PROBE Short-term scientific mission (STSM)

Virtual STSM: scientific report

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Project title (acronym)	Mixed-layer height in complex terrain: comparing observations (STRATfinder) and high-resolution simulations (WRF)

☒ I agree that this Virtual STSM application and final report are **made available online** on the PROBE COST action's webpage.

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Scientific report

1 ABSTRACT

The observation and modelling of the planetary boundary layer in complex terrain are one of the most debated topics inside the scientific community. In this STSM, we deal with the observation made by an Advanced LiDAR Ceilometer (ALC) installed at Aosta (Northwestern Alps, Italy) and the simulations done with a high-resolution implementation of the Weather Research and Forecasting (WRF) model. Three case studies are considered, spanning over different local and synoptic weather situations: local convection, advection of polluted air, and a persistent layer of aerosol over the Aosta Valley. The observations made with the ALC were elaborated with the STRATfinder code and compared with the WRF simulations. In particular, we focused on the Mixing-Layer Height (MLH) found by STRATfinder and computed with four different methods on the WRF outputs. The results show that the layer detection with STRATfinder in complex terrain is challenging, and a further improvement is needed to the code, while, on the four WRF computation methods, the Richardson number and the temperature-TKE method showed the best results.

2 INTRODUCTION

The STSM started a detailed assessment of automatic ABL height retrievals in the complex terrain setting of the Aosta Valley. Following research conducted in the area previously (Diémoz et al. 2019), the study had the objective to understand which ABL characteristics (sublayers) can be detected automatically by analysing ALC data (Lufft CHM15k) with the STRATfinder algorithm. To put algorithm performance and ALC profile observations at the single site into the 4-dimensonal ABL context at this complex location, high-resolution simulations with the WRF model were conducted. The work used the results of a recent MSc project (Golzio et al., 2021) which compared the performance of different turbulence schemes available in the WRF model (v4.1, Skamarock et al., 2019).

Given the complexity of the ABL in the Aosta valley, a limited number of case studies were selected to cover different conditions. The aim is to study both cases with surface-driven convection and those with a strong influence of advection. For the selected case study periods,

a) the STRATfinder algorithm will be applied to the ALC profile data of the Lufft CHM15k operated at by ARPA Valle d'Aosta at the Aosta E-PROFILE/Alicenet site to automatically derive the height of the mixed layer and the height of the atmospheric boundary layer (the residual layer at night).

b) Weather Research and Forecasting (WRF) model simulations will be conducted over the study area using the most effective set-up at 0.5 km and high-vertical resolution inside the PBL.

Finally, the ABL heights derived from observations were analysed for their ability to detect relevant ABL sublayers at the complex terrain location.

The three selected case studies are:

- January 2017: from 25th to 31st January, when a persistent layer of aerosol was detected over Aosta;
- May 2017: from 25th to 31st May, when an advected layer arrived on the Aosta site;
- July 2017: from 13th to 16th July, when local convection was measured over the Aosta Valley.

In this report, the most important results and an example (Figure 2) of the plots produced is shown, otherwise in the final presentation attached all the formulas and results are presented.

3 METHODS

3.1 Observations

The ALC data were treated with STRATfinder (Kotthaus et al. 2020), and the MLH is obtained at a 1-minute resolution. The backscattering is corrected with an overlap model explicitly built for the Aosta instrument. Considering the variance and the gradient of the corrected backscattering the STRATfinder code finds and follows the layers depicted by the ALC and gives as outputs the MLH, the ABLH and some other control flags, such as the presence of clouds (from the instrument diagnostics) and the presence of precipitations.

3.2 WRF

The version applied is 4.2.1 (Skamarock et al. 2019), and the set-up is described in the final presentation of the STSM (attached). The simulation is conducted on three two-way nested domains with the boundary condition given by the ERA5 reanalysis dataset. The inner domain has a 0.5-km of grid spacing and 62 vertical levels with 21 levels in the first 1000 m a.g.l. and the top at 5000 Pa. A high-resolution topography and land use are adopted following Golzio et al. 2021.

