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CORRECTION FUNCTION IN THE LIDAR EQUATION AND THE SOLUTION TECHNIQUES FOR CO_2 LIDAR DATA REDUCTION

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For lidar systems with long laser pulses the unusual behavior of the near-range signals causes serious difficulties and large errors in data reduction. The commonly used lidar equation is no longer applicable since the convolution of the laser pulse with the atmospheric parameter distributions should be taken into account. It is the purpose of this paper to give more insight into this problem and find solution techniques.

Starting from the original equation, the authors suggest a general form for the single-scattering lidar equation where a correction function Cr is introduced:

$$V(R)=CA\,\beta_\pi(R)T^2(R)Cr(R)/R^2 \qquad (1)$$

where

$V(R)=$ lidar return signal at range R
$\beta_\pi(R)=$ atmospheric backscattering coefficient
$T^2(R)=$ two-way transmittance of the atmosphere

The correction function Cr(R) derived from the original equation indicates the departure from the normal lidar equation:

$$Cr(R)=\int_0^{2R/c} P(t')Y(R,t')S(R,t')B(R,t')Tr(R,t')dt'/E \qquad (2)$$

where $P(t')=$ laser power as a function of time
$Y(R,t')=$ near-range receiving efficiency of the system
$= \eta(R-ct'/2)$
$S(R,t')= (1-ct'/2R)^2$
$B(R,t')= \beta_\pi(R-ct'/2)/\beta_\pi(R)$
$Tr(R,t')= T^2(R-ct'/2)/T^2(R)$
$E=$ energy of the laser pulse

EQ.(1) is very similar to the normal lidar equation except for the correction function Cr. It is therefore more convenient to use the lidar equation (1) than to use the original one because it is easier to compare the lidar signals of long laser pulse with those of the short pulses and discuss the changing of the signals by analyzing the features of correction function Cr. It is

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also easier to find a solution to the equation under certain circumstances.

EQ.(2) shows that Cr is a normalized, weighted, range dependent laser energy with weighting functions Y(R,t'), S(R,t'), B(R,t') and Tr(R,t'). The weighting functions modify the laser pulse shape in the following ways:

1. As t' increases, the inverse range square factor S(R,t') increases rapidly and strongly amplifies the contribution of the tail of laser pulse
2. Since atmospheric transmittance always decreases with range, Tr(R,t') increases with t' and also amplifies the laser tail
3. If $\beta_{\pi}(R)$ decreases with R, as usually happens in the vertical direction, B(R,t') increases with t' and amplifies the laser tail, otherwise it suppresses the tail
4. Y(R) increases rapidly and approaches 1 within a few hundred meters, Y(R,t') decreases with t' and more or less cancels the effect of S(R,t') and Tr(R,t')

Because of the properties of the weighting functions, the tail of the laser pulse has significant contributions to the magnitude of Cr(R), even when the tail is two to three orders of magnitude lower than the peak.

Numerical simulation shows that the general features of Cr(R) are as follows:

1. In most cases and for most of the range concerned, Cr(R) > 1, and there is always a big "hump" in the near range. The peak of the hump can be as large as 3.5 in horizontal observation for CO_2 lidar in long pulse operation at weak absorption wavelengths.
2. Cr(R) depends on laser pulse shape, particularly the length and form of the tail. The Cr(R) also depends on the configuration of the lidar.
3. The Cr(R) is sensitive to atmospheric transmittance and is very different for the on-line and off-line wavelengths, causing big errors in DIAL measurement if it is not considered.
4. The Cr(R) is sensitive to backscattering distribution.

Examples of Cr(R) for a coaxial CO_2 lidar system are shown in Fig.1. DIAL errors caused by the differences of Cr(R) for H_2O measurements are plotted against height in Fig.2.

Numerical analyses also show that Cr(R) at weak H_2O absorption wavelengths is not sensitive to the amount of water vapor, while the ratio of Cr(R) at R(18) and R(20) lines of CO_2 lidar is not sensitive to backscattering coefficient distribution. In addition, at CO_2 wavelengths the atmospheric transmittance is primarily independent of the backscattering coefficient. These facts lead to solution techniques for atmospheric backscattering distribution and water vapor content from CO_2 lidar signals. Iteration procedures are suggested and the convergence of the iteration has been proved by numerical tests.

