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Spectral analysis of time variations of PM_{10} concentrations observed in Busan

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1. Introduction

Particulate matter with the aerodynamic diameter $\leq 10\mu m$, which is called PM_{10}, is a potential carrier of its compounds into human and animal respiratory systems causing respiratory diseases. In addition, it has recently been recognized that particulate matter has climate forcing to offset warming caused by greenhouse gases such as carbon dioxide, and many global studies of direct forcing by diverse aerosol types have been carried out. However, so far, only a few studies of the meteorological influence on the urban PM_{10} concentrations have been done mainly due to the lack of the observed PM_{10}concentrations in many cities including Busan. Therefore most documented urban scale air pollutants including PM_{10} concentration analysis in association with the meteorological variables carried out by many researchers has used simple statistical methods like means and variance analysis only (Shah et al., 1985; Milionis and Davies, 1994). In Busan Metropolitan Area (BMA), however, a large database of hourly PM_{10} concentration measured at several sites in the urban area has been recently available since early 1990, but the characteristic features of time variation of observed PM_{10} concentrations have not been fully explored yet. For the purpose of understanding the mechanism of higher PM_{10} concentration, this study examines and explores various periodicities of the PM_{10} concentrations measured in BMA by using the power spectrum analysis.

2. Data and Method

Hourly PM_{10} concentration data are obtained from nine monitoring sites operated by the Korean Ministry of Environment (MOE) for the period of 1993 to 2004. During the same period, the meteorological variables including hourly measurement of wind speed, temperature, and daily mean surface pressure obtained at the Korean meteorological observation station located in BMA are used as input data for the cross-spectral analysis to examine the correlation between the PM_{10} concentration and each meteorological variable.

2.1. Fast Fourier Transform (FFT), detrending and filter : FFT is a simple algorithm that can compute the discrete Fourier transform much more rapidly than other available algorithms. This is because FFT has been factored and restructured to take advantage of the rapid binary computation processes of the digital computer. As a result, this FFT is restricted to data sets with $N=2^m$, where m is any integer. FFT has been used widely as a standard method in meteorology(Hies et al., 2000), analysis of turbulence(Sebald et al., 2000), and air pollution studies. Observed PM_{10} concentrations including meteorological variables were transformed logarithmically and linear trends were removed prior to all further analysis to remove red noise. Even after detrending process, the sharp edges of the data window cause what is known as leakage (end effect), where spectral estimates from any one frequency are contaminated with some spectral amplitude leaking in from neighboring frequencies. Therefore, in order to avoid this leakage, Kolmogorov-Zurbenko (KZ) filter (Eskridge et al., 1997) was used in this study.

2.2. Cospectrum : The cross spectrum analysis relates the spectra of two variables. When we define $G_A = |F_A(n)|^2$, and $G_B= |F_B(n)|^2$ as the spectral energy of frequency n for variable A and B, we can rewrite as $G_A = F_A^* \cdot F_A$, and $G_A = F_B^* \cdot F_B$, respectively for the variables A and B, where F_A^* and F_B^* are the complex conjugate of F_A and F_B, respectively. Let $F_A = F_{Ar} + i \cdot F_{Ai}$, and $F_B = F_{Br} + i \cdot F_{Bi}$, where r and i denote real and imaginary parts, respectively. Then cross spectrum between variable A and B is defined as

$$G_{AB} = F_A^* \cdot F_B = Co - iQ,$$

where Co is ($= F_{Ar}F_{Br} + F_{Ai}F_{Bi}$) is called the cospecctrum, and Q ($=F_{Ai} \cdot F_{Br} - F_{Ar} \cdot F_{Bi}$) the quadrature spectrum. The cospectrum is frequently used in micro meteorology because the sum over frequency of all cospectral amplitudes, Co, equals the covariance between A and B (Stull, 1988).

3. Results and Discussion

Aside from the typical and well-known periodicities such as diurnal and annual variations caused by anthropogenic influences, another three significant peaks of power spectrum density were identified ; 7 day, 21 day and 2.25 year periodicities. In order to examine the correlation between the periodicity of PM_{10} concentration and meteorological variables, we have used four time series of observed wind speed, temperature, surface pressure, and relative humidity.

The cospectrum at the period of 2.25 yr shows a positive correlation with wind speed with small phase shifts, a slight negative correlation with temperature, and little correlation with surface pressure, indicating no significant correlations with local meteorological variables in underlying PM_{10} concentration variation. This quasi-biennial oscillation requires further study with a long recorded PM_{10} measurement data. However, of particular interest regarding this 2.25 yr periodicity is the observed number of occurrence days of Asian Dusts showing a close periodicity of 2.25 yr, implying the importance of the quasi-biennial frequencies of transboundary process of particulate matter observed in Korea.

