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Effects of potential recirculation on air quality in coastal cities in the Yangtze River Delta

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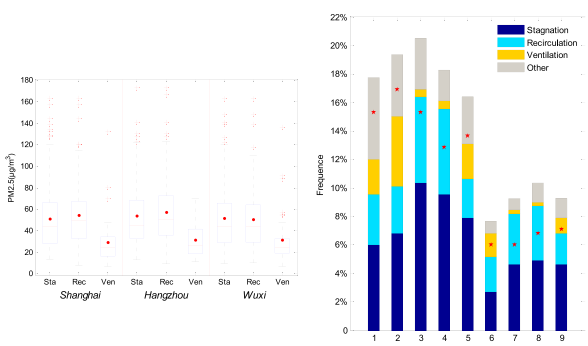
HIGHLIGHTS

- Stagnation and recirculation in the Yangtze River Delta often co-occurred.
- Stagnation and recirculation's occurrence was much greater than that of ventilation.
- Average $PM_{2.5}$ was higher under stagnation and recirculation.
- Recirculation had a slightly greater impact on Shanghai and Hangzhou than on Wuxi.
- The 2016 pollution episode was ruled by recirculation and by the presence of CT6.

GRAPHICAL ABSTRACT



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ABSTRACT

Air quality is closely related to the synoptic circulation and local wind field affecting a certain area as they have distinct influence on the path and speed of pollutants. The Yangtze River Delta is located on the eastern coast, and the air returning from coastal areas has a detrimental effect on air quality in the area. This study proposes to analyze if certain circulation types and the occurrence of recirculation are predominantly related to the occurrence of bad air quality in the Yangtze River Delta. Using sea level pressure data from 2006 to 2016, we used T-mode objective classification to classify circulation in the Yangtze River Delta into nine categories. At the same time, using the Allwine and Whiteman (AW) method, we categorized local winds in the region as ventilation, stagnation, and recirculation types, and we found that the local wind tends to be under recirculation conditions when the region was controlled by circulation types 3 (CT3, southeast low pressure), CT4 (northeast low pressure), CT7 (northwest high pressure), and CT8 (north high pressure, south low pressure, with a large pressure gradient). By comparing concentrations of pollutants and different local wind types, we found that recirculation tended to promote high pollution situations. Use of the HYSPLIT (Hybrid Single Particle Lagrangian Integrated Trajectory) model to simulate the diffusion of pollutants by recirculation in Shanghai in March 2016 confirmed this conclusion. The outputs of HYSPLIT model can show the track of air mass intuitively, and then reflect the effect of recirculation.

1. Introduction

The Yangtze River Delta is an economically vibrant area in China. Yet as a result of rapid industrialization and urbanization, it is experiencing

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problems such as air pollution, abnormal weather, and frequent extreme pollution events caused by high emissions (Ellsaesser et al., 1986; Junker and Liousse, 2008; Xu et al., 2016). The haze in the air pollution belt directly affects residents' productivity and quality of life (Dockery and Pope, 1994). In particular, small particles with a diameter <2.5 μm ($PM_{2.5}$), which can be directly inhaled into the lungs, are harmful to human health (Krewski et al., 2009; Shang et al., 2013). In China, about 83% of the population lives in an environment where $PM_{2.5}$ is >35 μg/m^{-3} (Liu et al., 2016). In 2013 the number of deaths due to excessive inhalation of $PM_{2.5}$ reached 1.37 million in China (Liu et al., 2016). Therefore, environmental issues have aroused widespread public concern.

Severe haze tends to be associated with high emissions and poor local diffusion (Levy et al., 2010; Mohan and Bhati, 2012; Ye et al., 2015a, 2015b). Urban industrial waste, residential emissions, and vehicle exhaust are major sources of pollution in large cities (Chan and Yao, 2008; Ma et al., 2012; Zhang et al., 2012a, 2012b; Sun et al., 2010). Reasonably reducing emissions is an important way of improving air quality (IPCC, 2007; Zhang et al., 2012a, 2012b). On the other hand, weather situations which promote good diffusion of air pollutants create conditions for a better air quality (Gao et al., 2011; Surkova, 2013; Russo et al., 2016).

