Raman/Depolarization Lidar Measurements of Asian Dust at Taipei (25.0°N, 121.5°E), Taiwan during 2/14~2/17/2004

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摘要

本論文報告了 RCEC/NTU 光達系統對 2004 年 2/14 至 2/17 間的沙塵事件中大氣懸浮粒子(氣膠與沙塵)的光散射性質如背向散射、消偏振率以及 Angstrom 係數的垂直分佈。在這波沙塵事件中，光達的觀測結果顯示沙塵主要分佈在 1.5 公里以下，大氣懸浮粒子的消偏振率在沙塵來襲時從背景值約 1% 上升至約 3%，其隨時間消長的趨勢則與地面氣膠質量濃度 (PM10) 的趨勢接近，兩者的相關係數爲R^2=0.604，顯示非球形粒子的增加可能是造成PM10 監測值的增加的原因。光達所測得的Angstrom 係數從背景值(約 2) 下降至約 1 左右，與散光儀的監測的結果相同，顯示大氣懸浮粒子的平均粒徑在沙塵期間有增加的趨勢。
關鍵詞：光達，亞洲沙塵

Abstract

The scattering properties (backscattering, depolarization, and Angstrom coefficient) of suspending particles during Asian Dust event (2/14~2/17/2004) were measured by RCEC/NTU LIDAR system. The results are compared with ground based particle measurements. Surface-ground measurements indicate Asian Dust pass through northern Taiwan from 2/14 to 2/17. Depolarization ratio of dust rises from 0.01 to about 0.03 at height below 1.5 km. The correlation between depolarization ratio and surface-ground mass concentration (PM10) is R^2=0.604 shows higher PM10 value is caused by existence of non-spherical particle. Angstrom coefficients of suspending particle measured by Lidar and Nephelometer decrease from background value (about 2) to ~1, shows the mean radius of particle tends to increase during this dust event.
Keywords: Lidar, Asian dust

1 Introduction

Dust storms originating in the Taklamakan, Gobi, Ordos deserts, or the Loess plateau (March-April-May) are frequent sources of dust in East Asian regions in the spring. The dusts can be transported world wide even across the Pacific Ocean. Under certain weather conditions, dust storms usually lead to high particle concentration in Taiwan and degrade the local air quality. In order to study how dust storms affect the local air quality of Taiwan, a Raman/Depolarization Lidar system owned by *Research Center for Environmental Changes, Academia Sinica* (RCEC) and *National Taiwan University* (NTU) was intensively operated from 2/10~2/20 to monitor the vertical profiles of the atmosphere. In this paper, the scattering properties (backscattering, depolarization, and Angstrom coefficient) of suspending particles measured by RCEC/NTU Lidar system are reported and the results are compared with other ground-base instruments (Nephelometer, Insitu IC, PM10, and PM2.5) nearby RCEC.

RCEC/NTU Lidar is a dual-wavelength Raman and Depolarization Lidar system and currently is installed in the main building of RCEC (25.0°N, 121.5°E). More details are provided in Table 1.

2 Method

The backscattering ratio R of particle is define as the backscattering intensity relate to the backscattering cause by air molecular:

$$R_\lambda(z) = 1 + \frac{\beta_a(z,\lambda)}{\beta_m(z,\lambda)}. \qquad (1)$$

Table 1: RCEC Lidar System

Laser	Nd:YAG (Big-Sky CFR-400)
Wavelength	532 and 355 nm
Pulse energy	65/60 mJ
Repetition rate	20 Hz
Height Resolution	7.5 m
Telescope	ϕ 40 cm
Focal length	160 cm
Channels	532 (S and P) and 355 nm (day and night time) 387 nm (night time only)

where β_m and β_a represent volume backscatter coefficient of air molecular and aerosol respectively. For day-time measurement, the calculations of $R(z, \lambda)$ is using the Klett's method [1] with a fixed lidar ratio of 60. For night-time measurement, the calculation of R is basing on Raman inversion algorithm [2] to improve the accuracy.

