of 1064 nm to operate at 532 nm. This wavelength was chosen to take advantage of the $1/\lambda^4$ term in the Rayleigh scatter cross section. Photons emitted from the laser are backscattered in the middle atmosphere and collected by four 1.25 m diameter parabolic mirrors, equivalent to one 2.50 m diameter mirror. These mirrors focus the returned photons into optical fibers that, in combination with detector optics, transmit the photons to a photomultiplier tube (PMT). From there, a multi-channel scalar (MCS) unit and its software package count the photoelectrons and record them to a PC.

The original Rayleigh lidar at ALO operated with only one laser and a single small receiving mirror. Through the addition of mulitple larger mirrors and a second laser, the new system is substantially more sensitive in its raw data collection.This increased sensitivity enables data to be acquired to greater altitudes and analyzed with better resolutions and precision.

The first observations with this system were recently acquired, on June 13, 2012. The first temperature profiles are shown in the next column to illustrate this improved capability. Future studies of atmospheric gravity waves and other middle atmosphere phenomena will benefit from these improvements.

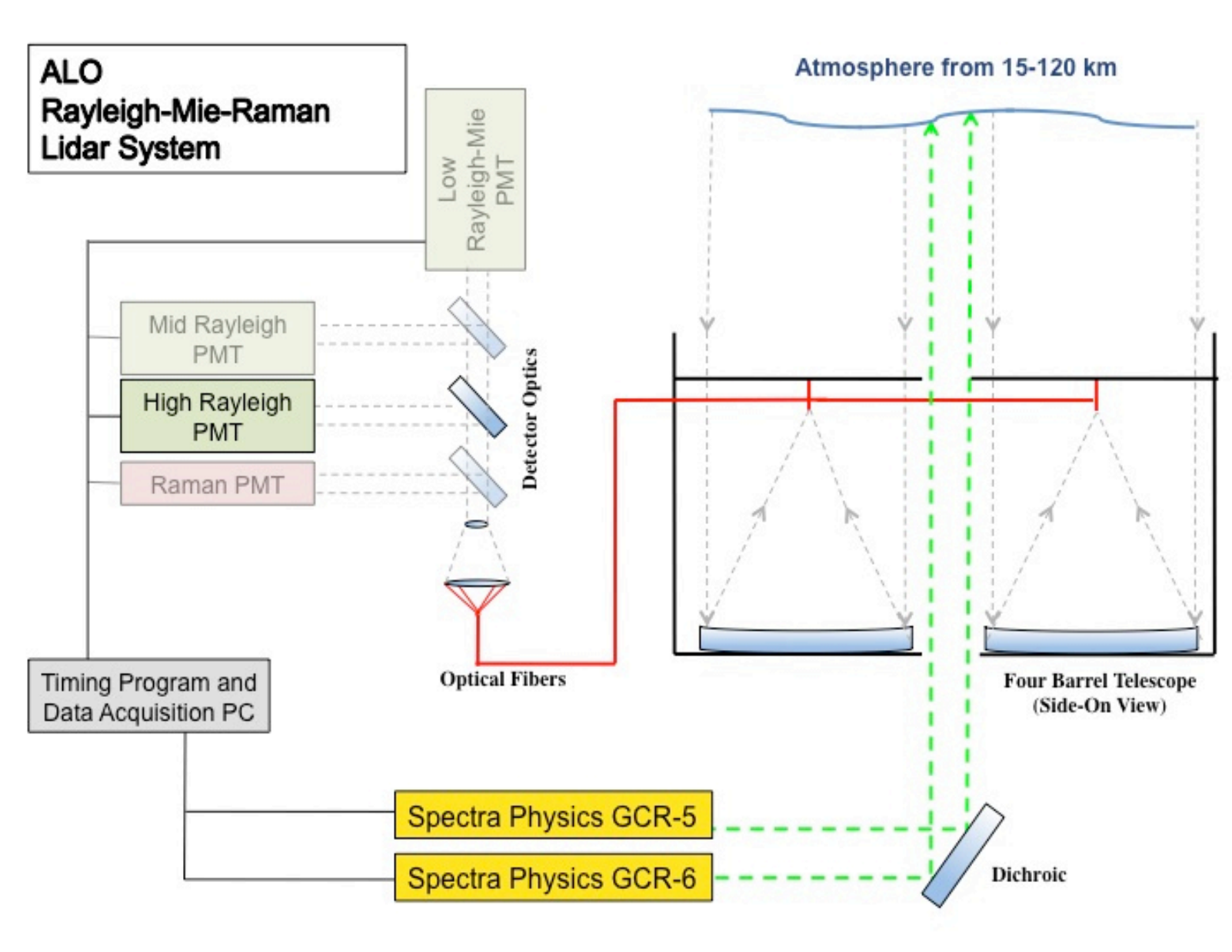

Figure 2. Current ALO Rayleigh lidar and planned upgrades.

Table 1. ALO Rayleigh Lidar Specifications	
Wavelength	532 nm
Power	42 W
Receiving Area	4.9 m^2
Power-Aperture Product	206 Wm^2

Raw Data Comparison

The increased sensitivity of the new system is evident in the raw data, seen as the average number of photoelectrons counted in two minutes. In Figure 3 (a) and (b), the photoelectrons are represented as "counts", and are plotted versus altitude. As can be seen in the figures, the new, large Rayleigh lidar detects, so far approximately 30 times more photoelectrons than the original configuation at an altitude of 60 km, which means that the new system is able to acquire data at higher altitudes than its predecessor. At approximately 90 km, the new system is able to gather significant data in two minutes whereas the old system has no perceivable count rate at this altitude.

