Science of the Total Environment 521–522 (2015) 135–143

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Multi-year ozone concentration and its spectra in Shanghai, China

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HIGHLIGHTS

- The spectral decomposition methods are used.
- The spectra of surface ozone have multi periods.
- The monthly mean of surface ozone has a significant seasonal variation.
- The intraseasonal cycling of ozone might be related to the MJO.

ARTICLE INFO

Article history:
Received 25 December 2014
Received in revised form 19 March 2015
Accepted 20 March 2015
Available online 30 March 2015

Editor: Xuexi Tie

Keywords:
Ozone concentration
Spectral decomposition
Semi-diurnal variation
Seasonal variation

ABSTRACT

The periodic properties of surface ozone variation were studied at five stations with different environmental conditions in Shanghai based on multi-year observations of ozone concentration and UV radiation using spectral decomposition methods. The spectra of surface ozone have distinct peaks at semi-diurnal, diurnal, intraseasonal, semiannual, annual, and quasi-biennial periods. The spectra for the frequency band larger than the semi-diurnal follow a −5/3 power law at all the stations. The diurnal peak values for all stations in different years are similar to each other, while the semi-diurnal peak values are somewhat different among the stations. The peak value of semi-diurnal cycle at the station Dongtan (ecological environment area) is smaller than that at the other stations. The monthly mean of surface ozone has a significant seasonal variation with a maximum in May, a secondary maximum in fall, a lower value in summer (July and August), and a minimum in December or January. However the seasonal variation of UV radiation monthly mean shows a relatively higher value in summer (July and August), and for other months it is closely related to the ozone monthly mean. These secondary peaks of the ozone monthly mean in fall might be caused by the UV radiation coming back to its relevant value after falling off during the Asia summer monsoon; it was not related to biomass burning. The intraseasonal cycling of ozone might be related to the MJO (Madden–Julian Oscillation). Further studies are needed to understand the relationship between the local ozone intraseasonal variation and the MJO. The quasi-biennial variation of ozone in Shanghai might be a local reflection of climate change and could be associated with ENSO (El-Nino Southern Oscillation). Further studies will be needed to understand the relationship of the quasi-biennial variation of ozone to ENSO.

1. Introduction

As the main photochemically produced atmospheric constituent, surface ozone (O_3) is a major pollutant that can cause serious damage to human health and ecological environment (Zhou, 1996; Berman et al., 1995; Jalaludin et al., 2004). Surface ozone is formed in the air as a result of complex photochemical reactions involving nitrogen oxides (NO + NO = NOx), carbon monoxide (CO), and various volatile organic compounds (VOCs), which mostly result from anthropogenic activities. The temporal variations of surface ozone have been widely studied for several decades (Danalatos and Glavas, 1996; Aneja et al., 1997; Olszyna et al., 1997; Sabutis et al., 1987; Raddatz and Cummine, 2001; Creilson et al., 2003). Many studies indicated that the temporal variations of ozone concentration have distinct regional characteristics (Girgzdiene, 1991; Hastie et al., 1993; Güsten et al., 1998; Chan et al., 1998).

Shanghai, situated on the east coast of China, is a metropolis with a total population over 24 million as of 2013. The rapid growing urbanization causes wide-ranging consequences for the environment (Geng

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http://dx.doi.org/10.1016/j.scitotenv.2015.03.082
0048-9697/

Table 1
Climate data for Shanghai (1971–2000).
Source: China Meteorological Administration[43].

Climate data for Shanghai (1971–2000)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average high C	8.1	9.2	12.8	19.1	24.1	27.6	31.8	31.3	27.2	22.6	17.0	11.1	20.2
Average low C	1.1	2.2	5.6	10.9	16.1	20.8	25.0	24.9	20.6	15.1	9.0	3.0	12.9
Precipitation mm	50.6	56.8	98.8	89.3	102.3	169.6	156.3	157.9	137.3	62.5	46.2	37.1	1,164.7
Avg. precipitation days (= 0.1 mm)	9.7	10.3	13.9	12.7	12.1	14.4	12.0	11.3	11.0	8.1	7.0	6.5	129.0
% humidity	75	74	76	76	76	82	82	81	78	75	74	73	76.8
Mean monthly sunshine hours	123.0	115.7	126.0	156.1	173.5	147.6	217.8	220.8	158.9	160.8	146.6	147.7	1,894.5
Percent possible sunshine	39	37	34	40	41	35	50	54	43	45	46	47	42.6

