Atmospheric Environment 71 (2013) 376–388

Contents lists available at SciVerse ScienceDirect

Atmospheric Environment

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

Influence of an enhanced traffic volume around beaches in the short period of summer on ozone

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HIGHLIGHTS

► We evaluated the impact of road traffic emissions around beaches on O_3 concentrations.
► The analysis was based on a numerical modeling approach during the beach opening period.
► The maximum negative impact of mobile emissions was predicted near the beach areas.
► O_3 destruction rate around the beach areas decreased by up to −5.5 ppb h^{-1} during the day.

ARTICLE INFO

Article history:
Received 13 June 2012
Received in revised form
30 January 2013
Accepted 4 February 2013

Keywords:
Beach
On-road mobile emission
O_3
Photochemical destruction
Process analysis

ABSTRACT

The impact of pollutant emissions by the significant amount of road traffic around beaches on the ozone (O_3) concentrations in the surrounding regions were evaluated using a numerical modeling approach during 6 days (29 July through 3 August) of the beach opening period (BOP) in 2010. On-road mobile emissions at several roads close to beaches in Busan, Korea during the study period were estimated from the emission factors, vehicle kilometers traveled, and deterioration factors. The emission data was then applied to the 3-D chemical transport model. A process analysis (PA) was also used to assess the contributions of the individual physical and chemical processes to the production or loss of O_3 in the study area. The model study suggested the possibility that road traffic emissions near the beach area can have a significant impact on the O_3 concentrations in the source regions as well as their surrounding/downwind regions. The maximum negative impact of mobile emissions on the O_3 concentrations was predicted near the beach areas: by −9 ppb during the day due to both the high NO_x emissions with the high NO_x/VOC ratio and meteorological conditions and −9 ppb at night due to the fast titration of O_3 by NO. The PA showed that the contribution of chemical process to the decrease in O_3 concentrations (up to −5.5 ppb h^{-1}) due to mobile emissions near the beach areas was the most dominant compared to the other physical processes.

1. Introduction

Road traffic is one of the major contributors to urban pollution and a dominant anthropogenic emission source for nitrogen oxide ($NO_x = NO + NO_2$), carbon monoxide (CO), and volatile organic compounds (VOCs) (Mayer, 1999; He et al., 2002; Tzirakis et al., 2006). Road traffic emissions contribute significantly to local and even global ozone (O_3) concentrations via peroxyacetyl nitrate (PAN) formation (e.g. leading to a contribution to O_3 concentrations of up to 15% in arctic latitudes) (Matthes et al., 2007). Air quality such as the concentrations of primary air pollutants (NO, CO, and VOCs) as well as secondary pollutants (O_3) can be considerably affected by the episodes of the concentration of the road traffic conditions in terms of time, space, and emission sources. This type of episode such as Beijing Olympic Game is the sudden increase in road traffic in a very small area during a short-term period, showing about 40%, 24%, and 14% increases for mean PM_{10}, CO, and NO_2 concentrations, respectively, and a 20% decrease for mean O_3 concentrations relative to the normal conditions (Wang and Xie, 2009). This episode (condition) can also occur in beach areas of a coastal city in Asia with high population density during the beach opening period (BOP) in summer due to the large numbers of vehicles. Therefore, the emissions of anthropogenic pollutants such as NO_x and VOCs from road traffic around the beaches during the opening period can be enhanced significantly, affecting the O_3 concentrations in the surrounding regions.

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1352-2310/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.atmosenv.2013.02.003

In the areas around coastal areas including the major ports or beaches, ship emissions are also a major anthropogenic source of a range of air pollutants (e.g. NO_x, CO, VOCs, and sulfur oxide (SO_x)), which have increased dramatically because of the heavy ship traffic due to expanding international trade (Corbett and Koehler, 2003; Endresen et al., 2003; Eyring et al., 2005). In the marine and/or coastal atmosphere, the significance of ship emissions on air quality has been reported with regard to their impact on the concentrations of air pollutants (O_3, NO_x, etc.), as well as radical formation (Lawrence and Crutzen, 1999; Eyring et al., 2007; Vutukuru and Dabdub, 2008; Collins et al., 2009; Song et al., 2010). For instance, the concentrations of NO_x, O_3, and hydroxyl (OH) radicals due to ship emissions over the oceans were estimated to increase by factors of 2, 2, and 1.2, respectively, whereas the NO_x and OH concentrations within the sea-lanes were estimated to increase by factors of 2 and 5, respectively (Lawrence and Crutzen, 1999). In the South Coast of California, ship emissions near ports and in heavily traversed ocean regions resulted in an up to 29 ppb increase in O_3 concentrations (Vutukuru and Dabdub, 2008).

The necessity for specific studies on anthropogenic pollutant emissions by transportation, such as road and/or ship traffic, in coastal areas including the beaches and ports during a short period is important for determining their environmental impact on the air quality in and around these areas. On the other hand, there is little data on the measurements of sporadic emissions and concentrations of O_3 precursors (e.g. NO_x and VOCs) from road traffic during BOPs. In addition, the data on the exhaust gas emissions from ships is incomplete. Therefore, it is difficult to provide a proper evaluation of the environmental behavior of pollutant gases when impacted simultaneously by road and ship traffic sources. In particular, no intensive assessments of the impact of such road traffic emissions on the coastal air quality have been made to our knowledge. This study examined the impact of enhanced mobile emission strength due to the significant changes in traffic density around the beach areas on the O_3 concentrations in the surrounding regions in Busan, Korea during the BOP in 2010. In addition, the contribution of individual physical and chemical processes to the O_3 concentrations in the study area was assessed using a process analysis (PA) method.

