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Rayleigh Lidar Temperature Studies in the Upper Mesosphere and Lower Thermosphere

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Introduction

Rayleigh lidar technology opened the middle atmosphere (from 30–90 km) to ground-based observations. The upgraded system at the Atmospheric Lidar Observatory (ALO) on the campus of Utah State University (41.74°, 111.81°) has shown that these ground-based observations can be extended to 109 km, with the goal of reaching 120 km. The resultant study of short and long-term temperature trends, using Rayleigh lidar, contributes immensely to the overall understanding of the properties and dominant physical processes in the middle atmosphere and Mesosphere-Lower Thermosphere (MLT) region. Temperature variations on short time scales, from minutes to days, give insight into the effects of waves (gravity waves, tides, planetary waves), while climatological studies of temperatures can help in the study of global change throughout the atmosphere .

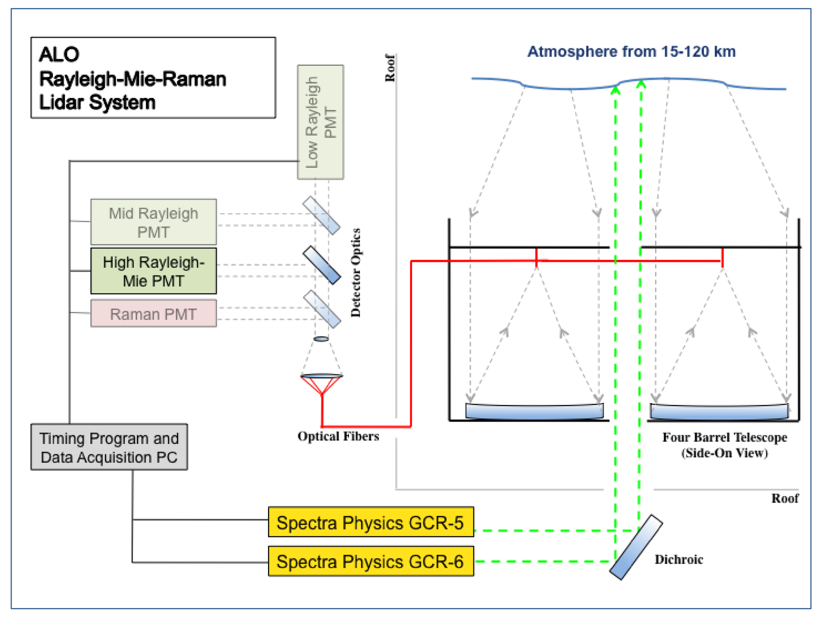

Figure 1. Diagram of the upgraded Rayleigh lidar at USU. Two lasers are used as the system's transmitter and four mirrors are used simultaneously as the systems primary receiving aperture.

Figure 1 shows a simplified diagram of the upgraded ALO Rayleigh lidar system. The major improvements to the system include the use of two, pulsed Nd:YAG lasers with a combined power output of 42 W and the use of four parabolic mirrors as one receiving telescope with an overall aperture area of 4.9 m^2.

Summer Rayleigh Lidar Data Campaigns

During the summer 2012 data campaign, observations were made over a month-long period (June 13–July 12). Data from eighteen nights gave good temperature profiles in the MLT region from 75 km up to a maximum of 109 km. Temperatures were reduced using the Chanin-Hauchecourne method, which was modified to use temperatures instead of pressures as the initial condition at the top altitude. The initial temperatures were taken from the MSISe00 model for each night, which is why the observed temperature profiles approach the MSISe00 curve at the highest altitudes in Figure 2. For a single temperature profile the altitude resolution was a little greater than 3 km and the integration time was typically a full night (about 4–6 hours in summer).

