Deep-Pathfinder: A Near-Real-Time Boundary Layer Height Detection Algorithm Based on Image Segmentation

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Abstract: The mixing layer height (MLH) indicates the change between vertical mixing of air near the surface and less turbulent air above. MLH is important for the dispersion of air pollutants and greenhouse gases and assessing the performance of numerical weather prediction systems. Existing lidar-based MLH detection algorithms typically do not use the full resolution of the ceilometer, require manual feature engineering, and often do not enforce temporal consistency of the MLH profile. Given the large-scale availability of lidar remote sensing data and the high temporal and spatial resolution at which it is recorded, this domain is very suitable for machine learning approaches such as deep learning. This paper introduces a completely new approach to estimate MLH: the Deep-Pathfinder algorithm, based on deep learning techniques for image segmentation. It is demonstrated that the algorithm can be applied in near-real-time.

1. Introduction

The concept of Deep-Pathfinder is to represent the 24-hour MLH profile as a mask (i.e., black indicating the mixing layer, white indicating the non-turbulent atmosphere above) and directly predict the mask from an image with backscatter lidar observations. Although the meteorological definition of the MLH is defined by a temperature gradient, the aerosol backscatter dominated lidar signal contains proxy information of the MLH.

Range-corrected backscatter lidar signal (RCS) data at 12-second temporal and 10-meter vertical resolution was obtained from Lufft CHM 15k ceilometers at five locations in the Netherlands (2020–2022). High-resolution annotations were created for 50 days, informed by a visual inspection of the RCS image, the manufacturer's layer detection algorithm, gradient fields, thermodynamic MLH estimates, and humidity profiles of the 213-meter mast at Cabauw.

2. Methodology

Our model is based on a customised U-Net architecture with MobileNetV2 encoder to ensure fast inference times (Fig. 1). A nighttime

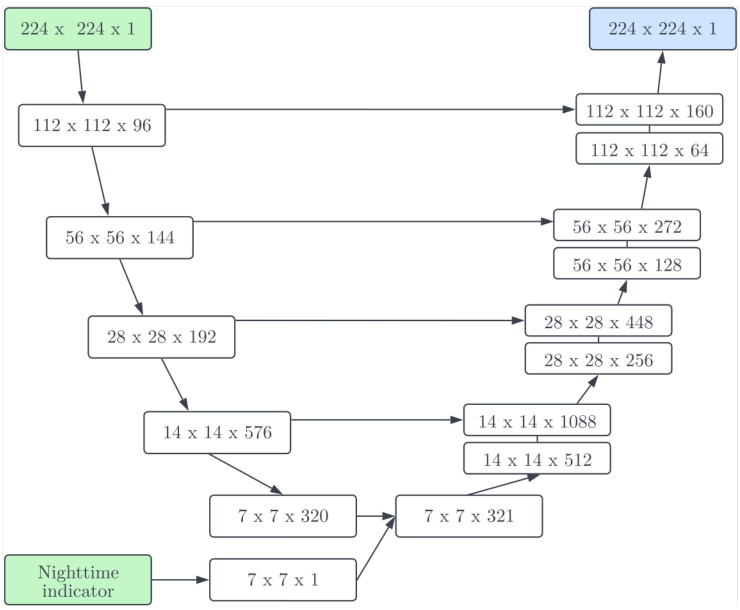

Figure 1. *Deep-Pathfinder neural network architecture with inputs (green) and output (blue), (from Wijnands et al.)*

