Performance Assessment and Application of Caeli — A high-performance Raman lidar for diurnal profiling of Water Vapour, Aerosols and Clouds

A. Apituley, K. M. Wilson, C. Potma, H. Volten[1] and M. de Graaf[2]

[1] *RIVM, P.O. Box 1, 3720BA Bilthoven, The Netherlands, Arnoud.Apituley@rivm.nl*
[2] *KNMI, P.O. Box 201, 3730AE De Bilt, The Netherlands*

ABSTRACT

Caeli is the CESAR Water Vapour, Aerosol and Cloud Lidar and is a multiwavelength, high-performance Raman lidar, capable of providing round-the-clock measurements. It is deployed at the Cabauw Experimental Site for Atmospheric Research (CESAR) in the Netherlands (51°58'N, 4°56'E). The instrument was developed as a key instrument for CESAR to strengthen the sites capabilities as a profiling station for atmospheric research and climate studies. Next to the lidar, other profiling techniques also routinely operated provide synergy in observations. Since the deployment at CESAR in May 2008, Caeli contributes to observation programmes and studies. The instrument is part of EARLINET, has provided data during the IMPACT and CINDI campaigns and provides correlative measurements for CALIPSO. Recently, the instrument was compared to its peers in the EARLINET Reference Lidar Intercomparison (EARLI09) in Leipzig. This paper describes the Caeli instrument configuration and shows examples of application of the data. Also, preliminary intercomparison results are shown from EARLI09.

1. INTRODUCTION

CESAR, the Cabauw Experimental Site for Atmospheric Research, is the Dutch focal point for collaboration on climate monitoring and atmospheric research and is situated on the KNMI meteorological research site near Cabauw in the Netherlands. CESAR addresses challenging topics in atmospheric research, especially the questions that are related to the interaction between clouds, aerosols and radiation and issues dealing with land-atmosphere interaction. These topics are approached via process studies, model evaluations, climate monitoring, development of new experimental techniques and supporting activities for satellite missions. For each of these approaches, specific demands are put on the instrumentation, mode of operation and overall infrastructure. The station fits in directly in a selected group of global monitoring networks that are currently operational or are being set-up to address the problems of climate change. Caeli[1] is part of the essential infrastructure for the CESAR observation programme aimed to provide detailed and relevant information on aerosols, clouds, radiation, turbulence and land surface fluxes for implementation in components of weather prediction, air quality and climate models [1].

Figure 1. Caeli in operation at CESAR during the CINDI campaign in June 2009.

2. INSTRUMENT DESCRIPTION

Caeli was set up as a high-performance, multiwavelength Raman lidar. The instrument provides backscatter and exctinction profiles, depolarisation and water vapour profiles. Data is collected, suitable for input to retrieval of aerosol micro-physical parameters based on so-called $3\beta+2\alpha$ schemes [2,3]. Tropospheric coverage is provided, including the PBL. Round-the-clock measurements are possible, implying daytime performance. The system is field deployed in a 20 ft. sea container for making it transportable. The setup requires external AC-power and an internet connection to operate. The instrument itself, including the electronics is mounted in a single rugged aluminium frame that can be wheeled in and out of the container in its entirety (Fig.2). Windows are mounted on top of the frame

[1] Latin: cælum (1) -i n. [the heavens , sky, air, climate]. Esp. [heaven] as the home of the gods; fig., [heaven] as the height of joy, renown, etc., (2) -i n. [the burin or engraving tool], (3) stellar constellation in the southern sky.

© 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 2. Caeli framework (3×1.2×2 m^3) before mounting to the container. The NFR (top) and FFR (bottom) receiver sections are normally closed, but now exposed for the picture. Electronics and computers are situated below the emitter optical table.

Table 1. Caeli main configuration parameters

EMITTER						
λ (nm)	1064		532			355
P (W)	12		5			10
DIV (mrad)	0.5		0.5			0.5
RECEIVERS						
FFR — 57 cm dia., F/3, 1.0 mrad FOV						
λ (nm)	1064	607	532	407	387	355
BW (nm)	1.0	0.3	1.0	0.3	0.3	1.0
T (%)	80	69	70	67	68	55
Block. (>)	10^{-4}	10^{-6}	10^{-4}	10^{-6}	10^{-6}	10^{-5}
Det.	APD	PMT	PMT	PMT	PMT	PMT
A/D	A	A/P	A/P	P	A/P	A/P
ND (typ.)	1.5	none	2.5	none	none	2.5
NFR — 15 cm dia., F/3, 1.4 mrad FOV						
λ (nm)	1064	607	532	407	387	355
BW (nm)	1.0	0.3	1.0	0.3	0.3	1.0
T (%)	80	69	70	67	68	55
Block. (>)	10^{-4}	10^{-6}	10^{-4}	10^{-6}	10^{-6}	10^{-5}
Det.	APD	PMT	PMT	PMT	PMT	PMT
A/D	A	A/P	A/P	P	A/P	A/P
ND (typ.)	2.0	none	2.5	none	none	2.5
POL —- 5 cm dia., F/3, Singlet, 5 mrad FOV						
BW (nm)			1.0			
T (%)			70			
Block. (>)			10^{-4}			
PBS			$\parallel$ / $\perp$			
Contr.			1 / 10^{-3}			
Det.			PMT / PMT			
A/D			A/P / A/P			
ND (typ.)			1.1			