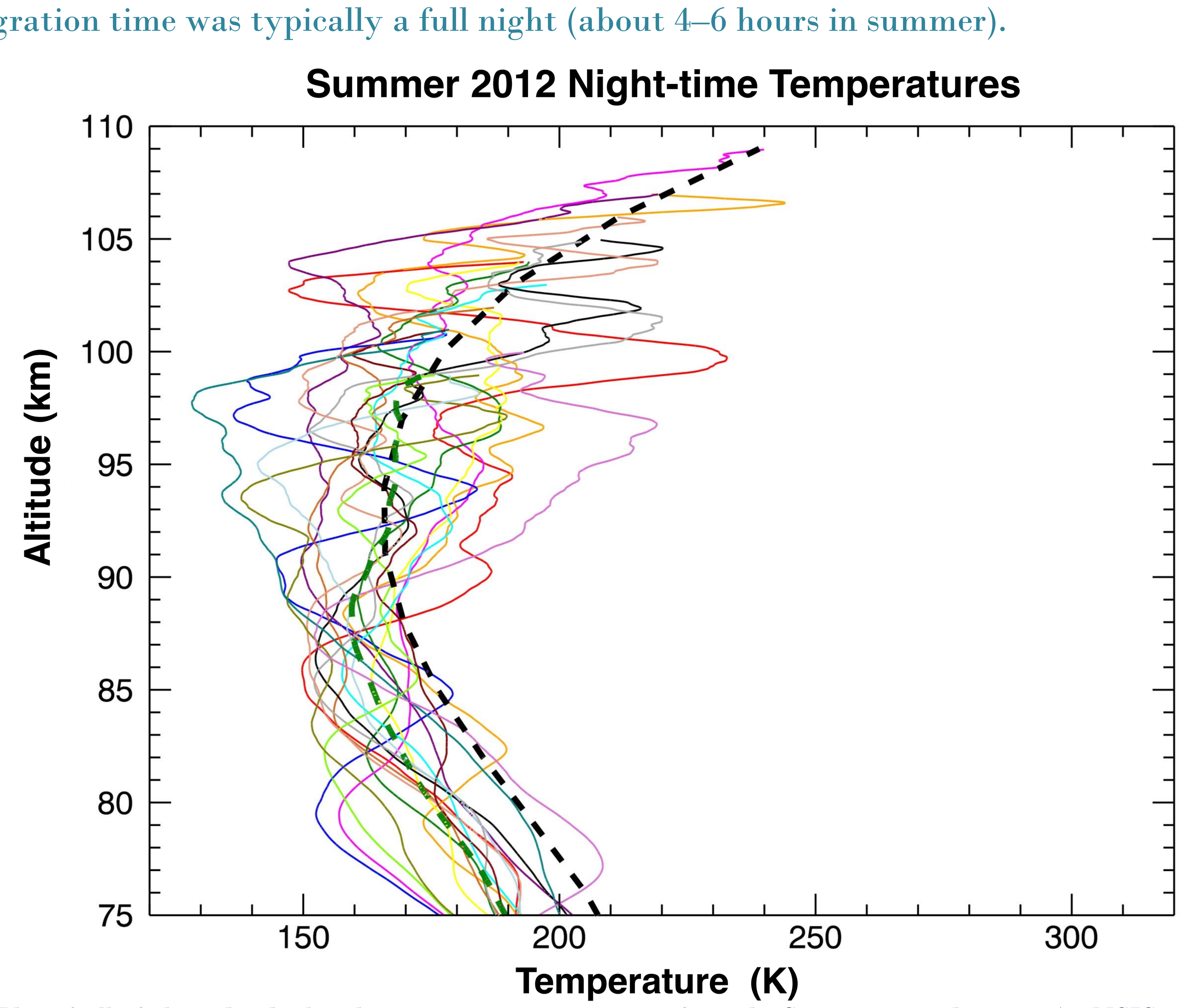

Figure 2. Plot of all of the individual night-time temperature curves from the Summer 2012 data set. An MSISe00 temperature curve, for the center night of the data campaign, June 27 (dashed black), and an average temperature curve for the whole data set (dashed blue) are plotted for reference.

In Figure 2, all eighteen night-time temperature profiles are plotted together along with an MSISe00 model temperature curve and an average curve for the whole data set. With this representation, one of the striking features is the variability from night to night. Some of this variability is due to wave activity, i.e., gravity waves, tides and/or planetary waves. Waves with large amplitudes similar to those seen in some of these nights' temperatures can produce particularly low temperatures at altitudes near the minima of the waves. This can affect the deduced mesopause temperature and its altitude. Low temperatures in the mesosphere produced in this way have been implicated in the formation of mid-latitude noctilucent clouds. Other nights show smaller waves.

