6-27-2004

Mesospheric Mid-latitude Density Climatology above Utah State University

Eric M. Lundell

Vincent B. Wickwar
Utah State University

Mesospheric Mid-latitude Density Climatology above Utah State University

Eric M. Lundell and Vincent B. Wickwar
Center for Atmospheric and Space Sciences
Logan, Utah 84322

Abstract Lidars have been used extensively to derive temperatures, but not absolute densities, in the mesospheric region of the atmosphere. We used observations since 1993 with the Rayleigh-scatter lidar at the Atmospheric Lidar Observatory (ALO) at Utah State University (41.7ºN, 111.8ºW) to create an absolute density climatology between 45 and ~95 km. The observations provide profiles of relative density to which an absolute scale is attached by normalizing the profiles at 45 km to the densities in the MSISe00 empirical model. We examine the density variations on several time scales—during the climatological year, from year to year, and over several weeks. We also compare the densities to those in the MSISe00 model.

INTRODUCTION

Lidars (Light Detection And Ranging) have been used extensively to remotely sense the Earth's atmosphere. Lidars have been used to measure aerosols; various wave phenomenon such as gravity waves, tides, and planetary waves; mesospheric inversion layers, and temperatures. Because of the limited altitude range of several techniques like radiosondes and radar, and the cost of others like rockets, lidars have become increasingly important for making ground-based observations from the stratosphere to the lower thermosphere, 30–105 km.

Since 1993 a large database of nearly 600 good nights of Rayleigh-scatter data from the mesosphere between 45 and ~95 km has been acquired at ALO (www.usu.edu/alo). This database has been examined to derive temperatures[1–3], detect noctilucent clouds[4], analyze tides and planetary waves[5], analyze gravity waves, and investigate mesospheric inversion layers (MILs). In this report, we derive a climatology of mesospheric neutral densities and examine its behavior.

PROCEDURES

On clear nights, laser light is shot towards zenith. Scattered light is received by a telescope, analyzed through a data acquisition system, and saved to a computer. The data acquisition process is the same as used for temperatures[3].

In selecting good data, the following three criteria are used:

- For each 2-minute integration, the mean count per altitude bin in the background region, 100–120 km, must be less than 20. (This eliminates twilight and periods when city lights are scattered from clouds.)
- The background count must be constant in altitude. (Avoids signal-induced noise.)
- The signal count per bin at 45 km must be greater than 60. (A typical value is 300.)

Relative densities are found by integrating the Rayleigh signal over 3 km in altitude and for various periods in time, correcting for range squared, and adjusting the altitude for the elevation of the lidar (1.47 km above mean sea level).

Profiles of relative density are normalized at 45 km to a measure of the absolute density, in this case the densities, $Dmod_j$, in the empirical MSISe00 model[6]. The data integrations in time vary, depending on the problem being addressed. Examples include night, Dn_i; a multi-year 28-night average, $DN28_i$; or a climalological average of all the nights, *DTot*. The comparison model integrations vary from a 28-day average, $DMod28_j$; to a 12-month average, *DMod*.

RESULTS

Because densities change by 3 orders of magnitude between 45 and ~95 km, they are best displayed as a percentage difference from a reference. **Figure 1** shows how the densities vary during the year relative to the climatological mean density, $(DN28_i\text{-}DTot)/DTot$. (To better bring out general features, the densities had additional smoothing, running averages over 1.5 km in altitude and 14 nights.) The figure shows that in the upper mesosphere, near 70 km, the densities vary from 23% below *DTot* in January to 23% above *DTot* in June. This is a large 60% density increase in summer relative to winter. While the densities in Fig. 1 are normalized to the model at 45 km, their variations at higher altitudes depend on the observations. **Figure 2** shows, for comparison, the relative variability of MSISe00, $(DMod28_j\text{–}DMod)/DMod$. Additional smoothing as in Fig. 1 has been applied. The patterns are similar, but the observed density depletions are deeper. The area of maximum density is also smaller and lower in altitude than that found in the model.

