SCATTERING PARAMETERS FOR THE LASER RADAR EQUATION

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ABSTRACT

1. Introduction

In this paper scattering parameters are discussed in order to analyze laser radar echoes as one of studies on quantitative measurements of air pollution. Water droplets which are components of haze, fog, and clouds are chiefly considered and scattering parameters are calculated in a range of ρ ($=2\pi r/\lambda$) from 0.01 to 200 at a wavelength of ruby laser for various refractive indices. Particle-size distribution N(r) must be known for the analisis of the laser radar equation. It influences greatly the scattering parameters as mentioned in the authors' previous paper.

The variation of the scattering parameters depending on ρ are known clearly, and water vapor can be quantified from the observed laser radar echoes.

2. Laser radar equation and scattering parameters.

The laser radar equation is given by

$$Pr = Po\ Ko \int_0^\infty N(r,R)\, \delta(r,\lambda,m)\, dr\ R^{-2} \exp\left(-2 \int_0^R \int_0^\infty N(r,R)\, Q(r,\lambda,m)\, dr\, dR\right) \qquad \text{------- (1)}$$

where Pr is the received signal power, Po is the radiation power of the transmitter, Ko is a constant dependent on the system, N(r, R) is particle-size distribution at a path length of R from the transmitter, and $\delta(r,\lambda,m)$ and $Q(r,\lambda,m)$ are the differential back-scattering cross section and the extinction cross section of a particle with a radius of r and the refractive index of m for the electro-magnetic wave at a wavelength of λ respectively.

In order to simplify Eq. (1) β is defined as follows.

$$\beta = \int_0^\infty N(r)\, Q(r,\lambda,m)\, dr \Big/ \int_0^\infty N(r)\, \delta(r,\lambda,m)\, dr \qquad \text{------- (2)}$$

N(r) must be known in order to get the values of β.

It can be represented in several models according to material and radii r of particles. On the other hand, the changes of δ depending on r are so complicated that β varies to a great extent. Therefore, α and $\overline{\alpha}$ are defined as follows.

$$\alpha = Q(r,\lambda,m) \,/\, \delta(r,\lambda,m) \qquad \text{-------} \ (3)$$

$$\overline{\alpha} = \int_{r_1}^{r_2} Q(r,\lambda,m)\,dr \,\Big/ \int_{r_1}^{r_2} \delta(r,\lambda,m)\,dr \qquad \text{-------} \ (4)$$

In Eq. (4) the values of r_1 and r_2 are taken in the ranges of $0.01 \sim 0.03\mu$, $0.02 \sim 0.04\mu$, ---- , $0.09 \sim 0.2\mu$, $0.1 \sim 0.3\mu$, --- .

3. Scattering parameters for various refractive indices.

The imaginary part m'' of the refractive index ($m=m'-jm''$) of water in the light region has been regarded as zero. However, it may be estimated in the order of 10^{-3} from the experimental values by M.Centeno and the theoretical ones by Debye. Conparing the value of α in case that m'' is zero with the one in case that m'' is 10^{-3}, it is found that these two values show a great difference when $\rho < 1$.

The changes of β and $\overline{\alpha}$ due to r are shown in Fig.1. β is greatly different from $\overline{\alpha}$ when $1 < r < 5\mu$, but it is almost equal to $\overline{\alpha}$ when $r<1$ or $r>5$. Particles of hase and fog have radii in the range from 0.01 to 1μ and from 1 to 100μ respectively, so $\overline{\alpha}$ may be taken the place of β.

4. An application of scattering parameters.

Laser radar echoes from clouds were observed by Osaka University on February 27 in 1973 and one of them is shown in Fig.2. In this experiment a laser radar beam was oriented at an elevation angle of 30°. It is apparent from Fig.2 that there are thin clouds above haze and that the laser radar echo from the clouds is intense.

The quantity of water vapor of the clouds was approximately calculated as about 10 mg/m^3 . So in this paper the scattering parameters are calculated when the quantity of water vapor is 10 mg/m^{-3} , and then the true quantity can be obtaind by use of the proportional method. The result is shown in Fig .3. In this figure a solid line shows the case in which extinction is taken into account and a dotted line shows the case in which it is neglected.

It is concluded that the selections of N(r) and scattering parameters may be valid since the maximun value of the quantity of water vapor becomes about 14 mg/m^3

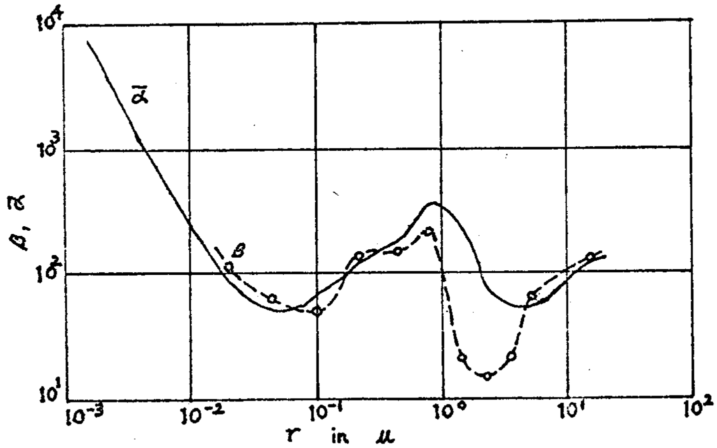

Fig.1. Comparison between β and α versus r.

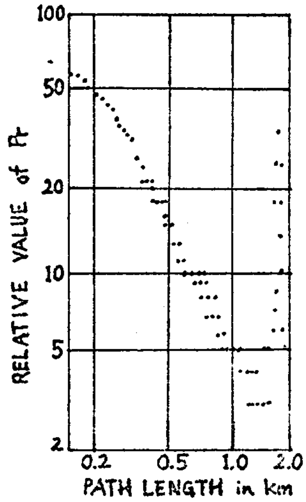

Fig.2. Echo from thin clouds versus path length.

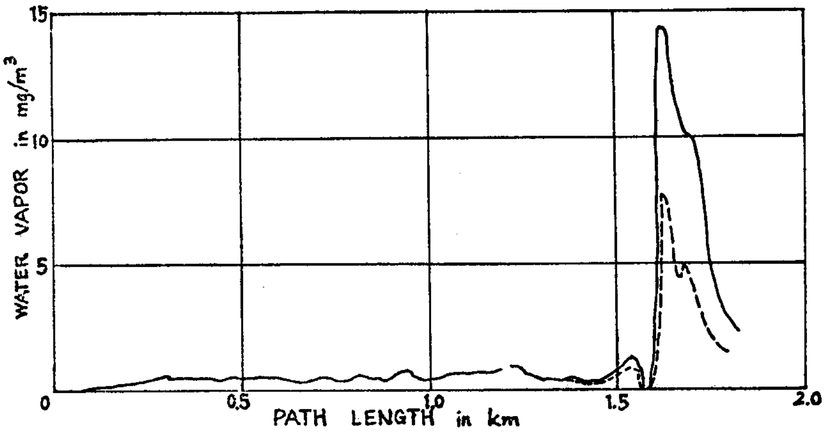

Fig.3. Water vapor versus path length.