Rayleigh Lidar MLT Temperatures

As expected, temperatures in this region during this period are quite low compared to the temperatures during other seasonal periods. Ignoring obvious wave structures, there is an underlying average of approximately 165 K near 87 km (Fig. 2), which could indicate the mesopause. However, four individual nights, exhibiting what appear to be wave like variations, clearly show temperatures only slightly greater than 150 K between 79 and 84 km (Figure 3a). Another set of four nights shows minima of about 140 K between approximately 94 and 100 km. This illustrates the fact that, from night-to-night the mesopause is not clearly present and can only be found through averages over large amounts of data, such as the MSISe00 model takes into account.

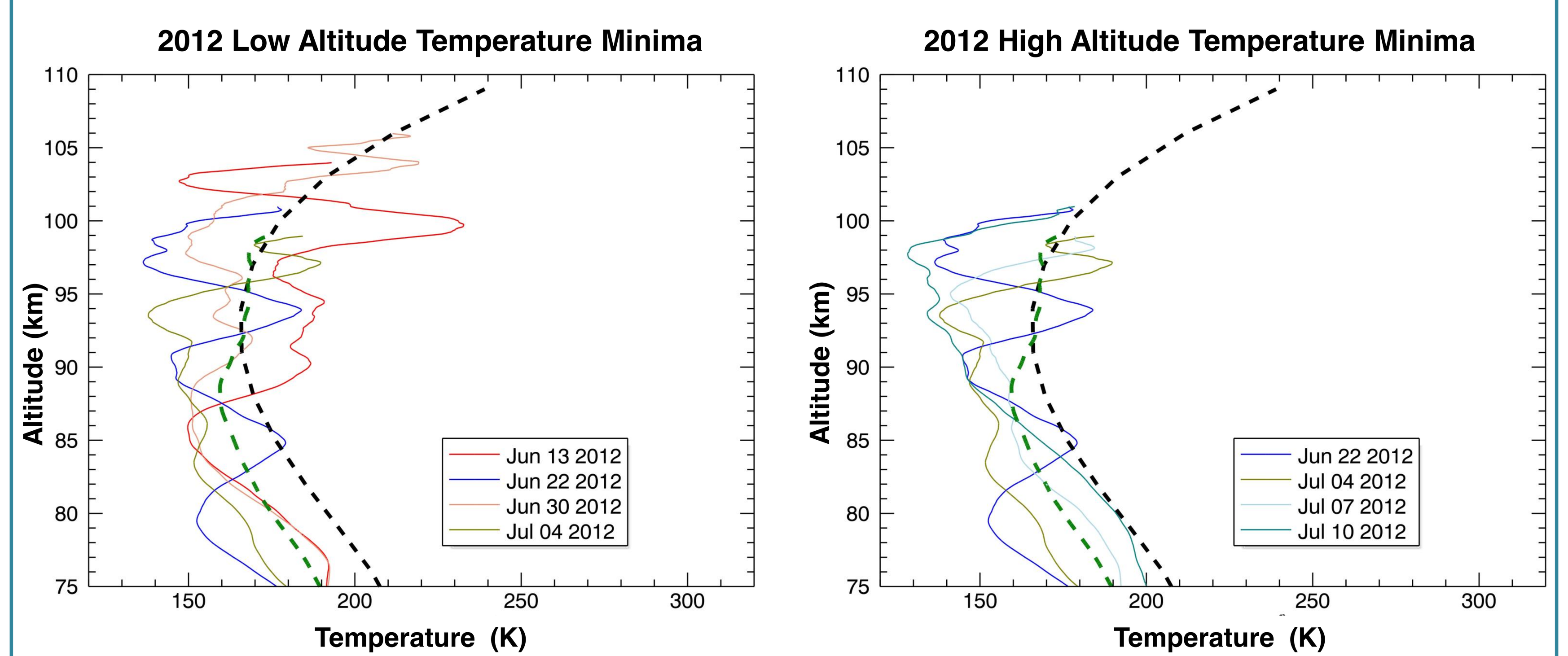

Figure 3. Selected temperature minima for Summer 2012 campaign. (a) Shows lower altitude temperature minima for nights of June 13. June 22, June 30, and July 04 of about 150 K between 79 and 84 km. (b) Shows the upper altitude temperature minima for nights of June 22, July 04, July 07, and July 10 of about 140 K between 94 and 100 km. Black dashed curve s on both plots is the MSISe00 model temperature curve for June 27, and the green dashed curves are the average for the whole data set.

