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The impact of synoptic circulation on air quality and pollution-related human health in the Yangtze River Delta region

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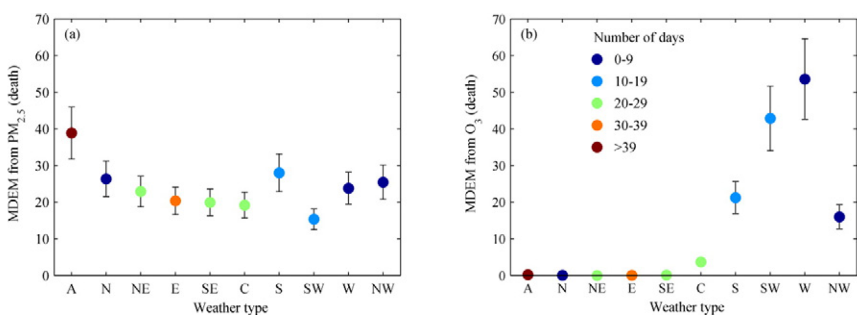
HIGHLIGHTS

- A synoptic circulation catalogue is developed for YRD via Lamb weather type method.
- Associations between circulation types and air quality parameters are investigated.
- For the first time the polluted synoptic circulation types are identified from health perspective.

GRAPHICAL ABSTRACT

Mean daily excess mortality (MDEM) from air pollution under different weather conditions.



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ABSTRACT

$PM_{2.5}$ and O_3 pollution are of concern for the Yangtze River Delta (YRD) region due to their adverse impact on human health. In conjunction with a complex distribution of emission sources, the synoptic circulation conditions control the temporal and spatial variability of air pollution levels and hence the pollution-related health burdens. In this study, a long-term synoptic circulation catalogue is developed by applying the automated Lamb weather type method to the ECMWF mean sea level pressure reanalysis for the YRD region during 2013–2016. Ten typical circulation types are examined in relation to the transport pathways and diffusion conditions, and then multi-site surface observations of $PM_{2.5}$ and O_3 are composited for different circulation conditions. The results show that each circulation type is characterized with distinct air mass origin, diffusion condition and air quality level. The anticyclonic type (Type A) corresponds to the highest regional $PM_{2.5}$ concentration (68.5 μg/m^3) due to the subsidence flow and long-range transport, while the westerly types (Types SW, W and NW) correspond to the higher regional maximum daily 8-h running average O_3 (MDA8 O_3) concentration (>100 μg/m^3) due to favorable local meteorological conditions. Regional transport causes an east-high and west-low $PM_{2.5}$ distribution in westerly types but a west-high and east-low $PM_{2.5}$ distribution in easterly types (Types SE, E and NE). In contrast, nearly all the types show an east-high and west-low O_3 distribution, suggesting the predominated impacts of precursor emissions. By using established exposure-response functions, the health impact assessment (HIA) shows that Type W poses the greatest public health risk with mean daily excess mortality of 77.3 (95% CI: 61.9, 92.6) deaths and O_3 pollution accounts for approximately 70% of this health burden.

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1. Introduction

Air pollutants, such as fine particulate matter ($PM_{2.5}$, particles with diameters of <2.5 μm) and ozone (O_3), can have significantly adverse impacts on human health (WHO, 2006). Exposure to elevated levels of surface air pollution can cause reduced respiratory function and cardiovascular problems (Shang et al., 2013). Using $PM_{2.5}$ and O_3 as indicator pollutants, it is estimated that poor air quality results in 3,297,000 deaths in the world in 2010 and China accounted for approximately 41% of this health burden (Lelieveld et al., 2015). However, because ground-level measurements of $PM_{2.5}$ and O_3 are unavailable for much of the world (e.g., China), the health impact assessment (HIA) have relied largely on estimates of ambient pollution levels from satellite data (Evans et al., 2013; Liu et al., 2017; Ma et al., 2016b; van Donkelaar et al., 2015) or chemical transport models (Brauer et al., 2012; Gao et al., 2015; Lelieveld et al., 2015; Wang et al., 2015a; Zhou et al., 2010).

The Yangtze River Delta (YRD) region (Fig. 1), located in the Eastern Eurasian continent, is one of the most active economic zones in China. It stretches across 4 provincial level administrative regions (Shanghai, Jiangsu, Zhejiang and Anhui) and comprises 26 cities, such as Shanghai, Nanjing, Hangzhou, Hefei, etc., and the total area is approximately 211,700 km^2. Over the past four decades, the YRD region has undergone rapid industrialization and urbanization, leading to tremendous increases in energy consumption and emission of air pollutants; as a result, severe air pollution are frequently happening under favorable meteorological conditions (Cheng et al., 2013; Ding et al., 2013; Fu et al., 2014; Huang et al., 2012b; Wang et al., 2015b). Synoptic weather influences surface pollutant concentration through the transport and accumulation processes. In the YRD region, serious $PM_{2.5}$ pollution usually occurs in winter as a result of strong accumulation of $PM_{2.5}$ and its precursors (Ming et al., 2017; Wang et al., 2015b). In addition, winter monsoon winds lead to long-range transport of air pollutants from northern China, enhancing local $PM_{2.5}$ pollution levels (Hu et al., 2014; Li et al., 2012). In contrast, peak O_3 usually occur in summer (Li et al., 2016; Xu et al., 2008). Summertime subtropical high conditions lead to subsidence flows, clear skies and increased surface temperatures. These meteorological conditions increase O_3 by reducing vertical mixing and enhancing O_3 production (Shu et al., 2016). Overall, high pollution levels greatly exceeding health-based standards are frequently recorded in YRD throughout the year (Ding et al., 2013), posing health risks to 150 million residents living in this region.

