Modelling of Aerosol Parameters Retrieval Algorithm Based on Mie Scattering Lidar: APRA

Siriluk Ruangrungrote*, Suthipan Chanthrasre and Arunee Intasorn

Department of Physics, Faculty of Science, Srinakharinwirot University, Bangkok, Thailand

Abstract

The software package APRA (Aerosol Parameters Retrieval Algorithm) was written in MATLAB R2008a. It allows the possibilities to determine the vertical profiles of tropospheric range corrected signals, depolarization ratios, aerosol volume backscattering coefficients and aerosol volume extinction coefficients from the measured dataset of Mie Scattering Lidar. In order to monitor the program efficiency, both pseudo and real data were used for the program demonstration, and finally the retrieved results from raw data of Mie Scattering Lidar measurement in Phimai district, Nakhon Ratchasima province of Thailand were performed and subsequently compared to the previous results retrieved manually from the same data.

Keywords: Software package, APRA, pseudo data, Fernald - Klett method, Mie Scattering Lidar

1. Introduction

In 1998, Hess *et al.* [1] proposed the software package named OPAC (Optical Properties of Aerosols and Clouds) to provide a tool for scientists who need to describe the optical properties of the atmosphere for climate-modeling purposes. OPAC comprises datasets of optical properties of cloud and aerosol components that describe average conditions in combination with easy-to-use software, which allows a possible calculation of any mixtures of these components.

Mie Lidar is an important tool for atmospheric remote sensing of aerosols and clouds research which is beneficial for climatology studies. Lidar equation solutions of Lidar sensing technique are published in plenty of Lidar literatures. Reagan *et al.* [2] reviewed the development and application of Lidar in 1989, some successful and widely used Lidar equation solution approaches were outlined, and they also mentioned that the exact way in which the solution to the Lidar equation was implemented, depending on the availability of both types of input and boundary value.

Motoaki *et al.* [3] observed the tropospheric aerosols by using a Mie Lidar during 2001-2002. They calculated aerosol backscattering coefficient with Fernald - Klett method and determined aerosol backscattering coefficient at the critical height (contains almost non aerosols) by using the matching method which assumed all signals from layers above 30 km in the mid-latitude regions as Rayleigh scattering by atmospheric molecules. The particle backscattering

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

Coefficient [4] is an absolute quantity, with the dimension of $m^{-1}sr^{-1}$, which represents the scattering rate in terms of a ratio of the backscattered power to the incident power per unit length in the light path and per unit solid angle. The backscattering coefficient is actually difficult to retrieve from a Lidar signal, because it contains inherently unknown parameters. Iokibe *et al.* [4] then had to calculate it from some suitable Lidar signals with the matching method as well.

According to the recent studies of some aerosol parameters retrievals, i.e., range corrected signals, depolarization ratios, aerosol volume backscattering coefficients and aerosol volume extinction coefficients, from the measured data of Mie scattering Lidar, installed at Phimai district, Nakhon Ratchasima province of Thailand (15° 13' 0" N, 102° 30' 0" E) [5-7], the development of Mie Lidar work in Thailand has been gradually performed in the past few years and the obtainable results are able to provide aerosol database in Thailand which is very useful for aerosol and cloud studies. However, most of the retrieved processes were done analytically and manually via Microsoft Excel and Mathematica programs with the raw data stored in a type of *.tar.gz file format which must be converted to text file format (*.txt) for running in both programs. With all past experiences, we have clearly understood the algorithm techniques and the physical properties of aerosols and clouds. Hence in this work, we intended to create a software package for a computerization of input data files in an attempt to calculate and obtain graphical plots of vertical profiles of all major aerosol parameters.

In order to monitor a reliability of the software package: APRA, the same retrieval algorithm technique and input dataset was repeated and compared with the previous obtainable work [7]. Therefore, the schematic process is presented in sequence as firstly the characteristic of input data in section 2.1, the retrieval algorithm technique in section 2.2 and finally the software package in section 2.3.

