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COMPARING WATER VAPOR MIXING RATIO PROFILES AND CLOUD VERTICAL STRUCTURE FROM MULTIWAVELENGTH RAMAN LIDAR RETRIEVALS AND RADIOSOUNDING MEASUREMENTS

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ABSTRACT

A study of comparison of water vapor mixing ratio profiles, relative humidity profiles, and cloud vertical structures using two different instruments, a multiwavelength Aerosol-Depolarization-Raman lidar and radiosoundings, is presented. The observations were taken by the lidar located in Warsaw center and the radiosoundings located about 30km to the North in Legionowo (Poland). We compared the ground-based remote sensing technology with in-situ method in order to improve knowledge about water content thought the atmosphere and cloud formation. The method used for retrieving the cloud vertical structure can be improved comparing the radiosonde results with the lidar observations, which show promising results.

1. INTRODUCTION

Clouds are key factor that rule climate. Improving methods for automatic and continuous description of clouds has a huge importance in order to determine the role of clouds in climate and their contribution to climate change [1]. The water vapor mixing ratio (WVMR), the relative humidity (RH) and the cloud vertical structure (CVS) in the atmosphere are important characteristics for describing the impact that clouds have in the atmosphere.

In the past, researchers undertook the approach for retrieval cloud layer structures only by using radiosounding (RS) data [2, 3]. There is ongoing work being done to improve these methods and compare them with the most advanced ground-based remote-sensing technologies, such as the Atmospheric Radiation Measurement (ARM) Program value added product, the Active Remote Sensing of Clouds (ARSCL), as well as with satellite data [4]. In this work the comparison was done in order to find a better approximation to the CVS profile, and to reveal the strengths and weaknesses of both ground-based instruments and in-situ radiosoundings. Now, the present study aim is to make similar comparisons between radiosounding methods and advanced multiwavelength lidar measurements in Poland. The idea is to see if the results obtained with ARSCL data product (which is a combination of measurements taken with cloud radar, micro-pulse lidar, and ceilometer) are comparable with those obtained with measurements taken by a multiwavelength Aerosol-Depolarization-Raman (ADR) lidar. Moreover, apart from CVS comparison, the WVMR and RH profiles retrieved from the RS are also compared, since the multiwavelength lidar provide profiles in Raman channel for water.

2. METHODOLOGY

The lidar measurements were taken in the Radiative Transfer Laboratory (RT-Lab) of the Institute of Geophysics, Faculty of Physics, University of Warsaw (Poland). The RT-Lab site located at central Warsaw (52.21º, N 20.98º E, 96m asl) joined the EARLINET [5] in 2015, contributing to the network activities with the 8-channel ($2\alpha+3\beta+2\delta$+VW) ADR lidar, that is a NeXT generation Polly XT system developed in a scientific cooperation with TROPOS, Germany [6]. Its detection channels are at 1064, 532 and 355nm (elastic), at 607 and 387nm (vibrational Raman for N_2), 407nm (Raman channel for H_2O), and 532 and 355 nm (elastic cross channels), using photon counting detection for all channels. Moreover, RT-Lab is part of the Poland AOD network (http://www.polandaod.pl).

The radiosoundings were launched in Legionowo station, which is the nearest radio sounding station (code: 12374), located about 30km to the North from the lidar at RT-Lab, and which frequency of radio sounding launches is 12h.

For the study we focused on one hand on the retrieval of WVMR and RH, and on the other, on the CVS. The main idea of our retrieval scheme is given below.

