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# Seasonal Variations of Relative Neutral Densities between 45 and 90 km Determined from USU Rayleigh Lidar Observations.

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## Abstract

**A Rayleigh-scatter lidar operated at the Atmospheric Lidar Observatory (ALO; 41.7°N, 111.8°W), part of Center for Atmospheric and Space Sciences (CASS) on the campus of Utah State University (USU), collected extensive data between 1993 and 2004. From the Rayleigh lidar photon-count profiles, relative densities were determined throughout the mesosphere, from 45 to 90 km. Using these relative densities three climatologies were derived, each using a different density normalization at 45 km. The first normalized the relative densities to a constant; the second to the NRL-MSISe00 empirical model which has a strong annual component; and the third to the CPC analyses model, which is similar to MSIS in that it has a strong annual oscillation. In each case the density profile for every night of a composite year was found by averaging the nighttime density profiles over a 31-day by 11-year window centered on that day. For each of the cases, the average annual density profile was found by averaging all the days. Then the daily percent differences were found relative to the annual density profile. Despite the different normalizations at 45 km, many common features were found in the seasonal behavior of the density profiles, a large seasonal variation maximizing in June at ~70 km, Another above 80 km is a large shift in the maximum to earlier in the year, and lastly sharp density fall off at almost all altitudes in early October. While these density normalizations provide initial information about mesospheric behavior, the current lidar upgrade will enable us to add an absolute scale to the density profiles.**


## Introduction

**Rayleigh lidar has been the major Ground-based technique for making mesospheric observations of absolute temperatures. Figure 8 shows The green (532 nm) laser beam from the upgraded Rayleigh lidar at the Atmospheric Lidar Observatory on the campus USU. It's predecessor operated from 1993 to 2004 collecting neutral relative number density and neutral absolute temperature data from 45-90 km. Figure 1 shows the 11-year temperature climatology (Herron, 2007). These show very distinct variations in both time and altitude. The densities have been studied much less because they are relative, not absolute. Here, we explore the neutral densities using 3 different normalizations at 45 km. The first, labeled "USU", is a constant value throughout the year. The second, labeled "MSIS", uses densities from the NRL-MSISe00 model (Picone et al., 2002) for each day of the year, this normalization is used due to popularity. The third, labeled "CPC", is an older meteorological model from the Climate Prediction Center (Gelman et al., 1986). It's values were applied to each night of data. A significant point is that despite the different normalizations, many of the same features are observed in all three case, but each model also has features that are unique.**

