สองวิธีสำหรับการหาค่าสัมประสิทธิ์การกระเจิงกลับเชิงปริมาตรของละอองลอย ชั้นโทรโพสเฟียร์โดยใช้ไลดาร์การกระเจิงแบบมี จังหวัดสุโขทัย

ศิริลักษณ์ เรืองรุ่งโรจน์ [1*] อรุณีย์ อินทศร [2] อัมพร รุ่งแจ้ง [3]

มหาวิทยาลัยศรีนครินทรวิโรฒ วัฒนา กรุงเทพฯ 10110

และ อัคนีวุธ ชะบางบอน [4]

จุฬาลงกรณ์มหาวิทยาลัย ปทุมวัน กรุงเทพฯ 10330

บทคัดย่อ

ได้มีการหาโพรไฟล์แนวดิ่งของสัมประสิทธิ์การกระเจิงกลับเชิงปริมาตรของละอองลอยชั้นโทรโพสเฟียร์ในจังหวัด สุโขทัยด้วย 2 วิธี คือวิธีความชันดัดแปลงและวิธีแบบเฟอร์นัลด์โดยใช้สมมติฐาน S_a = 35 sr, S_m = 8π/3 sr และ $\beta_m(z)$ = $\beta_m(z_c)$ เมื่อ z_c คือความสูงวิกฤตที่ 15 กม. (ระดับชั้นที่ปราศจากละอองลอย) โดย $\beta_a(z)$ มีค่าคงที่ทุกความสูง 6 ม. ผล ที่ได้พบว่าด้วยสมมติฐานข้างต้นค่าสัมประสิทธิ์การกระเจิงกลับเชิงปริมาตรของละอองลอยที่หาจากวิธีความชันดัดแปลง สูงกว่าค่าที่หาได้จากวิธีแบบเฟอร์นัลด์ประมาณ 10^2 เท่าและวิธีแบบเฟอร์นัลด์ยังคงเป็นที่ยอมรับได้ และมีประสิทธิภาพ มากกว่า เนื่องจากสามารถบ่งชี้แนวโน้มของละอองลอยและเมฆได้อย่างชัดเจน

คำสำคัญ : ไลดาร์แบบมี / วิธีแบบเฟอร์นัลด์ / วิธีความชันดัดแปลง / ความสูงวิกฤต / อัตราส่วนไลดาร์

* *ผู้นิพนธ์ประสานงาน E-mail : sirilukr@swu.ac.th*

[1] *อาจารย์ ภาควิชาฟิสิกส์ คณะวิทยาศาสตร์*

[2] *รองศาสตราจารย์ ภาควิชาฟิสิกส์ คณะวิทยาศาสตร์*

[3] *นิสิตระดับบัณฑิตศึกษา ฟิสิกส์ คณะวิทยาศาสตร์*

[4] *อาจารย์ ภาควิชาธรณีวิทยา คณะวิทยาศาสตร์*

Two Approaches of Tropospheric Aerosol Volume Backscattering Coefficient Determination using Mie Scattering LIDAR in Sukhothai

Siriluk Ruangrungrote [1*], Arunee Intasorn [2], Amporn Rungjang [3],

Srinakharinwirot University, Wattana, Bangkok 10110, Thailand

and Akkaneewut Chabangbon [4]

Chulalongkorn University, Patumwan, Bangkok 10330 Thailand

Abstract

The vertical profiles of tropospheric aerosol volume backscattering coefficients in Sukhothai province of Thailand were obtained from two approaches as modified slope method and Fernald method with assumptions of $S_a = 35$ sr, $S_m = 8\pi/3$ sr and also $\beta_m(z_c) = \beta_m(z_c)$, where z_c is at 15 km (aerosol-free layer) and $\beta_a(z)$ is constant for every 6-m heights. Results reveal that with these assumptions, the different values of volume backscattering coefficient retrieved by modified slope method are 10^2 times of one obtained by Fernald method in approximate. Hence Fernald method is still validated and more effective since it can evidently indicate aerosol and cloud trends.