From WRF outputs, the MLH is retrieved and calculated following the PBL scheme adopted (Nakanishi & Niino, 2006, 2009; Olson et al., 2019; Mellor & Yamada, 1982) and other three methods: the Richardson number, the parcel method, and the humidity gradient method. The formulation details are showed in the final presentation of the STSM.

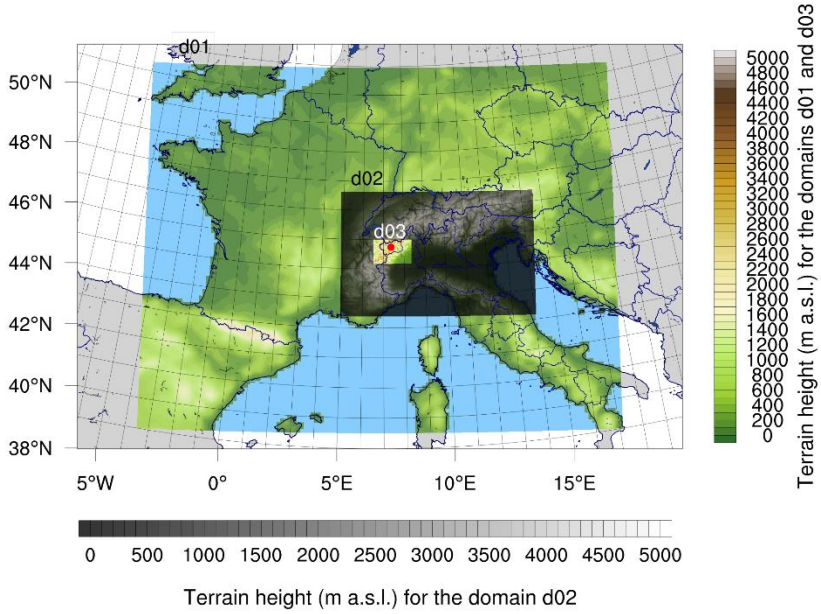

Figure 1 WRF domains with topography in colours (domains 1 and 3) and grey (domain 2). The red dot indicates the position of Aosta.

3.3 Comparison

Observations treated with STRATfinder were considered the reference, while the model outputs and computations were the tests. Simple statistics were elaborated considering the Root Mean Squared Error, Mean Absolute Error and BIAS.

4 RESULTS

The main results are summarised with the statistics in Table 1, while in Figure 2, a specific time (1230 UTC of 16th July 2017) is represented. In this case, the different methods agreed on the position of the MLH, except for the humidity gradient method that underestimates the MLH.

Table 1 The results of comparison between STRATfinder MLH (reference) and WRF MLH with four different methods. In bold are the best results. MLH statistics in metres.

Case	Variable	Richardson	Humidity	Parcel	MYNN2.5
January, 291 points	RMSE	849	1710	864	**776**
	BIAS	701	-631	719	**624**
	MAE	50	100	51	**45**
May, 284 points	RMSE	717	1264	808	**624**
	BIAS	358	-304	434	**238**
	MAE	43	75	48	**37**
July, 191 points	RMSE	**854**	1613	1097	987
	BIAS	140	-115	392	**78**
	MAE	**62**	116	79	71

