Automated Raman lidar measurements in the Amazon rain forest during the wet and dry season 2008

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ABSTRACT

Observations of the vertical aerosol structure over the Amazon rain forest were performed with the automated multiwavelength-Raman-lidar Polly^{XT}. The almost continuous measurements were taken in Brazil at 2°S, 60°W from January to November 2008. With Polly^{XT} vertical profiles of the backscatter coefficient at 355 nm, 532 nm, and 1064 nm, of the extinction coefficient at 355 nm and 532 nm, and of the particle depolarization ratio at 355 nm can be determined. Out of 2500 hours of data, a typical observation case for the wet (November-May) and dry season (June-October) is presented and intensively discussed in terms of optical aerosol properties and geometrical layer structure. Microphysical aerosol properties like effective radius and volume concentration are also calculated with an inversion algorithm. The analysis reveals, that for the wet season case aged biomass-burning aerosol from Africa dominated optical aerosol properties above 800 m. For the dry season case, biomass burning smoke from local fires was observed.

1. INTRODUCTION

The Amazon basin with its extensions of more than six million square kilometers contains the worlds largest tropical rain forest. Investigations of aerosol characteristics in this large area are important for the understanding of the local and global influence of Amazonian aerosol on radiation budget and cloud formation. Compared to its global importance, knowledge on aerosols in this region is still inadequate. Efforts have been made in this region to characterize aerosol properties in the framework of the Large-Scale Biosphere-Atmosphere Experiment in Amazonia (LBA). Several ground-based measurements have been performed but so far only a few studies of the vertical aerosol distribution were made. The vertical aerosol structure during the dry season was observed in Rôndonia, South-West Brazil, during the Smoke, Aerosols, Clouds, Rainfall and Climate (LBA-SMOCC) campaign (Chand et al. 2006). Airborne measurements were used to characterize the aerosol within the planetary-boundary layer and within the free troposphere. Frequently haze layers of biomass burning aerosol were found above the planetary-boundary layer. Saharan dust and biomass-burning plumes from long-range transport were observed in the wet season during the Cooperative LBA Regional Experiment (CLAIRE-98) in Surinam (Formenti et al. 2001). In spite of these interesting results there is still a lack of detailed knowledge of the vertical aerosol structure in this region.

For the first time in Amazonia, long-term observations of the vertical aerosol structure were made for a period of almost one year in 2008 in the framework of the European Integrated project on Aerosol Cloud Climate and Air Quality Interactions (EUCAARI). These measurements were performed with the automated polarization Raman lidar Polly^{XT} of the Leibniz Institute of Tropospheric Research (IFT).

2. EXPERIMENT

The lidar observations in Amazonia took place from January to November 2008. The experimental site was located ca. 50 km north of Manaus in the Brazilian part of the Amazon rain forest at 2° 35.5' S, 60° 2.3' W, 116 m asl (Fig. 1). The main wind direction in this region is usually north-east to east, thus typically no pollution from the city of Manaus is expected. The general weather conditions are characterized by a wet season and a dry season. The wet season lasts normally from end of November until May with monthly precipitation amounts of 240–300 mm. The dry season starts at the end of May and lasts until November. Average monthly precipitation rates in this season vary between 50 and 120 mm.

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Figure 1. Left: Map of northern South America. The red arrow shows the location of the field site for the lidar observations. Right: Field site with the satellite dish for internet connection and the lidar Polly^{XT}.

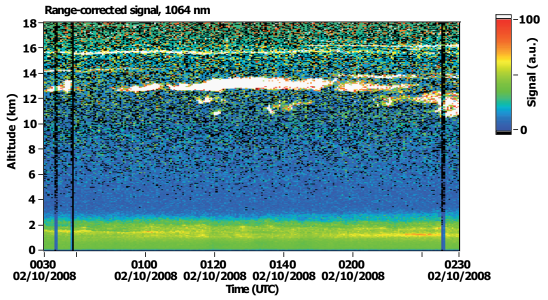

Figure 2. Temporal development of range-corrected signal at 1064 nm on 10 February 2008.