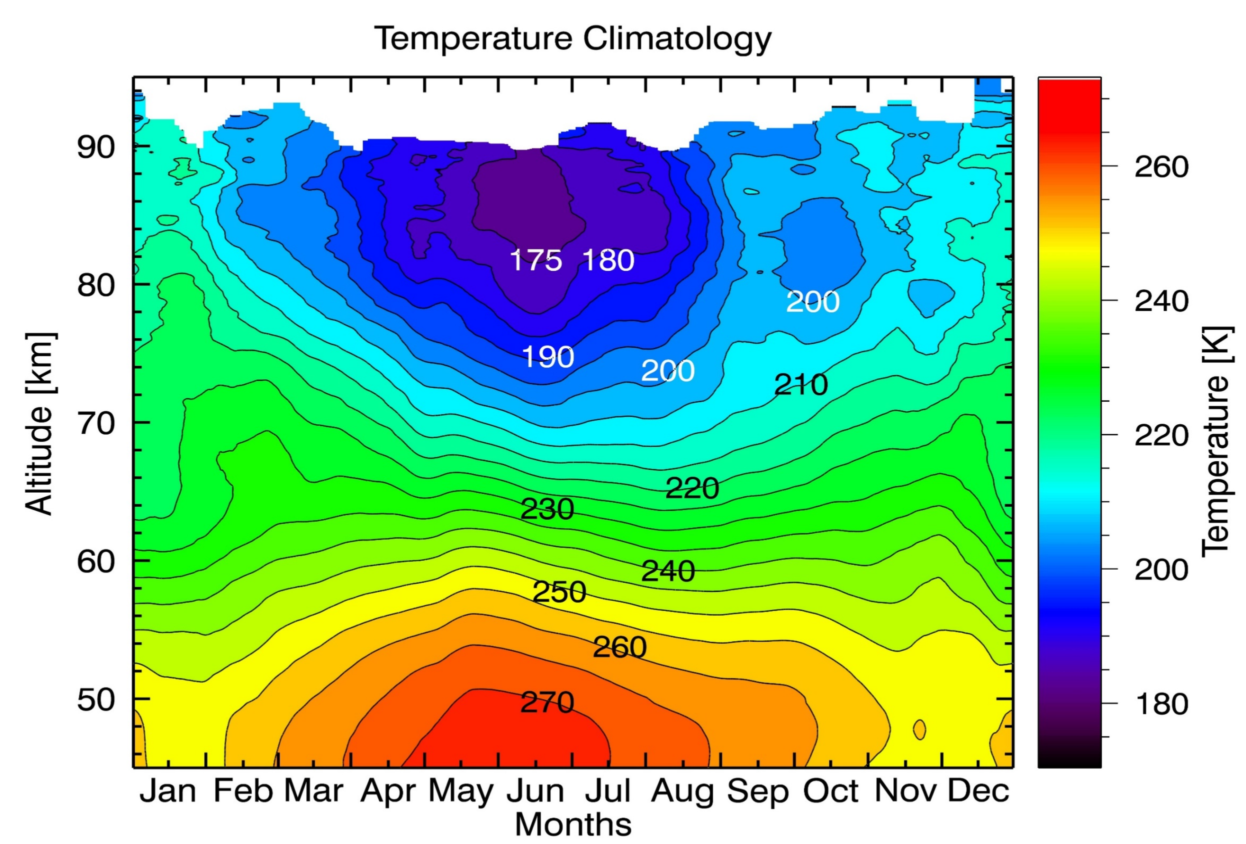


**Figure 1.** ALO Temperature Climatology. The Temperature climatology is found by taking the absolute all-night temperatures and averaging them over 31 days by 11 years, creating a composite year. This temperature climatology enables us to determine significant seasonal phenomena and altitude variations as well as special events where temperatures on individual days depart significantly from the climatology. The seasonal variation that is the most noticeable in the climatology is that the summer months show the largest temperature differences. Below 55 km the temperatures are the hottest in June. Above 75 km, up to approximately 90 km, the temperatures are the coldest in June.

## Analysis Procedures

### Data Reduction

**To calculate the relative densities from the lidar photon counts, the 2-minute raw data profiles were averaged for the entire night and the background was subtracted to obtain a signal profile for the whole night. The background-subtracted signal was then multiplied by range squared to obtain a relative density profile for the entire night. The profiles spanned the region from 45 to approximately 90 km. Because the range of densities vary by 3 orders of magnitude in this region, in figures 5-7 it was necessary to take the percent variation from the mean to better show what is happening throughout the year.**

### Method

**Three methods were used to normalize these relative density profiles at 45 km (Figure 2). The "USU" method normalized the densities to 4x10$^{22}$ m$^{-3}$. The "MSIS" method used values from the NRL-MSISe00 model normalized to each day of the composite year. The "CPC" method used CPC analysis data to normalize each of the 964 observed nights. The all-night profiles were averaged over 31 days by 11 years to create a composite year of profiles *n*(*h*). These averages are displayed at 3 selected altitudes in Figures 2-4. In addition, an annual average density profile <*n*(*h*)> was created by averaging all the days in each composite year. This was then used to find the relative density variations throughout the year, $\Delta n_R(h) = [n(h) - \langle n(h)\rangle] / \langle n(h)\rangle$. These relative density variations are shown as percentages in Figures 5-7.**