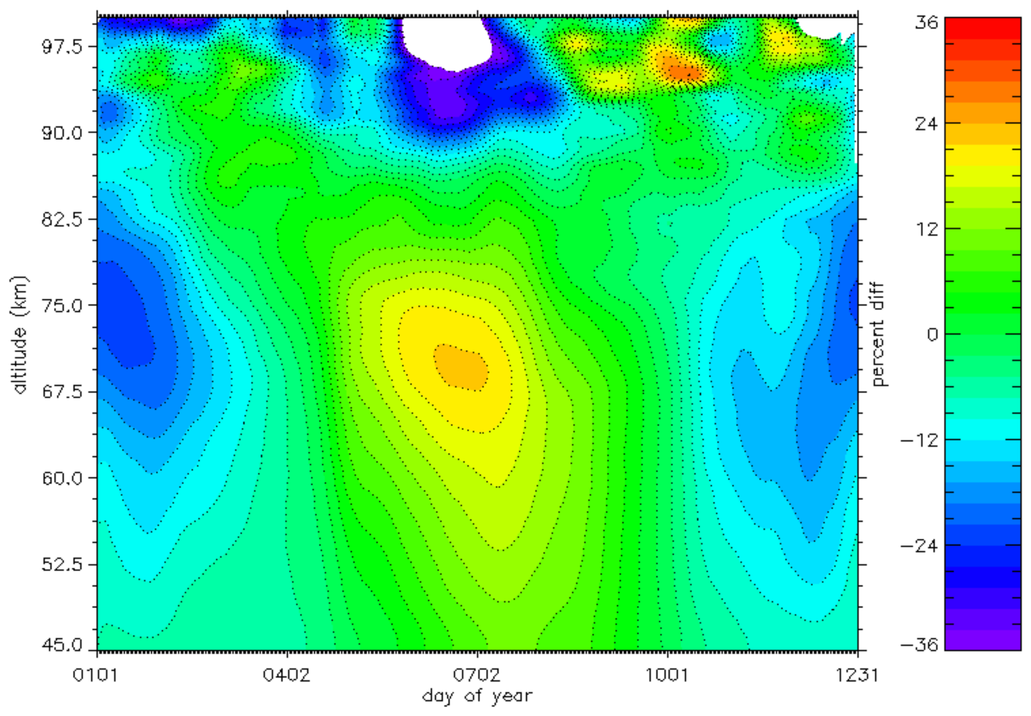

FIGURE 1. Variation of density differences relative to the climatological mean density. Densities normalized to MSISe00 at 45 km. (See text for details.)

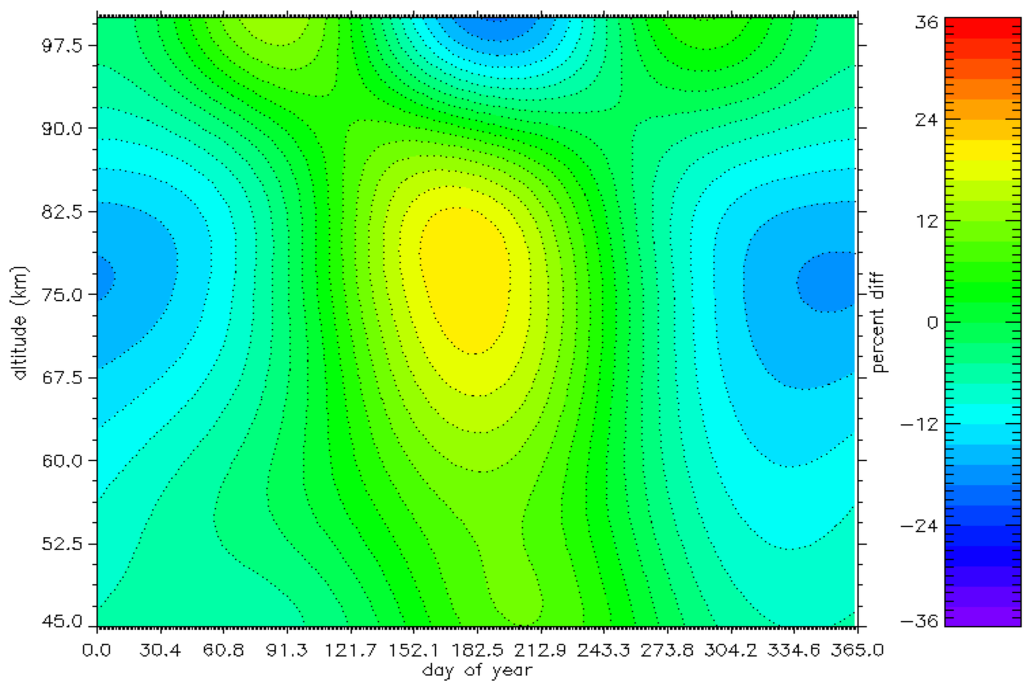

FIGURE 2. Variation of MSISe00 density differences relative to the mean MSISe00 value.

