Monte Carlo Simulations for Spaceborne Lidar

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1. Introduction

Because of their significant influences of clouds on climate, detailed measurements of clouds are needed. Recent effort to develop new spaceborne sensors, such as a cloud radar, a global imager(GLI), etc. will provide useful information about cloud microphysics. A Laser radar is also an useful sensor for cloud sensing from space and has provided interesting features of clouds in Lidar In-space Technology Experiment(LITE). One of the findings in the LITE is that the contribution of multiple scattering in the lidar returned signals can not be negligible. In this paper, we demonstrate the effects of multiple scattering on the measurements of spaceborne lidar.

2. Monte Carlo model

A Monte Carlo model is developed for simulation of multiply scattered lidar returned signals. The model used is essentially the same procedure described by Kunkel and Weinman(1976). The accuracy of our Monte Carlo code was confirmed by comparison of
the result of Multiple Scattering Lidar Experiments(MUSCLE) (Bissonnette, et al.1995). Our results are in good agreement with the results by other MUSCLE participants.

3. Multiple scattering

Figure 1 is an example of lidar return signals as a function of cloud optical thickness. A range in Fig.1 indicates a range inside the cloud from which the laser beam is cattered. The distance of the lidar from clouds is 1km, and C1 cloud is used. Although the reflected signals from the top of the clouds (range<10m) increase monotonously with the optical thickness (top line), signals from inside cloud decrease for thicker clouds than some threshold depending on the range in cloud. Small differences between the total signals(solid lines) and single scattering signals(dotted lines) suggest that the contribution of the multiple scattering is not large since distance of lidar from the clouds is small. However, the contribution of the multiple scattering can not be negligible if a lidar locates at a large distance from clouds. Figure 2 shows the effects of the distance. Total signals, single scattering signals, second order, and third order scattering signals detected by lidars located at 1km (Fig.2a) and 500km(Fig.2b) from the cloud are plotted. In Fig.2(a), most total signals are due to single scattering, while significant increases in the portion of the multiple scattering are observed in Fig.2b. Assumptions of no scattered radiation, single scattering solution, therefore, lead to considerable error in the estimation of cloud proprties.

4. Multiple field of view Lidar

Degree to which the multiple scattering contributes to returned signals is needed for an accurate estimation of cloud optical properties. A multiple field of view(MFOV) lidar provides useful information of the multiple scattering(Bissonnette and Hutt, 1990). To examine the potential of the MFOV lidar, we made Monte Carlo calculations. In the calculation, clouds are assumed to be 1km thick, and the single scattering albedo is taken to be unity. The cloud is comprised of water droplets with Log-Normal size distribution determined as

$$n(r) = \frac{a}{(2\pi)^{1/2} br} \exp(-(\ln r - \ln r_0)^2/(2b)^2),$$

where n is the number of drops(cm-3) and r is drop radius with a and b=0.35 being constant. r0 is the mode radius. The phase function is calculated by Mie theory for a wavelength of 1.064um and for a refractive index of 1.333. The distance of the lidar from clouds is 500km. The scattering by air is not considered. The ground reflectance is assumed to be zero.

Figure 3 shows multiple to single scattering ratios calculated for various receiver FOV angles. Cloud optical thickness is taken to be 17.5. Reflection from the layer near cloud top(range=0) shows no significant differences in the ratio among the FOV. As the cloud range comes to be larger, however, increase in the FOV leads to a siginificant increase in the ratio. The returned signals detected with smaller FOV contain less contribution of the multiple scattering. This suggests that the lidar with multiple field of viewing angles is useful to estimate degree to which the multiple scattering contribute in the received signals.

Figure 4 shows the effects of the beam divergences. A larger beam divergence leads to decreases in the returned signals for the receiver FOV of 0.05mrad(Fig.4a). As the FOV increase, the decrease in the signals is almost negligible(Fig4.b). Narrow beam, therefore is superior from the point of pure scientific purpuse.

5. Conclusions

Neglect of multiple scattering contribution in retrieval of cloud properties from spaceborne lidar data may leads to significant error. MFOV lidar is proved to be useful to estimate the contribution of the multiple scattering to the lidar signals.

Acknowledgements

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Bissonnette,L.R., et al.,1995: LIDAR multiple scattering from clouds. Appl.Pyhys. B60,355-362.

Hutt, D.L., L.R.Bissonnette, and L.Durand,1994: Multiple field of view lidar returns from atmospheric aerosols. Appl. Opt., 33, 2338-2348.

Kunkel,K.E., and J.A. Weinman,1976: Monte Carlo analysis of multiply scattered lidar returns. J.Atmos.Sci.,33,1772-1781.

