S3-6 Lidar Observation of Atmospheric Processes in Hong Kong

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1 Introduction.

The planetary boundary layer (PBL) is defined as the part of the troposphere that is directly influenced by the earth's surface, and responds to the surface forcing (Stull, 1988). The PBL is characterized by a high aerosol and water vapor concentration. In comparison, a relatively less aerosol and moisture concentrations are found in the free atmosphere, leading to a sharp contrast in lidar backscatter signal and making it possible to determine the PBL height. In addition, different aerosol and moist concentrations can be analyzed to show different energy and mass transport processes. Cooper and Eichinger (1994) have studied the urban PBL structures with a scanning lidar and radiosonde observations, presenting the detailed patterns of the nocturnal and daytime PBL structures, and showing the energy and mass exchange characteristics.

The Lidar system in the City University of Hong Kong has been developed for the atmospheric study over Hong Kong area. Some results have been presented including lidar measurement of wind velocity by tracking a single cloud movement, the study of the thermal internal boundary layer (TIBL) growth under sea-breeze circulation, and PBL structures during cold front passage. In this paper, these results have been summarized to show the research activities in Hong Kong. Finally, the future research objectives are also discussed.

2. Lidar System

The lidar at the City University of Hong Kong is a ground-based, backscattered system, consisting of a frequency-doubled Nd:YAG laser operated at 532 nm wavelength and 10Hz repetition rate. The pulse duration is 10ns and the range resolution can be up to 3m. The laser beam is launched to the atmosphere in the direction controlled by a PC computer-controlled scanner. The backscatter signal by aerosol is collected by a Newtonian telescope with 1.5m focal length. The signal intensity is proportional to the volumetric backscattering coefficient of the aerosol particles, atmospheric attenuation, and range correction (Cooper and Eichinger, 1994). Assuming a relationship between the volumetric backscattering coefficient and attenuation coefficients of the atmosphere, we can obtain relative extinction coefficient along the path. Generally, the extinction coefficient is associated with the aerosol particle concentration, size, and shape. Therefore, lidar-derived profile can produce a detailed picture of the PBL structures and characteristics. In particular, due to sparse radiosonde data, it is very difficult to analyze the PBL evolution. However, Lidar can provide us temporal continuous measurements. In addition, spatial scanning can also show us the two-dimensional PBL structures.

The lidar system is located on the top of a nine-story building which is about 57m high above the sea level, and within the Kowloon city centre of Hong Kong. The site is about 3km northwest of the Hong Kong Observatory (HKO) where other meteorological data including radiosonde data are obtained (See Figure 1). Some comparisons between the lidar and radiosonde data have been made to show their good agreement in determination of the mixing layer height (Mok et al. 1998).

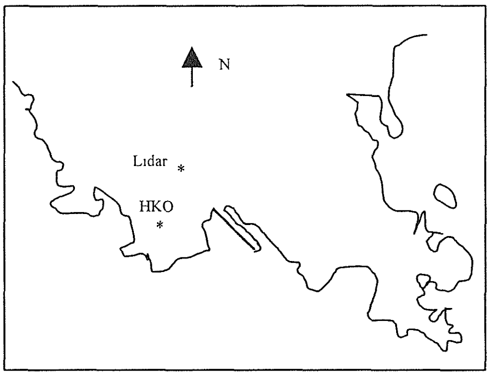

Fig. 1 Map of the Kowloon City of Hong Kong

3 Results

(1). Lidar Measurement of Wind Velocity

The principle of lidar measurement of wind velocity is realized by tracking a single cloud movement in a given time period. General consideration, the velocity of cloud measurement can indicate wind velocity. Leung et al (1995) have presented their measurement results including the change of wind direction and velocity with time and the comparison results of lidar and balloon wind measurements in Hong Kong (See Figure 2). A good agreement has been obtained to show the applicable perspective of lidar measurements of wind velocity. The error is mainly dependent upon the uncertainty of cloud displacement measurement due to the change of the cloud properties with time, but decreasing the measurement period can control this uncertainty.

