An Iterative Algorithm Using Near-End Boundary for Stable Lidar Inversion

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Mie lidars are widely used for aerosol and cloud measurements. To quantitatively retrieve the aerosol and cloud scattering parameters, the backscattering coefficient or extinction coefficient at near-end or far-end, or the optical depth of the total scatterers are usually used as a boundary in Mie lidar inversions. For most cases of lidar observations, the determination of near-end boundary values are much easier than that of far-end boundary values or total optical depth. However, as well known, the forward inversion using the near-end solution is unstable and sometimes produces physically meaningless result for optically dense scatterers such as the clouds. Numerical lidar return simulation and inversion algorithm study for the Mission Demonstration Satellite Lidar (MDS-lidar) are being carried out. In this paper, the inversion algorithms using the near-end solution (Barrentt, et al., 1967; Davis, 1969; Fernald et al., 1972), the far-end solution (Klett, 1981, 1985; Fernald, 1984) and the optical depth constrained solution (Balin, et al., 1987; Weinman, 1988; Kovalev, 1993) are firstly reviewed. Also the algorithms with multiple scattering correction for dense scatterer analysis (Platt, 1973; Weinman, 1976; Kunkel et al., 1976; Evans, 1984; Carnuth et al., 1986; Young, 1995) are reviewed. Then we discuss an iterative algorithm for cloud signal inversion. The method is essentially based on the multiple scattering corrected far-end solution and uses the near-end boundary as a reference to estimate the far-end boundary and iteratively performs backward inversion. Both sensitivity analysis and inversion simulations of generated C1 cloud signals by Monte-Carlo simulation have shown that this algorithm has much higher stability and less divergence than the forward inversion algorithm.

Iterative inversion algorithm

Using the relationship between the range corrected signals $X(r_m)$, $X(r_0)$ and extinction coefficient $\alpha(r_m)$, $\alpha(r_0)$ at the far-end r_m and near-end r_0:

$$\frac{X(r_m)}{\alpha^k(r_m)} = \frac{X(r_0)}{\alpha^k(r_0)}\exp(-2\tau) \tag{1}$$

To rewrite the far-end solutions for single scattering (Klett, 1981) and multiple scattering (Evans, 1984; Carnuth *et al.*, 1986):

Single scattering:

$$\alpha_{i+1}(r) = \frac{X^{1/k}(r)}{\dfrac{X^{1/k}(r_o)}{\alpha(r_o)}\exp(-2\tau_i/k) + \dfrac{2}{k}\int_r^{r_m} X^{1/k}(r')dr'} \tag{2a}$$

Multiple scattering:

$$\alpha_{i+1}(r) = \frac{X^{1/k}(r)}{\dfrac{X^{1/k}(r_0)}{\alpha(r_0)}\exp[-2\eta\tau_i/k] + \dfrac{2}{k}\int_r^{r_m} \eta X^{1/k}(r')dr'} \tag{2b}$$

$$\tau_{i+1} = \int_{r_0}^{r_m} \alpha_{i+1}(r')dr' \tag{3}$$

Application to dense clouds

$$\beta_{i+1}(r) = \frac{X(r)}{\frac{X(r_0)}{\beta(r_0)}\exp[-2\overline{S_1\eta}\tau_\beta^i] + \overline{S_1\eta}\int_r^{r_m} X(r')dr'} \tag{4}$$

$$\tau_\beta^{i+1} = \int_{r_0}^{r_m} \beta_{i+1}(r')dr' \tag{5}$$

$$\overline{S_1\eta} = \frac{X(r_0)}{\beta(r_0)}\frac{1}{\int_{r_0}^{r_m} X(r')dr'} \tag{6}$$

r_m : maximum range

r_0 : cloud top for space lidar and cloud base for ground-based lidar.

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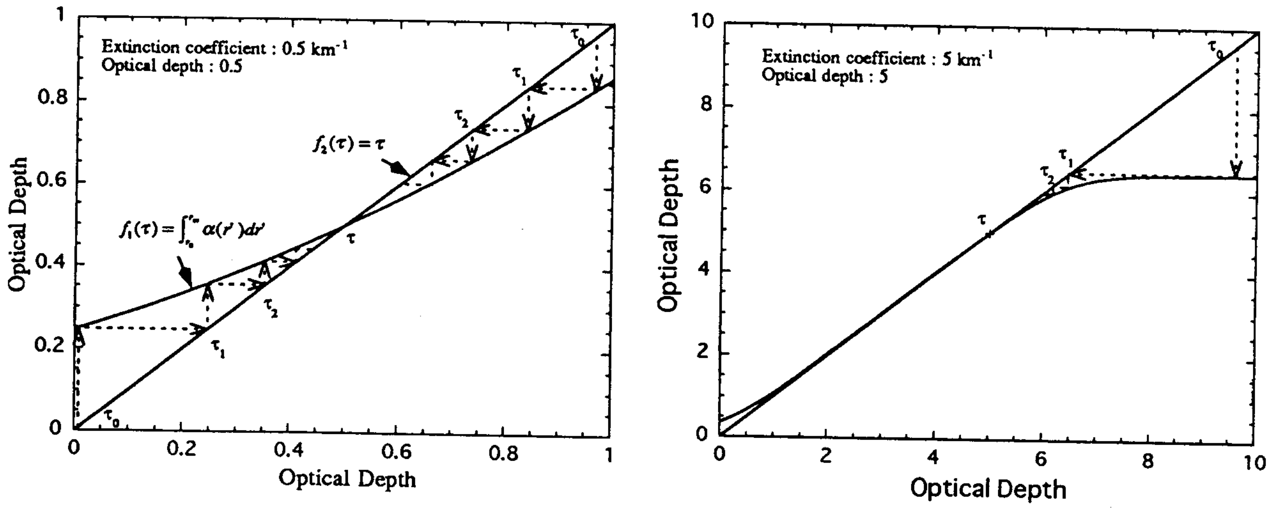

