Can insects be used as a tracer for mixing-layer height detection? - Methods and first results of mixing-layer height estimation from Ka-band radar measurements

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ABSTRACT

The backscattered signals of a Ka-band radar which were identified as insects (atmospheric plankton) have been used as tracer for the determination of the mixing-layer height (MLH). An algorithm to derive the top of the mixing layer has been developed on the basis of plankton reflectivity gradients. Applied to several days in summer 2007 promising results compared to radiosonde-derived mixed-layer heights as well as to model data can be recognized. Especially the daily growth of the MLH in the morning is much better mapped compared to those MLH derived from ceilometer measurements.

1. INTRODUCTION

The atmospheric boundary layer (ABL), which vertical extension is described by the mixing layer height, plays an important role for the exchange of heat, momentum and moisture between the surface and the free atmosphere. The MLH is one of the key parameters for the transportat and dispersion of air pollutants and an important input value for dispersion models. Therefore, a lot of efforts have been undertaken during the last decades to use ground-based remote sensing systems, like sodar, sodar/RASS, wind profiler radar or ceilometer for a continuous observation of the MLH [5, 2].

To derive macro- and microphysical cloud parameters millimeter-wave radars have been established as useful systems during the last years [4]. The radar is transmitting electromagnetic pulses and receives the signals backscattered by targets being in the atmosphere. The amplitude and the pulse-to-pulse phase changes of the backscattered signal are determined to evaluate the reflectivity which is proportional to the number and size of the particles, and the mean velocity of the targets. In addition to the backscattered signals from cloud and precipitation droplets, there are also returns from non-hydrometeors like dust or insects. Especially the boundary layer is contaminated by these targets (usually called as plankton) which have to be removed be-

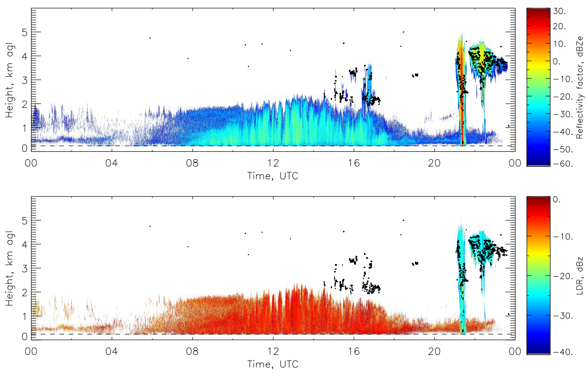

Figure 1. Time-height cross section of the reflectivity factor measured with the Ka-band radar MIRA36 on 28 April 2007. Black dots indicate the ceilometer (Vaisala LD40) measured cloud base.

fore applying cloud-retrieval algorithms. Since the upper boundary of the insect-contaminated range follows obviously quite well the height of the mixing-layer in its diurnal cycle, the idea arose to develop an algorithm to determine the maximum height of this plankton layer and to compare it with mixed-layer heights of other (well established) retrieval methods. Figure 1 shows an example of radar reflectivity on a day with a well developed convective boundary layer. Only few clouds (in this plot identifiable by the ceilometer measured cloud base) occurred between 15 and 17 UT as well as between 21 and 24 UT at 2 to 4 km height. The structure of the convective boundary layer is clearly indicated by high reflectivity values between 8 and 18 UT. The top of the boundary layer grows in the morning and decreases in the afternoon whereas the maximum height is about 2 km at 13 UT. The lower panel illustrates that the LDR of insects is significantly higher than for clouds and can therefore be used for the separation between hydro- and non-hydrometeors. In analogy to methods using ceilometer measured aerosol profiles for the MLH

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determination it is assumed that insects can also serve as tracer for a direct estimation of the MLH. In this paper a method is presented which derives the top of the mixing-layer based on plankton reflectivity gradients. For several days the results are compared against radiosonde, ceilometer and model-estimated MLH values.

2. INSTRUMENTATION

Since November 2003 the Richard-Aßmann Observatory Lindenberg of the German Meteorological Service (DWD) has been continuously operating a 35.5 GHz coherent and polarimetric cloud radar (named MIRA36) to measure vertical profiles of the reflectivity, Doppler velocity and spectral width between 240 m and 12 km height [3]. The system has a vertically-pointing cassegrain antenna with a polarization filter and two symmetrical receivers for simultaneous processing of co- and cross-polarized signals. This allows to calculate the Linear Depolarization Ratio (LDR) which is the ratio between the reflectivity of cross- and co-polarized channels. As illustrated in Figure 1, the LDR is high for non-spherical targets. As part of the standard data processing the LDR is used to separate between hydrometeors and non-hydrometeors (particularly insects) supplemented by independent information about the freezing level (radiosoundings or model data) [1]. These data which are classified as atmospheric plankton form the base for all subsequent analysis.

