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Temporal and spatial variation relationship and influence factors on surface urban heat island and ozone pollution in the Yangtze River Delta, China

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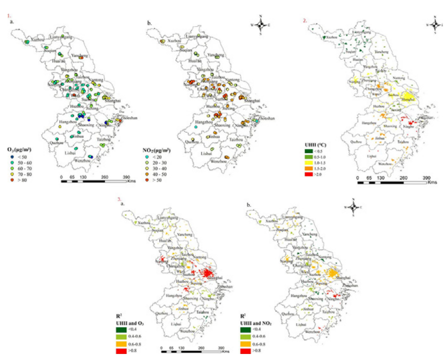
HIGHLIGHTS

- We established the temporal and spatial relationship between UHI and ozone pollution.
- There is a significant positive relationship between UHI and O_3 pollution in the YRD.
- Regional transmission exists in the UHI effect and O_3 pollution in the YRD.
- The UHI and O_3 concentration are mainly affected by the surface temperature and NDVI.
- Higher degree of urbanization indicates closer relationship of UHI and O3 pollution.

GRAPHICAL ABSTRACT

1. Spatial distribution of O_3 and NO_2 concentrations in the Yangtze River Delta (YRD) during 2015.
2. Spatial distribution of daytime UHII in the YRD during 2015.
3. The relationships between daytime UHII and O_3 and NO_2 concentrations in the YRD.



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ABSTRACT

Urbanization has led to an obvious urban heat island (UHI) effect in the Yangtze River Delta (YRD), China. The ozone (O_3) pollution in the YRD is getting worse. The UHI effect is a key factor that affects the O_3 level. Understanding the influences of the UHI effect on O_3 concentrations is necessary for improving air quality. In this study, the temporal and spatial relationship between UHI and O_3 in the YRD during 2015 was investigated. The influence factors of UHI effect and O_3 are both natural and artificial. Multi-source remote sensing data, which include land cover, land surface temperature (LST), Normalization Difference Vegetation Index (NDVI), and digital elevation model (DEM) data, were used to extract surface landscape elements. The results showed that: (1) the average hourly O_3 concentration was 61.83 μg/m^3 (30.92 ppb), the highest value was 105.32 μg/m^3 (52.66 ppb) at 15:00 and the O_3 peak was 82.50 μg/m^3 (41.25 ppb) in September. The O_3 concentrations and temperature have a similar variation trend both in diurnal and monthly. The O_3 concentrations in coastal stations are higher than those inland. (2) The average daytime UHI intensity was 1.24 °C, and the daytime O_3 concentration was 80.66 μg/m^3 (40.33 ppb). There is a positive relationship between UHI and O_3 in the YRD. The relationship in the central developed cities is higher than that in the northern and southern cities. (3) The related factors

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influencing UHI and O_3 include surface landscape, topography and population. The LST and NDVI are most important among these factors. (4) Due to various geographical backgrounds, the UHI intensities and O_3 concentrations show obvious spatial differences. This study provides a reference with which to better understand the relationship among UHI, O_3 and related factors. Furthermore, the issues of atmospheric and energy transmission in this region deserve further study.

1. Introduction

In recent decades, with the acceleration of urbanization processes, the urban heat island (UHI) effect and air pollution, which are caused by the expansion of urban areas, a reduction in vegetation coverage and an increase in anthropogenic emissions, have become the main environmental problems in urban areas (Cardelino and Chameides, 1990; Du et al., 2016; M. Li et al., 2017; Lo and Quattrochi, 2003). The UHI effect originally referred to air temperatures (AT) in the urban area that were significantly higher than those in the surrounding suburban area or the countryside (Arnfield, 2003). In recent years, with the application of land surface temperatures (LST) observed by satellite remote sensing, the surface urban heat island (SUHI) is used to define urban surface temperature that is higher than those in the suburbs or villages (Clinton and Gong, 2013; X. Li et al., 2017; Voogt and Oke, 2003; Zhou et al., 2014). Furthermore, studies have noted that surface urban heat (SUH) refers to the difference between the temperature of the core and its buffer. When the difference is positive (i.e., the temperature of the core is higher than the buffer), it indicates the surface urban heat island (SUHI). When the difference is negative, it is called the surface urban heat sink (SUHS) (Clinton and Gong, 2013).

Tropospheric ozone is a photochemical reaction generated from secondary pollutants that mainly come from its precursors, volatile organic compounds (VOCs) and nitrogen oxides (NOx), in the presence of sunlight, which has been confirmed by many studies (An et al., 2016; Cardelino and Chameides, 1990; Gao et al., 2017; Wang et al., 2016).