The depolarization ratio is define as the ratio of the return light of perpendicular to parallel polarizations, as given by the following equation:

$$\Delta = \frac{P_{\perp}}{P_{\parallel}}, \quad (2)$$

where $P_{\parallel}$ and $P_{\perp}$ are the integrated return power for parallel and perpendicular directions relative to the outgoing laser beam. The depolarization ratio is expected to be related with the particle shape [3]. For spherical particles, such as the stratospheric aerosols, Δ is close to zero. For non-spherical particles, the depolarization ratio is nonzero.

The Angstrom coefficient α as defined in Eq.3 is the negative of the slope of β with wavelength in logarithmic scale. Typical values of α range from >2.0 for accumulation mode aerosols. For aerosols and water droplets with diameters comparable with laser wavelength, $\alpha \approx 1$ and for very large particles (ice particle), $\alpha \approx 0$.

$$\alpha(z) = -\frac{d \ln \beta(\lambda)}{d \ln \lambda} \quad (3)$$

3 Results and Discussions

As shown in Fig. 1, the mass concentration ratio of coarse (2.5~10 μm) and fine (<2.5 μm) mode particles (C/F ratio) between 2/13~2/19 measured at Center Weather Bureau (CWB) shows the concentration of coarse particles is about 5 times that of the non-dust periods (note that the C/F ratio did not rise with PM10 increasing on 2/18). The mass ratio (Fig. 2) of solvable ion (measured by Insitu IC, installed at NTU) and PM10 (GuTing) shows that the mass of non-solvable particles is about 2 times that of the lower-dust periods (2/13 and 2/18). Figure 3 shows the time series of aerosol mass concentrations (PM10) measured at EPA GuTing station and the Angstrom coefficient calculated by nephelometer measurements (NTU). Good agreement was found between PM10 and α, indicating that the size of aerosols tends to increase as PM10 values increase. Thought there still need chemical analysis to identify the existence of dust (not finish yet), the results of above measurements indicate some transport pollutant passed northern Taiwan on 2/15 and we believe that is dersert dust.

Figures 4 and 5 show the height distributions of backscattering ratio and depolarization ratio observed by RCEC Lidar between 2/14 12:00L ~2/18 07:00L. A dense cloud (R_{max} > 500) with low depolarization ratio (Δ < 0.02) could be found at ~1.5km during 2/14 10:00L ~ 2/15 15:00L. Below 1.5 km, the Δ value is as low as ~0.01, and $R_{532} \approx 5$ on 2/14, indicating the suspending particles are mainly composites of spherical particles. Between 2/15 5:00L and 2/16 12:00L, a particle layer is found at a height between 300 m (the lowest height detection limit of RCEC/NTU Lidar) and 1500 m. The values of R slightly increase to about 10, and the values of Δ also increase to about 0.03. After 2/16 12:00L, both Δ and the maximum height of this layer decrease with time disappeared. This aerosol layer disappeared at 2/17 12:00L. Fig. 6 shows Angstrom coefficient α of aerosols measured by the lidar. In Fig. 6, Angstrom coefficients α below 1.5 km are close to 1 between 2/15 and 2/16 and fluctuate around 2 at during the rest of the period. This is similar to the temporal and spectral structure observered in aerosol depolarization ratio.

Figure 7 shows the comparison between lidar measured R_{532}(300 m) values with total scattering coefficient (550 nm) measured by nephelometer (installed at

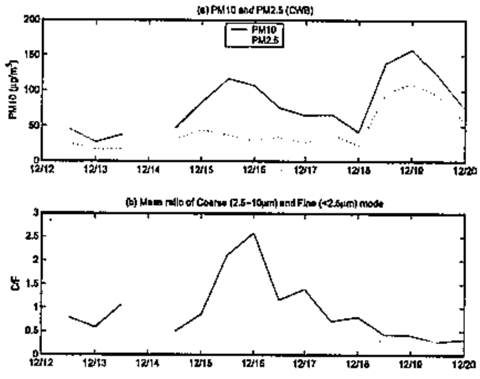

Figure 1: (a) Time series of PM10 and PM2.5 measured at CWB. (b) C/F Ratio of coarse and fine mode particles.