Frequency	35.5 GHz
Peak Power	30 kW
Transmitter type	Magnetron
Noise figure and Loss in receiver path	6.3 + 3 dB image noise
Loss in transmit path	1.3 dB
Antenna type	Cassegrain with pol. filter
Antenna diameter	1 m
Antenna gain	49 dB
Beam width	0.55 deg
Pulse length	200 ns
Vertical resolution	30 m
Pulse repetition freq.	7.5 kHz
FFT-Length	256
Min. measuring height	240 m
Max. measuring height	12 km
Averaging time	10 sec
Sensitivity at 5 km (0.1 s)	-40.3 dBZ

Table 1. Technical characteristics of the MIRA36.

3. ALGORITHM

As mentioned above, observations have shown that reasonable estimates for the MLH can obviously be obtained by analyzing the plankton contamination in the backscattered radar signal. Especially insects seem to have a maximum flying altitude that has a particular season-dependant relationship to the MLH.

A simple approach to retrieve the MLH is to evaluate the *gradient information* of the total reflectivity of the plankton signal component: for each time step one considers the vertical reflectivity profile and derives the modulus of the gradient. We then define the MLH as the height for which the modulus of the gradient is maximal. Since the individual profiles are typically corrupted by noise/other components one has to adapt the gradient estimation accordingly. We therefore assume an individual profile is modeled as $f(x) = g(x) + \varepsilon(x)$ with $|\varepsilon| < eps$ and $\sup_\xi |g''(\xi)| \leq M$. For computing a discrete approximation of f' via $d_h f(x) = \frac{f(x+h)-f(x)}{h}$ one has to know the optimal ratio h. By standard arguments one achieves $h_{opt} = \sqrt{\frac{4eps}{M}}$. The discrete derivative of the profile f is thus due to linear interpolation given by

$$f'(j) = \frac{1}{h_{opt}}(c_1 f(j+l) + c_2 f(j+l+1) - f(j)) \ , \quad (1)$$

where the filter mask is given by $c_1 = \frac{(l+1)\tau - h_{opt}}{\tau}$, $c_2 \frac{h_{opt}-l\tau}{\tau}$ and where τ is the height spacing of the sampled profile f and $l = [h_{opt}/\tau]$.

However, measurements show (see Figure 2), that there is no sharp boundary between regions being contaminated by insects (point targets) and regions being free of plankton.

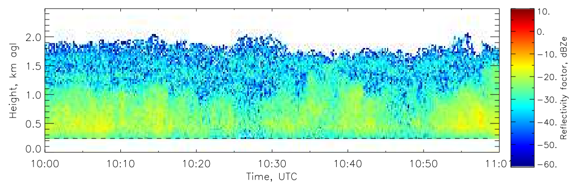

Figure 2. Extraction of Figure 1 which shows a diffuse upper boundary of atmospheric plankton.

In particular, a typical plankton echo is neither continuous with respect to time nor to height. Therefore, the computation of the gradient needs to be stabilized which we realize by a smoothing of f. However, the smoothing step must be sensitive enough in order to make sure that the MLH information remains within the signal. A smoothing model which we want to adapt to our problem is given by the diffusion equation

$$\frac{du}{dt} = \lambda \Delta u = \lambda (\frac{d^2u}{dx^2} + \frac{d^2u}{dy^2}) \ ,$$

where u denotes the 2-dim. backscatter profile with variables x and y. The basic idea when adapting the diffusion model is to adequately merge the individual point targets into a continuum of plankton that allows a stable computation of the gradient. Note that in our context y corresponds to height and x to time. The variable t corresponds to diffusion time and is not related to x! Within this notation the measured data are given by $u(x, y, t = 0) = u_0(x, y)$. The application of the diffusion model yields

$$u(x, y, t) = u_0 * e^{-(\|\cdot\|^2/2\lambda)}(x, y) \ ,$$

i.e. linear diffusion of backscattered data is given by the convolution with the Gaussian. In order to keep the edge or gradient information, we have to consider an edge-dependent diffusion model,

$$\frac{du}{dt} = \lambda \nabla(\phi(|\nabla u|)\nabla u),$$

where ϕ is scalar-valued function which is close to one for small and medium values of $|\nabla u|$ and small otherwise. However, this nonlinear model allows only for isotropic diffusion. More suited for our purpose is the anisotropic situation in which ϕ is replaced by a data dependant matrix-valued operator $D(u)$,

$$\frac{du}{dt} = \lambda \nabla(D(u)\nabla u) \ .$$

$D(u)$ realizes a rotation with angle perpendicular to the direction of maximum gradient. A simple iteration scheme that can be implemented is given for $n = 0, 1, 2, \ldots$ by

$$u_{n+1} = u_n + h\lambda \nabla(D(u_n)\nabla u_n) \ . \qquad (2)$$

We wish to remark, that also other smoothing models obtained by variational formulations involving TV-based or wavelet-based penalty terms deliver very similar results.