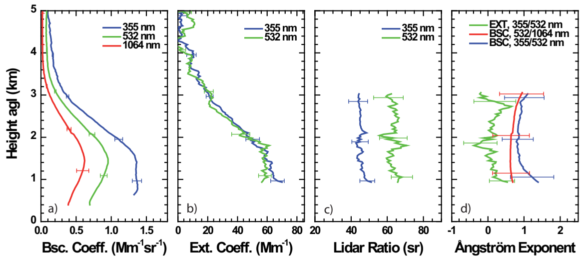

Figure 3. Vertical profiles of a) backscatter coefficient, b) extinction coefficient, c) lidar ratio and d) Ångstrom exponents for 10 February 2008 0030-0230 UTC.

The automated polarization-Raman lidar Polly^{XT} (Althausen et al. 2009) was used to perform the measurements. This multi-wavelength lidar emits linearly polarized light at the wavelength of 355, 532 and 1064 nm. The receiver has 7 channels. Vertical profiles of the backscatter coefficient are derived for the three emitted wavelengths. Profiles of extinction coefficient can be determined for nighttime observations at 355 and 532 nm using the Raman-scattered light at 387 and 607 nm. Cross-polarized light is detected at 355 nm and allows the determination of the particle depolarization. The spatial and temporal resolution of the six channels mentioned above is 30 m and 30 s, respectively. A fast analog channel with 7.5 m and 10 s spatial and temporal resolution, respectively, at 532 nm is used for the analysis of fast atmospheric processes. The system is designed to measure 24 hours a day, 7 days a week and can be controlled remotely via Internet. Additionally, the data is automatically transferred to a server and plots of the range-corrected signals are shown in near-real time on a website (polly.tropos.de). Figure 1 shows the field site. The satellite dish for the internet connection and Polly^{XT} are situated on a glade in the rain forest at the Silvicultura site of the National Institute for Amazonia Research (INPA).

3. OBSERVATIONS

The observations started on 22 January 2008 and lasted until 11 November 2009. During this almost one-year period, lidar measurements could be performed on 211 days resulting in more than 2500 hours of tropospheric observations. Nevertheless, fog development during night time at the canopy level prohibited detailed analysis of many wet-season observation cases. At daytime the high frequency of low-level clouds and rain also caused problems in data analysis. Therefore only a few measurement cases of the wet season can be used for the detailed analysis of vertical aerosol profiles. During the dry season, fog, low-level clouds and rain also disturbed lidar observation, but the frequency of occurrence of such events is much lower than during the wet season. One wet and one dry season case will be discussed as examples below.

3.1. Wet season case

The temporal development of the range-corrected signal at 1064 nm of a nighttime observation during the wet season (10 February 2008) is shown in Fig. 2. Stable aerosol condition were observed during the whole measurement period. The height of the well-mixed aerosol layer is approximately 3 km. Diverse cirrus clouds can be seen between 10 and 17 km. The corresponding vertical profiles of backscatter and extinction coefficient, lidar ratio, and Ångstrom exponents for the observation period can be seen in Fig. 3. Whereas a high spectral dependence of the backscatter coefficients can be seen, the vertical profiles of extinction coefficients are almost independent of wavelength. Maximum extinction coefficients of 60 Mm^{-1} occur around 1.5 km. Integration of the extinction profile yields a particle optical depth of about 0.15 (assuming height-independent extinction in the lowermost 1 km). Lidar ratios at 355 nm are considerably smaller (40-50 sr) than at 532 nm (60-70 sr), which corresponds to latter high backscatter-related Ångstrom exponents and rather low extinction-related Ångstrom exponents. Particle depolarization ratio does not exceed 5% (not shown). These specific optical properties are an unique and unambiguous characteristic of aged biomass-burning smoke (Müller et al. 2005). For the optical data set in the aerosol layer the inversion indicates effective radii from 0.35 to 0.45 µm. Back-trajectory calculations show (Fig. 4), that a trade wind dominated air-flow prevailed and aerosol from Africa could be a possible part of Amazonia's aerosol distribution. This is supported by a

