SCIENTIFIC REPORT

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Universität zu Köln, Germany

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Introduction

I went for a Short-Term Scientific Mission (STSM), which took place from 9th to 13th November 2015 at the Institut für Geophysik und Meteorologie, Universität zu Köln. The STSM goal was to begin the generation of a boundary layer (BL) classification. The STSM allowed me to network with some of the researchers in the same field, and thus greatly benefit from the group work.

Motivation and objectives

This work will eventually be incorporated into Cloudnet (Illingworth et al., 2007) and provide several products, with one being the BL classification. The classification is created in order to understand better the complex and continuously evolving BL. Its infinite number of states can be condensed into more perceptible finite number of states. The BL classification product requires several Doppler lidar quantities and can greatly benefit from additional quantities, e.g. sensible heat flux. In theory, the classification presented here can be carried out at any site where a scanning Doppler lidar is deployed and also where sensible heat flux measurement is available. However, the classification could also be carried out with only Doppler lidar measurements, but possibly with a reduced number of states that can be classified.

Harvey et al. (2013) proposed a BL classification method, which covered a number of states where clouds where present within the BL, but only two where clouds were not present. Building upon their work, we can extend the classification scheme to improve the classification of the non-cloudy periods as well.

Different weather forecast and climate models require different input parameters and schemes. For example, the scheme Harvey et al. (2013) discussed provides for the UK Met Office BL classification evaluation product. However, ECMWF, Meteo France, and Deutsche Wetterdienst would have different requirements. The goal of our work is to provide parameters that can be used in these different BL classification evaluation products.

Instrumentation

Halo Photonics Streamline scanning Doppler lidar

Halo Photonics Ltd manufactures the Doppler lidar used in this work (Fig. 1). The Halo Doppler lidar is commercially available and has been developed to perform continuous and autonomous long-term measurements (e.g. Pearson et al., 2009). The instrument emits laser pulses in the near infrared spectral region at 1.5 µm, and outputs a profile of back-scattered light intensity, in terms of signal-to-noise ratio (SNR), together with a radial Doppler velocity determined from the Doppler shift of the back-scattered light. Horizontal wind speeds can be determined from combining orthogonal beams when scanning off-vertical. If the telescope function is known, the attenuated backscatter coefficients can be calculated (Hirsikko et al., 2014). It is important to acknowledge that any error in the SNR will transfer to the Doppler velocity measurement uncertainty (Manninen et al., 2015). Thus, with some Halo Doppler lidar units, correcting for the artifacts present in the background SNR is essential (Fig. 2).

Figure 1. Halo Photonics Streamline scanning Doppler lidar at Jülich, Germany

The background SNR artifacts can be corrected with the background correction method presented in Manninen et al. (2015) and Vakkari et al. (manuscript in preparation). After the correction the data availability in the lowest most range gates can be increased as much as 50%, especially in regions with low aerosol loading. In locations where the data availability is not an issue, such as in Juelich, the correction is still essential for calculating the turbulent properties.

From the Halo Doppler lidar measurement, several quantities (and their uncertainties) can be calculated (Fig. 3), such as the top of the aerosol layer (note: not the height of the BL), vertical velocity skewness, turbulent kinetic energy dissipation rate (O'Connor et al., 2010), and the vector wind shear.

