MIXING LAYER HEIGHT DERIVED FROM RADIOSOUNDINGS AND GROUND-BASED LIDAR - COMPARISON AND ASSESSMENT

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1 INTRODUCTION

The inversion on top of the atmospheric boundary layer is a strong barrier for the transport of heat, momentum and matter from or to the earth's surface. The concentration of aerosols and gaseous constituents like water vapour which originate from the surface strongly depends on the height of the mixing layer. During daytime the mixing height (MH) over land increases and reaches a maximum value in situations with constant synoptic conditions.

In many applications the MH is taken from radiosoundings. Since the MH is strongly varying both in time and space an observation along a single line like a radiosonde track represents only an estimate of the MH. Continuous measurements with a ground-based lidar give time series of MH and allow to estimate the uncertainty associated with radiosonde values.

Data from field campaigns at the ARM-site in Oklahoma (USA) from September to December 2000 and at Lindenberg (southeast of Berlin, Germany) in May/June 2003 are used where extensive daytime lidar measurements and at least 4 radiosondes per day are available. The Oklahoma experiments were dedicated to the determination of atmospheric water vapour (ARM, 2004). Several remote sensing instruments took place, among then the Differential Absorption Lidar System (DIAL) of the Max-Planck-Institute for Meteorology, Hamburg (Bösenberg (1998), Bösenberg and Linné (2002), Ertel (2004)). The same instrument participated in the German evaporation experiment LITFASS-2003 within the project EVA-GRIPS (Regional Evaporation at Grid/Pixel Scale) (Beyrich et al., 2004).

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2 DETERMINATION OF THE MIXING HEIGHT

The most common determination of the mixing layer height, e.g. for comparison with model output is from radiosoundings which are available worldwide, mostly every 6 h. There exist several methods which can be deduced from definitions of the boundary layer, see e.g. the summary in Seibert et al. (2000). The MH can be determined by the parcel method, the maximum gradient of potential temperature, of relative humidity and of absolute humidity.

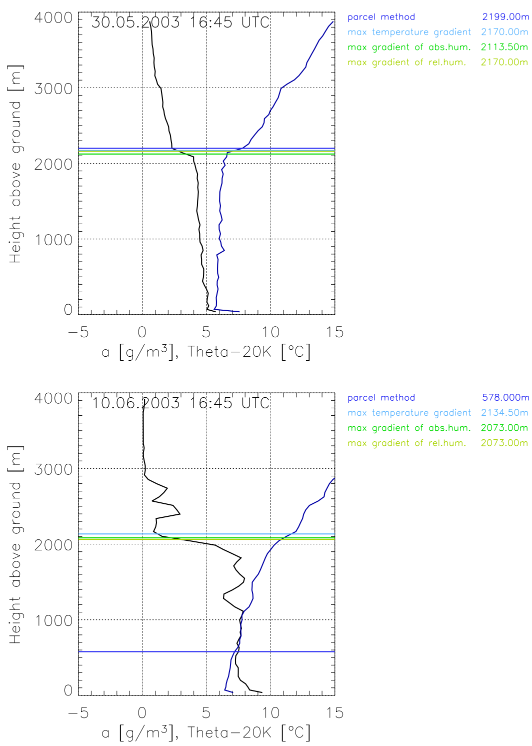

FIG. 1: Radiosonde profiles of potential temperature ($\Theta - 20K$, blue) and absolute humidity (black) and top of boundary layer determined by different methods. Upper panel: 30 May 2003 16:45 UTC, lower panel: 10 June 2003, 16:45 UTC, both at Lindenberg

In Fig.1 the four methods are compared. In situations with a clear convective boundary layer the results are the same (upper panel). The parcel method based on the assumption of a well-mixed layer is the most reliable but there are cases where the MH apparently is higher (lower panel).

Quasi-continuous measurements of the backscatter signal with the ground-based lidar determine the MH during daytime and thus can check the accuracy of radiosonde methods. The MH separates two regions with different properties, the well-mixed boundary layer and the stable free troposphere. The transition zone between both layers, i.e. the entrainment zone is characterized by a large variability of the trace substance concentration - aerosol concentration or water vapour density. The height of maximum variance of trace substance concentration is often identified as the ABL height (Stull, 1988). Since DIAL provides continuous high resolution observations of aerosol backscatter and humidity, the variance method can be applied as well as the gradient method, like for radiosoundings. The variance method yields values of the mean ABL height whereas the gradient method yields values of the instantaneous ABL (Lammert, 2004).

The combination of both methods - first find the mean MH with the variance method and then determine the time-variable MH with the gradient method - yields MH values on a short timescale, in this study 2 min or 10 min.