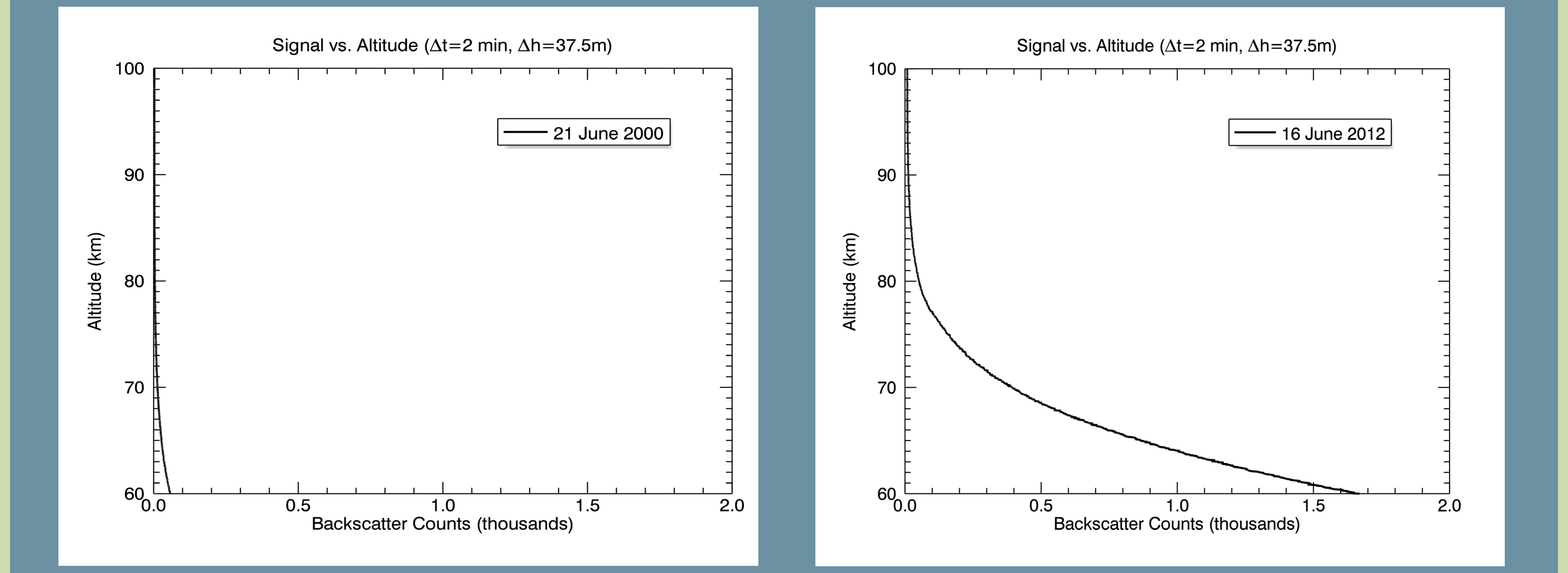

Figure 3. Signal vs. altitude plots for (a) the original ALO Rayleigh lidar (at left) and for (b) the new larger system (at right). A signifcant increase in the signal, or photoelectron counts, can be detected by the new system.

PMT Linearity

With the increased sensitivity of the new ALO Rayleigh Lidar, the high return signal causes PMT nonlinearity at lower altitudes, therefore, the photon counts below an altitude of approximately 65 km are undercounted, as expected.

