AUTOMATED LIDAR DATA ANALYZER (ALDA) FOR RAMSES – THE AUTONOMOUSLY OPERATING GERMAN METEOROLOGICAL SERVICE RAMAN LIDAR FOR ATMOSPHERIC MOISTURE SENSING

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ABSTRACT

The German Meteorological Service DWD is currently evaluating the new autonomously operating Raman lidar ***RAMSES*** [1] for routine profiling of the tropospheric water-vapor mixing ratio and relative humidity. Further products are backscatter ratio, particle extinction coefficient, particle backscatter coefficient, and lidar ratio. We describe the Automated Lidar Data analyzer (ALDA) for this system

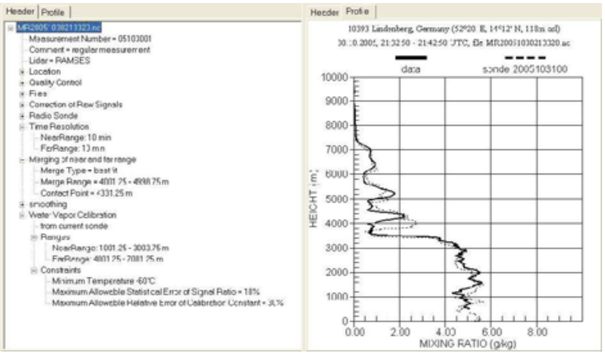
ALDA automatically analyzes lidar signals, performs quality control, and provides the derived product files to the operational weather forecast.

1. MODES OF OPERATION

ALDA provides three modes of operation.
The *online mode* is designed for the automatic analysis of lidar signals during an ongoing measurement and the visualization of the current products in realtime. There is also the possibility to analyze data of already finished measurements. In order to avoid inconsistencies it is not allowed to re-analyze a measurement as soon as results from this measurement have been provided to the operational weather forecast. All relevant data and information (raw signals, used parameters, protocol entries, and product files) are stored in a zip archive after the analysis of a measurement is finished.

The *view mode* allows visualization of any already existing lidar products in terms of profiles or time-series plots. The user can optimize, e.g., axis scaling, line style, fonts, or title of a plot interactively. As illustrated in Fig. 1, all plots are connected to hierarchical lists which display header information and input parameters of each single profile.

The *archive mode* is designed to manage the backup process of analyzed and archived measurements. If there are enough zip archive files to fill a backup medium (e.g. DVD) then the user receives an alert to perform a backup. Afterwards, original archive files are compared in terms of checksums to corresponding copies on the backup medium and deleted from hard disk automatically if the backup was successful. Archived measurements (data, used parameters, and corresponding protocol entries) can be reloaded from the backup medium if needed.



- MR20051030213320.nc
  - Measurement Number = 05103001
  - Comment = regular measurement
  - Lidar = RAMSES
  - Location
  - Quality Control
  - Files
  - Correction of Raw Signals
  - Radio Sonde
  - Time Resolution
    - NearRange: 10 min
    - FarRange: 10 min
  - Merging of near and far range
    - Merge Type = best fit
    - Merge Range = 4001.25 - 4998.75 m
    - Contact Point = 4331.25 m
  - smoothing
  - Water Vapor Calibration
    - from current sonde
    - Ranges
      - NearRange: 1001.25 - 3003.75 m
      - FarRange: 4001.25 - 7001.25 m
    - Constraints
      - Minimum Temperature -60°C
      - Maximum Allowable Statistical Error of Signal Ratio = 10%
      - Maximum Allowable Relative Error of Calibration Constant = 30%

Fig.1. ***ALDAs*** *view mode*: Profile plot and corresponding list with header information.

A *science mode* is in preparation and will allow for, e.g., interactive re-analysis of measurements with, e.g., individual quality control of raw signals and products. It has to be guaranteed that products from the *science mode* remain strictly separated from products which were derived with the *online mode* and which were already provided to the operational weather forecast.

Almost all parameters of the lidar data analysis can be optimized with ***ALDAs*** comprehensive graphical user interface. The user can select which products should be derived. Integration times and smoothing intervals can be specified individually for all products. They can be different for the signals from the near-range and far-range telescopes.

