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Ceilometer based retrieval of Shanghai's Boundary Layer Height

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1. Introduction

The atmospheric boundary layer is the lowest part of atmosphere (Stull, 1988) that interacts with Earth's surface directly. It's depth (hereafter z_i) is important in terms of weather forecasts, atmospheric diffusion and air quality.

Ceilometers are affordable LIDARs that can be used to retrieve z_i. Several Vaisala CL31/CL51 ceilometers have been deployed in Shanghai at different meteorological stations and airports. Thus allows the study of BL characteristic of this coastal megacity and providing valuable information for weather and/or air quality forecasts.

In order to achieve this goal, this study developed a modified ideal curve fit (m-IC) algorithm which can be used for automatic retrieval of z_i in large datasets. Further modifications were also made for conditions with cloud or aerosol layers in the lower troposphere (m2-IC). For example, if low clouds occur, m-IC will consider cloud top to be the z_i, but m2-IC will consider cloud base as z_i. And when multiple aerosol layers occur, m-IC will choose the top height of aerosol layer with largest change of backscatter coefficient, but m2-IC will choose the top height of lowest aerosol layer. Comparisons of the z_i retrieved by m2-IC and radiosonde during a mobile observation indicate that m2-IC is able to retrieve reasonable values.

2. Methods

2.1 The ceilometer and mobile observation

A Vaisala CL51 Ceilometer is mounted vertically in the back of a van thus can be used for both in-situ and mobile observation of backscatter coefficient (BSC) profiles for the retrieval of z_i.

On 27 July 2013, the ceilometer was driven from Fengxian bay starting at 04:45 am, through the city of Shanghai, to the north (Shidongkou, 30.93° N, 121.48° E) at 11:05 pm (Figure1). The measured BSC profiles are used to retrieve $z_{i,ceilo}$ across Shanghai and compared with radiosonde lunched at Baoshan Meteorological Office (Baoshan, Figure 1).

Fig. 1 The mobile observation on 27 July 2013, the path of which is given by dashed line. The map is derived from Google map

2.2 Algorithm to retrieve z_i based on Ceilometer

In this study, we used an algorithm that is modified version of the curve fit method after Steyn et al. (1999), which fits an ideal curve (Figure 2(a)) to the observed backscatter coefficient (BSC) profile to obtain $z_{i,icf}$:

$$B(z) = \frac{(B_m + B_u)}{2} - \frac{(B_m - B_u)}{2} erf\left(\frac{Z - Z_m}{S}\right) \quad (1)$$

where B_m and B_u are the mean value of backscatter values for the mixed layer and the lower free troposphere. S is used to define the depth of the sigmoid curve between B_m and B_u, and Z_m is the center of the transition zone, and its height equal to $z_{i,icf}$. The root-mean-square deviation between fitted curves and the observed BSC profiles are calculated, and the curve with minimum RMSD is considered as the best fitted one,

Instead of giving a single initial guess and do the robust literation (Steyn et al. (1999)), all heights from 100 m to 2 km with a 10 m step are used as the initial guess z_i. Since S is also needed to determine B_m and B_u thus to retrieve the ideal curve, we tested the impact of S on retrieved z_i by vary the S with fixed initial z_i. We found the impact of changes in S on the retrieved z_i is very small (Figure 2(b)). Therefore, once z_i is determined, we assume an entrainment zone equal to 20% of the depth of z_i, thus S, B_m and B_u are determined, and the curve is fitted. Therefore, the algorithm needs no more fixed initial guess and suitable for the automatic retrieval of z_i.