On average, the highest altitude limit of these temperature plots is 103 km. This limit can vary from night to night depending on the number of data files acquired, atmospheric transmission, mirror alignment, laser power and other instrumental parameters. Our highest altitude for temperature determination was on June 16, 2012, with a height of 109 km (Fig. 4a). This is the highest that Rayleigh lidar temperature data has reached. In fact, all of the data from the summer 2012 campaign reached into new territory for the ALO Rayleigh lidar system, which have historically had an upper altitude limit of 90 km. Looking more closely, we found that the data from the night of June 16, 2012 had good time resolution down to 1 hour while retaining an upper altitude limit of 107 km (Fig. 4b).

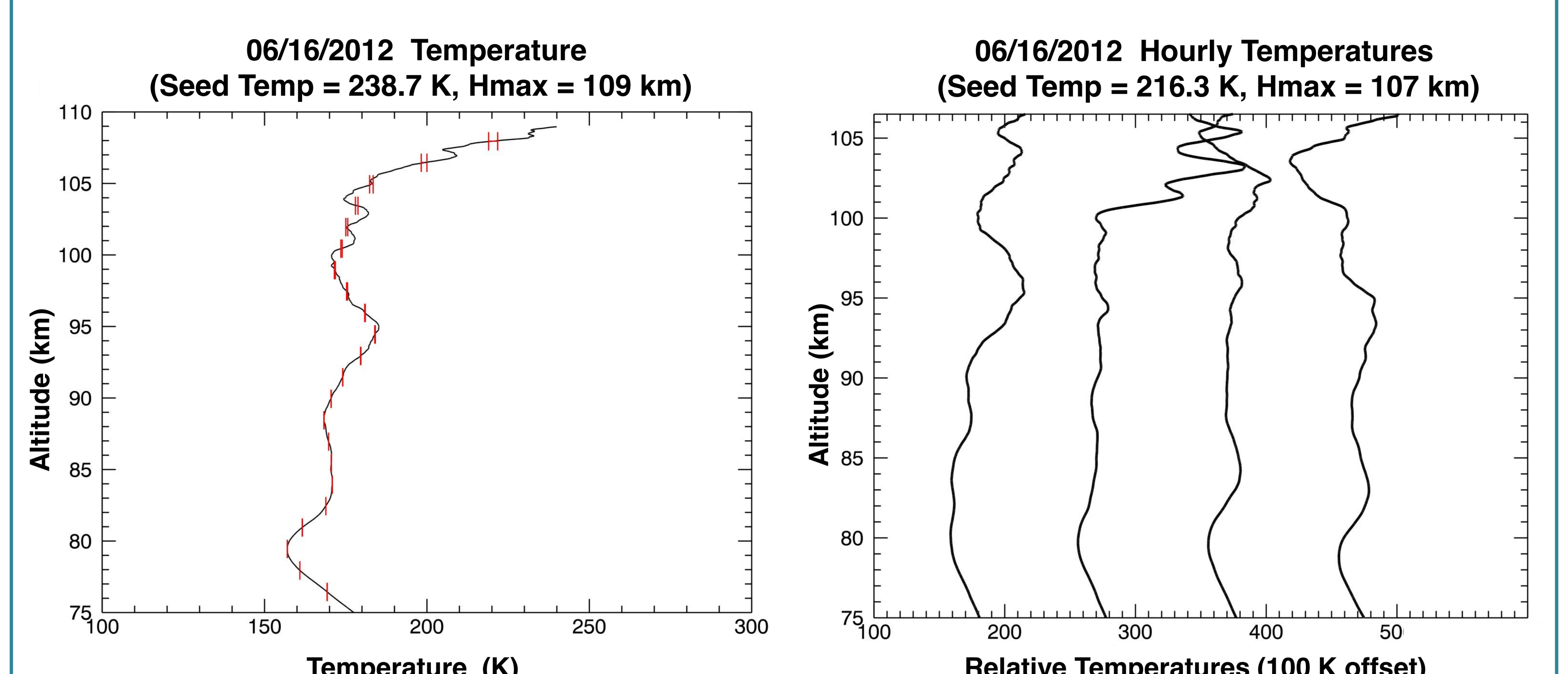

Figure 4. Temperatures for the night of June 16, 2012. (a) The data from this night gave the highest (in altitude) temperatures from the 2012 data campaign. (b) the shortest integration times for this night, while reaching 107 km in altitude, where 1 hour. Each curve shows a 1 hour data integration shifted successively by 100 K.

