EMS Annual Meeting: European Conference for Applied Meteorology and Climatology
9-13 September 2019 Copenhagen, Denmark

Statistical Analysis of Ceilometer Overlap Function

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Abstract: Automatic LIDARs and ceilometers (ALCs) are gaining in popularity in the atmospheric boundary layer and aerosols studies due to their low-cost and automatic unattended operation. However, incomplete overlap between the emitted laser pulses and the receiver field of view in biaxial ALCs significantly deteriorates their performance in the near range so the accurate knowledge of the overlapping function (OVL) is critical. Although theoretical determination of the overlap function is possible it requires reliable knowledge of all system parameters that are tough to be precisely determined in practice. Moreover, ALCs are exposed to the environmental factor as solar radiation and air temperature so the OVL can show temperature dependence due to the lack of temperature compensation in the external parts of the receiver optics. Therefore, individual experimental determination of the overlap function is not particularly useful in the real field measurements but the OVL should be routinely retrieved and the backscatter power should be continuously compensated for the inherent imperfection of the biaxial LIDAR systems. In this work, we utilize an experimental technique based on ceilometer measurements in optimal conditions (atmospheric boundary layer is well mixed and its height is in the complete overlap zone) in order to determine overlap function. Then temperature dependence of the OVL is statistically analyzed and modeled so the obtained regression model allows us to correct the ceilometer backscatter signal in non-optimal conditions. The presented approach has the potential to improve exploration of shallow atmospheric boundary and aerosol layers.

OVL determination:

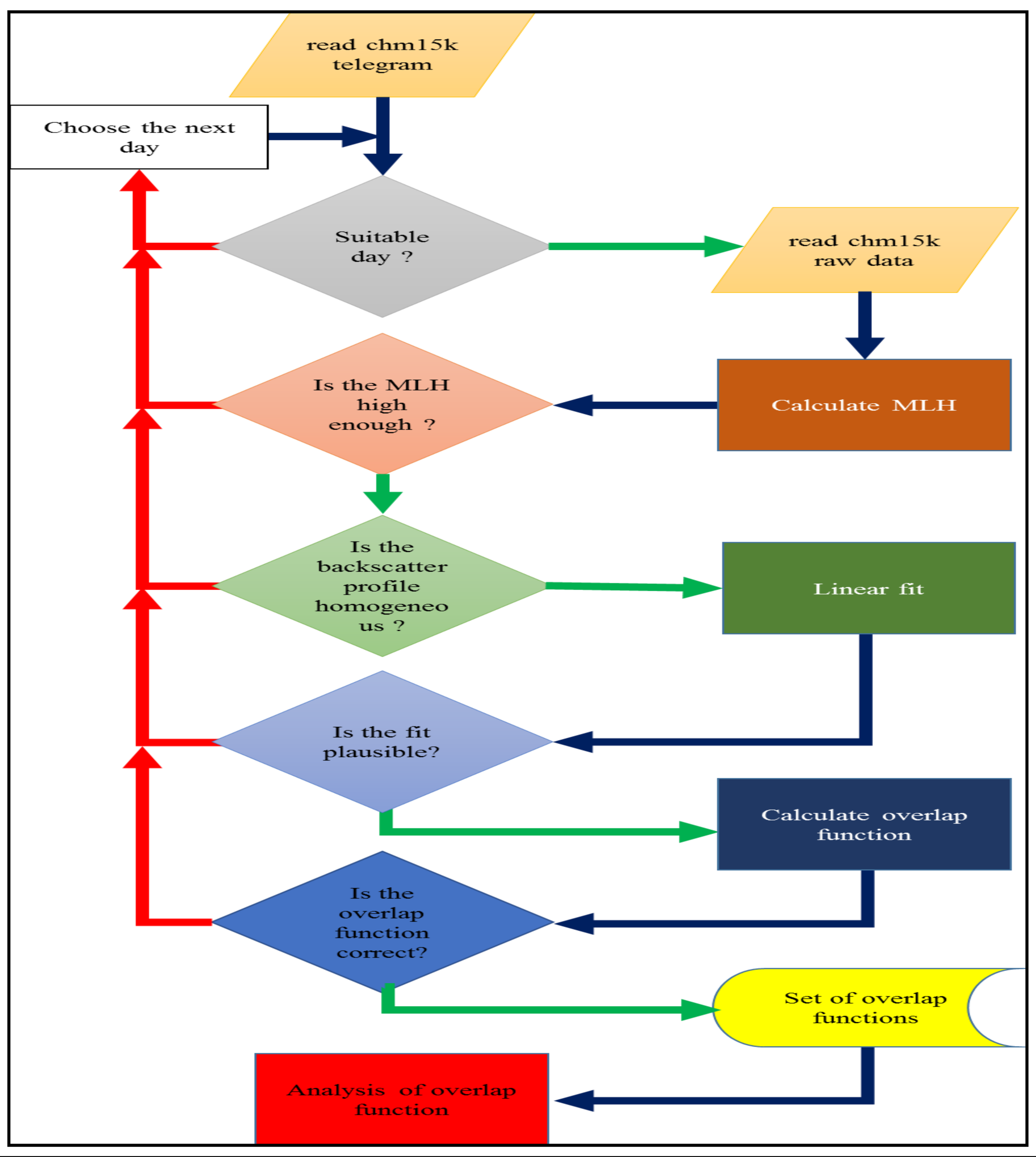
Suitable day: no precipitation neither low clouds (or 1st cloud layer base has to be higher than 4500m) from 16 to 17LT

