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Spatial distribution of wintertime air pollution in major cities over eastern China: Relationship with the evolution of trough, ridge and synoptic system over East Asia

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ABSTRACT

Hourly air quality index (AQI) data from the Ministry of Environment Protection of China are used to investigate spatial distribution of air pollution in major cities over eastern China (ECN) in winter 2015. The wintertime averaging identifies a pollution center in east Shanxi (IV, the identifier number in Fig. **1**), south Hebei (III), west Shandong (V) and Henan (VI) provinces with mean AQI > 100. Four typical types of air pollution spatial distribution are identified. The low level southerly winds are found to be associated with the occurrence of regional air pollution episodes over ECN. The spatial distribution of air pollution is mainly related to the low level meridional wind, which is determined by the specific evolution process of the trough, ridge and synoptic system. The longitudinal position, the deepening (or weakening) and the southward extension (or northward retreat) of the trough over East Asia are the crucial factors determining where the regional air pollution could occur. The influence of precipitation on air pollution is complicated; the initial stage of precipitation with limited precipitation amount promotes the secondary formation and hygroscopic growth of aerosol due to increased supply of moisture, thus favors an aggravation of air pollution; in contrast, only the persisting and intensifying of precipitation are accompanied with more effective wet scavenging and an improvement of air quality. Fireworks emission is found to exacerbate air pollution during the Spring Festival, resulting in a unique distribution of air pollution over a large area of China, suggesting that prohibiting fireworks is necessary under adverse synoptic situation.

1. Introduction

The frequently occurred fog and haze events over eastern China (ECN, generally to the east of 105° N; Zhao et al., 2013; Qu et al., 2015a) have adverse impacts on public health and human living (Pope and Dockery, 2006; Wang and Mauzerall, 2006; Xu et al., 2013; Xie et al., 2014). An evalution using monitoring from the US Embassy and consulates (Lowsen and Conway, 2016) identified tangible (though modest) improvements in air quality in Beijing, Chengdu, and Guangzhou, but no apparent progress in Shanghai, and a worrisome decline in air quality in Shenyang. Liang et al. (2016) addressed the $PM_{2.5}$ data reliability and consistency by cross-validating data from the US diplomatic posts and the nearby sites of the Ministry of Environment Protection of China (MEPC), and identified a moderate decline in $PM_{2.5}$ since 2014 in Beijing, Shanghai, Guangzhou, Chengdu, and Shenyang. Song et al. (2017) highligted the emerging of complex air pollution caused by particulate matter (PM) and O_3 that threatens the public health, especially in Chinese mega-city clusters. The air pollution over ECN has distinct regional contrast and seasonal variation; the areas with frequent fog and haze generally concentrate in north China, central China, the Pearl River Delta and the Yangtze River Delta (major areas with intensive anthropogenic emission); both the spatial coverage and the occurrence frequency of fog-haze in the winter and autumn are larger than the spring and summer (Sun et al., 2013a). The unfavorable diffusion conditions (weak surface winds) and high primary-pollutant emissions were found to induce heavy-haze pollution in the Beijing-Tianjin-Hebei region (BTH) due to southerly wind anomalies (high humidity) in the lower troposphere and orographic wind convergence along the Taihang and Yanshan Mountains (Wang et al., 2014).

In addition to emission and topography, the formation and evolution of fog, haze and air pollution are closely related to the synoptic system. For example, the long durative air pollution episodes over north

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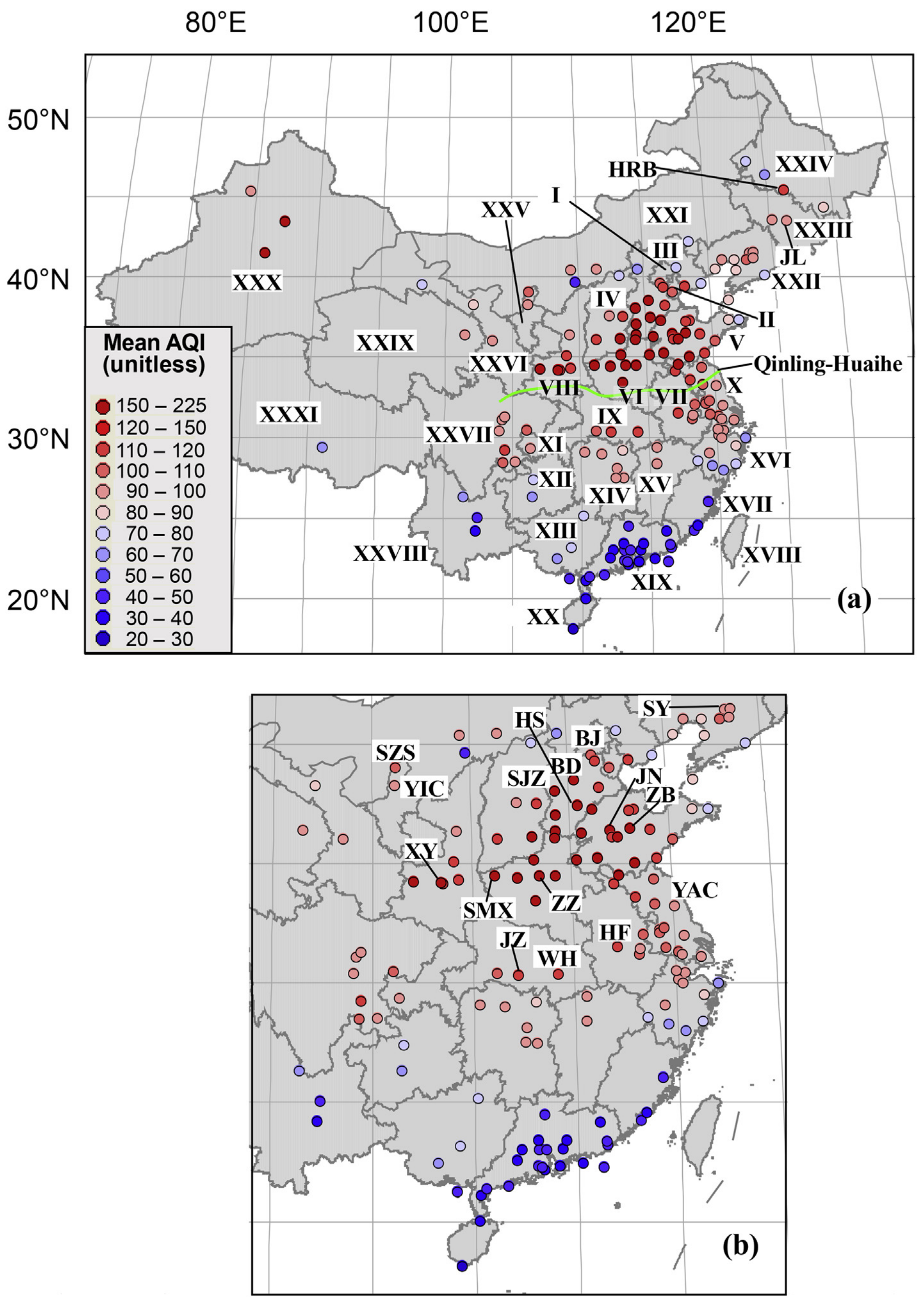