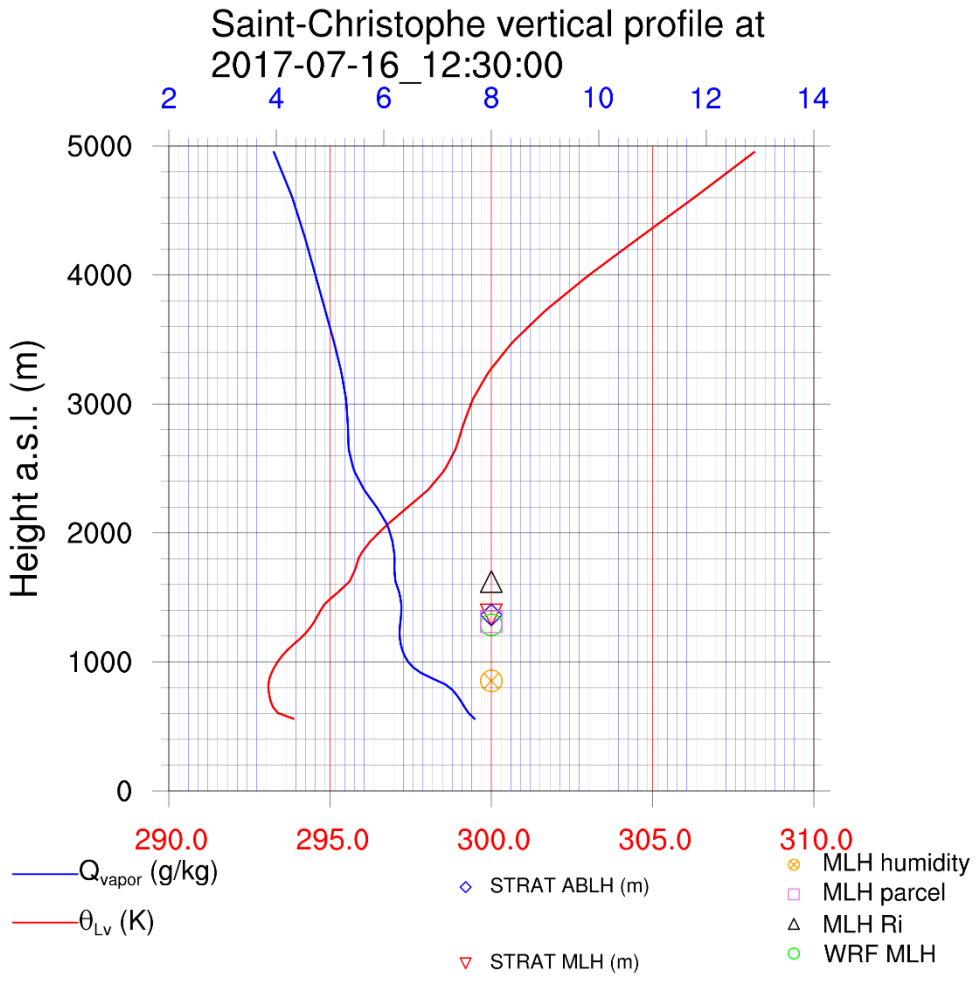

Figure 2 Vertical profile example of specific humidity (blue curve, top x-axis) and virtual potential temperature (red curve, bottom x-axis) over the Aosta St-Christophe ALC position, predicted by the WRF domain 3. Symbols indicate the MLH from the different methods.