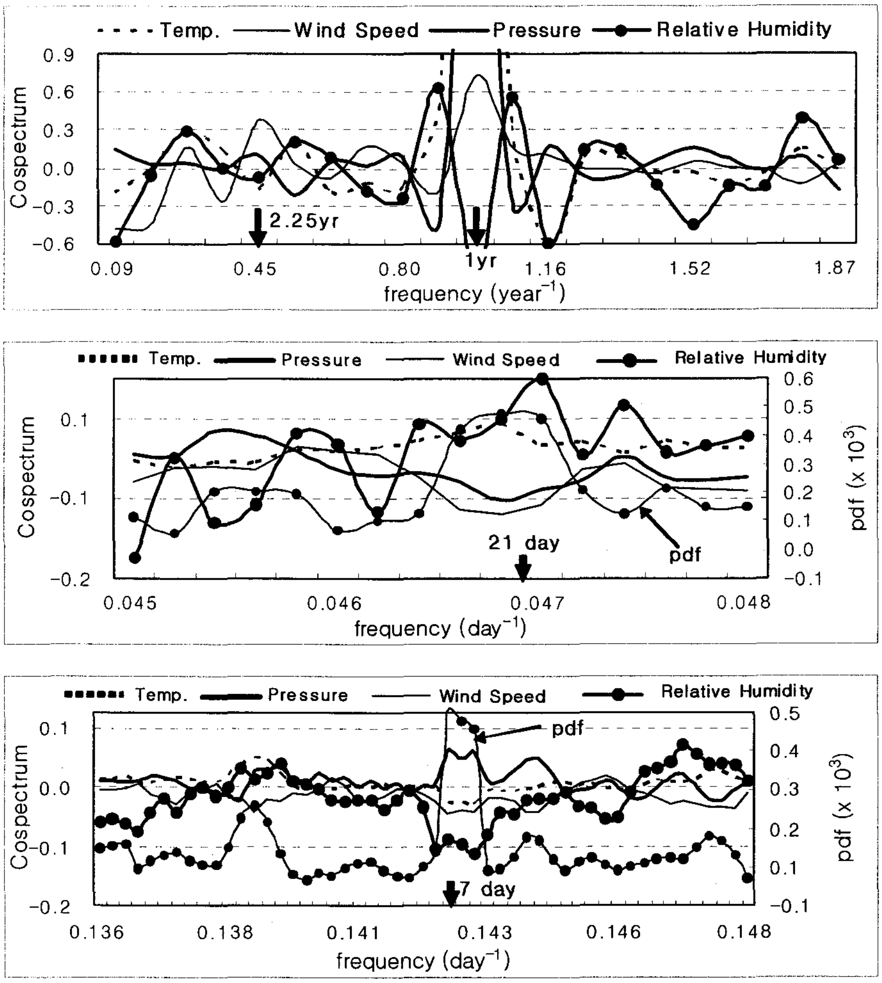

Fig. 1. Cospectrum between PM_{10} time series and some meteorological parameters of wind speed, temperature, and surface pressure in Busan Metropolitan area.

For relatively high frequencies including the period of 21 days and 7 days, significant values in the cospectra occur between the PM_{10} and wind speed. Looking at the period of 21 days, the observed PM_{10} concentration is negatively correlated with the wind speed, but consistently correlated positively with relative humidity. This relation might be due to the hygroscopic characteristics of aerosol that is leading to the secondary aerosol formation under the weak wind speed through condensation, coagulation, hygroscopic growth and heterogeneous chemistry.

However, the period of 7 days shows the negative correlation with wind speed and positive correlation with pressure. These relations mean that PM_{10} concentration tends to be high when the wind speed is weak and pressure is high, implying stagnant high pressure of synoptic condition resulting in high PM_{10} concentrations caused by weak ventilation due to the weak wind speed. The phase angle between PM_{10} concentration and wind speed is found to be approximately 186° out of phase. This is implying stronger dilution PM_{10} concentration by higher wind velocities inside the BMA and vice versa.

4. Summary and conclusion

In order to identify different scales of periodicities of PM_{10} concentrations observed over the Busan Metropolitan area, Fast Fourier Transform analysis was applied to the observed daily PM_{10} concentrations for the period of 1993 to 2004. The results show that, aside from the typical and well-known periodicities such as diurnal and annual variations, another three significant peaks of power spectrum density were identified 7 day, 21 day and 2.25 year periodicities. Cospectrum analysis indicates that the variations of 7 days are closely related to the synoptic meteorological conditions such as weak wind speed which are relevant to the stagnant high pressure system slowly passing through the Korean peninsula. The intraseasonal 21 day variation shows negative correlation with wind speed but consistently positive with relative humidity, which is related to the aerosol formation that can be achieved by hygroscopic characteristics of aerosol. However, the quasi-biennial 2.25 year variation is found to have some correlation with the occurrence frequency of Asian dust events whose periodicities have been recorded inter-annually over the Korean peninsula.

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