Diurnal variation of mixing height in Hong Kong

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ABSTRACT

Two Lidar measurements were taken in Hong Kong during 7th to 8th March and 29th to 30th August 2003 for studying the diurnal variation of urban boundary layer structure. Measurements were recorded by a mobile micro-pulse Lidar and a scanning Doppler Lidar. The first measurement was performed in early March when a cold font was influencing Hong Kong. Conversely, the second measurement was carried out in August on a day with hot and sunny weather. Result shows the mixing height increased throughout the day, peaked in the afternoon and decreased in the evening once solar heating ceased. Higher maximum mixing height can be observed in hot weather and high wind speed. Performances between the two Lidar systems were also examined. Mixing height estimation from both systems was close. Both systems measured a similar trend of the boundary layer growth. Comparisons were made between both Lidar profiles and potential temperature profiles from radiosonde data measured at Hong Kong Observatory (HKO)'s upper air station at King's Park near the urban area. General agreement can be observed.

1. INTRODUCTION

The depth of atmospheric boundary layer, ABL (mixing layer height, MLH) is an important quantity in meteorological and environmental issues. It affects pollutant dispersion, heat exchange, moisture and wind velocity etc. The thickness of the boundary layer is varying throughout the day and its growth is tied to the solar heating [1]. Generally ABL can be classified into convective boundary layer and stable boundary layer. Convective boundary layers usually occur in daytime when there is strong convection and solar heating in the atmosphere. Stable boundary layer is mainly dominant at night or under cold weather when the warm air transferred downward to the cooler surface. The depth of ABL also plays an important role in the studies of air pollution dispersion. Particle concentration below the mixing height is significantly higher than the free atmosphere. Pollutants are trapped below the MLH and dispersed by strong mixing. Therefore, a number of measurements and numerical models [2] have been developed to determine the boundary layer height.

A mobile micro-pulse Lidar and a scanning Doppler Lidar have been operated in Hong Kong since 2002. Hong Kong is a densely populated coastal city located in the edge of the large land mass of Asia. Because of the presence of the high rise building and intensely human activities, boundary layer has a complex structure. Application of Lidar provides an effective and convenient method to study the growth of urban boundary layer. Since the Lidar systems are operating in urban area or near the airport, they are designed to be eye-safe. In the next section, details and the working strategies of the two Lidar systems will be described. Two Lidar measurements taken on March and August 2003 were presented to illustrate the development of MLH during cool and hot weather conditions. Finally, comparisons were made between the Lidar and radiosonde data.

2. INSTRUMENTS

2.1 Lidar in City University of Hong Kong

An eye-safe Mie Lidar system has been developed by City University of Hong Kong (CityU) since November, 2002. For mobile measurements, the Lidar is installed inside a vehicle and powered by eight 12V batteries. The system is based on a Nd:YAG laser operating in 532nm wavelength. To achieve eye-safety, the beam diameter is expanded to 70 mm. The detector employed is a Schmidt-Cassegrain f/10 telescope with a f/6.3 focal reducer and 135 mm diameter. To minimize the sky background, a band-pass filter with 0.3nm FWHM is employed. A transient recorder operating at 20 MHz with 1k memory bins is used to perform data logging. This gives the system a maximum range of about 7.6 km with a spatial resolution of 7.5 m. The recorder performs both analogue and photon counting channels. Analogue channel performs better in the morning while photon counting channel gives a better range at night. Furthermore, an iris is used to adjust the field of view so that the Lidar can have better near-field performance at day time. Near-range correction is also applied to correct the diminished signal if the light is being out of focus at the field stop. Therefore, the Lidar is able to be operated in a near range of about 30 m.

The mobile Lidar is located at the urban area (Fig. 1) and it is mainly operated in vertical direction. To improve the signal to noise ratio in the far range, signals are integrated for about ten minutes. Backscattered signals are inverted to extinction profiles before the

MLH estimation. Data inversion is achieved by the Fernald's method [3] and is described in [4]. MLH can be identified by searching the distinct drop in the extinction profiles. In the mobile Lidar, this process is doing manually. On the day with cloud cover, the cloud base is taken as MLH. In addition, the Lidar is not operated during the periods of precipitation.