above the receivers and in ports for the laser beams to weather-proof the system. Remote control of the system is foreseen. Various control and diagnostic features are added to the system for this purpose, including an active laser power optimisation system and an aircraft protection radar [4].

2.1. Emitter and Receivers

A high-power Nd:YAG laser is used with second and third harmonic generation providing the wavelengths needed for the $3\beta+2\alpha$ configuration. Each wavelength is emitted via a separate beam path to optimally control alignment. The UV power conversion is maximised to optimise for the weakest signal from water vapour in the upper troposphere (UT). The UT water vapour measurements also requires a large aperture receiving telescope (FFR). Since a large telescope is blind for lidar signals from close to the instrument, a second, small telescope is needed to cover the near PBL range (NFR). Since the NFR and FFR are both fibre coupled to their receiver boxes and can consequently only measure total polarisation, a separate refracting telescope measures depolarisation (POL) at $\parallel$ and $\perp$ polarisations. The receivers for NFR and FFR are implemented exactly the same so that no systematic differences occur between them. The light emanating from the fibres towards the detectors is collimated and distributed via optical long pass filters. Remaining out-of-band light is blocked by narrow-band interference filters.

To cover the lidar signal dynamic range, simultaneous 12-bit analogue and 250 MHz photon counting data acquisition is used, except for the 1064 nm signals that are detected using APD's in analogue mode, and the 407 nm water vapour channels that are always in the photon counting regime. This is also implemented symmetrically between NFR and FFR. The system main parameters are listed in Tab.1.

2.2. Measurement Strategy

For aerosol extinction measurements, a well-defined and stable overlap between outgoing laser beam and receiver FOV is mandatory [5]. Therefore, before measurement sessions, the overlap of the total of 6 optical axes of laser beams and telescopes is optimised by first scanning the laser beams automatically through the FFR-FOV over a grid pattern. The optimum position for the laser beams is found where the three elastic lidar signals maximise at 3 km altitude. Next, the laser beams remain fixed while the NFR mirror is automatically scanned $\parallel$ to its own focal plane; the mirror moving with respect to the field stop remaining fixed, sweeps the FOV. Signals are optimised at 1 km. The POL receiver's $\phi\theta$-mount is manually tilted when necessary. This procedure requires more or less stable and cloud free conditions over about 10-15 min. The thermal and mechanical stability for the current configuration of the system was found to be high enough to require alignment checks only once during a measurement session, even if the session last a whole day or more. Thermal stability of the laser is particularly important and is achieved by a closed-off compartment in the instrument frame that is quite insensitive to the cycling of the containers HVAC.

Automatic filter wheels with 5 attenuation settings are used for all 6 elastic channels to match the signals from the detectors to the digitiser input. Settings are changed with varying backscatter conditions. Data is recorded every 10 s., which allows capturing dynamical atmospheric and cloud processes, while cloud contaminated aerosol profiles can be discarded in case of broken (low) cloud cover.

2.3. Data Processing

Quicklook images of all measurement sessions ordered in about 2-hour blocks are made at full 10s×7.5m resolution based on background subtracted and range corrected signals (RCS) at 1064 nm from both NFR and FFR and the uncalibrated $\|/\perp$ signal ratio for the POL receiver. Since Raman lidar measurements require averaging over about 30 min. to obtain sufficient signal to noise ratio (SNR), the quicklook images provide important background information to assess the atmospheric conditions at hand. Usually, if data has to be discarded due to presence of low clouds a full profile can still be derived for all data products from scenes displayed in such a quicklook. Under nighttime conditions, water vapour is also displayed as an image at full resolution to reveal dynamic processes. Quicklooks are publicly accessible of the web at http://cerberus.rivm.nl/lidar/. Examples are shown in Fig.3

No automatic retrieval is available yet for Caeli data. Radiosonde data are used to verify signal linearity and determine the boundaries of valid signal regions. Retrieval of all quantities is done for NFR and FFR data separately. Backscatter calibration is done at the far end of the measurement. Depending on circumstances, e.g. presence of high clouds, a clear-air reference or neutral (white) cloud reference is chosen. The resulting retrieved profiles from NFR and FFR are merged into composite profiles. Interactive data processing is implemented in IDL and can be run directly on a server in the container over the internet via ssh and $X11$ before raw data transfer. Aerosol backscatter and extinction retrieval algorithms were checked within EARLINET-ASOS. NetCDF output is generated suitable for submission in the EARLINET and CESAR databases.

