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Surface ozone pollution during the festival of Diwali, New Delhi, India

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Abstract

Pollution from carbon monoxide, nitrogen dioxide, sulphate and suspended particulate matter due to ignition of fireworks during the festival of Diwali is well established. Although surface ozone exhibits high natural variability throughout the year, any short term enhancement in ozone levels coupled with high level of pollutants during Diwali might prove to be deadly for a large number of elderly people and children with heart and respiratory ailments. Despite this fact, very little study on surface ozone pollution during the festival of Diwali has been reported from India so far. In the light of these observations, the changes in ozone concentration observed during Diwali at New Delhi in India have been studied to determine the amount and possible causes of ozone pollution apart from pollution due to ignition of fireworks. Compared to the normally observed ozone levels, the ozone concentration was higher during Diwali. The ozone levels were found to be higher in 2006 compared to 2004, and exceeded the ambient air quality standard for three hours. The results are discussed in light of enhanced vehicular traffic and emission of ozone precursor gases from fireworks, transport of ozone and climatic conditions during Diwali.

Introduction

Surface ozone is a harmful pollutant, which is associated with persistent decrease in lung function, pneumonia, influenza and asthma. It is produced by the photo oxidation of CO and hydrocarbons, in presence of adequate amount of nitrogen oxides (NO and NO_2) at low altitudes (Crutzen, 1974; Kirchhoff, 1988). Vehicular emissions also contribute to production of local surface ozone and its precursors (NOx, CO, and hydrocarbons). Niemeier et al., 2006, have observed that the surface ozone concentration increases by 30–50 parts per billion by volume (ppbv) due to enhanced vehicular traffic. Attri *et al.,* (2001) observed that when fireworks were lit during the festival of Diwali, there was a surge in ozone levels from 8.40 pm to 2.30 am the next morning, which was not linked with nitrogen oxide levels in the air. Further they observed from laboratory experiments that higher the amount of flammable materials in the fireworks, higher was the level of ozone that was produced. They showed precisely that in addition to emitting light in the visible region, metals at high temperature also emit radiation in the ultraviolet region. Consequences of this are that the high energy UV radiation are absorbed by molecular oxygen present in the air, resulting in the splitting of molecular oxygen into atomic oxygen, which in turn reacts with molecular oxygen to produce ozone.

Fireworks contain harmful chemicals such as potassium nitrate, carbon and sulphur apart from an array of chemicals such as strontium, barium, sodium, titanium, zirconium, magnesium alloys, copper and aluminum powder to create the colourful effects (Holmes, 1983). On burning they release gases such as carbon monoxide (CO) and nitrogen dioxide (NO_2) (Khaiwal *et al.,* 2003). High levels of pollution during the firework episodes are responsible for the higher occurrence of respiratory diseases (Bach *et al.,* 1972; Bach *et al.,* 1975; Becker *et al.,* 2000). Pollution from carbon monoxide, nitrogen dioxide, sulphate and suspended particulate matter due to ignition of fireworks during the festival of Diwali is well established. Although surface ozone exhibits high natural variability throughout the year, any short term enhancement in ozone levels coupled with high levels of pollutants from fire crackers may prove to be deadly for a large number of elderly people and children with heart and respiratory ailments. Despite this fact, very little study on surface ozone pollution during the festival of Diwali has been reported from India so far. In light of these observations, the changes in ozone concentration observed during Diwali time for the years 2004 and 2006 have been studied to determine the amount and possible causes of ozone pollution apart from pollution due to ignition of fireworks.

Monitoring site and measurements

New Delhi (28.38 ^{o}N, 77.17 ^{o}E), the capital of India, is located in northern India, and has an area of about 1,484 sq km. It is a densely populated, cosmopolitan city and has one of the highest living standards in India. Diwali, also known as the "Festival of Lights", is one of the most popular cultural and religious festival in Delhi during which millions of people light traditional lamps and ignite fireworks. It is usually celebrated in the month of October/November. The festive fever starts a few days prior to Diwali with people igniting fireworks, shopping for the celebrations and visiting each other and reaches a crescendo on the day of Diwali. The diurnal variation of surface ozone measured by the electrochemical method during Diwali has been obtained from India meteorological department (IMD) New Delhi. The surface ozone recording system comprises of a bubbler ozone sensor, a suction pump for drawing atmospheric air through the bubbler, an amplifier for the sensor current and a 0-1 μA strip chart recorder. The principle of ozone measurement is based on the titration of ozone in a potassium iodide (KI) sensing solution according the redox reaction:

$$2\ KI + O_3 + H_2O \rightarrow I_2 + O_2 + 2\ KOH$$

The amount of generated free iodine (I_2) is measured in electrochemical reaction cells. Continuous operation is achieved by a small electrically driven gas sampling pump which forces ambient air through the sensing solution of the electrochemical cell. Transported by the stirring action of the air bubbles, the iodine molecule makes contact with a platinum cathode and is reduced back to iodide ions by the uptake of 2 electrons per molecule of iodine. An electrical current proportional to the mass flow rate of ozone through the cell is generated. By knowing the gas volumetric pumping rate and the gas temperature the measured electrical current is converted to the ozone concentration in the sampled ambient air. The entire assembly is protected inside a weather hood, which is blackened from inside to absorb scattered light and painted white from outside to reflect sunlight.