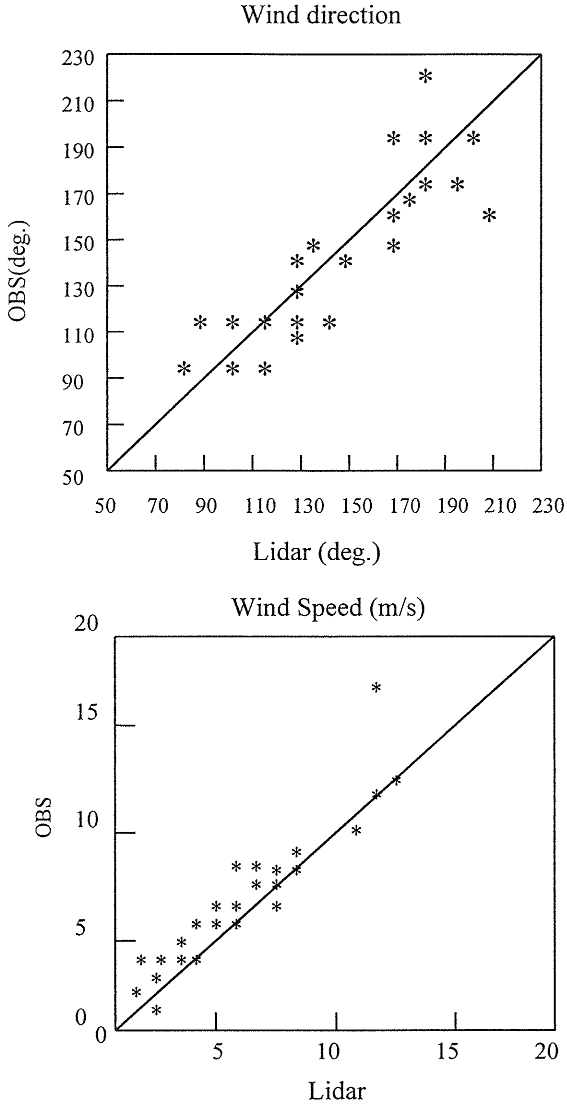

Fig. 2 A comparison of lidar and balloon wind measurement in Hong Kong (after Leung et al., 1995)

(2). TIBL Growth under Sea-breeze Circulation

Slab models provide a physical approach to the prediction of TIBL growth, and have been used widely in coastal air pollution dispersion because of their simplicity. The slab models have successfully predicted growth of the TIBL in many coastal regions. In order to void the singularity problem with near-neutral onshore flow, Luhar (1998) present an analytical slab model that can be used for neutral to strongly stable onshore flows. It has been tested to performance well in describing the growth of the TIBL in both the neutral and stable stratification using the Kwinana Coastal Fumigation Study (Luhar et al., 1998). However, the model needs to be tested by lots of measurements in different coastal sites especially with complex coastal line and complex terrain. Also, it should be tested against the neutral onshore flow which is always encountered in Hong Kong (Liu et al., 1999a). However, it is very difficult to measure TIBL height growth with the inland distance by launching radiosondes in many sites, while lidar can realized it by two dimensional scanning along the wind direction to obtain TIBL heights in different inland distances.

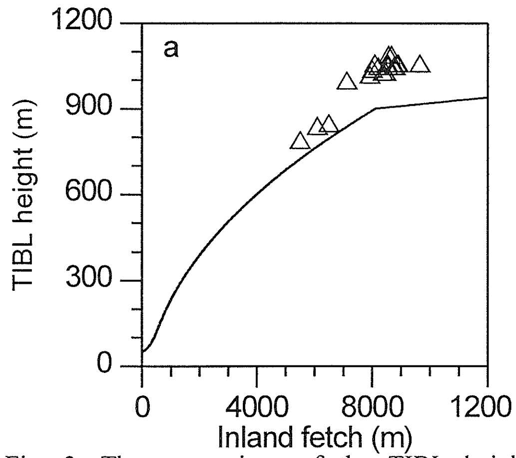

Fig. 3. The comparison of the TIBL height growth of the slab model prediction and lidar observation in Hong Kong on 1400 (LT) 31 March 1999. (Solid line: model calculation; Triangle: lidar measurement).

