SCIENTIFIC REPORT

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STSM: COST-STSM-ES1303-37107
TOPIC: Vertical and scanning turbulent properties from a Leosphere Doppler lidar
VENUE: Helsinki, Finland
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Host: Ewan O'Connor (FMI, Finland; University of Reading, UK)
Applicant: Shu Yang (Reykjavik University, IMO, Iceland)
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Introduction

This STSM was held at FMI in Helsinki, Finland from 2nd April to 7th April. The host was Prof. Ewan O'Connor, and Yang Shu was the visitor from Reykjavik University and Icelandic Met Office. The STSM focused on the uncertainty analysis of the Leosphere lidar systems deployed in Iceland.

Ground-based Doppler lidar instruments can provide high spatio-temporal resolution and continuous observations of various atmospheric parameters, including profiles of winds and turbulence. Doppler lidars have now been installed in a number of locations in Europe, which makes it possible and helpful to establish a Doppler lidar network from which the end users and other researchers can benefit.

During this STSM, we mainly focused on the Doppler lidar data from an instrument installed at Reykjavik, Iceland, and operated by the Icelandic Met Office (IMO). We, applied different processing methods and algorithms from several sources, examined the velocity variance and estimated the uncertainties in the measurements. We found that we could apply the currently existing methods designed for a different instrument, but that some more modification is needed to take the specific characteristics of this instrument into account. In the coming months, we will check more details of the current methods available, and these results will then contribute to the whole TOPROF Doppler lidar network.

Motivation and objectives

To establish a Doppler lidar network requires the harmonization of the processing procedure across the network. In Iceland, IMO and ISAVIA are running two Doppler lidars from the French manufacturer Leosphere, which are slightly different to the Doppler lidars built by Halo Photonics operated in Finland and other countries. Thus, to harmonize the processing across a heterogeneous network of instruments it is necessary and beneficial to test whether similar processing procedures applied at FMI can also be applied to the lidar in Iceland.

A similar Leosphere Doppler lidar system to those at IMO is operated by Jana Preissler for NUIG at the Mace Head Atmospheric Research Station in Ireland. Jana Preissler already has processing scripts prepared in Python which take the raw instrument output, convert this to netCDF, derive winds and generate quicklooks; these processing scripts were used as the starting point. The objective for this STSM was to check the instrument output, estimate the uncertainties in the measurements and propagate these through to the turbulent parameters derived. This included evaluating the background correction that is applied internally in generating the raw output. Since everything learnt in this process is also valuable to other Leosphere Doppler lidar operators in the network, a plan for future collaboration was another important objective.

Results and Achievements

IMO and Mace Head both use the long-range scanning version of the Leosphere Doppler lidar (Windcube 100S and Windcube 200S). In addition, after the previous STSMs held in Reykjavik, similar scanning sequences have also been implemented so the datasets from these sites are similar. Jana Preissler developed a set of Python scripts, which read the radial Doppler velocity and CNR (carrier-to-noise ratio, analogous to signal-to-noise ratio, SNR), and derive the wind data, including horizontal and vertical wind speed, from the various scans at Mace Head. With some simple modification, these scripts were easily adapted to the datasets from Iceland.

Figure 1 shows two cases of Doppler lidar data from Reykjavik; a turbulent day (24th March 2017) and a calmer day (31st March 2017). The amount of CNR is directly related to the number and size of particles in the atmosphere; more or larger particles means more signal and higher CNR. These plots show that signal is usually present in the boundary layer, and that clouds give a very strong signal; above the boundary layer there is usually no signal from aerosol, only from ice clouds. The blue colour in both plots therefore indicates the background noise which should be identified (and masked if required). Note that these two figures use a different colour scale; it is clear in the figure on the right that the background noise value is not homogeneous and varies from ray to ray.

