# Expansion of the German Meteorological Service Raman Lidar RAMSES

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## ABSTRACT

The German Meteorological Service Raman lidar for atmospheric moisture sensing (RAMSES) has been expanded to measure — in addition to water vapor, and particle backscatter and extinction coefficients — temperature and depolarization ratio day and night. Temperature profiles of the troposphere and the stratosphere are determined by combining the rotational-Raman technique with the Rayleigh- and Raman-integration techniques. For the detection of the rotational-Raman signals a new beamsplitter/interference filter receiver design has been implemented which is more compact and robust, and easier to align and optimize than previous experimental setups. Furthermore, the experimental setup allows of two independent methods for calibrating measurements of depolarization ratio. A brief description of the RAMSES receiver is given and first measurements are presented.

## 1. INTRODUCTION

Since August 2005, RAMSES has been monitoring the water vapor field and clouds at the Richard Aßmann Observatory of the German Weather Service at Lindenberg. Although measurements of high quality were obtained on a routine basis [1], their range of application was limited because, (1) the lidar operated only at night, and (2) the set of measured parameters was restricted to water vapor mixing ratio, particle backscatter coefficient and extinction coefficient. To overcome these limitations, the RAMSES receiver has been upgraded this year to permit also observations of temperature and depolarization ratio, and to allow of daytime observations. In this conference contribution, an overview of the optical layout of the new RAMSES receiver is given. Furthermore, the necessary modifications to the operational system control, and to the signal processing software are summarized. First measurements are presented to illustrate the data quality of RAMSES.

## 2. FAR-RANGE RECEIVER

RAMSES is a UV Raman lidar operating at a primary wavelength of 355 nm. Its original optical receiver was equipped with 3 detection channels each for the 80-cm far-range telescope and the 20-cm near-range telescope, analyzing signals at 355 nm, 387 nm and 408 nm, respectively [2]. While the near-range receiver remains the same except for new collimation optics, six channels have been added to the new far-range receiver, since besides measuring the vertical distribution of water vapor and of particle backscattering and extinction, analysis of depolarization effects as well as temperature profiling will be performed as well. The optical design has been changed also. Instead of detecting collimated light, we now image the primary telescope mirror onto the PMT cathodes (Hamamatsu R7400-03) in order to avoid range-dependent errors introduced by a spatially inhomogeneous photocathode sensitivity [3]. Due to limitations in space, the new far-range receiver had to be split in two horizontal layers (lower level and middle level), see Figure 1. The main telescope delivers the atmospheric signal in horizontal direction towards this receiver stack. The field of view is controlled by a motorized iris diaphragm, mounted on a x/y/z stage, so that different focal planes can be selected, if necessary. The dichroic beamsplitter directly after the collimator in the lower level transmits light $<$370 nm for observations of particle backscattering, depolarization ratios, and rotational-Raman and Rayleigh-integration temperatures (lower level), and reflects the remainder to the middle level. There the first beam splitter reflects light $<$410 nm for the measurement of the vibrational-rotational Raman signals of water vapor and molecular nitrogen (determination of water vapor mixing ratio, particle extinction, and Raman-integration temperature). Light $>$410 nm is transmitted and trapped in a beam dump to minimize the effects of background light, especially during daytime. To suppress any cross talk between the detection channels, each PMT detector was placed in a light-proof chamber into which light can enter only through a narrowband interference

© Proceedings of the 8th International Symposium on Tropospheric Profiling, ISBN 978-90-6960-233-2
Delft, The Netherlands, October 2009. Editors, A. Apituley, H.W.J. Russchenberg, W.A.A. Monna