Figure 3 presents the comparison results of the slab model and lidar measurements of the TIBL heights at 1400LT 31 March 1999. It clearly shows that the TIBL height grows rapidly near the coastal line. As the downwind distance increases, the slow TIBL height growth is found. In general, Figure 3 indicates that the slab model estimates of the TIBL height growth are smaller than those by lidar measurements probably due to the error of onshore flow stabilities at different heights that are obtained from the radiosonde data in HKO. Meanwhile, we found that TIBL heights are non-spatially uniform due to non-uniform heating of underlying surfaces and the effect of the complex terrain with numerous hills, which can not be identified by the slab model. Furthermore, It is expected that the TIBL might be three-dimensional structure over Hong Kong area due to its peninsula-like terrain, which will be investigated in the future.

Under this condition, this complex structure would require a three-dimensional numerical model (Cheng et al., 1999) and high spatial resolution measurements by lidar and other techniques.

(3). PBL Structure

a. A case study of nocturnal mixing layer

Most cities are anthropogenic sources of heat and pollution. Large coverage of buildings and streets can be found in the Kowloon City of Hong Kong, making both the surface albedoes and heat capacity larger than that in the rural area. Therefore, the air in the surface layer of the urban area is warmer than its surrounding, which gives rise to urban heat island (Stull, 1988; Oke, 1987). Figure 4 shows the temperatures measured in HKO (urban) and Lau Fu Shan (rural). The temperature in the urban area is always greater than that in the rural area.

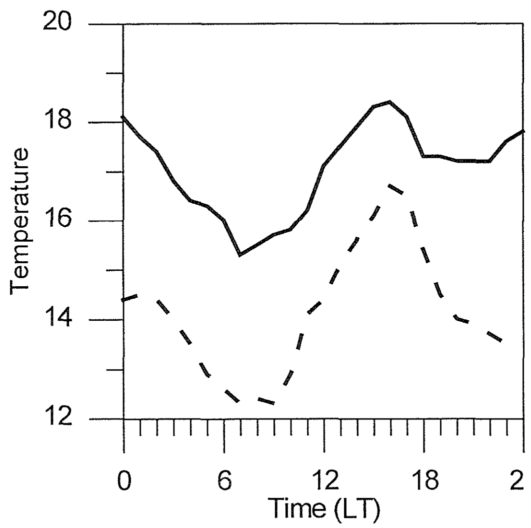

Fig. 4 Diurnal variation of the temperatures in the urban (solid line) and the rural areas (dashed line) in Hong Kong on 5 January 1998.

Lidar measurement has indicated the mixing layer height reaches its maximum of around 1100m at around 1600LT with the maximum ground temperature at that time. After sunset, the turbulence begins to decay due to no flux transport from the surface. With the cooling of the ground surface, stably nocturnal boundary layer forms that can be found from the radiosonde data obtained in HKO. From Figure 5, we can see that the stable boundary layer height can be estimated about 150m with the residual layer aloft up to 1000m where the capping inversion layer is located. At around 1800LT, the ground surface temperature suddenly decreases slowly, and there is no change at 2000LT and 2100LT. After 2200LT, the temperature begins to rise up to 17.6^{0}C at 2300LT and 17.8^{0}C at 2400LT. While the temperatures in its rural keep decreasing from 16.7^{0}C at 1600LT down to 13.4^{0}C at 2400 LT. The temperature in the urban is 4.4^{0}C higher than its rural area at 2400LT. At the same time, a shallow convective mixing layer was observed after 2100LT from the lidar data.