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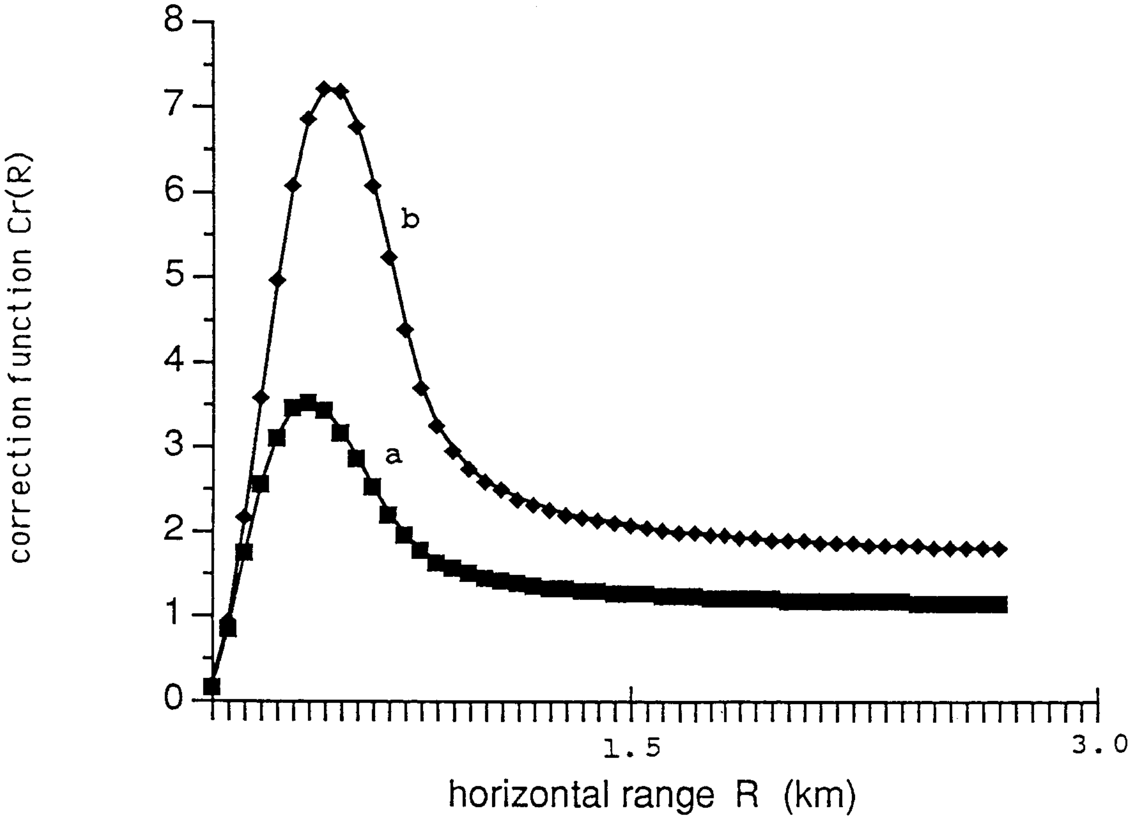

FIG.1 Cr(R) IN HORIZONAL CASE
(a) atmospheric extinction coefficient = 0.2/KM
(b) atmospheric extinction coefficient = 1.5/KM

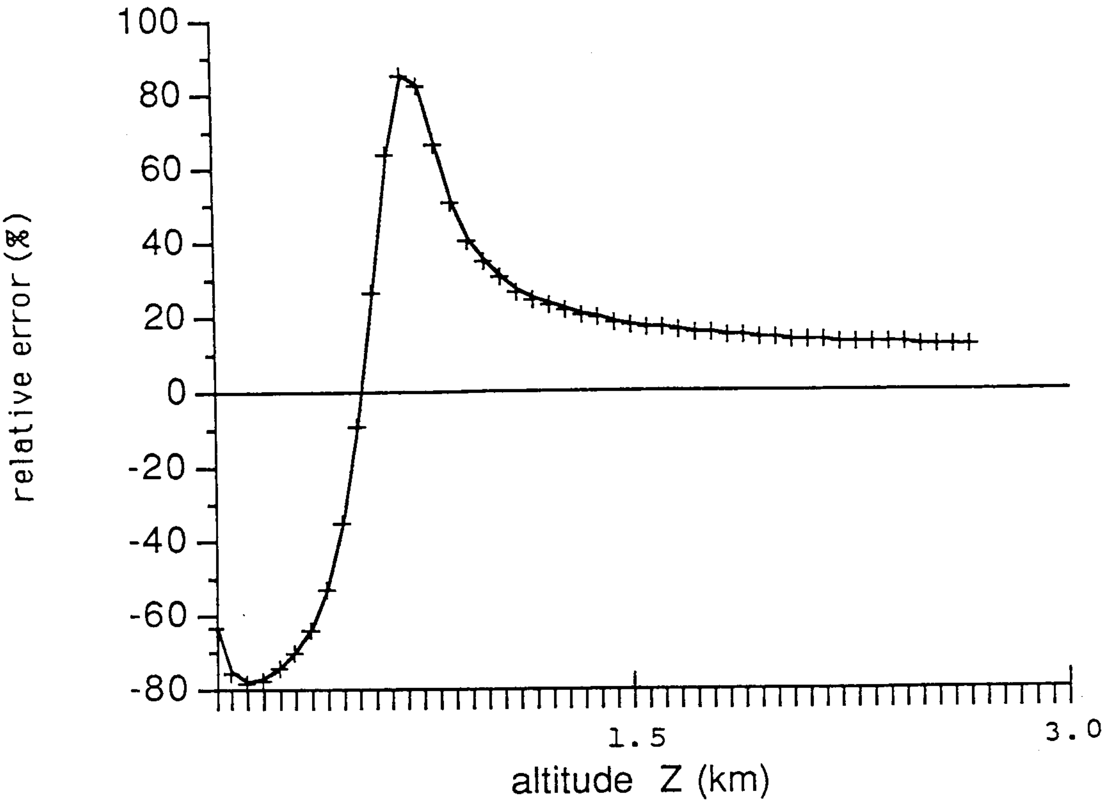

FIG. 2 ERRORS OF DIAL MEASUREMENT FOR WATER VAPOR CAUSED BY DIFFERENCES OF Cr

wavelengths: R(18) and R(20) of CO_2 laser

water vapor presure follows a negative exponential distribution with scale height = 2000 meter and surface value = 20 mb