MLH is high enough: 0.8 MLH > 1500 m.

Backscatter profile in the range 600—1350m is homogeneous: SD ($\ln(PR^2)$) < 0.06

Fit is plausible if the regression line slope is - 0.0005 < slope < 0

Overlap function is correct : whether max(OVL) < 1.01 in the range 600-1350m



Instruments and Data: Continuously operating CHM15k in the period 2011 – 2013 (the data are archived at the Sofia University).

Calculate MLH: all suitable profiles in the time interval are averaged and 1st derivative method is used to calculate MLH

Linear fit: ordinary least squares regression is used to perform the fit between 1350m and 0.8MLH

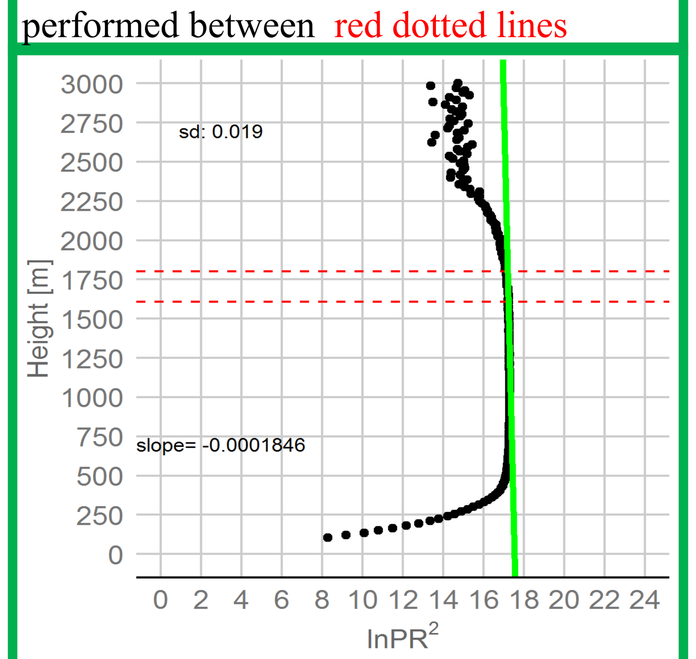
Overlap function: calculate OVL from 0 to 1500m as $OVL = \exp(\ln(PR^2) - LinearFit)$

OVL functions: OVL is smoothed through Friedmans's super smoother or local regression (loess)

