5-2021

Comparisons of Mesospheric Temperatures Between 70 and 110 km: USU Lidar, NASA's TIMED Satellite, and the MSIS2 Empirical Model

David M. Collins
Utah State University

PHYS 4900 Senior Project

Report April 2021

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David M. Collins

Vincent B. Wickwar, Mentor

Physics Department Utah State University

Abstract

Earth's atmosphere can be characterized by its temperature structure, dividing the atmosphere into natural discrete regions. The mesosphere (50 to ~100 km) has been the least studied. Rayleigh-scatter lidars (RSL) and rockets can obtain local, high-resolution measurements above one spot, while satellites looking almost horizontally obtain global measurements. These two methods of measuring atmospheric conditions are compared using the USU RSL and the SABER instrument on NASA's TIMED satellite. These measurements were graphed to show four sets of temperatures from several sources in the atmospheric region 70 km to 110 km above USU. The results show similar temperatures for many of the measured nights and some different temperatures, especially in the winter months.

Introduction

Study of the atmosphere is characteristically divided by the atmosphere's naturally occurring regions. The mesosphere extends from 50 km to ~100 km and is the least studied of these regions. Ground-based instruments, such as USU's green beam Rayleigh-scatter lidar (RSL), can be used to obtain atmospheric data in the mesosphere by observing the scattering of photons from gas molecules in the atmosphere to measure the number density. Absolute temperatures can then be derived from these measurements [1]. Other methods of measuring this region include rockets and satellites.

The Rayleigh-scatter lidar (RSL) at USU has been collecting data on a portion of the mesosphere since 1993. In 2014 and 2015, these measurements started at 70 km and were extended upward from 95 km to 110 km. Measurements in this region were also made by the SABER instrument on NASA's TIMED satellite and were used for comparison with the RSL measurements [2].

Procedure

The RSL and SABER data were graphed with their uncertainties using Python and compared over the same altitude (70 km to 110 km) and temperature (125 K to 325 K) ranges for each night. Viable nights had enough information to compare within the specified range. The RSL temperatures had already been reduced using two methods: the Hauchecorne-Chanin (HC) method and the newer Optical Estimation Method (OEM). These temperatures were compared to the SABER temperatures. Also included in these graphs and labelled as MSIS2 were profiles from the NRLMSIS2.0 empirical atmospheric model [3] .

After the graphs for each viable night were created and analyzed, averages for each month of the analysis were created. The graphs were examined, and the errors propagated for each individual night from the RSL and SABER measurements.

There were three regions of interest in these graphs. The regions from 70 km to 80 km, where there was much agreement expected; 80 km to 95 km, where the measurements were expected to coincide; and the region from 95 km to 110 km, where agreement was uncertain. These regions were used in the analysis to identify coincidences between the

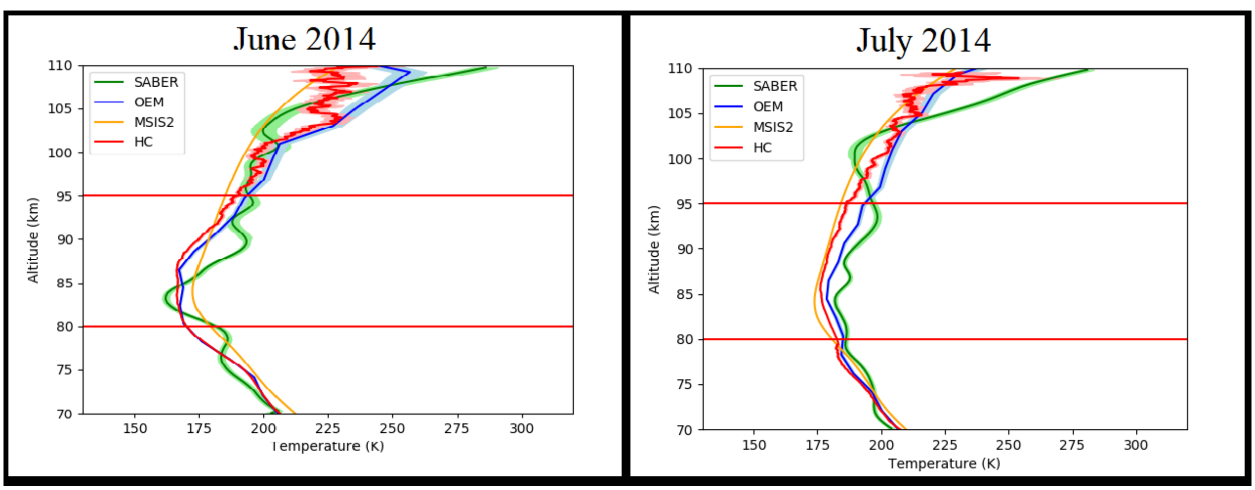
SABER and RSL data.

