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Enhanced surface ozone during the heat wave of 2013 in Yangtze River Delta region, China

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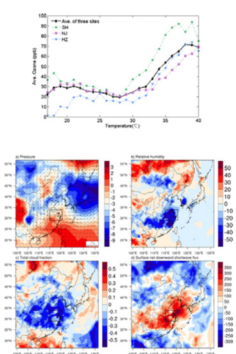
HIGHLIGHTS

- Hourly observational ozone data was used to quantify surface ozone change with temperature in summer of Yangtze River Delta.
- Use regional climate model RegCM-CHEM4 to reveal the main processes contributing to elevated ozone during heat waves.
- Investigations reveal that chemical reaction could not be ignored in future air quality and climate change studies.

GRAPHICAL ABSTRACT



In order to explore the relationship between heat wave and elevated ground-level ozone in Yangtze River Delta (YRD) region, we have investigated observational air temperature and ozone during summer of 2013, also applied with regional chemistry-climate model (RegCM-CHEM4). Observations indicate that YRD experienced severe heat waves with maximum temperature up to 41.1 °C, 6.1 °C higher than the definition of heat wave in China, and along with maximum ozone reaching 160.5 ppb, exceeding the national air quality standard (secondary level) as 74.7 ppb. Moreover, ozone was found to increase at a rate of 4–5 ppb K^{-1} within the temperature range of 28–38 °C, but decreased by a rate of −1.3–−1.7 ppb K^{-1} under extremely high temperature (Fig. 1). According to observations, a typical heat wave case (HW: 24/7–31/7) and a non-heat wave case (NHW: 5/6–12/6) were selected to reveal the mechanism between heavy ozone and heat waves. Numerical simulation discovers that, among chemical reaction, dry deposition, vertical turbulence and horizontal advection, chemical reaction plays the most important role in ozone formation when high temperature can result in 12 ppb ozone enhancement compared to NHW days. Chemical reaction can be influenced by several factors. High temperature environment usually controlled by anti-cyclone, and combined with sink airflow, leading to a more stagnant condition. During HW, less water vapor in YRD from south contributed to less cloud cover, which favored a strong solar radiation environment. As photochemical reaction strongly depends on the availability of solar radiation, ozone significantly increased during heat waves in YRD. High temperature also slightly promote the effect of vertical turbulence and horizontal advection, which beneficial to ozone remove, but the magnitude is much smaller than chemical effect. Our research suggests that the chemical reaction will potentially lead to substantial elevated ozone in a warmer climate, which should be taken into account in future ozone related issues.

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ABSTRACT

Under the background of global warming, occurrence of heat waves has increased in most part of Europe, Asia and Australia along with enhanced ozone level. In this paper, observational air temperature and surface ozone in the Yangtze River Delta (YRD) region of China during summer of 2013, and the regional chemistry-climate model (RegCM-CHEM4) were applied to explore the relationship between heat wave and elevated ground-level ozone. Observations indicated that YRD experienced severe heat waves with maximum temperature up

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to 41.1 °C, 6.1 °C higher than the definition of heat wave in China, and can last for as long as 27 days. Maximum ozone reached 160.5 ppb, exceeding the national air quality standard (secondary level) as 74.7 ppb. Moreover, ozone was found to increase at a rate of 4–5 ppb K^{-1} within the temperature range of 28–38 °C, but decrease by a rate of −1.3 ~ −1.7 ppb K^{-1} under extremely high temperature. A typical heat wave case (HW: 24/7–31/7) and non-heat wave case (NHW: 5/6–12/6) were selected to investigate the mechanism between heavy ozone and heat waves. It was found that chemical reactions play the most important role in ozone formation during HW days, which result in 12 ppb ozone enhancement compared to NHW days. Chemical formation of ozone can be influenced by several factors. During heat waves, a more stagnant condition, controlled by anti-cyclone with sink airflow, led to less water vapor in YRD from south and contributed to less cloud cover, which favored a strong solar radiation environment and ozone significantly increasing. High temperature also slightly promote the effect of vertical turbulence and horizontal advection, which beneficial to ozone remove, but the magnitude is much smaller than chemical effect. Our study suggests that the chemical reaction will potentially lead to substantial elevated ozone in a warmer climate, which should be taken into account in future ozone related issues.