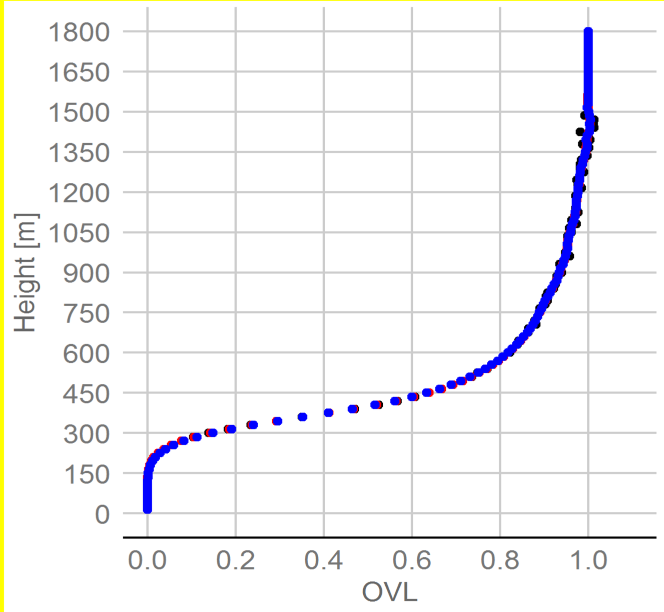
Results:

Ceilometer signal (left) and overlap function (right) on 24.03.2011

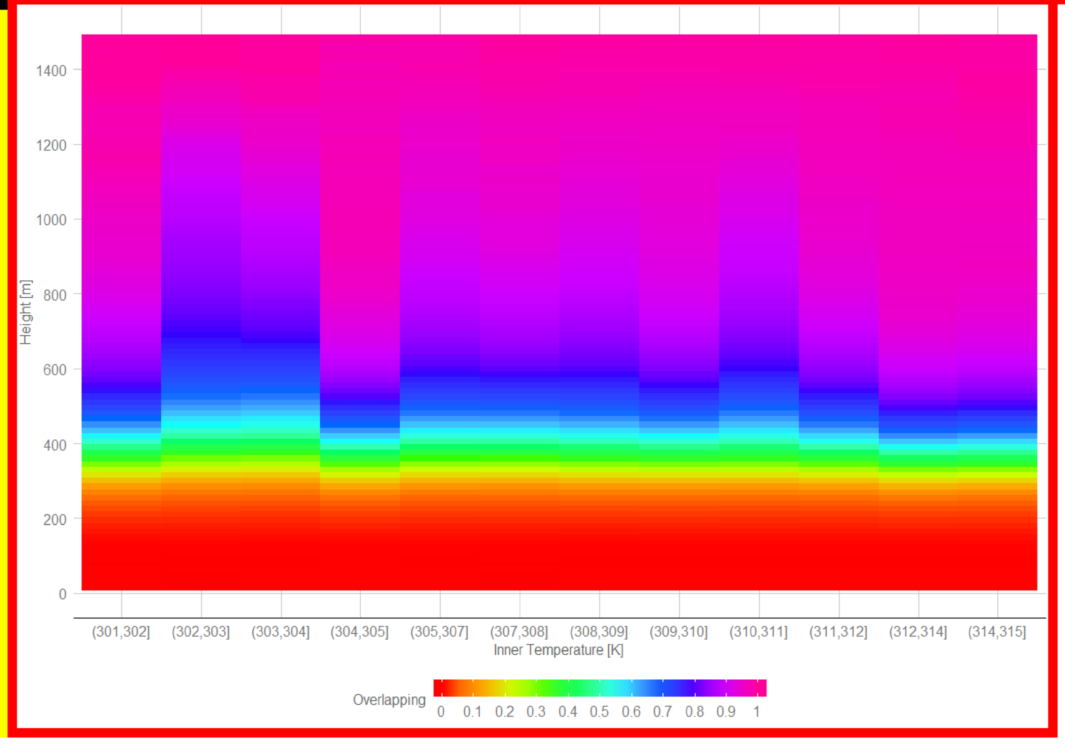
lnPR2 (black dots), linear fit (green line) is performed between red dotted lines