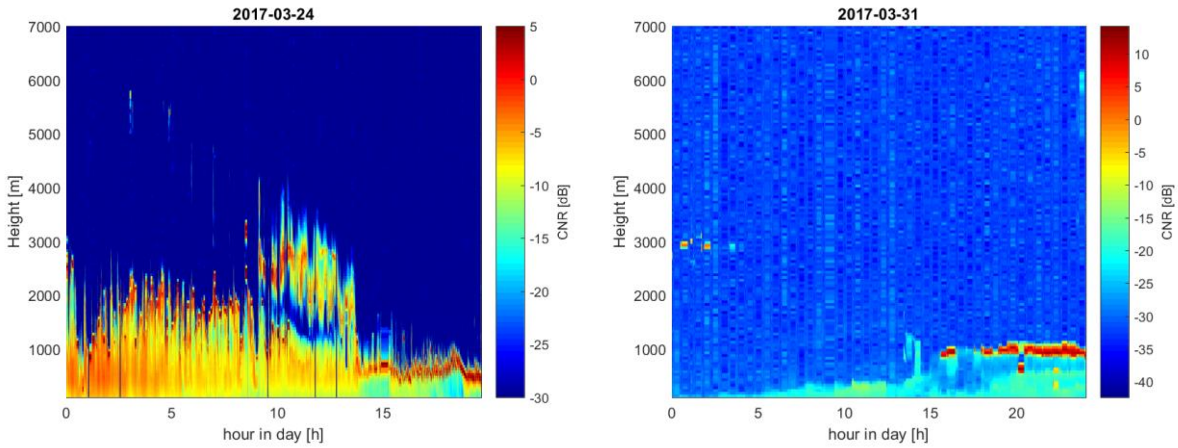

Figure 1. Time-height plots of CNR from a Leosphere Windcube200s for two days, 24th March 2017 (left) and 31st March 2017 (right), at IMO, Reykjavik, Iceland.

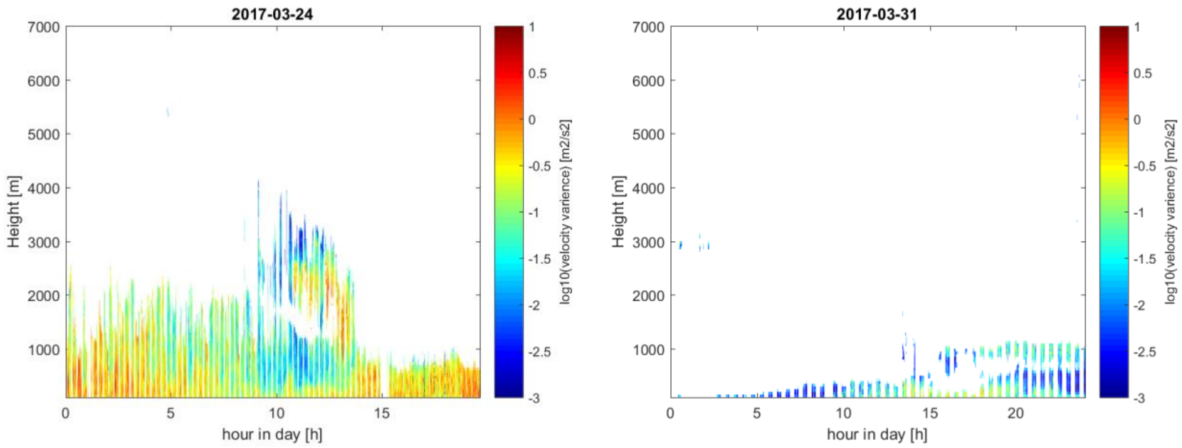

Figure 2. Time-height plots of the $\log_{10}$ of vertical velocity variance for the same dates as in figure 1.

Figure 2 displays the vertical velocity variance for the same two days as in Figure 1. Vertical velocity variance is a good proxy for the presence of turbulence, with higher values indicating stronger turbulence. These values can then be used to diagnose where mixing is occurring in the lower atmosphere, i.e. determine the presence of the mixing layer. For the calm day (31st March, 2017: Figure 2 right), the boundary layer was shallow and the diurnal change in the mixing layer can be observed, beginning to grow rapidly from close to the surface around 10 UTC to about 500 m and decay slowly in the evening. The clouds at around 1 km in the afternoon and evening are also turbulent but appear to be decoupled, i.e. the mixing does not reach all the way from the surface to the cloud as there is a calm layer in between. The 24th March 2017 (Figure 2, left) was a much more turbulent day which did not exhibit a typical diurnal cycle, in fact the mixed layer was shallower during the morning (300 m) than during the night (1 km). This is attributed to the presence of a strong front and associated clouds dominating the atmospheric motion during the night. The ice cloud seen between 1.5 and 3 km from 10 to 14 UTC is also strongly turbulent throughout most of the lower portion that is visible to the Doppler lidar. Note that we cannot see the full vertical extent of this cloud as the lidar signal is strongly attenuated in cloud.

