Spatiotemporal variability patterns of PM$_{2.5}$ in severe pollution events based on a large dataset from air quality monitoring stations over South Korea

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East Asia (i.e. Korea, China, and Japan) has suffered from severe air pollution every year concerning particulate matter less than 2.5 µm in diameter (PM$_{2.5}$).

▶ Annual PM average from 2015 to 2018 was decreasing rate (Fig. a).

▶ However, more frequent PM$_{2.5}$ events with greater intensity and longer duration contribute at least partially to higher mean PM concentrations for the spring seasons (January to March) (Fig. b).
Introduction

- Ambient PM$_{2.5}$ has longer residence time (i.e. days to weeks) because it neither settles nor coagulates quickly. Therefore, PM$_{2.5}$ is capable to transport to distant region.

- Therefore, analysis limited to narrow region may miss the flow of PM$_{2.5}$ associated with synoptic weather conditions. This means a wide range of comprehension not only regional growth of PM$_{2.5}$ concentrations but also the inflow of PM$_{2.5}$ from the surrounding areas is needed.

- We attempted to find statistically how the magnitude and duration of high PM$_{2.5}$ pollution over Korea distributed with a focus on spatiotemporal variations and categorized the characteristic patterns of events based on COD results.

- We also represented time-lag distributions with synoptic weather conditions, and we suggested the relationship between high PM$_{2.5}$ pollution events and weather condition considering time-lag corrected COD and R$^2$ results.
1. Data

- Hourly PM$_{2.5}$ concentration data
- 381 air quality monitoring stations (AQMS) in Korea
- January 1, 2015–September 30, 2019

2. High PM$_{2.5}$ pollution events

- We defined high PM$_{2.5}$ pollution period in a basis of watch alert standard in Korea for which hourly PM$_{2.5}$ concentration exceeds 75 µg/m$^3$ for at least two hours

3. Spatiotemporal variability

- Two statistical methods (Time-lag correlation and Coefficient of divergence) were used to see spatiotemporal heterogeneity

   - **Time-lag correlation**
     - calculates the different response time between a pair of sites
     $$ r = \frac{1}{T \sigma_a \sigma_b} \int_{t_0}^{t_0+T} (a(t) - \bar{a})(b(t + \tau) - \bar{b}) \, dt $$
     
     - $a, b$: simultaneously measured species
     - $t$: time
     - $\tau$: a time-lag applied to time series in $b$
     - $\sigma$: standard deviation for the pollutants $a$ and $b$
     - $T$: the number of data points

   - **Coefficient of divergence (COD)**
     - determines the divergence degree between a pair of sites
     $$ COD = \sqrt{\frac{1}{n} \sum_{i=1}^{n} \left( \frac{x_{if} - x_{ih}}{x_{if} + x_{ih}} \right)^{2}} $$

     - $x_{if}, x_{ih}$: the concentrations of one species for the $i$th time period at sites $f$ and $h$, respectively.
     - $n$: the number of observations
     - COD Value $\approx 0$: totally homogeneous
     - COD Value $> 0.2$: heterogeneously distributed

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*Figure 1. AQMS sites*
1. Spatiotemporal distribution of PM$_{2.5}$ for the high pollution events

We examined the spatial distributions of PM$_{2.5}$ for pollution periods using COD and the coefficient of determination ($R^2$) values calculated with a pair of time-series of PM$_{2.5}$ between the reference site (averaged for 25 AQMS in Seoul) and other monitoring sites.

The case I, case II, and case III represent 11 events (29.7%), 11 events (29.7%), and 9 events (24.3%) of 37 events in total, respectively.

COD and $R^2$ values in three high PM$_{2.5}$ cases showed characteristic distribution patterns.

Both COD and $R^2$ showed distinct boundaries (showed by dotted line) of heterogeneity and similarity.
2. Time-lag distribution of PM$_{2.5}$ for the high pollution events and corresponding air mass back-trajectory

This figure shows three representative time-lag distribution and synoptic weather condition for high PM$_{2.5}$ events of each categorized case.

Backward trajectory was analyzed using the NOAA HYSPLIT model to evaluate pollutant transportation pathway, and ground level weather maps which represent the pressure distribution from KMA were also analyzed.

Expansion of Siberian high caused westerly inflow of air mass in Event 1, pollutants with stagnant high-pressure was slowly moved to eastward in Event 2, and anticyclone stayed over Manchuria made downward inflow in Event 3.

The air mass inflow with the air pressure distribution well expressed time-lag distribution. This means time-lag distributions were highly related with the synoptic weather condition in high PM$_{2.5}$ events.
3. Time-lag corrected distributions of PM$_{2.5}$ for high PM$_{2.5}$ events

▶ We modified the time considering the time-lag of each site and obtained time corrected COD and R squared values.

▶ Time corrected COD showed wider homogeneous distribution with a slightly improve in most region but did not decrease noticeably.

▶ This can be explained by the absolute difference in concentration magnitude of each site.

▶ However, time corrected R$^2$ represented homogeneous over Korea. This means high PM$_{2.5}$ events was highly related to the movement of air mass.

Fig. Time-lag corrected COD and R squared distributions
Conclusion

- Time-lag correlation and COD results showed characteristic variability patterns.
- COD and $R$ squared values showed characteristic distributions,
- Time-lag distributions in high $PM_{2.5}$ events were related with air mass movement.
- Time-lag corrected COD values were slightly improved, and $R^2$ represented strong similarity in variability of $PM_{2.5}$ concentration.
- These results imply that high $PM_{2.5}$ events are mainly affected by synoptic weather condition.

Reference


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