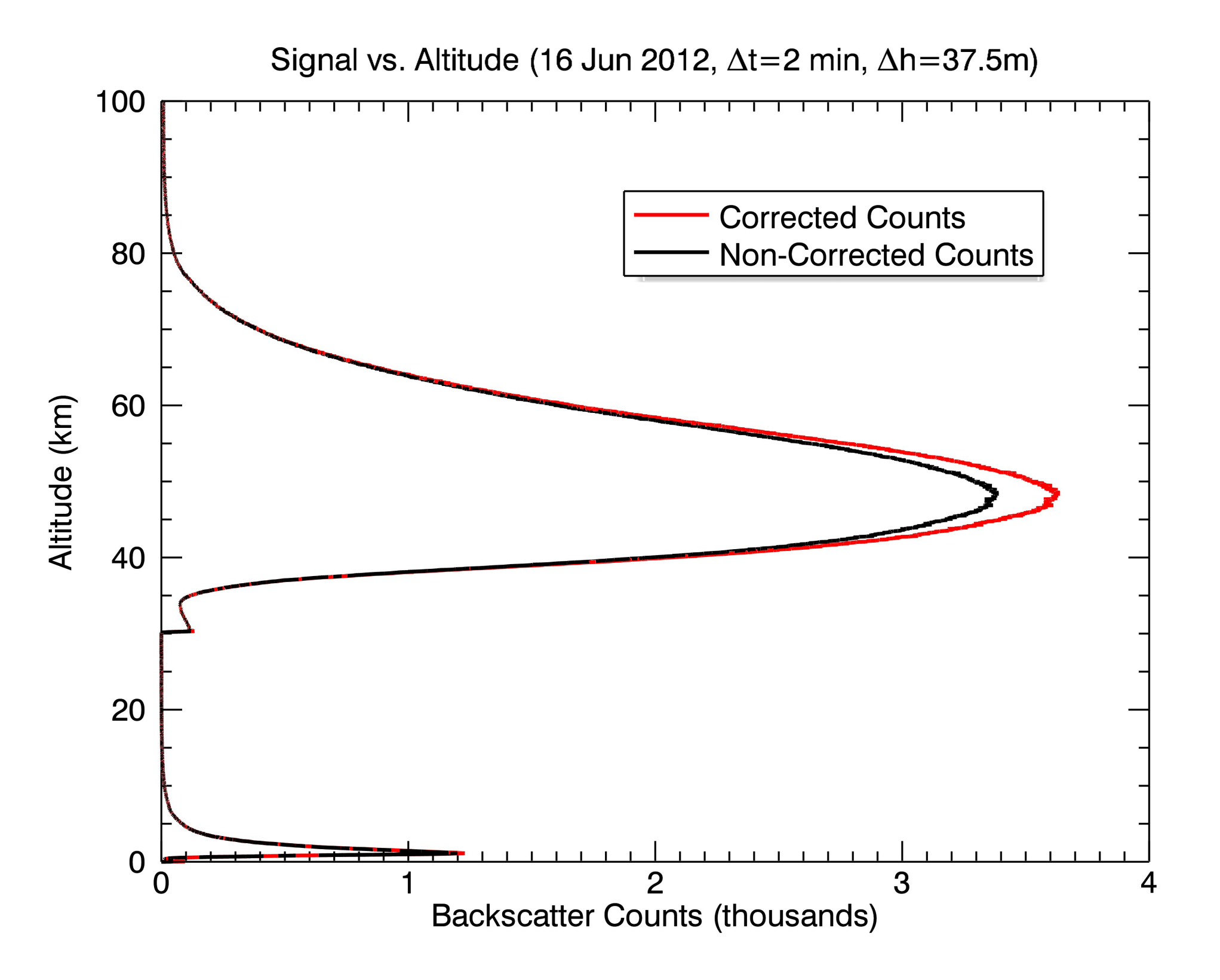

Figure 4. Effects of PMT nonlinearity on the return signal. The plot shows how, as the PMT goes nonlinear at lower altitudes, the MCS unit undercounts the photoelectrons (black curve). The red curve shows the corrected number of counts.

We are currently applying a dead-time correction to the counting rate to account for this effect. In the future, we will employ additional detector channels for lower altitudes, as indicated in Figure 2. In the mean time, linearity testing was conducted, finding a dead time of 18 ns. The data was then corrected according to,

$$N = M / (1 - \tau M) \qquad (1)$$

where N is the corrected number of photoelectron counts per second, M is the observed number of photoelectron counts per second, and τ is the dead time. This effect is illustrated in Figure 4. The black line shows the observed counts in two minutes; the red line the corrected counts. In that figure, the correction is significant from 35 to 65 km. In addition, Figure 4 shows the chopper opening a little above 50 km, the PMT gate turning on at 30 km, and a cloud at about 1 km.

First Temperature Results

The original ALO Rayleigh lidar operated from 1993 to 2004, developing an extensive data set spanning 11 years. From that an 11-year temperature climatology was developed. The new system has begun to add to this data set. As predicted, the system is probing higher into the atmosphere, making it, so far, to nearly 105 km, whereas the old system's upper limit for temperature data was 90 km. After more optimization of the system, this upper limit should increase even further.