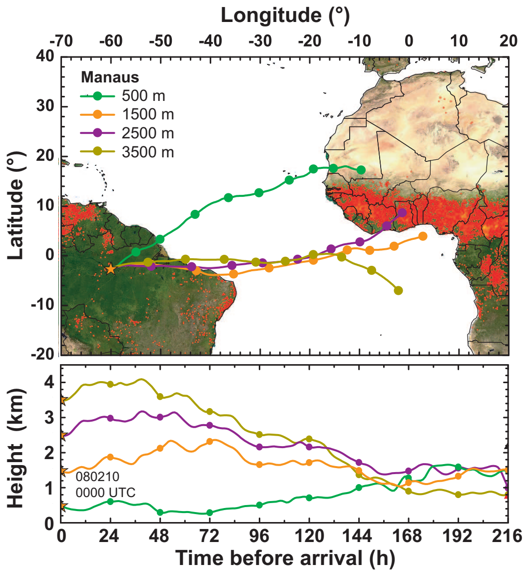

Figure 4. 9-day HYSPLIT backward trajectories (http://www.arl.noaa.gov/ready/hysplit4.html) ending at Manaus, Brazil, on 10 February 2008, 0000 UTC. The underlying fire map derived from MODIS observations (http://rapidfire.sci.gsfc.nasa.gov) shows all fires (red spots) detected during the 21-30 January period.

7-day composite image of MODIS aerosol optical depth (Fig. 5), which shows a high aerosol load over Central Africa and the Atlantic Ocean travelling westwards towards Amazonia. Because there is a very high fire activity in Central Africa (see Fig. 4), the source of this aerosol plume is most probably biomass burning. This figures and the vertical profiles from the lidar observation in accordance with rather large particle radii (growth during long-range transport) let one conclude, that optical aerosol properties above 800 m are dominated by biomass-burning smoke from Africa. This findings are in good agreement with results from long-term sun photometer measurements (Schafer et al. 2008) and satellites observations (Kaufman et al. 2005).

At the same time when the measurements in Brazil were performed, multi-wavelength lidar observations were also made on Cape Verde Islands during the Saharan Mineral Dust Experiment (SAMUM) II. Dust and smoke from Africa have also been observed there 7-10 days (approximate travel time to the lidar site – compare Fig. 4) before the aerosol plume reached Amazonia. This specific case of dust and smoke transport from Africa to South America observed with multiwavelength lidars on Cape Verde and in Amazonia is intensively described and discussed by Ansmann et al. (2009).

3.2. Dry season case

The temporal development of the range-corrected signal at 1064 nm on 15 August 2008 (dry season) is shown in Fig 6. A complex aerosol layer structure was existent during the one-hour nighttime observation.

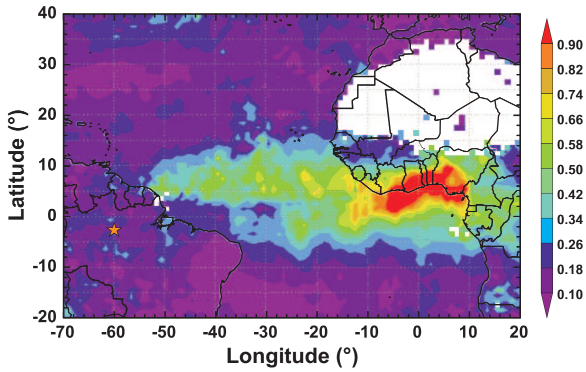

Figure 5. Mean particle optical depth (550 nm, 2-10 February 2008) observed with MODIS (http://disc.sci.gsfc.nasa.gov/giovanni/).

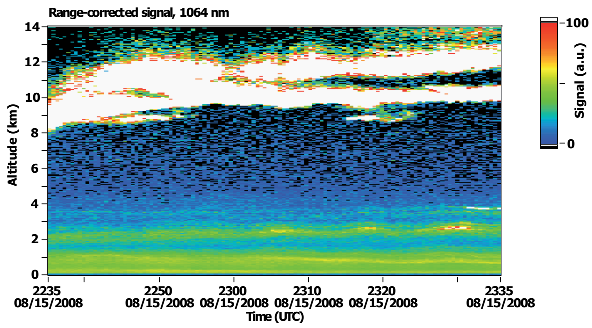

Figure 6. Temporal development of range-corrected signal at 1064 nm on 15 August 2008.

