Supplement

S.1 CABAM deep convection module

During spring and summer, peak MLH values frequently exceed 2000-2500 m at Palaiseau. Despite corrections and smoothing being applied to optimise the SNR (Sect. 2), uncertainty in the attenuated backscatter collected with the low-SNR ALC can be considerable at such distances from the sensor. Strong instrument-related background of this particular CL31 [24] may play a role. The noise can introduce vertical gradients in the attenuated backscatter that are occasionally falsely considered to mark boundaries between real atmospheric layers. At Palaiseau, noise-related layers are frequently detected within the mixed layer, causing the original CABAM algorithm [17] to systematically underestimate MLH during deep convective situations (not shown). To improve performance of the algorithm at Palaiseau, a new module detects and discards layers falsely created by instrument-related noise.

This *deep convection module* is applied when the average attenuated backscatter above a specified height exceeds a user set threshold and a high number of layer candidates are detected within a 24 h period. Any layers between solar noon and mid-afternoon ((noon + sunset)*0.5) that occur below the set threshold are discarded. This module is applied within CABAM algorithm just prior to the layer tracking.

S.2 Supplementary Figures

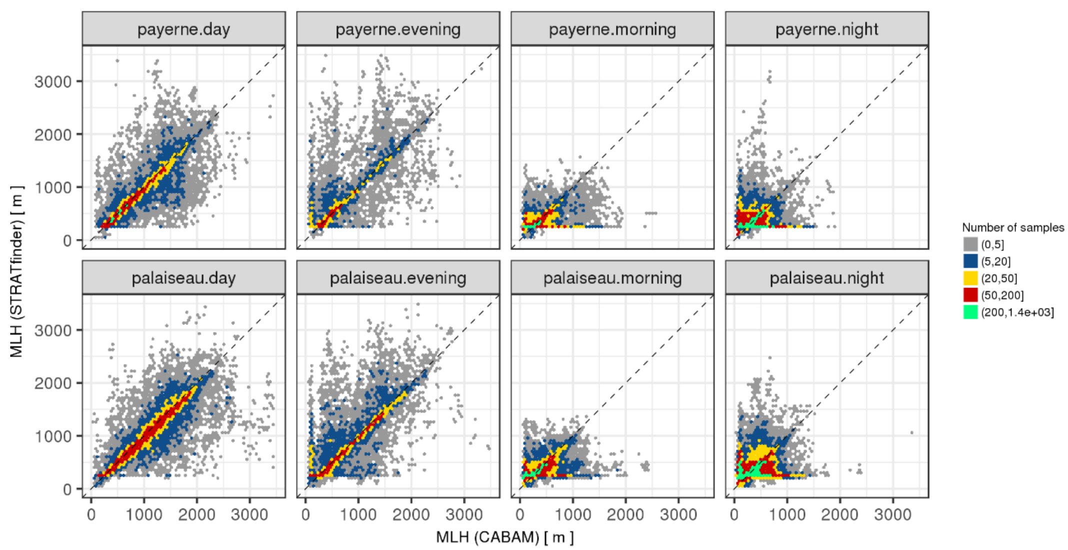

Figure S.1. MLH derived from high-SNR ALC observations using STRATfinder cf. low-SNR ALC using CABAM at (row 1) Payerne and (row 2) Palaiseau during (columns) the day (sunrise + 4h until sunset – 2h), evening (sunset ± 2h), morning (sunrise until sunrise + 4h), and night (sunset + 2h until sunrise).

S.3 Application to other ALC models

S3.1 Application of STRATfinder to Lufft CHM8k

The Lufft CHM8k uses a laser diode (Table 1) similar to the Vaisala sensors. The sensor reaches full (50%) optical overlap at 600 m (~230 m). As the CHM8k is a relatively new design, long-term measurements have not yet occurred. One of the first CHM8k in operation is located in Munich, Germany, at an urban site of the Meteorological Institute (48° 8′ 53″ N, 11° 34′ 23″ E) of Ludwig-Maximilians-Universität (LMU). Simultaneous CHM15kx measurements [46] are available for ~3 months (26/02/2019-02/06/2019). STRATfinder is applied to both sensors with the same settings as used at the other sites (Appendix A), except for the threshold to identify predominant molecular backscatter (3.6 a.u. (CHM15kx) and 3.0 a.u. (CHM8k) at LMU). This is necessary as the attenuated backscatter has not been absolutely calibrated prior to running the algorithm. No changes to the algorithm are required when supplying input data from the CHM8k.