2. Materials and methods

2.1. Study area

Busan, the target area in this study, is the second largest metropolis located on the southeastern tip of the Korean Peninsula with an area of 760 km^2 and a population of approximately 3.6 million. It is also the largest port city in Korea and the world's fifth busiest seaport according to the cargo tonnage (known as "Cargo Gateway of Asia"). Since the early 1990s, the city has rapidly become urbanized and industrialized with heavy road traffic (e.g. vehicle registration of approximately 1.2 million as of 2011) (Ministry of Land, Transport and Maritime Affairs (MLTM), 2012) and increased shipping activities (e.g. approximately 80% of container cargo and 40% of the total national imported and exported overseas cargo), particularly in coastal areas (Song et al., 2010 and references therein). This can cause a considerable increase in the emissions of a range of pollutant gases (from traffic activities, shipping, and industrial facilities) in coastal areas, which can affect the air quality (e.g. O_3 concentration) in and around these areas. In recent years (2006–2010), high O_3 days when the average O_3 concentration in an 8-h period exceeds 60 ppb (a national ambient air quality standard: 100 ppb as 1-h average and 60 ppb as 8-h; EU air quality standard: 60 ppb as 8-h) have been observed frequently at several coastal sites in Busan (e.g. approximately 30–50 days y^{-1}).

Busan has three main beaches, Haeundae (HU), Kwanganri (KA), and Songjung (SJ), with the main beach roads of 1.5, 2, and 2 km distances, respectively (Fig. 1). These beaches host enormous numbers of tourists during the BOP of 1 July through 31 August. The visitor information at HU and SJ beaches was obtained from the Busan Haeundae Police Station (http://www.bspolice.go.kr/haeundae/main/main.html), whereas that at KA beach was obtained from the Urban Management Information System of the Suyeong-gu District Office (http://www.suyeong.go.kr/06_suyoung/s7_1.asp). During two months (July to August) of the BOPs over the recent four years (2007–2010), the number of daily visitors to the three beaches ranged from 0.16 million to 0.26 million, 0.13 to 0.19, and 0.06 to 0.11 at HU, KA, and SJ beaches, respectively. The minimum and maximum values of total visitors during the entire BOP (4.0 and 15.8 million at SJ and HU beaches, respectively) between the three beaches accounted for approximately 8% and 31% of the total South Korean population, respectively. In addition, the visitors at HU (monthly mean of 6.1 million) and KA (4.8 million) beaches during the four years were a factor of up to 2.3 higher than that (2.6 million) at SJ beach.

2.2. Methods of analysis

To evaluate the effects of mobile emissions on the O_3 concentrations in the target area, numerical modeling was applied to a 6-day period (29 July through 3 August) including observation days (29 and 31 July and 1 and 3 August) of traffic volume at the major roads close to the three beaches during the BOP in 2010. The impact of on-road mobile emissions during the BOP was quantified by analyzing the difference in the model-predicted O_3 concentrations derived from two sets of simulation experiments: (1) with enhanced mobile emissions during the BOP (i.e. BOP case); and (2) with emissions in the normal situation (i.e. NOR case), including the land-based (point, area, and biogenic sources) and ship emissions in the two cases. Such impacts were evaluated in detail with regard to a comparison of the weekend (e.g. 31 July 2010) and weekday (e.g. 3 August 2010) of the BOP. In this study, to evaluate the influence of mobile emissions only, the time period and locations for the NOR case were assumed to be the same as the BOP case. On the other hand, the emissions during the BOP case were estimated based on in-situ measurement data of traffic volume during the 6-day study period, whereas those during the NOR case were calculated from the Clean Air Policy Support System (CAPSS) national emission inventory, which includes road traffic emissions calculated using vehicle number, vehicle type and its emission factor, and road-related information in each city and province, because the traffic volume for the NOR case during the study period was not counted. Detailed descriptions regarding the investigation of traffic volume and the estimation of on-road mobile emissions during the study period are provided in Section 2.3. Note that the difference in O_3 concentration between the BOP and NOR cases (BOP–NOR) represents the impact of mobile emissions in the beach areas during the BOP on the O_3 concentrations in the surrounding regions.

The PA method (the integrated process rate (IPR) and integrated reaction rate (IRR) analyses) was also applied during the observation period to quantify the contribution of physical (e.g. horizontal and vertical transport) and chemical processes of mobile emissions to the O_3 concentration. In the IPR and IRR analyses of O_3 in the target area, two sites close to the beach (e.g. Suyeong (SY) and Daeyeon (DY)), one site located outside the beach (e.g. Gijang (GJ)), and two sites (e.g. S1 for 31 July and S2 for 3 August) located downwind of the beach areas were selected for the comparison. Detailed information concerning the IPR and IRR analyses was given in the Community Multi-scale Air Quality (CMAQ) Science Documentation (http://www.epa.gov/asmdnerl/CMAQ/CMAQscie