1. Introduction

Along with the rising of global surface temperature (IPCC, 2014), heat waves have become a popular extreme weather phenomenon. Sufficient data and plenty of research showed that there has been a likely increasing trend in the frequency of heat waves since the middle of the 20th century in Europe, Australia and across much of Asia (Hartman et al., 2013). Heat waves gradually become a kind of common danger in the world due to their severe impacts on human health, climate change and socioeconomic factors (Robine et al., 2008; Beniston, 2004; Poumadère et al., 2006). Among all the impacts, heat wave effect on human health is most closely to us. In addition to living condition and people with medical illnesses (Semenza et al., 1996; Fouillet et al., 2006), how did heat waves affect human health? There is already extensive evidence suggesting that air pollutants related to temperature have adverse effects on health, including surface ozone (Sartor et al., 1995; Bernard et al., 2001; Patz et al., 2005; Fouillet et al., 2006; Tagaris et al., 2009). High ground-level ozone concentrations were an important co-exposure during heat waves which were reported during the 1976 heat wave (MacFarlane et al., 1997) and the 2003 heat wave (Fischer et al., 2004; Johnson et al., 2005; Filleul et al., 2006). Between 21% ~ 38% of the excess deaths in England (Johnson et al., 2005) and 40% of mortality in Netherlands (Fischer et al., 2004) were estimated to be attributable to ozone.

Surface ozone is a secondary pollutant formed in the atmosphere by chemical reactions, which has a significant influence on climate, environment and human health. The influences of surface ozone are getting more and more attention, especially on human health, which is also well established currently. As air pollutant, it is recognized that ozone impacts on human health occur above 50 ppb (WHO, 2006) and can negatively impact photosynthesis, forest productivity, crop yields and biomass accumulation (Ashmore, 2005; Ainsworth et al., 2012; Leisner and Ainsworth, 2011; Tai et al., 2014). In Europe, it is investigated that ozone contributes to 21,400 premature deaths annually (EEA, 2007). As greenhouse gas, ozone has a warming effect on the climate system, having radiative forcing on climate similar to other air pollutant (Lacis et al., 1990; Ramanathan and Feng, 2009; Szopa et al., 2013; Stevenson et al., 2013). Background surface ozone in the northern hemisphere is between 35 and 40 ppb, and elevated ozone value occurs in the years depending on the meteorological condition. The concentration of ozone reached as high as 200 ppb during the 2003 heat wave in France (Fiala, 2003). However, in some cities in the USA (WHO, 2006) and in mage-cities in Asia (Emberson et al., 2003) such magnitude is a common feature.

Since most polluted cities have experienced the greatest increase in temperature-related ozone pollution, plenty of work has been carried out for addressing its intensity and sensitivity experiments focused on temperature. Several remarkable surface ozone phenomena associated with high temperature have occurred in recent years, e.g., in Europe in 2003 (Fouillet et al., 2006), USA in current and future (Bell et al., 2007), Australia in 1993 and 2004 (Vaneckova et al., 2008), China in 2004 (Shan et al., 2008). Many numerical experiments were conducted

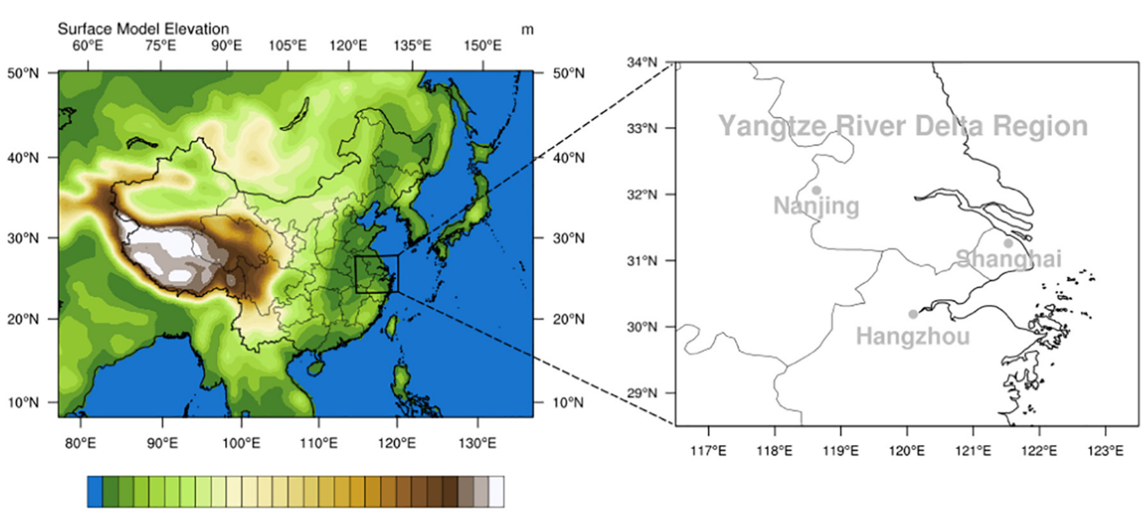

Fig. 1. Surface elevation of modeling domain (left) used in RegCM-CHEM4 covered most part of East Asia. Typical case study region Yangtze River Delta was amplified in the right, also showing the location of Shanghai, Nanjing and Hangzhou.

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