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Vincent B. Wickwar
Utah State University

Leda Sox
Utah State University

Joshua P. Herron
Utah State University

Matthew T. Emerick
Utah State University

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Mid-Latitude Rayleigh-Mie-Raman Lidar for Observations from 15 to 120 km

Vincent B. Wickwar[1], Leda Sox[1], Joshua P. Herron[2], Matthew T. Emerick[1]
[1]Physics and CASS; [2]Space Dynamics Lab; Utah State University, Logan, UT

www.usurayleighlidar.com

BACKGROUND

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. The lidar consisted of a 0.44-m diameter mirror, a frequency-doubled Nd:YAG laser operating at 532-nm at 30-Hz at either 18- or 24-W, giving power-aperture products (PAPs) of 2.7- or 3.6-Wm^2, respectively, and one detector channel. An example of what was accomplished with this system is shown as part of Fig. 1. The temperature climatology was based on ~5000 hours of observations carried out over ~900 nights. The temperatures, with 3-km altitude resolution, were averaged over periods of 31 days by 11 years.

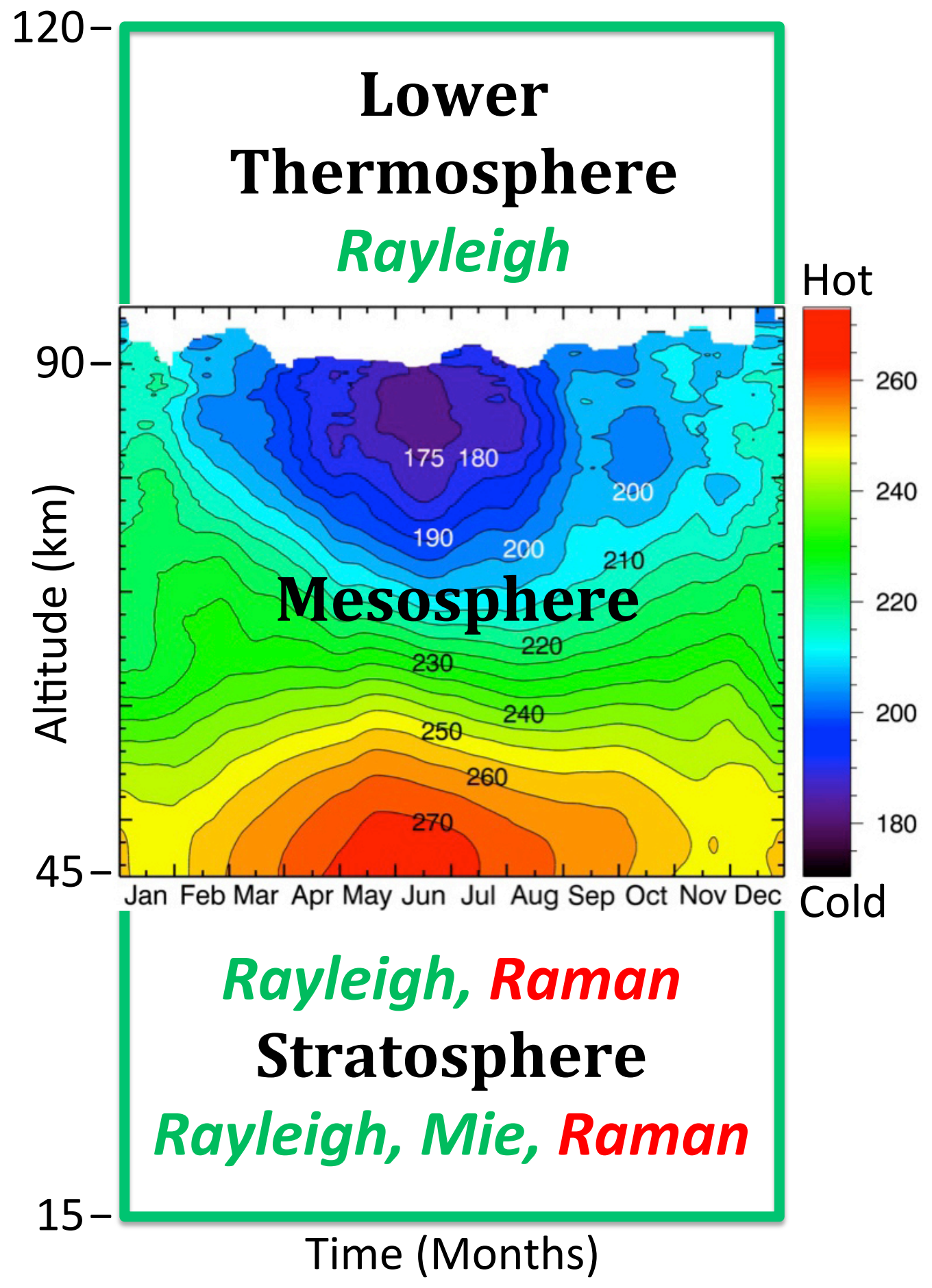

Figure 1. The original lidar observed Rayleigh scatter throughout the mesosphere. The upgraded lidar has so far extended that capability up to ~110 km and will extend it to at least 120 km. It will use a combination of Rayleigh, Mie, and Raman scatter to extend it down to 15 km.

The ALO Rayleigh lidar is currently being upgraded, as indicated in Fig. 1, to extend observations upward into the lower thermosphere and downward to the lower stratosphere.

THE UPGRADE

The upgrade has been very extensive. Among others things, it required a big lidar observatory and the outfitting of a laser and detector laboratory. The telescope collecting area was increased to almost 5-m^2 by using four co-aligned 1.25-m diameter mirrors. The laser power was effectively doubled to 42 W by using both the 18- and 24-W lasers. As a result the PAP was increased by ~70x to just above 200-Wm^2. Fibers carry the signal from each of the telescopes to the detector system, where the four signals are combined and detected. The lidar observatory was made big enough that the telescope can be tilted in zenith angle from 0° to 45°. (An unexpected good by product of the observatory size is that when Titus Yuan moved the Na Doppler lidar from CSU to USU, it could be set up next to the Rayleigh lidar, which will greatly facilitate collaborative experiments and observations.)

