Observation of Multiple Scattering effect in Clouds by a Dual FOV Polarization and Raman Lidar from Ground

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1. Introduction

Spaceborne lidar attracts many researchers of atmospheric science and climate because of its capability of global observation. Clouds as well as aerosols are common targets to be observed by the spaceborne lidar. Successful Lidar In-Space Technology Experiment (LITE) by NASA demonstrated the importance of multiple scattering by cloud particles. In some cases, this effect helped to observe the multi-layered structure of clouds.

The multiple scattering effect by clouds in lidar has been studied extensively in experiment and theory. The depolarization caused by multiple scattering has also been studied [1]. The inversion method including multiple scattering is necessary to derive the optical thickness of cloud and furthermore, micro-physical properties such as effective radius of cloud particles [2]. The experimental study of multiple scattering in clouds with ground-based lidar and the comparison of the observation with theory, both should be necessary to improve the analytical method of the data taken by Spaceborne lidars.

Recently we have adapted our ground-based lidar to observe the multiple scattering effects in clouds. Here we briefly report on the multiple scattering effects in clouds observed by a dual field of view (FOV) polarization lidar. We also show a result of simultaneous observation of cloud with a Raman lidar to derive the extinction profile in clouds.

2. Lidar System

We have observed the troposphere mainly in the atmospheric boundary layer (ABL) by lidar in Tokyo to investigate urban meteorology from 1993 [3]. The wavelength of used laser lights is 532 nm. Since the summer of 1995, we have employed two receiving telescopes to expand the dynamic range of detection [4]. Each telescope has a variable field stop and a function to measure depolarization ratio δ [1]. From another point of view, this system can be a useful tool to observe the effect of multiple scattering in clouds because it enables to measure the backscattering intensity and δ with different two FOV receivers simultaneously. The telescopes used are 25 cm and 20 cm in diameter, and the FOV of telescope can be varied from 1 to 4 mrad and from 1 to 6 mrad in 1 mrad step, respectively. In the present setup optimized for the ABL study, the measurement with a large FOV was hard to take reliable data with enough signal to noise ratio due to the strong near-filed backscattering. Thus we had to reduce the applying voltage of photo-multiplier tubes (PMT) used for light detection, *i.e.*, detection efficiency to avoid inconvenient saturation effect of PMT. More suitable scheme is to take a more distance between the axis of the larger FOV receiver and that of the laser beam at the lidar.

Raman scattering signal from nitrogen molecules in the atmosphere can also be observed in night with a telescope 30 cm in diameter which is located adjacent to the two telescopes described. In Raman channel, strong Rayleigh-Mie scattering was fully suppressed by filters. The Raman signals were counted in single photon counting mode, while the signals of elastic ones were recorded in analog mode.

3. Results of Observation

3. 1 Dual FOV Polarization Lidar

The ratio between backscattering intensities observed by dual FOV receivers can give a measure of multiple scattering process occurred in clouds. As increasing the FOV of receiver, larger effect is expected, because the multiple scattering cause a spreading forward light-corn around the primary laser beam in dense media. Here we present some results for water clouds at low altitude (1-2 km) and ice clouds at high altitude ($\geq$ 5 km).

3. 1. 1 Water Clouds at Low Altitude

In case of water clouds *e.g.*, stratocumulus, depolarization can be arisen only from the multiple scattering; *i.e.*, the δ takes a minimum value about zero at the cloud base and rapidly increases as increasing the penetration depth. We observed such clouds at low altitude by the dual FOV polarization lidar. The enhancement of backscattering intensity of larger FOV receiver was clearly observed as the laser beam penetrated the clouds. The rising behavior of δ value in clouds was more rapid for the larger FOV receiver. We have confirmed this relation by reversing the relationship of FOV of the two receivers. When both receivers had the same FOV, there observed no difference in backscattering intensity and δ.

3. 1. 2 Ice Clouds at High Altitude

We also observed Cirrus (ice-phase clouds) at high altitude, which cause a large δ about 30 % over the whole cloud. In this case, we have observed no enhancement in backscattering intensity and δ for the larger FOV receiver. Further collection of data with improved signal to noise ratio are necessary to discuss more details.

3. 2 Combination with Raman Lidar

We made the combined measurement of clouds at low altitude with the polarization lidar and Raman lidar. The extinction profile of aerosols is obtained from Raman scattering signal from nitrogen molecules with assuming the density profile of air molecules [5]. The derived extinction profile had a peak at more inside of clouds than the backscattering intensity profile. This tendency seems to be reasonable because the backscattering intensity in the inside of clouds is strongly reduced due to large attenuation. However, it has been reported that the multiple scattering in Raman signals is not negligible [6]. The effect reduces the extinction value especially at the bottom region of clouds.

4. Discussion and Summary

We have studied the multiple scattering in clouds in lidar by using dual FOV polarization lidar and Raman lidar. The significant effect due to multiple scattering was observed in the backscattering intensities and depolarization ratio in water clouds at low altitude; *i.e.*, the multiple-scattering intensity and depolarization increase as the laser beam penetrates the clouds. On the other hand, no clear evidence of multiple scattering was observed in the case of ice clouds at high altitude. This difference seems to result from difference of the optical density and the scattering properties of both the clouds. The water droplet clouds in low altitude have much thicker optical thickness than the cirrus at high altitude. That is to say, the depolarization ratio is rather sensitive to the multiple scattering in the case of water clouds.

