Impact of turbulence on aerosol vertical distribution measured by lidar at Chung-Li (25°N, 121°E)

C.W. Chiang[1,2], S.K. Das[2], J.B. Nee[2]
1. Research Center for Environmental Changes, Academia Sinica, Nankang, Taiwan
2. Department of Physics, National Central University, Chungli, Taiwan

Abstract

Aerosol backscattering signals measured by lidar have shown large fluctuations resulting from the turbulence of air in the lower atmosphere. The height difference between the aerosol backscattering signals and turbulence signals is relative with aerosol size as demonstrated by dual-wavelength lidar measurements. The heights and evolutions of aerosol boundary layer can also be determined by using the turbulence property. From three years observations (2002-2004), we found that the aerosol boundary layer shows seasonal and height variation. The concentration of ground pollutants has been affected by this seasonal and height variation of aerosol boundary layer.

1. Introduction

The planetary boundary layer (PBL) defined as the part of the troposphere that is directly influenced by the presence of the earth's surface, and responds to surface forcing with a time scale of about an hour or less. Turbulences, which are frequently observed in the nighttime boundary layer, transport litter heat, humidity, and other scalars such as pollutants. These turbulences can be generated locally by mean-wind shears and by mean flow over obstacles (Stull, 1988). However, accurate measurements representative of boundary layer heights are complicated due to interferences of temperature, humidity, cloud cover, wind speed and different aerosols constituents. The description of the boundary layer structure obtained from radiosonde made at synoptic hours can not contribute to a complete understanding of meteorology. Therefore, our purpose is to identify a method (Flamant et al., 1997; Laurent et al., 1999) that can be used on a large set of lidar data to understand the evolution of boundary layer during nighttime.

2. Methodology and Analysis

The aerosol content of the lower atmosphere fluctuates under the continuous influence of particle source and deposition mechanisms. These fluctuations in aerosol amount, particular in the atmospheric boundary layer, can easily be monitored by mean of a lidar as the scattering from aerosol particles contributes strongly to the lidar backscattered intensity in this region. Thus the inhomogeneities in aerosol content can be used as tracers of the structure and stratification of the boundary layer which can be attributed to the phenomena of convective activity and turbulence.

We define the range-squared signal (RSS) as Eq. (1).

$$RSS = P_R * z^2 \qquad (1)$$

where P_R is the lidar return signal, z is the range between the laser source and the target. The standard deviation is calculated from the temporal fluctuation of RSS at each altitude, as Eq. (2).

$$\sigma_{RSS} = [\frac{1}{N}\sum_{i=1...N}(RSS_i - \overline{RSS})^2]^{1/2} \qquad (2)$$

where N corresponds to the number of profiles. Each σ_{RSS} profile is obtained by 2.8 minutes. The top of boundary layer is determined as the maximum standard-deviation value of the RSS, but some standard-deviation profiles are eliminated due to extreme fluctuation, which caused by lower clouds.

Ångström coefficient is the index of particle size. Ångström coefficient (α) increases with decreasing particle size.

$$\alpha = \ln(\frac{\beta_{a_1}}{\beta_{a_2}}) / \ln(\frac{\lambda_2}{\lambda_1}) \qquad (3)$$

where β_{a_1} and β_{a_2} are aerosol backscatter coefficients which are obtained from lidar measurements at wavelength $\lambda_1 = 532\ nm$ and $\lambda_2 = 1064\ nm$, respectively.

3. Result and Discussion

3.1 The characteristics of the boundary layer

In this paper we focused on the mesoscale inversion (MIL) layer at nighttime due to this layer at nighttime is more stable than that layer with strong convection at daytime. Figure 1a shows the aerosol fluctuation derived from Eq.(2) in the night of Jan. 16, 2003. The aerosol fluctuations are observed at 0.7 to 0.9 km and a weak fluctuation layer around 2 km. The top of mesoscale inversion layer (MIL) is determined as the maximum standard-deviation value (SD) of range-squared signals (RSS) shown as line-circle symbol. Perturbation of this layer height is observed between 0.8 and 1.15 km during the observation period. It is known that such type of turbulences may be attributed to the air flow over orographic location, shear instability, or geostrophic wind factor. During the night, the intensity of fluctuation decreases with time shown as fig. 1(b) due to the depth of significant cooling increases with time.