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[*]   *Corresponding author E-mail address: sirilukr@swu.ac.th*

[1]   *Lecturer, Department of Physics, Faculty of Science.*

[2]   *Associate Professor, Department of Physics, Faculty of Science.*

[3]   *Graduate Student, Department of Physics, Faculty of Science.*

[4]   *Lecturer, Department of Geology, Faculty of Science.*

1. Introduction

LIDAR (Light Detection and Ranging) or Laser radar is a tool for atmospheric remote sensing of aerosols and clouds which have both direct and indirect influences on Earth's radiation balance. The intensive observations of tropospheric aerosols with Mie LIDAR at Shapotou in China were made during March to May 2001 [1]. The backscattering coefficient which represents an optical physical quantity of the scatterers, was determined for quantitative analysis. The particles detected by a polarization Mie LIDAR were distinguished and categorized into five types of cloud layers due to the depolarization ratios in few years later [2]. They expressed that only measured signal intensity is inadequate for establishing a cloud classification scheme, therefore the particle backscattering coefficient is taken into account for this consideration.

Owing to a relationship between backscattering coefficient and received signal from Mie LIDAR, the unknown variables are assumed by few different approaches to yield reliable results. The Fernald method [3] was used to determine backscattering coefficients in both works as mentioned above. For a preliminary analysis, it is interesting to investigate a reliability of volume backscattering coefficient determinations by two different approaches in contrast to the works done earlier.

A Mie scattering LIDAR was used to measure backscattering signals from lower troposphere on 14 January 2004 in Sukhothai province of Thailand (17° 0′ 21″ N, 99° 49′ 35″ E). In this LIDAR sensing technique, a pulsed laser light is emitted into the atmosphere making a possibility to measure trace components presented in the air and etc [3-5]. The backscattering light collected by a telescope is focused onto a photomultiplier tube (PMT) which

yields an electronic signal proportional to the received light flux. With the dual polarization measurement function, received polarization components are separated by two photomultiplier tubes as PMT1 and PMT2. Consequently, a vertical profile of range corrected signals was performed firstly for a determination of volume backscattering coefficient of tropospheric aerosol.

2. LIDAR System and Observation

The NIES Compact Mie scattering LIDAR [6] was installed at Sri Samrong district of Sukhothai province (as shown in Fig. 1) employs flash lamp pumped Nd:YAG laser for output energy of 30 mJ at 532 nm (and 20 mJ at 1,064 nm) with a dual polarization receiver of 20-cm Schmidt Cassegrain telescope.

Fig. 1 Mie scattering LIDAR.

The output from the PMT1 and PMT2 connected to CH 1 and CH 2 of the digital oscilloscope respectively. The LIDAR was set to operate for 5 min of every 15 min. Before every 5 min operation, the laser was warmed up for 1 min; the measurement

program average 4 times along height before data storage. Pulse repetition ratio was 20 Hz at maximum with pulse duration at 10 ns in approximate. The observation was performed on 14 January 2004 for every hour. Data at the heights from 6 m to 24 km were recorded with 6-m height resolution. Most of atmospheric aerosol content is concentrated in first few kilometers above ground level [4]. Therefore the average of all returned LIDAR signals at the heights beyond 15 km (almost aerosol-free layer) were calculated for subtraction from the backscattering signals at the heights below 15 km, since it was assumed as noise background caused by sky radiance and apparently there existed no aerosols at such heights.

3. Data Analysis Methods

From LIDAR theory basis, in the case of a coaxial LIDAR system (where the laser beam axis is parallel and close to the collecting mirror axis), the backscattering collected signal is [3]

$$P(z) = P_0 k \frac{c\,\tau}{2} \frac{A}{z^2} \beta(z) T^2(z) \qquad (1)$$

where k is a constant function of intrinsic efficiencies of the experimental apparatus, $c\tau$ refers to the laser pulse length in the atmosphere (the factor 2 refers to pulse round-trip), and A/z^2 is the solid angle comprised by the collecting mirror of area A. The term $\beta(z)$ is the volume backscattering coefficient, and the term $T(z)$ refers to the transmissibility offered by the atmospheric path to photons traveling from the ground to a given distance z. Usually this attenuation term can be described as a negative exponential by the so-called Bouguer-Lambert law which is essentially valid as the case of fairly transparent atmospheres. Additionally, several terms in Eq. (1) are constants, the equation can be presented

in term of range corrected or range normalized signal:

$$X(z) = P(z)z^2 = C\beta(z)e^{-2\int_0^z \alpha(z')dz'} \qquad (2)$$

Here $\alpha(z)$ is the atmospheric unit volume extinction coefficient and C is the system calibration factor.