Figure 3 shows how the density climatology compares to the MSISe00 model densities, $(DN28_i\text{–}DMod28_i)/DMod28_i$. (To bring out general features, additional smoothing has been applied as in Figure 1.) The most noticeable feature is the "Y"-shaped feature centered on the summer solstice in the lower mesosphere. The two "arms" show densities greater than the model, with a maximum at about 85 km. In early March the maximum is 15%; in late October it is 9%. Between these "arms", near summer solstice is

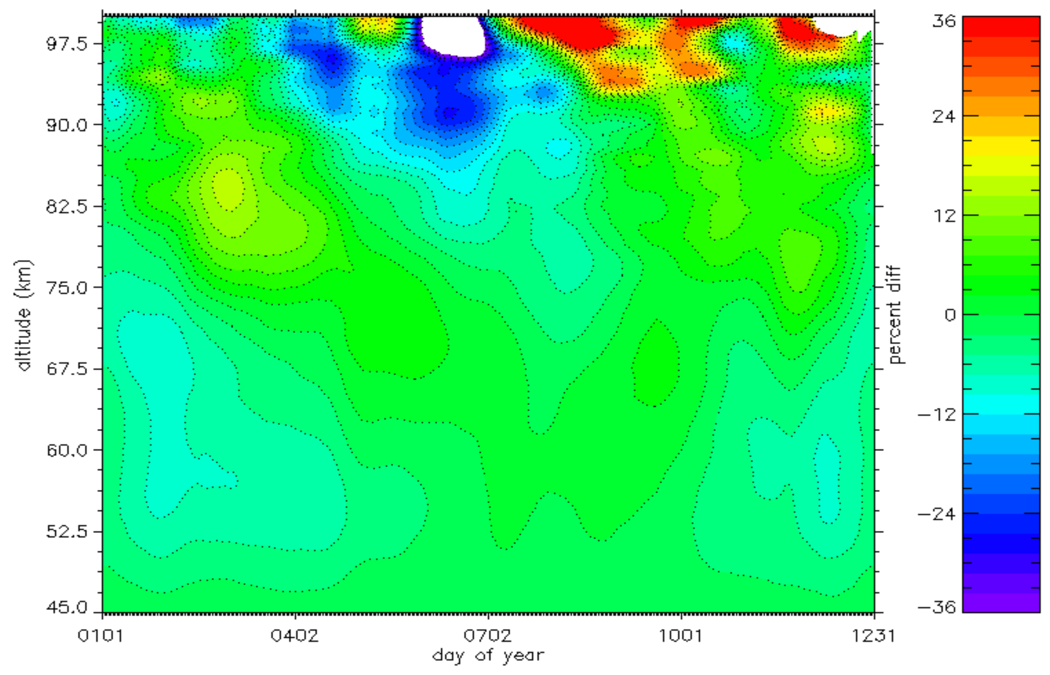

FIGURE 3. Variation of density differences relative to the MSISe00 model. Densities normalized to MSISe00 at 45 km.

the largest difference, a density depletion of 25% above 90 km. In early spring and late fall in the lower mesosphere, 50–70 km, a 7% density depletion occurs.

Figure 4 shows the interannual density variability given by $(Dn_i\text{-}DTot)/DTot$. Each night is normalized to MSISe00 at 45 km. To bring out general features and bridge short data gaps, the densities were additionally averaged over 28 days. Bridged short data gaps give rise to periods of constant densities. Small data gaps are due to either the laser being down or lack of good data. The large data gap in 1997 arose from lack of funding. The upper cutoff, where the noise drops below 16 standard deviations, is lower that in the other figures because it is based on 1-night averages instead of multi-year 28-night averages.