Source: China Meteorological Administration

et al., 2008). One of the most serious environmental problems is the enhanced ozone concentration in Shanghai, so it is vital and urgent to gain a good understanding of ozone production in Shanghai. Xu and Zhu (1994) reported that in certain situations local circulations affect the ozone concentration of urban Shanghai by using a series of O_3-NOx observations. Xu et al. (1997) studied the seasonal cycles of surface ozone and NOx in Shanghai. They found that ozone concentration has a maximum in spring and a minimum in summer, which is quite different from those in North America and Europe where a spring and spring-summer maxima are widely observed (e.g., Seinfeld et al., 1991; Colbeck and Mackenzie, 1994); the summer minimum in Shanghai was attributed to the onset of the summer monsoon. The diurnal ozone cycle in Shanghai, however, follows the typical pattern with a maximum in the afternoon and a minimum at night (Geng et al., 2008).

Previous studies on the temporal variations of ozone in Shanghai mainly focused on the diurnal and seasonal cycles, and there is a lack of understanding of the various periodic variations of ozone at other time scales and the possible reasons for these variations. This paper employs multi-year ozone data from five monitoring stations across the Greater Shanghai area to analyze periodic variations in ozone, the temporal variation of the periods and the difference between different site locations using spectral and wavelet analysis methods. The relationship between ozone and ultraviolet (UV) radiation is examined at one of the five locations where UV observations are also available.

The paper is organized as follows: The descriptions of geography and climate in Shanghai are given in Section 2. In Section 3, the monitoring sites, data and methods used in this study are described. In Section 4, the results are analyzed and discussed. The summary of results is given in Section 5.

2. Geography and climate of Shanghai

Shanghai sits on the Yangtze River Delta on China's eastern coast and faces the East China Sea, which covers an area of 6340.5 km^2. It is located on a peninsula between the Yangtze and Hangzhou Bay, as well as Chongming Island and a number of smaller islands. It is in the subtropics and is under the influence of the summer and winter Asian monsoons. From mid-June to early or mid-July, the meiyu (baiu) rainy season occurs in Shanghai, with increased precipitation and cloud cover, and decreased sunshine. A summary of the monthly means of the Shanghai surface meteorological variables is given in Table 1. Shanghai is one of the most industrialized cities with the largest adjacent metropolitan areas in the world. Shanghai also suffered from industrial and automobile pollutant emissions. Until 2013, there are more than 2.7 million automobiles in Shanghai.

3. Monitoring sites, data and method

The five monitoring sites in this study are selected to represent different environmental conditions (Fig. 1). The easternmost site, Dongtan, is located in an ecological area on Chongming Island. Baoshan is located north of Shanghai in a large steel industrial area. Pudong is located in a suburb and close to a large city park. Down town Xujiahui is a business and human activity center with serious traffic and air pollution problems. Jinshan is located south of Shanghai in a large petrochemical complex. Details of the ozone monitoring stations are shown in Table 2. All monitoring instruments are located on top of tall buildings at least 15 m off the ground. The observations at Baoshan, Pudong, Xujiahui and Jinshan are from January 2006 to December 2012 and at Dongtan from January 2008 to December 2012. At the Dongtan site, UV radiation is also measured data from January 2009 to December 2012.

Ozone concentration is measured using an EC9810 Ozone Analyzer (Ecotech, Australia) at all five sites and a photometer is used to measure UV at the Dongtan site. The ozone instrument is automatically set to zero and includes an optional external valve manifold and external calibration sources. The instrument meets the technical specifications of the US Environmental Protection Agency (EPA). Quality control checks are performed every three days including the section of the shelter and instruments as well as zero, precision and span checks. The filter is replaced once in every two weeks and the instrument is calibrated monthly. The O_3 concentration is recorded every minute. UV radiation is measured with UV-S-AB-T radiometers (KIPP&ZONEN, The Netherlands) and recorded every minute.