Hourly Sampling of $PM_{2.5}$ at an AERONET site in Higashi-Osaka, Japan: Dust Events During Spring 2006

Sonoyo Mukai, Mitsuru Nishina, Itaru Sano, Masayoshi Yasumoto,

Yuzuru Nakaguchi, Nobukazu Iguchi and Shoji Mizobuchi

Kinki University, RIST and Faculty of Science & Technology

3-4-1 Kowakae, Higashi-Osaka, 577-8502, Japan

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Abstract

To monitor urban atmospheric particles, we have undertaken simultaneous measurements of aerosols and suspended particulate matter (SPM) at Kinki University Campus, Higashi–Osaka, Japan, since 2004. The largest dust event recorded during our long-term observations was detected during the spring of 2006.

We also examined the relationship between $PM_{2.5}$ concentrations and aerosol properties obtained from radiometry using a multi-spectral photometer located at a NASA/AERONET station. We found a linear correlation between aerosol optical thickness and $PM_{2.5}$ concentrations for both ordinary days and days with dust events. This fact indicates that aerosol characteristics can be estimated from SPM data, and vice versa. Combining radiometric aerosol information with surface-level particulate mass measurements is useful in studying air quality and aerosol properties.

Keywords: Atmospheric aerosols, AERONET, $PM_{2.5}$, SPM

1. Introduction

A multi-spectral photometer (CE-318, Cimel Electronique) has been used to measure urban aerosols at Kinki University Campus, Higashi–Osaka, Japan, since 2002 as part of the NASA/AERONET project [1]. It is well known that the aerosol distributions of Asia are complex due to the increasing emissions of sulfuric, nitric, carbonaceous, and other aerosols associated with continuing economic growth. Aerosols involving soil dust, which are named Kosa, Yellow sands, or Asian dusts, are also significant. Accordingly, urban areas in

Asia are interesting sites for studying aerosols [2].

Anthropogenic small aerosols dominate the air over urban areas because of local emissions such as those from diesel vehicles and chemical industries [3]. These small atmospheric particles play an important role in human health and climate change [4]. To elucidate the correlation between aerosol properties and concentrations of in situ atmospheric particles at the surface, measurements of SPM concentrations as PM_{10} ($\leq 10\ \mu m$), $PM_{2.5}$ ($\leq 2.5\ \mu m$), and OBC (optical black carbon) have been undertaken at the AERONET/Higashi–Osaka site since March 15, 2004, using SPM-613D instrument manufactured by Kimoto Electric, Japan. It is difficult to relate SPM data directly to aerosol properties, but SPM data approximately represent the mass concentration of atmospheric particles at the surface. In other words, air pollutants potentially bear a relationship to the emission and transportation of aerosols [5]. Simultaneous monitoring of aerosols using an AERONET/Cimel and SPM using the SPM-613D located at the Kinki University Campus enables us to determine the relationship between aerosol properties and the particulate mass [6]. We note that the SPM sampler works continuously, even on cloudy and rainy days, whereas radiometry is only available during daylight hours on clear days [7, 8].

The present paper introduces a large-scale dust events detected from both AERONET and SPM data during the spring of 2006.

2. Dust events during the spring of 2006

Figure 1 shows the results of the monitoring of atmospheric particles over Higashi–Osaka from 15 March to 30 April 2006, where measurements of PM_{10} (black lines) and $PM_{2.5}$ (gray area) are plotted against the left-hand scale, and aerosol optical thickness (AOT; τ_a) at a wavelength of 0.87 μm (open circles) is plotted against the right-hand axis. High PM_{10} and AOT values among these data indicate that several dust events occurred at Higashi–Osaka during the spring of 2006. It is apparent that a high concentration of atmospheric particles occurred on the days of April 8, 18, and 24, when the Japanese Meteorological Observatory also reported "Kosa flying" in Osaka. High concentrations of coarse mode particles, PMc, which is defined by the difference between PM_{10} and $PM_{2.5}$, occur simultaneously with high values of column AOT during dust events [9]. On these days, the coarse mode particles are abnormally dominant. The most outstanding dust event during the survey period occurred on April 8th. Satellite composite imagery for the Japan region derived from Terra/MODIS data for April 6–8 2006 is presented in Fig. 2, where soil and dust in the air is represented by a yellow–brown color. Dust-free air appears over the Higashi-Osaka site (indicated by a red cross on each image in Fig. 2) on April 6th and 7th, but yellow–brown air appears over northwest Japan on April 7th. Thick dust then covers western Japan on April 8th. It is apparent from the images that the dusty air mass is carried from the Chinese mainland on westerly winds.