Simple calculation of the data taken by the dual FOV polarization lidar, in which we assumed that the depolarization caused from only multiple scattering [1], underestimates the contribution of multiple scattering. The comparison of data with more sophisticated numerical calculations *e.g.,* Monte-Carlo simulations is required. If we can include the polarization in the calculation, it must be interesting to survey a possibility to obtain additional micro-physical information of clouds [7].

Raman lidar is useful to derive the extinction profile of clouds. To estimate the multiple scattering effect in the Raman scattering, it must be useful to employ a multi-FOV Raman lidar.

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References

[1] *e.g.*, S.R. Pal and A.I. Carswell, "Multiple scattering in atmospheric clouds: lidar observations", Appl. Opt. **15**, 1990 (1976)

[2] L.R. Bissonnette and D.L. Hutt, "Multiply scattered aerosol lidar returns: inversion method and comparison with *in situ* measurements", Appl. Opt., **34**, 6959-6975 (1995)

[3] T. Marayama, M. Furushima, A. Oda, N. Iwasaka, and K. Kai, "Depolarization Ratio Measurements in the Atmospheric Boundary Layer by Lidar in Tokyo", J. Meteo. Soc. Japan **74**, 571-578 (1996)

[4] T. Murayama, M. Furushima, Ayato Oda and N. Iwasaka, "Aerosol Optical Propeties in the Urban Mixing Layer Studied by Polarization Lidar with Meterological Data", to appear in "Advances in Atmospheric Remote Sensing with Lidar" (Springer) edited by A. Ansmann et. al. (1996).

[5] A. Ansmann, M. Riebesell, U. Wandinger, C. Weitkamp, E. Voss, W. Lahmann, and W. Michaelis, "Combined Raman Elastic-Backscatter LIDAR for Vertical Profiling of Moisture, Aerosol Extinction, Backscatter, and LIDAR Ratio", Appl. Phys. **B55**, 18-28 (1992)

[6] U. Wandinger, "Influence of multiple scattering on DIAL, Raman, and High Spectral Resolution Lidars- A common MUSCLE study", presented in 18th ILRC at Berlin.

[7] M. Kerscher, W. Krichbaumer, M. Noormohammadian and U.G. Oppel, "Polarized Multiply Scattered LIDAR Signals", Opt. Rev. **2**, 304-307 (1995)

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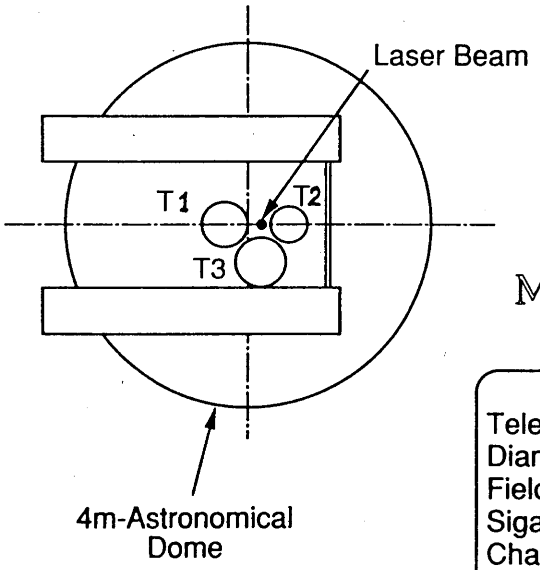
4. Summary

Lidar System

Setup (Top of view)



Emitter

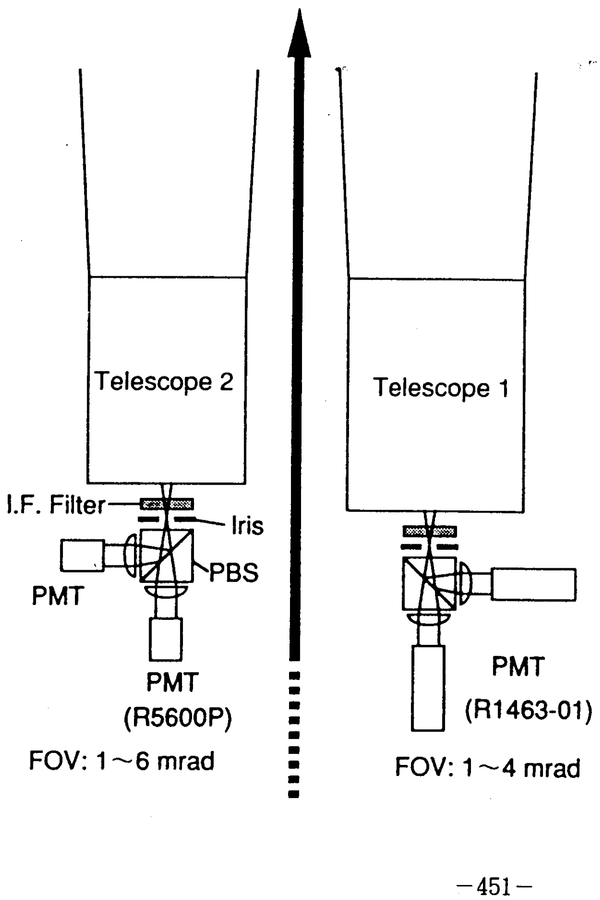
Laser	Nd:YAG
Wavelength	532nm (SHG)
Pulse Energy	250mJ (max.)
Pulse Width	10ns
Repetition rate	10Hz
Beam Divergence	< 0.2 mrad

Multi-Receiver system

to expand dimanic range of detection

	Tel. 2	Tel. 1
Telescope Type	Scmidt Cass.	Scmidt Cass.
Diameter	20.3cm	25.4cm
Field of View	3mrad (typ.)	1mrad (typ.)
Siganl Processing	8bit ADC	8bit ADC
Channels	P, S	P, S