In recent years, with the rapid development of urbanization and industrialization processes, O_3 pollution has become more serious in the Yangtze River Delta (YRD) region, where many ground sites have exceeded the standard limit (Huang et al., 2011; M. Li et al., 2017; She et al., 2017). Some ground monitoring stations even reached 280 μg/m^3 (140 ppb), which exceeded 40% of the limit value of 1-hour average O_3 concentration of 200 μg/m^3 (100 ppb), according to the "Ambient air quality standards" (GB3095-2012) published by the Chinese Ministry of Environmental Protection. In addition, O_3 is the main component of photochemical smog. It also has been reported that tropospheric ozone pollution has a detrimental effect on human health and crop growth because of its strong oxidation characteristics (Chen et al., 2008; Lo and Quattrochi, 2003; Wang et al., 2016).

The main factors that affect the variation of ozone concentrations are ozone precursor emissions and weather conditions (Cardelino and Chameides, 1990; Ding et al., 2013; Elminir, 2005). However, the ozone concentrations vary between the backgrounds of different cities (T. Wang et al., 2017). Its relevant factors include ozone precursor emissions, meteorological conditions, and the UHI effect. It is a noteworthy concern that there is a relationship between the UHI effect and O_3 concentrations. The UHI effect is closely related to the entire urban ecosystem. Urban size and shape, land cover type, vegetation cover and population all directly and indirectly affect the spatial and temporal changes in UHI intensity (Du et al., 2016; Mathew et al., 2016; Zhou et al., 2014). Related research has shown that the increase of ozone and its precursor emissions caused by the UHI effect and changes in meteorological conditions in urban areas are directly and indirectly related to elevated O_3 concentrations (Cardelino and Chameides, 1990; Khiem et al., 2010).

The urban land surface parameters have a significant impact on UHI effect and air quality. M. Li et al. (2017) using MODIS surface parameters, simulated the air quality in the YRD and showed that the surface parameters play important roles in the land-atmosphere coupling system and that the land-sea breeze may aggravate air pollution in the coastal cities. The transport of air pollutants between cities is also a matter of concern. Zhu et al. (2015) demonstrated that the ozone and its precursors in the Shanghai metropolitan urban land surface affected the downstream city of Kunshan with its UHI circulation.

The urban form has a significant influence on the UHI effect and air quality. As urbanization changes the number and distribution of urban patches, it leads to temperature changes in the inner city and intercity. On the other hand, high-density buildings within the city obstruct winds that cross through the urban area, thereby aggravating the UHI effect and the accumulation of air pollutants (Khiem et al., 2010). In the study of the relationship between the urban form and air pollution, the size and shape of urban patches had a significant effect on the air quality in the YRD (She et al., 2017). However, previous studies have focused on the analysis of the UHI effect and air pollution in a single city or unilateral factor, and less research has focused on the transport patterns of intercity heat energy and air pollution over an entire region and multiple factors.

In this study, we focus on the temporal and spatial relationship among the UHI effect, O_3 and its precursors, as well as the related influence factors of the UHI effect and O_3 pollution, in the YRD during 2015. The YRD urban agglomeration is one of the fastest-growing, densest regions of population and buildings in China. The UHI effect in the YRD region has been of concern. In recent years, the number of exceeded ozone standard days with sunny, high-temperature weather is also particularly prominent. Moreover, the diversity and heterogeneity of the landscape pattern in the YRD region makes the relationship between the UHI and ozone pollution worth investigating.

Section 2 describes the study area, materials and methods. Section 3 presents the temporal and spatial distribution characteristics of O_3, NO_2, and land surface parameters, the relationship between UHI and O_3 and NO_2, as well as the related influencing factors on daytime UHI, O_3 and NO_2. In addition, Section 4 presents our conclusion.

2. Study area, material and methods

2.1. Study area

The YRD urban agglomeration is one of the six metropolitan areas in the world. It is located in eastern China, adjacent to the East China Sea, and it belongs to the subtropical monsoon climate. The annual average temperature is 16.9 °C. In this paper, the YRD consists of Shanghai city, Jiangsu Province and Zhejiang Province, with a total of 25 cities. It covers an area of 220,030 km^2, with a population of >140 million in 2015. The geomorphic type is diverse; in the north it is mainly plains, whereas in the south, it is mainly low mountains and hills. As shown in Fig. 1, there are obvious spatial differences among the land cover types in the YRD.

2.2. Materials

2.2.1. Ground measurement data

In this study, hourly ground-level O_3 and NO_2 measurements were collected from the China Environment Monitoring Center (CEMC) (http://106.37.208.233:20035/) from January 1, 2015 to December 31,