A filter has been applied in Figure 2 to remove the background noise from the plots. We used a threshold of CNR -27 dB, with CNR values below this being discarded. The accuracy of using a single threshold value still needs to be examined, as the background CNR may vary from ray to ray. Since the uncertainties in the radial Doppler velocities are derived from CNR (e.g. O'Connor et al., 2010) it is important that the CNR estimate is also reliable. This is even more important when deriving turbulent parameters. We know that the observed vertical velocity variance can contain not only a turbulent contribution, but also contributions from the uncertainty in the velocity estimates, and potentially also from variations in the terminal fall velocities of the particles from which the signal is received. Hence the observed variance is:

$$\sigma_{observed}{}^{2} = \sigma_{turbulence}{}^{2} + \sigma_{uncertainty}{}^{2} + \sigma_{fallspeed}{}^{2}. \qquad (1)$$

Unless the signal is coming from precipitation, the fall speed term $\sigma_{fallspeed}{}^{2}$ can be safely ignored. In high CNR conditions the Doppler velocity uncertainty is relatively small and the observed variance is a result of the turbulent fluctuations only. However, often the CNR is low enough that the uncertainty term becomes significant; at very low CNR the uncertainty will dominate the observed variance so that the turbulent contributions can no longer be derived reliably.

There are 2 issues to address:

1. Does the background CNR value vary from profile to profile (and within a profile)?
2. Is the CNR value reliable?

If a fixed CNR threshold can applied universally, as in Figure 2, then the signal can be filtered easily. However, it is not easy to disentangle how instrument specifications, internal data processing and the atmospheric conditions all affect the noise. Figure 3 shows an example where we can see the difference between sequential vertical profiles of CNR. The temporal resolution is about 1 second so very little change is expected from ray to ray, especially in aerosol in the boundary layer difference from one to another could be significant. However, there are occasions when significant variation from ray to ray is seen. In this way, if we set a fixed CNR threshold, some noise could be saved and some useful information could be neglected.

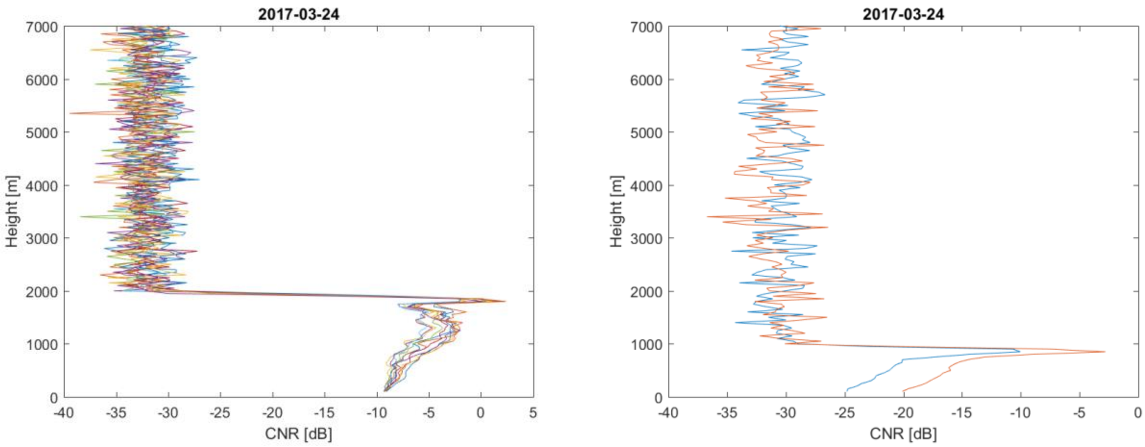

Figure 3. Ten (left) and two (right) sequential vertical profiles of CNR from two time periods during 12th November 2016 at IMO, Reykjavik, Iceland.