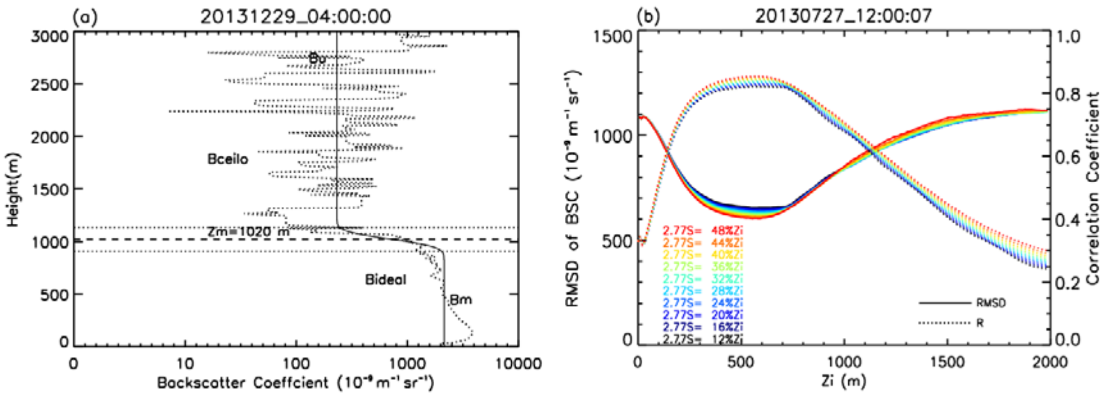

Fig. 2 (a) The backscatter coefficient profile (Bceilo, vertical dotted line) measured at 04:00:00 at 12 December 2013 and corresponding best fitted ideal curve (Bideal, vertical solid line), the $z_{i,icf}$ is equal to Z_m (1020 m, horizontal dashed line); (b) The dependence of correlation coefficient (R) and root mean square difference (RMSD) between measured backscatter coefficient and fitted ideal curve on z_i and S for the backscatter measured at 12:00:07 at 27 July 2013.

A BSC profile may be significantly different from ideal. Such as rainy condition, which will destroy the boundary layer structure and not suitable for the algorithm to work, are removed from current study. Besides, cloudy and aerosol layer conditions are identified, and two processes are tried to retrieve more reasonable results under such conditions. With the two processes, the algorithm is named m2-IC. The main points of two processes are:
(1) Cloud examining process: when the z_i retrieved by m-IC ($z_{i,m\text{-}IC}$) is identified as cloud top, it will be replaced by the height of cloud base, $z_{i,c}$ is the z_i after cloud examining process.
(2) Aerosol examining process: when multi- aerosol layers structure is identified below $z_{i,c}$ the top of the lowest aerosol layer will be chose as the z_i after aerosol and cloud examining process.
(3) Several thresholds are needed for the process:
1. BSC of typical cloud as the criterion for the existing of cloud.
2. BSC of typical boundary layer height as the criterion for the existing of gap between aerosol layers.
3. Height range for the existing of gap between aerosol layers.

3. Comparison with Radiosonde during the mobile observation

M2-IC is applied to the BSC profiles observed during the mobile observations, the time-height section of BSC and retrieved z_i are showed in figure 3 (b). The variation of both BSC profiles and retrieved z_i show a pattern of typical land boundary layer as indicated by figure 3 (a). At 01:15 pm and 07:15 pm, two radiosondes were lunched at Baoshan Meteorological Office (Baoshan, 31.40° N, 121.45° E, Figure 1). At 01:15 pm, the ceilometer located few kilometers away from Baoshan and at 07:15 pm, the ceilometer located at Baoshan, thus providing two chances for the comparison between z_i retrieved by radiosonde ($z_{i,r}$) and ceilometer ($z_{i,ceilo}$). The $z_{i,ceilo}$ and $z_{i,r}$ are marked as white diamonds and red cross in figure 3 (b), respectively. $z_{i,r}$ is retrieved by the vertical variation of meteorological parameters given in figure 3 (c, d). At 01:15 pm, only one height with large variation of specific humidity, relative humidity and potential temperature is show in the radiosonde and agrees well with the $z_{i,ceilo}$. At 01:15 pm, two heights with large variation of specific humidity, relative humidity and potential temperature are seen. The upper one agrees well with the $z_{i,ceilo}$, and the lower one reflect the height also with large variation of BSC. Refer to figure 3 (a), the upper height reflects the top height of residual layer and the lower height reflect the top of mixed-layer, thus the upper height is $z_{i,ceilo}$ and also agrees well with $z_{i,ceilo}$.