Aerosol up to 5 km was observed. The residual layer extended up to ca. 1.6 km. A lofted aerosol layer centered at ca. 2.5 km can be seen. Diverse clouds were present above 9 km. Figure 7 shows the vertical profiles of backscatter and extinction coefficient, lidar ratio, and Ångstrom exponents at different wavelengths. Values of backscatter and extinction coefficient show a clear spectral behavior. Maximum extinction coefficients of 130 Mm^{-1} and 80 Mm^{-1} for 355 and 532 nm, respectively, occur in the residual layer. Values up to 100 Mm^{-1} and 45 Mm^{-1} are observed in the lofted aerosol layer at 2.5 km. Integration of the extinction pro-

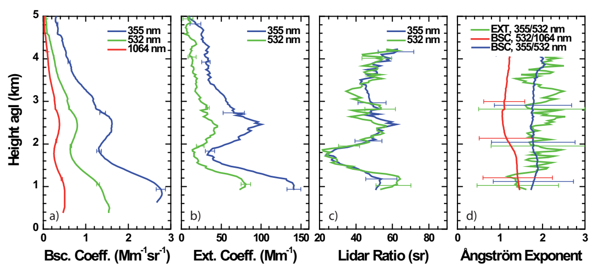

Figure 7. Vertical profiles of a) backscatter coefficient, b) extinction coefficient, c) lidar ratio, d) Ångstrom exponents for 15 August 2008 2235-2335 UTC.

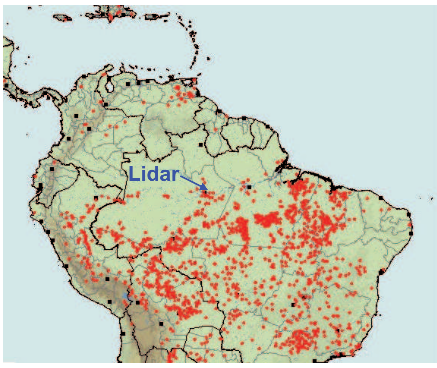

Figure 8. MODIS fire counts for 14-15 August 2008. Blue arrow shows the location of the lidar. (NASA/GSFC, MODIS Rapid Response: rapidfire.sci.gsfc.nasa.gov)

file yields a particle optical depth of about 0.3 and 0.15 for the two wavelengths (assuming height-independent extinction in the lowermost 1 km). The corresponding vertical profiles of the lidar ratio for the two wavelengths are almost spectral independent. The values vary between 35 and 55 sr. Relatively high extinction-related Ångstrom exponents (about two) indicate small aerosol particles. The inversion of the optical data set gives a rather low single scattering albedo (0.945$\pm$0.05) and small particle radii (0.13$\pm$0.01 μm) for the two aerosol layers. This optical and microphysical properties are in good agreement with observations of local biomass-burning smoke in Amazonia (Reid et al. 1998). Figure 8 shows the fire counts in northern South America on that day. A high burning activity can be seen in the south and south-west of the measurement site. Many fire spots were also detected close (around 100 km) to the field site. Therefore one can conclude, that local and/or regional biomass-burning aerosol dominated the optical aerosol properties on 15 August 2008.

4. CONCLUSION AND OUTLOOK

Multiwavelength lidar observations were performed in Amazonia for an almost-one year period with about 2500 hours of observations time. In the wet season lots of cases with low-level clouds, fog and rain were observed. The aerosol layer height was typically between 1.5 and 3 km. Some cases of lofted layers (up to 4 km) has been observed. An example case of the wet season (10 February 2008) was presented and showed that aged biomass-burning aerosol from Africa dominated optical aerosol properties at the measurement site. In the dry season the aerosol layer top was typically between 1.8 - 4.5 km. A frequent occurrence of lofted aerosol layers was observed. The example case of the dry season (15 August 2008) showed the observation of local biomass-burning smoke in two different layers.

In the future, a statistical analysis of the whole data set in terms of geometrical, optical and microphysical aerosol properties will be made as well as comparisons with diverse aerosol models.

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