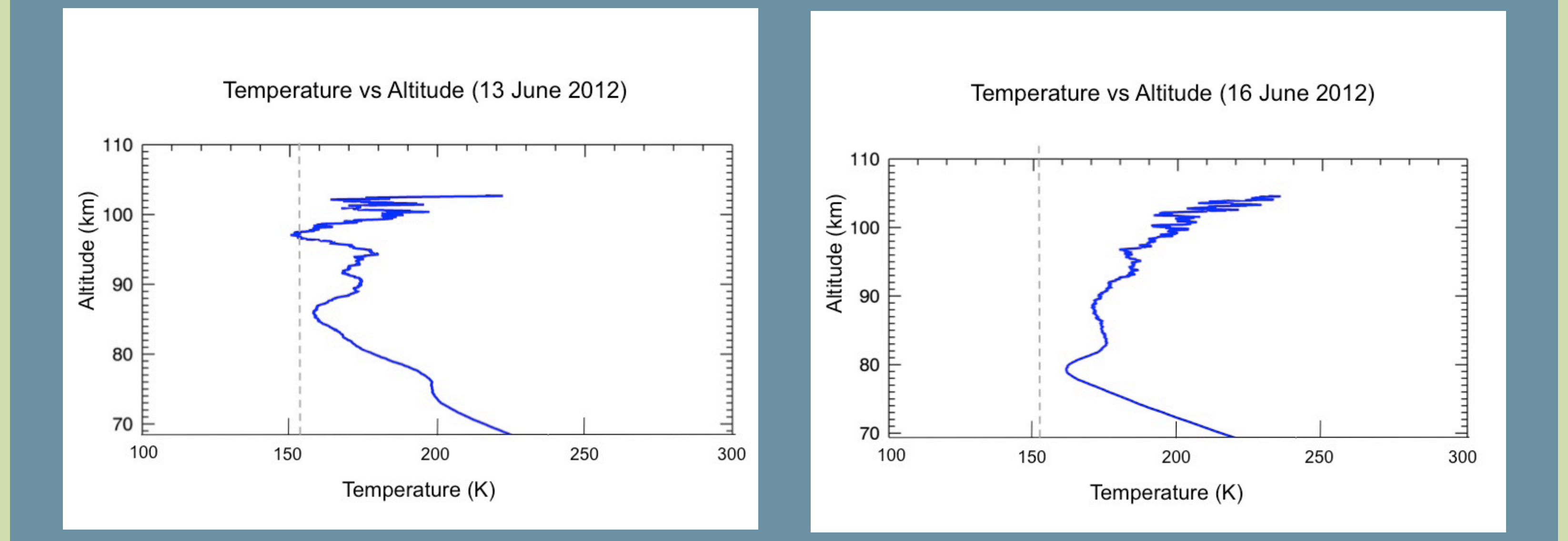

Figure 5. Temperature vs. altitude with all-night integrations for (a) 13 June 2012 with one laser and (b) 16 June 2012 with both lasers.

Figures 5(a) and 5(b) show the first two temperature profiles observed near the summer solstice. The recorded temperatures near the mesopause approach the conditions that are needed for the formation of noctilucent clouds (NLCs), such as those previously observed by the ALO Rayleigh group. NLCs form at high altitudes (82-85 km) and usually above 50° latitude. Observers are currently taking data with the system every clear night with the goal of making additional NLC observations.

Improved Atmospheric Gravity Wave Studies

Another important study that will benefit from the increased sensitivity of the new, very large Rayleigh system is that of atmospheric gravity waves (AGWs). Like the temperature climatology, AGW studies were carried out with data taken using the original Rayleigh lidar, having first been explored by Kafle (2009).