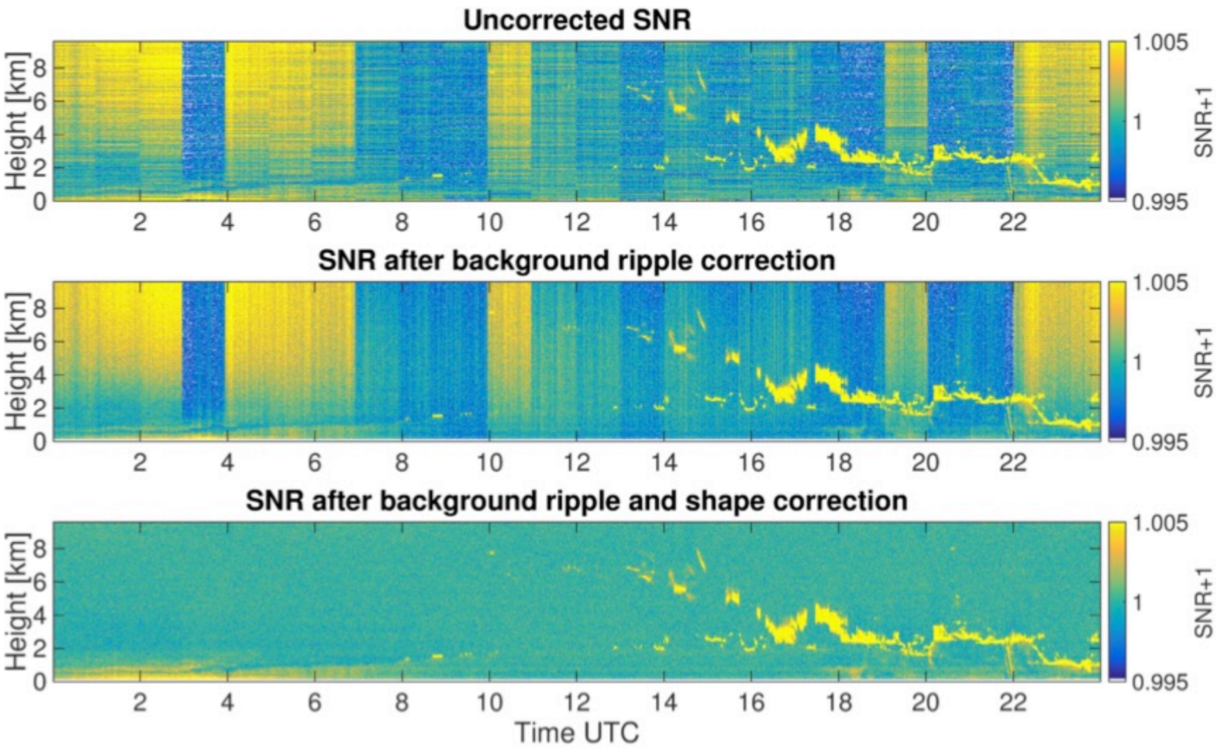

Figure 2. An example day of the Halo Doppler lidar SNR, which requires background correction: (top) uncorrected SNR; (middle) SNR after background ripple correction; (bottom) corrected SNR. 9 June 2014 at Hyytiälä, Finland.

