Diurnal Cycle of Mixing Height Measured by Lidar

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ABSTRACT

The height of mixing layer measured by a lidar is presented in this paper. Lidar observed mixing heights are highly linearly correlated with radiosonde data. In clear day, mixing heights usually start to quick grow at 8:00L ~ 10:00L and then remain at maximum height at 1 km ~ 1.6 km for about one hour. In general, mixing height evaluate with surface ground temperature increase or decrease. Under certain weather condition such as winter monsoon, mixing height is found remain at higher altitude and not decent with temperature decreases. Seasonal averaged mixing height also shows the maximum and minimum mixing heights are happened at summer and winter respectively.

1. INTRODUCTION

The ABL is the lowest atmospheric layer that is closest to the surface and has highest influence for human being. During the early morning and other period of stability the mixing depth is important to are pollution, since it is one of the two principal variation (the other is wind) that govern pollutant. Since ABL has high temporal and spatial variation, understanding of ABL requires good observational data of the dynamical process. Earlier scientists used balloon to study ABL behavior. However, balloon measurement can collect ABL data only at synoptic hour and it is very expensive. So the remote sensing instruments such as lidar that can observe ABL variation almost continuously became more popular than balloons.

The daily cycle of radiative heating causes a daily cycle of sensible and latent heat fluxes between the earth and the air. However, these fluxes cannot directly reach the whole atmosphere. They are confined by the troposphere to a shallow layer near the surface that is the Atmospheric Boundary layer (ABL). Therefore ABL is directly influenced by the presence of the earth's surface, and responds to surface forcing with a timescale of about one hour or less Stull [1]. The forces come from friction drag, evaporation and transpiration, heat transfer, pollutant emission and terrain induced flow modification.

In this paper, mixing height is determined by a Raman/depolarization lidar system and 16 radiosondes launched around middle day to obtain vertical atmospheric profiles for comparison. The results showing lidar and radiosonde data are highly linearly correlated with R^2=0.9. We found mixing height basically is controlled by surface temperature and wind. But under certain weather system such as winter monsoon, mixing height would remain at higher altitude and not decent with temperature decreases. We also found sometime strong wind shear will suppress the evolution of mixing height. Seasonal averaged mixing height is presented, the results show the maximum and minimum mixing heights are happened at summer and winter respectively, and the pattern of diurnal cycle in spring and autumn are very similar.

2. METHOD

The lidar and radiosonde site are located at the weather observatory of the National Taiwan University (25°00'N, 121°32'E), which is located in the southwestern part of the Taipei Basin. RCEC/ASNTU Lidar is a dual-wavelength Raman and Depolarization Lidar system (manufactured by Zenon SA, Greece). The lidar system employs the second and third harmonics of Nd:YAG laser at 532 nm and 355 nm. More details are provided in Table 1. This system is 24 hours operated to probe the atmosphere in the height range between 0.3 km and 8 km.

Table 1. RCEC/ASNTU Lidar Specification

Laser	Nd:YAG (Big-Sky CFR-400)
Wavelength	532/355 nm
Pulse energy	65/60 mJ
Repetition rate	20 Hz
Transient Record	12 bits A/D converter at 20 MHz and 250 MHz photon counting (Licel TR20-40)
Height Resolution	7.5 m
Telescope	diameter 40 cm, focal length 160 cm
Channels	532 (*S* and *P*), 355 nm, and 387 nm (nighttime only)

The signal detected by LIDAR is usually described in terms of the range-squared-corrected signal (*RSCS*), which is defined as

$$RSCS=[P(\lambda,z)-P_0(\lambda,z)]\times z^2 \qquad (1)$$

where $P(\lambda,z)$ and $P_0(\lambda,z)$ denote the power of the backscattered light and the background signal from an altitude of z, respectively.

Given that the aerosol concentration in the mixing layer is significantly higher than in the free troposphere, the cap of the mixing layer is characterized by a deep gradient of the aerosol backscattering signal. Flamant et al. [2] proposed that the altitude of the top of the mixing layer could be obtained from the profile of the derivative of the LIDAR signal (i.e. *RSCS*). In this study, both aerosol backscatter profile and the altitude with the minimum of the first derivative of *RSCS* are used to determine the mixing height.

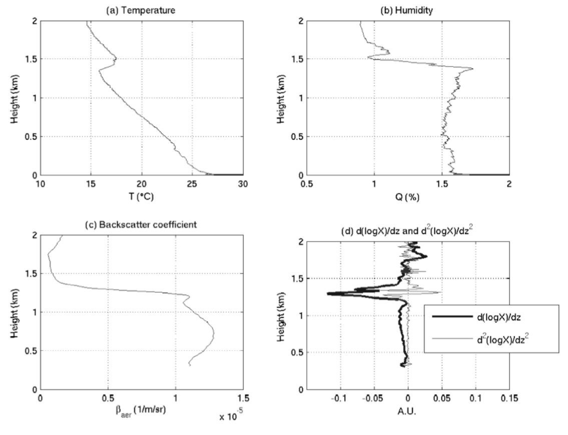

Fig. 1. (a) Temperature and (b) mixing ratio of water vapor observed by radiosonde launched at 2005/3/16 14:00. (c) Backscattering coefficient (532 nm) measured by lidar at same time. (d) First derivative and second derivative of range corrected lidar single (*RSCS*).