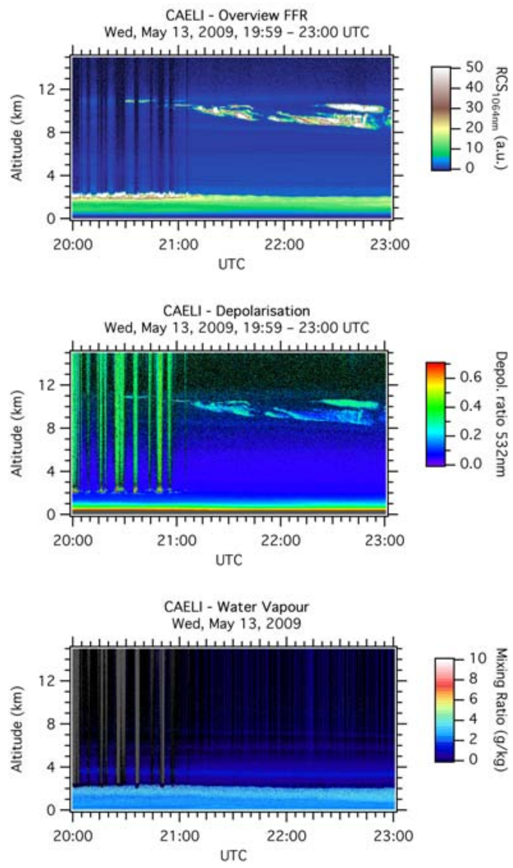

Figure 3. Quicklook imagery for FFR and POL receivers and a water vapour plot with merged data from NFR and FFR

3. PERFORMANCE

Instrument performance can be shown right at the instrumental level. A number of plots are presented in Fig.4 that show the RCS at selected wavelengths, normalised to a Rayleigh scattering background calculated using radiosonde data. Fig.4(a) shows the FRR signal from 1064 nm that shows good linear behaviour up to 15 km where some stratospheric aerosols (volcanic?) are visible. Fig.4(b) shows that the 387 nm Raman signal is valid throughout the troposphere during daytime. In Fig.4(c) and (d) the 607 nm signal is shown for daytime and nighttime respectively, revealing that daytime preformance is currently limited for 607 nm to the boundary layer, but at night the system has full tropospheric coverage. Somewhat better performance is obtained with the 407 nm water vapour Raman channels. For the NFR and FFR elastic channels not shown, the performance is better than shown here.

In May 2009 Caeli participated in the EARLINET [6] Reference Lidar Intercomparison (EARLI09) in Leipzig, where twelve lidars from the network were brought together. The overall picture form the preliminary results from this campaign confirm the performance expected from Caeli. What was also learned from the intercomparison is that an overlap correction [5] or a sharper overlapfunction is needed for measurements in the PBL.

4. DEPLOYMENT

Caeli is field deployed at Cabauw since May 2008. There it participated in the joint EUCAARI/EUSAAR IMPACT/LONGREX campaign [7]. The first diurnal cycles of measurements were taken during this campaign that focussed on the role of aerosols in the air quality-climate interactions and the standardisation of aerosol measurement techniques for application in so-called supersites. EARLINET measurements are done at a regular schedule. These data are put into the EARLINET and CESAR databases. In collaboration with other stations in this network a correlative observation programme is carried out for CALIPSO that can be regarded as the starting point of a unique long- term, global, 4-dimensional data set that will substantially improve our knowledge on the role of aerosols and clouds in the Earths climate system. Other experiments that Caeli was involved in are LUAMI for water vapour in Nov. 2008 [8] and the CINDI campaign in Jun.-Jul. 2009.

During the CINDI campaign, the main focus was on retrieval of NO_2 columns and profiles with the Max-DOAS technique. Explicit knowledge about the vertical profile of light scattering is needed to understand the retrieved NO_2 products. Data from the instrument is further used for testing new methods and algorithms [9].

