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Extremely Sensitive Rayleigh-Scatter Lidar at USU

Vincent B. Wickwar
Utah State University

Leda Sox
Utah State University

David Barton
Utah State University

Matthew T. Emerick
Utah State University

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Rayleigh lidar opened a portion of the atmosphere, from 30 to 90 km, to ground-based observations. Rayleigh-scatter observations were made at the Atmospheric Lidar Observatory (ALO) at Utah State University (USU) from 1993–2004 between 45 and 90 km, creating a very dense data set consisting of ~5000 hours of observations carried out over ~900 nights. The lidar had a mirror of area 0.15 m² and a frequency-doubled Nd:YAG laser operating at 532 nm at ~21 W, giving a power-aperture product (PAP) of ~3.1 Wm². An example of what could be accomplished with this system is the mesospheric temperature climatology in Fig. 1. It was derived using a 3-km altitude resolution and averages over a window of 31 days by 11 years. The sensitivity of the ALO Rayleigh lidar is currently being increased by a factor of 65 to extend observations upward into the lower thermosphere and downward into the lower stratosphere, Fig. 1. The upward extension from 90 to 120 km takes the observations into new territory.

THE UPGRADE

The upgrade has been very extensive. It required a big lidar observatory and the outfitting of a laser and detector laboratory. The telescope collecting area was increased to almost 5 m² by using four co-aligned 1.25-m diameter mirrors. Fibers carry the light from each of the telescopes to the detector system, where the light is combined and detected. The laser power was almost doubled to 42 W by using both 18-W and 24-W lasers. As a result the PAP was increased to 205 Wm².

NEW HIGH-ALTITUDE DATA — 70 TO 112 KM

Data were acquired with the upgraded system from 13 June–12 July 2012, 1 May–1 June 2013, and 20 June 2014. Temperatures were derived from the relative densities using the usual Rayleigh assumptions from 70 km to a maximum of 112 km, Fig. 5 (a–c). The maximum altitude was determined by where the ratio of signal-to-standard deviation dropped to 16. This was controlled by laser power, telescope alignment, detector alignment, seeing conditions, and PMT sensitivity. The initial temperatures came from the MSISe00 model. The minimum altitude was determined by where the response of the high-altitude PMT became nonlinear.

Each of the 25 profiles came, typically, from a 4–6 hour night with a 3-km altitude resolution. The uncertainties derived from Poisson statistics are far less than 1 K at 70 km and ~12 K at the top altitude, Fig. 5c. Averaged results are presented in Fig. 5d.

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Some Initial Results & the Future

A striking result in the new temperatures shown in Fig. 5a is their great variability. Starting at 70 km, the spread is ~20 K. Above 90 km, it increases rapidly becoming 60 K at 95 km. Some of the variability is from clearly defined, long-wavelength waves with different phases. Some, in Fig. 5a & b, are from day-to-day variability. There is also a hint in the averages in Fig. 5d of inter-annual variability. Another result from this great day-to-day variability is that the concept of a mesopause altitude has to refer to an average. On any given day, it can appear lower or higher by many kilometers because of this variability. The limited 2012 and 2013 data have it at 83 km, as does the original ALO climatology, Fig. 5d. The more extensive 2012 data have it at 88 km in close agreement with MSIS.

Below 80 km the averaged temperature curves and the ALO climatology show close agreement. They are consistently lower than MSIS, reaching 10–12 K at 70 km. Above 95 km they show differences from MSIS as great as 30 K.

For the future, the top altitude in this newly accessible region will be increased by improving alignment, switching to a PMT with greater quantum efficiency and, when possible, adding two more lasers.

While this lidar opens the 100–120 km region to ground-based observations at one mid-latitude location, it also shows the possibility of producing affordable instruments operated by a small research groups that could be situated in many locations around the world.