3.1 Fernald method

It can be seen that inherent unknown parameters in Eq. (2) make difficulties to retrieve volume backscattering coefficient from lidar signal. Normally Fernald method [1-7] is applied to the following transforming lidar equation:

$$\beta_a(z) + \beta_m(z)$$
$$= \frac{X(z)C(z)}{\dfrac{X(z_c)}{\beta_a(z_c) + \beta_m(z_c)} + 2S_a \int_z^{z_c} X(z')C(z')dz'} \qquad (3)$$

whereas

$$C(z) = \exp\left[2(S_a - S_m)\int_z^{z_c} \beta_m(z')dz'\right]$$

where both S parameters are lidar ratios, the subscripts a and m stand for aerosol and molecule, respectively, and z_c is critical height. As mentioned earlier, the critical height in this work is at 15 km, which means that $\beta_a(z_c) = 0$ $m^{-1}sr^{-1}$ according to Klett-Fernald's far-end method [8-9], and then $\beta_m(z_c)$ can be retrieved from Eq. (2) with the lidar ratio relative equation from light scattering theory that

$$S_m = \frac{\alpha_m(z)}{\beta_m(z)} = \frac{8\pi}{3} sr \qquad (4)$$

accompanied by the assumption of homogeneous atmosphere with one constant value of $S_a = 35$ sr for all heights (frequently used as a reference value for dust particle), and also $\beta_m(z) = \beta_m(z_c)$.

Generally, $\beta_m(z)$ are given by matching the signal profiles with theoretically calculated molecular profiles. Moreover, Biral [4] showed as an exponential function in the range of 0.05 – 0.01 km^{-1} in descending order with heights from 0 - 15 km . Subsequently, $\beta_a(z)$ and $\alpha_\alpha(z)$ are assumed to be constant for every 6-m height resolution. Hence the vertical profiles of aerosol backscattering coefficient are obtained by using the reduced equation as

$$\beta_a(z) + \beta_m(z) = \frac{X(z)C(z)}{\dfrac{X(z_c)}{\beta_m(z_c)} + 2S_a\sum_{z_i}^{z_c}[6\,X(z_i)C(z_i)]} \quad \textbf{(5)}$$

where

$$C(z) = \exp[2(S_a - S_m)\beta_m(z_c)(z_c - z)]$$

3.2 Modified slope method

Slope method is suitable for lidar positioned to probe horizontally [4], since $\beta(z)$ and $\alpha(z)$ are in fact not constant with height. So a modification of previous slope method is required by assuming both quantities are constant for every 6-m height resolution and the derivative of $D(z)$ [$D(z) = ln\,X(z)$] from Eq. (2) is

$$\frac{dD(z)}{dz} = \frac{1}{\beta(z)}\frac{d\beta(z)}{dz} - 2\alpha(z) \quad \textbf{(6)}$$

with the condition of spatial homogeneity in $\beta(z)$ and $\alpha(z)$, therefore

$$\alpha = \frac{-1}{2}\frac{dD}{dz} \quad \textbf{(7)}$$

From the slope of straight line plotted between ln $X(z)$ and z for each 6-m range provided the vertical profile of $\alpha(z)$. And then $\beta_a(z)$ (where $\beta(z) = \beta_a(z) + \beta_m(z)$) are determined by using $S_a = 35$ sr, $S_m = 8\pi/3$ sr and $\beta_m(z) = \beta_m(z_c)$ from Fernald method.

The assumption of constant $\beta_m(z)$ at all height in this work is made, since we observed first $\beta_m(z)$ values at different expected aerosol-free layers, i.e., 10 – 15 km for every 1-km resolution in the period of cloud absence. This investigation was done with an expectation of high-concentration aerosol in the atmosphere where being rather condensed in the first few kilometers [1] above ground level.