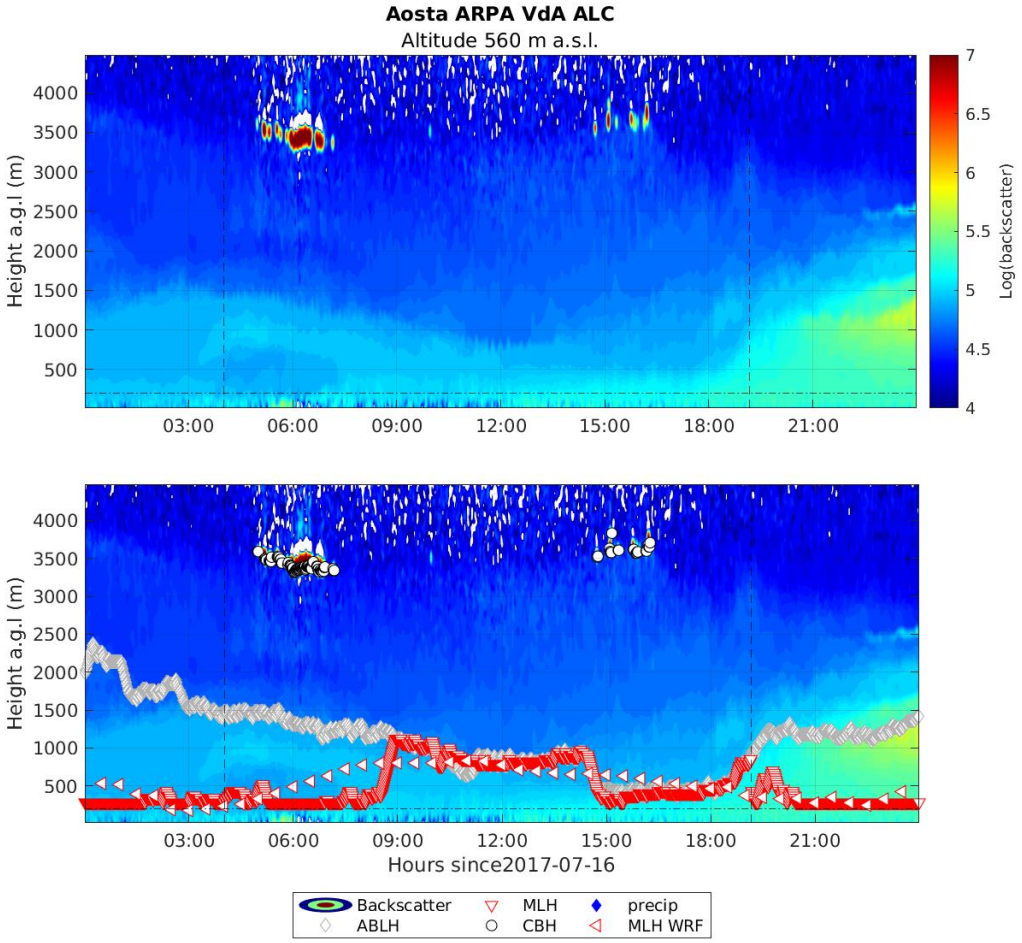

Figure 3 Backscatter from the ALC on 16th July 2017, in the lower panel, there are superimposed the MLH from STRATfinder (red downwards triangles) and WRF MLH (MYNN2.5 scheme, red leftwards triangles) and the ABLH from STRATfinder (grey diamonds).

However, the results of the three different methods present sometimes very different behaviours, indicating that a single solution (from the modelling point of view) is not possible. From the statistics emerges that the implemented MLH in the PBL routine of WRF (MYNN2.5) is the most trustworthy, followed by the Richardson number method.

5 CONCLUSIONS

This STSM highlights the importance of studying the boundary layer, both from the observational and modelling points of view. It is interesting to relate the complex dynamics of an Alpine valley with the pollutant dispersion and detection with an ALC and to clarify the capability of correctly detect the layers with the automated code of STRATfinder. This study shows some weaknesses of the STRATfinder, but it is necessary to underline the highly complex case studies adopted. Also WRF works close to its limit inside the “grey zone”, where the turbulence (sometimes the main responsible of pollutant dispersion) must be parametrised and directly resolved.

However, it is possible to summarise the outcoming of this STSM as follow:

- During each episode, the particulate concentrations changed considerably (see, e.g. Diemoz et al. 2019), so it is essential to study these episodes for air quality purposes.
- The humidity gradient method shows high discrepancies: sometimes, the layer is too deep. For this reason, it was necessary to implement in the code an upper threshold at 5000 m a.s.l.
- The Richardson number method and the MYNN2.5 scheme show the best results: their formulas are strictly defined.

- The layer detection with STRATfinder in complex terrain is challenging, and further improvement is needed, especially in the night-day transition and at the transition between two days.

A publication is expected after all the shortcomings listed above are resolved.

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22nd September 2021 Alenio Golzio **Date, signature of visiting scientist**	27 Sept 2021 S. Kotthaus-Bousbaad ..... **Date, signature of host representative**