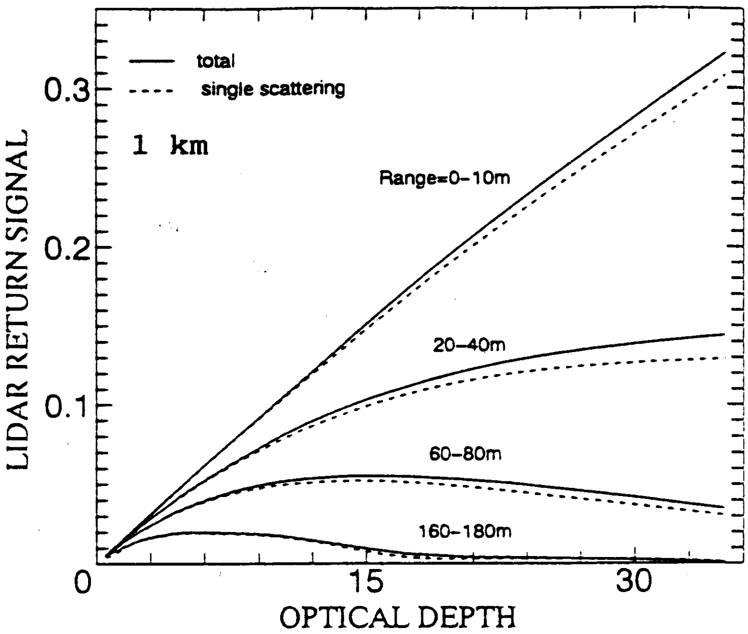

total
single scattering
1 km
Range=0-10m
20-40m
60-80m
160-180m
LIDAR RETURN SIGNAL
0.3
0.2
0.1
0
15
30
OPTICAL DEPTH

Fig.1

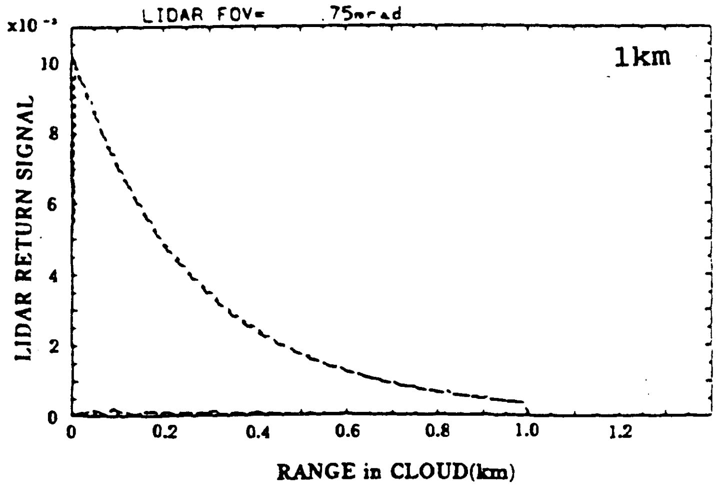
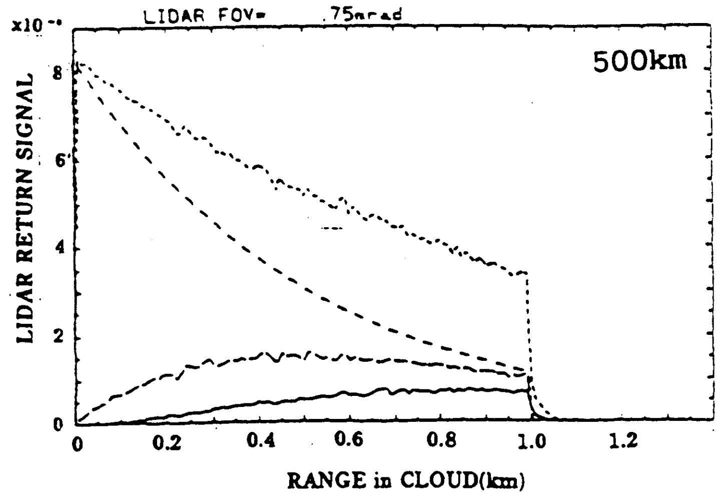

LIDAR FOV= .75mrad
x10⁻³
1km
LIDAR RETURN SIGNAL
10
8
6
4
2
0
0.2
0.4
0.6
0.8
1.0
1.2
RANGE in CLOUD(km)

Fig.2 (a)


LIDAR FOV= .75mrad
500km
LIDAR RETURN SIGNAL
8
6
4
2
0
0.2
0.4
0.6
0.8
1.0
1.2
RANGE in CLOUD(km)

(b)