2.1. Water vapor mixing ratio and relative humidity

The mixing ratio of water vapor to dry air is obtained from nighttime observations. The available lidar wavelength for water vapor detection is not in the solar-blind region and thus the daytime measurements are roughly affected by background light noise. The WVMR profile (*m(z)*) is obtained from the measurement of the water-vapor to the reference signal ratio, where the reference gas is nitrogen [7] (eq. 1).

$$m(z)=K_m\frac{P_{\lambda_{H_2O}}(z)}{P_{\lambda_{Ref}}(z)}\times\frac{\exp\{-\int_0^z[\alpha^{aer}_{\lambda_{Ref}}(\xi)+\alpha^{mol}_{\lambda_{Ref}}(\xi)]d\xi\}}{\exp\{-\int_0^z[\alpha^{aer}_{\lambda_{H_2O}}(\xi)+\alpha^{mol}_{\lambda_{H_2O}}(\xi)]d\xi\}} \quad (1)$$

The $P_{\lambda H2O}(z)$ and $P_{\lambda Ref}(z)$ are the return signals from distance z at the laser wavelength for the water-vapor (at 407nm) and the Raman reference wavelength (at 387nm, a vibrational Raman channel for N_2). The α^{aer} and α^{mol} describe the extinction of light (either in the water-vapor or the reference wavelength), by aerosol particles and air molecules. Extinction coefficients (α) are derived from the Raman signal profile of the reference gas (eq. 2) [7].

$$\alpha^{aer}_{\lambda_0}(z)=\frac{d/dz\left\{\ln\left[N_{Ref}(z)/P_{\lambda_{Ref}}(z)z^2\right]\right\}-\alpha^{mol}_{\lambda_0}(z)-\alpha^{mol}_{\lambda_{Ref}}(z)}{1+\left(\lambda_0/\lambda_{Ref}\right)^k} \quad (2)$$

The $N_{Ref}(z)$ is the molecular number density of the reference gas. The λ^{-k} describes the wavelength dependence of particle scattering; k=1 is used except for ice clouds for which we set k=0.

The overall system constant $K_m = K_{\lambda Ref} / K_{\lambda H2O}$ can in principle be deduced from the known Raman cross sections and the measured properties of the detector used. In practice it was determined from a comparison of the lidar measurement with critically evaluated data from a radiosonde ascent [7].

Furthermore, relative humidity profiles are obtained as the ratio between the MWVR (from RS and lidar respectively) and the saturation vapor pressure (calculated with Clasius-Clapeyron equations).

2.2. Cloud vertical structure

The CVS is determined from RS using the method by [8] conveniently modified as explained in [4], hereafter entitled as method COS14. Specifically, the method for determining cloud tops and bases is based in RH thresholds applied to the RS profile. As a first step, the RH with respect to liquid water is converted to RH with respect to ice when the temperature is below 0°C. Then, moist layers are identified by applying some conditions, which are related to a minimum RH threshold (min-RH) and to a minimum thickness (400 m). Subsequently, moist layers are defined as cloud layers through some additional steps: (a) if the maximum RH within the layer is greater than the corresponding maximum RH threshold (max-RH) for the base of this moist layer, (b) the base of cloud layers is set at least at 280m above ground level, and (c) two contiguous layers are considered as a single-layer cloud if the distance between these two layers is less than 300m or the minimum RH within this distance is greater than the corresponding inter-RH threshold value. Note that instead of single-humidity thresholds to define a cloud as in earlier works [2, 3], this method is based on altitude-dependent thresholds, which vary between 70% and 95% depending on the specific threshold (min-RH, inter-RH, and max-RH) and on the altitude (greater values of humidity thresholds correspond to lower atmospheric layers) [4, 8].

First approximation to the CVS from multiwavelength lidar is taken from visual inspection of the plotted signals at 1064nm. Then, to determine CVS more accurately, thresholds are applied to the profiles of backscatter coefficients (at 355, 532 and 1064nm; eq. 3), extinction coefficients (at 355 and 532 nm; eq. 2), as well as depolarization ratios (at 355 and 532; which are determined by the ratio between the cross polarized signal to the total signal).

