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Effect of forest canopy on the tropospheric ozone concentration of Indian States

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ABSTRACT
The tropospheric ozone concentration for few Indian States have been studied using the data obtained from the Tropospheric Ozone Residual (TOR) method to determine the impact of forest canopy on atmospheric ozone and the importance of plant emissions to our climate. The impact of forest canopy on tropospheric ozone concentration depends on factors like the amount of isoprene and monoterpene emitted by the plants, the type and area of forests, humidity and background NO_x levels. The NO_2, isoprene and humidity levels in the forests of northeastern India are found to be higher compared to those observed over the remaining parts of India. This may be one of the reasons why the ozone concentration observed in the forests of northeast India is also higher compared to that observed over the remaining parts of India.

INTRODUCTION

The total ozone concentration in the troposphere depends on the ratio of its supply from the stratosphere and the rate of its destruction on the earth's surface (Junge 1962; Van Dop, Guicherit, & Lanting 1977). Ozone is also produced and destroyed in the troposphere due to chemical reactions involving free radicals (Crutzen 1974). Surface ozone is produced photo chemically due to NO_x and reactive hydrocarbons in presence of solar radiation (Kirchhoff 1988). Even in densely populated countries, it is difficult to imagine that it is plants, and not humans, which emit most of the organic compounds like isoprene and monoterpene into the air globally. These hydrocarbons emitted from forests react with NO_x produced from automobile exhausts and factory byproducts transported from the cities, to produce pollutants like ozone in the atmosphere, which may damage the tissues of plants and animals. Hence, if we want to understand how our climate system works and how it is likely to change in the future, it is important to look at emissions not only from human activity but also from the biosphere. In view of these considerations, the effect of forest canopy on the tropospheric ozone concentration of a few Indian states has been studied in this paper.

BIOSPHERE- ATMOSPHERE LINK

The forests of India are ancient in nature and composition. They are rich in variety and shelter a wide range of avifauna, mammals and insects. Worldwide, plants emit more than one thousand million tonnes of organic compounds. About half of this is a gas called isoprene ($C_5 H_8$). Another important group is the monoterpene ($C_{10}H_{16}$), which gives pine trees and fruits their characteristic smell. Plants emit these gases through their leaves and their needles, not only in response to stress such as drought, but also during normal growth.

A study by the National Centre for Atmospheric Research in 2001 showed that volatile organic compounds emitted by autumn leaves combine with certain types of industrial emissions to create smog, and, in some cases, they play a role in global warming(Viswanathan 2004). Research at the University of California, Berkeley suggests that pollution from oak trees is destroying the pine forests of the Sierra Nevada Mountains. They found that the oaks were producing about 40 to 70 per cent ozone which is damaging and killing Jeffrey and ponderosa pines — the dominant species in the forest (http://www.scienceblog.com/community). The detective work that led to the incrimination of trees began after American cities found that ozone levels failed to decline even after anti-pollution measures were carried out. Ozone is formed by the effect of sunlight on nitrogen oxides and hydrocarbons. It was thereafter concluded that some trees such as oak and poplar, were producing huge amounts of a hydrocarbon called isoprene, which dominated in the formation of ozone. Trees have been blamed for up to 65 per cent of ozone-forming chemicals in Houston. A study of the Ozark forests, along with other EPA studies, showed that trees in heavily forested countries in the region might emit up to 300 tons of isoprene per day (Viswanathan 2004). About half of the isoprene eventually turns into formaldehyde. Isoprene, like other naturally emitted chemicals, poses a danger when wind carries it into the urban areas or near other pollution sources.