2. Instrumentation and Algorithm

2.1 Lidar System and Observation

The NIES Compact Mie Scattering Lidar [8] installed at Phimai district of Nakhon Ratchasima province (as shown in Figures 1 and 2, respectively) is coupled with a personal computer for data storage as filename.tar.gz (*.tar.gz). Mie Scattering Lidar employs flash lamp pumped Nd:YAG laser for output energy of 30 mJ at 532 nm (and 20 mJ at 1064 nm) with a dual polarization receiver of 20-cm Schmidt Cassegrain telescope. The output from the PMT1 and PMT2 connected to CH 1 and CH 2 of the digital oscilloscope respectively. The Lidar is operated 5 min for every 15 min. Prior to every 5 min operation, the laser is warmed up for 1 min and after 5 min observation; the measurement program average 4 times along height before storing data. Pulse repetition ratio is 20 Hz at maximum with pulse duration at 10 ns in approximate. The observation was performed for every hour. Data from 6 to 24000 m are recorded with 6-m height resolution. The measured raw data are transferred to the personal computer and next converted to input data type of filename.txt before being executed by APRA.

2.2 Retrieval Algorithm

Owing to most of the atmospheric aerosol content concentrated in first few kilometers from ground level, the average of all returned Lidar signals from height beyond 15 km are calculated for subtraction from the backscattering signals at the levels below, since it is assumed as noise background caused by sky radiance and apparently there exists no aerosols at such heights. And thus the critical height (Z_c) (aerosol-free layer), in this work is 15 km, which means that $\beta_a(z_c) = 0$ $m^{-1}sr^{-1}$ since β_a is aerosol volume backscattering coefficient.

Figure 1 Mie scattering LIDAR.

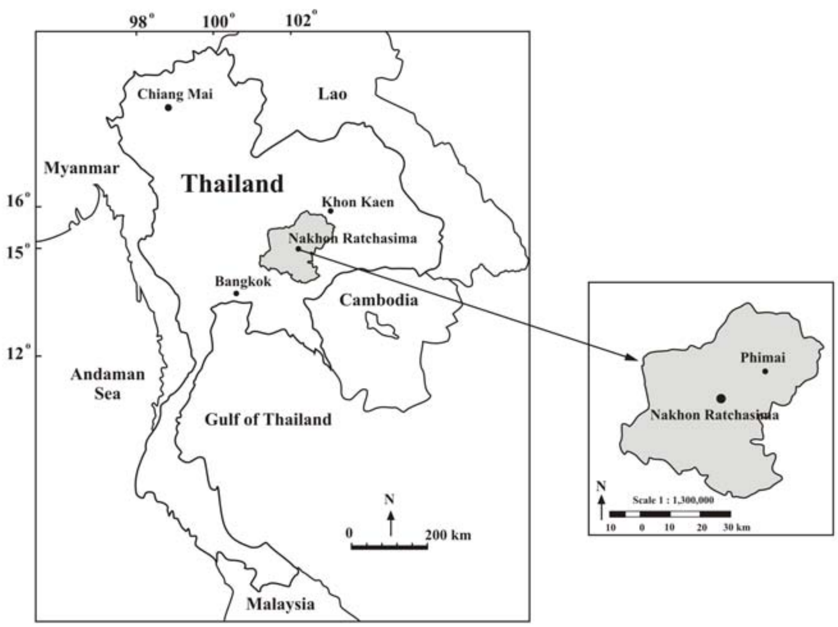


Figure 2 The research site at Phimai district, Nakhon Ratchasima province.

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 [2]

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

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 volume extinction 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 Eqn 1 are constants, the equation can be presented in terms of range corrected or range normalized signal:

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

Here $\alpha(z)$ is the atmospheric volume extinction coefficient and C is the system calibration factor. Normally Fernald method [3] is applied to the following transformed Lidar equation:

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

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 the critical height at 15 km, which means that $\beta_a(z_c) = 0$ m^{-1}sr^{-1}, and then $\beta_m(z_c)$ can be retrieved from Eqn 3 with the Lidar ratio relative equation from light scattering theory that

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

accompanied by the assumption of homogeneous atmosphere with a constant value of S_a for all height, and also $\beta_m(z) = \beta_m(z_c)$. Consequently, a constant S_a must be a fixed input value for each case depending on the type of observed aerosols, i.e., S_a = 35 sr [9] is frequently used as a reference value for dust particles.