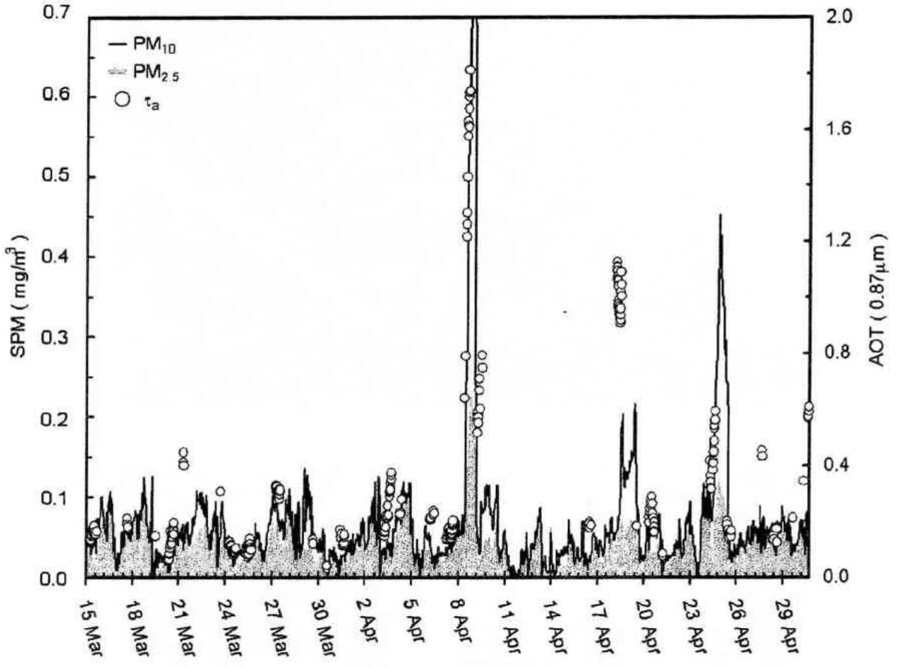

Fig.1 Measurements of atmospheric particles over Higashi-Osaka from 15 March to 30 April 2006. The values of PM_{10} and $PM_{2.5}$ are denoted by black lines and gray shading, respectively, and aerosol optical thickness at a wavelength of 0.87 μm is represented by open circles.

Figure 3 shows values of TSP/PM_{10} (black lines) and $PM_{2.5}$ (gray area) measured at Higashi–Osaka from 5 March 2004 to 30 April 2006, where the winter season during 2005 is excluded. Note that a TSP filter is used for data collected during the period March to May in 2004 and 2005. The data show that the spring of 2006 was an intense dust season. The upper and lower panels in Fig. 4 show AOT (τ_a) at a wavelength of 0.87 μm and the Ångström exponent (α) for all days for which measurements are available during the same period as that shown in Fig. 3. Note that the measuring instrument was calibrated at NASA/GSFC from January to March 2005. The dashed lines at a value of 0.4 in the AOT (0.87 μm) panel and at 0.8 in the α–panel are presented for reference. Values of $\tau_a(0.87)$ in excess of 0.4 indicate substantial aerosol loading. In general, values of the Ångström exponent of less than 0.8 indicate large particles such as soil dust. Roughly speaking, heavy dust events are represented by AOT (0.87 μm) > 0.4 and $\alpha < 0.8$. It is apparent from Fig. 4 that the radiometric properties of aerosols recorded on April 8, 18, and 24, 2006, when SPM data also indicated a dust event, show typical features of soil dust.

The coincidence of temporal variations in SPM and variations in the column AOT data confirms the findings of previous investigations [10]. These data indicate that several dust events occurred at Higashi–Osaka during spring, and that intense dust events were detected during the spring of 2006.