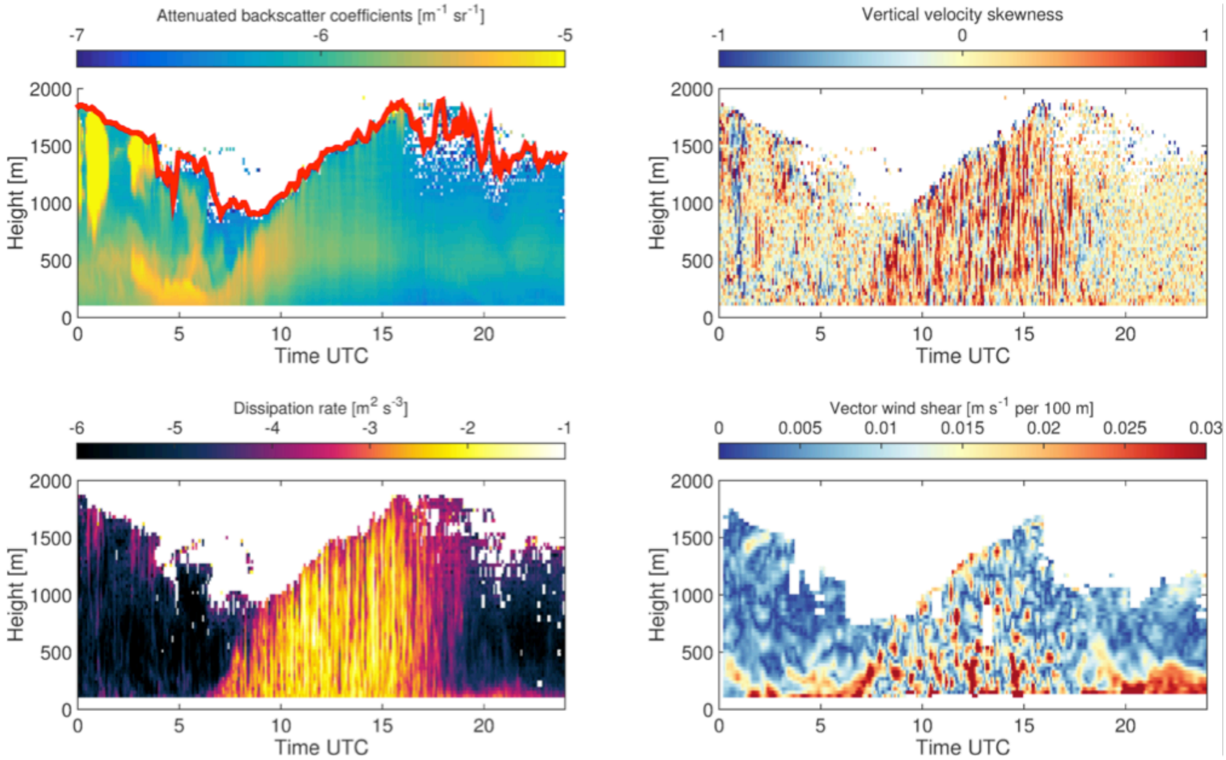

Figure 3. The Halo Doppler lidar quantities used in the boundary layer classification: (top left) attenuated backscatter coefficients and top of aerosol layer; (top right) vertical velocity skewness; (bottom left) turbulent kinetic energy dissipation rate; (bottom right) vector wind shear on 1 April 2013 at Jülich, Germany.

Eddy Covariance stations

The sonic anemometer measures the three components of the wind and the sonic temperature, which is equivalent to the virtual temperature, at a rate of 20 Hz. Standard eddy covariance methods can be used to calculate sensible and latent heat fluxes (e.g. Harvey et al., 2013). In the method discussed here, the sign of the sensible heat flux at 10 min temporal resolution is then used in estimating the stability of the surface layer.

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Figure 4. Eddy covariance stations (blue) are located 5 and 8.5 km from the Halo Doppler lidar (red), at Jülich, Germany.

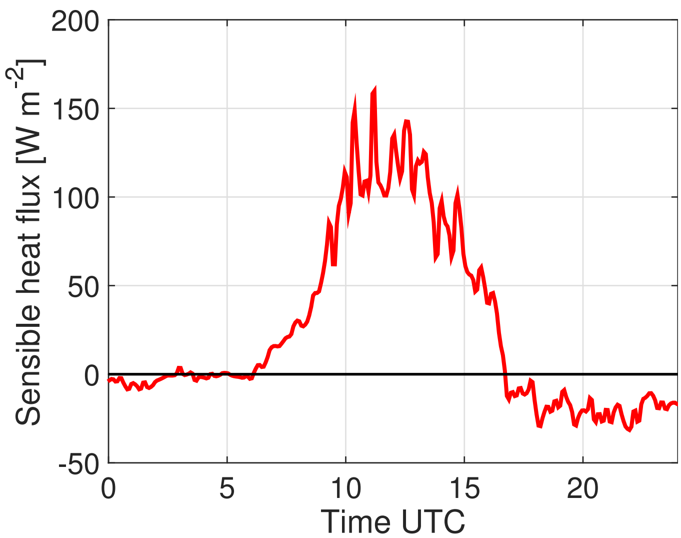

Figure 5. Sensible heat flux calculated with standard eddy-correlation methods from three wind components and sonic temperature measured by the sonic anemometer on 1 April 2013 at Jülich, Germany.

Results

The result can be seen as a proof-of-concept and is very preliminary. To classify the BL into small number of predefined states, we used specific thresholds for each of the quantities (Table 1). In the future we plan to move towards dynamic thresholds and assigning probabilities to the different states of the BL. With the thresholds, the quantities are reduced to two states, and together they comprise a bit field, which can then be used with a chosen logic to classify the BL.

Figure 6 illustrates the two states where the different Halo Doppler lidar quantities are reduced. The attenuated backscatter coefficients are used in detecting the top of the aerosol layer, but also whether or not there are clouds present within the aerosol layer. Turbulent kinetic energy dissipation rate is used in detecting turbulent parts of the BL. The vertical velocity skewness can be used with the information on cloud presence and turbulence to assess whether the turbulence is cloud driven or surface driven. Since the example day used here is assumed to be mostly cloud free, vertical velocity skewness was not used in our logic. The vector wind shear information is used in detecting time periods when wind shear is high and, in combination with the dissipation rate, whether the shear is a result of convection or some other mechanism (typically friction-induced).

Table 1. Overview of the thresholds chosen for the boundary layer classification.