Since, $\beta_a(z)$ and $\alpha_a(z)$ are assumed to be constant for every 6-m height resolution. The vertical profiles of aerosol backscattering coefficient can be obtained by using the reduced equation as

$$\beta_a(z)+\beta_m(z)=\frac{X(z)C(z)}{\frac{X(z_c)}{\beta_m(z_c)}+2S_a\sum_{z_i}^{z_c}\left[6X(z_i)C(z_i)\right]} \qquad (5)$$

when

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

yielding the aerosol volume extinction coefficients α_a by a relation of $\alpha_a = S_a\beta_a$.

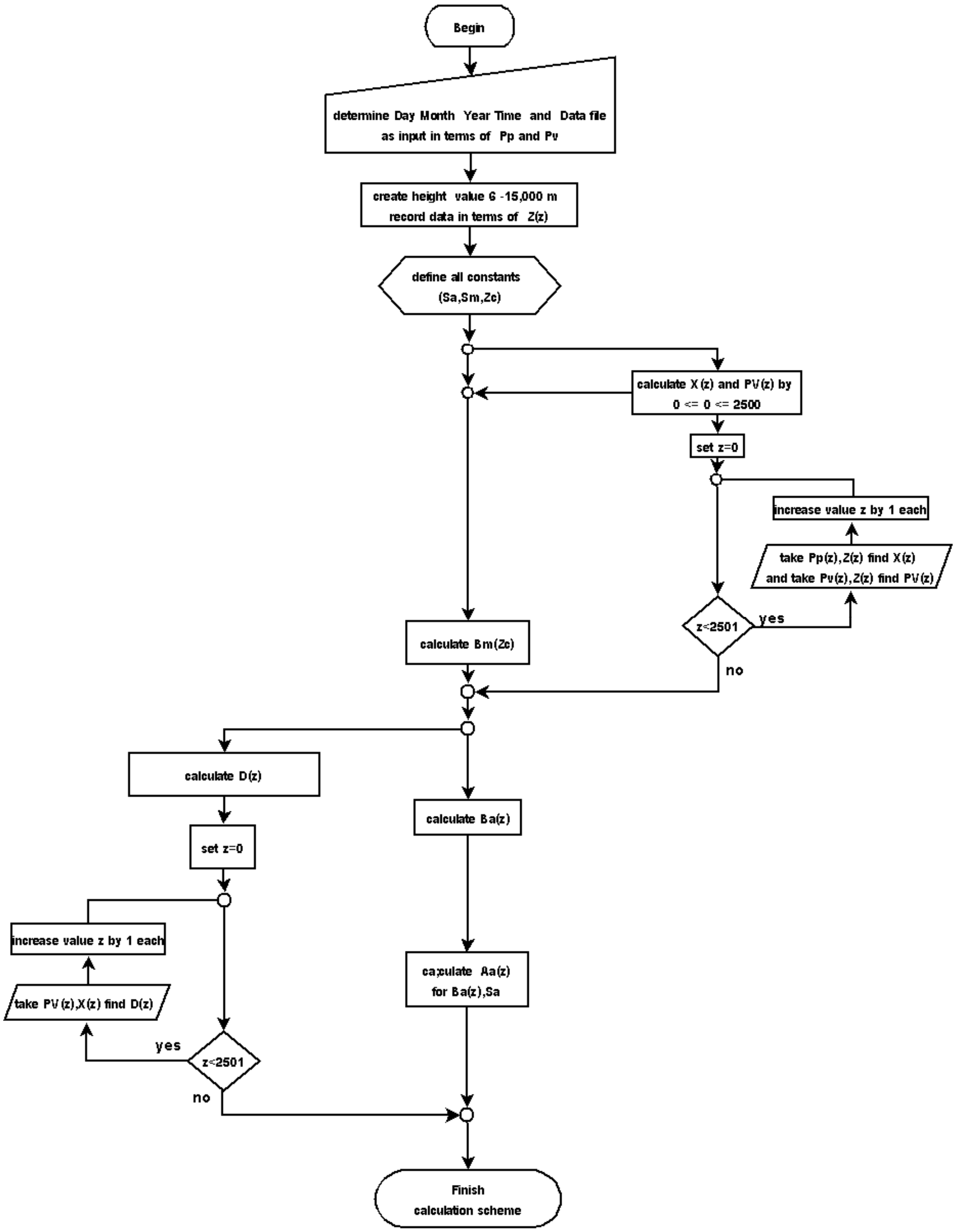
Additionally, depolarization ratios (δ) are calculated to support the additional analysis, because aerosol scattering varies in complicated behavior depending on size distribution and aerosol particle indices of refraction [4], and depolarization ratio itself can imply either spherical or non-spherical aerosol particles. In order to determine depolarization ratio [5], the ratio of returned signals in polarization planes between perpendicular and parallel to the polarization of transmitted laser pulse is given by