Synoptic-scale circulation and local meteorological conditions have important effects on air quality (Levy et al., 2010; Surkova, 2013; Russo et al., 2016). One way of identifying for potential air-contamination may be determined from the frequency of occurrence of unfavorable meteorological conditions exceeding a predetermined threshold (Surkova, 2013). However, these are characteristics of each individual area and are based on information about local sources of emissions, frequency of low atmosphere inversions, low wind speed, air stagnation and cases of fog (Surkova, 2013). Such detailed information is not always easy to collect and a simple and effective alternative approach to assess whether or not weather conditions are favorable for air ventilation, recirculation and stagnation is preferred (Levy et al., 2010; Mohan and Bhati, 2012; Russo et al., 2018).

AW; Allwine and Whiteman (1994) proposed an objective and quantitative method to identify if a certain station was under stagnation, ventilation, and recirculation conditions. The advantage of this method is that it does not require surface or upper layer meteorological observations, depends little on atmospheric diffusion and prior transport conditions, and considers only hourly wind components (Allwine and Whiteman, 1994). This approach has been applied all over the world (e.g. Levy et al., 2010; Mohan and Bhati, 2012; Surkova, 2013), mostly due to simplicity of the application and data requirements. Following the approach of Levy et al. (2010), Russo et al. (2016) used the AW method in combination with K-clustering classification to study the effects of potential recirculation in coastal areas on air quality in three cities in Portugal. These approaches stress that when circulation that favors the diffusion of contaminants is accompanied by ventilation, air quality is best whereas when circulation associated with recirculation or stagnation occurs, air quality is poorer. However, Russo et al. (2016) applied a variation of the AW method to the wind field outputs of the MM5 high-resolution model forced by the ERA40 reanalysis data-driven mesoscale model. This approach, although allows for the application of the AW method were wind measurements are not available or have gaps, requires a huge amount of computation, and the simulation accuracy of the large-span time range is insufficient.

Of course, many studies have used other methods (Seagram et al., 2012; Surkova, 2013). However, those methods require detailed three-dimensional wind data for the area to be studied. Such data are

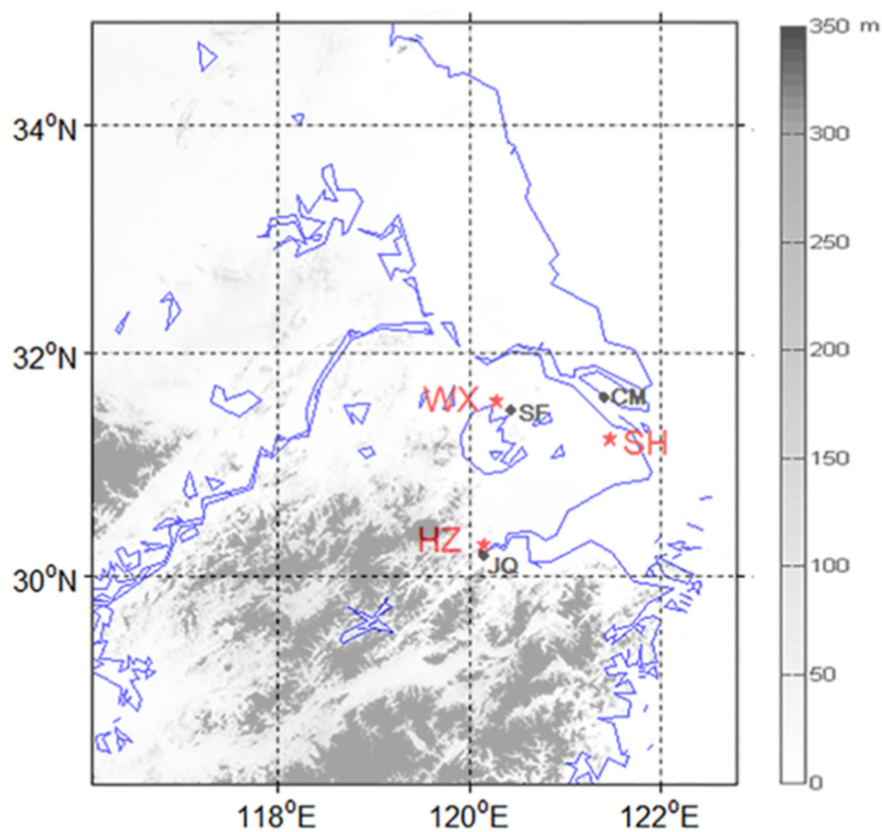

Fig. 1. Location of the three cities and corresponding wind field observation stations, namely, Shanghai (SH), Chongming (CM), Hangzhou (HZ), Janqiao (JQ), Wuxi (WX), and Shuofang (SF). Red stars indicate cities, and black circles indicate stations. The shaded part represents the surrounding topography of the case study area. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)