Fig. 1 Iterative inversion process simulated for two homogeneously distributed scatterers with extinction coefficient of 0.5 and 5.0 km^{-1} and thickness of 1 km.

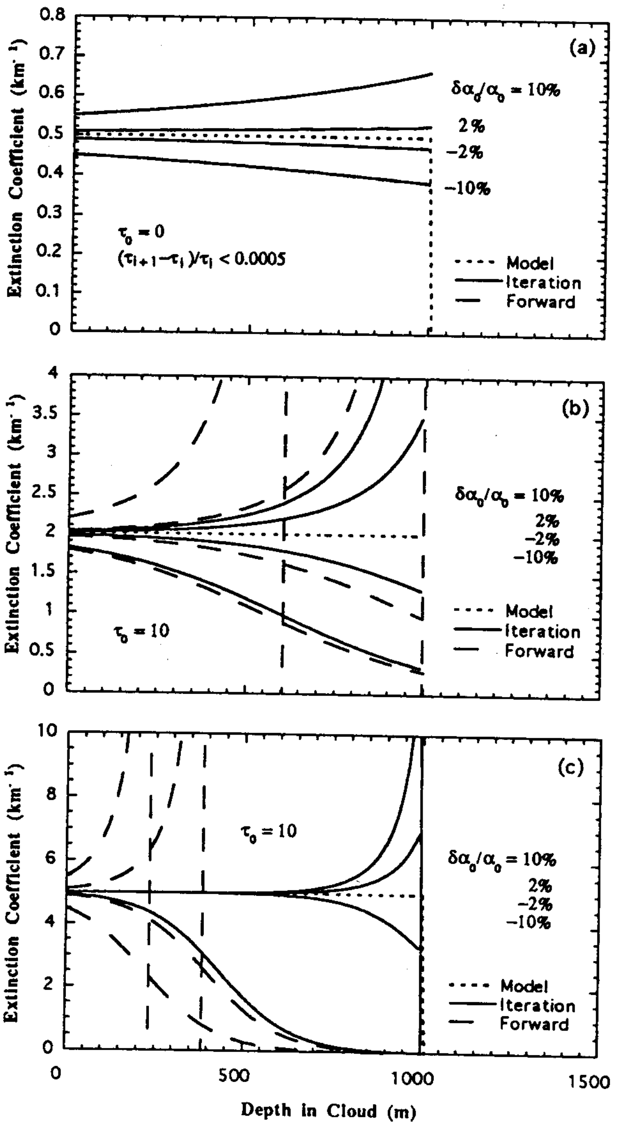

Fig. 2 Comparisons of extinction coefficient retrievals using iterative inversion algorithm and forward inversion algorithm (near-end solution) for three homogeneously distributed clouds.

