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Mesospheric Mid-latitude Density Climatology above Utah State University

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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 (41.7°N, 111.8°W) 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.

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, \( (D_{\text{Norm}} - D_{\text{Mod}})/D_{\text{Mod}} \). (To 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 \( D_{\text{Tot}} \) in January to 23% above \( D_{\text{Tot}} \) 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, \( (D_{\text{Mod}28} - D_{\text{Mod}})/D_{\text{Mod}} \). 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, \( (D_{\text{Norm}} - D_{\text{Mod}28})/D_{\text{Mod}28} \). (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 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 \( (D_{\text{Norm}} - D_{\text{Tot}})/D_{\text{Tot}} \). 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 20 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 in the other figures because it is based on 1-night averages instead of multi-year 28-night averages.

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

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 occurs on still shorter time scales. Figure 5 shows daily density differences relative to the overall average, \( (D_{\text{Norm}} - D_{\text{Tot}})/D_{\text{Tot}} \), for 3 periods within 5 weeks during winter. Presumably these differences are the density manifestation of MILs.

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.

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REFERENCES sleep