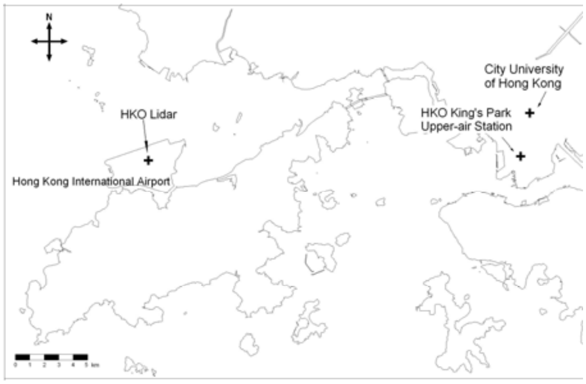

Fig. 1 Locations of the Lidar and the HKO upper-air station are shown in the map

2.2 Lidar in Hong Kong International Airport

A scanning Doppler Lidar has been set up in Hong Kong International Airport (HKIA) since May 2002 (Fig. 1). The system is operated by Hong Kong Observatory and primarily used for monitoring windshear around the airport. Additionally, it also provides backscattered signal simultaneously for spatial aerosols detection. The infrared Lidar is operating in 2.022μm wavelength and gives a measurement range of nearly ten kilometers with range resolution about 100m. It has pulse energy about 2mJ and aperture diameter 10cm. The system operates continuously and automatically. Its scanning strategy comprises plan position indicator (PPI) scans and range height indicator (RHI) scans continuously throughout the day which provide two dimensional and high spatial resolution pictures of the atmosphere to study the aerosol distribution. Depending on the scanning strategy which will be modified as required to facilitate windshear detection, the Lidar performs each PPI and RHI scans every 2 to 5 minutes.

Data from RHI scans are used to determine the boundary layer height. Before the MLH estimation, data inversion is performed by using the Klett's method [5]. The inversion method is described in [6]. To determine the MLH, extinction is averaged horizontally to form a signal profile. The technique for mixing height estimation is similar to the one described in Marsik [7]. The Lidar profiles are analyzed for an entire day and structural features are tacked from profile to profile. This method can avoid mistaking other atmospheric features for the true mixing height.

3 DIURNAL VARIATION OF MIXING HEIGHT

Two set of 24-hour measurements taken from 7th to 8th March, 2003 and from 29th to 30th August, 2003 will be presented in this section. In order to investigate the correlation between MLH growth and meteorological data, wind speed, wind direction, temperature and relative humidity are also plotted. In the first measurement period, Hong Kong was influenced by northerly winds behind a cold front and the temperature at the airport dropped from 15 degrees in the afternoon of 7th to 12 degree Celsius in the 8th morning. While during the second measurement period, a ridge of high pressure dominated and the weather was hot and sunny. These two measurements illustrated urban boundary layer development during cool and hot weather conditions. Results from the two Lidars and radiosonde are compared and discussed.

3.1. Study on 7th March, 2003

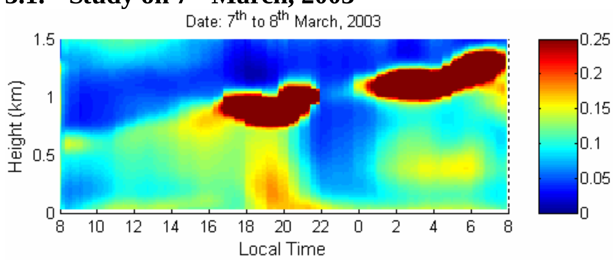

Fig. 2 Extinction coefficient measured by the Doppler Lidar on 7th to 8th March, 2003

Under the influence of northerly winds behind a cold front, temperature in the airport dropped to about 10 Degree Celsius on 8th March, 2003 morning (Fig. 4). High cumulus clouds were located at about 2km throughout the day. In Fig. 2 the extinction coefficient measured by the HKO Doppler Lidar clearly showed the development of the boundary layer. The thickness of boundary layer could be recognized from stronger return signal below the MLH. In order to analyse the growth of the mixing height, the MLH is extracted and plotted together with the MLH measured by the mobile Lidar and radiosonde data in Fig. 3.

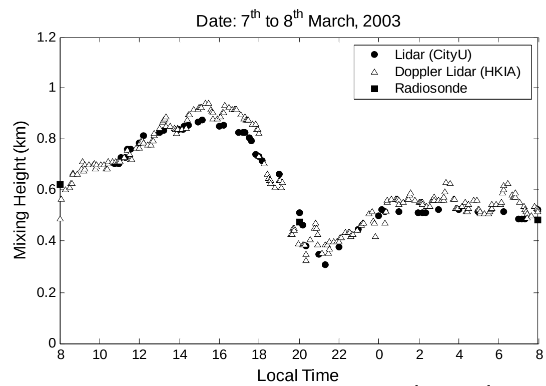

Fig. 3 Retrieved mixing height on 7th to 8th March, 2003

At 8 a.m., both estimations from radiosonde and Lidar data indicated the depth of the boundary layer was approximately 600m. The depth was relatively higher comparing with the normal since the fresh northeasterly winds (~35km/hr) were prevailing and induced more convective turbulence. As the solar heating increased, the thermal and mechanical forcing induced the growth of the boundary layer. It rose up gradually and reached the maximum height of 900m at approximately 3p.m.