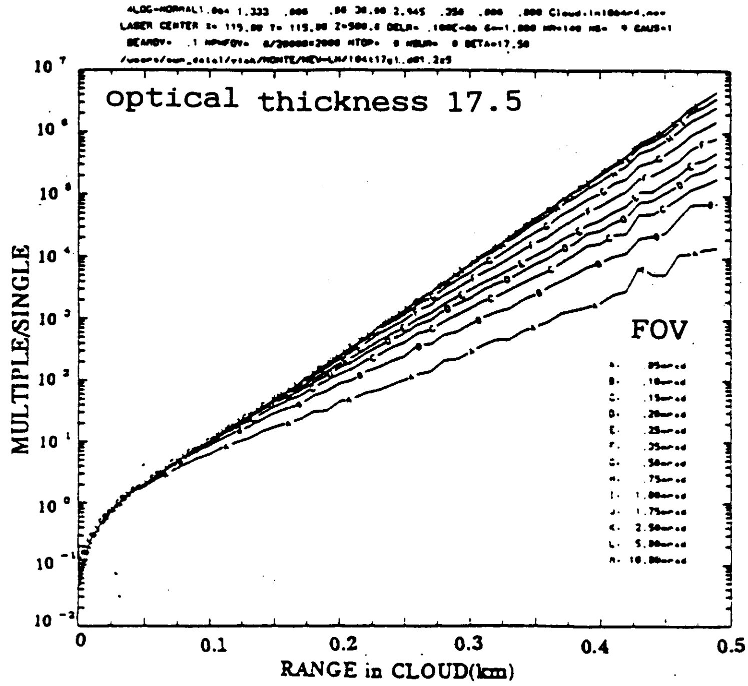

optical thickness 17.5
MULTIPLE/SINGLE
RANGE in CLOUD(km)
FOV
0
0.1
0.2
0.3
0.4
0.5

Fig.3

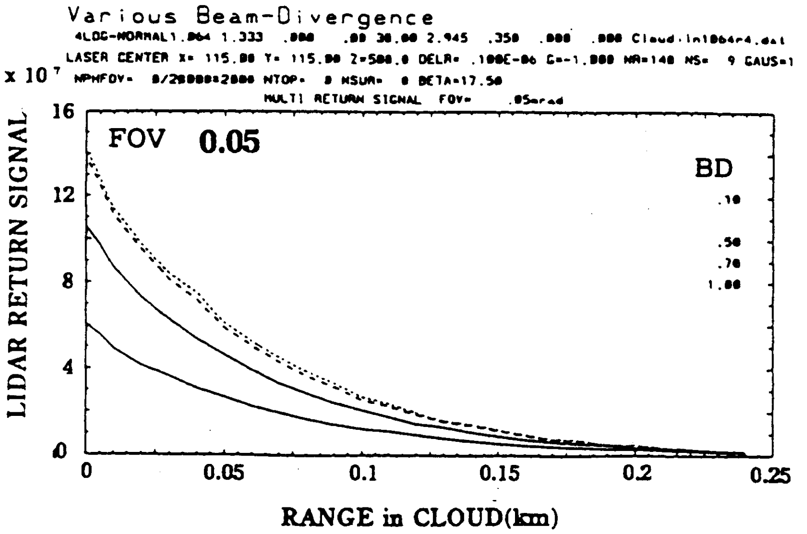
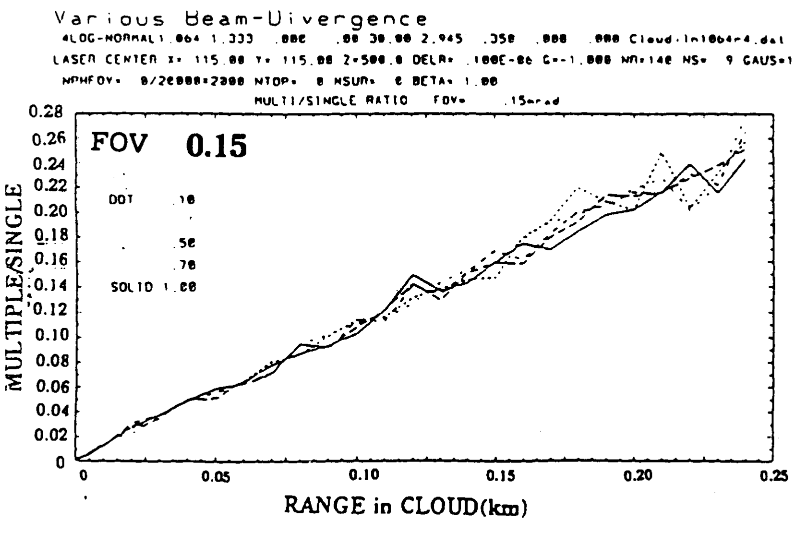

Various Beam-Divergence
x 10^7
LIDAR RETURN SIGNAL
FOV 0.05
BD
.10
.50
.70
1.00
16
12
8
4
0
0
0.05
0.1
0.15
0.2
0.25
RANGE in CLOUD(km)

Fig.4 (a)


Various Beam-Divergence
MULTI/SINGLE RATIO
FOV 0.15
DOT .10
.50
.70
SOLID 1.00
MULTIPLE/SINGLE
RANGE in CLOUD(km)
0
0.05
0.10
0.15
0.20
0.25

(b)