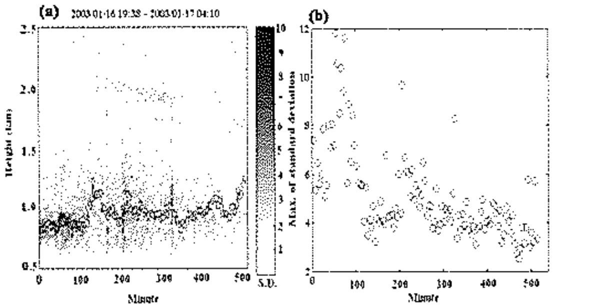

Figure 1(a). The perturbation behavior derived from aerosol scattered signals. The top of boundary layer (-o-) determined as the maximum standard-deviation value and (b) the intensity of fluctuation decreases with time on Jan. 16, 2003.

We compared the mean height of the inversion layer measured by lidar during 20:00 to 21:00 o'clock (local time compare to the time of launch radiosonde) with temperature inversion and wind shear. The result from 2002-2004 is shown in fig.2. In fig.2 only show the mean height of temperature inversion due to its uncertainty is large and in fact, sometime the inversion layer determined by temperature inversion is loosely. The height of inversion layer shows the periodic variation and the highest of inversion layer observed in summer related with strong convection. The average height of inversion layer measured by lidar is around 0.57 km. It also shows better correlation between the height measured by lidar and determined by wind shear.

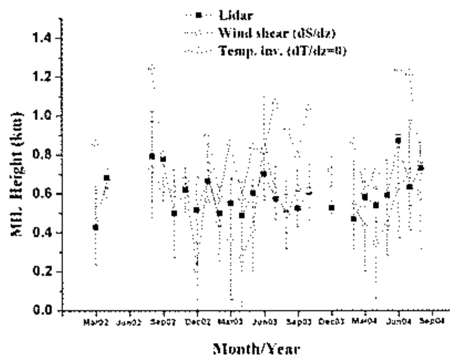

Figure 2. The heights of boundary layer from the lidar measurements (■) and temperature inversion (△) and wind shear (○) derived from radiosonde data between March 2002 and August 2004.

3.2 The effects of the boundary layer height

The hour variations of inversion layer height and PM10 shown as fig.3. In this figure the inversion layer has anti-correlation with the ground base particulate measurements. This appears natural considering descending the layer height should be related to increase of aerosol loading, but not for all hour variation, we consider that is due to other factors such as transport of pollution or land-sea breeze.

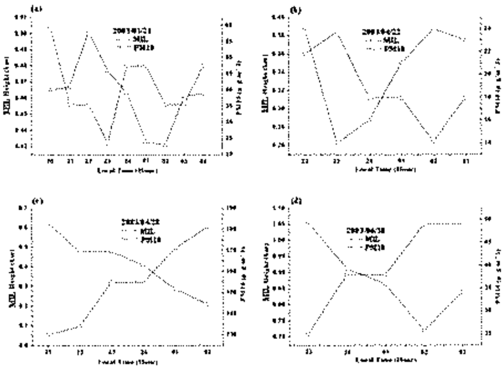

Figure 3. The hours variation of the boundary layer height and PM10 on (a) Mar. 21, 2003 (b) Apr.22, 2003 (c) Apr. 28, 2003 (d) Jun. 30, 2003.