For a given region, the synoptic circulations characterize a certain atmospheric condition through its close association with various meteorological factors such as wind speed and direction, temperature, relative humidity and precipitation (Zhang et al., 2012; Zheng et al., 2015). Consequently, the classification of synoptic circulations can be used as a downscaling tool to categorize the impact of meteorology on surface air pollutants (Chen et al., 2008; Demuzere et al., 2009). Globally many studies have been carried out to investigate the direct linkages between synoptic circulations and air quality (Bei et al., 2016; Dayan and Levy, 2002; Demuzere et al., 2009; Hegarty et al., 2007; Jiang et al., 2017; Pope et al., 2015; Zhang et al., 2012). Most of those studies emphasized that good air quality often occurs under cyclone conditions and poor air quality is frequently associated with anticyclonic conditions. However, air quality/synoptic type relationships can differ by different times, locations and pollutants due in part to orographic effects and spatial distribution of emissions. Several studies have examined the relationship between synoptic circulations and air quality in the YRD cities (Yu et al., 2017; Yu et al., 2015; Zhang et al., 2010). Consistently, these single-city studies found that high pollution episodes are often associated with cold high pressure systems. In addition, Zheng et al. (2015) investigated the relationship between the degree of regional pollution and the patterns of large-scale atmospheric circulation over the whole eastern China (including YRD) in October using long-term aerosol optical depth and NCEP reanalysis data. They found that synoptic systems can modulate the spatial patterns of air flows, diffusion conditions and subsequently, the spatial variability in the observed aerosol optical depth. However, as shown above, most of YRD's studies were focused on analyzing a small number of high pollution days or the air quality conditions in single city, and more importantly, there are very limited studies that included analysis of the O_3 pollution.

This article extends the abovementioned YRD's studies by using multi-site data to examine the impacts of synoptic circulations on $PM_{2.5}$ and O_3 levels in the whole YRD region. We provide a full insight into how synoptic types affect the transport pathways, diffusion conditions, air quality and pollution-related health burdens. In this study, for the first time the polluted synoptic patterns are identified for the YRD region from public health perspective. The results are expected to be helpful for air quality forecasting and public health management in the YRD region.

2. Material and methods

2.1. Large-scale meteorological data

Gridded mean sea level pressure (MSLP) data from the European Centre for Medium Weather Forecast (ECMWF) Re-analysis Interim (ERA-Interim) for the larger East Asia region (95°E–145°E, 51°N–11°N, 1° × 1° horizontal resolution) (Fig. 1a) were used to determine the weather types at the regional scale. To get the best performance of weather classification, the daily MSLP data averaged from four time points (0200, 0800, 1400 and 2000 Beijing Time) were chosen to

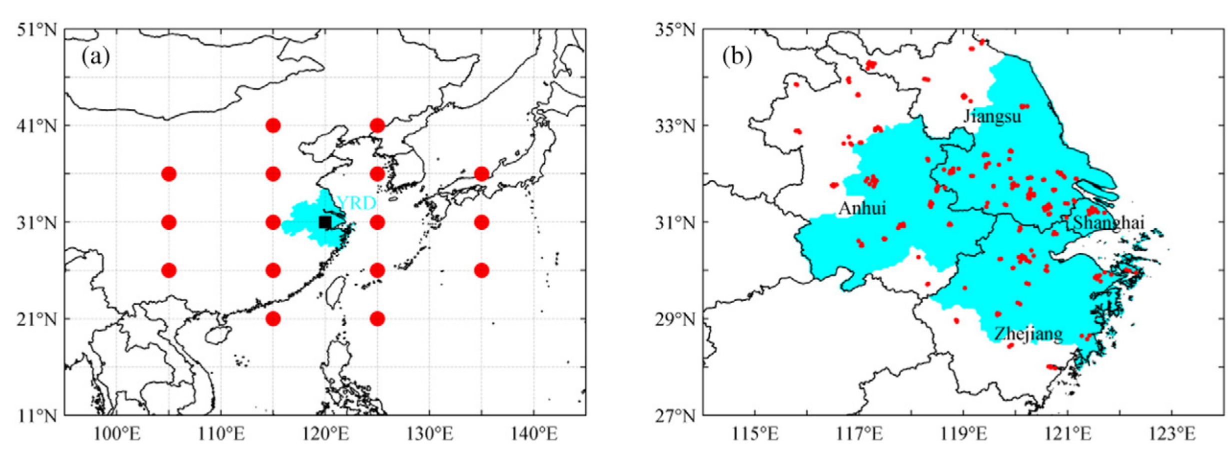

Fig. 1. (a) Location of the YRD region and (b) spatial distribution of air quality monitoring sites. The 16 red points in Fig. 1a show the location of the 5° × 10° MSLP grid used for Lamb weather type classification. The red dots in Fig. 1b show the air quality monitoring sites.