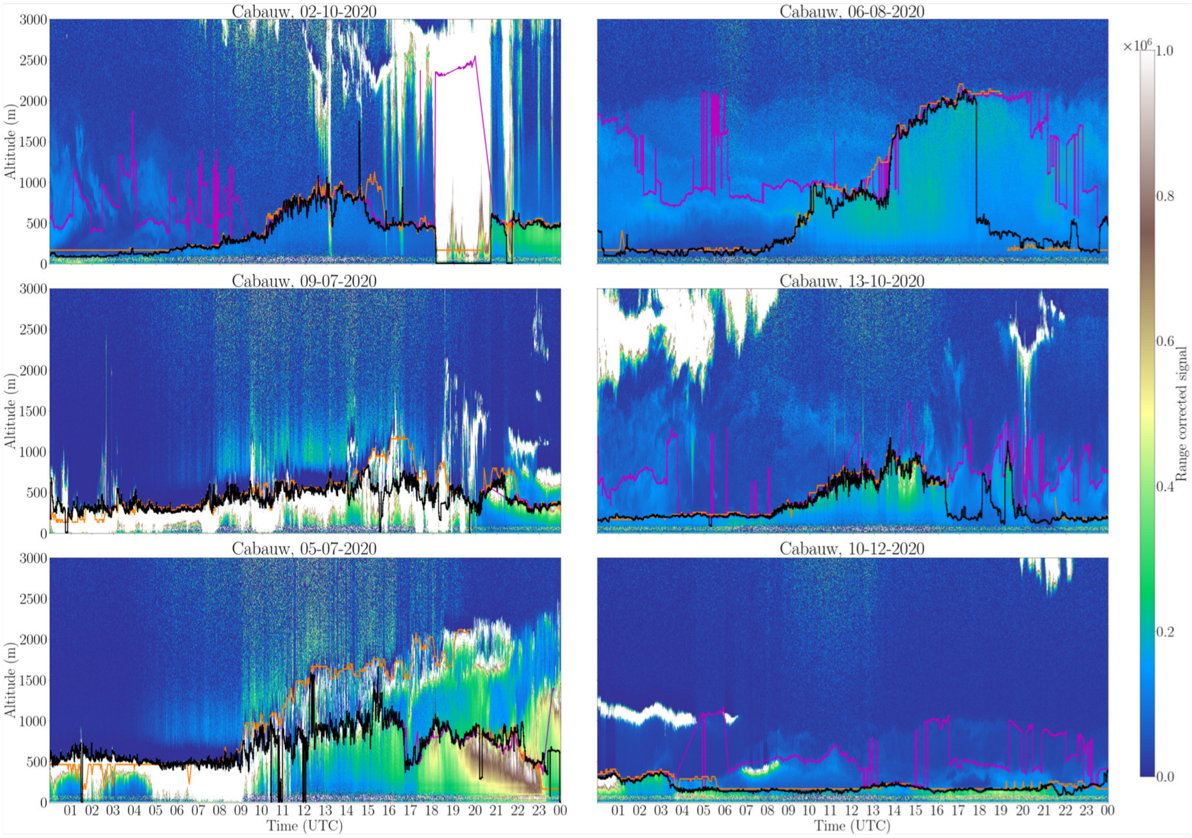

Figure 2. *Performance comparison of Deep-Pathfinder (black), STRATfinder (orange) and Lufft (purple) on selected days at Cabauw. (from Wijnands et al.).*

variable indicated whether the sample occurred between sunset and sunrise and hence, whether an estimate of the stable or convective boundary layer was required. Model calibration was performed on the Dutch National Supercomputer Snellius. First, input samples were randomly cropped to 224x224 pixels, covering a 45-minute period and maximum altitude of 2240 meters. Then, the model was pre-trained on 19.4 million samples of unlabelled data. Finally, the labelled data was used to fine-tune the model for the task of mask prediction. Performance on a test set was compared to MLH estimates from ceilometer manufacturer Lufft and the STRATfinder algorithm (Kotthaus, 2020).

3. Results

Results (Fig.2) showed that days with a clear convective boundary layer were captured well by all three methods, with minimal differences between them. The Lufft wavelet covariance transform algorithm contained a slight temporal shift in MLH estimates. Further, it had more missing data in complex atmospheric conditions. STRATfinder estimates for the nocturnal boundary layer were consistently low due to guiding restrictions in the algorithm. In contrast, Deep-Pathfinder followed short-term fluctuations in MLH more closely due to the use of high-resolution input data.

Wijnands et al., also show the performance of the algorithm in the presence of clouds. The final conclusion is, that our study shows that computer vision methods for image segmentation can be adapted to successfully track layers in data recorded by ceilometers.

4. Near-Real Time performance

As shown in previous studies, layer attribution can be improved by taking into account temporal consistency (de Bruine, 2017).

Although existing path optimisation algorithms have greatly improved the temporal consistency of MBLH estimates, they can only be evaluated after a full day of ceilometer data has been recorded. Deep-Pathfinder retains the advantages of temporal consistency by assessing MBLH evolution in 45 min samples. However, our algorithm can also produce near-real-time (NRT) estimates by using the most recent 45 min of data and extracting the current MBLH from the right-hand side of the output mask. The availability of NRT MBLH estimates from a large-scale ceilometer network could be used for the advancement of NWP models. Finally, it makes a deep learning approach as presented here valuable for operationalisation, as near-real-time MBLH detection better meets the requirements of operational users in aviation, weather forecasting, and air quality monitoring.

A NRT implementation has been realised for a single location (Cabauw) and is currently under evaluation, as well as experimental implementation for several other stations in the vicinity of the city of Rotterdam (NL) related to a field campaign.

Acknowledgements

This research has been supported by the Nederlandse Organisatie voor Wetenschappelijk Onderzoek (NWO) through computation resources on the Snellius high-performance computing system (grant no. EINF-3035) and through the Ruisdael Observatory for atmospheric science (grant no. 184.034.015).

5. References

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