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Urban air quality, meteorology and traffic linkages: Evidence from a sixteen-day particulate matter pollution event in December 2015, Beijing

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ABSTRACT

A heavy 16-day pollution episode occurred in Beijing from December 19, 2015 to January 3, 2016. The mean daily AQI and $PM_{2.5}$ were 240.44 and 203.6 μg/m^3. We analyzed the spatiotemporal characteristics of air pollutants, meteorology and road space speed during this period, then extended to reveal the combined effects of traffic restrictions and meteorology on urban air quality with observational data and a multivariate mutual information model. Results of spatiotemporal analysis showed that five pollution stages were identified with remarkable variation patterns based on evolution of $PM_{2.5}$ concentration and weather conditions. Southern sites (DX, YDM and DS) experienced heavier pollution than northern ones (DL, CP and WL). Stage P2 exhibited combined functions of meteorology and traffic restrictions which were delayed peak-clipping effects on $PM_{2.5}$. Mutual information values of Air quality–Traffic–Meteorology (ATM–MI) revealed that additive functions of traffic restrictions, suitable relative humidity and temperature were more effective on removal of fine particles and CO than NO_2.

Introduction

Severe air pollution issues have become 'new normal' in megacities in China since 2013. One of the most serious haze events occurred in December 2015 with 65.5% pollution days over the whole month. This of course attracts considerable concern from both the public and government agencies for adverse effects on human health (Miller et al., 2007; W.T. Liu et al., 2016; Wu et al., 2016; Guo et al., 2016; West et al., 2016), urban air quality (Pleijel et al., 2016; Yassaa, 2016), global climate (Baklanov et al., 2016; Makar et al., 2015) and vital contributions to emission reduction tasks of air pollutants (Thaker and Gokhale, 2016; Kwak et al., 2016). In urban areas of northern China, vehicles and coal combustion are considered to be major emission sources of fine particles in winter (L. Liu et al., 2016; Wang et al., 2015; Wang and Hao, 2012). The odd–even traffic restrictions during Olympic games (Wang et al., 2009), APEC (Wang et al., 2016) and Marathon games (Zhao and Yu, 2016) greatly reduce the emissions of CO, BC and UFP from vehicles, indicating that large improvements of urban air quality have been occurred by implementing provisional traffic restriction measures (Thaker and Gokhale, 2016; Kwak et al., 2016). Simultaneously, meteorological factors, such as wind direction, wind speed, temperature and relative humidity, are largely responsible for formation, accumulation and dispersion of gaseous pollutants and ambient particles (Kumar et al., 2008; Wehner and Wiedensohler, 2003; Zhou et al., 2016; Chen et al., 2012). Good air quality is likely to occur with high temperature

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and low humidity (Zheng et al., 2013), while higher concentrations of particulate matter (PM) occur at low and high wind rather than moderate wind speed (Yin et al., 2016). Particle minima concentration in summer is associated with higher temperature and better mixing (Laakso et al., 2003), and lower concentrations of particles that are less than 2.5 μm in diameter ($PM_{2.5}$) coincides with pollution transport by southerly wind (Pasch et al., 2011). NO_2 and O_3 tend to exhibit highest average concentrations with humidity less than 40%, while peak concentrations of PM_{10}, SO_2 and CO accompany with humidity above 80% (Elminir, 2005).

Although an improved understanding of relationships between air quality and synoptic meteorology, air quality and traffic restrictions has been revealed, we still have little knowledge about combined effects of meteorological conditions and traffic patterns, as well as the instant and delayed effects of provisional traffic measures on air pollutants during severe haze events.

Many association rules for two variables have been published with good performance. Of the most relevant studies, maximum information coefficient method was proposed to detect dependence of two-variable relationships (Reshef et al., 2011). Joe (Joe, 1989) tried to use relative entropies to measure the multivariate dependence and conditional dependence. Hosseini et al. (Hosseini et al., 2012b) made traffic speed predictions in 24 hr with mutual information and found it largely reducing the prediction error variance. Therefore, the present study will be the first to combine quantification impacts of traffic restrictions and meteorological conditions based on mutual information theory, detecting multivariate association rules in the field of air quality analysis.