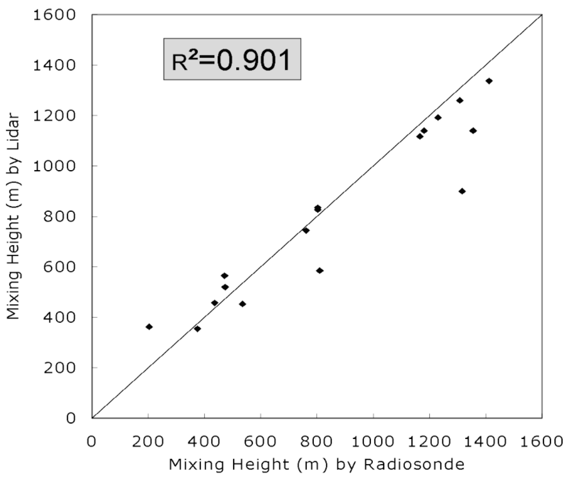

Fig. 2. Scatter diagram of mixing heights measured by lidar and radiosonde. The correlation is R^2=0.901.

In Fig. 1, radiosonde data (launched at 2005/3/16 14:00L) shows a temperature inversion about 2 °C located at 1.4 km, and water vapor is almost well mixed below the inversion layer. Lidar backscatter profile measured at the same time is very similar to water vapor profile indicating aerosol is also distributed below the mixing layer. To verify the method proposed by Flamant et al. [2], the first derivative and the second derivative of range corrected lidar single (*RSCS*) is shown in Fig. 1d for comparison. As shown in Fig. 1d, both minimums of 1st and 2nd derivative are very close to mixing height. As shown in Fig. 2, lidar observed mixing heights are highly correlated with radiosonde measurement (launched around middle day) with correlation R^2=0.9, indicating lidar method could be applied for most of cloudless condition. In this study, minimum of the 1st derivative of *RSCS* is applied on seeking mixing layer. Owing to system limitation, the minimum detectable mixing height is about 200~300 m.

3. RESULTS

Fig. 3 shows 5 cases measured on 2005/3/10, 4/21, 4/29, 5/18, 5/20 and 5/30 that mixing height exhibits clear diurnal cycle. According to Fig. 3, mixing height at nighttime is about 0.2 ~ 0.5 km. Mixing height start to up quickly growing at 8:00L~10:00L and reach maximum height about 1.0 ~ 1.6 km at 12:00L ~ 14:00L. Usually, mixing height would maintain at maximum height for about one hour and then begin to slowly (comparing to growing) decent. In general, the evolution of mixing height is found to be associated with surface ground temperature. Three selected cases measured on 2005/4/21, 5/30 and 5/18 is shown in Fig. 4 to demonstrate the relationship between mixing height and surface ground temperature. According to Fig. 4, surface temperature and mixing height are highly linearly correlated with R^2=0.668, 0.886 and 0.601 respectively, but the slope and intercept of regression lines are different, which indicate the dynamics of mixing height evolution is not dominated by surface temperature only.

Weather system or wind speed is found to be another important factor controlling the height of mixing layer. Fig. 5 shows evolution of mixing height measured during 2005/3/20 09:00L and 3/21 18:00L along with surface temperature and wind direction and wind speed. According to Fig. 5, mixing layer varies with surface temperature at daytime. While a front passing through (during 3/20 15:00L ~ 3/21 07:00L, wind direction change to NE), mixing layer did not decent with temperature decreases but remaining about 1 km.

Fig. 7 shows another lidar and radiosonde results measured at 2005/3/16 11:00L (same day as Fig. 1). The surface temperature at 11:00L and 14:00L is 24°C and 26°C respectively. By the regression lines shown in Fig. 4, the mixing height difference should be about 200 m ~ 300 m, but both radiosonde and lidar data show the mixing layer at 11:00L is about 900 m lower than that at 14:00L. Radiosonde data shows (Fig. 6e) the wind direction start at change from SE to NW at about 500 m, implying the height of mixing layer might be suppressed by wind shear.

Fig. 7 shows the seasonal averaged diurnal cycle of mixing height and surface temperature. The maximum and the minimum mixed heights are happened on summer and winter as expect. At springtime, the mean temperature is lower than autumn, but the diurnal cycle of mixing height is very similar which may caused by winter monsoon.