$$\delta(z)=\frac{P_{\perp}(z)}{P_{//}(z)} \qquad (6)$$

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

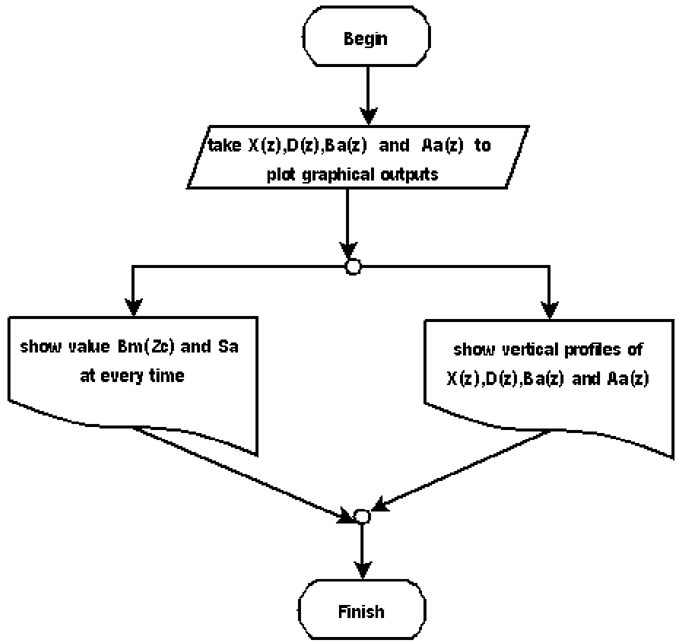
2.3 The Software Package

The software package APRA was written in MATLAB (MATrix LABoratory) in which all parameters are transformed into vector and matrix forms. Graphical plots of aerosol vertical profiles of range corrected signals, depolarization ratios, volume backscattering coefficients and volume extinction coefficients are provided as outputs. Flowchart of the analysis procedure of input data is shown in Figure 3. The first run was investigated with the input pseudo data for a preliminary program trial, and finally the real data of 7 February 2005 obtained from the former method [7] were used as the input for running APRA. Finally both previous and current outputs were compared to each other for a validation.



(3a)

Figure 3 Flowcharts of the software package APRA (3a) calculation scheme and (3b) graphical output.