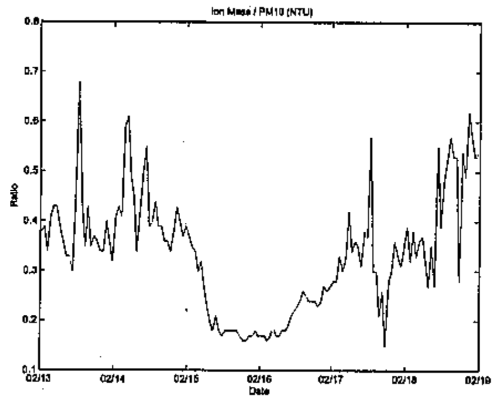

Figure 2: Mass ratio of solvable ions (NTU) and PM10 (GuTing).

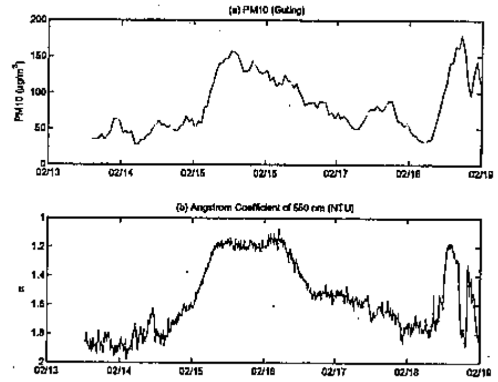

Figure 3: Time series of (a) aerosol mass concentrations (PM10) measured at EPA GuTing station and (b) Angstrom coefficients measured by nephelometer at NTU.

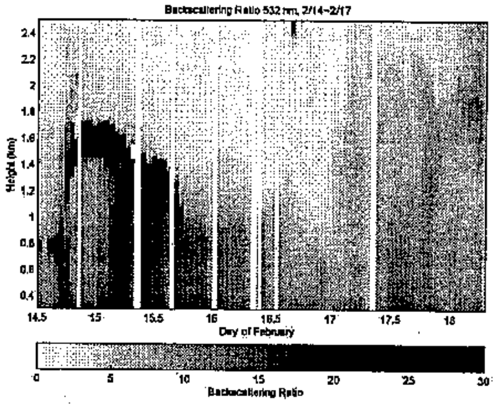

Figure 4: Backscatter Ratio of 532 nm observation between 2/14 12:00L ~2/18 07:00L.

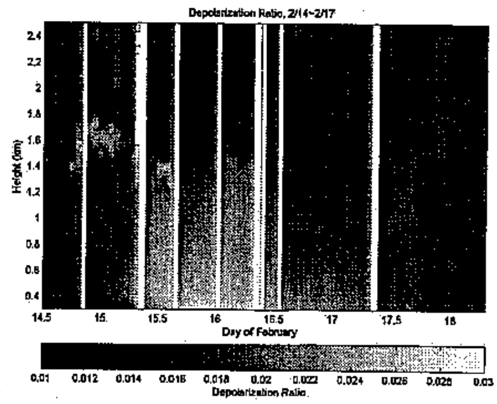

Figure 5: Depolarization ratio observation between 2/14 12:00L ~2/18 07:00L.

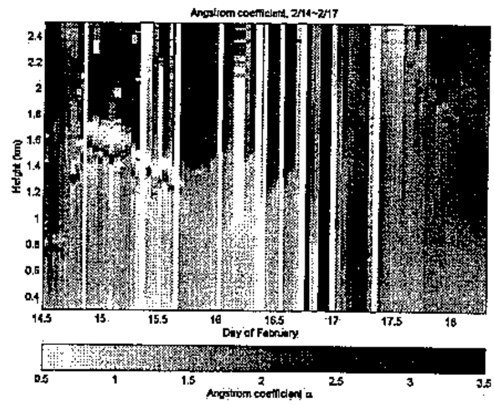

Figure 6: Height distribution of aerosol Angstrom coefficient measured by RCEC Lidar.