Receiver Optics



N2 Raman Channel (T3)

Diameter : 30.4 cm

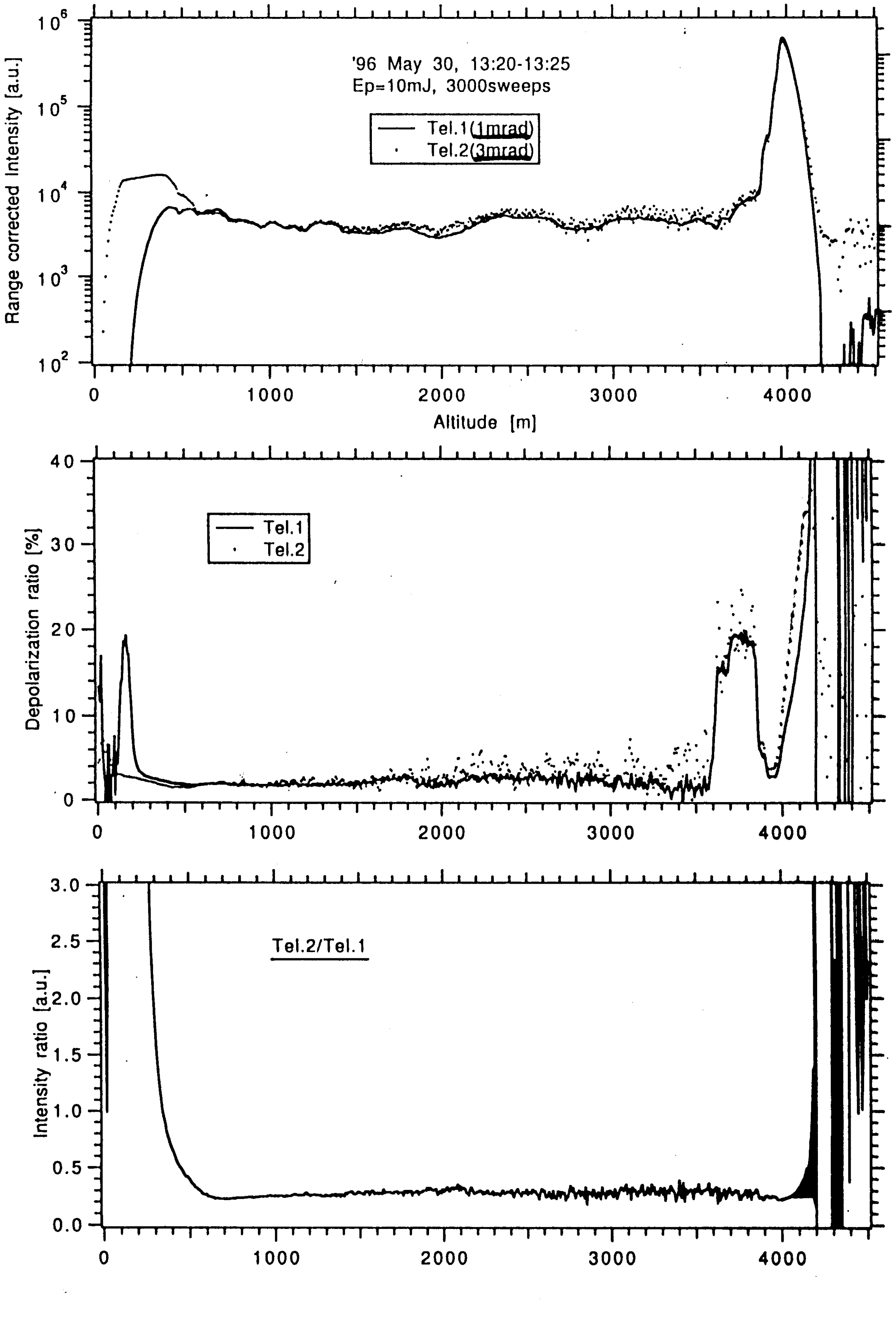
PMT: R5600P-01

