RAMSES - GERMAN METEOROLOGICAL SERVICE RAMAN LIDAR FOR ATMOSPHERIC MOISTURE SENSING

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ABSTRACT

In 2005, the water-vapor Raman lidar *RAMSES* was installed at the Richard Aßmann Observatory in Lindenberg of the German Meteorological Service. Main objectives are to validate numerical weather prediction models, and to contribute to CM-SAF and to GVaP. *RAMSES* is designed for unattended nighttime measurements. In this paper, a short overview of *RAMSES* automation, optical layout, operational system control, and signal processing is given. Furthermore, some measurements from the international LAUNCH-2005 campaign are presented to illustrate the operational product generation and the data quality of *RAMSES*.

1. INTRODUCTION

In 2005, the German Meteorological Service (DWD) complemented the suite of remote-measurement instruments of its Richard Aßmann Observatory at Lindenberg, Brandenburg, with the water-vapor Raman lidar system *RAMSES* (Raman lidar for atmospheric moisture sensing) in order to qualify as a special observational site of highest level for long-term monitoring of tropospheric water vapor. In addition to its tasks within the DWD (model validation in particular), the upgrade is strongly connected to the Global Water Vapor Project (GVaP) of the World Meteorological Organization Global Energy and Water Cycle Experiment (WMO-GEWEX) [1], and to the European Satellite Climatology Project (CM-SAF) [2] for which it is planned to serve as a ground reference site to assist the optimization of retrieval algorithms for spaceborne instruments as well as to validate the satellite observations in general. Because all objectives are long-term activities and require a continuous operation of the lidar, *RAMSES* was specifically designed for unattended and dependable operation. During the current test phase, *RAMSES* is restricted to nighttime measurements. Following this test phase, *RAMSES* will be upgraded to water-vapor measurements during daytime and to temperature measurements using the rotational Raman technique. *RAMSES* is one of the few operational lidar systems worldwide (such as the Cloud and Radiation Testbed (CART) Raman lidar *CARL* [3] at the Atmospheric Radiation Measurement Program's Southern Great Plains site in Oklahoma, USA). The LAUNCH-2005 campaign (Lindenberg campaign for the assessment of humidity and cloud profiling systems and its impact on high-resolution modeling) at Lindenberg in the late summer of 2005 allowed of a first scientific deployment as well as an extensive investigation of the data quality and system stability of *RAMSES*. After a description of the instrument, a measurement example of this campaign is presented.

2. TECHNICAL DESIGN

The German Meteorological Service commissioned the German technology company Kayser-Threde, Munich, to build *RAMSES* in 2004, following the preparation of a system design concept. All *RAMSES* subsystems are housed in a standard air-conditioned 20-foot container (Fig. 1). The external chillers and heat exchangers for air conditioning and laser cooling are installed in a shed attached to the container. The container's interior is divided into a temperature-stabilized instrument cabin and a room for the operators. In the instrument cabin, the optical bench with the laser and the transmitter optics, the thermally insulated telescope hall, and the optical bench with the lidar receivers (section 3) are mounted on a single,

Fig. 1. The Raman lidar system *RAMSES* at the Richard Aßmann Observatory of the `DWD` in Lindenberg, Germany.