5. CONCLUSIONS AND OUTLOOK

Caeli has been sucesfully field deployed in various experiemnts. The system performs well at all wavelengths and is providing quality controlled data for EARLINET, CESAR and contributes to other projects and campaigns that were conducted at CESAR. Valid aerosol extinction profiles currently start at about 1 km altitude. To improve this a slighly smaller telescope is planned to replace the current NFR. Adequate daytime performance has been achieved for all elastic channels and the 387 nm Raman channel over the full range. The 607 nm and 407 nm channels are currently limited to the boundary layer during daytime. In order to improve daytime performance, the receiver FOV needs to be reduced and the outgoing laser beams have to be expanded.

ACKNOWLEDGMENTS

Respective parts of this work were funded by EARLINET, ESA-CALIPSO, Climate Changes Environment and the Netherlands Space Research.

REFERENCES

[1] Russchenberg, H., et al., Ground-Based Atmospheric Remote Sensing in the Netherlands: European Outlook. IEICE Trans. Com. E88-B(6):2252-8, 2005.

[2] Müller, D., et al., Comprehensive particle characterization from three-wavelength Raman-lidar observations: case study. Appl. Opt. 40(27), 2001.

[3] Veselovskii, I., et al.,. Information content of multiwavelength lidar data with respect to microphysical particle properties derived from eigenvalue analysis. Appl. Opt. 44(25), 2005.

[4] Duck, T.J., et al., Aircraft-protection radar for use with atmospheric lidars. Appl. Opt. 44(23), 2005.

[5] Wandinger, U., Ansmann, A. Experimental determination of the lidar overlap profile with Raman lidar. Appl. Opt. 41(3), 2002.

[6] Pappalardo, G., et al., EARLINET for long term aerosol observations, Proc. 8th ISTP, Delft, 2009

[7] Friess, U. et al., Retrieval of Aerosol Proles using Multi Axis Differential Optical Absorption Spectroscopy (MAX-DOAS), Proc. 8th ISTP, Delft, 2009

[8] Wirth, M., et al., Intercomparison of Airborne Water Vapour DIAL Measurements with Ground Based Remote Sensing and Radiosondes within the Framework of LUAMI 2008 ,Proc. 8th ISTP, Delft, 2009

[9] Graaf, M. de, et al., Aerosol microphysical properties from inversion of tropospheric optical Raman lidar data, Proc. 8th ISTP, Delft, 2009

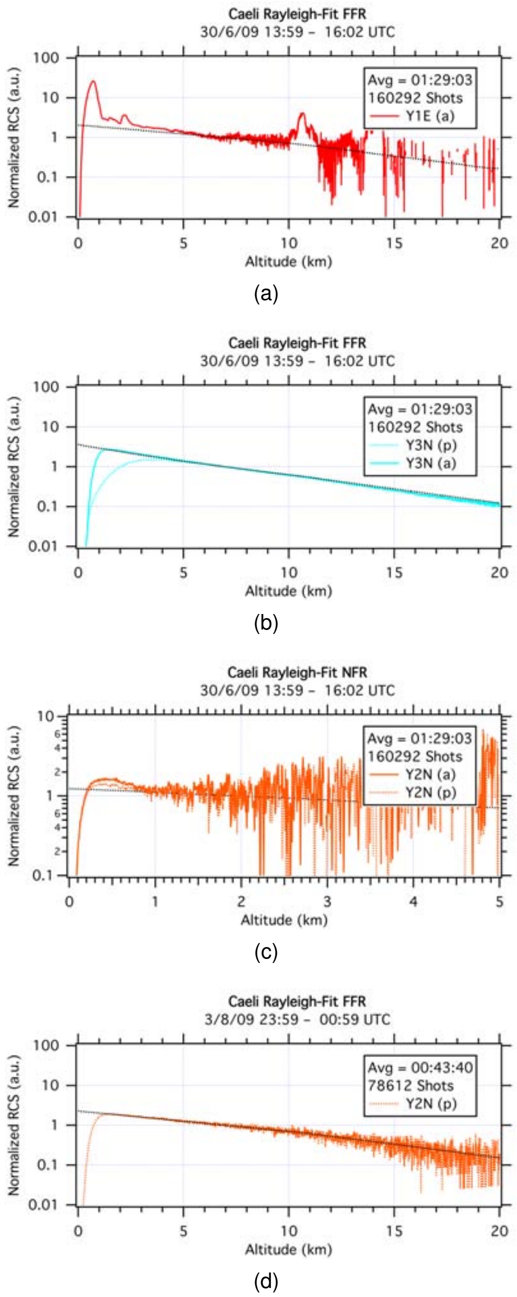

Figure 4. Rayleigh fits for daytime (a)-(c) and nighttime (d). Wavelenth indication is Y1E=1064 nm, Y3N=387 nm, Y2N=607 nm. Analogue (a) and photon counting (p) data are shown where applicable.