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Analysis of the Surface Ozone During Summer and Autumn at a Coastal Site in East China

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Abstract The levels and temporal variations of surface ozone at a coastal site in East China during summer and autumn were analyzed and the influences of meteorological parameters on ozone were investigated. An inland city was chosen as a comparison site. The main results and conclusions of this study are: (1) ozone pollution, with a maximum 1 h concentration of 150.98 ppbv, was severe during summer and autumn at the coastal site; (2) the ozone level was obviously higher at the coastal site than that at the inland site in September; (3) besides temperature and solar radiation, sea-land breeze circulation is an important factor influencing the ozone level at the coastal site, and sea breeze often induce high ozone levels (the average ozone concentration for sea breeze was about 13 ppbv higher than that for land breeze).

Keywords Surface ozone · Meteorological condition · Coastal site · East China

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Surface ozone is considered as a natural greenhouse gas and also as an important secondary air pollutant with damaging impacts on human health, crops, and vegetation. Elevated ozone levels have been observed at some urban and non-urban sites in China (Wang et al. 2007). In addition, the impact on the yields of crops by ozone exposure has been estimated (Chameides et al. 1999; Wang and Mauzerall 2004). However, there are limited studies has been reported on the ozone pollution at coastal site in East China, where has been undergoing rapid economic growth, urban expansion, and transportation development, in addition to the adverse effect on air pollution condition caused by coastal recirculation (e.g., Oh et al. 2006; Levy et al. 2009).

The purpose of this study was to measure and analyze surface ozone at a coastal site in East China during summer and autumn seasons.

Materials and Methods

This study was conducted in the Yantai Economic and Technological Development Zone (YETDZ), located in the eastern coastal region of Shandong province, to the west of Yantai City (see Fig. 1). The averaged ozone concentration, temperature, daily solar radiation, wind speed, and daily sunshine duration were 40.6 ppbv, 24.6°C, 1628.7 MJ/m^2, 2.6 m/s, and 7.0 h respectively in YETDZ during the study. Measurement of surface ozone was carried out at the Environmental Monitoring Station of YETDZ (37°33′N, 121°15′E). The site is about 200 m to the south of the Yellow Sea.

Ozone was continuously measured by a Thermo Environmental Instruments Inc. (USA) UV photometric analyzer (model 49C) from 5 July to 30 September. The Lower

Fig. 1 Locations the observational sites at Yantai Economic and Technological Development Zone (YETDZ) and Jinan

Table 1 Statistical results of measured ozone concentrations at YETDZ from July to September 2005

Month	Mean (ppbv)	Median (ppbv)	Maximum (ppbv)	PEC (%)	n	SD
July[a]	41.02	38.11	150.98	14	622	25.15
August	39.64	39.27	115.28	11	719	21.44
September	41.43	38.24	135.81	22	679	25.44
Total	40.62	38.82	150.98	47	2020	24.00

PEC percentage of hourly averaged ozone concentrations exceeding the Chinese National Ambient Air Quality Standard Grade 2 (hourly average ozone concentration of 0.20 mg/m^3, about 100 ppbv)

[a] Values for July are from 5 to 31 July

detectable limit is 1.0 ppbv and the precision is ±1 ppbv (Thermo Environmental Instruments Inc. 2000). The height of the air intake was 22.5 m above the ground, which was installed on the top of a building. Air samples were collected through Teflon inlet tubes, with a particulate filter to prevent particles from entering into the instrument. As part of the National Environmental Monitoring Network, the observational site follows strictly the National Standards on environmental monitoring. Meteorological data used in this study were received from Fushan Meteorological Monitoring Station of YETDZ, which is nearby the study site. Based on the observational data, the levels and temporal variations of surface ozone were analyzed and the influences of meteorological conditions on ozone were investigated.

An inland city, Jinan, was chosen as a comparison site for the study to show the ozone characteristics of coastal site. The type of ozone analyzer used in Jinan is same to that in YETDZ. The meteorological data of Jinan were obtained from China Meteorological Data Sharing Service System (http://cdc.cma.gov.cn/). More information about the observational study in Jinan could be found in Shan et al. (2008).