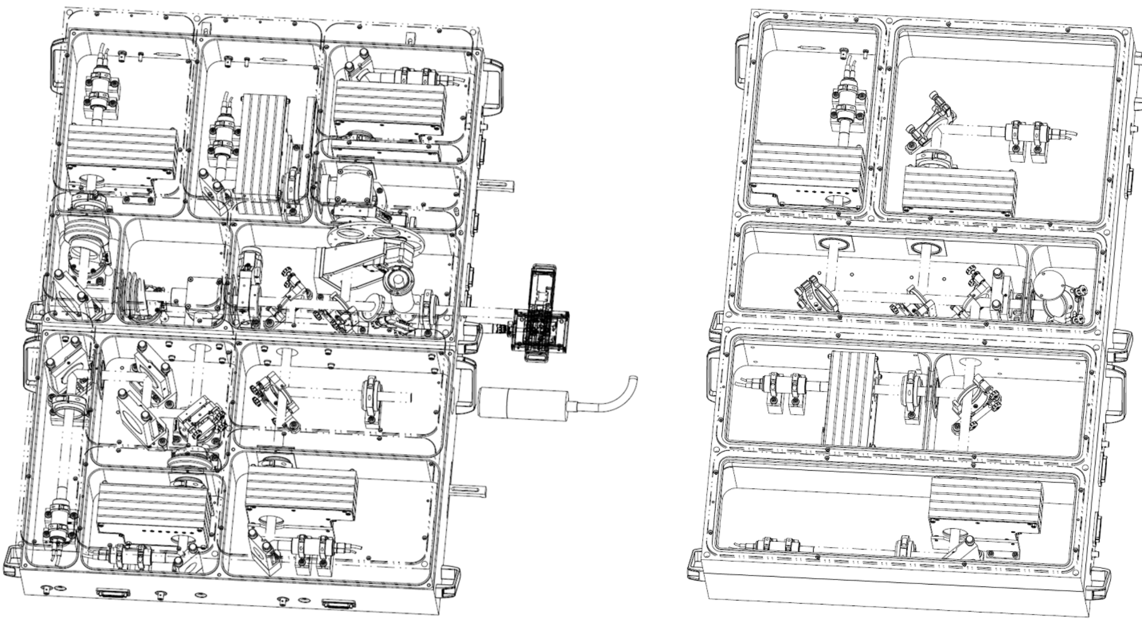

*Figure 1. Six-channel receiver section (lower level) for depolarization and temperature measurements (left) and three-channel receiver section (middle level) for water vapor measurements (right). Sizes: 780 mm $\times$ 1100 mm $\times$ 234 mm).*

filter. The only exception is the setup for the depolarization measurements which employs a single filter (at a time) for both detection channels (lower layer). Finally, all rotational and vibrational-rotational Raman channels are protected by steep long-wave-pass edge filters against, respectively, elastic backscattering and background light.

The housings were milled out of a solid block of aluminium and were segmented in a front and aft section each; connected by precision alignment dowel pins. Each of the above-mentioned chambers is equipped with an individual cover, so that maintenance work at a single optical channel can be carried out without interfering with the other channels. All channels (except for two with gated PMTs) are equipped with a set of five motor-driven neutral density filters for individual intensity adaptation of the optical receiver signals. Additionally in the lower layer, two motorized rotators with $\lambda/2$ plates and two actuators with linear polarizers are implemented for polarization-plane adjustments and for the suppression of polarization cross talk, respectively. The motor-controlled filter wheel with a set of interference filters of different spectral widths is necessary for the calibration technique described in [4]. A four-quadrant detector is also installed for actively stabilizing the transmitter-receiver alignment.

The modified near-range receiver is stacked on top of the middle layer and fiber-coupled to the 20-cm telescope (not shown). Data acquisition (12 channels; Licel transient recorders TR20-160, combined analog and photon-counting signal detection) and motion of all actuators is controlled by LabView-8 software.