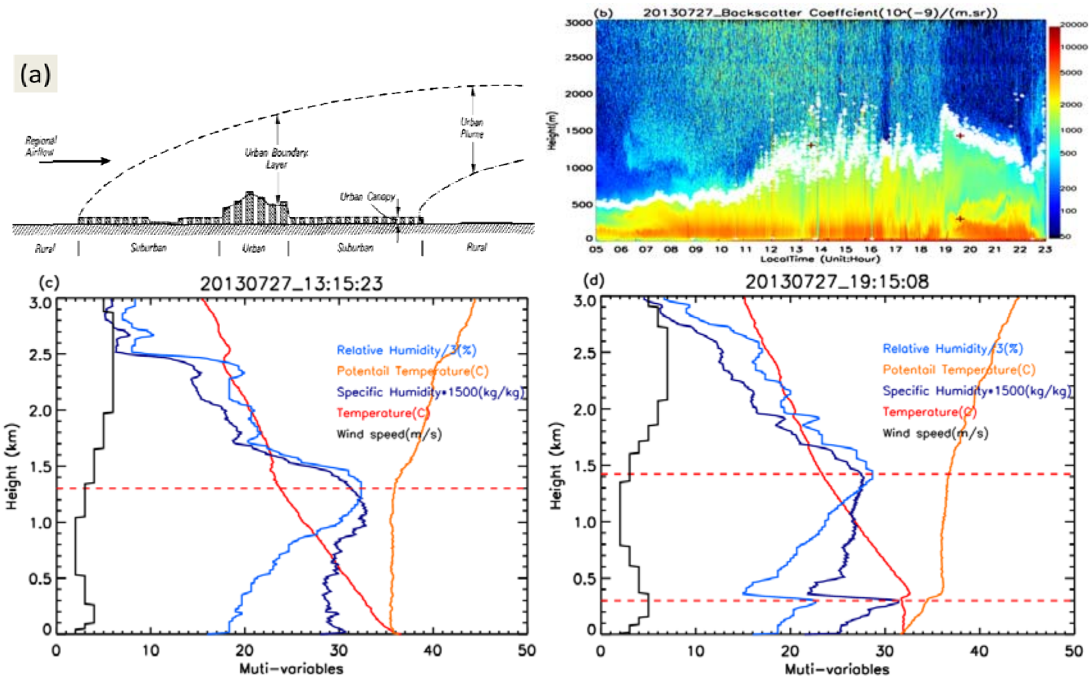

Fig. 3 Comparison between ceilometer and radiosonde, (a) illustration of typical diurnal variation of continental z_i after Oka (1976); (b) time-height cross section of ceilometer measured backscatter coefficient; radiosonde measured vertical profile of meteorological parameters at around (c) 02:00 pm and (d) 08:00 pm on 27 July 2013. Note the dashed line in (c) and (d) indicate the height with large variations of meteorological parameters, the same height are marked by red crosses in (b) at the corresponding time.

4. Conclusions

1) The modified ideal curve fit algorithm m2-IC is more applicable for long term z_i automatic retrieval than the original one because no initial guesses are required and the retrieval test all possible heights instead of robust iteration.
2) The comparison between z_i retrieved by m2-IC radiosonde during a mobile observation show good agreements, indicate the m2-IC is able to retrieve reasonable z_i.
3) Apply m2-IC to other ceilometers installed in Shanghai will provide good chance to understand the dynamical characteristics of z_i in important megacity.
4) More comparison between m2-IC and radiosonde is undergoing to test the applicability of m2-IC under different conditions.

Acknowledgment

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