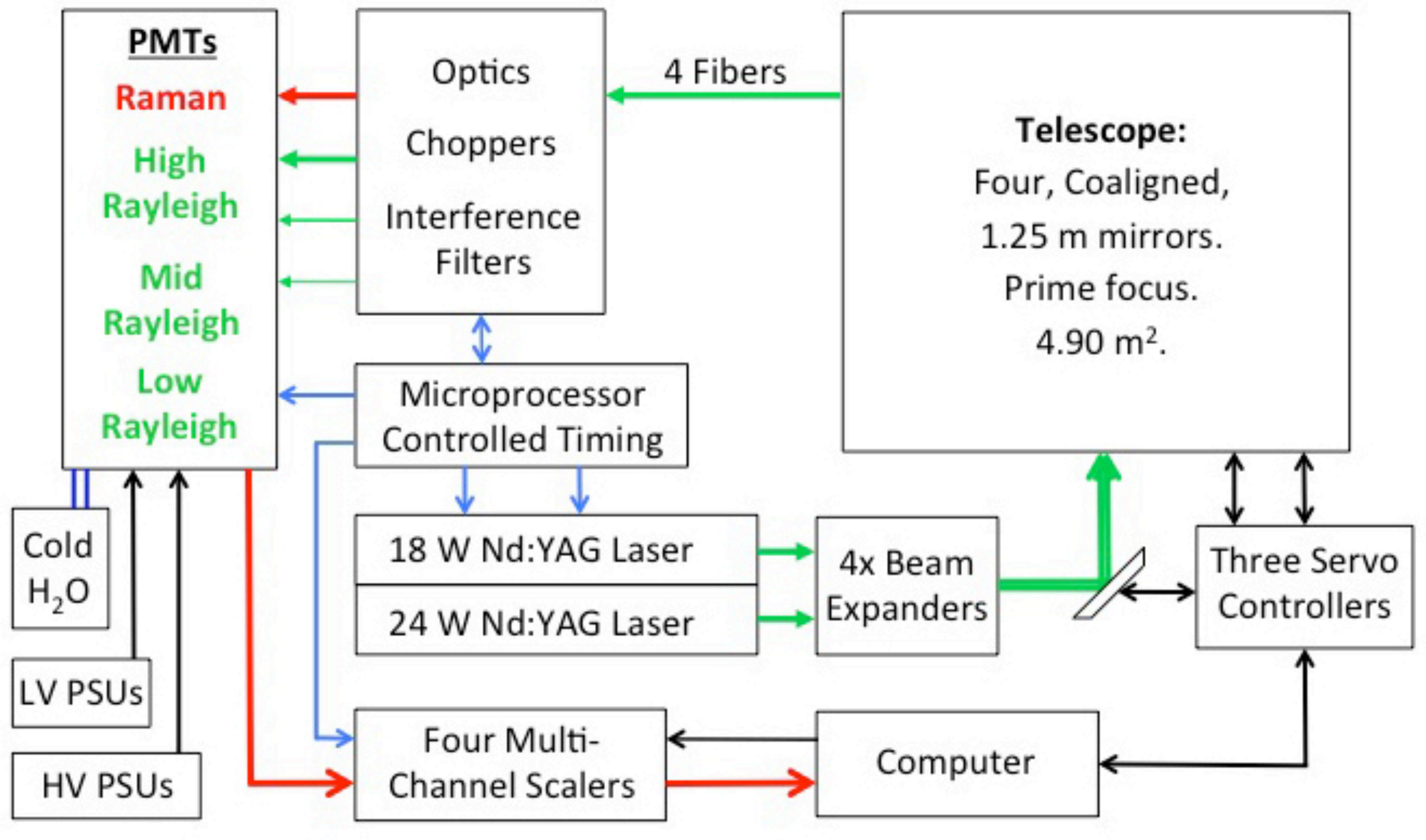

Figure 2. Schematic block diagram of the upgraded Rayleigh lidar system. The high-altitude Rayleigh detector channel is the only one installed for these initial observations.

Fig. 3 shows the telescope cage and associated hardware for the Rayleigh lidar. Fig. 4 shows the Rayleigh Lidar in operation with its two green beams. Three orange beams from the Na Doppler lidar are visible in the background.