## 3. DATA PROCESSING

RAMSES data analysis, quality control, and dissemination are performed with ALDA, the Automated Lidar Data Analyzer. The receiver upgrade made a substantial revision and expansion of the software necessary. The new version of ALDA provides five modes of operation, the *online mode* for the automatic analysis of lidar signals during a running measurement and visualization of the current products in realtime; the *view mode* for the visualization of already existing lidar products (profiles or time series plots); the *archive mode* for managing the backup process of analyzed and archived measurements; the *science mode* as a versatile tool for, e.g., interactive re-processing of measurements with individual quality control of raw signals and products, and for the manual, optimized retrieval of calibration constants (calibration constants that have been obtained automatically in *online mode* can be visualized and checked); and the *statistics package* (in preparation) for the retrieval of climatological mean profiles (e.g., monthly or seasonal means) of all RAMSES products: tropospheric water-vapor mixing ratio and relative humidity, backscatter ratio, particle extinction coefficient, particle backscatter coefficient, lidar ratio, depolarization ratio, and temperature (rotational-Raman and integration techniques applied).

With the new receiver, RAMSES will perform measurements during daytime also. The daytime capability of RAMSES is achieved by the use of narrow interference filters and a narrow field of view. With narrow interference filters, the signal intensity depends on the actual temperature in the scattering volume. The upgraded

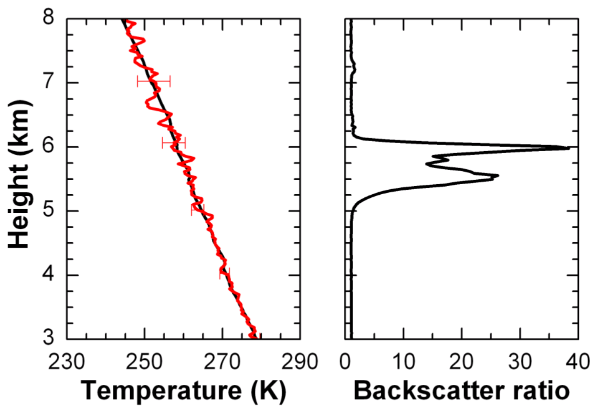


*Figure 2. Temperature measurement in the presence of a cirrus cloud on 27 July 2009. (left) Rotational-Raman temperature (red curve, with statistical-error bars), and radiosonde temperature (black curve), (right) particle backscatter ratio. Starting at 22:55 UT (the radiosonde launch time), 1200 s of lidar data are integrated. The resolution of the raw data is 30 m, rotational-Raman signal profiles are smoothed with a sliding-average length of 3 and 5 height bins between 3–6 and 6–8 km, respectively.*

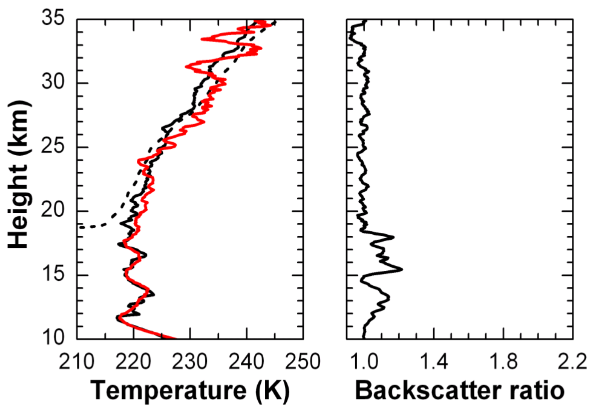


*Figure 3. Temperature measurement in the presence of stratospheric aerosol on 28–29 July 2009. (left) Rotational-Raman temperature (red curve), Rayleigh-integration temperature (dashed black curve), and radiosonde temperature (launched at 22:57 UT, black curve), (right) particle backscatter ratio. Lidar data between 21:00 and 01:00 UT are integrated. The resolution of the raw data is 90 m. The sliding-average length used to smooth the rotational-Raman signal profiles increases with height (7 height bins at 10 km, 15 height bins above 21 km), it is 13 height bins throughout the stratosphere for the determination of Rayleigh-integration temperature, and 3 height bins for aerosol backscatter ratios.*

ALDA version corrects for this temperature effect by applying the correction scheme described in [5]. Furthermore, for extinction retrievals it is necessary to correct the near-range lidar signals for the incomplete overlap between the receiver's field of view and the laser beam. We use the method of [6] to determine the overlap function and to correct for it. Finally, ALDA will utilize both the photon-counting and the analog signals provided in parallel for each channel by the Licel data acquisition system.