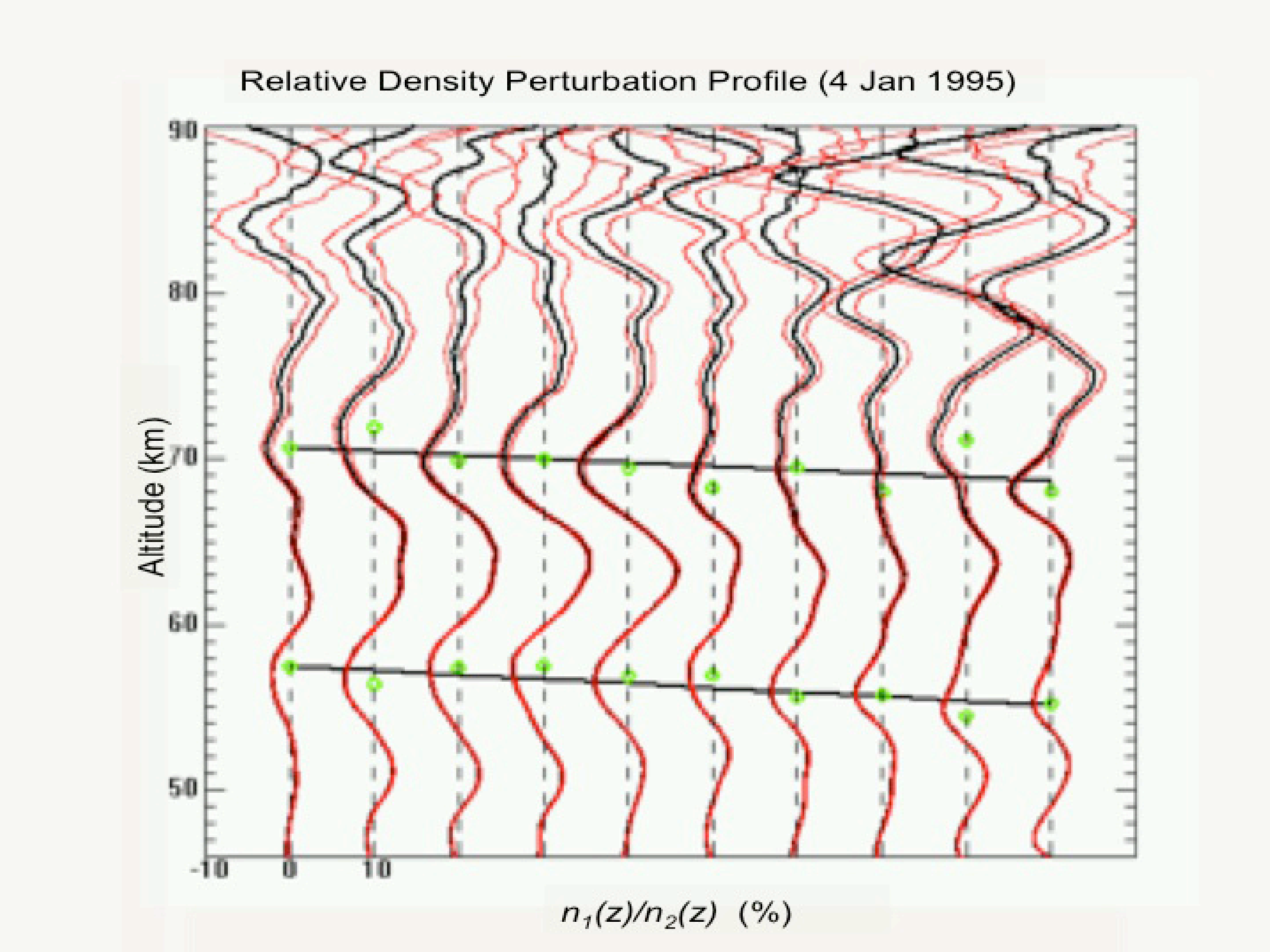

Figure 6. Relative density perturbation profiles from 4 January 1995. Each profile is offset by one hour and the horizontal axis gives +/-10% density fluctuation from central dashed vertical lines. The lines connecting green dots give a measure of horizontal phase velocities. (Kafle 2009)

From the raw data, relative density perturbations or temperature perturbations can be analyzed to show AGW activity. As can be seen in Figure 6, AGW structures such as vertical wavelength and phase velocity appear in relative density perturbation profiles. This analysis from the original lidar's data set will be extended with the new data. With the increased sensitivity, a greater altitude range can be examined along with parts of the spectrum with shorter periods (less than an hour), and smaller vertical wavelengths, (less than 6 km.) Of particular interest will be extending gravity wave studies upward from the simplicity of much of the mesosphere into the more complex mesopause.

Additional Future Work

Along with continuing optimization of the lidar's various systems, there will be further upgrades as well. As can be seen in Figure 2, three more PMT detection channels (the pale PMTs) will be added to the system. One of these channels will be for continuing Rayleigh scatter measurements down to approximately 40 km (the original lidar's lower limit), another channel will measure both Rayleigh and Mie scatter from 15-65 Km and the final channel will measure Raman scatter from 15-45 km (Table 2). The rate at which this will occur, and the examination of scientific problems with this unique system will depend on significant future funding.

Table 2. RMR Lidar Altitude Ranges

High Rayleigh	Mid Rayleigh	Low Rayleigh-Mie	Raman
65-115 km	40-90 km	15-65 km	15-40 km

Conclusion

Presented above are first observations from the new ALO very large Rayleigh lidar consisting of four collecting mirrors and two lasers, whose signals have been combined into one PMT detection channel. Having proved the feasibility and functionality of such a system to reach significantly higher altitudes, we will now proceed with additional detector channels that will be used to gather data from a larger altitude range than was previously possible by any other remote sensing systems. Additionally, temporal and spatial resolution of the new system will allow for unprecedented measurements of phenomena throughout the middle atmosphere.

Acknowledgements

The construction of the very large lidar facility was made possible by funds from NSF, AFOSR and USU. We gratefully acknowledge support from the Rocky Mountain NASA Space Grant Consortium, the Howard L. Blood Graduate Scholarship program, the USU Physics Department, USU, and personal contributions to enable us to obtain the first data from this facility.