Temperature and wind speed started to fall off in the evening. With weaker driving forces, the growth of the mixing layer slowed down. The boundary layer dropped rapidly between 5 p.m. to 8 p.m. when the sun set and solar heating decreased. Meanwhile a stable layer was formed near the surface which grew to a depth of about 400 m. Since the moisture evaporated into the mixing layer in daytime, clouds occurred at approximately 700 m after sunset. At midnight, wind speed increased again and induced further significant growth of the boundary layer. It finally reached 600m and became stable throughout the night.

Although the maximum mixing height measured by the Doppler Lidar was a bit higher than the mobile Lidar in CityU, the estimations of mixing height between the two Lidar systems were close throughout the day. Both systems measured a similar trend of the boundary layer growth. Radiosonde data taken at 8 p.m. was also compared in Fig. 3 and a good agreement could be observed. This showed the Lidar measurement of mixing height was reliable.

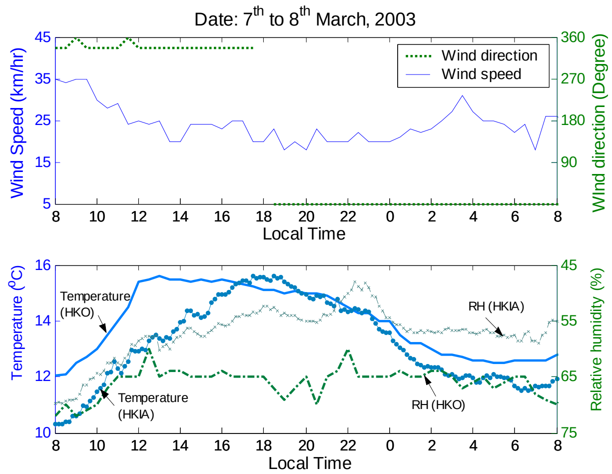

Fig. 4 Meteorological data measured on 7th to 8th March, 2003

3.2 Study on 29th August, 2003

Similar boundary layer development can be observed on 29th to 30th August 2003. The extinction coefficient measured by the Doppler Lidar and retrieved MLH are showed on Fig. 5 and 6 respectively. During the measurement period, Hong Kong was influenced by a ridge of high pressure and the weather was fine. The temperature climbed to about 32 Degree Celsius by noon (Fig. 7). The sky was mostly clear with small portion of cloud cover. Since west to southwesterly winds from the sea was prevailing, visibility remained high throughout the day.

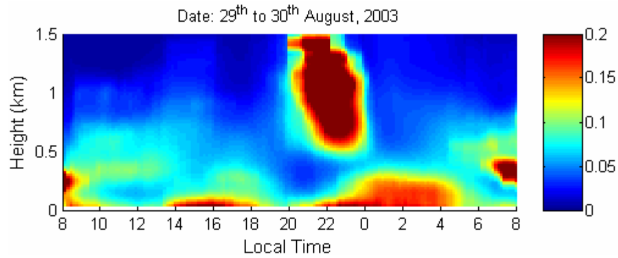

Fig. 5 Extinction coefficient measured by the Doppler Lidar on 29th to 30th August, 2003