DATA AND ANALYSIS

The tropospheric ozone data obtained from the Tropospheric Ozone Residual (TOR) method for the four seasons – summer (March-May), monsoon (June – August), autumn (September – November) and winter (December – February) of the years 1998- 2000 for urban sites and forests located nearby for different Indian states has been studied to determine the impact of forest canopy on atmospheric ozone. Dr. Jack Fishman at NASA Langley Research Center in Hampton developed the TOR method of deriving tropospheric ozone from satellite measurements (Fishman, Wozniak, & Creilson 2003). TOR was initially developed utilizing coincident observations of total ozone from the Total Ozone Mapping Spectrometer (TOMS) instrument and stratospheric ozone profiles from the Stratospheric Aerosol and Gas Experiment (SAGE) instrument. At present, the total column amount of ozone from the TOMS instrument is being used, but the stratospheric ozone profiles from the Solar Backscattered Ultraviolet (SBUV) instrument have replaced the profiles from SAGE. The change from the SAGE instrument to the SBUV instrument was made because of the greater data density provided by the SBUV instrument. Gridded global values of tropospheric column ozone are available between 50°N and 50°S with 1° latitude by 1.25° longitude horizontal resolution up to December 2000. The distributions are determined by subtracting the empirically corrected stratospheric column ozone amount derived from the SBUV instrument from the total column ozone measurements made by TOMS. The temperature and dew point measured at the airports of different Indian cities for the year 2004 has been obtained from the website www.wunderground.com to study the effect of humidity on plant emissions. The maximum temperature and dew point data obtained on a daily basis has been averaged seasonally. The columnar tropospheric NO_2 values measured by GOME for the year 2000 have been obtained from the website http://www.temis.nl/. The GOME instrument was launched on the European ERS – 2 satellite in 1995 and it provides global gridded values of tropospheric column NO_2 with 0.25° latitude by 0.25° longitude horizontal resolution. Industrial Pollution due to NO_2 ($\mu g/m^3$) in different Indian States from 1998 to 2000 has been obtained from the website of Central pollution Control Board, Ministry of Environment & Forests, New Delhi, India. Yearly mean isoprene levels in different Indian forests for the year 1990 have been obtained from the global model by Guenther et al (1995). The total columnar ozone concentration in the atmosphere is expressed in Dobson Units (1 DU is about 2.7×10^{16} molecules/cm ^{2}). The map of India indicating different Indian States in figure 1 has been obtained from the Website: Maps-india.com. There may be minor errors due to instrumental uncertainties in the data obtained from GOME and the ones estimated in the TOR and isoprene model. We have not made any effort to synthesize them, and have assumed that these uncertainties have been reduced while taking the average of a large number of observations which have been directly taken from GOME and the TOR and isoprene models.

RESULTS AND DISCUSSION

The effect of forest canopy on the tropospheric ozone concentration depends on factors like (1) The amount of isoprene and monoterpene emitted by the plants, which in turn depends on the type and area of forests and humidity levels. (2) Background NO_x levels.

Several studies have shown that high ambient humidity levels or mechanical disturbances such as rain can enhance the emission of monoterpene (Street, Hevitt & Mennicken 1997; Schade, Goldstein & Lamanna 1999). Biogenic monoterpene emission contributes to photochemical ozone production (Chameides et al., 1988). The effect of isoprene on tropospheric chemistry depends on the initial NO_x level (Makar & McConnel 1992). Ozone concentration is enhanced by the addition of isoprene, if the initial NO_x level is high or medium, and depleted if the initial NO_x is low. Oxidation of isoprene by OH and NO_3 produces RO_2 (alkylperoxy) radicals.

$$RO_2 + NO \rightarrow RO + NO_2$$
$$NO_2 + h\nu \rightarrow NO + O$$
$$O + O_2 + M \rightarrow O_3 + M$$

The tropospheric ozone data for the four seasons – summer, monsoon, autumn and winter of the years 1998- 2000 for urban sites and forests located nearby for different Indian States has been studied to determine the impact of forest canopy on atmospheric ozone. The map of India indicating different Indian States is shown in Fig.1.

Figure 1. Political map of India.