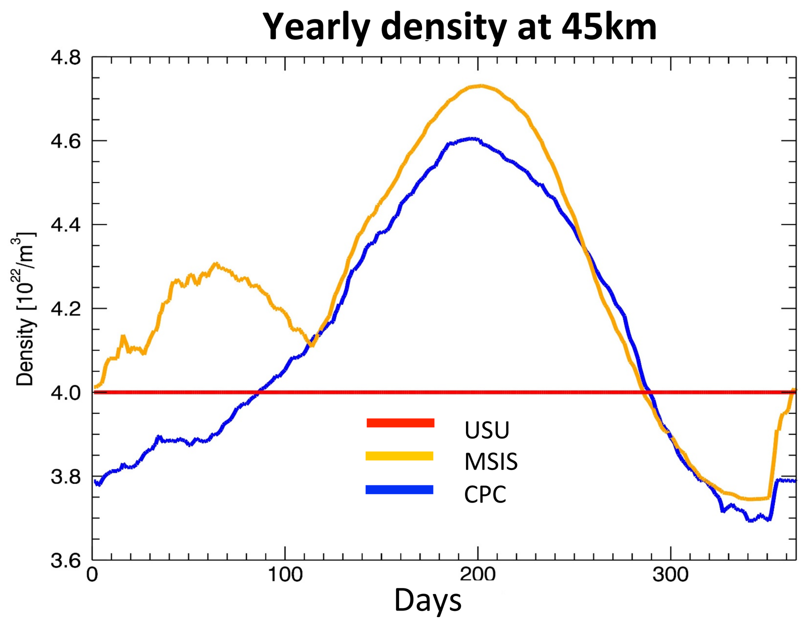


**Figure 2.** Normalization densities at 45 km. The USU normalization is a constant, set at 4x10$^{22}$ m$^{-3}$. The MSIS normalization has an annual oscillation with maxima at day 210 (July 29$^{th}$). There is also a Smaller maxima around day 60 (March 1$^{st}$). The CPC normalization has a large annual oscillation with a maximum near day 200 (July 19$^{th}$). CPC and MSIS look similar at this altitude.

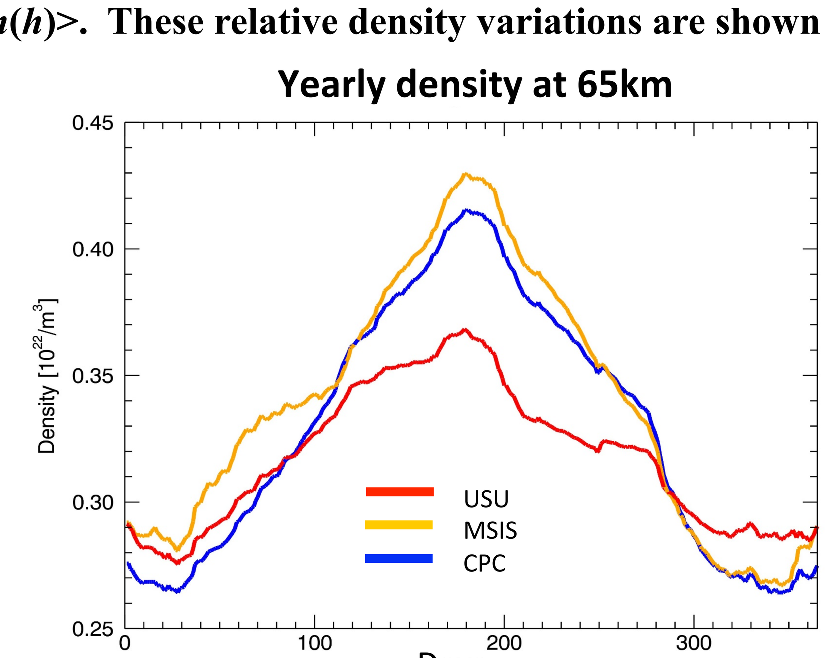


**Figure 3.** Inferred annual density variations at 65 km. All three normalizations are dominated by the annual variation with a summer maximum at day 180 (June 29$^{th}$) and a winter minimum at day 28 (Jan. 28$^{th}$). In the USU curve there is a distinct shoulder near day 270 (Sept. 27$^{th}$), followed by a sharp drop off after day 275 (Oct 2$^{nd}$). This shoulder also appears in the CPC and MSIS curve with its slow fall off after day 180 and sharp drop off after day 275. Each normalization has a peak around day 180 (June 29$^{th}$).