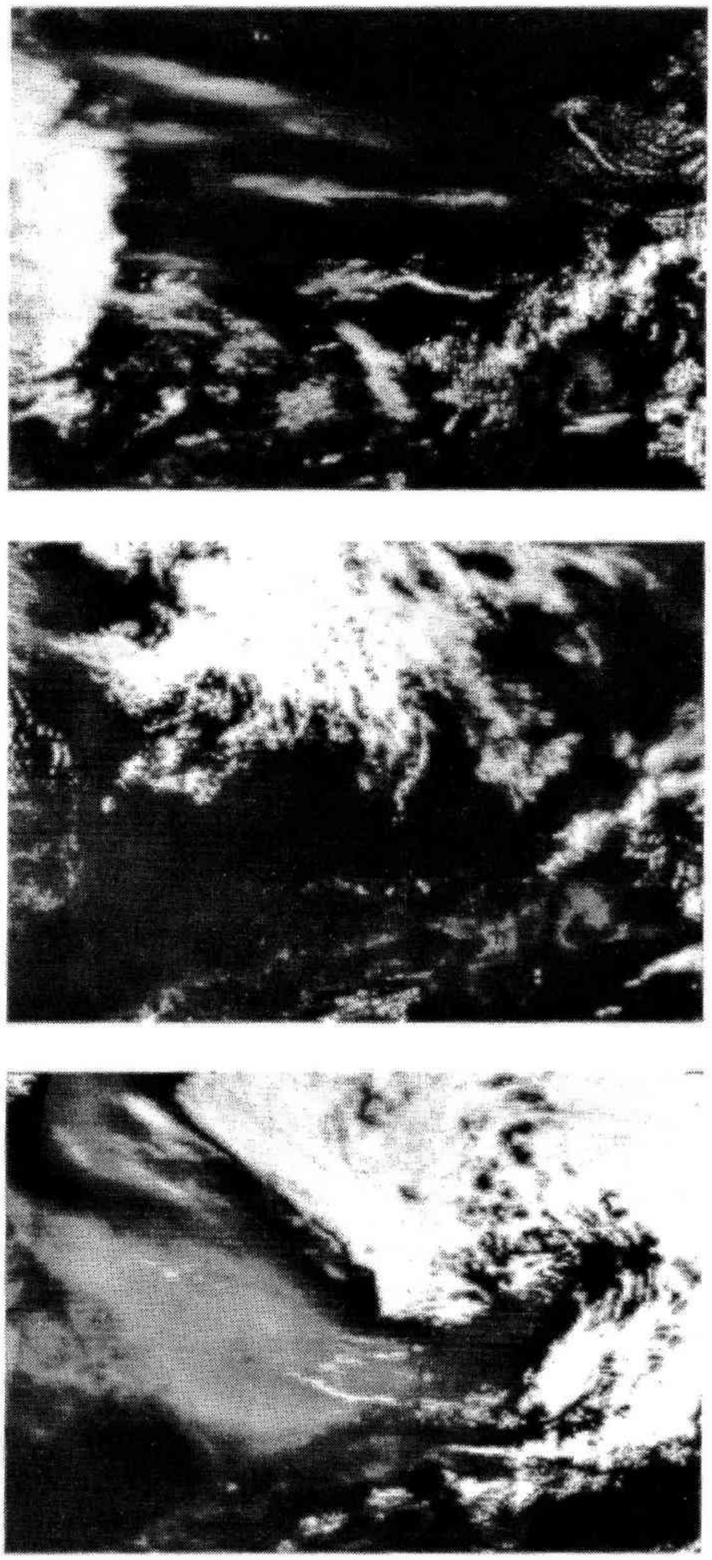

Fig. 2 Composite satellite images of the Japan region derived from Terra/ MODIS data for 6 (top), 7 (middle), and 8 (bottom), April 2006, where the red cross indicates the location of the Higashi-Osaka site.