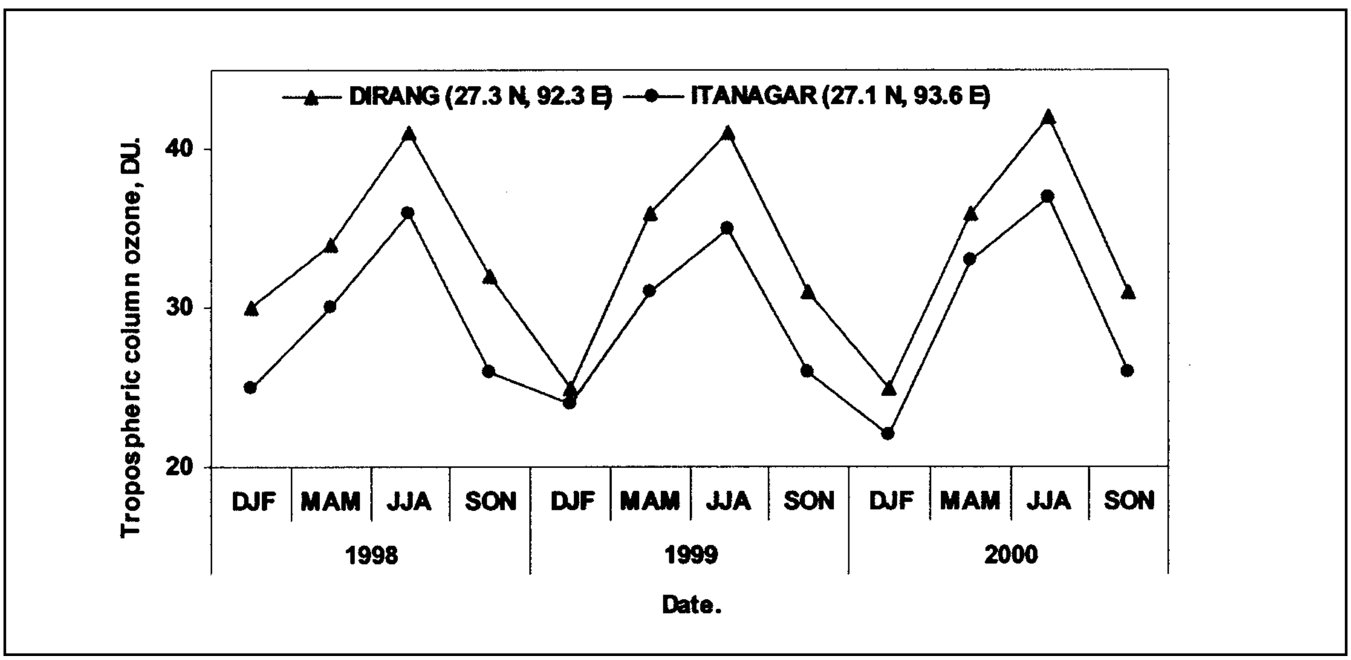

Figure 2. Tropospheric column ozone (DU) in Arunachal Pradesh.

General aspects of Indian forests

ARUNACHAL PRADESH: The vegetation of Arunachal Pradesh can be classified into tropical, sub-tropical, pine, temperate and alpine forests. Pine forests extend both in the subtropical and temperate belt in between 1000 m to 1800 m elevation and are found in Dirang valley of Kameng district. In Fig.2, the tropospheric column ozone found in the forest region of Dirang is compared with that for urban region Itanagar.

WEST BENGAL: The mangrove forest of Sunderbans in West Bengal extends over an area of 2,320 sq.km (Mukherjee 1975). Champion (1936) classified the Sundarbans as moist tropical seral forest, comprising beach and tidal forests. In Fig.3, the tropospheric column ozone found in the forest region of Sunderbans is compared with that for urban region Kolkata.

JHARKHAND: Nestling in low hilly terrain, at an average altitude of 1800 ft, the 183.89 sq. km Hazaribaug national park in Bihar has abundant thick forests of jute, timber, banyan tree and pipal. In Fig.4, the tropospheric column ozone found in the forest region of Hazaribaug is compared with that for urban region Dhanbad.

ASSAM: Kaziranga in Assam comprises of thick forests of teak and bamboo. In Fig.5, the tropospheric column ozone found in the forest region of Kaziranga is compared with that for urban region Jorhat.