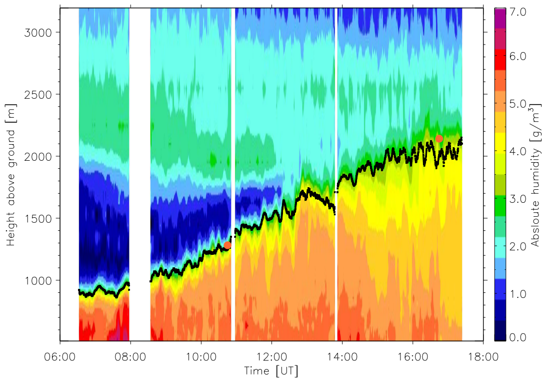

FIG. 2: Time-height cross-section of absolute humidity on 30 May 2003 at Lindenberg and mixing height from backscatter signal. Red dots are radiosonde MH.

Fig.2 shows an example of the time series of the MH, determined from the backscatter signal with a resolution of 2min, plotted together with the time-height cross-section of the absolute humidity. The red dots in Fig. 2 mark the results of the MH determination from radiosoundigs. This example shows a good agreement between the MH of DIAL and radiosonde.

For all campaigns the MH is determined for 10 min time intervals of the radiosonde launch time and then averaged to a mean 1 h-value with a standard deviation of 10 min values within 1 h. In Fig.3 the MH on both timescales are compared showing considerable differences which are due to the variability within one hour. The maximum differences are 150 m, the standard deviation within the 1 h-interval can be as large as $\pm 200m$ due to single convective eddies. This range of uncertainty is assumed to describe the spatial variability of MH as well and holds for lidar and radiosonde comparison.

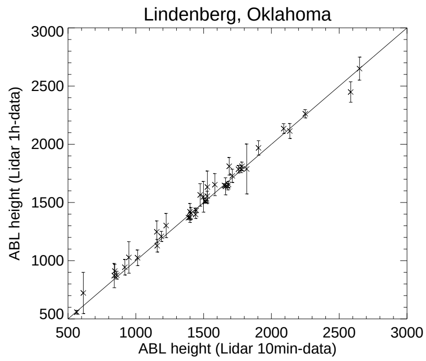

FIG. 3: Mixing heights at radiosonde launch time determined by lidar backscatter for 10 min and 1 h time intervals together with standard deviation of MH within zhe 1 hour interval.

3 COMPARISON AND ASSESSMENT

Approximatly 50 radiosoundings and simultaneous lidar measurements are compared in Fig.4. Both the absolute humidity gradient and the parcel method are presented. Besides a good agreement of most values, there is a considerable number of values with radiosonde MH from humidity gradient exceed the lidar MH by more than 500 m and radiosonde MH from the parcel method are by more than 500 m lower than lidar MH. The large differences between radiosonde and lidar MH have several reasons.

There may be a second inversion above the boundary layer with a stronger humidity gradient, this is often the residual layer of the day before which has not yet been reached by the growing convective boundary layer (MH radiosonde gradient method too high).

On the other hand, in the afternoon the starting temperature measured by the radiosonde may be too low to allow a parcel to rise to the MH (MH radiosonde parcel method too low, compare Fig.1, lower panel). The difficulty of choosing the right starting temperature is also discussed in Seibert

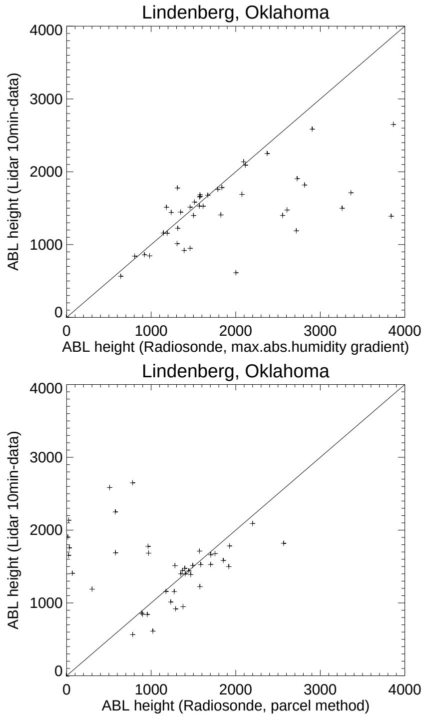

FIG. 4: Mixing heights at radiosonde launch from radiosonde and lidar for ARM experiments and LITFASS-2003.

et al. (2000). In those cases the humidity gradient method gives better results.

Individual convective eddies reach different top heights and the radiosonde track does not give a representative value. This effect is illustrated by Fig.5.