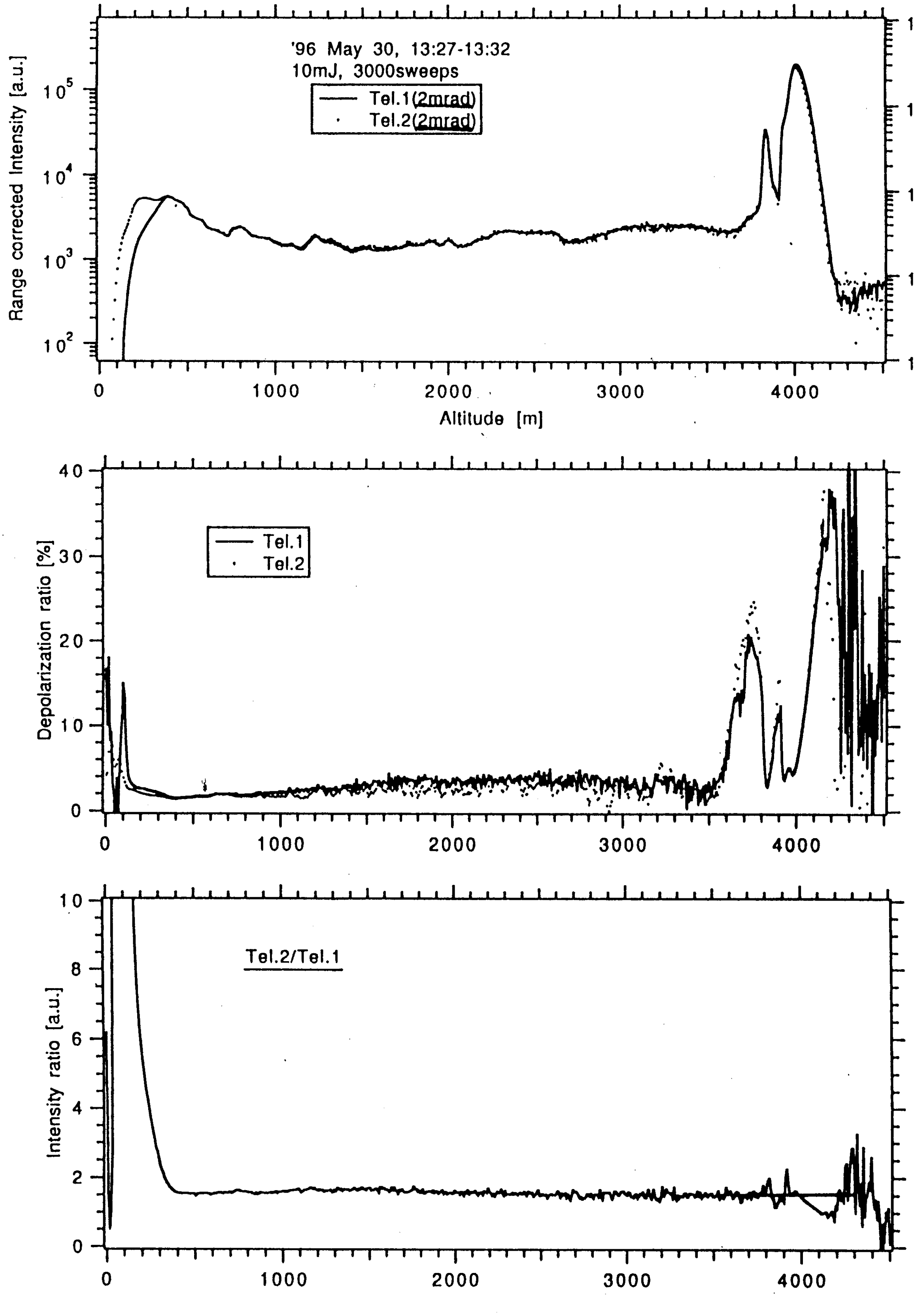
Filters:
I. F. Filter (λ_p=607nm, $\Delta\lambda$=4.5nm)
Colored Glass OG570(3mm)× 2