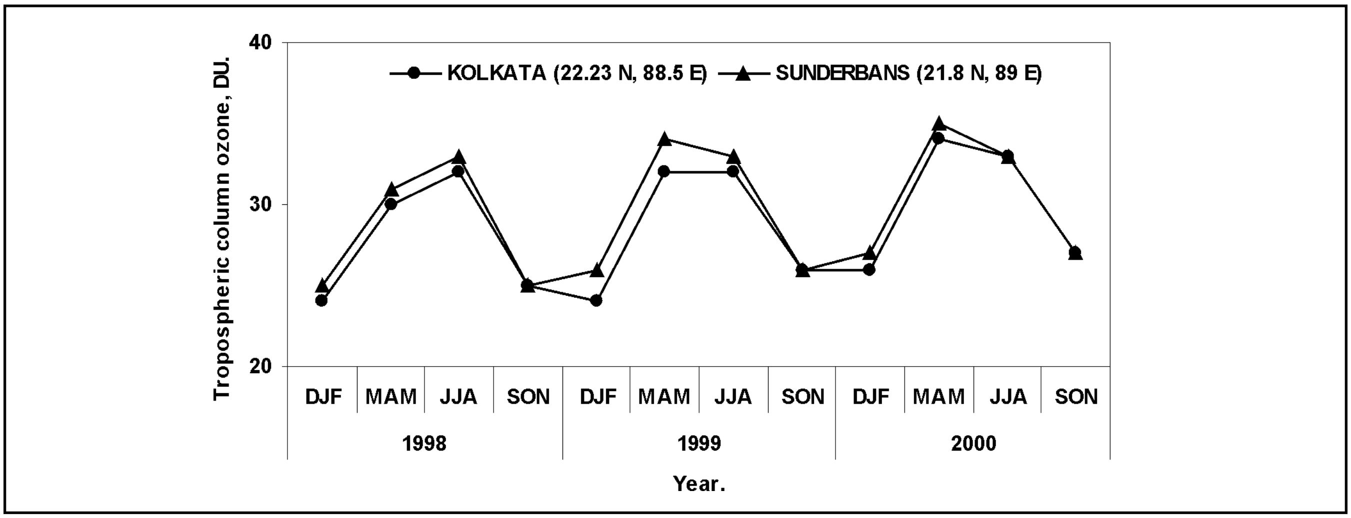

Figure 3. Tropospheric column ozone (DU) in West Bengal.

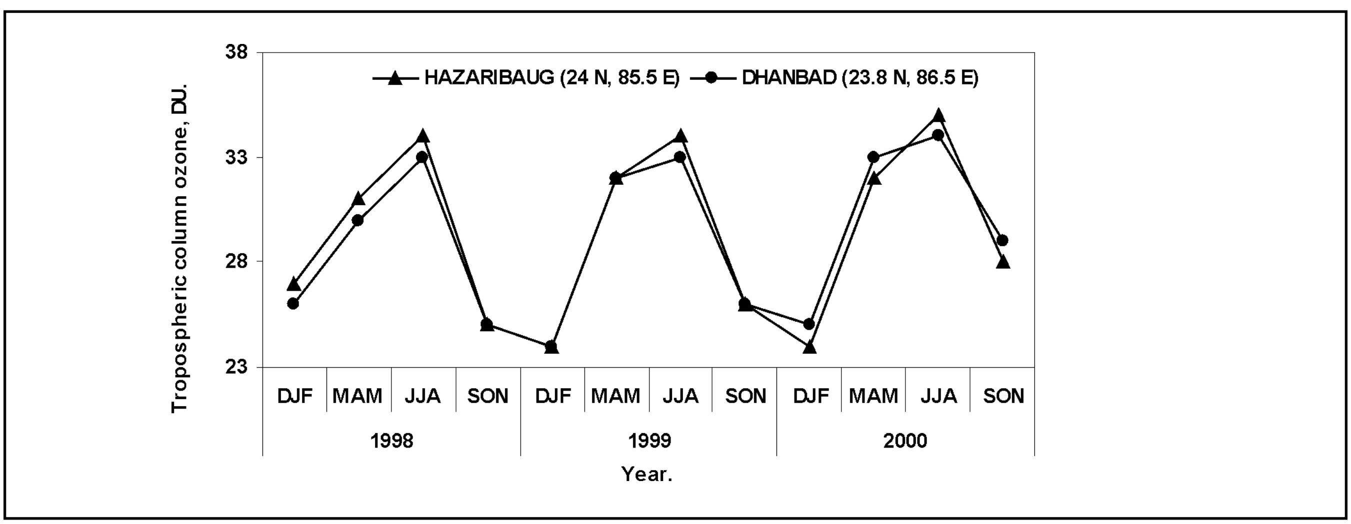

Figure 4. Tropospheric column ozone (DU) in Jharkhand.

