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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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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 through the mesosphere, from 45 to 90 km. Using these relative densities the 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-MMS00 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 day of a composite year was found by averaging the nighttime density profiles for a 31-day by 1-day window centered on that day. For each of the cases, the average annual density profile was found by averaging all the days.

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 with 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. Operation began in 1993 to 2004 collecting relative neutral density and neutral absolute temperature data from 45 to 90 km. Figure 9 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-MMS00 model (Picone et al., 2002) for each day of the year, this normalization is useful 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 seen in all three cases, but each model also has features that are unique.

**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 a range squared to obtain a relative density profile for the entire night. The profiles spanned the region from 45 to approximately 90 km. Because of 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^-3. The “MSIS” method used values from the NRL-MMS00 model normalized to each day of the composite year. The “CPC” method used 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. These average all-night density profiles <n(t)> were created by averaging all the days in each composite year. This was then used to find the relative density variations throughout the year. The densities still start to increase in January, but the relative densities in June through August.

**Conclusions**

There were three significant differences normalized were applied at 45 km to 11 years of mesospheric, relative, number density profiles acquired by the Rayleigh lidar at ALO. Despite these different normalizations, many of the same features were seen in the resulting 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 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 maximum 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 slight of a 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 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 MSIS00 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 whole mesosphere 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.

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