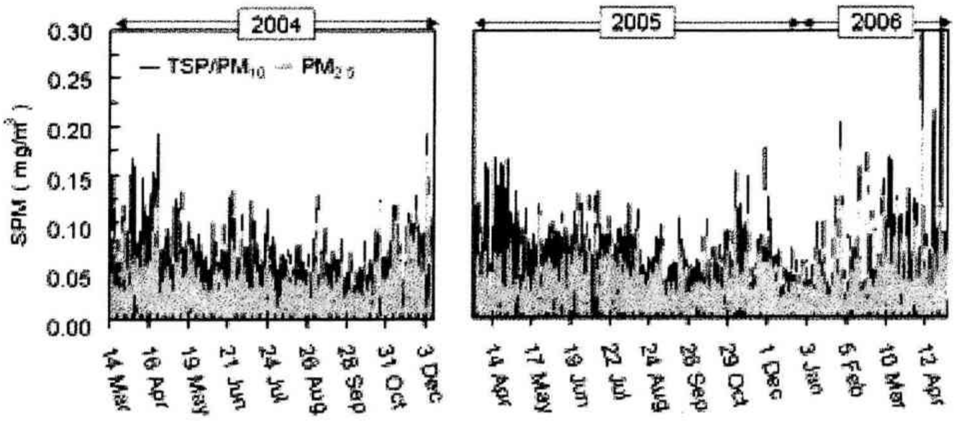

Fig. 3 SPM data measured at the Higashi-Osaka site from 15 March 2004 to 30 April 2006.

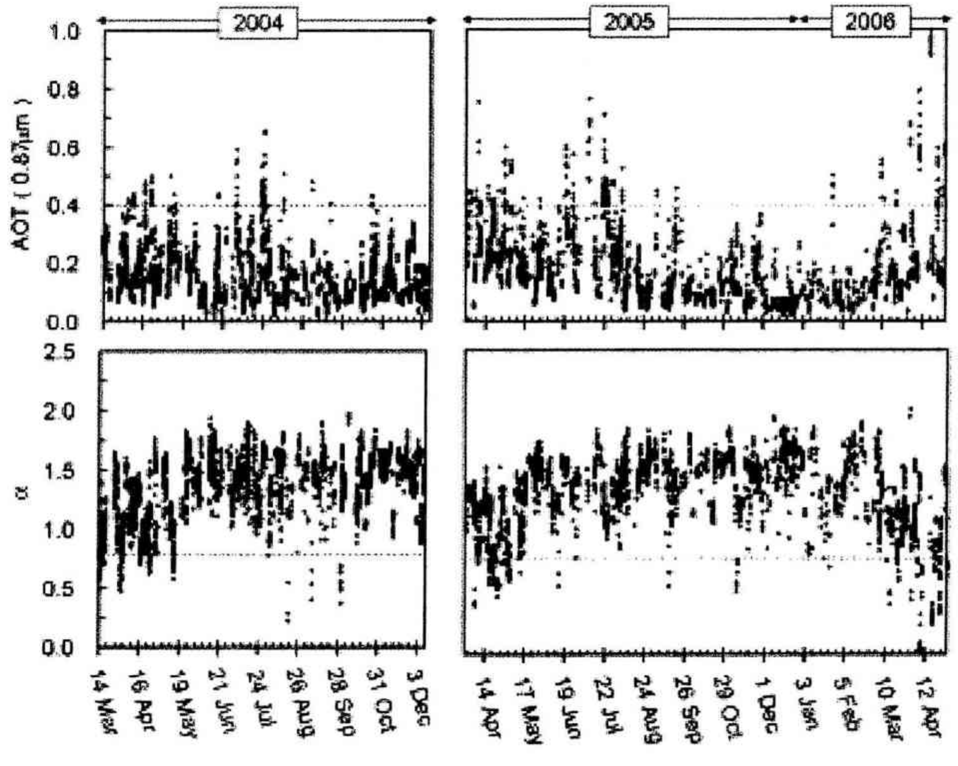

Fig.4 Radiometry of aerosols during the same period as that shown in Fig. 3, showing values of AOT (τ_a) at a wavelength of 0.87 μm and the Ångström exponent (α).

3. Relationship between AOT and $PM_{2.5}$

As noted above, long term simultaneous monitoring of aerosols and SPM reveals similar patterns of temporal variations for both datasets. For example, the SPM concentration correlates with AOT [10, 11]; however, it is not so simple to relate SPM data directly to aerosol properties. A number of differences exist between aerosol radiometry and SPM sampling: the SPM sampler works continuously at the surface, while atmospheric radiometry is only available during daylight hours on clear days.

