One-year measurements of aerosol vertical profiles in Gual Pahari, India

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ABSTRACT

A seven-channel Raman-lidar called Polly XT is described. The lidar system is completely remotely controlled and all measurements are performed automatically. In addition, first results from a one year campaign of lidar measurements of aerosol vertical profiles in Gual Pahari, India are presented. Boundary layer heights derived from the lidar measurements are compared with values from ECMWF (The European Centre for Medium-Range Weather Forecasts) model and radio soundings. Moreover, example profiles of backscatter, extinction and lidar ratio are presented.

1. INTRODUCTION

The effects of atmospheric aerosols and their interactions with clouds have the largest uncertainty in climate forcing estimates (e.g. [1]; [2]). Particles affect and change various climatically important factors, like the cloud reflectivity and lifetime. The influence of particles on radiative balance depends on their optical properties and vertical profiles. Advanced lidar systems, which can determine the optical properties of aerosols in a quantitative way and enable to estimate the main microphysical properties, can provide ground truth for the retrieval of aerosol products from space-borne instruments.

In Southern Asia only a few measurements of aerosol vertical profiles have been carried out, and mostly as short campaigns. Though, these countries have an important role in the battle against pollution and climate change. The largest and most persistent of pollution-caused hazes, the "brown cloud", covers an area of 10 million km^2 over the Southern Asia and concerns more than 50 % of the world's population. This particulate air pollution is assumed to originate from fossil fuel and biomass burning. The polluted air is likely to have significant harmful effects on human health and regional climate over Southern Asia (e.g. [3]; [4]; [5]). Overall, it is suggested that the atmospheric brown cloud in Asia contributes to the regional lower-tropospheric warming as much as the recent increase of the anthropogenic greenhouse gases ([5]).

2. THE INSTRUMENT

We have established a one year campaign of lidar measurements to measure aerosol vertical profiles in Gual Pahari (28º26'N, 77º09'E, 243 m a.s.l.), India. The station is surrounded by agricultural farm fields and forests, about 30 km south of Delhi. The lidar measurements are conducted from March 2008 to March 2009. The measurements belong to the frame of the EUCAARI (European Integrated project on Aerosol Cloud Climate and Air Quality interactions) project ([6]).

The instrument used, is a seven-channel Raman-lidar called "POLLY XT–POrtabLe Lidar sYstem eXTended" ([7]). Fig. 1 shows the Polly XT instrument with open doors. The instrument is inside a waterproof cabinet which is connected outside with two cables; one for electrical power and one for internet connection. The internet connection is used to control the instrument remotely and to receive the measurement data automatically. Inside the cabinet, the laser head, emitter optics, and the receiver optics with the telescope are situated on an optical table, which is mounted vertically in the rear of the cabinet. The computer, power supply for the laser, and the uninterruptible power supply (UPS) are situated beneath the optics. The inner part of the air conditioning system is installed on the left door.

Figure 1. *PollyXT with open doors. 1: laser head, 2: laser power supply, 3: beam expander, 4: receiver telescope, 5: receiver with 7 channels, 6: power supply for PMT cooling unit for the 1064 channel, 7: computer with data acquisition and interface cards, 8: UPS, 9: air conditioner, 10: sensors for outdoor temperature and rain, and 11: roof cover. (picture credits: [8]).*

A rain sensor, a temperature sensor and the roof cover are on top of the cabinet. The rain sensor is connected to the roof cover to assure a proper shut-

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down of the instrument during rain. When the sensor detects rain, a signal is sent to the data acquisition software which in turn shuts down the laser and ends the measurement. The roof cover is a metal plate which protects the quartz plates in the roof on the emitter output and on the receiver input. The quartz plates are used to transmit the emitted and backscattered light and to avoid air exchange between the cabinet and the environment surrounding it. This enables efficient air conditioning. Parts of the system can be controlled remotely i.e. the computer with Keyboard-Video-Mouse (KVM) – switch, the power distributor, and the UPS via an internet router. The computer itself contains PCI cards for data acquisition and in addition all interfaces to control the other system parts.

The type of the laser used is Inlite III from Continuum. It emits energy simultaneously approximately 180 mJ, 110 mJ, and 60 mJ at 1064 nm, 532 nm, and 355 nm, respectively. The emitted radiation is linearly polarized at 355 nm. The divergence of the laser is less than 1.5 mrad. A beam expander is used to enlarge the beam from approximately 6 mm to about 45 mm before it enters the atmosphere. The backscattered signal is collected by a Newtonian telescope which has a main mirror with a of 300 mm and a focal length of 900 mm. The receiver's field of view is 1 mrad.

Surface temperature and surface pressure are also measured during the lidar measurements. These data are used to determine the Rayleigh scattering by the automatic data retrieval algorithm which assumes a standard atmosphere. The output of the instrument includes vertically resolved backscattering coefficients on three wavelengths (355, 532 & 1064 nm) and extinction coefficients on two wavelengths (355 & 532 nm). The vertically integrated extinction coefficient gives the AOD (Aerosol Optical Depth) and also the size/composition-dependent Ångström exponents can be derived. Lidar ratio, the ratio between extinction and backscatter, depends on the size distribution, shape and chemical composition of particles. This makes it possible to get some estimates of the particle size distribution and chemical composition. Also the height and the changes of the boundary layer and night-time residual layer can be defined together with the height and thickness of different cloud and aerosol layers. The depolarisation channel (355 nm) of the lidar makes it possible to estimate the ratio of ice crystals and water droplets in clouds. The vertical resolution of the system is 30 meters. Depending on the cloudiness the whole troposphere can be monitored (up to few tens of kilometres).