$$\begin{aligned}\beta^{aer}_{\lambda_0}(z)=&[\beta^{aer}_{\lambda_0}(z_0)+\beta^{mol}_{\lambda_0}(z_0)]\\ &x\frac{P_{\lambda_{Ref}}(z_0)P_{\lambda_0}(z)N_{Ref}(z)}{P_{\lambda_0}(z_0)P_{\lambda_{Ref}}(z)N_{Ref}(z_0)}\\ &x\frac{\exp\{-\int_{z_0}^z[\alpha^{aer}_{\lambda_{Ref}}(\xi)+\alpha^{mol}_{\lambda_{Ref}}(\xi)]d\xi\}}{\exp\{-\int_{z_0}^z[\alpha^{aer}_{\lambda_0}(\xi)+\alpha^{mol}_{\lambda_0}(\xi)]d\xi\}}-\beta^{mol}_{\lambda_0}(z)\end{aligned} \quad (3)$$

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3. RESULTS

Examples of lidar signals are shown in Figs. 1a and b. Both observations are at 1064nm over Warsaw since we want to see cloud particles. Fig. 1a shows lidar range-corrected signals during 29/07/14 from 18 to 24h UTC, where aerosol complex structures in boundary layer are visible from the overlap level up to 2500 m approximately, whereas a thinner aerosol layer is discernible at 4000 m. Fig. 1b shows range-corrected signals on 30/07/14 from 12 to 17h UTC. This period was partially cloudy: discontinuous cloud layer with the base at 1000 m, and other higher clouds between 2000 and 4000 m are distinguished. Note that cloud signatures are clearly distinguished from aerosol layers since the signal behind their bases are very attenuated.

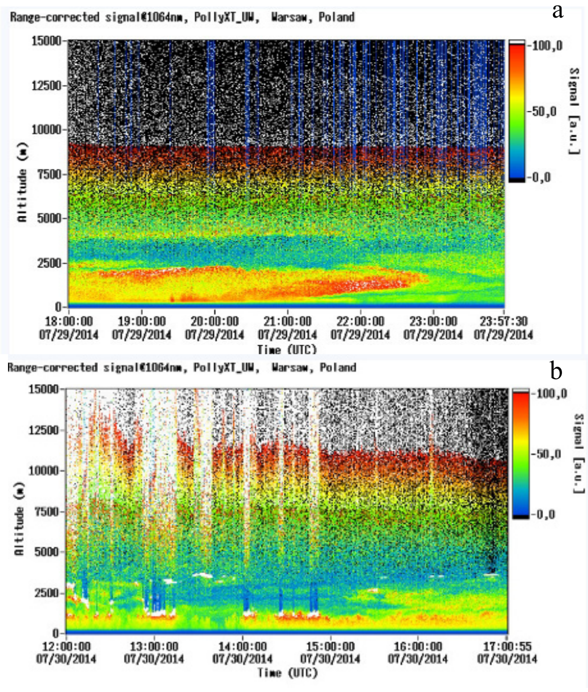

Fig. 1. a) Lidar signals at 1064nm over Warsaw on 29/07/14 from 18 to 24h, and b) on 30/07/14 from 12 to 17h UTC. These figures are available at http://polly.rsd.tropos.de/.

3.1. Water vapor mixing ratio

WVMR profile was calculated from Raman multiwavelength lidar signals over RT-Lab (Warsaw) from 23 to 24 on 29/07/14. According to lidar range corrected signals inspection there were no clouds during this period (Fig. 1a). Overall system constant (K_m) has been determined as 5. In Fig. 2a the MWVR lidar profile is plotted along with the MWVR profile obtained by the RS. The two profiles agree well from the overlap level (540 m) to 3 km, and from 4.6 to 8 km, although at higher heights the MWVR profile obtained by the lidar become noisier.

In Fig. 2b the RH from 3 sources is plotted. The first one is directly taken from the RS over Legionowo on 30/07/14 00UTC, secondly the RH derived from the MWVR from the same RS, and finally the RH derived from multiwavelength lidar signals from 23 to 24h UTC on 29/07/14 over central Warsaw. The figure shows good agreement between the RH calculated from lidar signals with the RH calculated from the RS up to 3 km, and between 4.3 and 6 km. The differences found between 3 to 4.3 km and above 6 km could be due to the distance between the lidar site and the RS launching station, which is about 30 km.