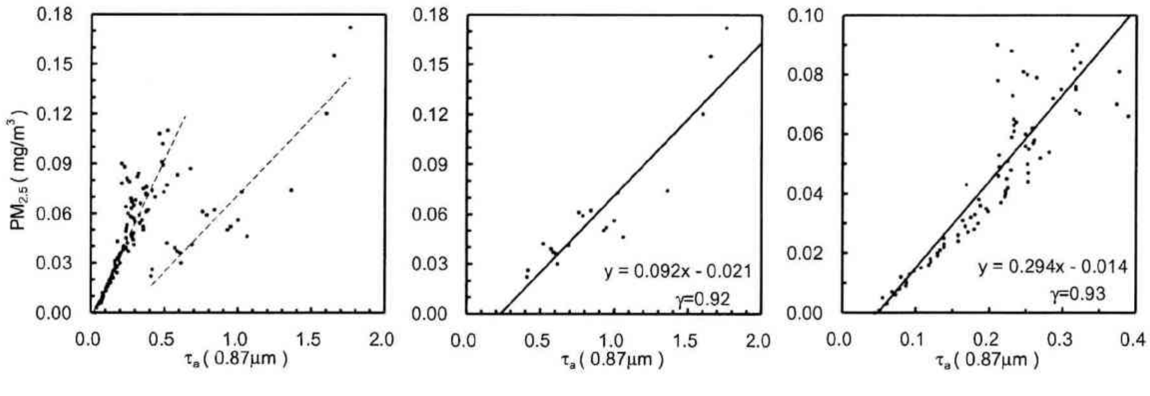

Fig.5 Scattergrams of τ_a(0.87 μm) plotted against $PM_{2.5}$ for the Higashi–Osaka site from 15 March 2004 to 30 April 2006. Left-hand panel: all data, Middle panel: dust events with τ_a (0.87 μm) > 0.4 and $\alpha < 0.8$, Right-hand panel: ordinary days with $\tau_a \leq 0.4$.

The left-hand panel in Fig. 5 shows a scattergram of τ_a (0.87 μm) plotted against $PM_{2.5}$ for the Higashi-Osaka site from 15 March 2004 to 30 April in 2006. The linear correlation between the two variables appears weak on the whole, but is relatively strong for the two subgroups indicated by the dashed lines. This observation suggests that the measurements should be classified as either dust events or ordinary days. The middle and right-hand panels in Fig. 5, where the solid lines (and equations) and γ represent the regression line and the correlation coefficient, respectively, show scattergrams of τ_a(0.87 μm) plotted against $PM_{2.5}$ for dust events with τ_a(0.87 μm) > 0.4 and $\alpha < 0.8$, and ordinary days with τ_a(0.87 μm) ≤ 0.4, respectively. Both figures show a good correlation between the variables.

Values of γ are 0.92 for dust events and 0.93 for ordinary days. This relationship between τ_a and $PM_{2.5}$ highlights the possibility that $PM_{2.5}$ concentration (y; mg/m^3) can be estimated from aerosol optical thickness (x) at a wavelength of 0.87 μm according to the following equation:

$$y = \begin{cases} 0.092x - 0.021 & \text{for dust events,} \\ 0.294x - 0.014 & \text{for other days.} \end{cases} \quad (1)$$

The obtained relationship between aerosol properties derived from AERONET radiometry and the particulate mass simultaneously obtained using the SPM-613D instrument means that satellite-derived aerosol information can be used to complement SPM data in areas without an AERONET site. This provides the potential to estimate air quality at a global scale. Alternatively, aerosol properties on cloudy or rainy days, or at night, can be estimated from SPM data

4. Summary

Long-term simultaneous monitoring of aerosols and SPM revealed the typical aerosol characteristics and seasonal variations over the industrial city of Higashi-Osaka [9]. Our measurements reveal that large amounts of soil dust were transported to Higashi-Osaka from the Chinese mainland on westerly winds during the spring of 2006.

We draw the following conclusions regarding the relationship between aerosols and particulate mass:

I. A linear correlation exists between $PM_{2.5}$ concentrations and aerosol optical thickness.

II. The correlation improves when analyzing subsets of the data for ordinary days and for days that were affected by dust events.

