EPJ Web of Conferences **119**, 09003 (2016) DOI: 10.1051/epjconf/201611909003
*ILRC 27*

# Application of Cabauw lidar data for Campaigns, New Methodology Development and Satellite Validation Activities

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## ABSTRACT

Cabauw lidar data were used for the development of several new methods, as well as in the validation of new techniques based on other sensor data. The potential of the site that is equipped with a suite of in-situ and remote sensing equipment provides the possibility to develop new methods, and test them using independent observations.

Examples are shown for several recent campaigns conducted at the site, new methods developed using lidar data, and for satellite validation, including preparation for future missions.

## 1. INTRODUCTION

The Cesar Observatory in Cabauw [1], located in the western part of The Netherlands (51.971° N, 4.927° E) in a polder 0.7 m below mean sealevel. At the site a large set of instruments is operated to study the atmosphere and its interaction with the land surface. The site is currently equipped with a range of lidar systems (Fig. 1, Tab. 1). Caeli, the Cabauw Water Vapour, Aerosol and Cloud lidar, is a high-performance multi-wavelength Raman lidar and is part of EARLINET. It is one of the key instruments installed at the site. Also operated at the site are a UV-backscatter lidar with depolarisation and a ceilometer. The CHM15k was operated at the site for a test campaign.

**Table 1.** *Cabauw lidar sytems and capabilities. The right column 'Oper' indicates round-the-clock operation. Polarisation sensitivity is indicated by (δ).*

| | Wavelength (nm) | | | | | | | Oper |
|---|---|---|---|---|---|---|---|---|
| **Lidar** | 1064 | 904 | 607 | 532 | 407 | 387 | 355 | 24/7 |
| Caeli | ✔ | | ✔ | ✔ (δ) | ✔ | ✔ | ✔ | |
| UV-lidar | | | | | | | ✔ (δ) | ✔ |
| LD40 | | ✔ | | | | | | ✔ |
| CHM15k | ✔ | | | | | | | ✔ |

## 2. CAMPAIGNS

### *2.1 PEGASOS (2012)*

A campaign with the PEGASOS Zeppelin [2] in Cabauw was held in 2012 to quantify the magnitude of regional to global feedbacks between atmospheric chemistry and a changing climate and to reduce the corresponding uncertainty of the major ones. During the campaign in Cabauw, the lidar measurements were used to identify atmospheric layers, traced by the aerosol content, while in-situ trace gas measurements were carried out from the Zeppelin platform and balloon borne $NO_2$ sondes [3].

### *2.2 ACCEPT (2014)*

In the ACCEPT campaign – Analysis of the Composition of mixed-phase Clouds with Extended Polarization Techniques – a novel set of instruments to retrieve ice crystal microphysical properties in a large size range from micrometer to cm-scales was investigated. Co-located measurements

**Figure 1.** *Overview of the CESAR site in Cabauw, The Netherlands (left), Caeli (middle) and the UV-lidar (ALS450) with the CHM15k (right).*

DOI: 10.1051/epjconf/201611909003

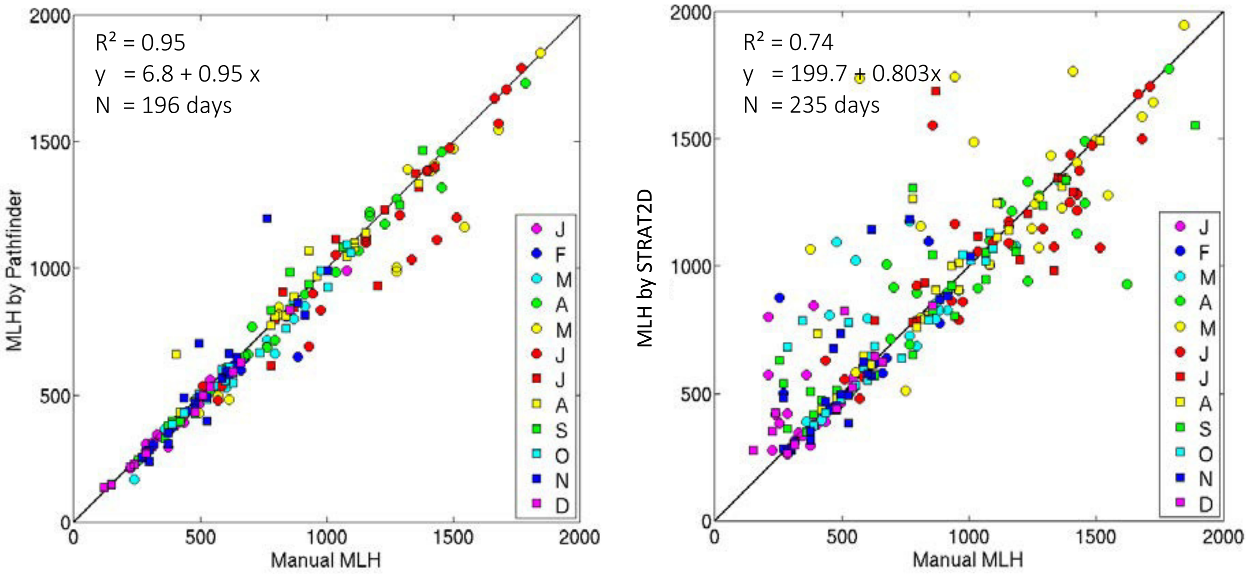


**Figure 2**. *Full year analysis of MLH retrievals at midday. (a) Pathfinder, (b) STRAT2D [8]. The reduced spread of the Pathfinder results indicates better consistency of the MLH retrieval over STRAT2D.*

