Ground-Based Observations with a Rayleigh-Mie-Raman Lidar from 15-120 km

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What is Atmospheric Lidar?

Lidar stands for Light Detection and Ranging. In its most simple form, a lidar system is made up of a laser transmitter that acts as a probe of the medium that is being investigated (in this case, the atmosphere), a telescope to collect the returned signal, and electronics that are used to measure the returned signal. The transmitted laser light is pulsed, which enables us to measure returned laser pulses that have undergone scattering processes with molecules, atoms and particles in the atmosphere.

Rayleigh, Mie, and Raman scattering are three distinct types of light-particle interactions that can be measured by lidar systems. Rayleigh scattering happens when the size of the scattering particle is much smaller than the wavelength of the incident light. In the atmosphere, Rayleigh scattering dominates at altitudes above ~35 km (i.e., the upper Stratosphere and all of the Mesosphere) where N₂ and O₂ are the dominant molecules. Mie scattering happens when the scattering particles are much larger than the wavelength of incident light. In the atmosphere, this type of scattering happens at lower altitudes (in the Troposphere and Stratosphere) where aerosols and other large particles are present. Raman scattering is different from the other two scattering processes in that it is an inelastic process. In the case of the green wavelength (532 nm) lidar at Utah State University, laser pulses will be absorbed by N₂ molecules and then light at a red wavelength (607 nm) will be emitted. Raman scattering measurements are needed in order to use the Klett inversion algorithm, which enables the separation of Rayleigh and Mie measurements during signal processing.

The original Rayleigh lidar operated at the Atmospheric Lidar Observatory (ALO) on the campus of USU from 1993-2004. It’s density and temperature measurements extended over most of the Mesosphere (45-90 km). It’s Power-Aperture-Product (PAP), which is a measure of a given lidar’s sensitivity, at most 3.7 m². There is currently a new Rayleigh-Mie-Raman Scatter lidar being developed from an upgraded version of the original Rayleigh lidar. As can be seen in the system diagram in Figure 2, this system will use two lasers for a combined transmitted power of 42 W and uses four mirrors to give an overall receiving aperture area of 4.9 m². These upgrades to the old Rayleigh lidar now give the system a PAP of 207 Wm²; this means the new instrument will be more than 70 times more sensitive than the original. By adding more receiving channels, we will be able to measure over a greater dynamic range and go from altitudes of 45-90 km to altitudes of 15-120 km. In order to compensate for the varying types of light-particle interactions that happen in this range, as described above, the different altitude channels will be designated as two Rayleigh scatter channels, one Rayleigh-Mie scatter channel and one Raman scatter channel. Thus, the new system will be a Rayleigh-Mie-Raman scatter lidar.

What is Aeronomy?

Aeronomy is a branch of atmospheric science, which deals with the chemical composition, physical properties, relative motion, and reactions to radiation from outer space that the Earth’s and other planets’ atmospheres exhibit. It is different from meteorology in that it is not the study of the weather in the atmosphere. Important topics in Aeronomy research include, gravity waves, tides, planetary waves, the ionosphere, the neutral atmosphere, space weather, Noctilucent Clouds (NLCs), upper atmospheric chemistry, upper atmospheric lighting, discharges, airglow, metallic layers, meteoric dust, planetary aeronomy. Sudden Stratospheric Warmings, long term trends. Figure 3 gives examples of the observation ranges of instruments used in Aeronomy research.

What Can the RMR Lidar Measure?

With the original ALO Rayleigh lidar 11 year data set, many studies of various aeronomy topics have been conducted and are being continued with the newly upgraded system (Fig. 7). The Rayleigh lidar’s raw data are proportional to the relative density of the atmosphere. By normalizing the measured relative densities to model densities at the lowest altitude, absolute densities can be obtained (Fig. 4). By using the property of hydrostatic equilibrium of and the ideal gas law, we can derive absolute temperatures (Fig 5 & 6). With either the relative densities or absolute temperatures, perturbations can be analyzed to give vertical wavelengths and phase speeds of gravity waves (or buoyancy waves), which are the same type of wave as in clear-air turbulence and that buffer the jet unison reentry. NLCs have also been measured with the Rayleigh lidar, which extended the knowledge of their occurrence equatorward, to midlatitudes, whereas NLCs were previously thought to be a polar phenomenon.

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Figure 1. A photo of the both of the lidar systems at the Atmospheric Lidar Observatory at USU. The orange beam belongs to a Sediment Lidar System and the green beam belongs to the RMR lidar described in this poster. Photo by Thomas Amely.

Figure 2. A system diagram of the new RMR system being built at USU. Credit: Leda Sox

Figure 3. Diagram of the atmosphere with conceptual images of various instruments that measure upper atmospheric properties and their measurement ranges. Credit: NASA