Lidar Measurements of Atmospheric Transmissivity.

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(ricevuto il 14 Aprile 1994; revisionato il 20 Febbraio 1995; approvato il 16 Marzo 1995)

Summary. — The possibility of performing atmospheric-transmissivity measurements by lidar is considered. In the present paper two distinct methods have been successfully applied. The first one is based on the detection of the Raman return from molecular nitrogen. An alternative method is based on the simultaneous detection of the elastic and Ne Raman returns. Measurements based on both techniques are discussed in detail, the second technique producing more accurate results. Through this technique an estimation of the Ångström coefficient can also be obtained.

PACS 94.10.Gb – Absorption and scattering of radiation.
PACS 42.68.Wt – Remote sensing; LIDAR and adaptive systems.

1. – Introduction.

Recent progress in the study of radiative transfer within the atmosphere has led to the request of accurate measurements of atmospheric transmissivity at any wavelength from the UV to the far IR. A special interest for the UV region comes also from the development of new methods for the detection of very high-energy cosmic rays through the UV Cherenkov light emitted by the electromagnetic showers generated in the atmosphere, few kilometres above surface level[1].

Though the atmospheric density as a function of height can be expressed by a simple exponential law (see eq. (5) in subsect. 2.1), the overall transmissivity profile has a non-trivial behaviour. It is well known that anthropogenic aerosols, whose concentration varies rapidly in time, strongly affect the transmissivity profile below 2 km of height, causing a different behaviour with respect to what expected at a higher altitude. Moreover, the atmospheric transmissivity in the near UV is affected by different constituents; within the region of 320–400 nm it is almost entirely dominated by elastic scattering from aerosols and molecules. The spectral range 230–320 nm is characterized by ozone absorption: in this range scattering and
absorption contributions to atmospheric transmissivity are comparable. For wavelengths below 250 nm absorption by molecular oxygen becomes relevant. Absorption from several minor species (i.e. CO$_2$, SO$_2$, NO, CH$_2$, etc.) has also to be expected below 300 nm [2-5]. In particular, SO$_2$ has a strong absorption band around 293 nm, whereas NO is electronically active around 230 nm.

Scattering contribution to atmospheric transmissivity is the result of both Mie (aerosols) and Rayleigh (molecular species) scattering. Whenever the atmospheric temperature profile is known, molecular scattering can be estimated from Rayleigh scattering theory.

Several authors considered the possibility to measure both scattering and absorption contribution to atmospheric extinction. In particular Cooney [6, 7] proposed to measure atmospheric-extinction profiles from simultaneous measurements of the Raman lidar return relative to both oxygen and nitrogen. According to Cooney approach, if the aerosol scattering is not negligible with respect to molecular absorption, a single power ratio measurement gives only an estimation of the difference of extinction coefficients at two wavelengths. The atmospheric transmissivity can then be obtained only by multiwavelengths measurements and by the application of a finite-difference integration algorithm.

Ansmann et al. [8-10] proposed a method for determining aerosol extinction profiles based on the Raman lidar return. Their approach, used to give vertical profiles of aerosol extinction, backscatter and lidar ratio, assumes a $\lambda^{-1}$-dependence of the aerosol extinction and needs the presence of a clear-air region where the aerosol scattering is negligible with respect to molecular scattering. In a very recent paper Kovalev [11] proposed an iterative inversion method for the retrieval of aerosol extinction profiles based on the use of a range-dependent backscatter-to-extinction ratio. Kovalev procedure is reliable only if the aerosol backscattering is negligible with respect to molecular backscattering in some region within the measured range. Such constraint is necessary to define the boundary conditions for the inversion.

The above-mentioned authors proposed methods to measure aerosol extinction, whose contribution to atmospheric transmissivity is difficult to evaluate. Furthermore, atmospheric transmissivity is also affected by molecular scattering. This contribution can be computed from a standard atmosphere temperature profile introducing an uncertainty on atmospheric transmissivity equal to $dT_M/T_M = 0.1$ [12, 13]. The uncertainty is lower if a measured temperature profile is available. Furthermore, the problem of evaluating the transmissivity profile down to surface level (0-400 m) was not considered by any author.

In the present paper two alternative techniques to measure atmospheric transmissivity are proposed. The first one is based on the detection of the N$_2$ Raman return only. In this case the transmissivity profile can be retrieved if a standard or measured density profile is available. Although the retrieval of the transmissivity profile is affected by a systematic error discussed in the text, this technique can be successfully applied even in the absence of an aerosol-free region. We also propose a more reliable approach based on the simultaneous detection of the elastic and N$_2$ Raman returns. Both techniques can be applied to any spectral range far from any major absorption band. If molecular absorption is not negligible, both techniques can be applied if absorbing species have a constant mixing ratio and their absorption cross-section has a small variability within the spectral region around the laser wavelength. If the absorption cross-section changes appreciably within this spectral range, atmospheric transmissivity is still evaluable if the absorption cross-section at