In our first experiments we have observed that choosing the diffusion iteration index $n = 20$ in (2) yields a reasonable smoothing of the backscattered profiles f. Denoting the anisotropically smoothed backscatter profile array by $u_{20}(x, y)$, we still have to derive the gradient with respect to height as given in (1). The maximum value per time step is then defined at individual time steps x by

$$MLH_{u_{20}}(x) = \arg_j \max(|u'_{20}(x, j)|) \ .$$

This function represents the essential Plankton boundary layer and yields therefore also an estimate for MLH. As many data examples indicate, this estimate contains usually many local oscillations of the MLH. This can be circumvented by an additional outlier removal due to a simple median filtering,

$$\widehat{MLH}_{u_{20}}(x) = med_N(MLH_{u_{20}}(x)) \ , \qquad (3)$$

where N denotes the filter length ($N = 50$ time steps yields a suitable smoothing).

4. EXAMPLES

The method described above has been applied to selected cases in 2007 where mixing-layer heights derived from co-located Jenoptik CHM15k ceilometer measurements with a method described in [6] were available. In addition MLHs derived from radiosoundings (4 times a day) and the COSMO-EU model (DWD) are shown as further reference in Figure 3. The radiosonde values base on Richardson Number criterion [7]. Note, that the lowest radar MLH is given by the minimum range gate of the radar at 240 m agl.

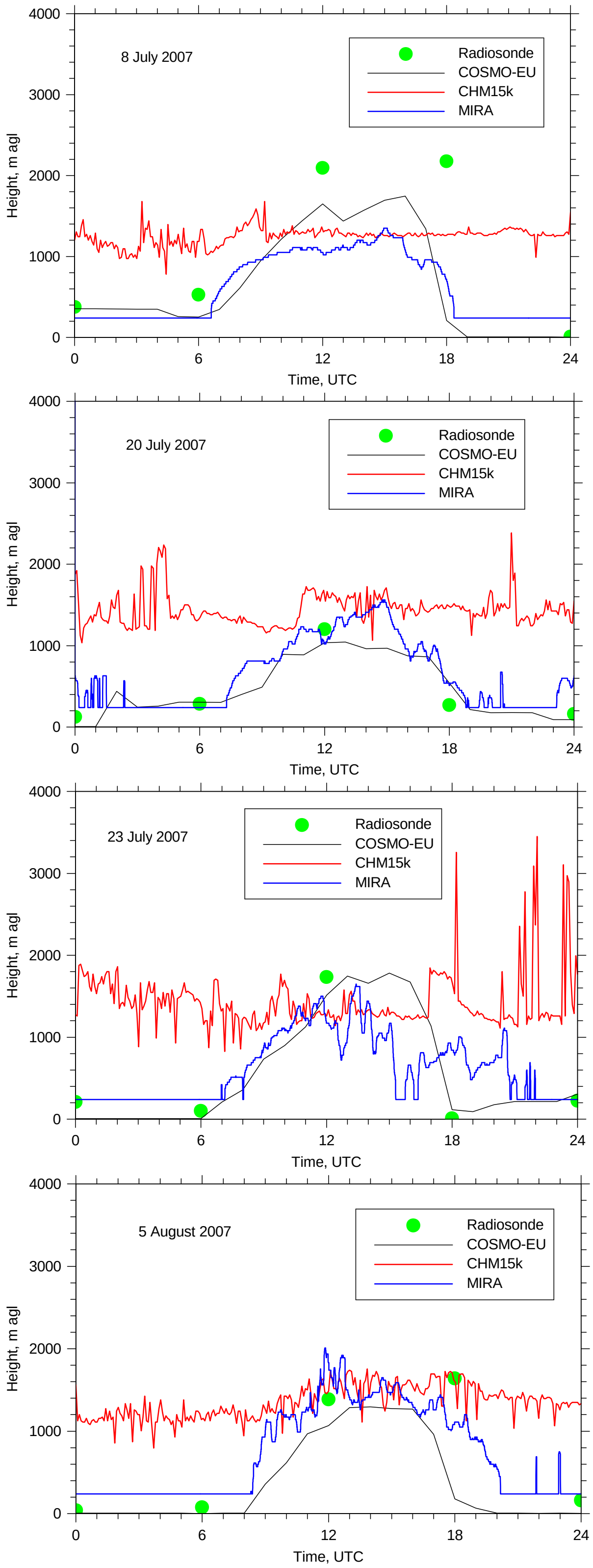

Figure 3. Mixing-layer heights derived with different methods for selected days in summer 2007.