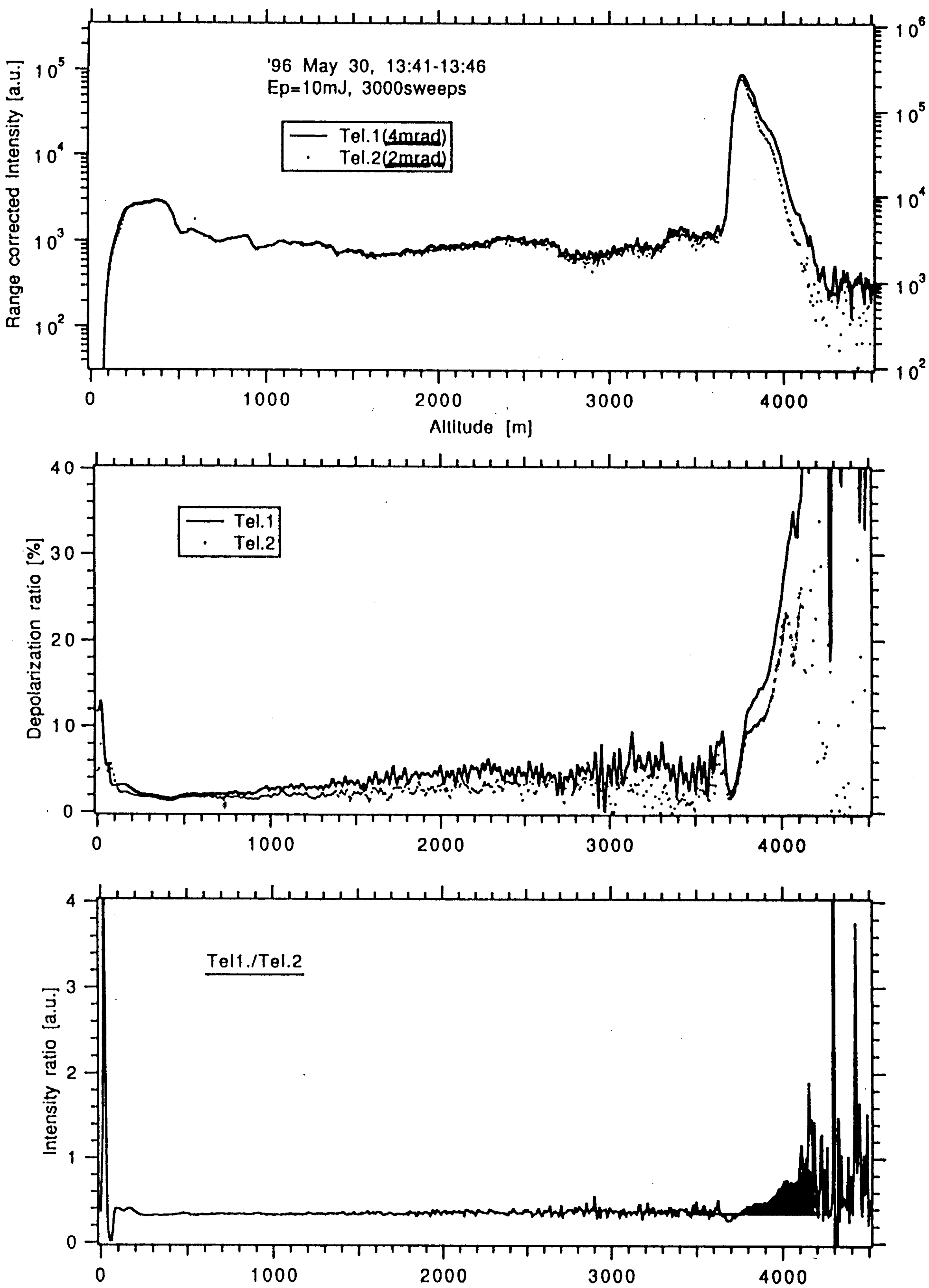
Transmittance@607.3nm = 63.5%

Suppression@532nm > 1×10^{13}

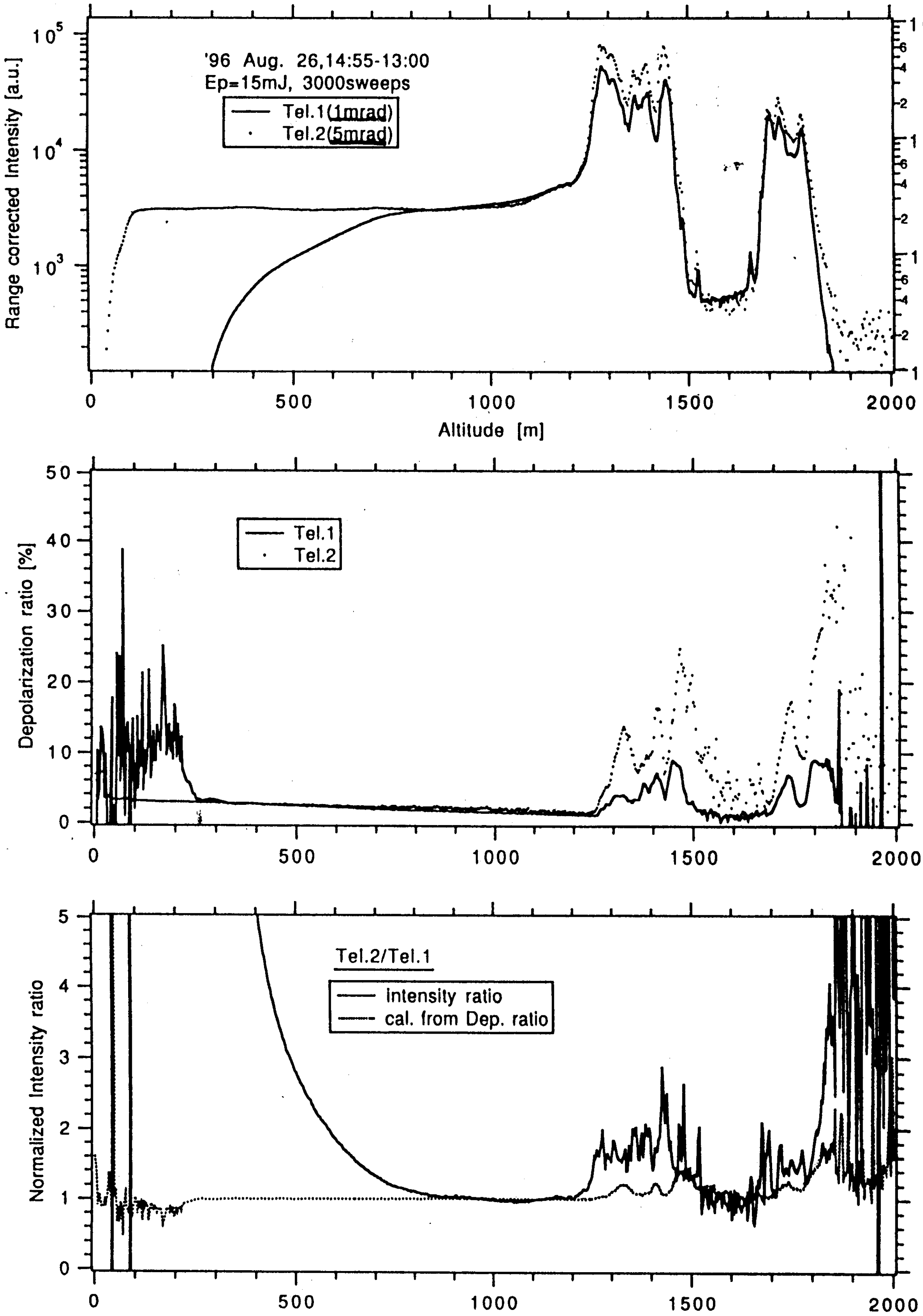
Obsevation by Dual FOV Polarization Lidar