In this study, we present the spatiotemporal characteristics of air pollutants, meteorology and road mean space speed during a 16-day severe pollution episode in Beijing. Then, on basis of classical information theory, we propose an index called Mutual Information of Air quality–Traffic–Meteorology (ATM–MI) to describe combined effects of meteorology and traffic restrictions. Integrated understanding of air pollutants and meteorology, as well as knowledge about traffic restrictions is beneficial to detect the combined influence on air quality from multi-factors, reduce severe pollution events and decrease their hazardous effects with effective measures.

1. Theory and methods

1.1. Data resources

Hourly concentrations of gaseous pollutants and fine particle are derived from the public website of Beijing Municipal Environmental Monitoring Center (http://zx.bjmemc.com.cn/) ranging from December 17, 2015 to February 29, 2016. To correspond to different regional functions, six sites have been selected as follows: YDM (traffic site), DX (industrial site), WL (cultural and educational site), DS (commercial site), CP (residential site) and DL (background site) (Hu et al., 2015). With respect to meteorological data, hourly mean values of temperature, relative humidity, wind direction and wind speed are presented in detail for corresponding district where each monitoring site locates from public information of China Meteorological Administration (http://data.cma.cn). These factors have been reported with significant roles on urban air quality (Xu et al., 2015; Zhang et al., 2015). Simultaneously, from an open source data center (http://www.navinfo.com.cn/news/index.aspx), we collect average vehicle speed on urban roads with a temporal resolution of 5 min. In order to match other two types of data, traffic data have been hourly averaged to create a new data set. All these data are stored in the SQL Server database.

1.2. Air quality–Traffic–Meteorology mutual information

Mutual information, one of many quantities measuring how much one random variable tells about the other, was first introduced in information theory by Shannon in 1948 (Shannon,

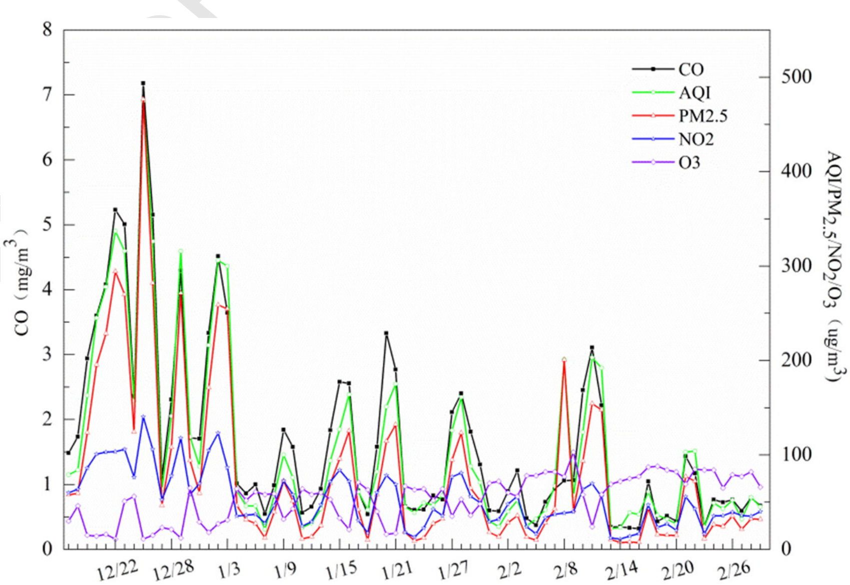

Fig. 1 – Daily mean concentrations of AQI, particulate matter ($PM_{2.5}$) and trace gases (CO, NO_2, O_3) from December 17, 2015 to February 29, 2016 in Beijing.

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