Monte Carlo Simulations for Spaceborne Lidar

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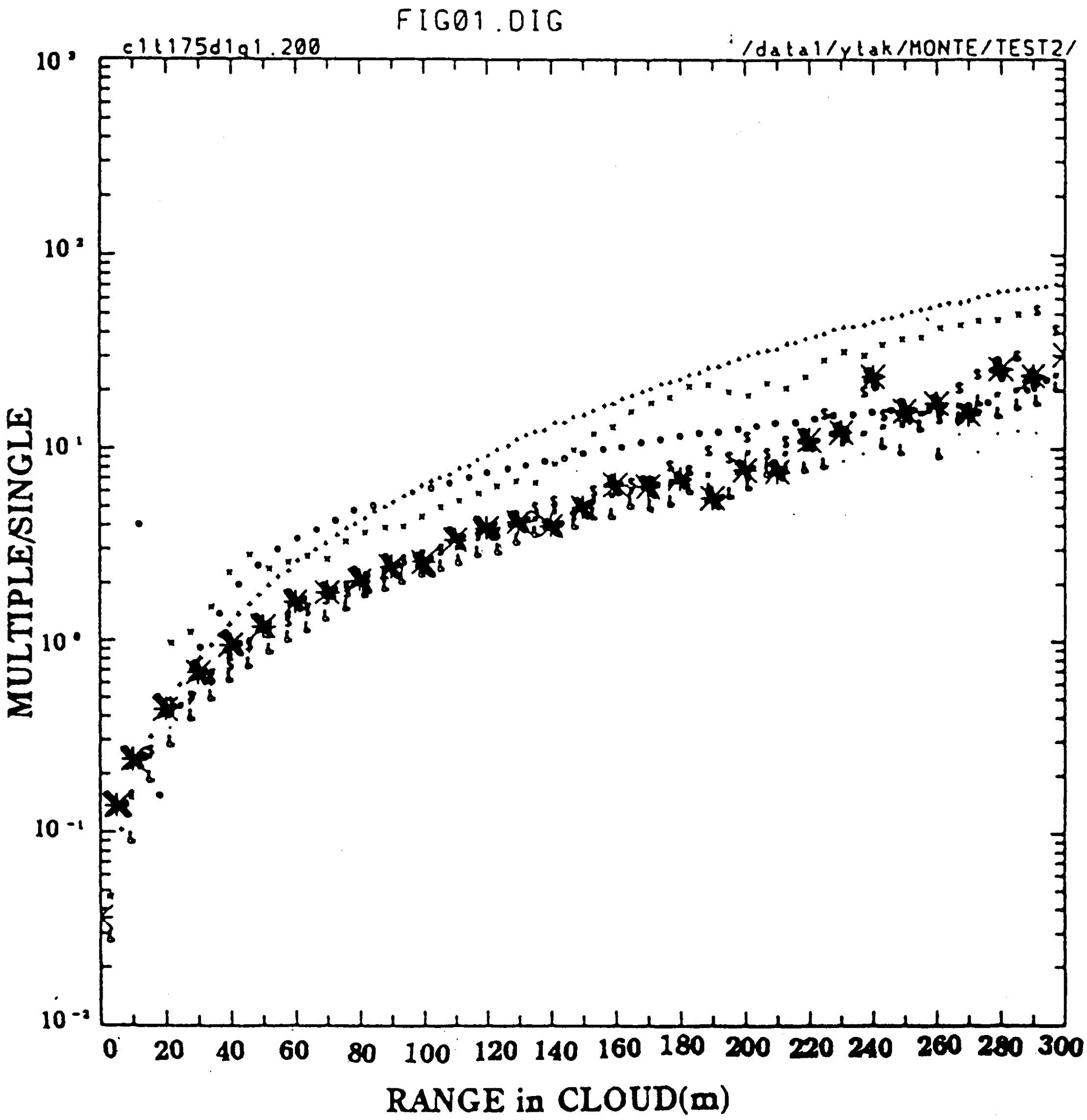
A Monte Carlo model was used to examine the effects of multiple scattering on sapceborne lidar measurements. The results show that "single scattering solution" leads to bias in the retrieval of cloud properties associated with the significant increase in the multiple scattering. An accurate estimate of the cloud properties requires what portion of the multiple scattering included in the lidar return signals. One of the methods to do so is using a multiple field od view (MFOV) lidar. We have proposed a model to determine the contribution of the multiple scattering from spaceborne MFOV lidar measurements by using the Monte Carlo simulations for MFOV lidar.

衛星搭載ライダにおける多重散乱効果をモンテカルロ法により調べた。その結果多重散乱が無視できず，受信信号を単散乱として雲の特性を推定するとバイアスが生じることが確認された。このバイアスを補正するために受信信号に含まれる多重散乱の割合を複数のFOVを持つライダにより推定する方法を開発した。モンテカルロ法の計算結果との比較ではある程度までは推定できることが分かった。