3. PRELIMINARY RESULTS

Preliminary results reveal up to 5 km thick aerosol layers, with AOD well above one. The lidar-based AOD values were in line with the values obtained from MODIS (The Moderate Resolution Imaging Spectroradiometer, [9]) satellite instrument. Often a multi-layer aerosol structure is observed and with backward trajectories the sources of various layers can be defined.

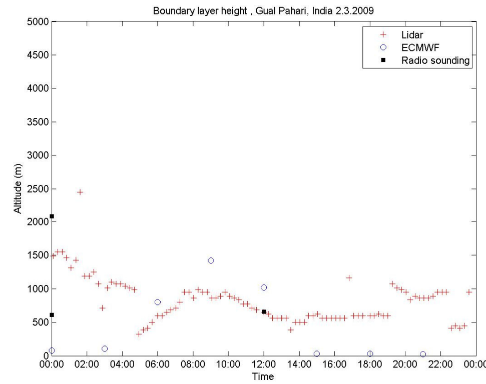

Figure 2. *Boundary layer height for one day (2.3.2009) at Gual Pahari, India from PollyXT lidar (red crosses), ECMWF model (blue circles) and Radio soundings (black squares). Time in the plot is UTC (local time is UTC+5.5 hours).*

Figure 2 presents an example of the planetary boundary layer (PBL) evolution during a day. The red crosses show the boundary layer top derived from the PollyXT measurements based on the work of [10]. Although multiple aerosol layers were present during the day (ca. 5 – 14 UTC), the detection of the boundary layer top is good. Before 5 UTC and after 14 UTC, the lidar detects the residual layer during local night time. The blue circles show the boundary layer based on ECMWF model. During the day, the model and the lidar measurement are in good agreement. The black squares show the boundary layer estimated from radio soundings. Temperature and relative humidity data were used to the estimate the PBL top from the soundings. The 12:00 UTC (17:30 local time) sounding matches the lidar measurement extremely well. Naturally, not all days have as good agreement between the measurements and the model as this example. The example in Figure 2 shows the typical behaviour that even though the model and lidar values have the same day-time pattern the model values are slightly higher than what is observed with the lidar. The low temporal availability of the sounding makes the comparison difficult. Also the vertical resolution of the soundings close to the ground level is moderate.

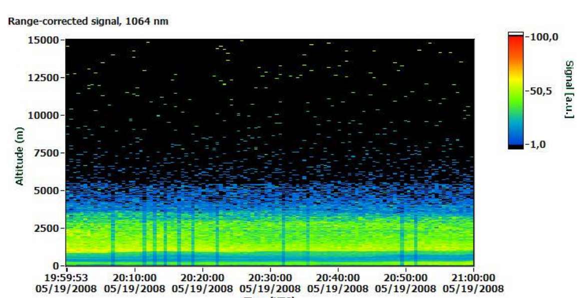

Figure 3. *One hour time series of backscatter signal at 1064 nm from 19.5.2008 at Gual Pahari, India. Time in UTC.*

Figure 3 presents an example of one hour time series of backscatter signal at 1064 nm. During this day the layer structure is very complex and the retrieval of the boundary layer top height is very difficult. The aerosol layers reach up to 5 km. Thick aerosol layers are observed frequently. Also multi-layer structures are common.

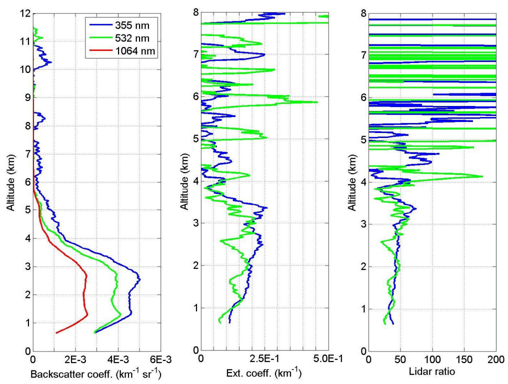

Figure 4. *Left: One hour average backscatter coefficient for 355 nm (blue), 532 nm (green), and 1064 nm (red) from 19.5.2008 at Gual Pahari, India. Middle: One hour average extinction coefficient for 355 nm (blue), and 532 nm (green) from the same day. Right: One hour average lidar ratio for 355 nm (blue), and 532 nm (green) from the same day.*

Figure 4 presents averaged backscatter coefficients, extinction coefficients and lidar ratio at several wavelengths for the example hour shown in Figure 3. The profiles of backscatter coefficients show multiple aerosol layers inside the boundary layer. Lidar ratios at 355 and 532 nm were both around 40 sr^{-1}. AOD of 0.5 was integrated from the vertical extinction coefficient. The value is somewhat lower than the AOD of 0.8 derived from MODIS measurements for the same day. One reason for the difference between the instruments is that MODIS measurements were done 12 hours earlier than the lidar measurement. For the calculation of AOD from the lidar measurements, information on extinction is required. This information can be achieved from Raman scattering. Unfortunately, Raman measurements are not made during the day, whereas MODIS is a passive instrument which measures solar radiation, meaning that it can measure AOD only during the daytime. Thus, the comparison of lidar and MODIS derived AOD values is not straightforward.

4. CONCLUSIONS

First results from a one year campaign of lidar measurements of aerosol vertical profiles in Gual Pahari, India are presented. Planetary boundary layer heights can be reliably retrieved from the lidar measurements and aerosol layer structures inside the boundary layer can be identified. Moreover, AOD values based on vertical extinction coefficient profiles were in the same range as the AOD values from MODIS.

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