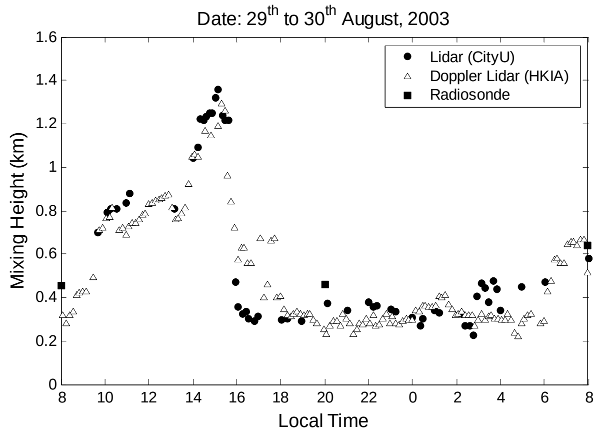

Fig.6 Retrieved mixing height on 29th to30th August, 2003

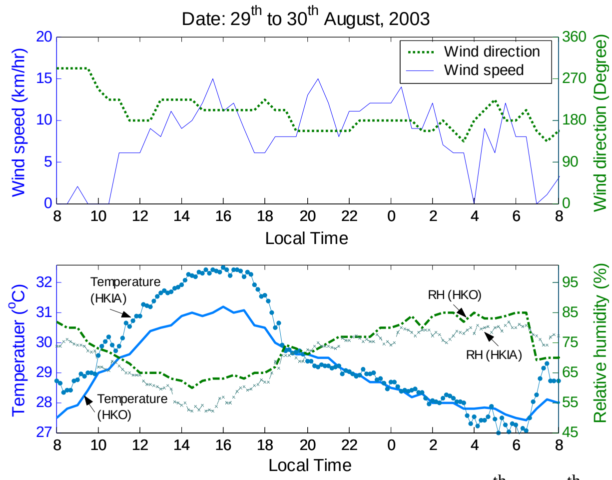

Fig. 7 Meteorological data measured on 29th to 30th August, 2003

At 8 a.m., the estimated mixing height was approximately 300m. It increased gradually during the day and reached a maximum height of 1300 m at about 4 p.m. The boundary layer decreased gradually after 4 p.m. As the air cooled down, clouds occurred at about 600 m after sunset. The height of the boundary layer finally dropped to 300 m where it remained for most of the night. As the sun rose higher in the sky, the boundary layer began to grow again on 30th August, reaching 600 m at 8 a.m.

Comparing with the previous measurements taken in March, the second measurement had higher maximum mixing height. In March, high clouds and cold weather limited the growth of the boundary layer. With weaker thermals, the MLH exhibited slower growth. Therefore, the maximum mixing height in August was over 1300 m and was 400 m higher than that observed in March. Besides, the two measurements also demonstrated the importance of wind on the development of stable boundary layer at night. Although the second study was performed in hot summer with higher surface temperature throughout the day, the height of stable layer was lower comparing with the first measurement. The main reason is the wind speed in the first study was much higher. After the sun set, the mechanical forcing induced by wind become the main source affecting the growth of the boundary layer. Therefore, stronger winds contributed to a relatively higher stable boundary layer at night.

4. COMPARISON BETWEEN LIDAR AND RADIOSONDE PROFILES

Lidar data are compared with radiosonde data taken on 7th March, 2003 8 p.m. in Fig. 8. The extinction profiles of the mobile Lidar of CityU and HKO Doppler Lidar at HKIA are plotted together with the potential temperature profile of the radiosonde for comparison. By locating the distinct drop of the extinction profiles, the boundary layer can be identified at about 400 m from both Lidar profiles. From the Lidar (HKIA) profile, cloud can also be observed at about 900 m. The MLH was inferred with the potential temperature profile from radiosonde profiles. The MLH can be identified by searching the sharp increase in potential temperature. Therefore, from the radiosonde data, the MLH was estimated at about 400 m which is in agreement with the lidar results. Another increase in potential temperature can also be identified at the cloud height.

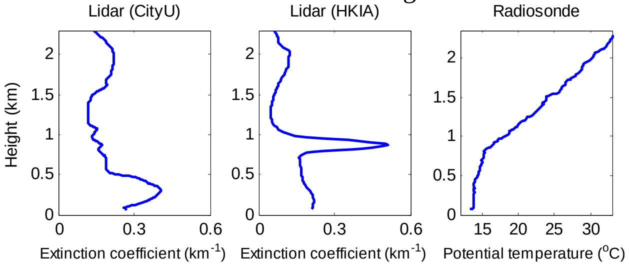

Fig. 8 Comparison between Lidar and radiosonde profiles measured at 8 pm on 7th March, 2003

5. CONCLUSIONS

A mobile micro pulse Lidar and scanning Doppler Lidar have been used to study the diurnal variation of urban boundary layer in Hong Kong. Two set 24-hour measurements were performed in March and August 2003. Results showed the growth of mixing height is tied to the solar heating and wind speed. Higher maximum mixing height could be observed in hot weather and high wind speed. The development of the mixing layer was also demonstrated. Mixing height increased gradually in the morning and reached the maximum height in the early afternoon. Once the solar heating ceases, the mixing height dropped rapidly. It became stable again at night. A comparison of the mixing height estimates between the two Lidar systems and radiosonde data is performed. Similar trend of the boundary layer growth could be observed from both Lidar systems.

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