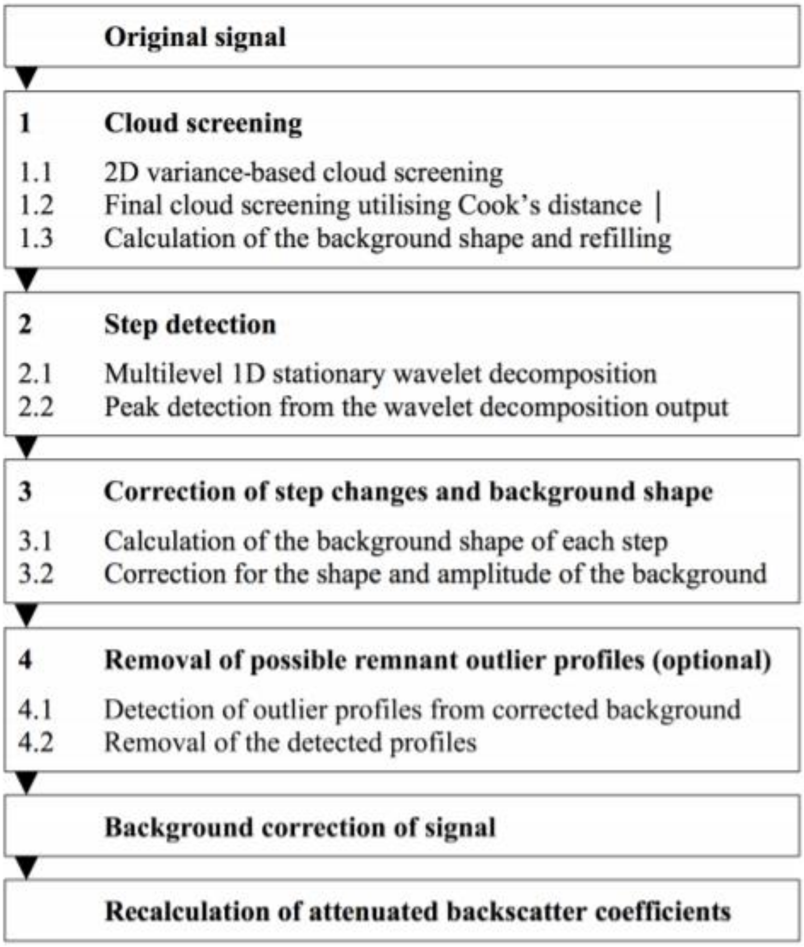

Figure 4. Workflow of the Halo lidar background correction algorithm (Manninen et al., 2015)

Manninen et al. (2015) developed an algorithm for correcting the background signals to improve the CNR. The workflow is presented in Figure 4. This algorithm was originally designed fror the Halo Doppler lidar systems in Finland, and has been tested on other Halo doppler lidar systems. In clean air situations (low CNR values) applying this method can improve the data availability by 50% (Manninen et al., 2015) because it permits the use of a lower CNR threshold. Previously, a higher threshold was necessary to reliably filter out the noise because the background CNR was not quite constant.

We applied this algorithm to a dataset from Reykjavik (Figure 5). Some modifications to the code were necessary, as these routines were designed for the Halo instruments and not a Leosphere Windcube system. Some differences between the systems include how the CNR values are represented; Leosphere store these in dB (10 $\log_{10}$) format, while Halo stores these as linear values of SNR +1, so transformation is needed. Similar to Manninen et al. (2015), we find that the background correction algorithm can also correct the striped features in the background noise of the Leosphere Doppler lidar – the left panels in Figure 5 show the corrected background CNR is much smoother. Also evident in Figure 5 is that many aerosol features visible in the lower right panel would also be filtered by a CNR threshold necessary to filter the noise. After correction (lower left panel) the CNR threshold for filtering out noise can be reduced and these valid features would remain after filtering.

