The lidar profiling technique (Fiocco, 1963) is based on the study of the interaction between a laser radiation sent into the atmosphere and the atmospheric constituents. The interaction process of a dispersed medium consisting of aerosol or cloud particles suspended at random in the atmosphere can be described by the Beer-Bouguer-Lambert law as:

$$I = I_0 exp(-\alpha(\lambda)L)$$

where I_0 is incident light intensity, $\alpha(\lambda)$ is light intensity transmitted through the medium in the forward direction (i.e. parallel to the incident light), is volumetric extinction coefficient; and L is geometric distance between emitter and receiver. The transmitted light is partially reflected or scattered back to the instrument. Radiation (photons) backscattered by the target is collected by a telescope, used as a receiver, and processed to yield information about the observed target. The processing consists of a spectral selection step, made by using a combination of optical elements, and a detection phase operated by means of different devices, such as photomultipliers or avalanche photodiodes, depending on the detected wavelength. The detectors convert the radiation in output electrical signals that, suitably processed, provide vertical profiles of the atmospheric properties as well as the concentration of atmospheric constituents.

Lidar signal in the troposphere

Light scattering in the atmosphere includes a large variety of elastic and inelastic processes. The backscattered lidar signal typically consists of elastic scattering from both molecules and particles and of inelastic scattering due to rotational Raman transition in molecules. Lidar elastic return is the result of both aerosol and molecular backscattering as well of aerosol extinction at all operating wavelengths. Molecular extinction also contributes but in a negligible way. Raman lidar return is the results of molecular backscattering and aerosol extinction as aerosol scattering is at a different wavelength than the Raman return wavelength and, therefore, not received by the Raman channel.

Molecular scattering

Atmospheric molecules, though much smaller than the wavelengths of light, provide a contribution to the radiation backscattered by the atmosphere. Because molecules are smaller than the wavelength typically used in lidar system (ranging between 266 nm and 2 µm), they scatter short wavelengths (which are more nearly comparable to the size of the molecules) better than long wavelengths (Measures, 1992). Molecular scattering occurs under the Rayleigh scattering regime, i.e when the size of the scatterers a is much lower than the radiation wavelength λ, i.e. $\frac{2\pi a}{\lambda} << 1$. Rayleigh scattering has a simple classical origin: the electrons in the atoms, molecules or small particles radiate like dipole antennas when they are forced to oscillate by an applied electromagnetic field (Miles, 2001). Scattering from molecules is of major importance for lidar since the signal from the molecules can be used as a lidar calibration source. Lidar calibration is required for obtaining the system constant needed for particle backscattering coefficient profile retrievals. The conventional calibration approach is to normalize the lidar return to a given molecular reference value in the upper troposphere or stratosphere. This is challenging to apply in the near-IR because of the weak molecular scattering and, above all for ceilometers, of the low signal-to-noise ratio. Moreover, the uncertainty due to the use of a calibration value of the molecular scattering equal to zero (i.e. no aerosol scattering), that is often considered in the signal inversion, can be furthermore critical at infrared wavelengths (larger than 35%), while at lower wavelengths the uncertainty in much lower (within 10 %).

Extinction due to aerosols

The term extinction addresses the loss of light in the atmosphere from a directly transmitted beam. Two different mechanisms contribute to extinction: absorption and scattering. Normally, most of the extinction in the Earth's atmosphere is due to scattering. Most of the aerosol particles are so weakly absorbing that their extinction is almost entirely due to scattering, rather than absorption. However, certain aerosol types, like soot (carbon), are quite efficient absorbers and their extinction is largely due to their absorption power. In terms of refractive index, non absorbing particle are characterized by a negligible values of the imaginary part of the complex refractive index. Aerosol extinction can be retrieved with very low assumptions exploiting the significant advantage coming from the use of Raman backscatter. Raman backscatter occurs when the scattering molecules transit from one energy state to another before reemitting the incident light. This results in scattering at shifted frequency/ wavelength equal to the difference (the combination) of the incident light frequency and the frequency gap between the final and the initial energy states of scattering molecules. The frequency/wavelength shift depends on the transition type and has a different value for different types of scattering molecules (Serikov et al., 2009). The fraction of the total energy scattered at that wavelength (i.e., the Raman cross-section) is typically three orders of magnitude smaller than for elastic scattering, which allows its practical application to remote sensing of only the most abundant molecules in the atmosphere, like nitrogen or water vapor.

For complete description of optical properties and inversion methods see report by F. Madonna (CNR-IMAA, Italy): Lidar Fundamentals