Results and Discussion

Table 1 shows some statistical characteristics of the hourly averaged ozone concentrations at YETDZ in each month during the study, as well as the percentages of the concentrations exceeding the Chinese National Ambient Air Quality Standard Grade 2 (hourly average ozone concentration of 0.20 mg/m^3, about 100 ppbv). The mean concentrations of ozone in different months followed the order of September > July > August. The 3 months all presented several ozone values exceeding the National Ambient Air Quality Standard, with the maximum 1 h value (150.98 ppbv) observed at 1700 hours July 26. Most exceeded values were observed in September, indicating that photochemical pollution at the observational site is still

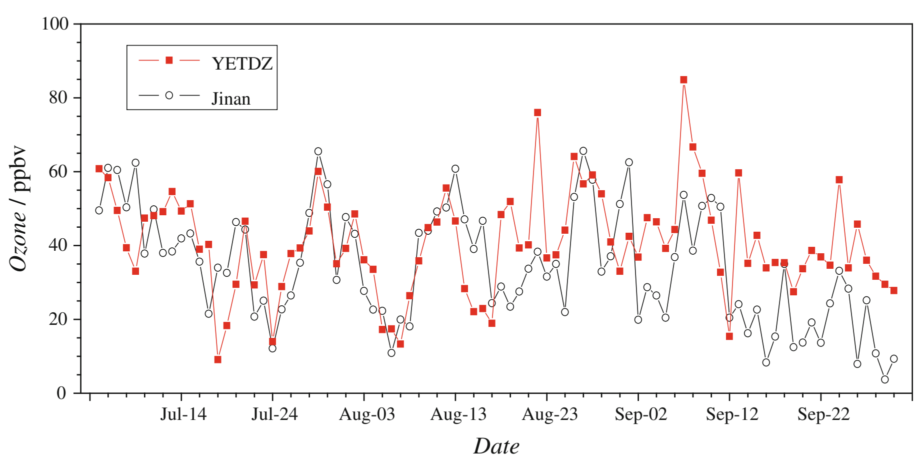

Fig. 2 Variations of daily averaged ozone concentrations observed at YETDZ and Jinan from July to September 2005

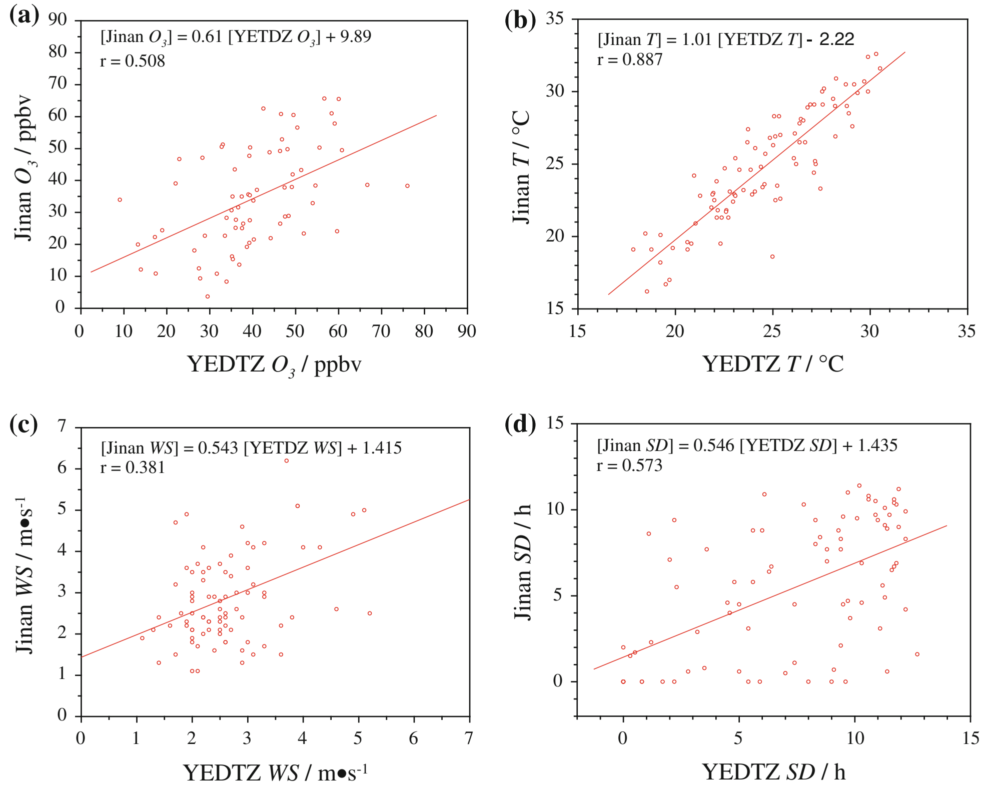

Fig. 3 Liner correlation analysis of daily averaged O_3 concentrations (**a**), temperatures (**b**), wind speeds (**c**), and total sunshine durations (**d**) at YETDZ and Jinan from July to September 2005. *T* temperature, *WS* wind speed, *SD* total sunshine duration

serious in autumn. The high summer and autumn ozone level will inevitably cause the yield reductions of the summer time crops in the coastal areas.