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System Improvements

Over the course of the past year, major improvements to the system have been completed with the help of additional electrical and mechanical engineering support. The timing of the Rayleigh lidar system is now run with an Atmel ATmega168 micro controller and accompanying software. New sockets, which control the voltage to the photomultiplier tube (PMT) dynodes and the gating of that voltage, are also being developed. The alignment process of the telescopes has been significantly improved through the use of servo motors, which control the x and y positions of the fiber holders at the focus of the parabolic mirrors. A new alignment program is being developed (Fig. 5) to control the servo motors, which will allow for both manual and automated alignment. This new set-up has already improved the alignment procedure – a complete alignment of the telescopes, which would have taken two nights, now takes a couple of hours with much greater precision than before.

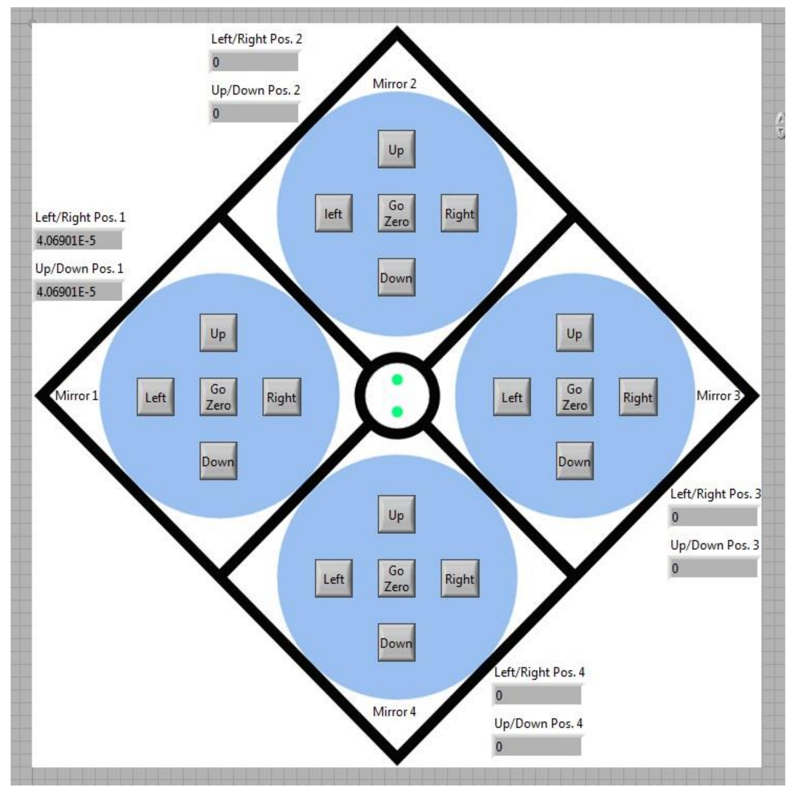

Figure 5. Screen shot of the new telescope alignment Labview VI. (courtesy of the Laser Pointers Mechanical Engineering capstone project team)