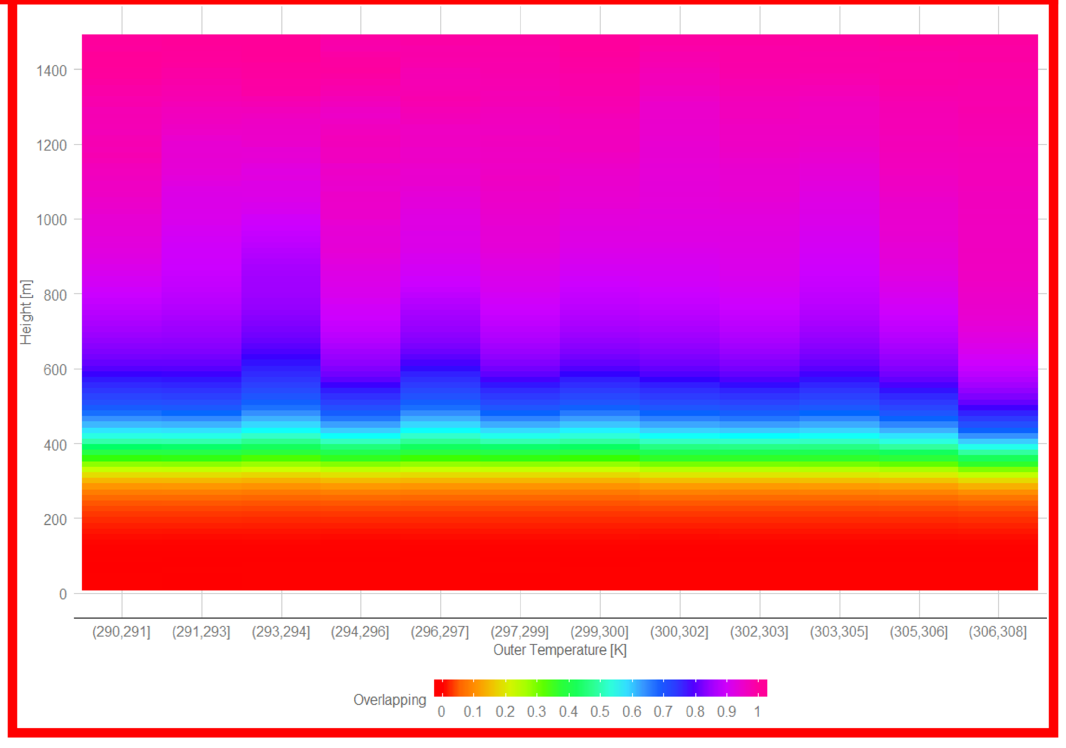


OVL (black dots), super smoother (blue) and loess (red)



OVL temperature dependence based on 72 days (left—inner Temp; right—outer Temp).





OVL statistical model:

Build a simple β-regression model (height is treated as a factor, ceilometer's inner and outer temperatures are the covariates):