3.3 Depolarization ratio

To distinguish clouds from aerosol layers, depolarization ratios (δ) are provided [10]. Depolarization ratio is the ratio of returned signals in polarization planes between perpendicular and parallel to the polarization of transmitted laser pulse, given by

$$\delta(z) = \frac{P_\perp(z)}{P_{//}(z)} \quad \textbf{(8)}$$

where $P_\perp(z)$ and $P_{//}(z)$ are perpendicular and parallel polarization components in the backscattering returned signals, respectively.

4. Result and discussion

Fig. 2 shows the vertical distributions measured on 14 January 2004 of range corrected signal X, depolarization ratio δ and the comparison of aerosol backscattering coefficients β_a determined by Fernald method and modified slope method, respectively. Table 1 reports $\beta_m(z_c)$ values at different z_c in the period of cloud absence, the results indicate very small variations of β_m in each kilometer. Consequently, an assumption of constant $\beta_m(z)$ at all heights is probably validated. In Fig. 2, the vertical profile of volume backscattering coefficient done by modified slope method shows a complexity, however, it interestingly can perform the starting

point of disturbance signal treated as noise, as same result as done by Fernald method, corresponding to the low vertical distribution of range corrected signal found in Figs. 2b and 2d. Due to high disturbance signal above 4 km, the plots hence are presented in the location of 4 km below. Figs. 2a and 2c show the multiple scattering with an increment of depolarization ratios from cloud base above 2 km, while each vertical profile of volume backscattering coefficient indicates similar tendencies.

Table 1   An archive of $\beta_m(z_c)$ values at different expected aerosol-free layers at the height z_c without cloud observation.

| Z_C (km)	$\beta_m(z_C)$ (m^{-1}sr^{-1})	Variations with respect to $\beta_m(z_c)$ at Z_C= 15 km
15	3.39×10^{-5}	1
14	3.53×10^{-5}	1.04
13	3.93×10^{-5}	1.16
12	4.12×10^{-5}	1.22
11	4.35×10^{-5}	1.28
10	4.94×10^{-5}	1.46