2. DATA ANALYSIS

RAMSES uses two telescopes to detect the elastically backscattered signal at 355.7 nm and the vibration-rotational Raman signals of nitrogen and water vapor at 386.5 and 407.5 nm, respectively. For each integration time interval (typically 30 sec) those six signals and corresponding header information of the actual measurement are stored in the netCDF file format [2]. The netCDF raw signal files are tranferred to the data analysis computer (DAC) where they can be analyzed by ***ALDA.***

The steps of data analysis are as follows:

1) read raw signals
2) quality control of the raw signals
3) corrections of the raw signals (range, background, dead time)
4) look for a new radiosonde
5) time averaging of raw signals
6) correction of atmospheric transmission
7) smoothing
8) calculation of products from near-range signals and far-range signals independently
9) merging of near-range and far-range products
10) final quality control
11) provide final products in netCDF file format
12) create a zip archive containing all relevant data and information

Steps 1 to 11 are repeated until an ongoing measurement is finished or until all raw signals of a finished measurement are processed.

2.1. Mixing ratio

The water-vapor-to-dry-air mixing ratio is calculated from the ratio of the water-vapor Raman signal to the nitrogen Raman signal. A calibration factor has to be applied to this signal ratio to derive the mixing ratio. Those calibration factors are determined independently for the signals from both telescopes with the method illustrated in Fig. 2 and described in [3].

If calibration factors are derived for both telescope ranges, either from an actual radiosonde or from previous measurements, they are applied to all signal ratios of the measurement period (typically one night).

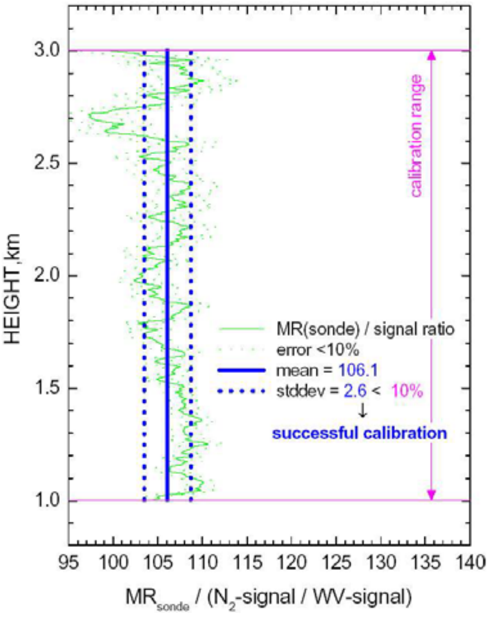


Fig.2. Near-range calibration factor: calculation and quality control.

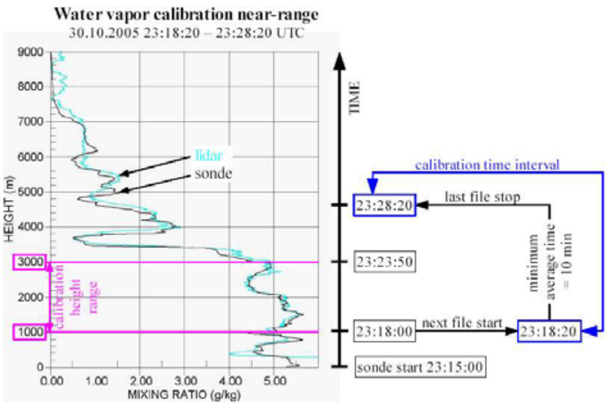


Fig.3. Determination of calibration time interval.

2.1.1. Calibration from radiosonde

The individual calibration factors can be derived during the actual measurement by comparing them to mixing-ratio profiles from the on-site operational radio soundings (00, 06, 12, 18 UTC). ***ALDA*** actively checks the internal Oracle database of the DWD whether there is a new sonde available. Then the calibration is performed with those lidar signals which were detected when the sonde flew through the user-defined calibration height range as illustrated in Fig. 3. Data points with signals in saturation or with too large statistical uncertainties (user-defined threshold) are exluded from the calibrations.

The individual calibration factors *cf* of both telescope ranges are converted into general lidar calibration constants *cc* with the relation

$$cc = cf\,\frac{\eta_{wv}}{\eta_{N_2}}\,. \qquad (1)$$

η_{WV} and η_{N_2} are the transmission values of the neutral-density filters of the water-vapor and nitrogen channels, respectively. After a final quality check, the calibration constants are stored in the DAC database.

2.1.2. Calibration from previous measurements

If there is no radiosonde available during the lidar observation the calibration factors are calculated from the stored calibration constants from the DAC database using Eq. 1 as illustrated in Fig. 4.