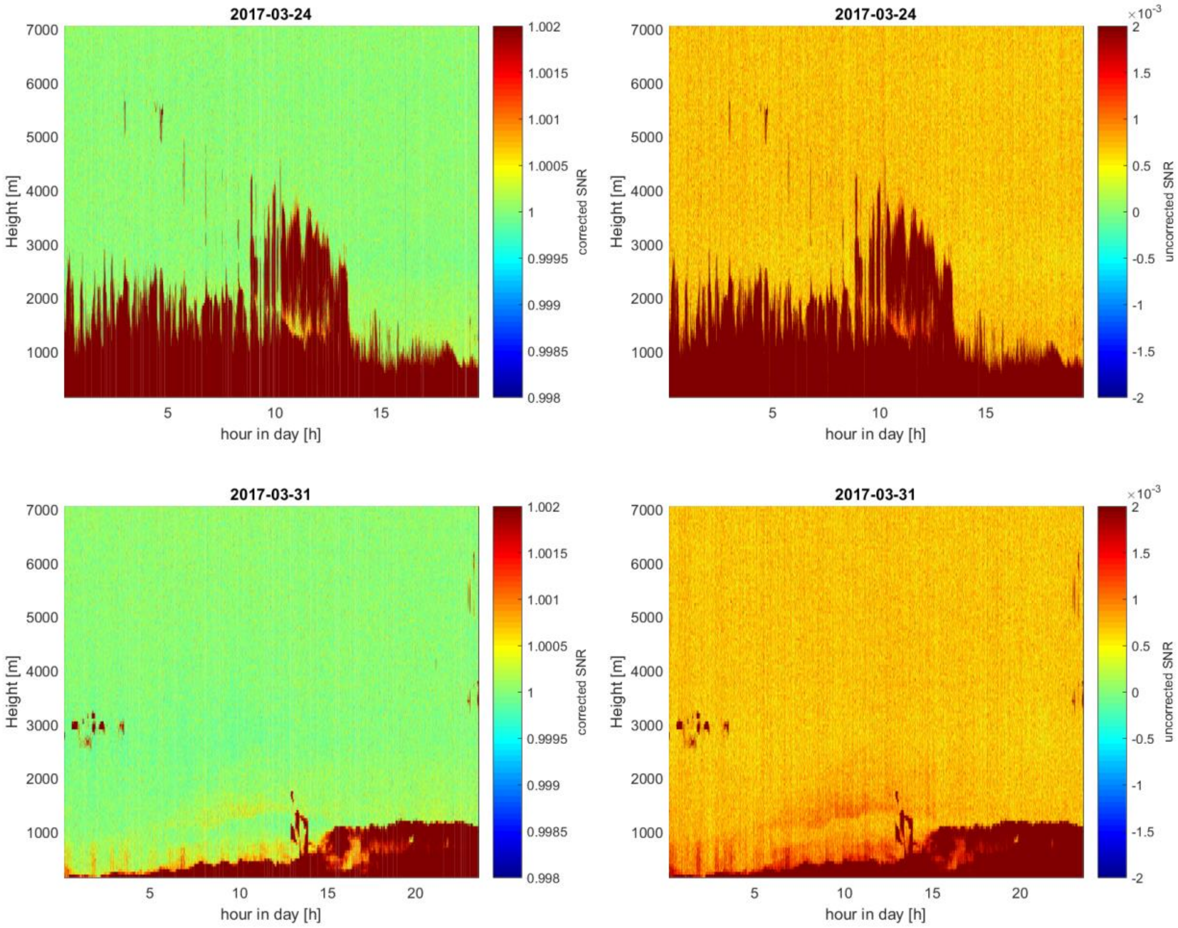

Figure 5. Corrected (left) and uncorrected (right) signal-noise-ratio (SNR) for 24th March 2017 (top) and 31st March 2017 (bottom) at IMO; Reykjavik, Iceland.

With the corrections applied to the CNR data, we can then implement turbulence retrievals, such as deriving eddy dissipation rate (EDR) from the vertical velocity variance, with more confidence now that we have better estimates for the uncertainty term in Equation 1. In this STSM we applied the EDR algorithm developed by O'Connor et al. (2010), using a characteristic horizontal wind to estimate the scale length, and the vertical velocity variance both corrected and uncorrected for the uncertainty contribution. Figure 6 shows the comparison between the EDR results with and without background correction. In all cases, the algorithm produces the expected range of EDR values, however, the EDR data availability was different depending on whether a background correction was applied. For the calm day (31st March, lower two plots in Figure 6), implementing the correction increases the data availability, such as between 03 and 10 UTC in the lowest 500 m, and between 16 and 23 UTC from 500 m to 1 km.

However, in some regions, data availability decreased after applying the correction for the turbulent day (24th March, upper two plots in Figure 6); this implies that the uncertainty term in Equation 1 after correction is now too large. This may be attributable to the difference in how the CNR is stored for the Leosphere system; all noise values are positive (in logarithmic space), whereas the background correction scheme expects a distribution centred on zero (i.e. positive and negative values). Due to the limited time available during the STSM, this possibility was noted but not tested; modification of the background correction scheme to take logarithmic noise values will be performed in the near future.

The next step will be to calculate the horizontal length scales required by the EDR algorithm using the observed horizontal winds.