Monte Carlo Model for multiply scattered lidar return signals

● <u>Method</u>

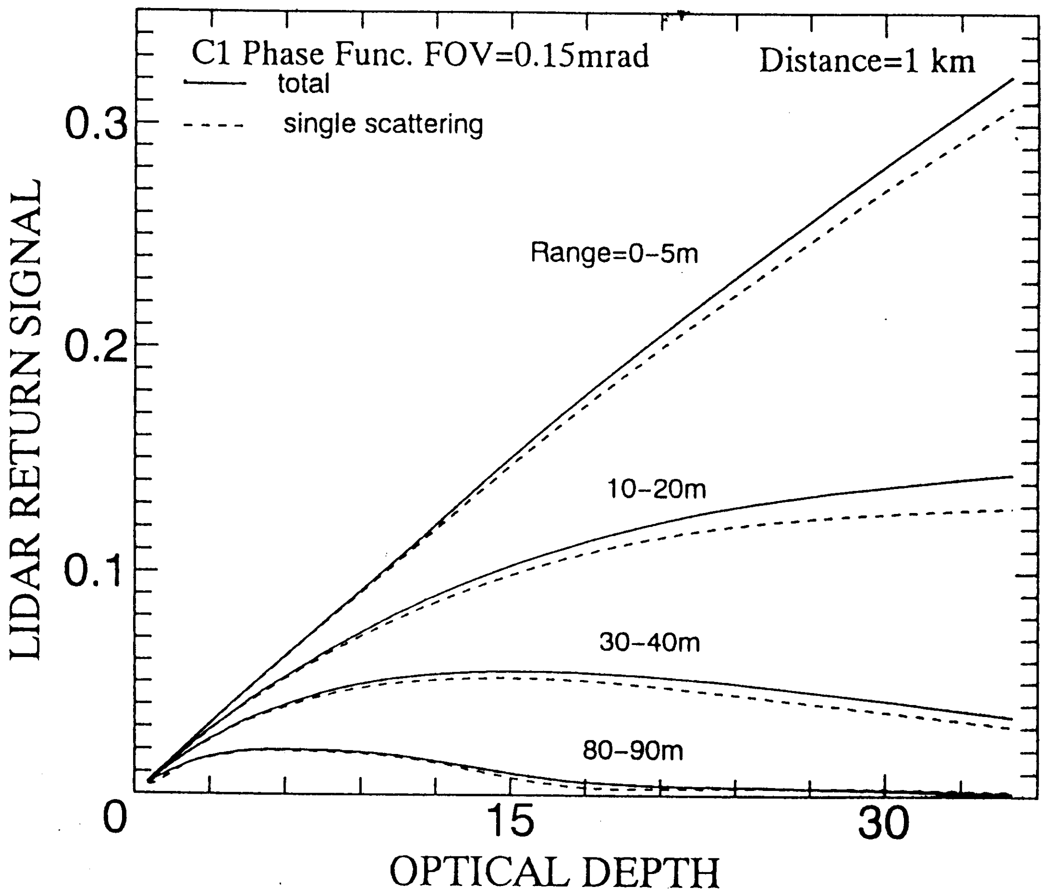
Kunkel and Weinman (1976)