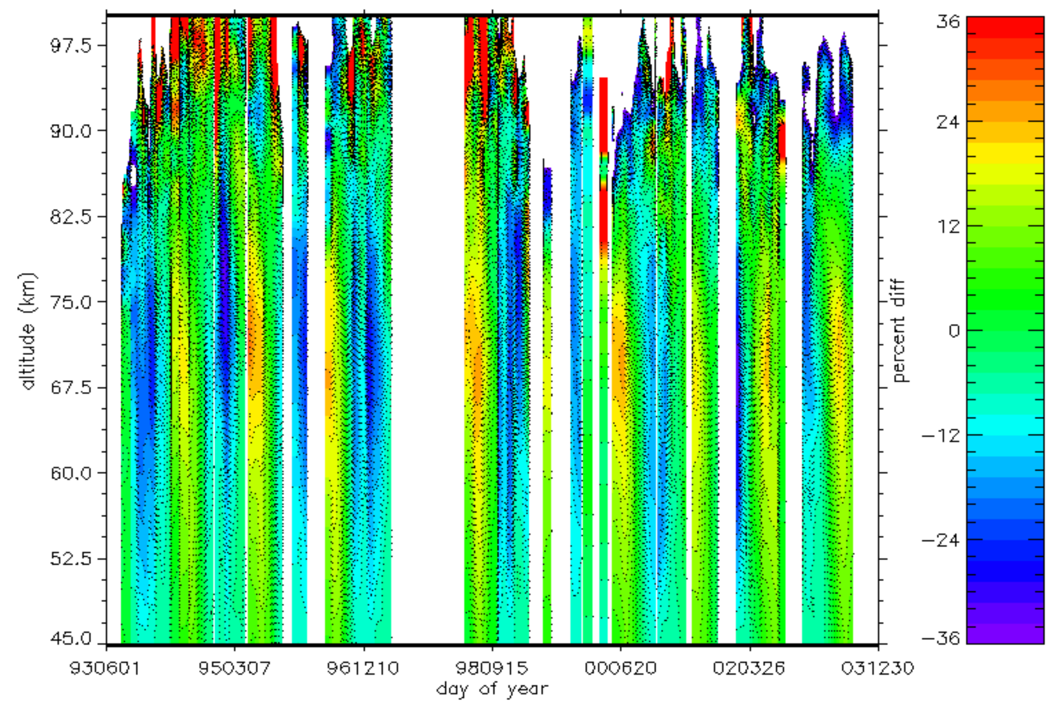

FIGURE 4. Interannual variability of density differences relative to the climatological average. Densities normalized to MSISe00 at 45 km.

The interannual variability is roughly a factor of 2. In winter, densities drop between −10% and −18% below the average density. The altitude of the minimum also varies, probably reflecting interannual variability in the mesospheric inversion layers. In summer, the densities rise by between 10% and 22%. In addition the last 3 winters, as a group, are more dense by about 9% than all the previous winters. Similarly, the last 3 summer are about 1% less dense than the previous ones.

Considerable density variation also occur on still shorter time scales. **Figure 5** shows daily density differences relative to the overall average, $(Dn_i\text{-}DTot)/DTot$, for 3 periods within 5 weeks during winter. Presumably these differences are the density manifestation of MILs.

The first 2 profiles are from late December 1994; the next 4 from early January 1995; and the last 4 from late January 1995. Each day is offset from the previous one by a 25% difference. Each group shows distinctly different profiles. In all cases there is reduced density in the upper mesosphere, as seen in Figure 1. However, the altitude of the minimum varies considerably. In January, the minimum density is considerably lower in the second group than in the first, reaching 35% below the climatological mean. There is also a density increase at the highest altitudes, which moves up and down in altitude along with the density reduction. Overall, there appears to be a month-long downward progression of these features.