Given the frequent complex clouds and rain during the short measurement period at LMU, low MLH data availability does not allow meaningful statistics. However, it can be concluded from analysis of case study days for different ABL conditions that STRATfinder CHM8k MLH is very similar to the CHM15kx observations (**Figure S.2**, **Figure S.3**). Differences in detected ABLH highlight the importance of the molecular scattering threshold on the search region for the ABLH. As this in turn restricts the daytime maximum search region for the MLH, it is critical for the attenuated backscatter analysed across an ALC network to be absolutely calibrated in near real time so one consistent value can be applied.

While STRATfinder MLH from the two sensors is in very good agreement most of the time, results from the CHM8k clearly overestimate MLH in the afternoon of the 17th May (**Figure S.3**). On this day, the ABL at the LMU site is particularly complex with an elevated aerosol layer persisting above the MLH and clouds forming around 3000 m agl in the afternoon. In this case, the CHM8k attenuated backscatter makes detecting the layer boundary at the top of the mixed layer difficult, whereas it is clearly delineated from the CHM15kx observations. This causes a discrepancy in the STRATfinder results. A longer measurement period is needed to quantify the general capabilities of the CHM8k sensor for detecting the ABL heights, however, the easy applicability of the automatic STRATfinder algorithm is demonstrated based on this dataset.

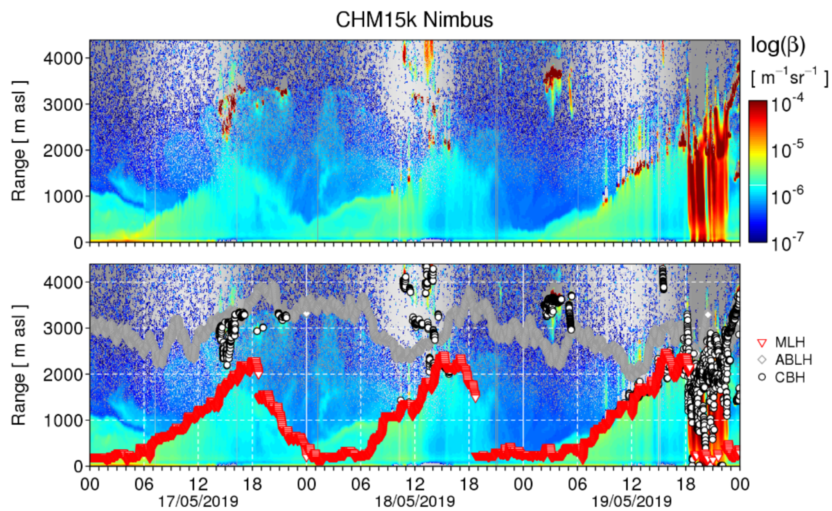

Figure S.2: Attenuated backscatter from the CHM15kx at the LMU site for the period 17-19 May 2019 with (lower panel) cloud base height (CBH) and STRATfinder MLH and ABLH.