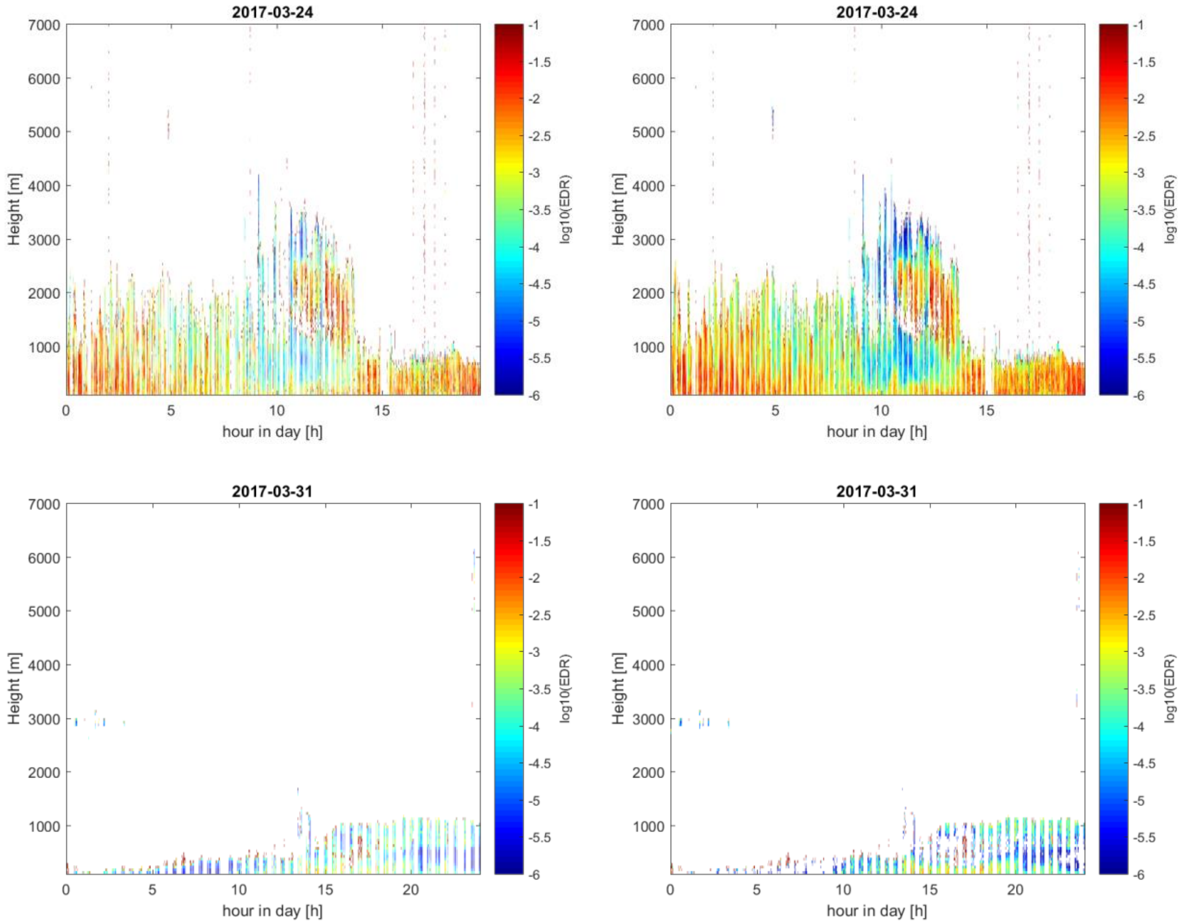

Figure 6. Eddy dissipation rate (EDR) on 24th March 2017 (top) and 31st March 2017 (bottom) from IMO, Reykjavik, Iceland. The left panels used the data after background correction, right panels before background correction.

Conclusions

In summary, this STSM was productive and successful. We applied a number of pre-existing algorithms, including data processing and turbulent property retrieval methods, to data from the Leosphere lidar system at IMO. The results are promising; we noted that similar retrievals can be applied to the different types of Doppler lidar, essential for harmonising the output from a heterogeneous network. However, some more modifications to the algorithms are necessary to account for some of the technical differences between the various instruments, and also in how the raw data is stored. Moreover, the CNR corrections will also impact the wind profile data uncertainties and will be incorporated in these routines in the future as well.

The scientific report will be posted on the TOPROF website: www.toprof.eu.

References

Manninen, A. J., O'Connor, E. J., Vakkari, V., & Petäjä, T. (2016). A generalised background correction algorithm for a Halo Doppler lidar and its application to data from Finland. *Atmospheric Measurement Techniques*, *9*(2), 817-827.

O’Connor, E. J., Illingworth, A. J., Brooks, I. M., Westbrook, C. D., Hogan, R. J., Davies, F., & Brooks, B. J. (2010). A method for estimating the turbulent kinetic energy dissipation rate from a vertically pointing Doppler lidar, and independent evaluation from balloon-borne in situ measurements. *Journal of atmospheric and oceanic technology*, *27*(10), 1652-1664.

Confirmation by the host institution of the successful execution

The host institution confirms the successful execution of this STSM

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13,4,2017