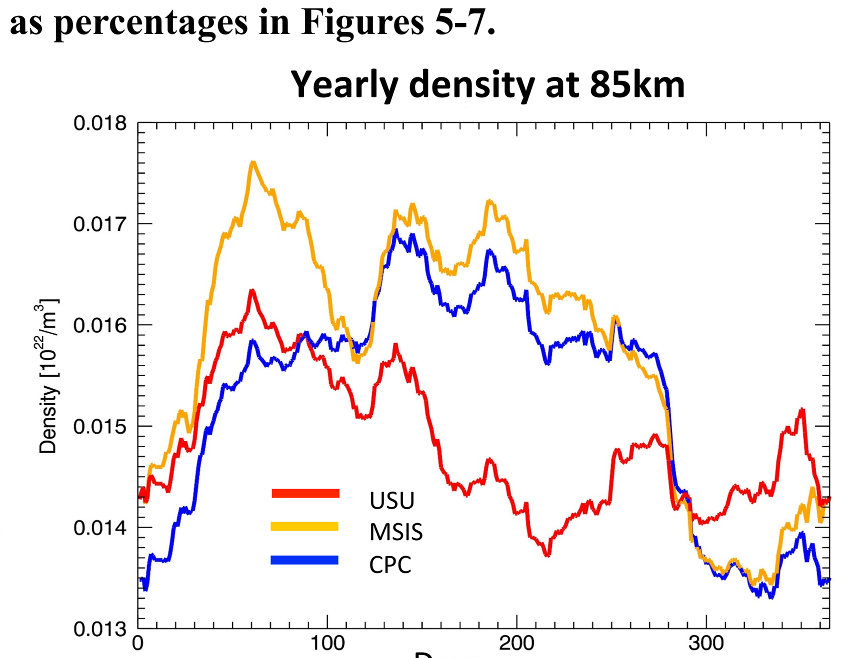


**Figure 4.** Inferred annual density variations at 85 km. Many of the features have shifted earlier and become more complicated (and noisy). A sharp rise rise shifts earlier, Occurring in February. The maximum at day 180 in Fig 2 shifts to day 138 (May 18$^{th}$) and, depending on the curve, may only be a relative maximum. A sharp fall off occurs right after day 275 as at 65 km. A relative minimum exists at approximately day 1 (Jan. 1$^{st}$) for USU and CPC. This minima does not occur in MSIS.

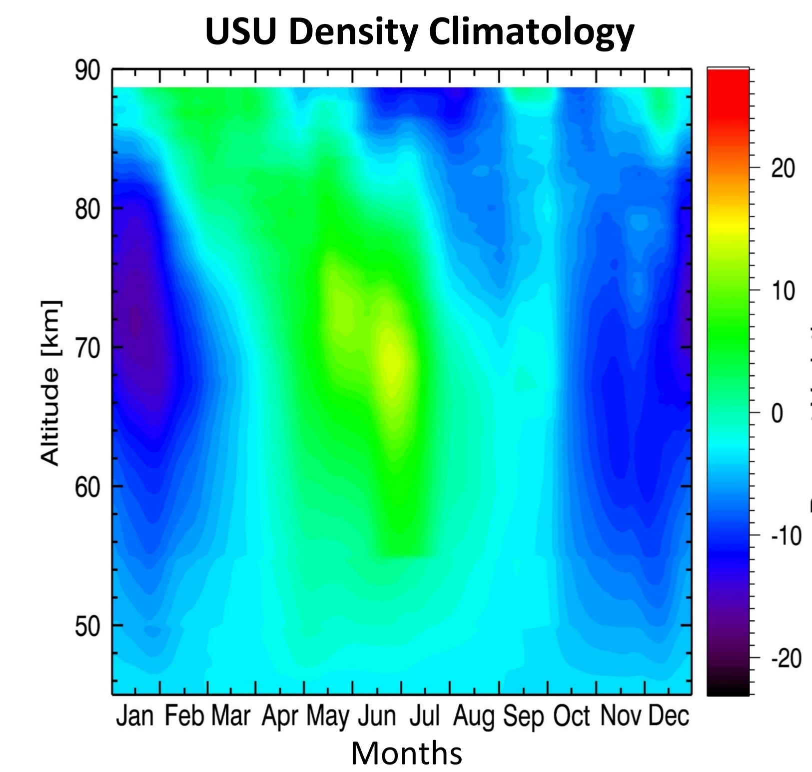


**Figure 5.** Climatology of relative density differences — USU. The lowest relative density occurs near 70 km in January; the greatest near 70 km in late June. The greater relative densities occur earlier at higher altitudes, setting in above 85 km in January. And they have a relative minimum in July and August. At 70 km The relative densities increase rapidly from winter to summer and fall off more slowly after the relative maximum. In early October an abrupt fall off occurs at essentially all altitudes. Also note the minimum at 86 km around June.