The seasonal variation of inversion layer height, aerosol optical depth (AOD) and relative humidity made in 2002-2004 is shown as fig.4. The AOD in 0.5-1 km is the highest in summer (Jun. to Aug.) with the mean value around 0.12 and lower mean value is 0.04 occurred in the fall (Sep.-Nov.). The variations of the inversion layer height and relative humidity show the similar trend that appear maxima mean value in summer, and minima mean value in winter. Therefore, the higher inversion layer and heavier relative humidity occurred in summer may be the reasons for the AOD in 0.5-1 km appear the highest in summer. The higher heights of inversion layer mean stronger turbulence, which carried more pollutant or large particles to higher altitude and produced more scattering. The increase of relative humidity will cause hygroscopic aerosols to grow and the scattering cross section of the aerosols to increase.

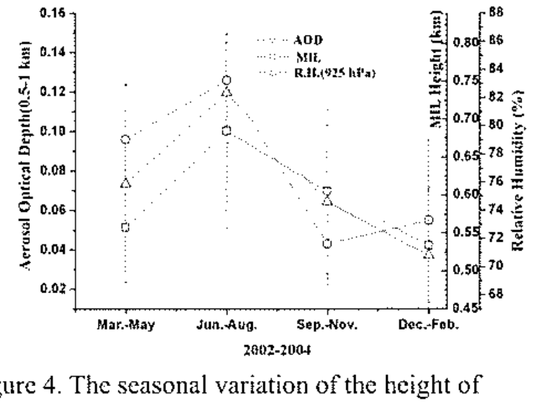

Figure 4. The seasonal variation of the height of boundary layer (□), aerosol optical depth (○) and relative humidity (△) during 2002-2004.

3.3 The aerosol size distribution in the boundary layer

Fig. 5 shows the normalized mean of standard-deviation value and range-squared signals on Apr. 22, 2003. The difference between the two signals is around 0.75-0.94 km. From the result of using dual-wavelength lidar measurement, the height distribution of Ångström coefficient is also shown. The larger aerosol particles are distributed below the subject layer. Therefore, difference between the standard-deviation value and range-squared signals is mainly caused by the large size of particles. The large particles produced stronger intensity of range-squared signal (larger optical depth) but less turbulence under stable atmospheric condition.

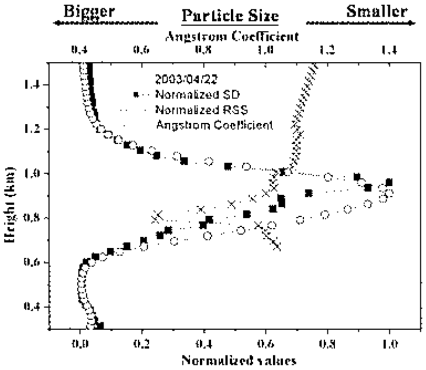

Figure 5. The normalize mean of standard-deviation value (■) and range-squared signals (○) and Ångström coefficient (x) on Apr. 22, 2003.

4. Summary

From three years observations (2002-2004), we found that the aerosol boundary layer shows seasonal and height variations which have been affected the concentration of ground pollutants. The higher inversion layer and heavier relative humidity occurred in summer may be the reasons for the aerosol optical depth in 0.5-1 km appear the highest in summer. The height difference of the fluctuation signals and backscatter signals are mainly caused by aerosol size distribution, which is demonstrated by using dual-wavelength lidar operating at 532 nm and 1064 nm.

Reference

Chiang, C.W., et al., 2004: "Lidar measurements of spring dusts in 2002 at Chung-Li (25°N, 121°E)", TAO, 15, 813-824.

Flamant, C., et al., 1997: "Lidar determination of the entrainment zone thickness at the top of the unstable marine atmospheric boundary-layer", Boundary-Layer Meteorol., 83, 247–284

Laurent, M., et al., 1999: "Urban boundary-layer height determination from lidar measurements over the Paris area", Appl. Opt., Vol. 38, 945-954.

Stull R.B.,1988: An Introduction to Boundary Layer Meteorology, Kluwer Academic Pulishers, Dordrecht.