The daily temporal variation of aerosol vertical profile in terms of range corrected signal, depolarization ratio and volume backscattering coefficients determined by both methods are shown in Fig. 3. It can be seen that both volume backscattering coefficient retrievals yield similar trends in strong scattering at upper layer which are caused by clouds. Moreover, it would be estimated from color scales that the different values of volume backscattering coefficient retrieved by modified slope method are 10^2 times of one obtained by Fernald method in approximate. Finally, from Figs. 2 and 3 it can be seen the correspondences of all four vertical profiles whereas cloud absence at such heights from 04.00 – 16.00 LCT. Also there existed fine and small aerosols with depolarization ratio less than 5% above 1 km.
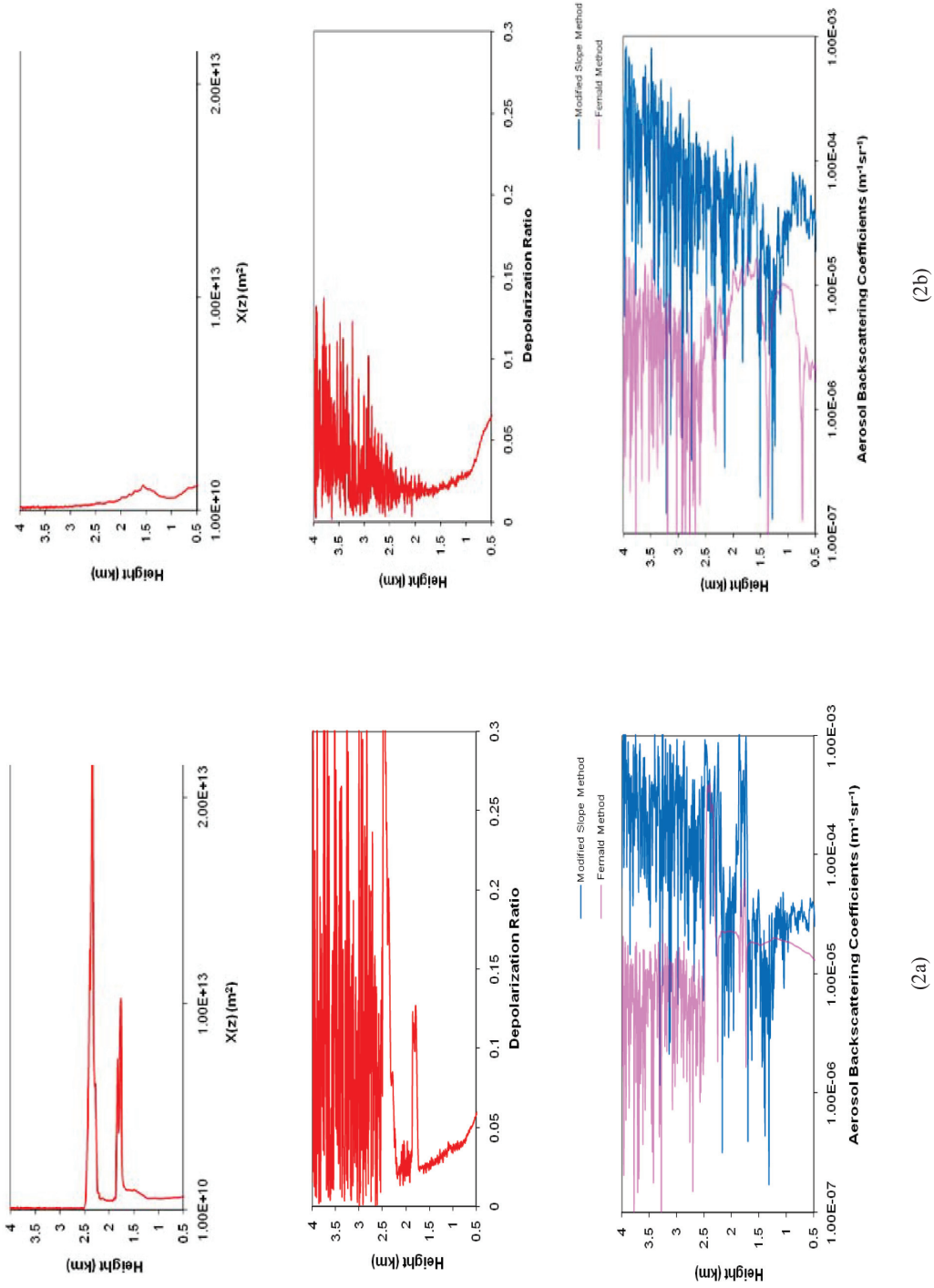
Fig. 2 The 14 January 2004 vertical profiles of range corrected signal X, depolarization ratio and aerosol backscattering coefficients determined by modified slope method and Fernald method at (2a) 03.00, (2b) 04.00, (2c) 17.00 and (2d) 22.00 LCT, respectively.
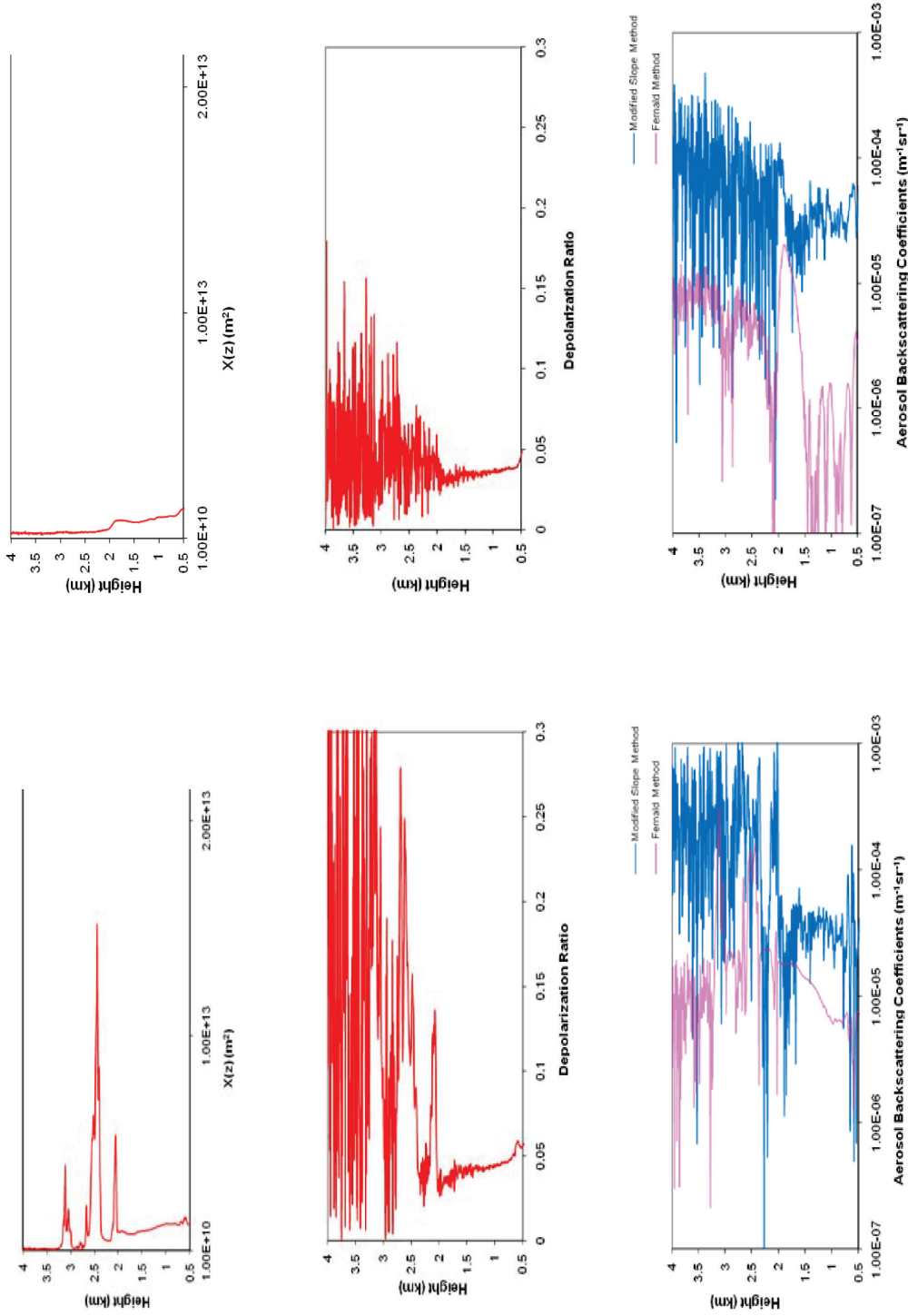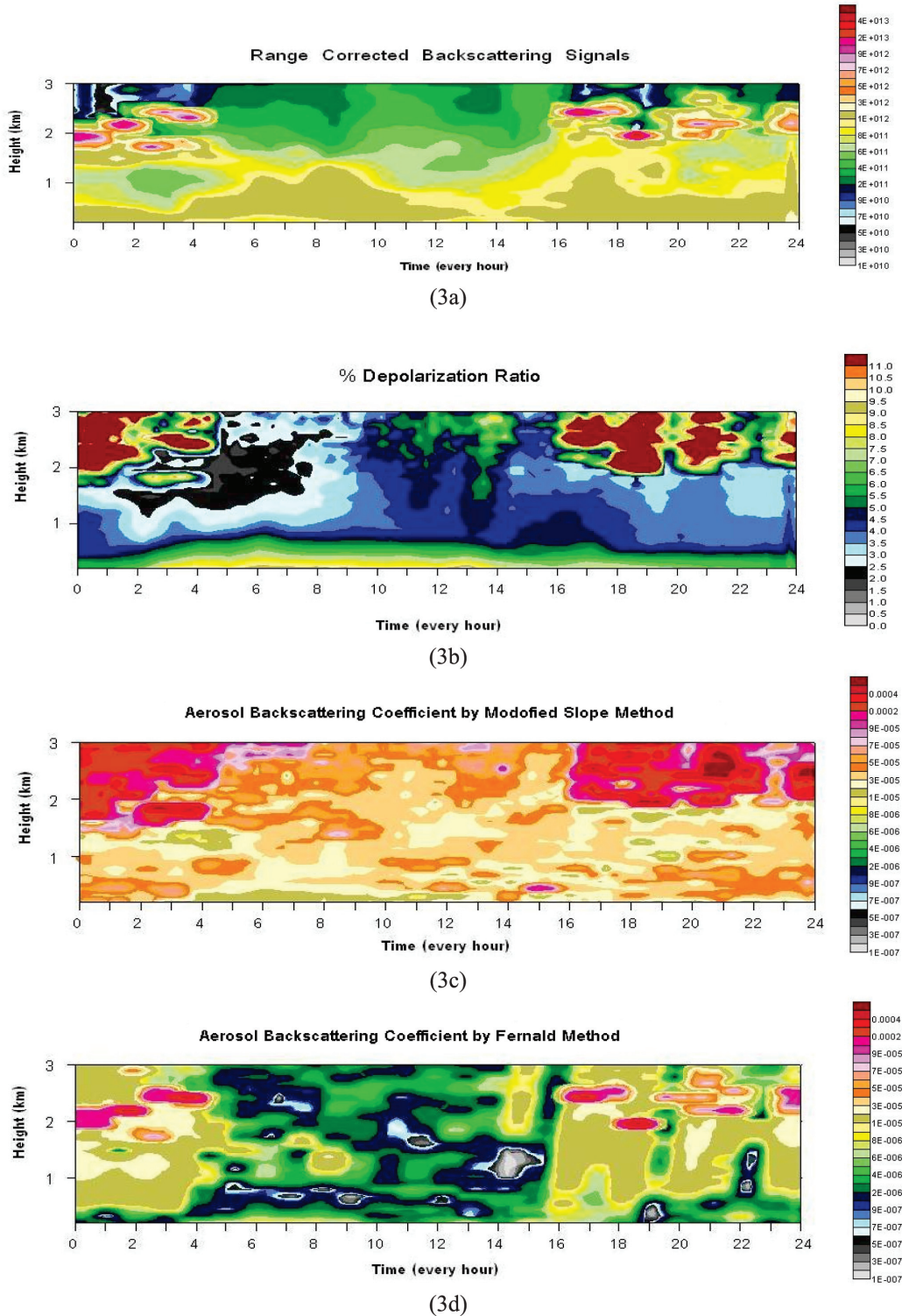
Fig. 2 (Cont.) The 14 January 2004 vertical profiles of range corrected signal X, depolarization ratio and aerosol backscattering coefficients determined by modified slope method and Fernald method at (2a) 03.00, (2b) 04.00, (2c) 17.00 and (2d) 22.00 LCT, respectively.