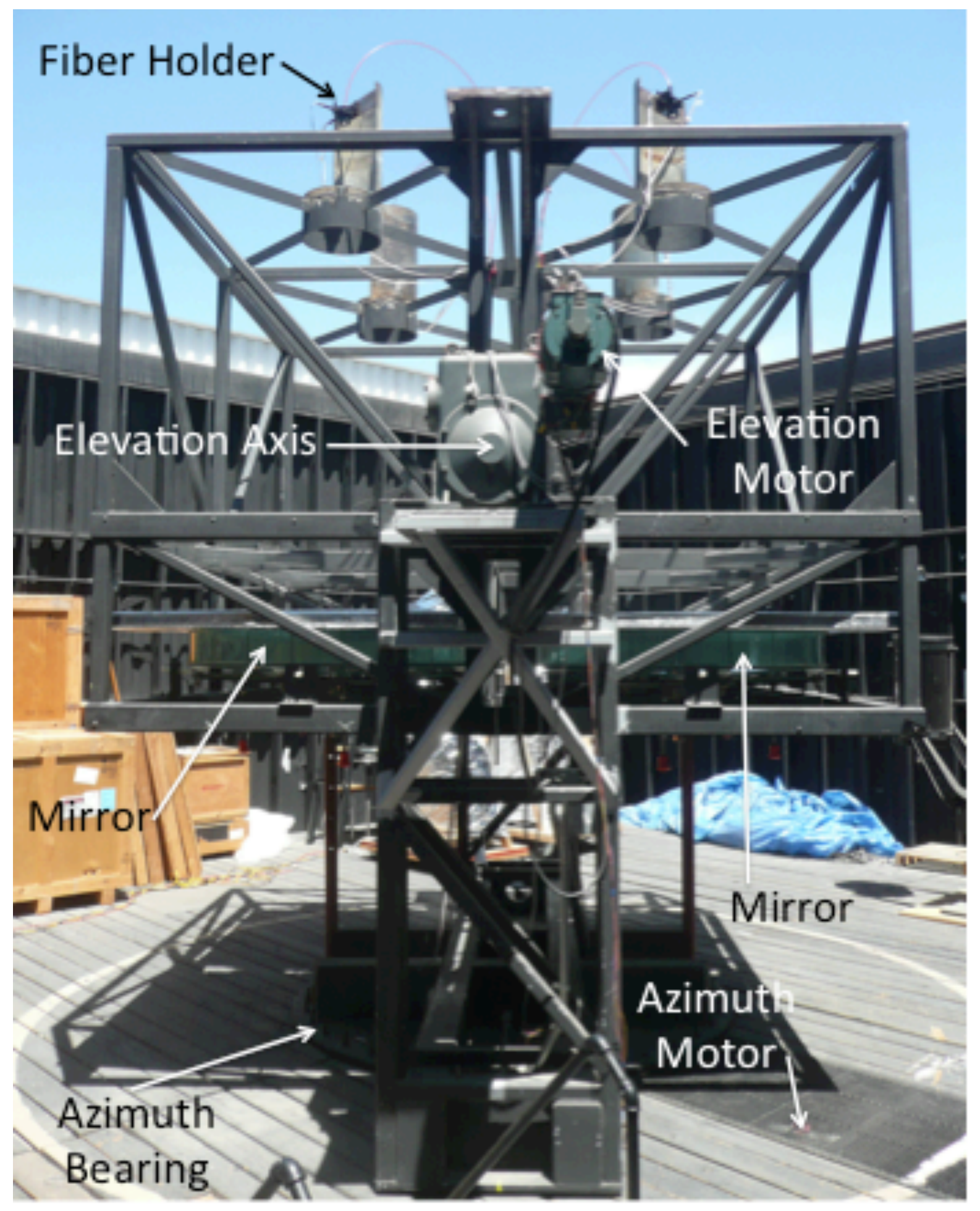

Figure 4. Two green beams passing straight through the telescope cage. (The turning mirrors are not needed for vertical operation.) [Photo courtesy of Thomas Amely.]

Figure 3. Telescope Cage. The cage is 3-m square and 2.5-m high. It can tilt ±45° off of zenith and can rotate ±540° in azimuth. New hardware will keep the mirrors secure when the cage is tilted. It holds four 1.25-m mirrors, two of which can be seen. They focus the backscattered signal onto 1.5-mm fibers. The fibers are supported in new fiber-holder assemblies and their position controlled by servos. The laser beams come from below along the azimuth axis. Four turning mirrors keep them aligned with the telescope's optical axis.

FIRST NEW DATA — 75 TO ≤ 109 KM

From 13 June – 12 July 2012, data were acquired on 18 nights with the upgraded system. The data were reduced to temperatures, using the usual Rayleigh assumptions, from 75 km to a maximum of 109 km. The minimum altitude was determined by using just one detector. The maximum altitude was determined by telescope alignment and laser power. (By July 2013 the maximum altitude achieved was 115 km.) The extensive 2012 temperature results are shown in Fig. 5.

Each thin colored profile comes, typically, from a 4–6 hour night with a 3-km altitude resolution. The uncertainties derived from Poisson statistics are less than 1 K at 75 km and ~12 K at the top altitude. The thicker dashed profiles represent a multi-night average of these 2012 temperatures, an average from the ALO climatology for the same time of the year, and the MSISe00 model temperatures for 21 June.