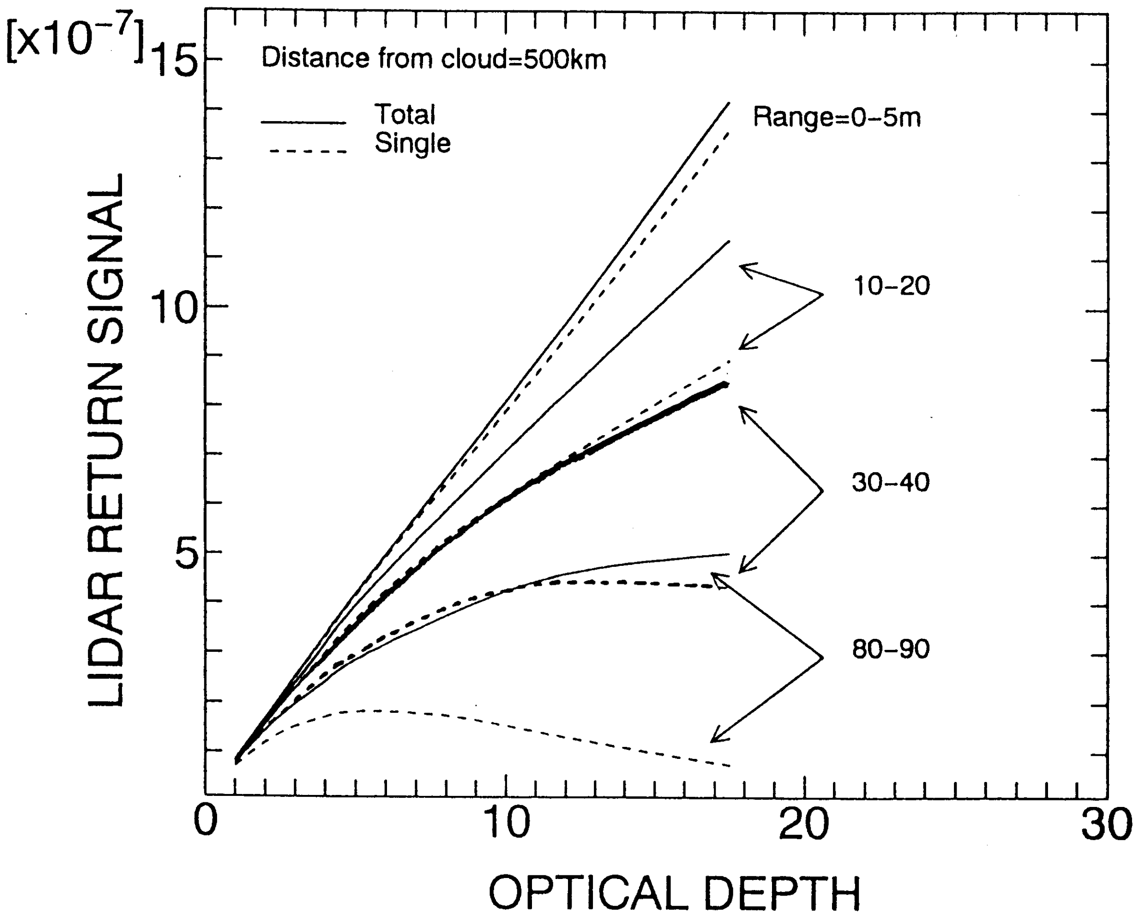


Why multiple scattering?

Spaceborne lidar :

- Large distance to clouds
- Increases in the distance lead to increase in the contribution of multiple scattering


C1 Phase Func. FOV=0.15mrad
total
single scattering
Distance=1 km
Range=0-5m
10-20m
30-40m
80-90m
0.3
0.2
0.1
0
15
30
LIDAR RETURN SIGNAL
OPTICAL DEPTH


[x10⁻⁷]
15
10
5
Distance from cloud=500km
Total
Single
Range=0-5m
10-20
30-40
80-90
0
10
20
30
LIDAR RETURN SIGNAL
OPTICAL DEPTH

- *Ground-based lidar:*
  Single scattering solution

- *Spáceborne lidar:*
  Multiple scattering contribution can not be negligible because the lidar located at large distance from clouds

Cloud and Monte Carlo Model

Lidar

- ◆Wavelength: 1.064μm
- ◆Beam Divergence : 0.1 -- 1.0$mrad$
- ◆Receiver FOV: 0.0--10 $mrad$
- ◆Altitude: 500km

Clouds

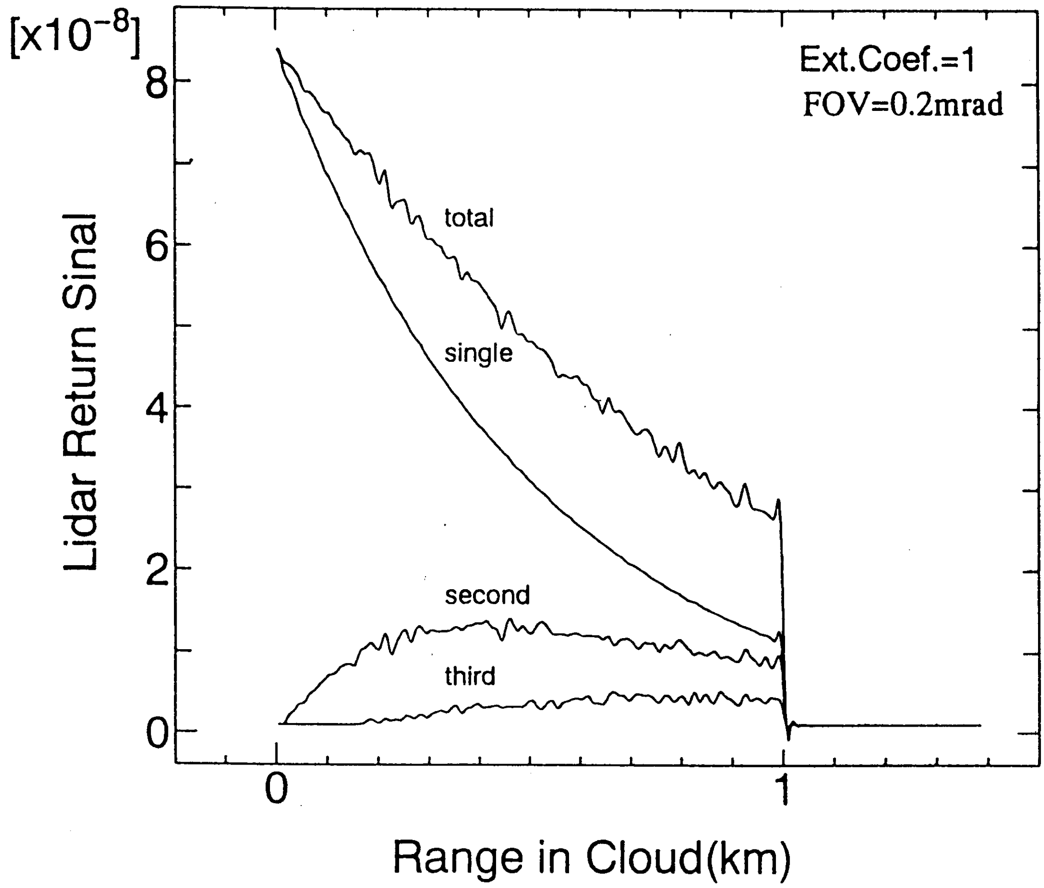
- ◆Cloud Height: 10-11km
- ◆Extinction Coefficient: 0.5--35km^{-1}