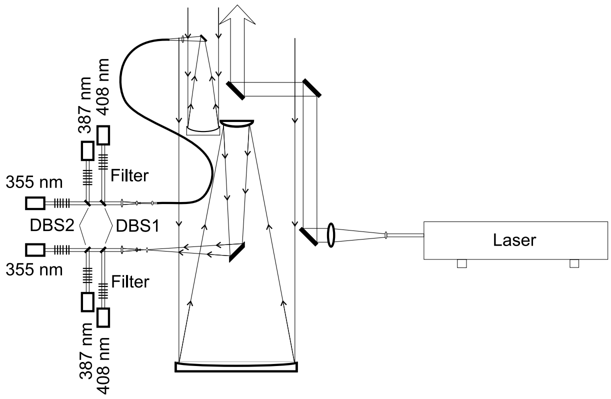

Fig. 2. Optical setup of *RAMSES*. DBS1, DBS2 — dichroic beamsplitters

solid three-leg structure to shield the measurement system from vibrations. The telescope hall is covered with an autonomously operating hatch which, independently of the system control computer (`SCC`), terminates lidar operation and seals the container in case the redundant environmental sensors signal precipitation or unacceptably high levels of sunlight. This approach ensures that the lidar is protected from adverse ambient conditions even if the computerized system control fails.

A prerequisite for the intended deployment of *RAMSES* in the German Meteorological Service operational network is an unattended operation and data evaluation. This goal is achieved by a cluster of three computers, the `SCC` which monitors and controls the lidar hardware; the measurement execution computer `MEC`, which performs the actual lidar measurement; and the data analysis computer `DAC`, which generates the measurement products and uploads the results to the data base of the observatory. `SCC` and `MEC` are located in the lidar container whereas the `DAC` resides in another building. The `DAC` logs up each raw data file transfer from the `MEC` to prevent file system inconsistencies. In case of a network or computer failure of either the `DAC` or the `MEC`, all raw data files not completely written via the local network can thus be identified and resubmission is initiated.

All data files have the network common data format `netCDF`. System control and data acquisition software are written in `LabVIEW`; the data evaluation employs `Delphi` (see section 4). A number of display windows with numerical and graphical information provide the user with a comprehensive overview of the lidar's status and operation, be it on a local computer or via the internet using virtual private network technology. The system status is monitored and recorded continuously in specific status files for further performance assessment. In the event of a major malfunction, *RAMSES* will alert technical staff via short message service.

3. OPTICAL SETUP

The optical setup of *RAMSES* is shown in Fig. 2. The source of radiation is an injection-seeded frequency-tripled Continuum 9030 Nd:YAG laser with a total pulse energy of up to 1.6 J. Only third-harmonic radiation at 354.7 nm is emitted into the atmosphere. The typical pulse energy at this wavelength chosen for operational conditions is 300 mJ. The pulse repetition rate is 30 Hz. The laser beam is expanded tenfold and directed onto the axis of the far-field telescope with three beam-folding mirrors.

The receiving optics is presently optimized for nighttime water-vapor measurements throughout the troposphere. *RAMSES* is operated with two receiver telescopes simultaneously. The far-field Cassegrain telescope with a main mirror diameter of 790 mm is preferably used for measurements above 1 km height. The receiver field of view can be chosen between 0.2 and 1 mrad. For measurements in the lower atmosphere a fiber-coupled Newton telescope with a mirror diameter of 200 mm and a fixed receiver field of view of 3 mrad is used. The near-field telescope is installed close to the secondary mirror of the far-field telescope. Its optical axis, which can be tilted against the laser beam, has a distance of 256 mm to the laser beam axis.

Two nearly identical receiver boxes for the far-field and the near-field channels are deployed. They are constructed such that identical optical path lengths for all channels are realized. After the beam collimation, dichroic beamsplitters and interference filters separate the elastically backscattered light at 354.7 nm and the vibrational-rotational Raman signals of water vapor at 407.5 nm and of nitrogen at 386.5 nm. Details of the filters and beamsplit-

Table 1: *RAMSES* beamsplitters and filters.

Receiver	near field			far field		
Channel wavelength	354.7 nm	386.5 nm	407.5 nm	354.7 nm	386.5 nm	407.5 nm
Dichroic beamsplitter 1, reflectivity	1.6%	0.7%	>99%	1.6%	0.7%	>99%
Dichroic beamsplitter 2, reflectivity	0.3%	>99%	–	0.3%	>99%	–
Interference filter bandwidth (FWHM)	1.95 nm	2.08 nm	1.78 nm	1.98 nm	2.08 nm	1.74 nm
Interference filter transmission	58%	78%	84%	60%	86%	88%

ters are given in Table 1. Motor-driven pre-calibrated neutral-density filters with different transmission can be inserted in front of the photomultiplier tubes (PMT). All optical signals are recorded with selected Hamamatsu R1924A PMTs with a diameter of the active area of 22 mm. Data acquisition is performed with Licel analog/photon-counting transient recorders.