Parameter	**Attenuated backscatter coefficients**	**Vector shear**	**Vertical velocity skewness**	**Dissipation rate**	**Sensible heat flux**
Resolution time, height	5 min 30 m	5 min 30 m	5 min 30 m	5 min 30 m	10 min
Threshold	10^{-6}	0.015 m s^{-1} per 100 m	0	10^{-4} m^2 s^{-3} 10^{-3} m^2 s^{-3}	0 W m^{-2} ±10 W m^{-2}

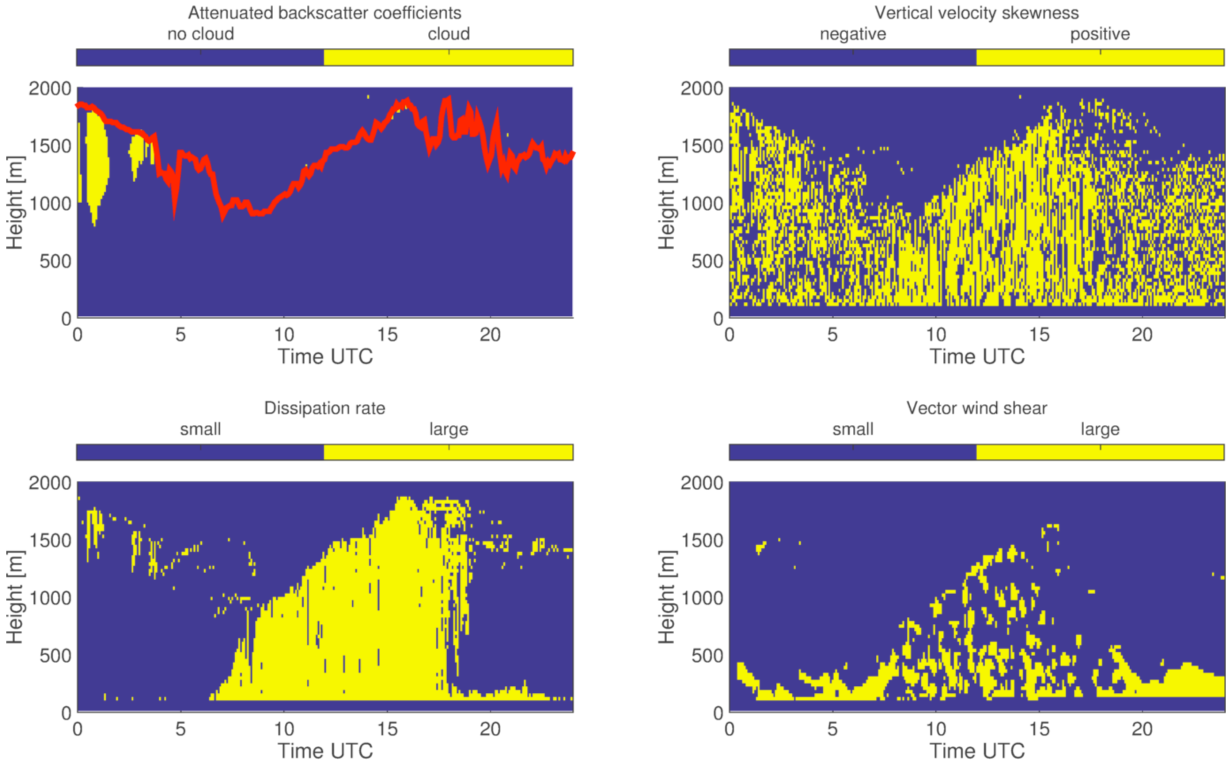

Figure 6. The Halo Doppler lidar quantities used in the boundary layer classification are classified into two states after applying the initial thresholds: (top left) attenuated backscatter coefficients and top of aerosol layer; (top right) vertical velocity skewness; (bottom left) Turbulent kinetic energy dissipation rate; (bottom right) vector wind shear on 1 April 2013 at Jülich, Germany.

The sensible heat flux data is reduced into three states. If the sensible heat flux is between ± 10 W m^{-2} it is assigned to be neutral, if below -10, stable, and if above +10, unstable (Fig. 7).

The Table 2 shows the logic used for the classification. For example, to be classified as a friction-induced (shear) surface layer, heat flux has to be negative but larger than -10 W m^{-2}, dissipation rate has to be larger than 10^{-3} m^2 s^{-3}, and the vector shear has to be larger than 0.015 m s^{-1}.