of the off-zenith pointing polarization-lidar Polly-XT of TROPOS was exploited to detect layers of horizontally aligned planar crystals, causing specular reflections which affect only the signal measured with zenith-pointing Caeli [4].

*2.3 Ceilometer tests (2014)*

The Raman lidar Caeli as well as the UV-lidar and the LD40 acted as reference instruments in the selection procedure for a new ceilometer for the Dutch ceilometer network [5]. During the tests in November 2014 – January 2015, a wide range of conditions were observed from which the performance of the CHM15k under test could be verified against the requirements for the ceilometer network.

## 3. NEW METHODOLOGY DEVELOPMENT

*3.1 Volcanic Ash*

A new practical method for estimations of the mass load of volcanic ash based on UV-lidar depolarization lidar data was developed. The key point of this method is to estimate the extinction based on the measured aerosol (ash) depolarization ratio. The extinction can subsequently be used for mass estimations. The method was tested using the Raman lidar extinction data using observations from the Eyjafjallajökull eruption in 2010 [6].

Also, a method was introduced to derive integral properties of the aerosol size distribution, e.g., aerosol mass, from tropospheric multi-wavelength Raman lidar aerosol extinction and backscatter data, using an adapted form of the principal component analysis (PCA) technique. [7] Since the refractive index of general tropospheric aerosols is variable and aerosol types can vary within one profile, an inversion technique applied in the troposphere should account for varying aerosol refractive indices. Using PCA, provided a sufficiently complete set of appropriate refractive index dependent kernels is used, no a priori information about the aerosol type is necessary for the inversion of integral properties. This method was tested and applied to Caeli Raman lidar observations.

*3.2 Pathfinder Mixed Layer Height Tracking*

A new method for tracking the height of the mixed layer (MLH) using graph theory was developed. For independent verification, the collocated data from the wind profiler were used, as well as manually derived MLH. It was found that the new method outperformed other known methods for MLH tracking, especially in cases where other methods tend to jump back and forth between different layers [9] as shown in Fig.2.

*3.3 Aerosols from smartphone spectropolarimetric measurements*

A novel approach was developed actively involving the general public using their smartphones to form an atmospheric measurement network for aerosols at high spatial and temporal resolution.

This was established using iSPEX [10], a low-cost, mass-producible optical add-on for smartphones with a corresponding app. The aerosol optical thickness (AOT) maps derived from iSPEX measurements are in good agreement with the spatial AOT structure derived from satellite imagery and temporal AOT variations derived from ground-based precision photometry. Since relating the column integrated AOT measurements to (ground level) air quality is not straightforward, the Raman lidar measurements were used to separate the tropospheric AOT contribution from the total column.

## 4. SATELLITE VALIDATION ACTIVITIES

### *4.1 Aerosol Layer Height (ALH) from the $O_2$ A band*

The lidar data was used for testing a new technique to derive the aerosol layer height from passive satellite observations in the $O_2$ A-band, that can be applied in future operational earth observation platforms [11]. For a number of selected cases, Cabauw lidar data was used to assess the performance of the new ALH algorithm. The ALH algorithm will be implemented in the Sentinel-5 precursor processor suite [12]. Validation activities are planned for the Sentinel-5p/TROPOMI validation.

### *4.2 ESA ADM-Aeolus aerosol and cloud product and ESA EarthCare aerosol and cloud product validation*

Future work will include validation activities for the upcoming European satellite missions Aeolus [13], and EarthCare [14] using the lidars, radars and other profiling instruments at the Cabauw site as core instruments.

## 5. CONCLUSIONS

A range of examples has been given of the application of lidar data in campaigns in the recent past for atmospheric studies as well as new method development. Lidar data has also been used for validation of new satellite retrieval methods and will be used in the near future for the validation of new satellite instruments.

For a number of applications, the simultaneous availability of an advanced, operator controlled lidar running side by side with automated lidars has been very beneficial for method development and validation.

## ACKNOWLEDGEMENTS

This work was partially supported by the Netherlands Institute for Space Research, project number GO-2005/075, the ESA project AO/1-7017/11/NL/MP, and the financial support for EARLINET in the ACTRIS Research Infrastructure Project by the European Union under grant agreement n. 262254 in the 7th Framework Programme (FP7/2007-2013) is gratefully acknowledged.

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