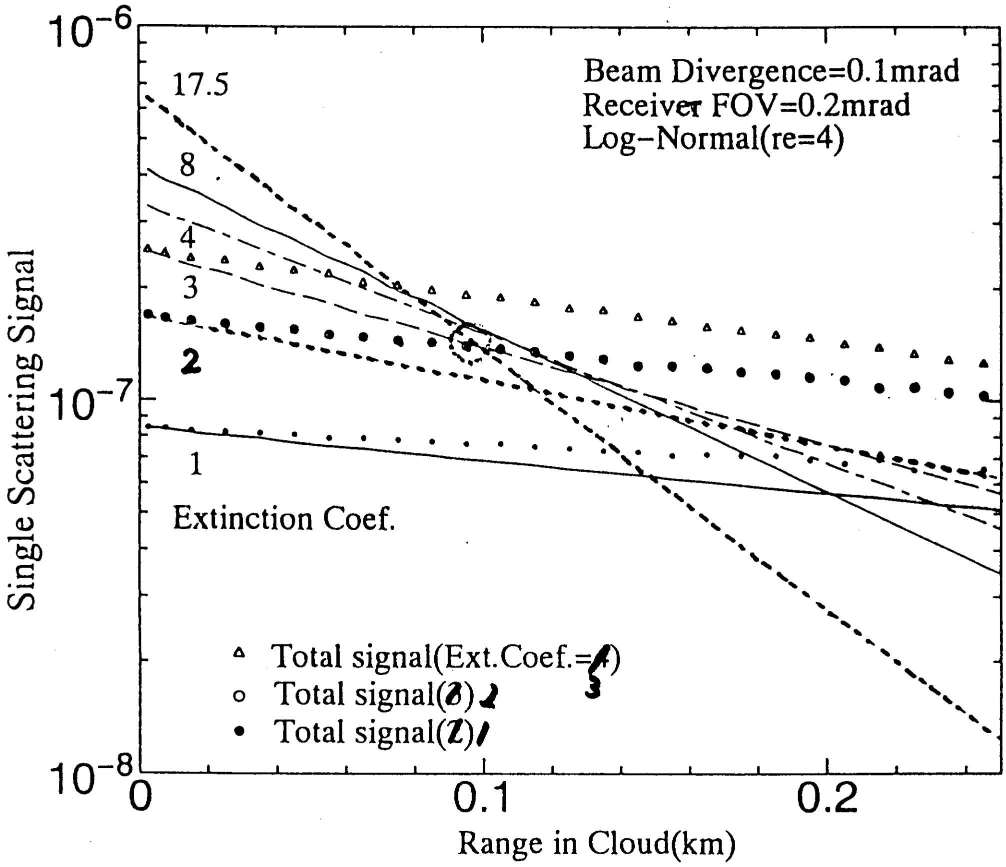
Log-Normal size distribution

$$n(r) = \frac{a}{(2\pi)^{1/2} br} \exp\left(-(\ln r - \ln r_0)^2 / (2b)^2\right)$$

r_0,=Mode Radius (2--36), b=0.35

- ◆Refractive Index : 1.333
- ◆Single Scattering Albedo: 1


[x10^-8]
Ext.Coef.=1
FOV=0.2mrad
total
single
second
third
Lidar Return Sinal
Range in Cloud(km)


Beam Divergence=0.1mrad
Receiver FOV=0.2mrad
Log-Normal(re=4)
17.5
8
4
3
2
1
Extinction Coef.
Total signal(Ext.Coef.=4)
Total signal(8) 2
Total signal(2) 1
Single Scattering Signal
Range in Cloud(km)

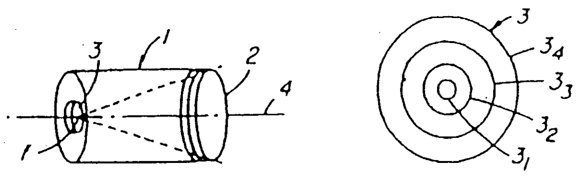
- Assumption of no scattered radiation, *"Single scattering solution" is* not appropriate for spaceborne-lidar.
- Multiple Field of View (MFOV) lidar has been proposed for this solution
- We examine its potential of MFOV lidar.

Multiple Field of View Lidar

Lidar with detectors of multiple field of view arranged as a circular central detector.