ACKNOWLEDGEMENTS

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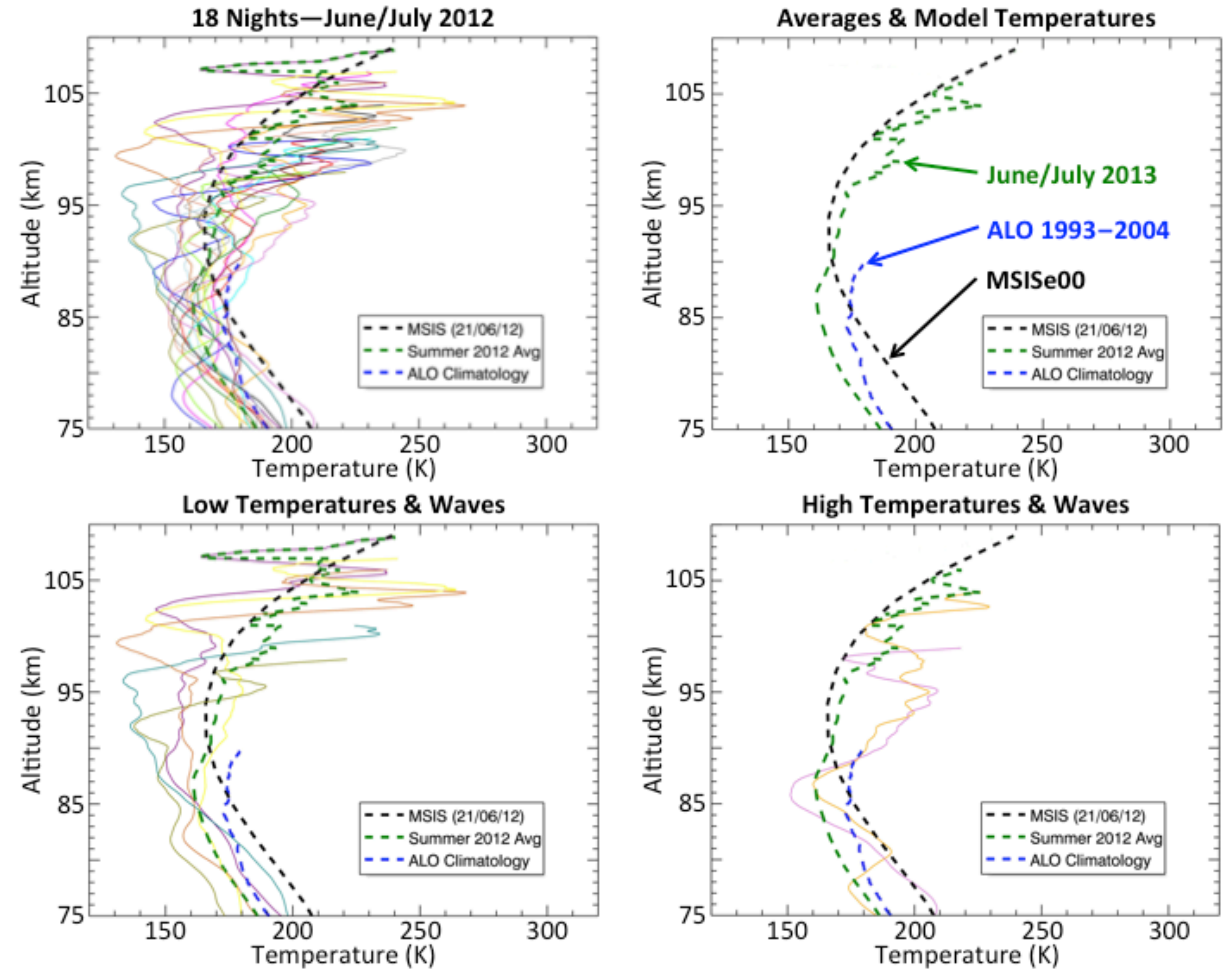

Figure 5. Temperatures from the June/July 2012 campaign. (a) Temperature profiles for all the nights. (b) The averaged temperature profile for the campaign, the profile for the same period in the ALO climatology, and the corresponding MSIS profile. (c) The profiles with the lowest temperatures (and some higher altitude, high temperatures). (d) The profiles with the highest temperatures near the mesopause.

SOME INITIAL RESULTS

A striking result in the new temperatures shown in Fig. 5a is their great variability. Starting at 75 km, the spread is ~45 K. Above 85 km, the spread becomes much greater. The nights with the lowest temperatures and those with some of the highest temperatures are shown in Figs. 5c & 5d. In both cases, they show large amplitude waves over 5–10 km regions contributing to these extreme temperatures.

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, more likely, higher because of these large amplitude waves. These new data and the ALO climatology show the solstice mesopause to be at 85 to 86 km, significantly below MSIS's 93 km, and even more below the 104 km of the lowest individual day.

The averaged temperature curves show close agreement, as expected, at 75 km. The difference might reflect interannual variability. Below 85 km they are consistently lower than MSIS, reaching 20 K at 75 km. Surprisingly, the new average is lower than that of the ALO climatology and they diverge with altitude, reaching just over 10 K at 90 km. The initial temperatures occur high enough that the new results should be very accurate at 90 km. The initial temperatures for the ALO climatology are based on the CSU Na climatology, which are believed to be accurate. Factors being investigated include spatial differences on the two sides of the Rockies, something affecting the Rayleigh temperatures, and/or something affecting the Na temperatures.