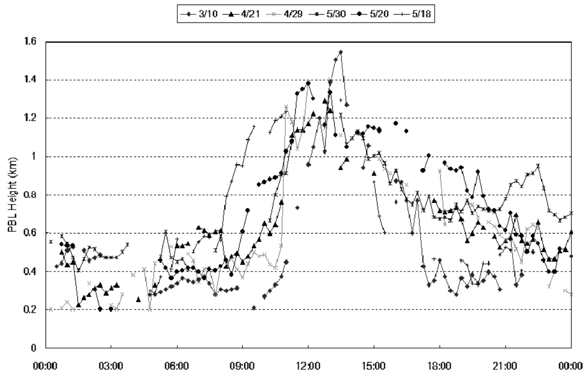

Fig. 3. Diurnal variation of mixing heights obtained by lidar on 2005/3/10, 4/21, 4/29, 5/30, 5/20 and 5/18.

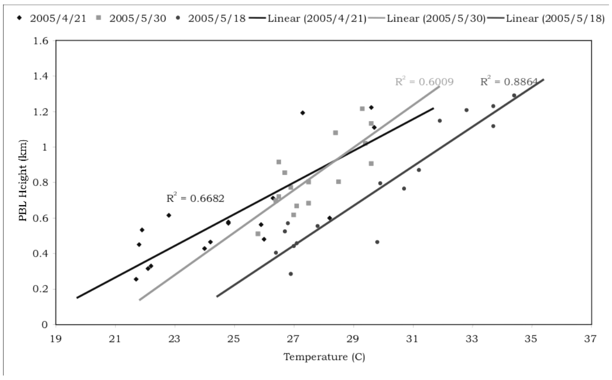

Fig. 4. Correlations between mixing height and surface temperature for three selected cases measured on 2005/4/21, 5/30 and 5/18. The correlations R^2 are 0.668, 0.886 and 0.601 respectively.

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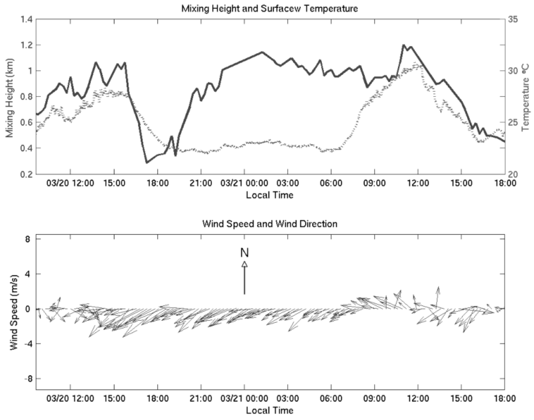

Fig. 5. Mixing height, surface temperature and wind-barb measured during 2005/3/20 09:00L ~ 3/21 18:00L.

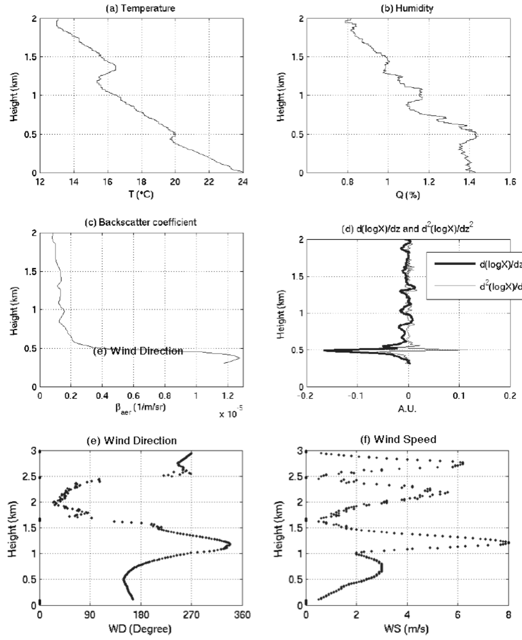

Fig. 6. (a)-(d) Same as Fig. 1 but measured at 2005/3/16 11:00L. (e) Wind direction and (f) wind speed measured by radiosonde.

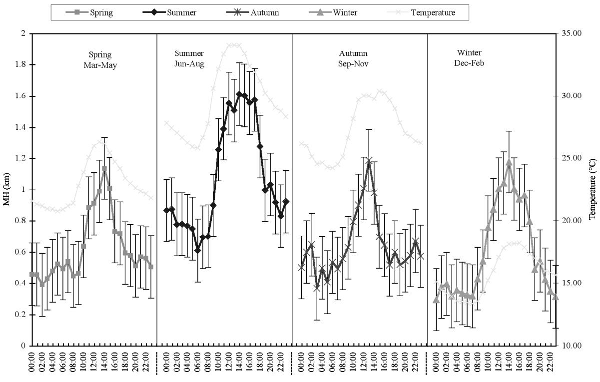

Fig. 7. Seasonal averaged diurnal cycle of mixing height and surface temperature.