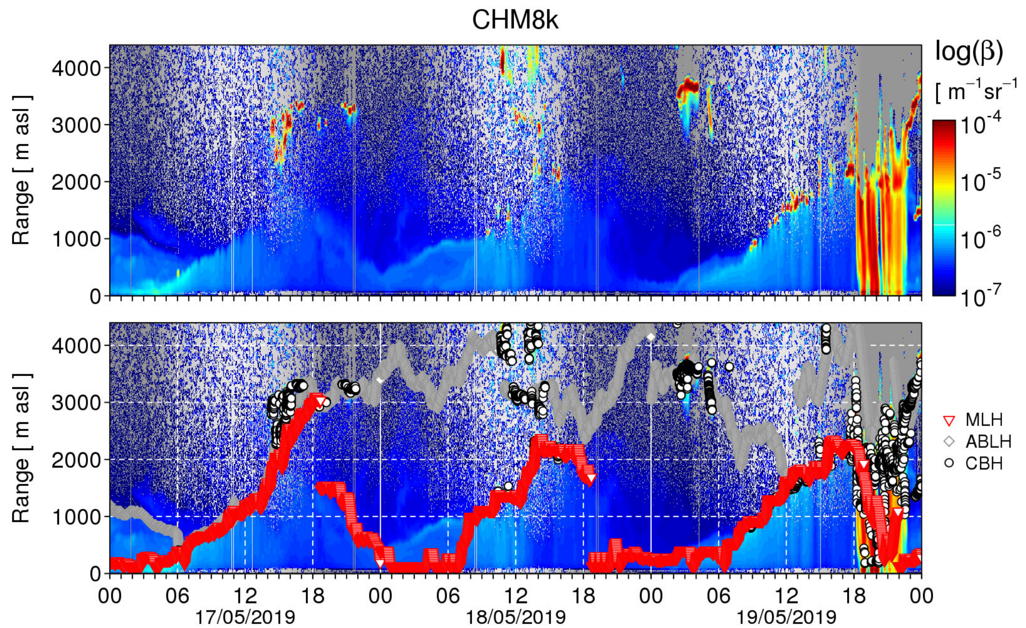

Figure S.3: As **Figure S.2** but for CHM8k.

S3.2 Applcation of CABAM to Vaisala CL51

The Vaisala CL51 is similar to the CL31 model (Table 1) but covers a greater range (up to 15 km). Its optical overlap is complete at about 500 m but reaches 90% at ~200 m range. The manufacturer indicates (personal communication, Christoph Münkel, 2015) that the overlap is corrected internally by the ALC firmware.

At Palaiseau, a Vaisala CL51 was operated beside the other ALC sensors for ~19 months (20/06/2017 – 27/01/2019). Like the CL31, attenuated backscatter is corrected for instrument-related background and near range effects (Sect. 2). The CABAM algorithm application to these data used mostly the same settings as for the CL31 (Appendix A). However, the deep convection module is not activated given the higher SNR of the CL51 (cf. CL31) means noise is less likely to introduce artificial layers within the mixed layer (i.e. leading to false layer detection). No changes to the algorithm are required when changing to input from this other ALC.

After application of the quality control filter, data availability of MLH detected by CABAM from the Vaisala CL51 observations is very similar to the CL31 (**Table S. 1**). The CABAM MLH statistics for the two Vaisala ALC (cf. STRATfinder) show the CL51 has better performance: coefficients of determination are slightly higher and linear regression slopes a little closer to unity. Daytime CL51 has reduced MBE and RMSE and reduced scatter (**Figure S.4**). The higher SNR of the CL51 reduces uncertainty in MLH detection (cf. CL31) especially during deep convection. At night the CL51 generally retains the good CABAM performance as the capability of tracing shallow layers is similar to when using the CL31 (**Figure S. 5**). The better performance with CL51 input remains when only considering MLH > 300 m, i.e. avoiding times of shallow-layer uncertainty associated with the STRATfinder reference heights (Sect. 3.4).

Table S. 1: Comparison statistics for MLH determined at Palaiseau by STRATfinder applied to CHM15K data and CABAM applied to CL31 and CL51 observations for periods when results from all methods are available. Data are stratified by time of day: NT (night-time: sunset + 2h until sunrise), MO (morning: sunrise until sunrise + 4h), DT (daytime: sunrise + 4h until sunset -2h), and EV (evening: sunset -2h until sunset +2h). Statistics are: number of samples (N), mean bias error (MBE), mean absolute error (MAE), root mean square error (RMSE), hit rate (HR) with a threshold of 300 m, slope (a) and intercept (b) of linear relation, and coefficient of determination (R^2).