Fig. 1. (a) Mean air quality index (AQI) in 160 Chinese cities during winter 2015. The Chinese provinces are numbered and presented with their identifier number as following: I (Beijing), II (Tianjin), III (Hebei), IV (Shanxi), V (Shandong), VI (Henan), VII (Anhui), VIII (Shaanxi), IX (Hubei), X (Jiangsu), XI (Chongqing), XII (Guizhou), XIII (Guangxi), XIV (Hunan), XV (Jiangxi), XVI (Zhejiang), XVII (Fujian), XVIII (Taiwan), XIX (Guangdong), XX (Hainan), XXI (Inner Mongolia), XXII (Liaoning), XXIII (Jilin), XXIV (Heilongjiang), XXV (Ningxia), XXVI (Gansu), XXVII (Sichuan), XXVIII (Yunnan), XXIX (Qinghai), XXX (Xinjiang), XXXI (Xizang). The Qinling-Huaihe as the boundary line of north and south China is illustrated with a green line. The locations of Harbin (HRB) and Jilin are also presented. (b) Locations of the interested cities for case study and backward trajectory analysis, including Beijing (BJ), Baoding (BD), Shijiazhuang (SJZ), Hengshui (HS), Jinan (JN), Zibo (ZB), Shenyang (SY), Shizuishan (SZS), Yinchuan (YIC), Xianyang (XY), Zhengzhou (ZZ), Jingzhou (JZ), Wuhan (WH), Hefei (HF) and Yancheng (YAC). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

China in autumn and winter were associated to a slow displacement of weak synoptic system, with pollution center corresponding to the convergence area (Ren et al., 2004). The stagnation, swing, displacement and evolution of the convergence zone can result in accumulation of pollutants from different sources, and a variety spatial distribution of heavy pollution center in north China (Su et al., 2004). Chen et al. (2008) found that the synoptic pressure patterns and their evolvements were the main causes of regional air pollution; the increasing phase, maximum values, and decreasing phase of the air pollution index sequences in 10 cities over north China were accordant with the pressure patterns of high pressure, the succedent low-pressure system and front zone. The weakly intrusion of cold air from high-latitudes or weak wind over the coastal areas of ECN in the autumn could result in a static and stable weather, consequently PM pollution (Zhou et al., 2013). The severe fog-haze episode over north China in January 2013 was associated with a weak meridional circulation over the middle latitudes, no significant cold air activity in the north, an abnormal warm and humid airflow from the south, and the central to eastern China under control of a uniform pressure (Zhang et al., 2013). The severe wintertime haze events in north China were related to the weakened northerly winds and the development of inversion anomalies in the lower troposphere as well as the weakened East Asian trough and the northward East Asian jet (Chen and Wang, 2015). Gao et al. (2015) studied the influence of emission and synoptic situation on air pollution in Beijing during the 2014 Asia-Pacific Economic Cooperation Conference. The convergence of cold air and summer monsoon was associated to air pollution during autumn in Beijing (Gao et al., 2017). Wu et al. (2017) investigated the atmospheric circulation and dynamic mechanism of the 49 regional persistent haze events (RPHEs) in BTH during 1980–2013, and categorized the severe RPHEs into the zonal westerly airflow (ZWA) type and the high-pressure ridge (HPR) type; they also highlighted the descending montion at the mid-lower level associated with a reduction in the planetary boundary layer (PBL) height and an inversion in the lower troposphere, which consequently trapped the abundant pollution and moisture in the lower PBL, favoring the occurrence of RPHEs. He et al. (2017) classified the four seasons circulations into nine types using the