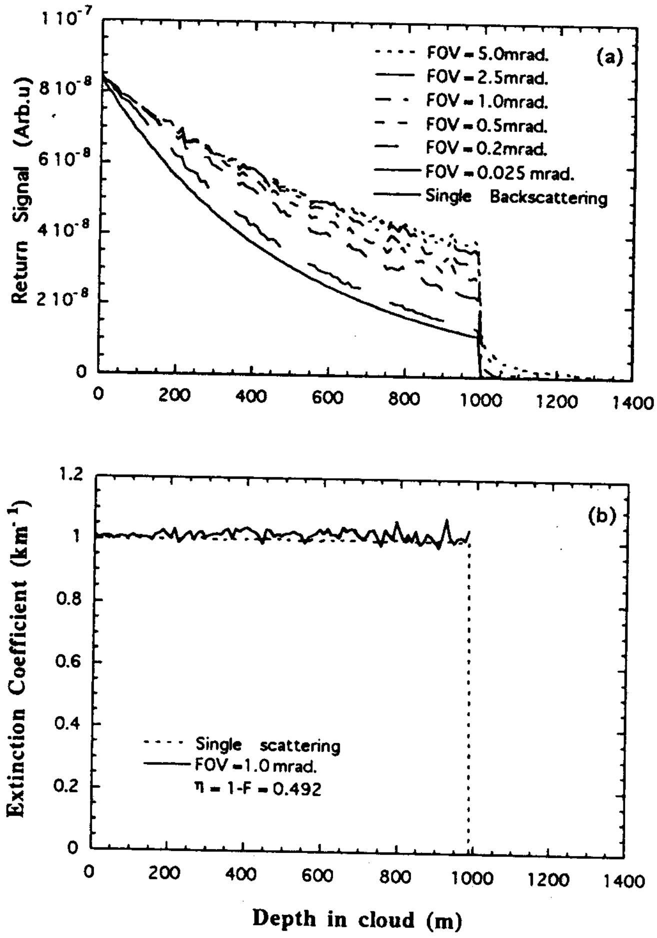

Fig. 3 (a) Lidar return signals obtained using Monte-Carlo simulation for MDS-lidar, and (b) retrieved extinction coefficients from the single scattering lidar return signal (dotted line) and the multiple scattering lidar return signal (solid line) using the iterative algorithms for single scattering and multiple scattering, respectively.

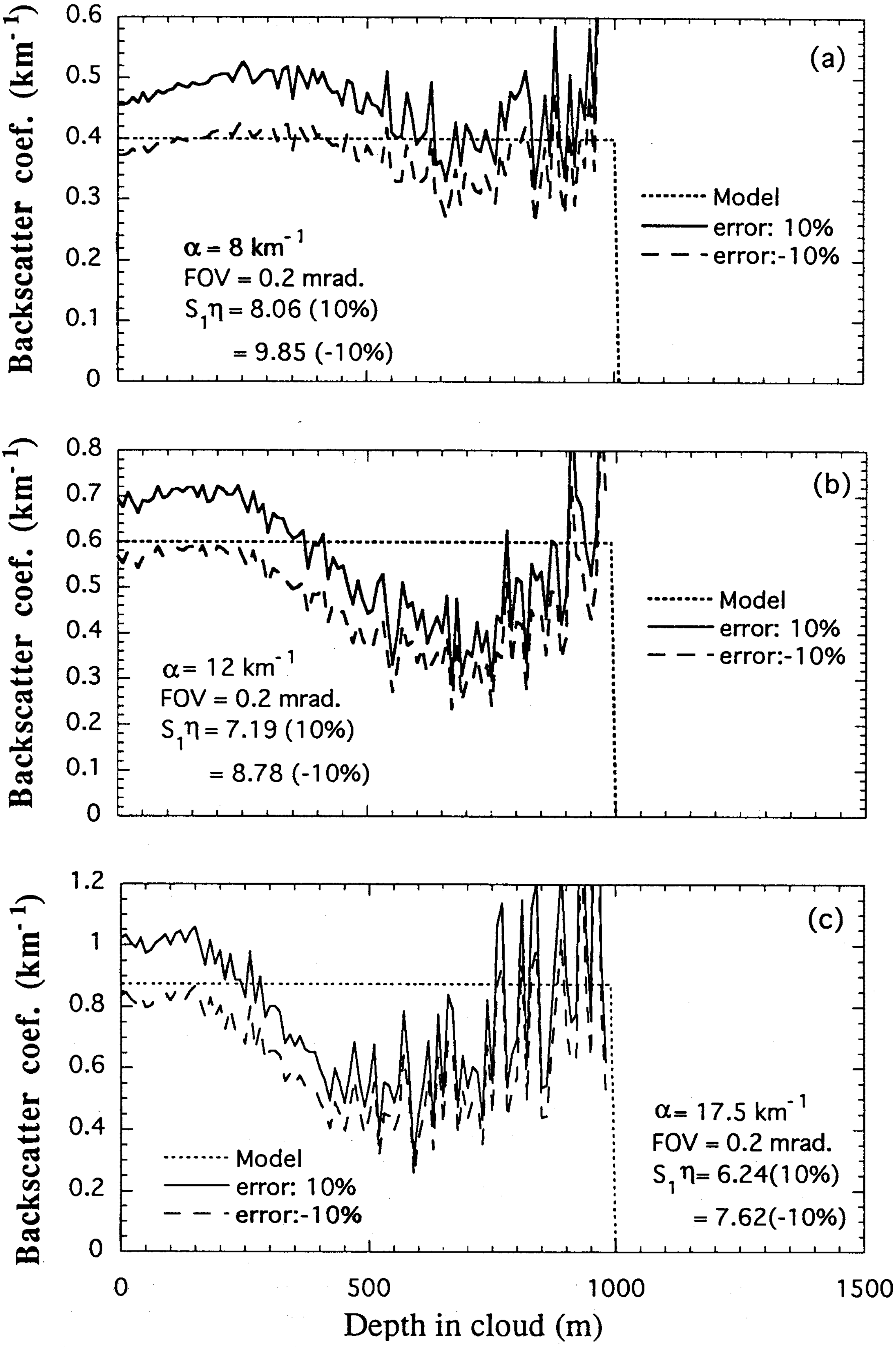

Fig. 4 Simulations of dense cloud backscattering coefficient retrieval using the iterative algorithm. Used lidar signals were generated with Monte-Carlo method for homogeneously distributed C1 model clouds with extinction coefficents of 8, 12 and 17.5 km^{-1}.