2.2. Relative humidity

The relative humidity is calculated from mixing-ratio profiles and a temperature profile. The temperature profiles from the radio soundings before and after the measurement are used to derive the actual temperature profile by means of temporal interpolation. The larger the time difference between the measurement and the sounding, the larger are the temperature errors and the

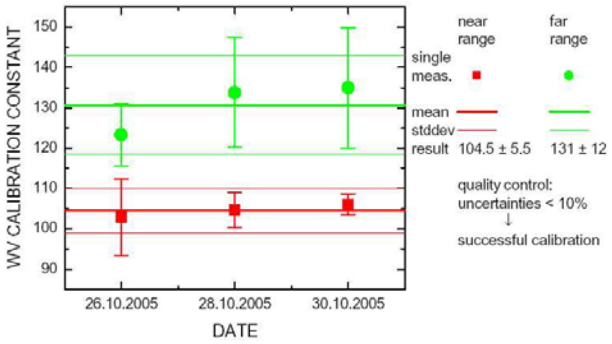


Fig.4. Calibration from previous measurements.

resulting uncertainties in relative humidity. Fig. 5 illustrates this behaviour.

2.2. Backscatter ratio

The backscatter ratio is calculated from the ratio of the elastically backscattered signal to the nitrogen Raman signal. A calibration factor is neccessary to derive the backscatter ratio.

In contrast to the mixing ratio, the backscatter profiles of both telescope ranges are not calibrated independently of each other. The calibration of the far-range profile is performed first. A height interval of user-defined width, e.g., 500 m, is shifted through the user-defined calibration height range (e.g., 3-12 km) to find the interval with the lowest mean signal ratio (see Fig. 6, left). The far-range calibration factor then is determined with the assumption that the mean backscatter ratio within this minimum interval is 1. Finally, the calibration factor for the near-range profile is determined such that both profiles fit within the merge range as described in Fig. 6, right.
Similar to the water-vapor calibration, general backscatter calibration constants are derived for both telescope ranges and stored in the DAC database. Backscatter calibration factors can also be derived from previous calibrations, if the calibration from the actual mesurement is not possible.

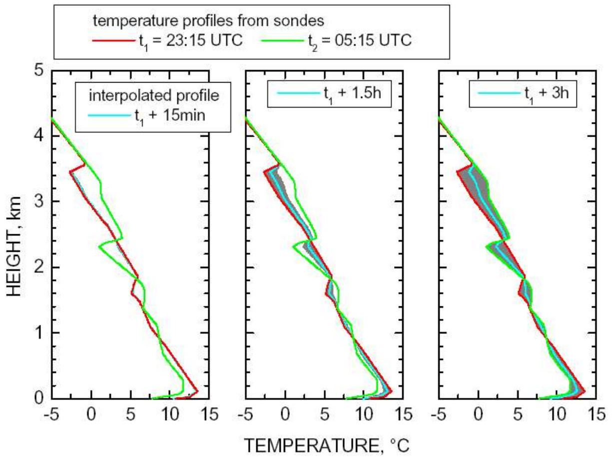


Fig.5. Temporal interpolation between temperature profiles of two sondes. Shaded areas denote uncertainty of the resulting temperature profile.

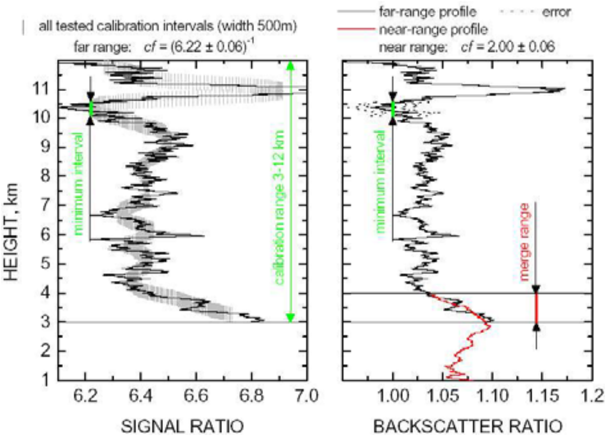


Fig.6. Backscatter-ratio calibration

2.3. Backscatter coefficient

The backscatter coefficient is calculated from backscatter-ratio profiles by subtracting Rayleigh backscatter profiles. Rayleigh backscatter profiles are derived from profiles of the air density which are calculated from temperature and pressure profiles from the on-site radio soundings.