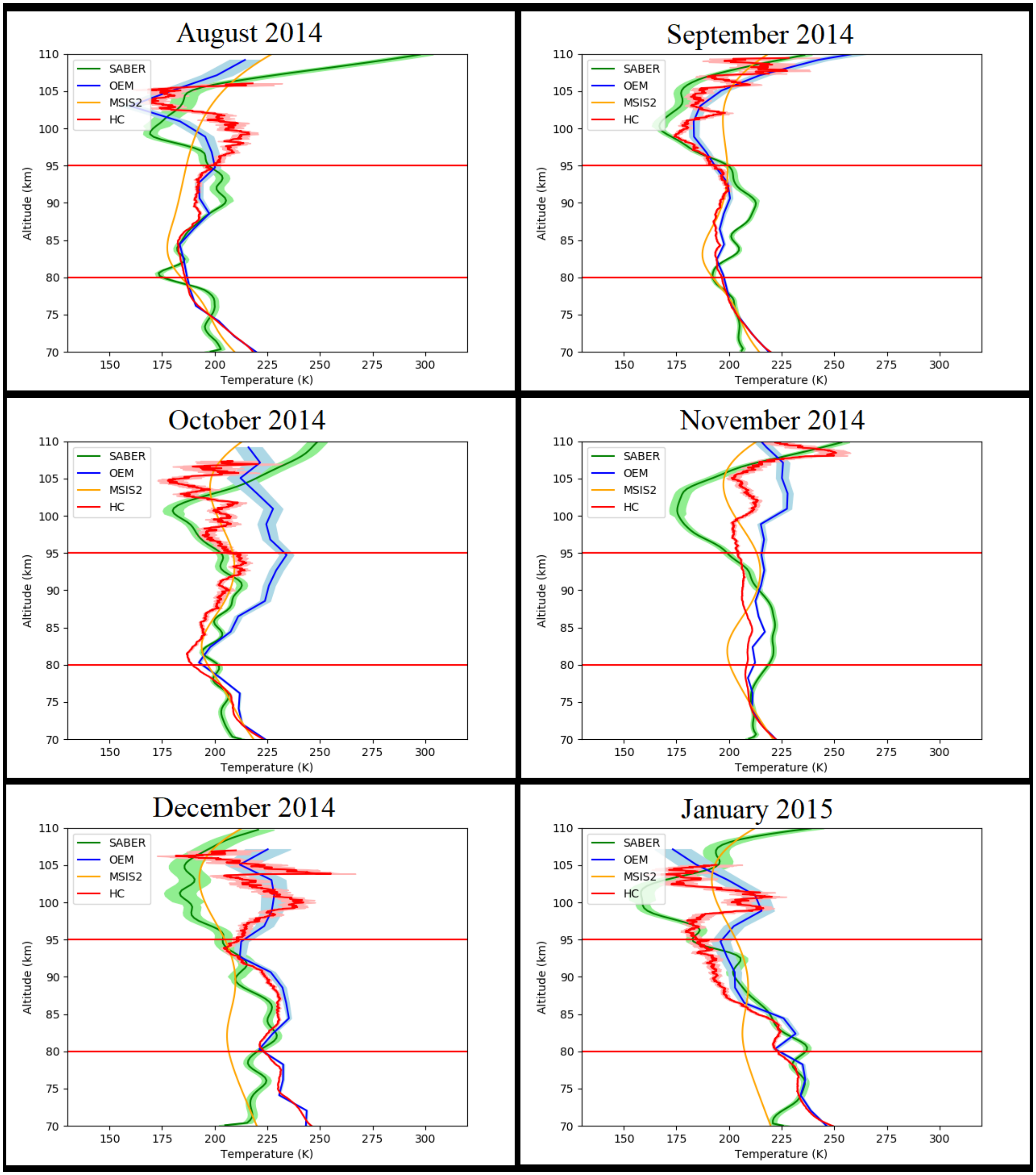
Data and Analysis

All the curves showed good similarity in June and July with a distinct mesopause near 85 km,which was expected. The SABER temperatures were significantly higher than any of the others above 105 km. Temperatures in this region were expected to increase toward the higher thermosphere temperatures. However, it was only the SABER temperatures that increased significantly.

The temperatures below 85 km agreed very well between SABER, RSL, and the MSIS2 model for June through September, February, and March. However, in October through January,the temperatures at 95 km and above showed up to 25 K differences. In all months, The SABER temperatures dropped to a minimum near 100 km, creating a difference of up to 50 K below the other temperatures at that altitude. In particular, the RSL temperatures did not show these low temperatures.

The MSIS2 model temperatures at 85 km and below in December and January were also considerably lower than the observed RSL and SABER temperatures, but this could have been due to the lack of viable nights with comparable data during those winter months. Several of the nights in the winter months were discarded from these averages because of instrumental concerns. This can be seen in the behavior of the RSL and SABER data in the graphs of the monthly averages (see Figure 1).