Upcoming Work

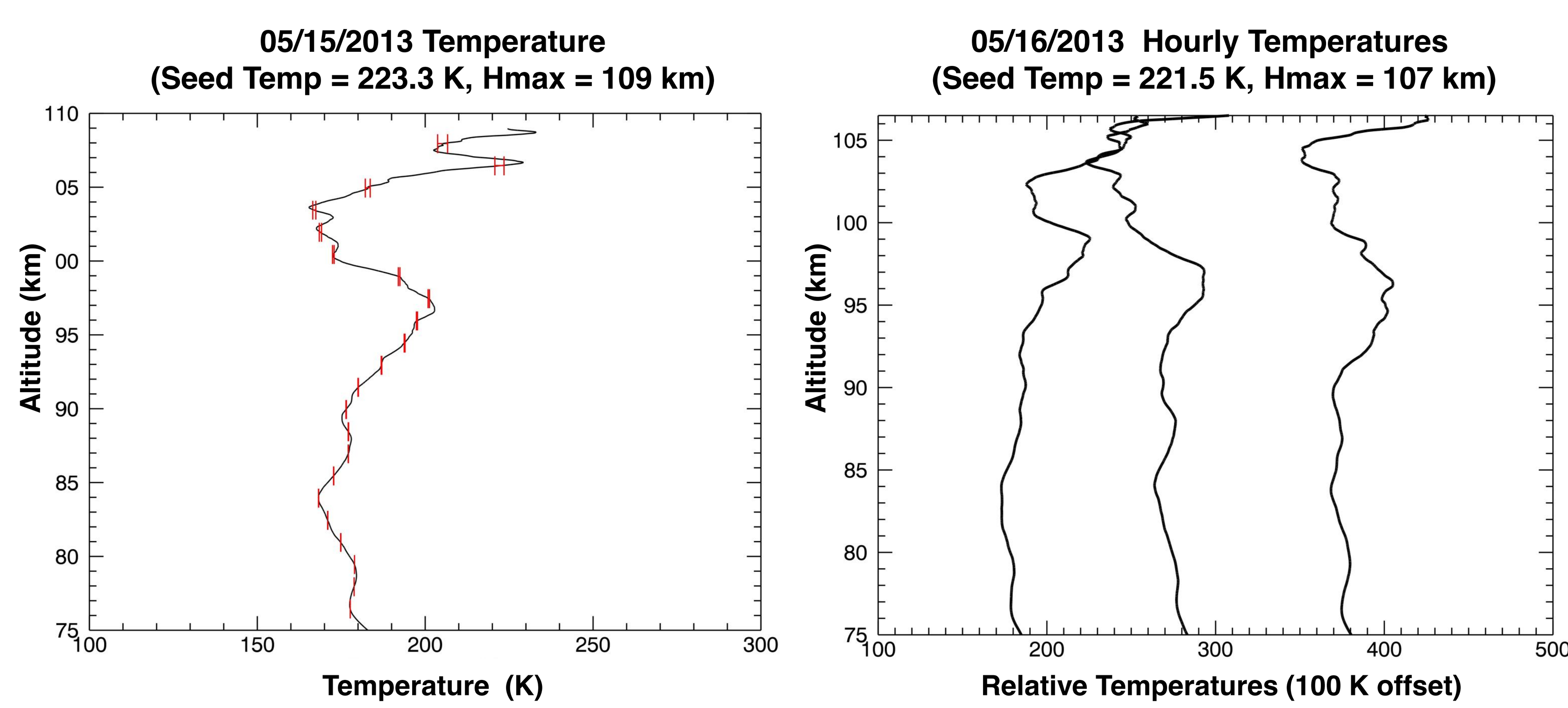

Figure 6. Temperatures for the night of May 15, 2013. (a) The two hours' worth of data give temperatures up to the an altitude of 109 km, as high as the highest night from 2012. (b) the shortest integration time for this night, while reaching 107 km in altitude, was 30 minutes. Each curve shows a 30 minute data integration shifted successively by 100 K.

Through the improved receiver telescope alignment, laser power optimization, new PMT socket development, and full night data collection, an upper altitude limit in temperature data of 120 km will be reached. This improvement in data collection also implies shorter integration times. As seen in the most recent observations, made in May 2013 (Figure 6), the sensitivity of the instrument has increased. The temperatures now have an upper altitude of 109 km from just two hours of data instead of 4-5 hours, previously. Short integrations can be obtained in 30 minutes instead of 1 hour. With finer adjustments, the all-night top altitude will reach 120 km. Additional detection channels will allow us to extend the data collection range, and thus temperature data range, downward from 120 km to about 15 km. The additional channels will be comprised of two Rayleigh scatter channels for the measurement of the MLT region, one Rayleigh and Mie scatter channel for the measurement of the Stratosphere and one Raman scatter channel to be used in the separation of the Rayleigh and Mie signals that come from the Stratosphere. The extension of the range of the instrument will enable studies of density and temperature throughout the Stratosphere, Mesosphere and Lower Thermosphere. Such studies will help us ascertain the coupling mechanisms between atmospheric regions such as gravity waves, tides and planetary waves, all of which propagate throughout the atmosphere, and coupling phenomena such as Sudden Stratospheric Warmings.

The fully upgraded ALO Rayleigh lidar is in a prime location to make comparisons with many different instruments also located at ALO and USU including: the Na Lidar, Airglow imagers and temperature mappers, a meteor wind radar and an Ionosonde, as well as satellite-based instruments. With whole groups of different, but complimentary, instruments conducting data campaigns together, we will be able to gather the most complete observations of the whole middle atmosphere.