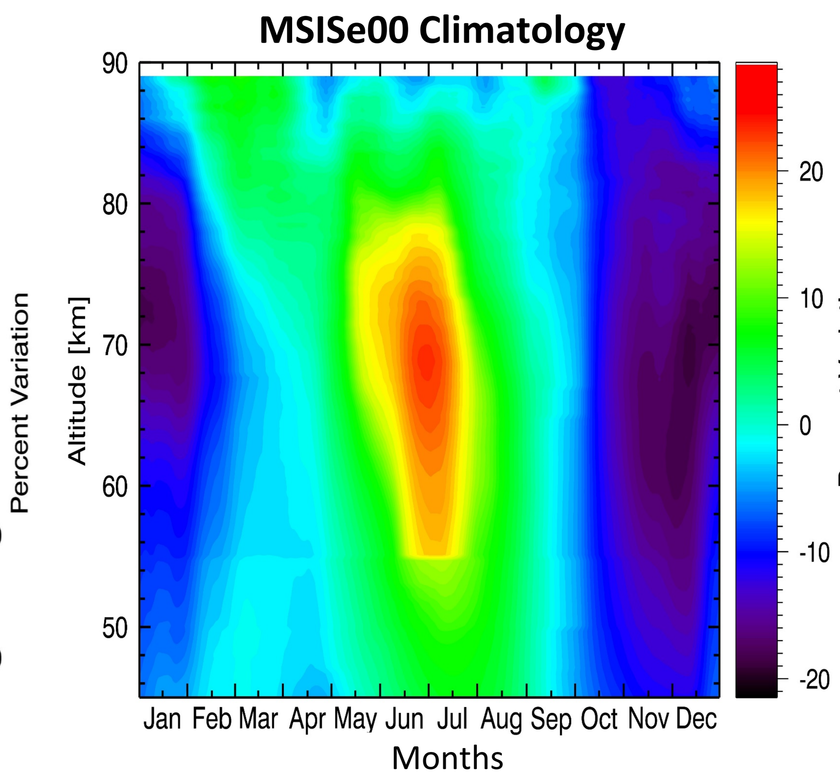


**Figure 6.** Climatology of relative density differences — MSIS. Because of the large annual variation imposed at 45 km, this analysis shows a large relative variation throughout the year. The lowest and highest relative densities occur near 70 km in December and in late June early July, respectively. At the highest altitudes, the relative densities still start to increase in January, but the relatively low densities in July and August are greatly diminished. The abrupt change at all altitudes in the first week of October is more accentuated. There is also a density oscillation at 89 km from March to September

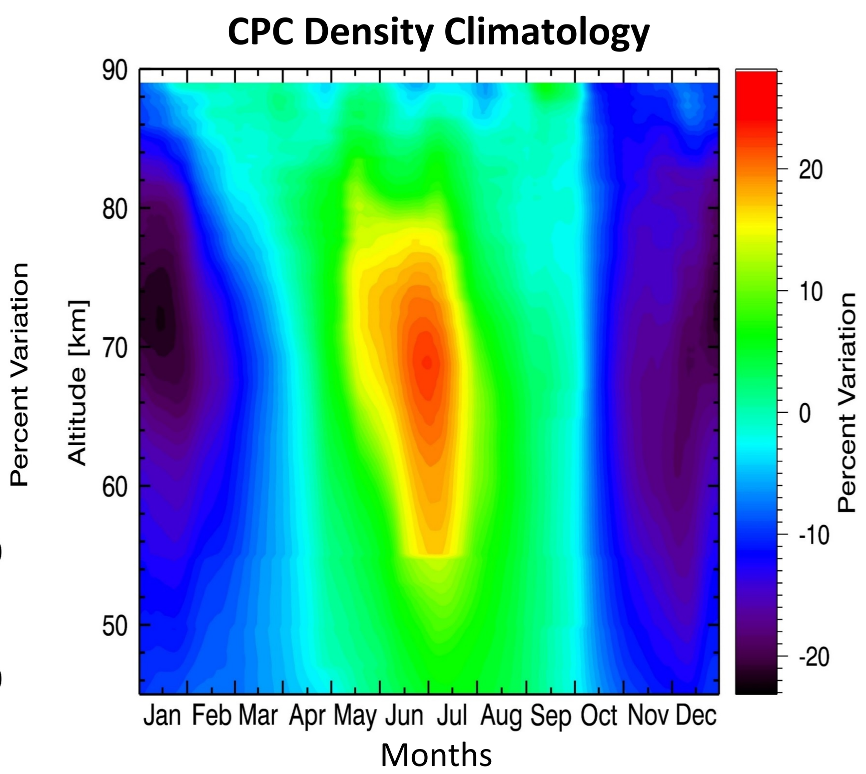


**Figure 7.** Climatology of relative density differences — CPC. This follows a similar pattern to that of the MSIS normalization, particularly above 60 km. This includes a large relative maximum around 70 km and a minimum at 89 km both centered on late June, early July. This phenomena occurs in both MSIS and USU as well. At lower altitudes the normalization has a greater effect on the pattern. The change in densities from Spring to Summer and Summer to Fall is the smoothest throughout all altitudes in this model. This model contains a density oscillation at 89 km between the months of March and September.