August 2014
September 2014
October 2014
November 2014
December 2014
January 2015
SABER
OEM
MSIS2
HC
Altitude (km)
Temperature (K)
110
105
100
95
90
85
80
75
70
150
175
200
225
250
275
300

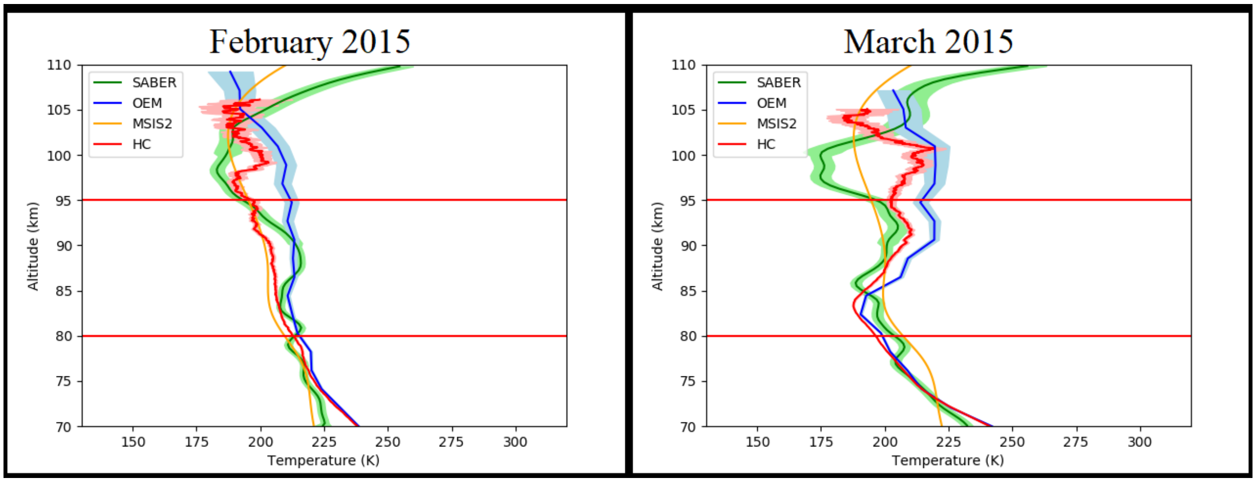


Figure 1. Comparison graphs of the averages of the RSL (both HC and OEM), SABER, and MSIS2 temperatures available for each month. For each graph, the green lines are the temperatures recorded by SABER, the blue lines are the RSL temperatures reduced using the new Optimal Estimation Method (resolution of 2 km), the yellow lines are the from NRL's newest empirical model, and the red lines are the RSL temperatures reduced using the original Hauchecorne-Chanin method. The horizontal lines are the different areas of interest to identify coincidences at different atmospheric subregions. A link to the graphs for individual days is found in Addition Resources.

Conclusions and Future work

The LIDAR measurements showed considerable agreement with the SABER data for the regions of interest, especially for months with more data. But there are important differences that need continuing analysis. These differences could come from many sources, such as instrument error or incorrect assumptions in the analysis. One item of interest is the SABER data's pattern to sharply increase above 105 km, which the RSL temperatures and the MSIS2 model lack. This pattern difference could be caused by the measuring methods and the atmospheric compositions for the recorded nights in this study. The noted correspondences seen in the results demonstrate that the readings and analysis for the higher altitudes from a green beam RSL have potential to be a future method of measuring these altitude regions.

Acknowledgements

The author recognizes Jonathan Price for his assistance in acquiring the SABER data that was used in this study, the USU RSL data, and in the comparisons and analysis of the graphs. The author also recognizes those responsible for production of USU RSL data.

References

[1] Wickwar, Vincent B, Herron, Joshua P, Wynn, Troy A, Lundell, Eric M. “Results from the Middle Atmosphere with the Rayleigh-Scatter Lidar at USU’s Atmospheric Observatory .” Digital Commons, USU, Aug. 2004, digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1010&context=atmlidar_post.

[2] Remsber, E. E., Marshall, B. T., Garcia-Comas, M., Krueger, D., Lingenfelser, G. S., Martin-Torres, J., et al. (2008). Assessment of the Quality of the Version 1.07 Temperature-versus Pressure Profiles of the Middle Atmosphere from TIMED/SABER. Journal of Geophysical Research, vol. 113, no D17, doi:10.1029/2008jd010013.

[3] Emmert, J. T., Drob, D. P., Picone, J. M., Siskind, D. E., Jones, M. Jr., Mlynczak, M. G., et al. (2020). NRLMSIS 2.0: A whole-atmosphere empirical model of temperature and neutral species densities. Earth and Space Science, 7, https://doi.org/10.1029/2020EA001321

Additional Resources

Link to graphs and poster: https://bit.ly/3t4xiAe