(3a)

(3b)

(3c)

(3d)

Fig. 3 A daily temporal variation and aerosol vertical cross sections of (3a) range corrected signal, (3b) % depolarization ratio and (3c)-(3d) aerosol backscattering coefficients determined respectively by modified slope method and Fernald method, on 14 January 2004 are shown in color scales.

5. Conclusion

Although an assumption of constant molecular backscattering coefficient for all height is applied in this work, results reveal that the retrieval of tropospheric volume aerosol backscattering coefficient profiles by two different approaches are satisfied based on tropospheric aerosol analyses, because the similar tendencies of climate in troposphere are obtained. According to the difficulties of retrieving volume backscattering coefficient from lidar signals with the exact values of some parameters, the investigation of observed $\beta_m(z_c)$ values to be constant for all heights is possibly acceptable. Instead of using the matching method to provide molecular backscattering profiles as usual in Fernald method, the obtainable vertical profiles of backscattering coefficient can indicate aerosol and cloud trends with this simple approach and also all analyzed aerosol backscattering coefficients are in the normal order of its value in the atmosphere. However, Fernald method is still more appropriate and practical than modified slope method for retrieving aerosol backscattering coefficient profiles. From an experience of backscattering coefficient retrieval, further study on the possibility of this method is compulsory in order to classify clouds with the depolarization ratio, backscattering coefficient and aerosol optical depth measured by Mie LIDAR.

6. Acknowledgements

7. References

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