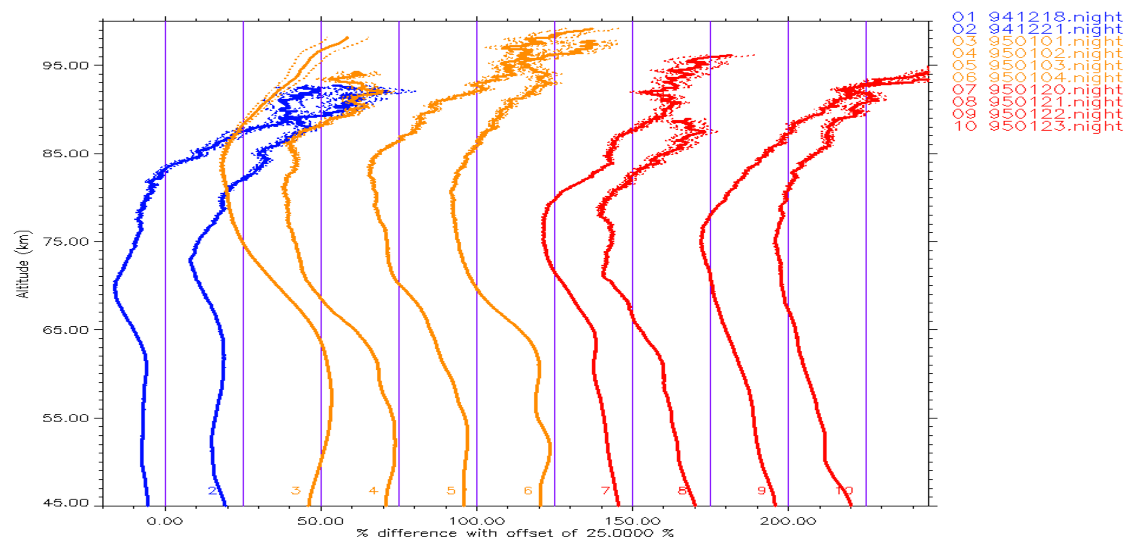

FIGURE 5. Variability of density differences relative to the overall average for 3 winter periods within 5 weeks. Densities normalized to MSISe00 at 45 km.

CONCLUSIONS

- A mesospheric density climatology has been derived from 10 years of ALO Rayleigh-scatter lidar data. Here, it is normalized to MSISe00 absolute densities at 45 km. (In the future, the ALO relative densities could be normalized to another source of absolute densities.)
- At higher altitudes, it shows differences of up to 25% from the MSISe00 densities.
- The climatology shows summer densities 60% greater than winter densities in the upper mesosphere.
- It shows considerable interannual variability: 10–18% depletions in winter and 10–22% enhancements in summer.
- It may also show greater densities in the most recent data compared to older data.
- In winter, the MIL signature appears to be density depletions of up to 35% in the upper mesosphere and density increases at the very highest altitudes.

ACKNOWLEDGEMENTS

We gratefully thank Joshua Herron for his work with the raw data and the many people who made the observations. This project was in part supported by NSF grant ATM-01234145.

REFERENCES

[1] Shepherd, M.G., B. Reid, S. Zhang, B.H. Solheim, G.G. Shepherd, V.B. Wickwar, and J.P. Herron, Retrieval and validation of mesospheric temperatures from Wind Imaging Interferometer observations, *J. Geophys. Res.*, *106* (A11), 24813–24829, 2001.

[2] Wickwar, V.B., T.D. Wilkerson, M. Hammond, and J.P. Herron, Mesospheric temperature observations at the USU / CASS Atmospheric Lidar Observatory (ALO), in *Remote Sensing of the Atmosphere, Environment, and Space*, edited by U.N. Singh, T. Itabe, and N. Sugimoto, pp. 272–284, Proceedings of SPIE, 4153, 2001.

[3] Herron, J.P., Mesospheric temperature climatology above Utah State University, MS thesis, Utah State University, Logan, 2004.

[4] Wickwar, V.B., M.J. Taylor, J.P. Herron, and B.A. Martineau, Visual and lidar observations of noctilucent clouds above Logan, Utah, at 41.7°N, *J. Geophys. Res.*, *107* (D7), 10.1029/2001JD001180, 2002.

[5] Nelson, K.L.M., Lidar Observations of Oscillations in the Middle Atmosphere, MS thesis, Utah State University, Logan, 2004.

[6] Hedin, A.E., Extension of the MSIS thermosphere model into the middle and lower atmosphere, *J. Geophys. Res.*, *96* (A2), 1159–1172, 1991.

ALO, 2004