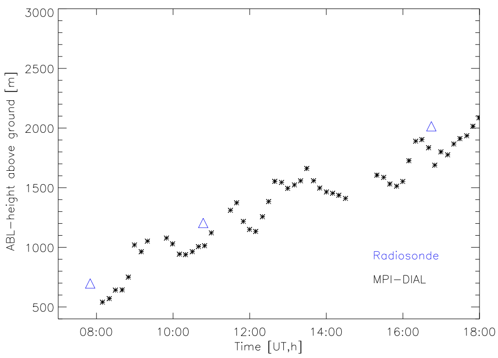

FIG. 5: Time series of 10 min values of mixing height from lidar and radiosonde mixing heights at Lindenberg on 10 June 2003.

Convective boundary-layer clouds may disturb both radiosonde and lidar methods as illustrated by the time-height cross-section of the backscatter gradient (Fig.6). At 10:45 UTC the radiosonde methods gives MH of 2500 to 2800 m and the lidar gives a MH of 1800 m.

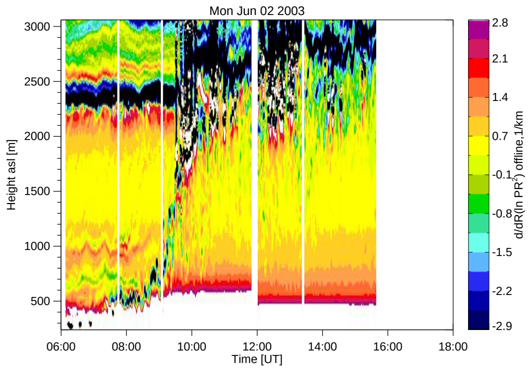

FIG. 6: Time-height cross-section of logarithmic gradient of range-corrected backscattered signal at Lindenberg on 10 June 2003.

4 CONCLUSIONS

The comparison of MH determined by radiosondes and simultaneous lidar backscatter reveals a good agreement in situations where the evolution of the convective boundary layer is clear. The average differences between the methods are 150 m. This lies within the range of the lidar MH standard deviation of 10 min values in 1 h.

Large differences occur if the systems analyse different structures, mostly inversion layers at upper heights like the residual layer of the day before. The radiosonde launch time 10:45 UTC is a crucial time in central Europe since the new boundary layer may not have reached the residual layer and thus two layers are present. The same problem arises at all locations where radiosondes are launched in the morning hours. At those times the parcel method is more appropriate for radiosonde data than any of the gradient methods. In the afternoon, the humidity gradient is a better indicator for the MH when the near-surface temperature decreases and the parcel method gives too low MH.

Radiosondes yield estimates of the variable MH for a certain time and space and should be interpreted within a range of uncertainty. Lidar systems continuously show the evolution of the convective boundary layer and thus the MH determination is more consistent and avoids errors like tracking higher layers. Moreover, they quantify the variability of the MH.

ACKNOWLEDGEMENTS

This work was partly funded by the German Federal Ministry for Education and Research (BMBF) within the German Climate Research Programme (DEKLIM).

Radiosonde data were available within the ARM Southern Great Plains Campaigns and LITFASS-2003 (German Meteorological Service, DWD).

REFERENCES

ARM (2004). Atmospheric radiation measurement (arm) program, southern great plains site: http://www.arm.-gov/docs/sites/sgp/sgp.html.

Beyrich, F., Bange, J., Berger, F. H., Bernhofer, C., Foken, T., Hennemuth, B., Leps, J.-P., Lüdi, A., Meijninger, W. M. L., and Mengelkamp, H.-T. (2004). Energy and water vapour fluxes over a heterogeneous land surface: The LITFASS-2003 experiment. In *The 16th Symposium on Boundary Layers and Turbulence*, Portland (ME), USA. American Meteorol.Soc.

Bösenberg, J. (1998). Ground-based differential absorption lidar for water-vapor and temperature profiling: methodology. *Appl.Optics*, 37:3845 – 3860.

Bösenberg, J. and Linné, H. (2002). Laser remote sensing of the planetary boundary layer. *Meteorol.Z.*, 11:233 – 240.

Ertel, K. (2004). Application and development of water vapor DIAL systems, Dissertation Univ. Hamburg, http://www.sub.uni-hamburg.de/opus/volltexte/2004/2027/.

Lammert, A. (2004). Untersuchung der turbulenten Grenzschicht mit Laserfernerkundung, Dissertation Univ. Hamburg, http://www.sub.uni-hamburg.de/opus/volltexte/2004/2103/.

Seibert, P., Beyrich, F., Gryning, S.-E., Joffre, S., Rasmussen, A., and Tercier, P. (2000). Review and intercomparison of operational methods for the determination of the mixing height. *Atmospheric Environment*, 34:1001–1027.

Stull, R. (1988). *An introduction to boundary layer meteorology*. Kluwer Academic Publisher, Dordrecht.