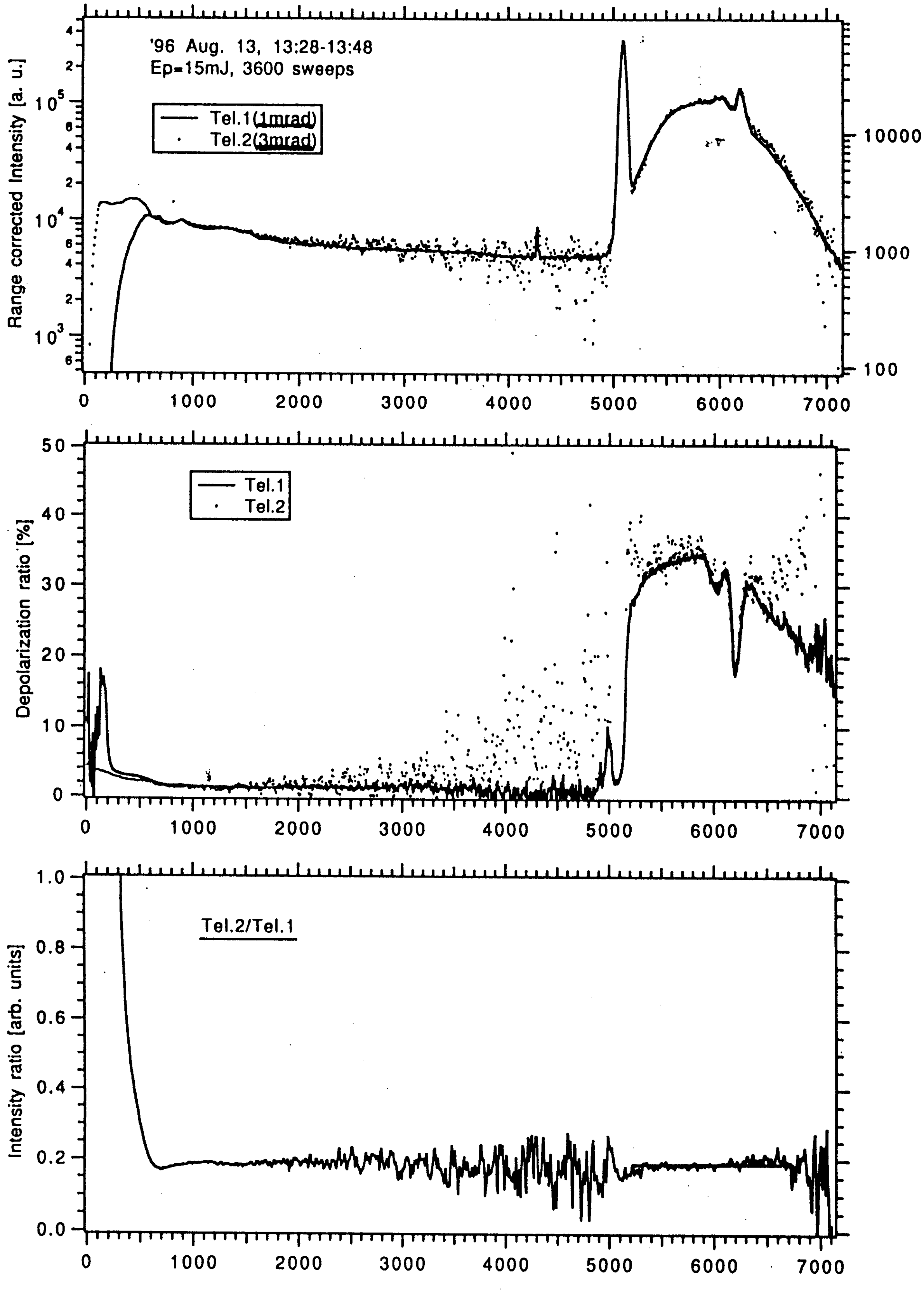

'96 May 30, 13:27-13:32
10mJ, 3000sweeps
Tel.1(2mrad)
Tel.2(2mrad)
Range corrected Intensity [a.u.]
Altitude [m]
Tel.1
Tel.2
Depolarization ratio [%]
Tel.2/Tel.1
Intensity ratio [a.u.]


'96 May 30, 13:41-13:46
Ep=10mJ, 3000sweeps
Tel.1(4mrad)
Tel.2(2mrad)
Range corrected Intensity [a.u.]
Altitude [m]
Tel.1
Tel.2
Depolarization ratio [%]
Tel1./Tel.2
Intensity ratio [a.u.]