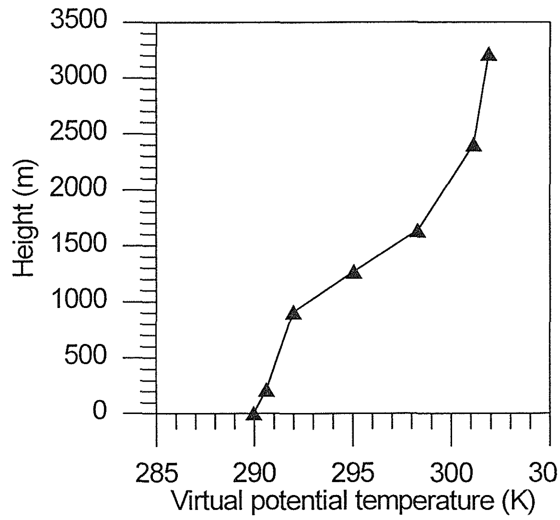

Fig. 5. The radiosonde measurement of the PBL structure at 2000LT of 5 January 1998.

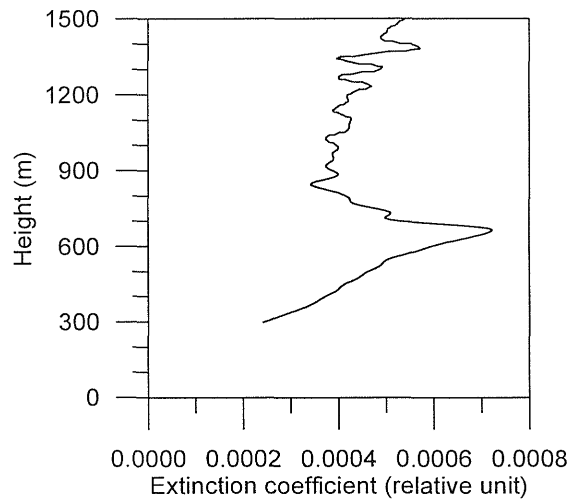

Fig. 6. Lidar measurement of the nocturnal convective mixing layer at 2200LT of 5 January 1998.

Figure 6 shows an example of the lidar observation at 2200LT. The convective mixing layer height can be obviously observed around 700m. Such a high nocturnal mixing layer is unusually observed in other urban sites. Because of the shallow stable boundary layer (around

150m), the rapid growth can be found in the residual layer once the convective boundary layer erodes and reaches the top of the stable boundary layer. At that time, the fumigation is occasionally found to be similar to the morning mixing layer erosion because the pollutant in the residual layer is transported down to the surface.

b. PBL structures during a clod front passage

The PBL structures are not only influenced by local turbulent transports, but also by advective activities, subsidence and rising. In winter, the cold air activities have occasional affect on the PBL structures in Hong Kong. The evolution processes of the PBL have been studied during a cold front passage by integrating both the standard meteorological data and the lidar observations on 4 January and 5 January 1998. It has given a better understand the heat and mass transport over complex terrain and under the conditions of dry cold advective and warm moist air advective (Liu et al., 1999b). In the different stages of the cold front passage, the PBL structures change significantly due to subsidence and rising associated with the cold air advection and the local urban heat island climate. Because of the sparse radiosonde data, the complex PBL structures and their evolution could be analyzed more reliably by integrating standard meteorological data and lidar data, rather than by traditional techniques alone.

4 Summary

The complex atmospheric processes occurring in the PBL leads to the different aerosol and water vapor concentration profiles. Lidar system can be used for determining the PBL structure by coupling with other meteorological data. Its continuous measurement can provide us much useful information such as wind speed, wind direction, the TIBL height growth, the PBL structures under different weather conditions. Our study will focus the vertical structures under sea- and land- breeze conditions, three dimensional TIBL structure and urban PBL characteristics.

5 Acknowledgements

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