NTU). Good agreement was found between these two instruments indicating that the lidar observed aerosol layer (300 m $\sim$ 1500 m) has similar characteristics to the surface layer. Figure 8 shows the time series of lidar depolarization ratio versus height and the near by particle concentration (PM10) measurements (EPA XiZhi station). Comparing Δ(300 m) value with PM10 between 2/14 12:00 and 2/17 12:00 (Fig. 9) results in a the correlation coefficient of R^2=0.604. According to ground based measurements, the rising of PM10 value is cause by dust, therefore, this high correlation implies that the changing of depolarization ratio should be associated with the dust.

For Asian dust, the Δ value is found to be varied from 0.1 to 0.3 [4; 5], which is much higher than the Δ value we found during this dust event. Since this dust event is transported within boundary layer, the shape of dust may be changed by coating with water vapor and other pollutants which may lead to lower the dust depolarization ratio. Of course another possible reason could be that spherical aerosols may still contribute more scattering than dust. More evidence and studies are needed to answer this question.

4 Summary

The scattering properties of Asian dust arrive northern Taiwan during 2/14 $\sim$ 2/17/2004 are summarized as follows:

1. The maximum height of dust layer is lower then 1.5 km. Lidar measured backscattering ratio and Angstrom coefficient show good agreement with nephelometer results.

2. The depolarization ratio of dust is about 0.03. The Angstrom coefficient of dust is about 1.

3. The concentration of coarse mode particles is about 5 times than of local pollutants. The non-solvable particles contribute about 2 times mass more than non-dust periods.

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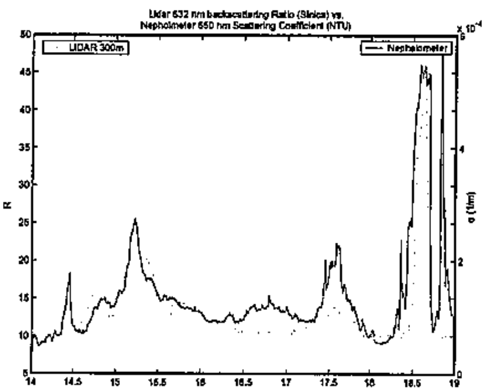

Figure 7: The comparison between lidar measured R_{532}(300 m) values with total scattering coefficient (550 nm) measured by nephelometer (NTU).

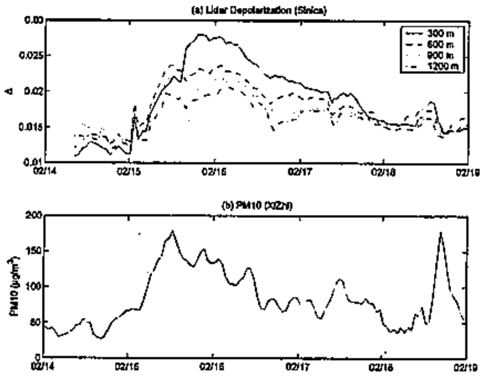

Figure 8: (a) Lidar depolarization ratio at varies heights (above 300 m) (b) PM10 measured at XiZhi.

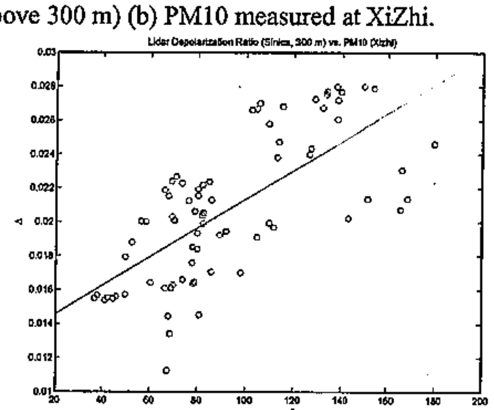

Figure 9: Comparing Δ(300 m) values with PM10 between 2/14 12:00 and 2/17 12:00. Yields a correlation coefficient of R^2=0.604.

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