All days are characterized by a well developed ABL. On all shown July days 3-7 okta of cumulus clouds developed in the morning and the afternoon. On 20 and 23 July a shower and a thunderstorm, respectively, occurred after 18 UT. The 5 August was cloudless.

It can be seen, that the radar-estimated MLHs follow quite nicely the diurnal cycle of the MLH evolution with a striking growth in the morning and the transition to lower heights in the late afternoon. This corresponds to the MLH variations given by the model data.

Looking to the absolute values, there is obviously a good agreement to model data under stable conditions. However it must be considered that the radar MLHs represent the minimum range gate of the radar in most cases. The ceilometer is not able to depict the MLH at night. Probably it represents the residual layer instead of the nocturnal MLH.

Under unstable conditions at times, when the ABL is fully developed, the MLH differences between ceilometer and radar are smaller than 500 m, in most cases smaller than 200 m, whereas the radar MLH tends to be lower than the ceilometer values. With respect to the model data, positive and negative deviations can be observed. The large deviations of radiosonde-derived MLHs on 8 July may be a result of uncertainties in the retrieval techniques.

5. SUMMARY AND OUTLOOK

An algorithm which smoothes the radar reflectivity gradient profiles and estimate mixing-layer height has been developed and successfully applied to plankton classified radar reflectivity data for a few cases. The results show a good agreement to radiosonde derived MLHs and model data. Especially the transition from stable to unstable conditions and vice versa is mapped much better than by mixed-layer heights derived from a ceilometer. However, some more investigations are necessary in order to evaluate the general validity of this radar-derived MLHs.

For example, the temperature will influence the flight behavior of insects essentially and so it is necessary to find out on which temperature range the proposed method works. Another open question is how strong the insect distribution is dominated by either convective/turbulent processes or by their own flight power. [8] found out that insects frequently occur above ceilometer detected aerosol layers particulary in the morning. Nevertheless, insects may be a better tracer because they are bigger and heavier than aerosol particles and probably more linked to vertical mixing than aerosol, which may originate also from advective transport or past accumulation processes.

REFERENCES

[1] Bauer-Pfundstein, M. R. and Görsdorf, U.: Target separation and classification using cloud radar Doppler-spectra, 33rd International Conference on Radar Meteorology, 6-10 August 2007, Cairns, Australia, 2007.

[2] Emeis, S., Münkel, C., Vogt, S., Müller, W. J., and Schäfer, K.: Atmospheric boundary-layer structure from simultaneous SODAR, RASS, and ceilometer measurements, Atmospheric Environment, 38, 273–286, 2004.

[3] Görsdorf, U. and Handwerker, J.: A 36 GHz high sensitivity cloud radar for continuous measurements of cloud parameters - Experiences of 2-years operation and system intercomparison -, ISTP, Seventh International Symposium on Tropospheric Profiling; Needs and Technologies, Boulder, 12.-16.06.2006, 2006.

[4] Kollias, P., Clothiaux, E., Miller, M., Albrecht, B., Stephens, G., and Ackerman, T.: Millimeter-wavelength radars; New Frontier in Atmospheric Cloud and Precipitation Research, Bull. Amer. Meteor. Soc., 88, 1608–1624, 2007.

[5] Seibert, P., Beyrich, F., Gryning, S.-E., Joffre, S., Rasmussen, A., and Tercier, P.: Review and intercomparison of operational methods for the determination of the mixing height, Atmospheric Environment, 34, 1001–1027, 200.

[6] Teschke, D., Reichardt, J., and Engelbart, D.: Wavelet algorithm for the estimation of mixing layer height with ceilometers., Reviewed and revised papers presented at the 24th International Laser Radar Conference (ILRC), 23 - 27 June 2008, Boulder, pp. 313–316, 2008.

[7] Vogelezang, D. and Holtslag, A.: Evolution and model impacts of alternative boundary layer formulations, Boundary-Layer Meteorology, 81, 245–269, 1996.

[8] Wood, C. R., O'Connor, E. J. O., Hurley, R. A., Reynolds, D. R., and Illingworth, A. J.: Cloud-radar observations of insects in the UK convective boundary layer, Meteorol. Appl., 0, 2008.