Comparison of Coincident Rayleigh-Scatter and Sodium Resonance Lidar Temperature Measurements from the Mesosphere-Lower-Thermosphere Region

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Introduction

Light Detection and Ranging (lidar) is a ground-based remote sensing technique that has been used to study the middle and upper atmosphere for over four decades [1, 2]. Atmospheric lidars transmit laser beams into the atmosphere and then use optical and electronic detector systems to measure backscatter resulting from the interaction between the transmitted photons and atmospheric particles. Two of the most widely used lidar techniques for the study the upper atmosphere are Rayleigh-scatter and sodium-scatter lidar

1. Lidar Systems’ Specifications

The original RS lidar system ran at a midlatitude site (42°N, 112°W), on the campus of Utah State University (USU), from 1993-2004 [4]. During this time, it gathered temperature data in the 45-90 km altitude range. It has since had an instrumentation upgrade (see Fig. 1) and has been used to collect temperature data from the 70-115 km range since summer 2014. The Na lidar system ran on the campus of Colorado State University (41°N, 105°W) from 1990-2010 [5]. Since 2010, it has been operating at the same USU site as the RS lidar under the configuration [6] also shown in Figure 1.

2. Lidar Temperature Retrievals

To better compare the two lidar datasets, the temperatures from each lidar, at a given altitude, were plotted in a time series in Figure 3. They show that at and below 90 km, the RS temperatures were generally colder than the Na temperatures. At 95 km and above, the RS temperatures are on average warmer than the Na temperatures.

3. Temperature Comparison

(RS) Lidar and sodium (Na) resonance lidar. RS lidar systems measure elastic backscatter from O2, N2, and Ar particles in the atmosphere. RS lidar backscatter measurements give relative neutral density profiles, which are then used to calculate absolute temperature profiles. Na lidar measures resonant scatter from sodium atoms which form a layer in the 80-105 km region of the atmosphere where meteors typically ablate. From these measurements, Na density, temperature and zonal and meridional winds can be deduced. This comparison of RS and Na lidar temperature data is the first study to show results from collocated two lidar observations [7] presented a comparison of these two techniques from sites several hundred kilometers apart. Their results gave a temperature difference between the two types of lidar and agreement when compared backscatter lidar measurements in this initial study, we will examine 19 nights of simultaneous measurements spread throughout one year.

Figure 3. Comparison of lidar temperatures versus altitude [7] of two nights. Orange curves show Na temperature and green curves show RS temperature.

The two lidars’ temperature retrievals are done using completely different methods. RS lidar temperatures were calculated using a modified version of the Chain-Hauchecorne methodology based on the backscatter power [1, 4]. Na lidar temperatures were derived using the method described in Krueger et al., [2015] which is based on the spectral shape of the returned signal. In Figure 3 (a) and (b) for 85 and 90 km the season variation of the mesopause is observed. There appears to be no seasonal dependence in the temperature differences between the two datasets. Hourly temperature perturbations were calculated from the both lidars’ temperature measurements for 25 Sept 2015. To calculate the perturbations, for each lidar, an all-night average was subtracted from the hourly averages. The two lidars’ simultaneous observations lasted 10 hours, from about 3:30 AM to 12:30 PM UT. There is good agreement between the two lidars’ hourly temperature perturbations. Both lidars capture what appears to be an 8-hour period wave with an amplitude of roughly 20 K and a downward phase velocity of 2 m/s.

Figure 4. Hourly temperature perturbations for 25 Sept 2014 as measured by the RS lidar (top) and Na lidar (bottom).

In Figure 2, we see that over the full measurement year (June 2014-June 2015), the best agreement between the two techniques happens between about 83-90 km. This can also be seen on the temperature difference map in Figure 3 (a) (top) and in Figure 5 (top) where the correlation between the two datasets is greater than 0.9 in this altitude range. The best agreement across the full range of altitudes is seen on the nights of the fall and spring equinoxes (Fig. 2 (b) and (e)). A night close to the fall equinox (25 Sept 2014) was chosen to examine the hourly temperature perturbations from both lidars. The perturbation plots (Fig. 4) show good agreement from hour-to-hour and the same 8-hour wave can be seen in both datasets.

The RS lidar temperature is shown to be colder than those of the Na lidar at 85 and 90 km (Fig. 3 (a) and (b)). A similar observation was made in Argall and Sica, [2007]. They compared RS and Na lidar climatologies from several different sites over an altitude range of about 80-95 km and found that on average the RS temperatures were 7 K cooler. While our data show the RS temperatures being colder, our difference is not as strong—having an average of only about 2 K. At 95 km and above, our data shows that the RS temperatures are on average increasing warmer as one goes up in altitude, reaching an average maximum temperature difference of 16 K at 105 km (Fig. 3 (c)-(e)).

4. Discussion

Conclusions and Future Work

We have presented a comparison of simultaneous temperatures acquired by Rayleigh-scatter and sodium resonance lidars collocated at USU. Several conclusions can be reached through this work:

• The two temperature datasets show the best agreement between about 83 and 90 km.
• The best agreement, spanning all altitudes, is seen near the fall and spring equinoxes (Fig. 2 (b) and (d)).
• Below 90 km, RS lidar temperatures are on average slightly cooler than Na lidar temperatures. At 95 km and above the RS temperatures are significantly warmer than the Na temperatures.
• On an hourly scale, temperature perturbations calculated independently for each lidar’s dataset, show good agreement between the two techniques.
• The two sets of temperatures show better correlation as a function of altitude, temperature and time of year.
• Occasionally, in summer months, the RS lidar observed a lower-in-altitude mesopause, which the Na lidar did not capture (Fig. 2 (g)). These comparisons need to be continued with additional simultaneous observations.

The apparent warmer RS temperatures above 95 km needs to be further investigated.

References