III. Each of the two subsets has unique correlation characteristics.

These facts indicate that aerosol characteristics can be estimated from SPM data, and vice versa. We note that combining radiometric aerosol information with surface-level particulate mass data looks to be a promising approach to gaining a better understanding of air quality and the atmospheric environment [12, 13].

Acknowledgements

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References

[1] Holben, B.N., Eck, T.F., Slutsker, I., Tanré, D., Buis, J.P., Setzer, A., Vermote, E., Reagan, J.A., Kaufman, Y., Nakajima, T., Lavenu, F., Jankowiak, I., Smirnov, A. AERONET - A federated instrument network and data archive for aerosol characterization, *Rem. Sens. Environ.*, **66**, 1–16, 1998.

[2] Sano, I., Mukai, S., Okada, Y., Holben, B.N., Ohta, S. Takamura, T. Optical properties of aerosols during APEX and ACE-Asia experiments, *J. Geophys. Res.*, **108**, 8649, doi:10.1029/2002JD003263, 2003.

[3] Takegawa, N., Miyakawa, T., Kondo, Y., Jimenez, J.L., Zhang, Q., Worsnop, D.R. and Fukuda, M. Seasonal and diurnal variations of submicron organic aerosol in Tokyo observed using the Aerodyne aerosol mass spectrometer, *J. Geophys. Res.*, **111**, D11206, doi:10.1029/2005JD006515, 2006.

[4] Balasubramanian, R., Qian, W.-B., Decesan, S., Facchini, M.C., Fuzzi, S. Comprehensive

characterization of $PM_{2.5}$ aerosols in Singapore, *J. Geophys. Res.*, **108**, 4523, doi:10,1029/2002JD002517, 2003.

[5] Mukai, S., Sano, I., Holben, B.N. Aerosol properties over Japan by sun/sky photometry, *Water, Air and Soil Pollution*, **5**, 133–143, 2005.

[6] Derimian, Y.,Karnieli, A. Kaufman,K.J., Andrea,M.O., Andrea, T.W., Dubovik, O., Maehaut, W., Koren, I. and Holben, B.N. Dust and pollution aerosols over the Negev desert, Israel: Properties, transport, and radiative effect, *J. Geophys. Res.*, **111**, D05205, doi:10.1029/2005JD006549, 2006.

[7] Wang, J., Christopher, S.A. Intercomparison between satellite-derived aerosol optical thickness and $PM_{2.5}$ mass: Implications for air quality studies, *Geophys. Res. Letters*, **30**, 2095, doi:10.1029/2003GL018174, 2003.

[8] Kacenelenbogen,M., Leon, J.-F., Chiapello, I. and Tanre, D., Characterizetion of aerosol pollution events in France using ground-based and POLDER-2 satellite data. *Atmos. Chem. Phys. Discuss*, **6**, pp.6299-6316, 2006.

[9] Mukai, S., Sano, I., Satoh, M. Holben, B.N. Aerosol properties and air pollutants over an urban area, Atmospheric Research, (in press).

[10]Smirnov, A., Holben B.N., Savoie, D., Prospero, J.M., Kaufmann, Y.J., Tanré, D., Eck, T.F. Slutsker, I.S. Relationship between column aerosol optical thickness and in situ ground based dust concentrations over Barbados, *Geophys. Res. Letters*, **27**, 1643–1646, 2000.

[11]Goloub, P., Deuzé, J.L., Herman, M., Marchand, A., Tanré, D., Chiapello, I., Roger, B., Singh, R.P. Aerosol Remote Sensing over Land from the Spaceborne Polarimeter POLDER, Proc. *IRS2000*, 115–116, 2000.

[12]Donkelaar, A. van Martin, R. V. and Park, R. J. Estimating ground-level $PM_{2.5}$ with aerosol optical depth determined from satellite remote sensing, *J. Geophys. Res*, (in press).

[13]Gupta, P., Christopher, S.A., Wang, J., Gehrig, R., Lee, Yc and Kumar, N. Satellite remote sensing of particulate matter and air quality assumed over global cities, *Atmos. Environ.* (in press).