Temperature profiles of the troposphere and the stratosphere are determined by combining the rotational-Raman technique with the Rayleigh- and Raman-integration techniques. For the calibration and calculation of the temperature profiles with the rotational-Raman technique we use the formulas of [7]. These temperature measurements allow also for the independent retrieval of profiles of relative humidity without the need of radiosonde profiles.

Accurate measurements of the volume depolarization ratio require a careful calibration of the lidar raw data. The new receiver is designed to allow of two independent methods for this purpose [4, 8]. ALDA will calculate particle depolarization profiles from the profiles of volume depolarization and particle backscatter coefficient.

## 4. MEASUREMENT EXAMPLES

At the time of writing, the lower layer of the far-range receiver has been installed and is now being tested. We present temperature observations in the troposphere and stratosphere, first measurements with the complete system will be shown at the conference.

Figure 2 compares the rotational-Raman temperature profile measured with RAMSES with temperature data obtained from the routine midnight radiosonde sounding during the night of 27–28 July 2009. Lidar data are integrated over 20 minutes, starting at the launch time of the sonde. The profiles agree very well, with no signs of the cloud, present between 5 and 6.2 km, affecting the lidar measurement. The blocking of elastically backscattered light by a combination of a steep long-wave-pass edge filter and a narrowband interference filter is thus sufficient to allow of RAMSES measurement of temperature in clouds with backscatter ratios of at least 40.

Figure 3 shows RAMSES measurements of stratospheric temperature during the night of 28–29 July 2009. Both the rotational-Raman and the Rayleigh-integration technique have been applied. Up to the burst height of the radiosonde (35 km), which is used as the reference in this case, all temperature profiles agree well. Two observations are worth mentioning. First, the rotational-Raman profile gets rather noisy above 30 km. This is due to a 10-fold attenuation of the Raman signals. In order to avoid signal nonlinearities in the lower troposphere, we had to insert neutral-density filters in the two detection channels. However, this will probably not be necessary for future temperature observations because initial tests suggest that, without attenuation, the rotational-Raman signals might be strong