4. OPERATIONAL DATA ANALYSIS

The analysis of the lidar signals is performed with the Automated Lidar Data Analyzer (*ALDA*) which is explained in detail in a separate contribution to these proceedings [4]. This software application is designed to derive water-vapor-to-dry-air mixing ratio and relative humidity autonomously from the six lidar signals during a measurement in real-time. Further products are backscatter ratio, particle backscatter coefficient, particle extinction coefficient, and particle lidar ratio. *ALDA* also carries out the quality control and provides the derived products to the operational weather forecast.

The calibration of the water-vapor measurement is usually done during the actual observation by comparison to routine radio soundings performed on-site (0, 6, 12, 18 UTC). The calibration constants of all measurements are stored in a relational data base so that in case there is no radiosonde available during a lidar observation, it may be calibrated with recent calibration constants.

Almost all parameters of the lidar data analysis can be optimized with *ALDA*'s comprehensive graphical user interface. The user can select the products to be derived. Integration times and smooth intervals can be specified individually for all products. They can be different for the two telescope ranges.

ALDA's view mode permits the visualization of any product in the form of profiles or time series plots. The user can change the plot style interactively. Header information and input parameters are listed for each displayed profile accordingly.

5. MEASUREMENT EXAMPLE

Fig. 3 shows the temporal development of the moisture profile from sunset to sunrise on 30–31 October 2005 as observed with *RAMSES* during the `LAUNCH-2005` campaign. Data analysis and visualization were performed with *ALDA*. Moist layers with relative humidities up to 85% were observed as high as 7.5 km. An interesting feature of the water-vapor profile is the dry layer at about 3.5 km which thinned from 300 m to only 50 m in thickness over the course of the measurement. Finally, Fig. 4 highlights the excellent agreement between *RAMSES* and the local radiosondes launched at 23:15 and 5:15 UTC of the

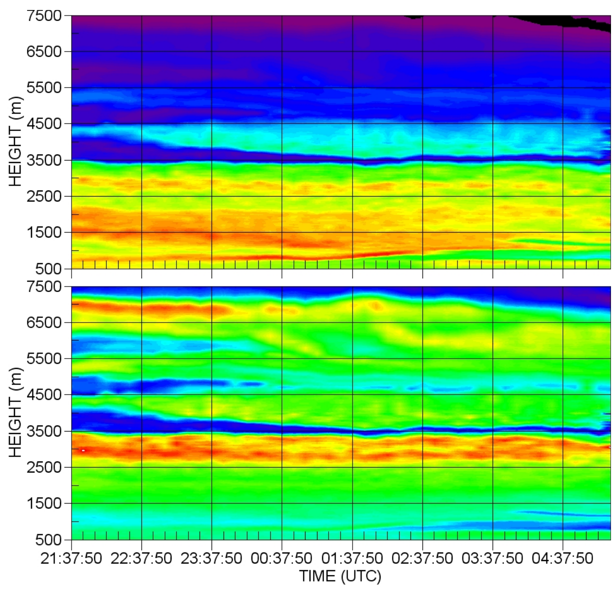

Fig. 3. Time series of mixing ratio (0 –6 g/kg, top) and relative humidity (0 – 85%, bottom) observed over Lindenberg, Germany, in the night of 30–31 October 2005. The time resolution is 10 minutes, the height resolution ranges from 67.5 m to 307.5 m.