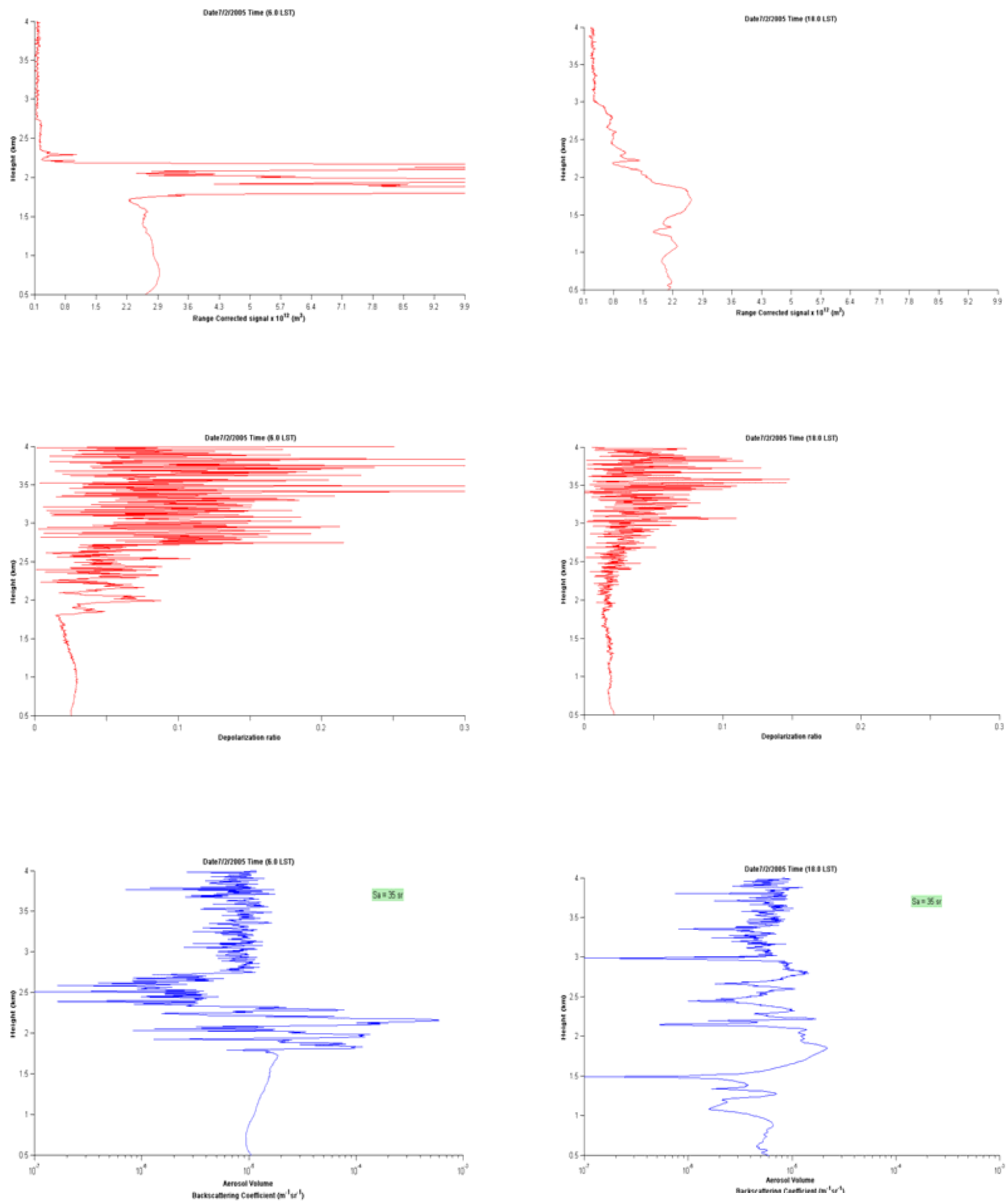


(3b)

Figure 3 (cont.) Flowcharts of the software package APRA (3a) calculation scheme and (3b) graphical output.