mean model is: OVL ~ height + innerTemp + outerTemp

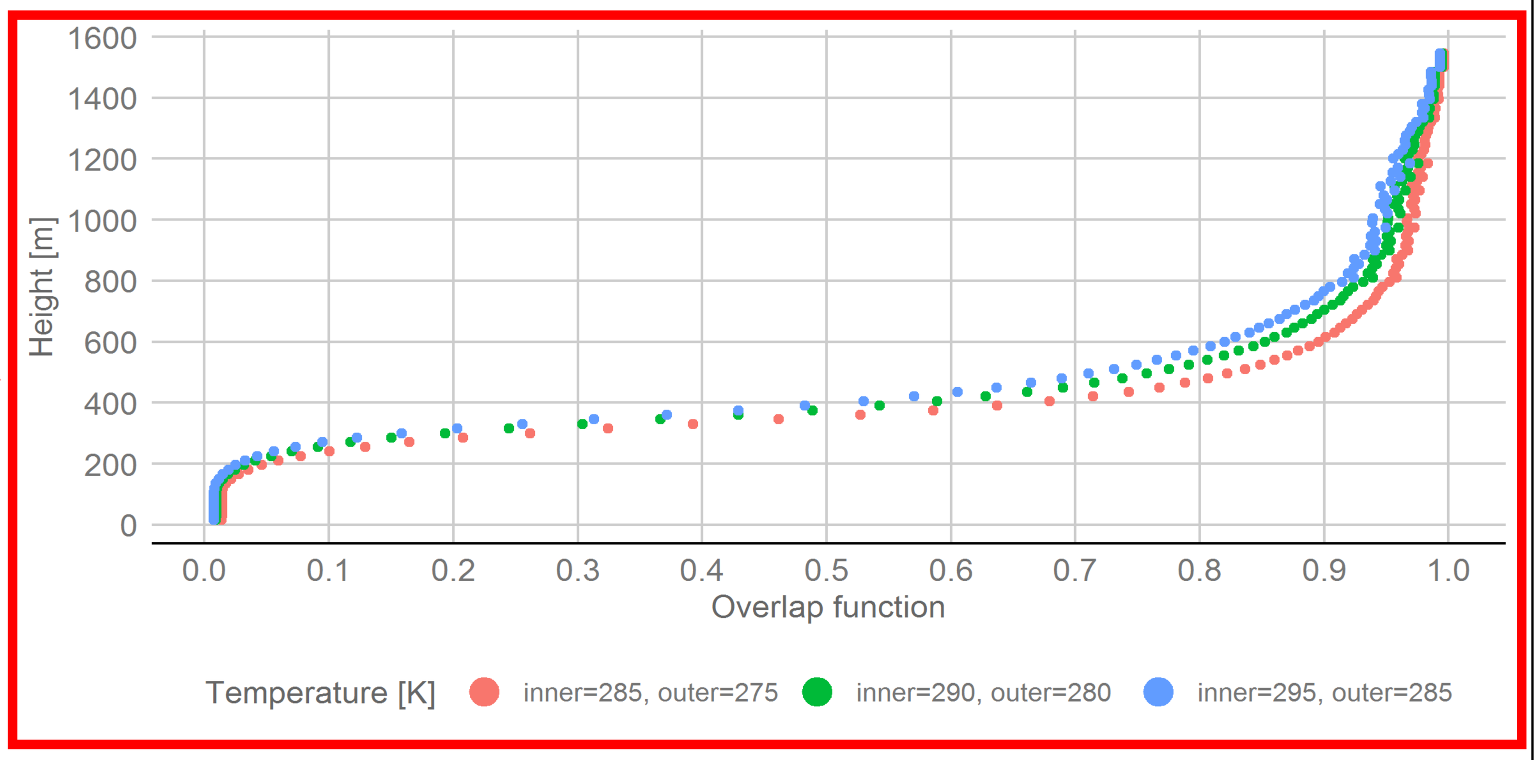
precision is constant. Model pseudo R^2: 0.89

Cross validation : training set—2011-2012, test set—2013

R^2=0.98; RMSE=0.056; MAE=0.035

Predict OVL in hypothetical conditions:

innerTemp=285K
outerTemp=275K
innerTemp=290K
outerTemp=280K
innerTemp=295K
outerTemp=285K



Conclusions: The incomplete overlap between the emitted laser pulses and the receiver field of view in biaxial ALCs significantly deteriorates their performance in the near range so the OVL should be known and taken into account before ALC data processing. Although analytical solutions of OVL exist their practical usefulness is doubtable, additionally ALCs are exposed to environmental factors so the OVL can show temperature dependency. In this work, we utilized an experimental approach that allowed us to determine OVL of continuously operated CHM15k during favorable conditions. Additionally, we built a simple statistical model that was cross-validated against test dataset. The model will allow us to correct near-range ceilometer signal when presented technique cannot be applied and thus it will allow us to explore of shallow atmospheric boundary and aerosol layers.

Acknowledgments: This study was funded by Sofia University grant 80-10-107 ("Biaxial Ceilometers Overlap Function") and The Bulgarian National Science Fund grant DN04/7 ("Study of the Planetary boundary layer structure and dynamics over complex terrain and urban area"). Part of the work has been carried out in the framework of the National Science Program "Environmental Protection and Reduction of Risks of Adverse Events and Natural Disasters", approved by the Resolution of the Council of Ministers № 577/17.08.2018 and supported by the Ministry of Education and Science (MES) of Bulgaria (Agreement № D01-230/06.12.2018).