The weather condition at New Delhi during Diwali has been obtained from the website http:// www.wunderground.com. Concentration of CO and NO_2 and information on the growth of motor vehicles at New Delhi has been obtained from the website of Central Pollution Control Board.

Results and discussions

The factors affecting photochemical formation of ozone are intensity of solar radiation and the concentration of precursor gases like NO_x, CO and Hydrocarbons. Chemical reactions involving ozone production and removal occur within a time scale of few hours (Raj et al., 2003). Atmospheric ozone exhibits high natural variability over hourly, diurnal, synoptic, weekly, seasonal, and long-term time scales (Varotsos and Cracknell, 2004) and is highly influenced by regional/long range transport (Beig *et al.,* 2007).

To delineate the effects of festivities on the measured ozone concentration, the ozone data before and after Diwali (± 2 days to ± 7 days) were averaged and used as background (normal), while the ozone concentration a day prior to, on the Diwali day and a day after Diwali were averaged and plotted to represent the effect of Diwali for the years 2004 and 2006 (Fig. 1a and 1b). The diurnal variations in ozone for the year 2005 could not be studied as the data is incomplete due to the presence of clouds, rain and thunderstorms during the period of Diwali (http://www.wunderground.com).

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Surface ozone levels from 120 to 200 parts per billion by volume (ppbv) or more are harmful to human beings (Singh, 2005). The ambient air quality standards formulated and adopted by the United States Environment Protection Agency (USEPA), for ozone is 120 ppbv for 1-hour average and 80 ppbv for 8-hour average (Khitoliya, 2004). The surface ozone levels during the year 2006 were found to be exceeding the ambient air quality standard (120 ppbv) for three hours by 5.4 - 13.3 ppbv (Fig. 1b).