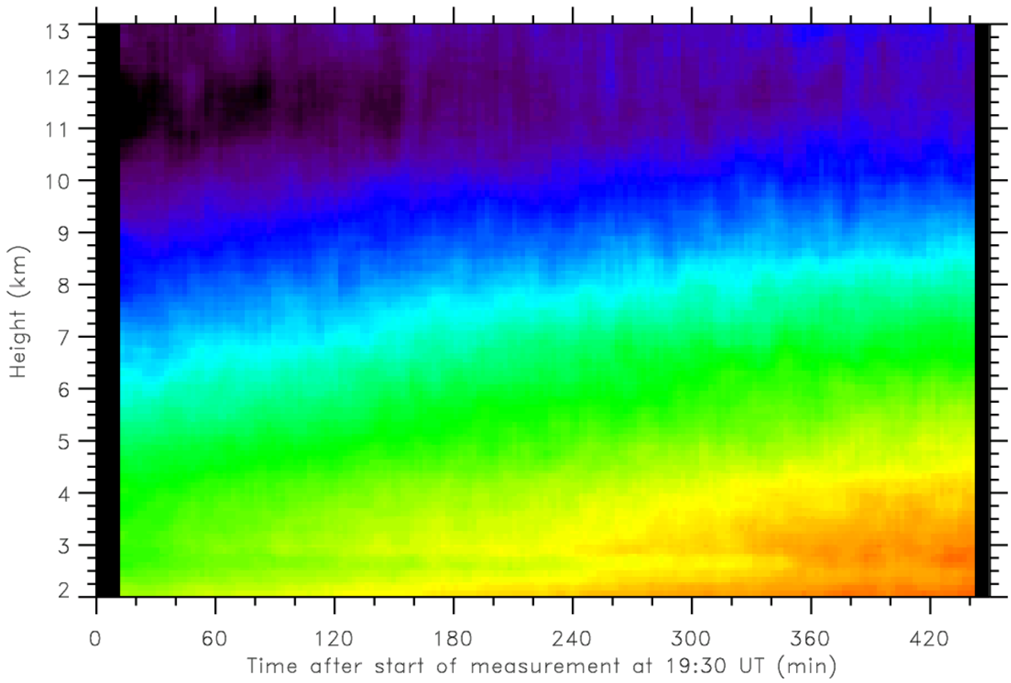


*Figure 4. Temporal evolution of tropospheric temperature as measured with RAMSES on 28–29 July 2009. The rotational-Raman technique is applied. For each profile, 600 s of lidar data are integrated, the calculation step width is 120 s. The resolution of the raw data is 90 m, signal profiles are smoothed with a sliding-average length of 3, 5, 7, and 9 height bins between 3–6, 6–9, 9–12, and 12–13 km, respectively. The display range is from 210 K (black) to 290 K (red).*

enough for analog detection, and that these analog Raman signals could be used for the temperature determination in the troposphere. If so, the neutral-density filters could be omitted and night-averaged rotational-Raman temperature profiles up to 40–50 km would become available. Second, in contrast to the Rayleigh-integration temperatures the rotational-Raman temperatures are not affected by the volcanic aerosol present in the lower stratosphere between the tropopause and 18.5 km.

Finally, Figure 4 illustrates the temporal evolution of tropospheric temperature during the same night. Over time, a general warming of the troposphere can be observed. The most interesting feature is the inversion below 3 km which is formed by advection of warm air masses in front of a trough over western Europe.

## REFERENCES


[1] Berger F. H., J. Reichardt, A. Beljaars, J. Güldner, C. Heret, 2009: Evaluation of modeled water vapour profiles using Raman lidar data, this conference.

[2] Engelbart D., J. Reichardt, I. Mattis, U. Wandinger, V. Klein, A. Meister, B. Hilber, V. Jaenisch, 2006: RAMSES - German Meteorological Service Raman lidar for atmospheric moisture sensing, *Reviewed and Revised Papers Presented at the 23nd International Laser Radar Conference*, 24-28 July 2006, Nara, Japan, pp. 683-686.

[3] Freudenthaler V., 2004: Effect of spatially inhomogeneous photomultiplier sensitivity on lidar signals and remedies, *Reviewed and Revised Papers Presented at the 22nd International Laser Radar Conference*, 12-16 July 2004, Matera, Italy, pp. 37-40.

[4] Reichardt J., R. Baumgart, T. J. McGee, 2003: Three-signal method for accurate measurements of depolarization ratio with lidar, *Appl. Opt.*, 42, pp. 4909-4913.

[5] Whiteman D., 2003: Examination of the traditional Raman lidar technique. I. Evaluating the temperature-dependent lidar equations, *Appl. Opt.*, 42, pp. 2571-2592.

[6] Wandinger U., A. Ansmann, 2002: Experimental determination of the lidar overlap profile with Raman lidar, *Appl. Opt.*, 41, pp. 511-514.

[7] Behrendt A., J. Reichardt, 2000: Atmospheric temperature profiling in the presence of clouds with a pure rotational Raman lidar by use of an interference-filter-based polychromator, *Appl. Opt.*, 39, pp. 1372-1378.

[8] Alvarez J. M., M. A. Vaughan, C. A. Hostetler, W. H. Hunt, D. M. Winker, 2006: Calibration technique for polarization-sensitive lidars, *J. Atmos. Ocean. Technol.*, 23, pp. 683-699.