Optimum Wavelengths of Laser Radars

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In a recent note Boudreau (1970) discusses the problem of choosing the optimum wavelength for a laser radar used for Raman studies of the atmosphere. By considering the effect of Rayleigh scattering along the atmospheric path, he derives an expression for the range beyond which a decrease in the wavelength used will decrease rather than increase the radar sensitivity. The purpose of this note is to point out a number of complicating factors which indicate that some caution should be exercised in applying the formulas derived by Boudreau.

Boudreau assumes a constant molecular density along the propagation path and derives, for example, a distance of 163 km as the distance beyond which a decrease in wavelength of a ruby laser measuring the Raman return from N_2 would decrease the signal return. Laser radars are most frequently used to obtain vertical profiles of the atmosphere, in which case both the Rayleigh scattering losses and the Raman scattering itself would be quite negligible long before a height of 163 km is reached. In fact about 95% of the molecular scattering losses occur below a height of 20 km. It is clear then that the atmospheric scale height and the elevation angle of the radar must be taken into account.

A much more important omission in the analysis presented by Boudreau is the lack of any consideration of the effect of aerosols. Scattering by particulate matter in the troposphere furnishes the main contribution to atmospheric extinction over most of the optical spectrum. The very comprehensive tables of atmospheric extinction coefficients published by Elterman (1964) make this clear. Taking the example of a one-way vertical path through the atmosphere we find, at a wavelength of $0.7\,\mu$, that Rayleigh scattering alone accounts for a loss of only about 3%. Elterman's tables, including the additional effects of aerosol scattering and ozone absorption, give a figure of 18%, most of which is due to aerosol scattering. At the ultraviolet wavelengths discussed by Boudreau, ozone absorption plays an important role.

Another factor, albeit a minor one, arises from the statistical limitations involved in measuring the very weak signals normally associated with laser radars. In many applications the intensity of the return is measured by counting photons. Since for a given transmitted energy we have less photons in our signal at shorter wavelengths, we immediately have a linear wavelength factor to be included in any calculation of sensitivity.

Yet another point concerns the gains in photomultiplier sensitivity which can be achieved by going to shorter wavelengths. Boudreau quotes Leonard (1967) as stating that a factor of 25 can be obtained in going from 0.6943 to $0.3371\,\mu$. In fact it is possible, using multiple reflection techniques, to obtain quantum efficiencies up to about 15% at the former wavelength, so the maximum gain is not greater than a factor of 7.

The result of these various factors is that it is not possible to derive a general expression for the optimum wavelength to be used in a laser radar, and that each particular application must be analyzed separately. For the case of a vertical pointing radar, measuring Rayleigh scattering in the upper atmosphere, a thorough analysis indicates that the optimum wavelength would be $\sim 0.4\,\mu$ and that the gain in sensitivity over a ruby system operating at $0.6943\,\mu$ would be a factor of about 6. In view of the comparatively high state development of the ruby laser, this indicates that it is still probably the best for high-altitude Rayleigh scattering measurements. Shorter wavelengths are worthwhile for Raman scattering mainly because of the very poor quantum efficiency of available photocathodes in the infrared.

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