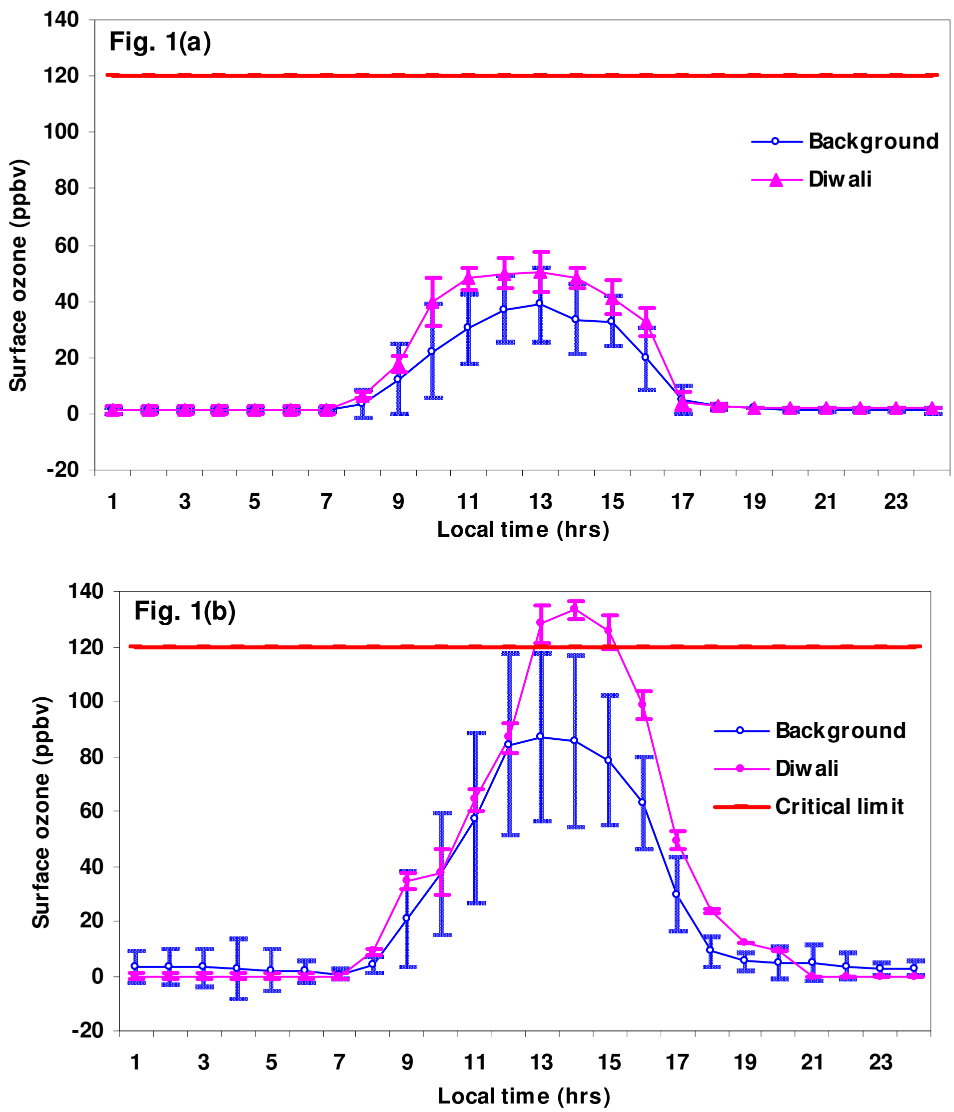

Fig. 1: Diurnal variation of surface ozone (ppbv) for the years (a) 2004 and (b) 2006 at Delhi. Bars indicate 2σ deviation (Source: India Meteorological Department).

According to the National Ambient Air Quality Standards (NAAQS), the limit for lethal nitrogen dioxide is 80μg/m^3 and lethal carbon monoxide is 2000 μg/m^3. The ambient NO_2 and CO levels (μg/m^3) measured at a residential location B.S.Z Marg (I.T.O) at New Delhi during Diwali 2006 is shown in fig. 2. The NO_2 and CO levels were found to be low on the day of Diwali but increased steadily for four days after Diwali and built up gradually in the atmosphere.

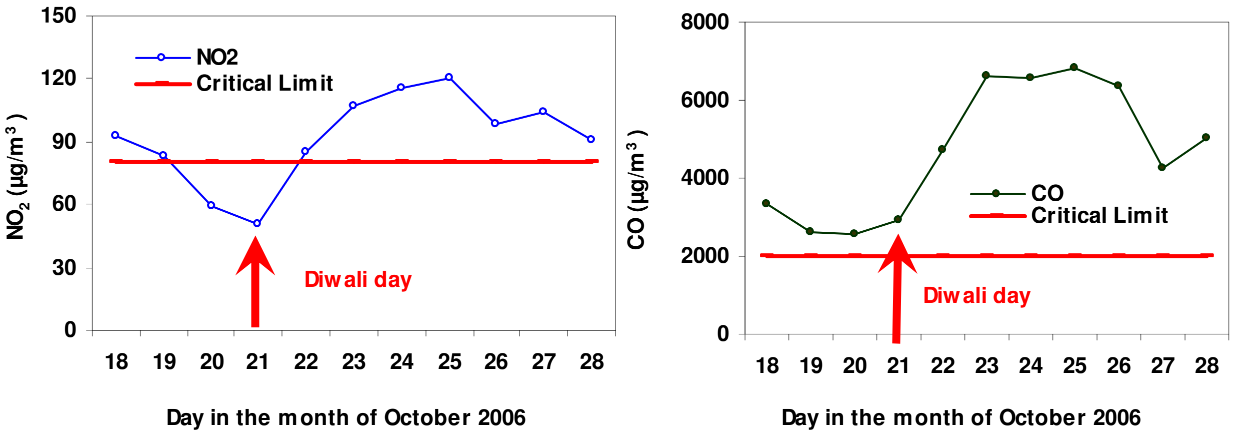

Fig. 2: Ambient NO_2 and CO (µg/m^3) measured at B.S.Z Marg (I.T.O) during Diwali 2006 (Source: Central Pollution Control Board).

Comparison between yearly average NO_2 (µg/m^3) and NO_2 levels on the Diwali day at various monitoring stations at New Delhi during the years 2004 and 2006 is shown in table 1, which indicates that the NO_2 levels at most of the places were higher on the day of Diwali compared to the other days.