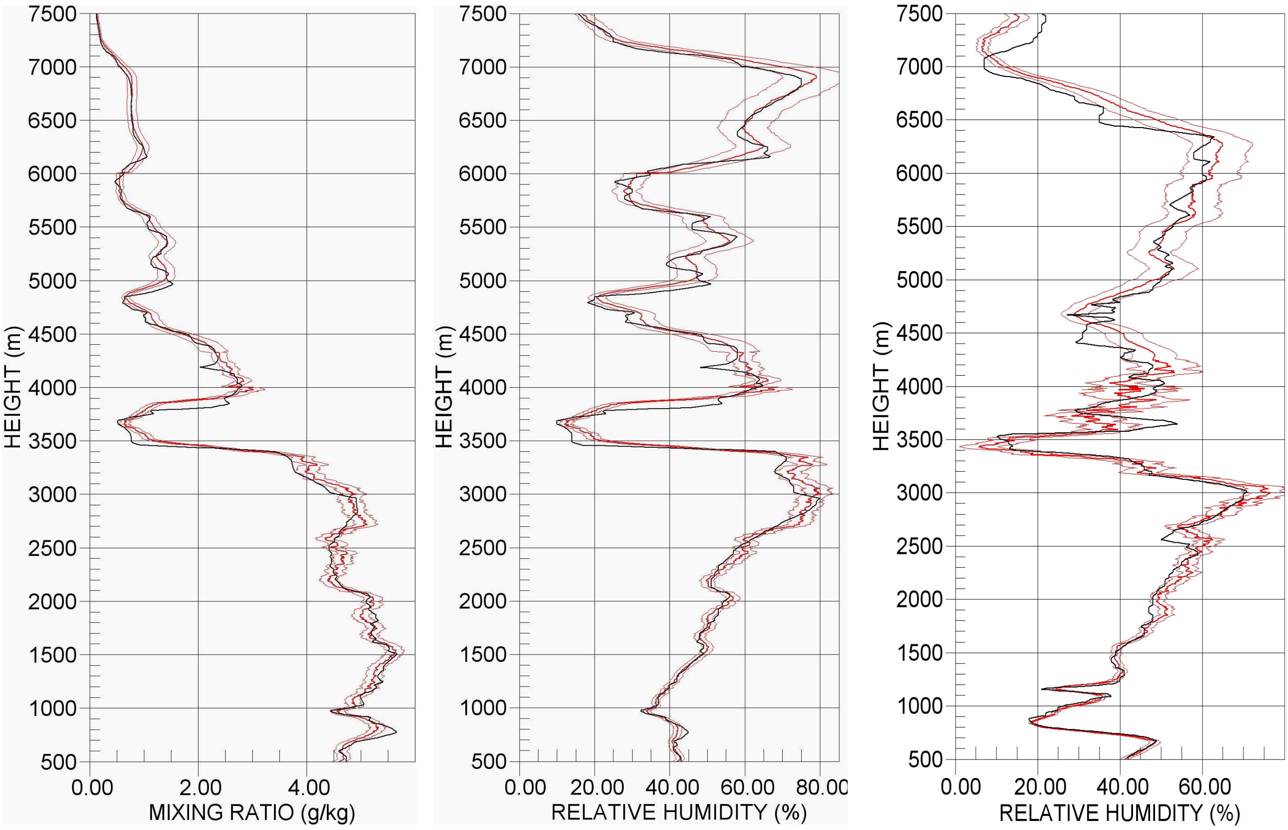

Fig. 4. Profiles of mixing ratio (left) and relative humidity (center, right), observed over Lindenberg, Germany, between 23:13 and 23:23 UTC on 30 October 2005 (left, center), and between 5:03 and 5:13 UTC on 31 October 2005 (right). Bold (red) lines correspond to the lidar profiles, thin (red) lines indicate the measurement uncertainties. Dotted (black) lines show the profiles from the 00 UTC radiosonde (left, center) and from the 06 UTC radiosonde (right). The height resolution is the same as in Fig. 3.

same night.

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