2.4. Extinction coefficient

Extinction coefficients are calculated using the method described in [4]. The derivative of the nitrogen signal is determined with a linear fit method. It is possible to have up to five different smoothing lengths within an extinction profile. To avoid offsets at the transition

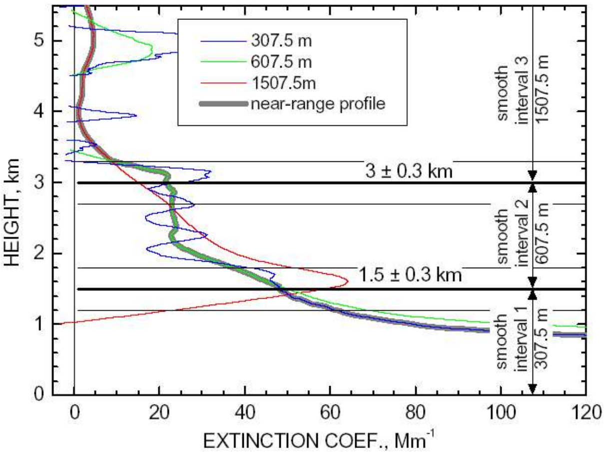


Fig.7. Three differently smoothed extinction profiles are merged within ± 300 m height intervals at the boundaries of the three smoothing intervals.

between two smoothing intervals, the whole extinction profile is calculated for each of the selected smoothing lengths. Fig. 7 illustrates how those differently smoothed extinction profiles are merged within a user-defined height interval at the boundary of the two smoothing intervals. This merging is performed to derive the best fit of the differently smoothed profiles.

2.5. Lidar ratio

Lidar-ratio profiles are derived as ratio of the corresponding extinction profile and the corresponding backscatter profile.

2.6. Merging of near-range and far-range profiles

The product profiles derived from the near-range signals and the product profiles from the far-range signals are merged to obtain a total profile from the ground to the tropopause as illustrated in Fig. 8. The user can define a merge range where typically both profiles are similar. Further, it can be selected which criterion is used to find automatically the 'best' contact point of the two profiles. Three criterions are available:

1) best fit between the profiles
2) select the profile with the lowest uncertainty
3) select the profile with the best height resolution

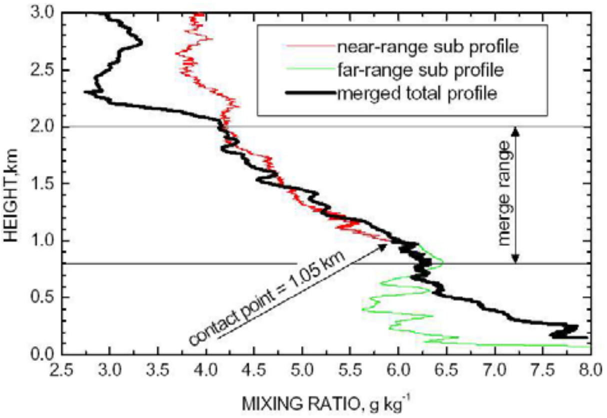


Fig.8. Merging of mixing-ratio profiles which were derived from near-range and far-range signals. The user-defined parameters are: range: 0.8 – 2 km; type: 'best fit'. The derived contact point is at 1.05 km.

3. TECHNICAL IMPLEMENTATION

ALDA was developed using Borland Delphi 7 professional [5]. ***ALDA*** is based on modern, robust, and reliable software development standards. ***ALDA*** is built ontop of an object-oriented multi-threading framework which handles memory management and prevents memory leaks. ***ALDA'***s object architecture is designed to guarantee realtime capability of dataflow, database persistence of configuration data and easy object-oriented access to the netCDF data file standard.

ALDA makes extensively use of the power of relational databases.

- All configuration data of ***ALDA*** are persistently stored in the database.
- All access to raw data files, intermediate files, and result files is kept consistently by registering of every file in the database.
- The DAC database journalizes the transfer of each netCDF raw data file from the measurement execution computer (MEC) to prevent file system inconsistencies. In case of a system crash of either the DAC or the MEC not completely written raw data files are identified by checking the database journal and are submitted again by the MEC.
- ***ALDA'***s source code does not depend on the type of the used database. We use the popular open-source database MySQL [6].

The displayed graphics of ***ALDA'****s view mode* are based on an interactive graphic component taken from the ProEssentials v5 package by Gigasoft Inc. [7].

4. REFERENCES

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