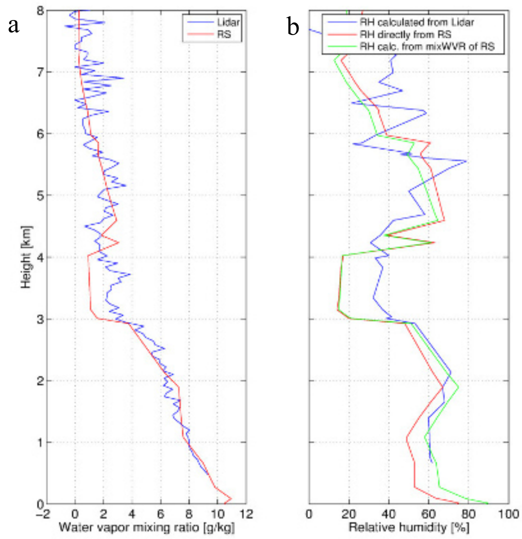

Fig. 2. a) MRWV to dry air profile from RS (in red), derived from Raman multiwavelength lidar signals (in blue); b) RH humidity profile obtained directly from RS (in red), derived from the WVMR from the RS (in green) and derived from Raman lidar signals (in blue). RS launched on 30/07/14 at 00UTC over Legionowo and lidar signals evaluated from 23 to 24 on 29/07/14 over RT-Lab (Warsaw).

3.2. Cloud vertical structure

The comparison between the CVS from lidar signals and from the COS14 RS methodology [4] has been made for two different RS launchings. The first RS evaluated with COS14 method was on 30/07/14 at 00UTC and it did not reveal any cloud layer, which agrees with the visual inspection of the IR lidar signals (Fig. 1a).

The second RS evaluated is on 30/07/14 at 12UTC and it reveals a low level cloud layer (from 1.3km to almost 3km) (Fig. 4 right), which agrees with the three layers seen on lidar signals for the same time period over Warsaw (Fig. 1b). Although the COS14 RS method only retrieves 1 layer (Fig. 4 left), it seems a good approximation to the 3 layers structures seen on lidar signals.

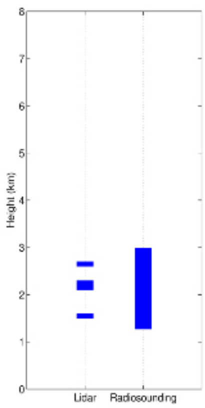

Fig. 4. CVS derived from the visual inspection of lidar signals at 1064nm over Warsaw (left), and cloud layer derived from COS14 radiosounding method from Legionowo (right), both on 30/07/14 at 12h UTC.

4. CONCLUSIONS

A comparison of the WVMR and RH between multiwavelength ground-based lidar (from 23 to 24h on 29/07/14) based on Warsaw, and RS measurement (at 00h UTC on 30/07/14) launched in Legionowo, were retrieved up to 8km successfully, and revealed a good agreement between the two methodologies at most heights, although the WVMR lidar derived showed noise. The differences in some parts of the WVMR and RH profiles could be due to geographical distance between the instruments. The comparison between CVS derived from visual inspection of ground-based multiwavelength ADR lidar and RS for two study cases produce good agreement. Despite on the second case, COS14 method only retrieves 1 cloud layer where the lidar derived 3, the cloudy height range is good determined by the lidar.

Combining lidar measurements and their retrievals with other technologies, such as RS, is very important in order to get a better knowledge about water content thought the atmosphere and CVS. Such studies have potential to improve methods for automatic and continuous description of clouds [4] and will very useful to provide better inputs for modelers. In future, more comparisons will be performed for other case studies since it will be very useful for testing and eventually improving RS methods. Moreover, comparing RS methods retrievals with different multiwavelength systems operating around the world opens a huge range of possibilities.

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