Water Droplet Cloud

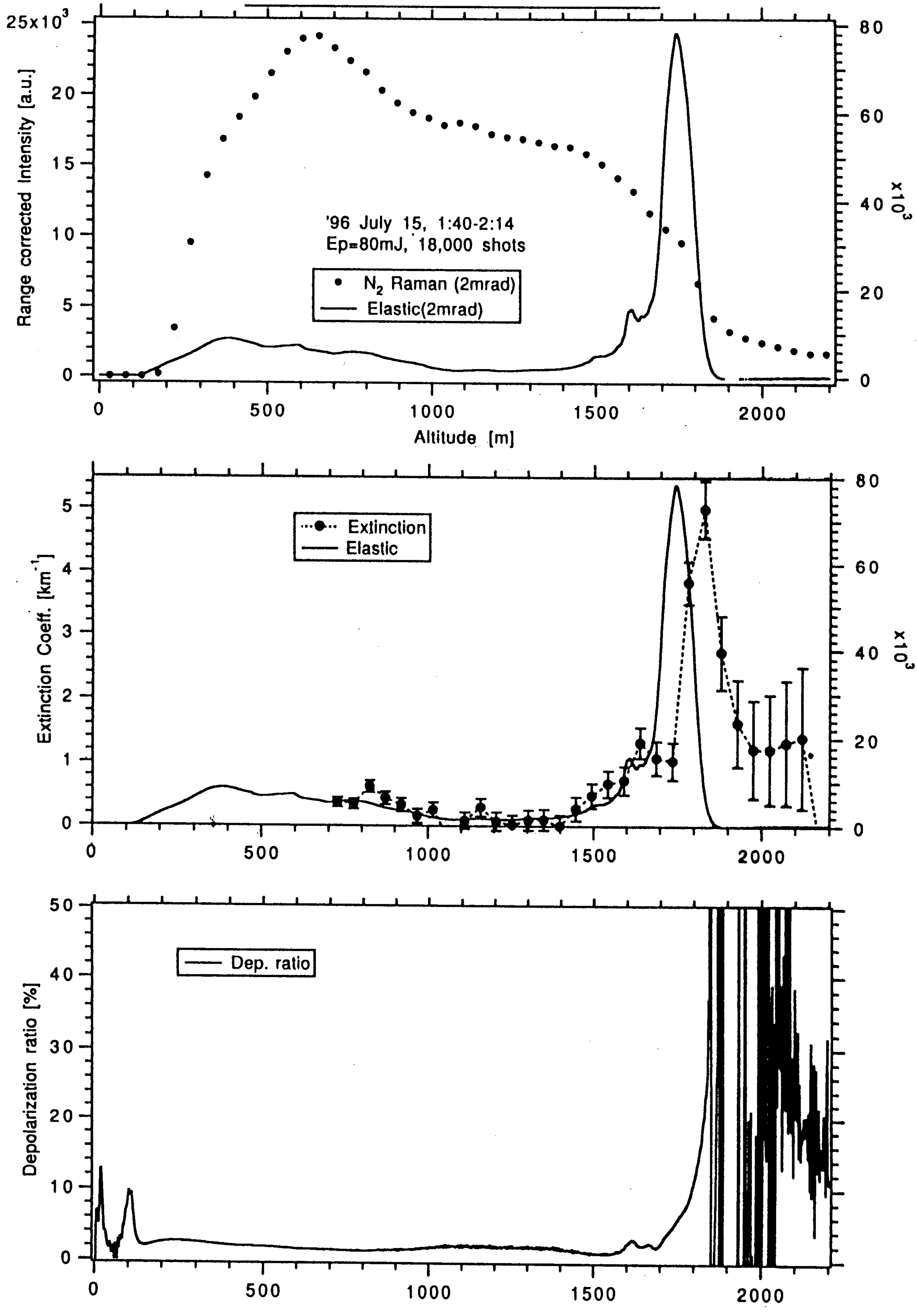


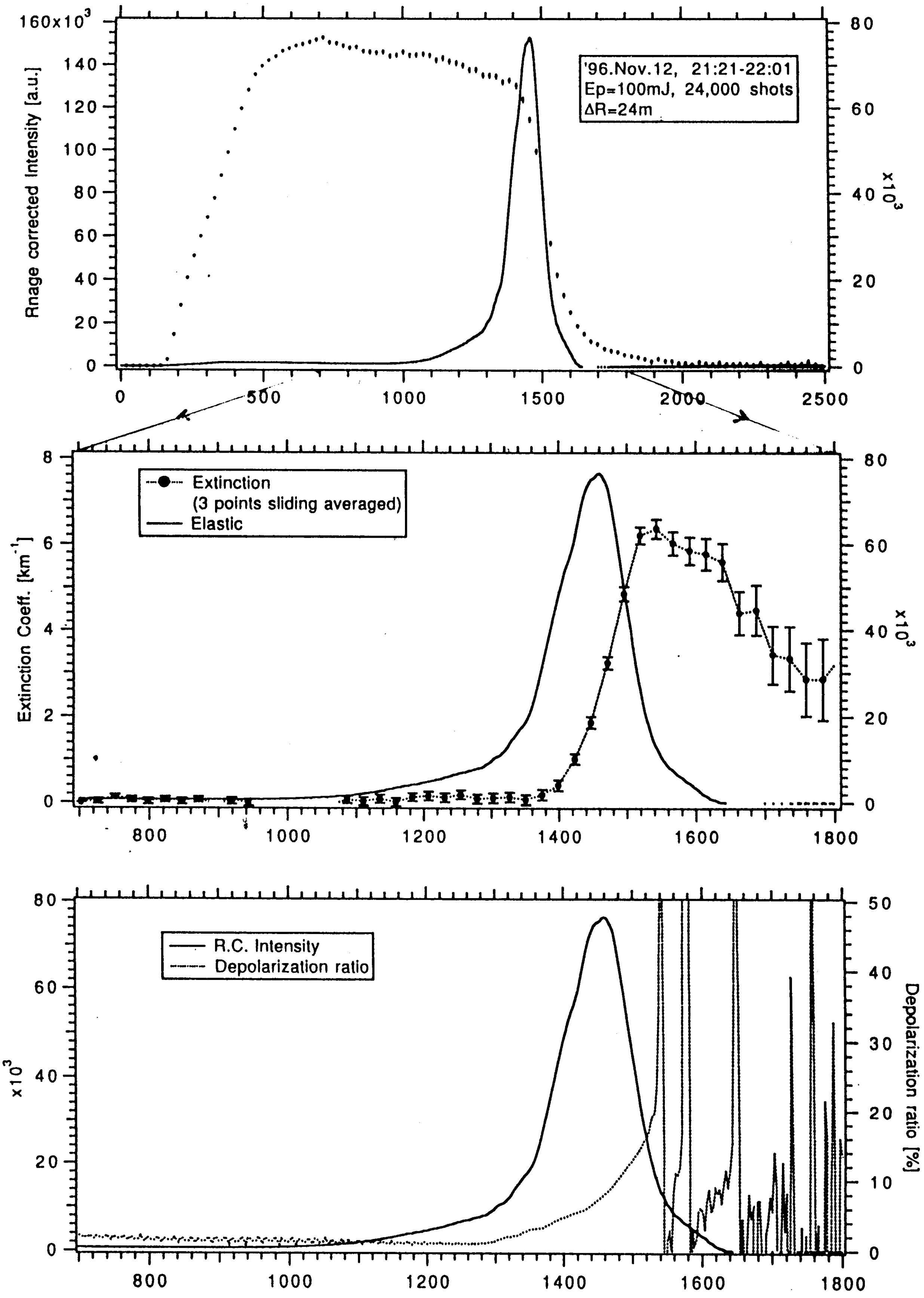
Ice Cloud



'96 Aug. 13, 13:28-13:48
Ep=15mJ, 3600 sweeps
Tel.1(1mrad)
Tel.2(3mrad)
Range corrected Intensity [a. u.]
Tel.1
Tel.2
Depolarization ratio [%]
Tel.2/Tel.1
Intensity ratio [arb. units]

Obsebation with Raman Lidar





'96.Nov.12, 21:21-22:01
Ep=100mJ, 24,000 shots
ΔR=24m
Rnage corrected Intensity [a.u.]
160x10³
140
120
100
80
60
40
20
0
x10³
80
60
40
20
0
0
500
1000
1500
2000
2500
Extinction
(3 points sliding averaged)
Elastic
Extinction Coeff. [km⁻¹]
8
6
4
2
0
x10³
80
60
40
20
0
800
1000
1200
1400
1600
1800
R.C. Intensity
Depolarization ratio
x10³
80
60
40
20
0
Depolarization ratio [%]
50
40
30
20
10
0
800
1000
1200
1400
1600
1800

Simple Estimation of Multiple Scattering from Depolarization Ratio in Water Cloud

(from S.R. Pal and A.I. Carswell, App. Opt. 15 (1976) 1990)

In water-droplet clouds, the depolarization arise from only the multiple scattering process.

If the backscattering due to the multiple scattering totally lose the initial state of polarization, we can write

$$\frac{P_T}{P_1} = \frac{P_{//} + P_{\perp}}{P_{//} - P_{\perp}} = \frac{1 + \delta_p}{1 + \delta_p}$$

,where P_T: Total Backscattering Intensity,
P_1: Single Backscattering Intensity,
δ_p : Depolarization Ratio ($\equiv P_{\perp}/P_{//}$).