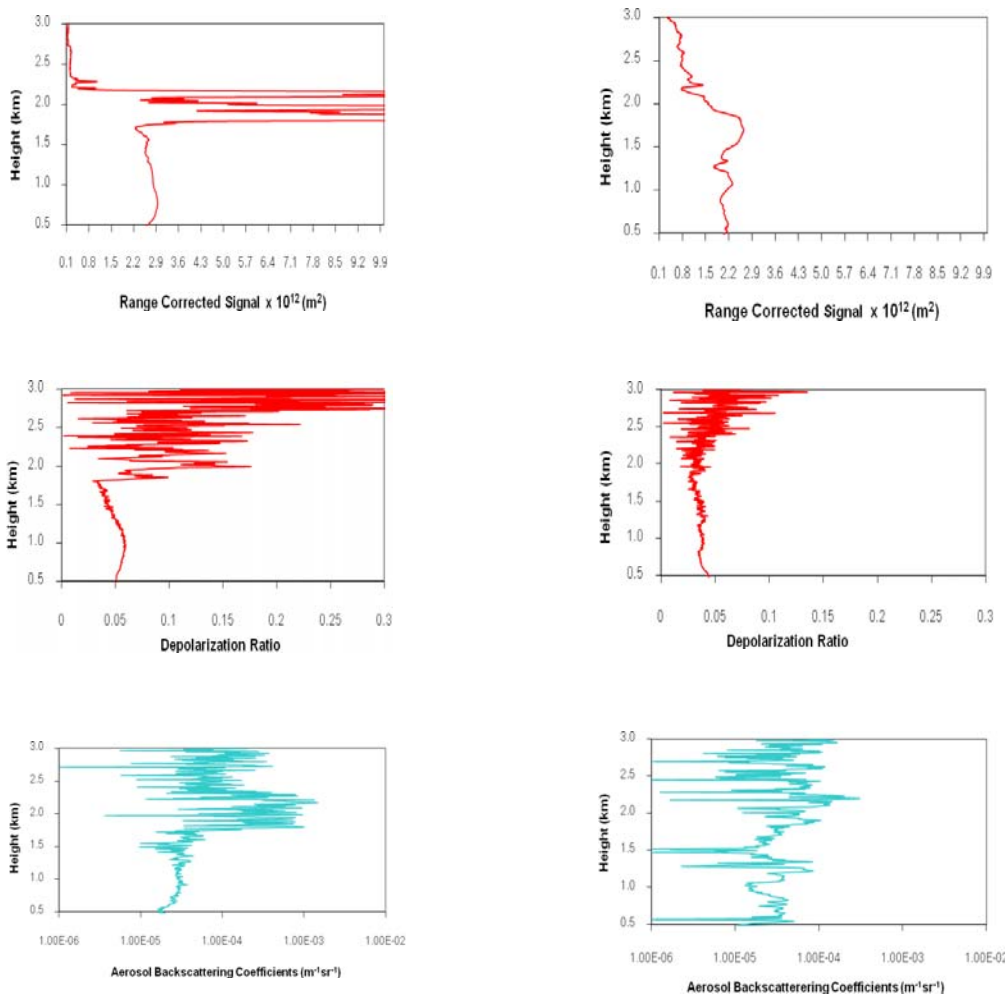
3. Results and Discussion

With an expectation of high-concentration aerosols in the first few kilometers [3] above ground level, thus only the output of vertical distributions in the location below 4 km height measured on 7 February 2005 of range corrected signal (X), depolarization ratio (δ), aerosol volume backscattering coefficients (β_a) and aerosol volume extinction coefficients (α_a) are performed as shown in Figure 4. While Figure 5 shows the previous results of three parameters [7] which were retrieved analytically and manually via Microsoft Excel and Mathematica in order to make a comparison. Both results are in good correlation which confirms a reliability of APRA for the retrieval of aerosol parameters with a running time less than 3 minutes per file and only one program to be run.



(4a) 06.00 (4b) 18.00

Figure 4 APRA outputs of 7 February 2005 vertical profiles of range corrected sign depolarization ratio, aerosol backscattering coefficient and aerosol extinction coefficient at (4a) 06.00, and (4b) 18.00 LST, representing cloudy and cloudless skies respectively.



(5a) 06.00

(5b) 18.00

Figure 5 Results from the former method of 7 February 2005 vertical profiles of range corrected signal, depolarization ratio and aerosol backscattering coefficient at (5a) 06.00, and (5b) 18.00 LST, representing cloudy and cloudless skies respectively.

4. Conclusions

The software package APRA consumes less time and is very helpful as an all-in-one program for both graphical and analytical retrievals of aerosol parameters, i.e., range corrected signal, depolarization ratio, aerosol volume backscattering coefficients and aerosol volume extinction coefficients which are all primary parameters for aerosols and clouds studies in Thailand. Moreover we expect to develop APRA additionally to retrieve other relevant parameters in an effort to progress the possible analysis in this field of work in Thailand. Lastly, with validated APRA, it would be practical and convenient to conduct our Mie scattering Lidar research for the regional observations of monthly, seasonal annual variation of aerosols and clouds in the atmosphere, especially various events of air pollutions.

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