Simulation

FOV: 0.05, 0.1, 0.15, 0.2, 0.25, 0.35, 0.5, 0.75, 1.0, 1.75, 2.5, 5.0, 10.0 (half angle)



Bissonnette (1993)

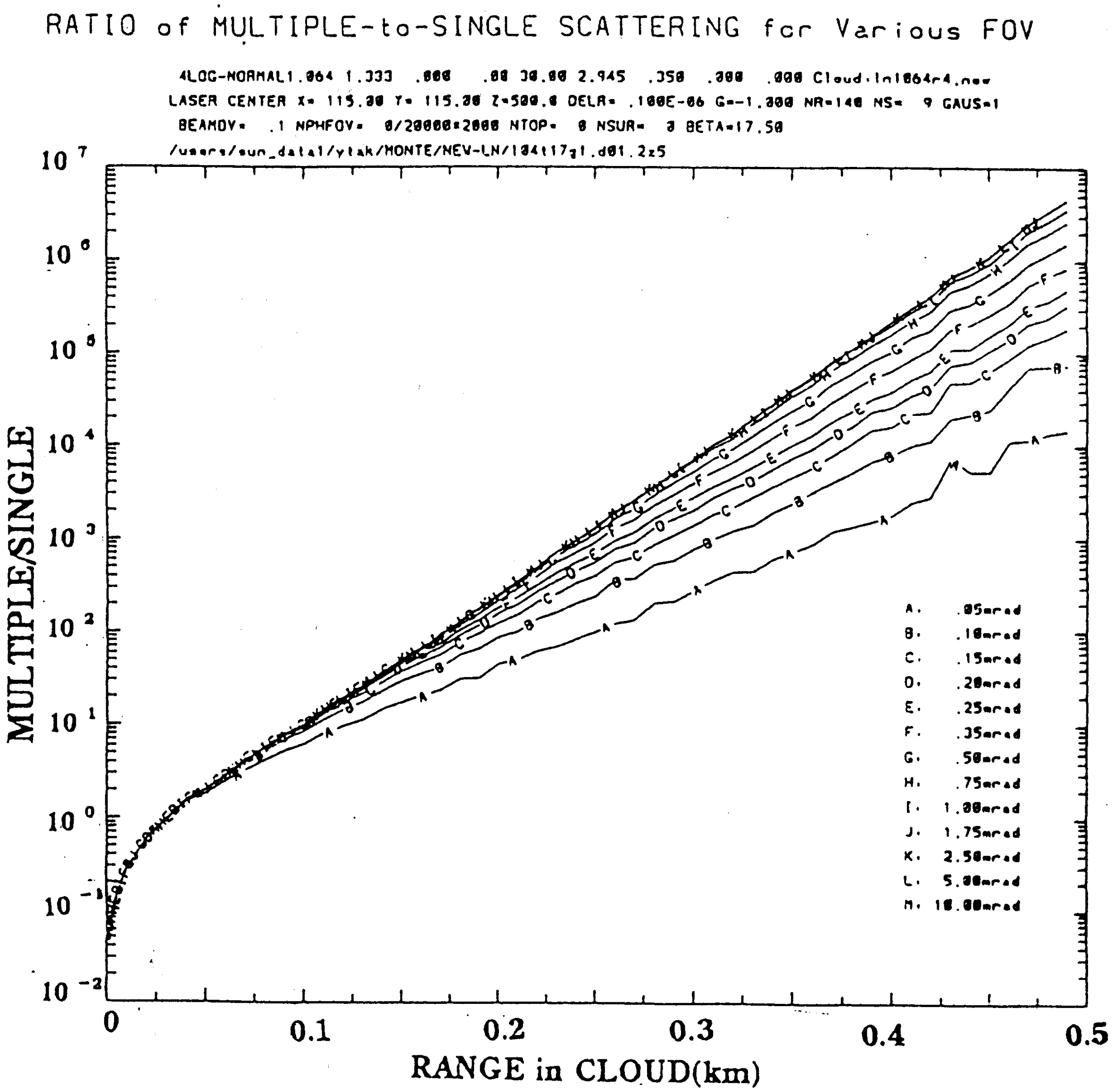


図4.2-2(2) 受信信号強度中の多重散乱寄与／単散乱寄与比のＦＯＶによる違い
（光学的厚さ：Ｂ＝17、ビーム拡がり幅：0.1mrad）

Model of Multiple Scattering Signal

Lidar return signal (S_t) is given by

$S_t(f) = S_s + S_m(f)$

S_s : Single scattering signal

S_m : Multiple scattering signal

f : Field of viewing angle

S_s is independent of field of view, therefore difference between two signals of FOV, f1 and f_2 shows multiple scattering difference.

$S_t(f_1) - S_t(f_2) = S_m(f_1) - S_m(f_2)$

Assuming S_m is proportional to the receiver area,

$S_m \propto$ receiver area $= a \cdot f^2$

then multiple scattering signal for FOV, f is

$$S_m(f) = [S_m(f_1) S_m(f_2)] \cdot f^2 / (f_1^2 - f_2^2)$$