In this case, the ratio of backscattering intensities measured by two FOV a, b receivers is given as,

$$\frac{(P_T)_a}{(P_T)_b} = \frac{\left(\frac{P_T}{P_1}\right)_a}{\left(\frac{P_T}{P_1}\right)_b} .$$

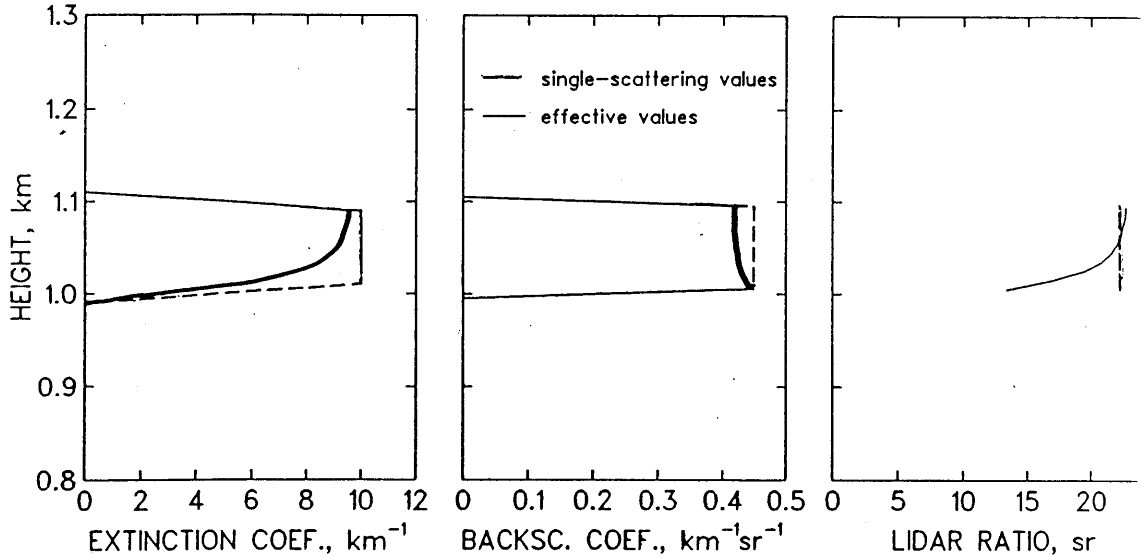
Result:

The calculated value is smaller than the experimental one.

It means that the forward scattered lights considerably conserve the initial polarization state ?

U. Wandinger
presented at 18th ILRC

Derived atmospheric parameters



Summary

1. In the case of water clouds, the multiple scattering (MS) effects on the backscattering intensity and depolarization ratio increase as increasing the penetration depth in clouds.

The depolarization ratio is rather sensitive to the multiple scattering.

2. In the case of ice clouds, no large effects by MS on the back scattering intensity and depolarization ratio were observed.

3. Combined observation with a Raman Lidar shows the predicted effect on the derived extinction profile of clouds. (U. Wandinger, 1996)

Perspective

[Observation]

- Improvement of S/N especially for Cirrus clouds at high altitude.
- Accumulation of data.
- Dedecated Lidar for multiple scattering.

[Analysis]

- Comparison of observed results with the Monte-Carlo Simulation.
- Can we get additional information from the depolarization ratio ?