	CL31					CL51				
	All	NT	MO	DT	EV	All	NT	MO	DT	EV
N	28587	11798	5299	7146	4344	28686	11833	4925	7427	4501
MBE [m]	3	-12	3	81	-82	0	-8	19	43	-71
MAE [m]	190	177	157	188	270	155	143	131	144	228
RMSE [m]	319	271	246	336	460	269	234	217	260	393
HR[%]	80	80	84	82	71	84	86	87	86	74
a	1.08	1.75	2.13	1.12	0.92	1.02	1.12	1.77	1.04	0.94
b [m]	-49	-302	-436	-47	1	-16	-56	-275	0	-14
R^2	0.66	0.08	0.19	0.67	0.52	0.75	0.15	0.23	0.79	0.61

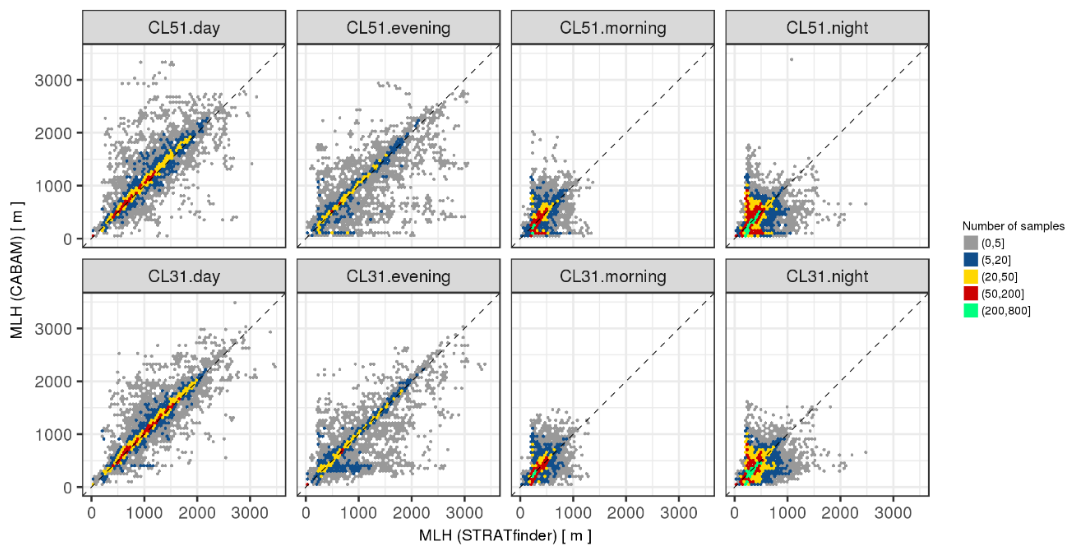

Figure S.4: MLH at Palaiseau derived using CABAM with two low-SNR ALC models: (row 1) CL51 and (row 2) CL31, compared to STRATfinder MLH with high-SNR ALC CHM15k measurements when all are available, stratified by time of day: (from sunrise + 4h until sunset – 2h), evening (sunset ± 2h), morning (sunrise until sunrise + 4h), and night (sunset + 2h until sunrise).

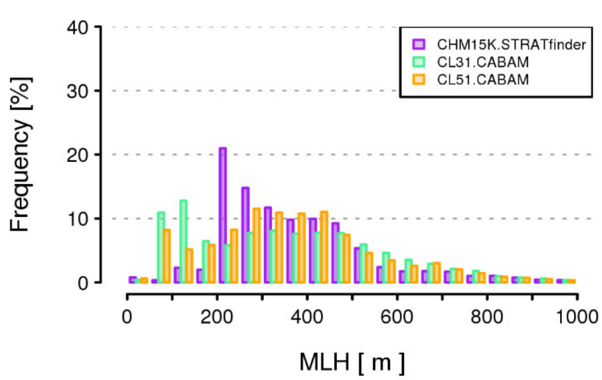

Figure S. 5: Night time (sunset + 2h until sunrise) frequency distribution of MLH up to 1000 m at Palaiseau obtained by STRATfinder from CHM15k, and CABAM from CL31 and CL51 observations when data from all three are available (N=9933).