## Conclusions

**Three significantly different normalizations were applied at 45 km to 11 years of mesospheric, relative, number density profiles acquired by the Rayleigh lidar at ALO. Despite the different normalizations, many of the same features were seen in the resultant density climatologies as well as some significantly different features. What stands out the most in Figures 2-7:**

- **A very strong seasonal variation in relative densities around 70 km with low relative densities in January and high relative densities at the end of June. Depending on the normalization, the summer-winter variation ranges from ±15% to ±25%.**
- **The increase in relative densities occurs earlier at altitudes above 70 km, starting in January above 85 km and increasing rapidly in February and March. It is followed by a decrease in June and continuing into August for the USU normalization.**
- **Between 85 and 70 km, the density increases have a downward progression of ~1 km every 3 to 4 days. In the USU normalization, the later density decreases have a similar downward progression. (While reminiscent of the downward progression for temperature decreases in the same altitude region and time of the year, the density progression is faster, up to twice as fast.)**
- **At 85 km, this density decrease leads to a minimum in the relative densities in June through August. By 70 km, this minimum is limited to August.**
- **At 85 km the CPC and MSIS normalizations, in contrast, lead to almost constant densities, with perhaps a hint of a slight decrease in July and August. The biggest difference among these normalizations is this very big relative density decrease in July and August in the USU normalization, but not in the MSIS and CPC normalizations.**
- **In September at 85 to 90 km a relative maximum occurs in the densities at roughly all altitudes for all 3 normalizations. It is followed by a dramatic decrease in relative densities at almost all altitudes, simultaneously, a week into October. The appearance of this rapid decrease in density in all of the models in October strengthens the argument that a strong semiannual variation exists in the mesospheric densities.**

## Future Work

**In addition to the MSISe00 model and CPC analyses, additional reanalysis models now exist that will provide neutral densities at 45 km. The effects of these different normalizations will be explored. These density climatologies can also be used to look for unusual events by comparing individual days to the density and temperature climatologies. In addition, a major lidar upgrade is underway, Figure 8. It will enable observations to be carried out to 120 km, i.e., through the mesopause region and well into the lower thermosphere. As part of this upgrade, the observations will also be extended downward to 15 km, i.e., to the lower stratosphere. This will enable density normalization by having an overlap between 15 and 30 km where the reanalysis models are more accurate because of extensive meteorological observations. As a result of this we will have ground-based information on absolute neutral densities extending into the lower thermosphere for the first time.**


**Figure 8.** Upgraded Rayleigh lidar. The original Rayleigh-scatter lidar consisted of a frequency-doubled Nd:YAG laser operated at 532 nm with a repetition rate of 30 Hz. During part of the period, a laser was used that had an average power of 18 W and during the other part it had 24 W. The backscattered light was collected by a 44-cm dia. telescope, focused onto a mechanical chopper, collimated, and passed through an interference filter to a cooled, green-sensitive photomultiplier tube. The new lidar uses both lasers and four 1.25-m diameter mirrors.


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## References


**Picone, J. M., A. E. Hedin, D. P. Drob, and A. C. Aikin (2002), NRLMSISE-00 empirical model of the atmosphere: Statistical comparisons and scientific issues, J. Geophys. Res., 107(A12), 1468, doi:10.1029/2002JA009430.**

**Gelman. M. E., A. J. Miller, K. W. Johnson, and R. N. Nagatani (1986), Detection of long term trends in global stratospheric temperature from NMC analyses derived from NOAA satellite data. Adv. Space Res., 6, 17–26.**

**Herron, J.P. (2007), Rayleigh-Scatter Lidar Observations at USU's Atmospheric Lidar Observatory (Logan, UT) — Temperature Climatology Comparisons with MSIS, and Noctilucent Clouds, PhD Dissertation, Utah State University, Logan, UT.**