Table-1: Comparison between yearly average NO_2 (µg/m^3) and NO_2 levels on the Diwali day at various monitoring stations at New Delhi during the years 2004 and 2006 (Source: Central Pollution Control Board). R = Residential Area, I = Industrial Area

Location	Average NO_2 in 2004	NO_2 on the day of Diwali in 2004	Average NO_2 in 2006	NO_2 on the day of Diwali in 2006
B.S.Z Marg (ITO) (R)	60	107	56	51
Sirifort (R)	35	51	38	41
Janakpuri (R)	41	42	51	45
Nizamuddin (R)	45	100	49	54
Shahazada Bagh (I)	47	93	48	53
Shahdara (I)	39	80	43	37

Compared to the normally observed ozone levels, the ozone concentration was found to be higher during Diwali from 8.00 am to 5.00 pm for both the years 2004 and 2006. This is because presence of sunlight and a time lag of around 5–7 hours are required for the precursor gases (CO, hydrocarbons and nitrogen oxides), which are released into the air by the ignition of firecrackers and enhanced traffic at night to produce ozone to its maximum potential (Beig *et al.*,2007). Apart from photochemical formation of ozone due to the emission of precursor gases from fireworks and enhanced traffic, the general wind pattern from NW and N direction during Diwali might have also resulted in advection of polluted continental air from higher latitudes to Delhi. It could also be possible that the low surface

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air temperature during winter must have resulted in suppressed convection and downward transport of ozone. Unlike Attri *et al.,* (2001), no enhancement in ozone concentration was observed at night during Diwali time. This may be because, either the instrument used at IMD may not be sensitive enough to measure the reported small surge in ozone levels at night or the place where the fireworks were being ignited was not close enough to IMD, where the measurements were being recorded. Hence the high level of surface ozone during Diwali observed in this study may be due to an increase in vehicular traffic, emission of ozone precursor gases from fireworks, transport from higher latitudes and suppressed convection.

The ozone concentration during Diwali was found to be higher in 2006 compared to 2004 by about 83 parts per billion by volume (ppbv). This may be due to an increase in population density, resulting in higher vehicular traffic, NO_2 emission and ignition of crackers in 2006 compared to 2004 as shown in fig. 3.

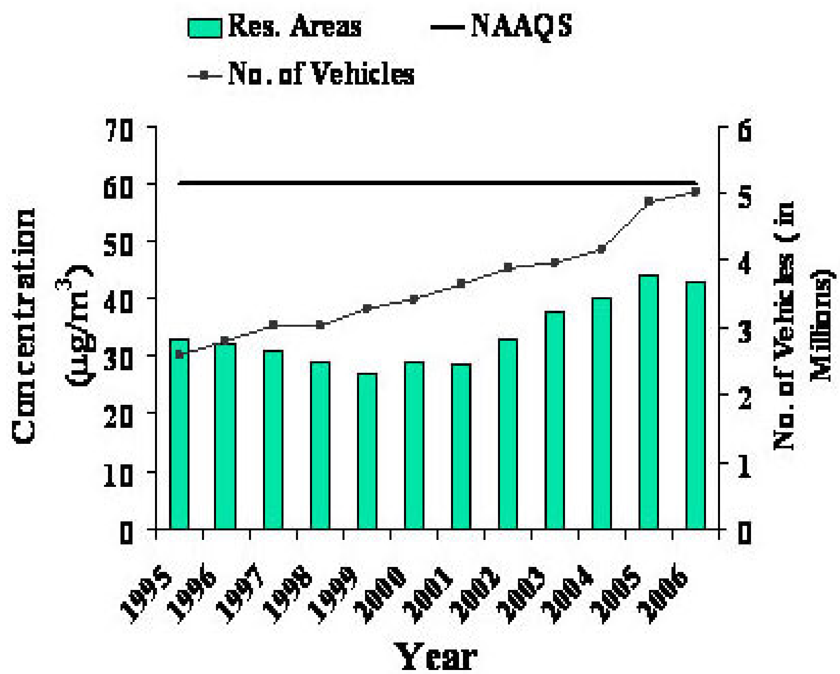

Fig. 3: Annual average concentration of NO_2 (µg/m^3) in residential areas and growth of motor vehicles in New Delhi from 1995 - 2006 (Source: Central Pollution Control Board, Annual report 2006 – 2007, Pg. 39).

Conclusions

The surface ozone levels measured at New Delhi, during the festival of Diwali was found to be higher compared to the normally observed values, which may be attributed to an increase in vehicular traffic, emission of precursor gases from fireworks, transport from higher latitudes and suppressed convection. The ozone levels were higher in the year 2006 compared to 2004 and were found to be exceeding the ambient air quality standard for three hours, indicating high levels of ozone pollution. The high ozone levels combined with pollution due to fireworks might be critical for elderly people and children with heart and respiratory ailments.

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Dr. Nandita Ganguly is a senior faculty member with the Physics department of St.Xavier's College, Ahmedabad. Her research interests include study of atmospheric ozone, aerosols and related fields.