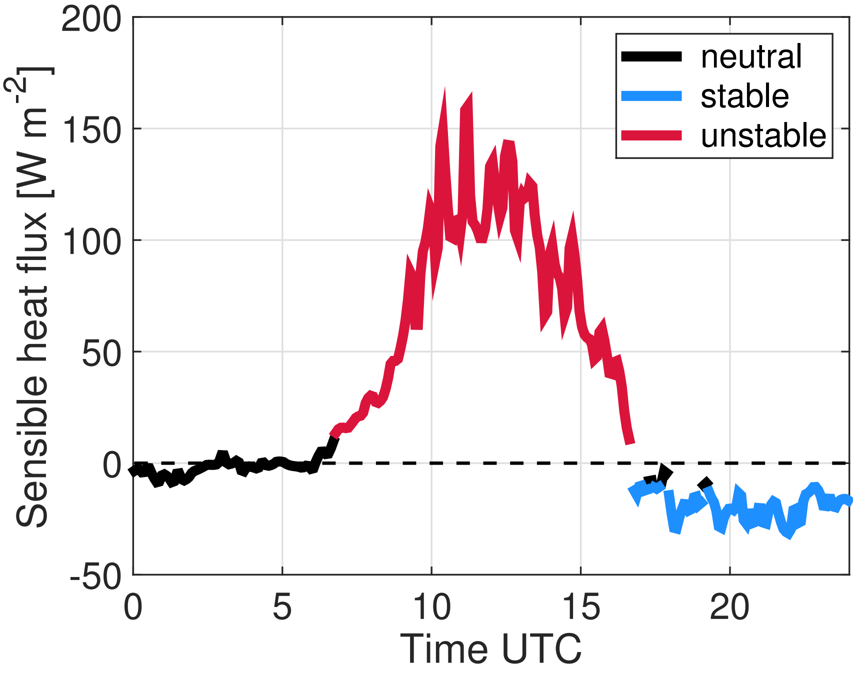

Figure 7. Sensible heat flux classified into three states after applying the heat flux threshold, on 1 April 2013 at Jülich, Germany.

Table 2. The decision logic which uses the bit field to unambiguously assign a combination of bits to every boundary layer class.

	Heat flux	Heat flux neutral	Dissipation rate	Within aerosol layer	Vector shear
Neutral	-	0	-	-	-
Stable	0	1	-	-	-
Unstable	1	1	-	-	-
Residual	-	-	0	1	-
Convective	1	1	1	-	-
Shear or surface layer	0	1	1	-	1
Decaying	0	1	1	-	0

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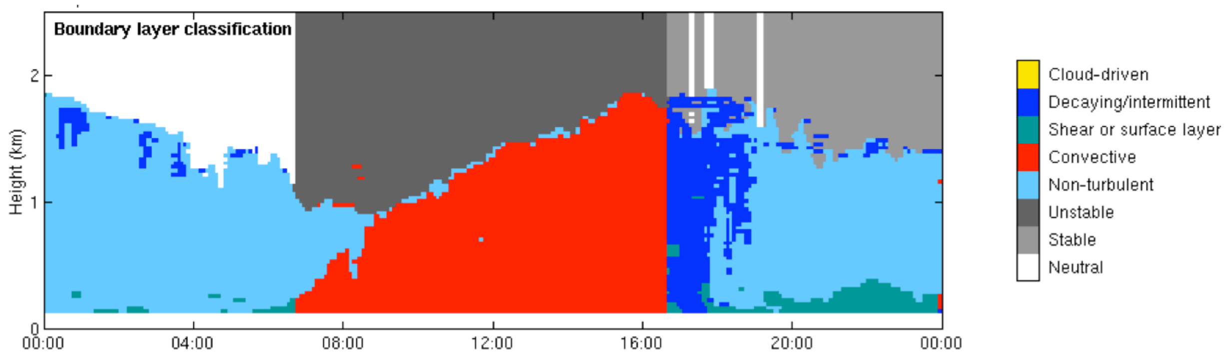

Figure 8. The initial results of the boundary layer based on 1 April 2013 at Jülich, Germany. Note that the neutral, stable and unstable states shown in the figure illustrate the BL states based on the surface sensible heat flux, and are not related to height but plotted into the background for illustration purposes.

Figure 8 illustrates the preliminary results of the BL classification for 1 April 2013 at Jülich, Germany. Based on our method, we can separate the day into neutral, unstable, and stable states. Also, the BL can be classified as non-turbulent, shear or surface layer, convective, and decaying/intermittent types. By inclusion of the vertical velocity skewness and cloud detection, additional information on cloud driven turbulence could be obtained.

Conclusions

We have shown that BL classification can be carried out successfully with using Doppler lidar quantities in combination with sensible heat flux information. In order to estimate the uncertainty of our classification, uncertainties of the calculated quantities have to be incorporated together with assigning probabilities for the different BL types.

This STSM has been successful in the sense that proof-of-concept was successful, and we have worked closely together outside of our usual research groups.

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