Figure 2 presents the variations of daily averaged ozone concentrations from July to September at YETDZ, as well as at an inland city, Jinan, for comparison. Compared with July and early August, the ozone level showed a little elevated from late August to September at YETDZ, while ozone level kept decrease from late August to September at Jinan. The daily variation trends of ozone at the two sites were similar with each other, which is associated with the similar meteorological conditions due to the relative short distance between them. According to the liner correlation analysis, the correlation coefficients for the daily averaged ozone concentrations, temperatures, wind speeds, and total sunshine durations at YETDZ and Jinan were 0.508, 0.887, 0.381, and 0.573 respectively (see Fig. 3).

Figure 4 presents the averaged diurnal variations of ozone concentrations in each month (from July to September) at YETDZ, as well as at Jinan for comparison. The diurnal variation of ozone at the two sites both showed a typical pattern for polluted areas, characterized by high concentrations during mid or afternoon, low concentrations during early morning, and big variation magnitude between daytime and nighttime. The two sites had similar diurnal

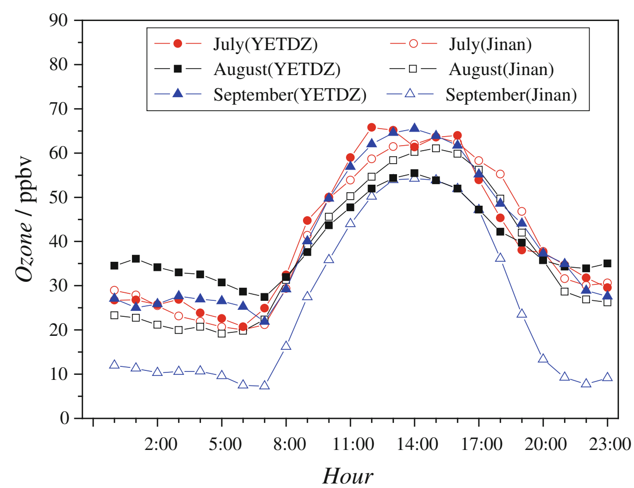

Fig. 4 Diurnal variations of ozone concentrations in each month at YETDZ and Jinan

ozone variation trends in July. However, the ozone levels were lower during daytime and higher during nighttime at YETDZ than that at Jinan in August. In addition, the ozone levels were obviously higher both in daytime and nighttime at YETDZ than that at Jinan in September. The different ozone levels in autumn indicate the different atmospheric environment between coastal site and inland site, even with a relatively short distance.

The diurnal variations of solar radiation, temperature, and wind speed in each month (from July to September) at YETDZ are shown in Fig. 5. The diurnal variations of ozone at YETDZ presented the minimum value for July at 0600 hours, while that for August and September appeared at 0700 hours (see Fig. 4). This statistical characteristic can be explained by the different average times of sunrise for different months, as is shown by the different levels of solar radiation in the early morning. Both levels of temperature and solar radiation in different months followed the order of July > August > September, which is different with the order for ozone concentrations. This result indicates that some other important factors also contribute to the ozone level at YETDZ besides temperature and solar radiation. Both temperature and wind speed for each month showed a similar diurnal pattern, with high values during daytime and low values during night, which was consistent with the diurnal variation of ozone.

Though the direction of the coastline in this region is about 90°–270°, we adopted the direction of 45°–315° as the boundary to discriminate sea breeze and land breeze in the study, for the sake of avoiding the emission influences from Yantai City and the western land area. The ozone concentrations corresponding to the wind directions are shown in Fig. 6. We can see that, the ozone level distributed in sea breeze region was obviously higher than that in land breeze region. According to the calculation, the average ozone concentration for sea breeze and land breeze were 50.52 and 37.53 ppbv respectively, which indicate that ozone level associated with sea breeze is higher than that associated with land breeze.

The hours and frequencies of sea/land breeze during daytime and nighttime in each month are shown in Table 2. The frequency of sea/land breeze was calculated by the following equation: $F = (h_d \, or \, h_n)/(h_d + h_n)$, where F is

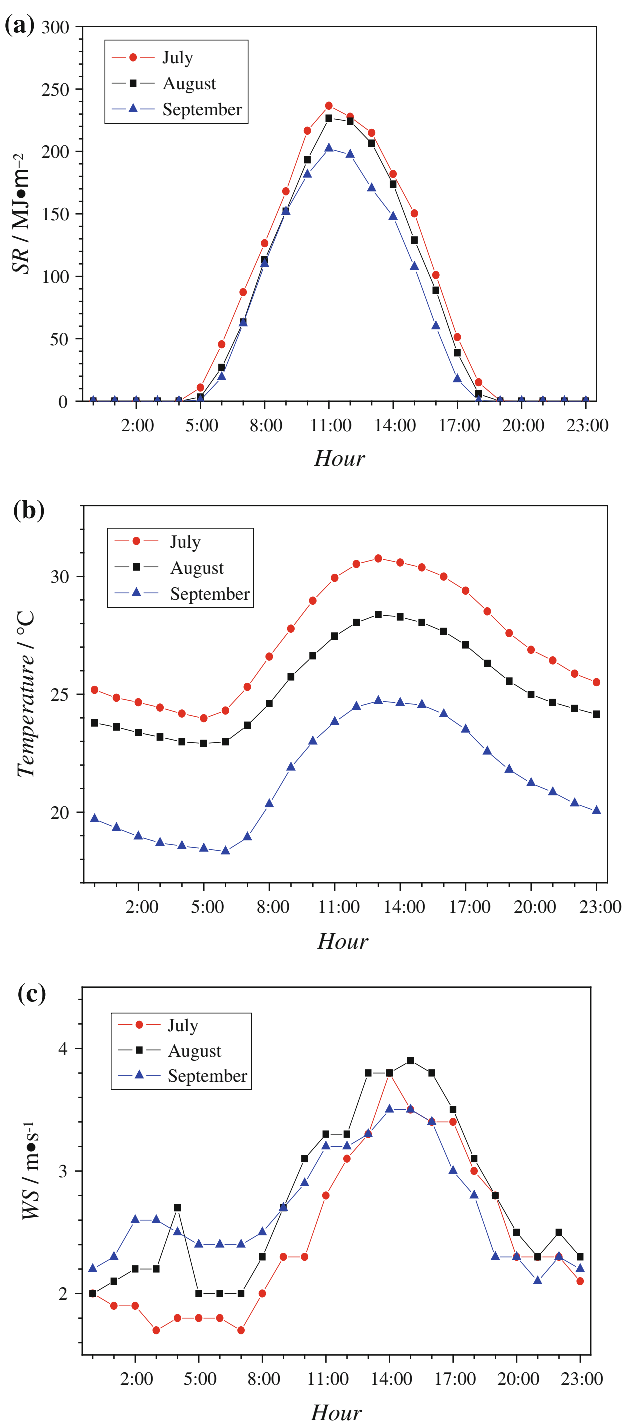

Fig. 5 Diurnal variations of solar radiation (**a**), temperature (**b**), and wind speed (**c**) in each month at YETDZ. *SR* solar radiation, *WS* wind speed

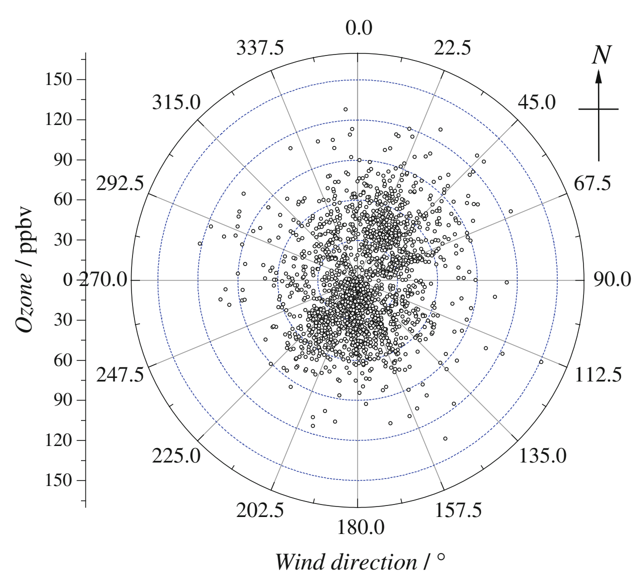

Fig. 6 Ozone concentrations according to wind directions

Table 2 Hours and frequencies of sea/land breeze during daytime or nighttime in each month

Wind type	July[a]		August		September	
	Daytime (h/%)	Nighttime (h/%)	Daytime (h/%)	Nighttime (h/%)	Daytime (h/%)	Nighttime (h/%)
Sea breeze	86/74.8	29/25.2	94/54.0	80/46.0	138/65.7	72/34.3
Land breeze	238/44.7	295/55.3	278/48.8	292/51.2	222/43.5	288/56.5

[a] Values for July are from 5 to 31 July

the frequency, h_d and h_n are the hours of sea/land breeze during daytime and nighttime respectively.

More sea breeze cases were observed during daytime (0800–1900 hours) than during nighttime (2000–0700 hours) in each month, while land breeze cases were contrary, indicating that sea-land breeze circulation (wind circulation with SB during daytime and LB during nighttime in a day) might have occurred frequently. The frequency of sea-land breeze circulation occurred in August is obviously lower than the other 2 months. Compared with in July and September, the diurnal variation of ozone levels in August presents anomalously lower during daytime and higher during nighttime at YETDZ (see Fig. 4). Since the ozone level was higher during sea breeze than land breeze, the anomalous diurnal variation of ozone in August might be related to the less sea-land breeze circulation. In addition, the highest ozone level of September might be associated with the highest frequency of sea breeze.

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