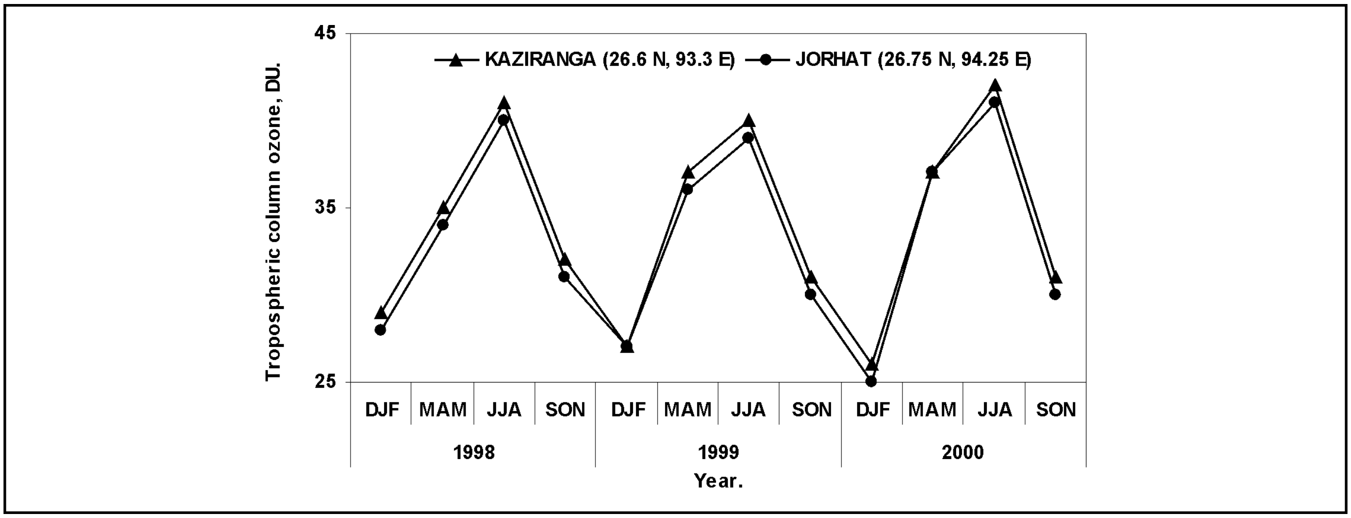

Figure 5. Tropospheric column ozone (DU) in Assam.

HIMACHAL PRADESH: Thick dense forests comprising of Pine, deodar and oak trees are found in the Kullu region of Himachal Pradesh. In Fig.6, the tropospheric column ozone found in the forest region of Kullu is compared with that for near by urban region Gurdaspur in Punjab.

GUJARAT : The total area under the Gir national park of Gujarat is about 2,450 hectares. This sanctuary is gifted with a vegetation which is full of mixed deciduous, with stands of Teak, Sheesham, Pipal, Khair trees, Bamboo, Acacia, Jamun, Tendu and Dhak trees, interspersed with large patches of grasslands. On the hills, the trees are sparse and stunted. In Fig.7, the tropospheric column ozone found in the forest region of Gir is compared with that for urban region Rajkot.

MADHYA PRADESH: Thick forests of teak, sal, fir and bahera are found in the Bandhavgarh forests of Madhya Pradesh. Hill slopes have forests of Tendu. In Fig.8, the tropospheric column ozone found in the forest region of Bandhavgarh is compared with that for urban region Jabalpur.

Tropospheric ozone constitutes about 10% of the total ozone content. However, as it is toxic to the living system, even a small increase in tropospheric ozone concentration may cause persistent decrease in lung function, pneumonia, influenza, asthma, decrease in crop yield etc. From the above figures, it is observed that the tropospheric column ozone in forest areas are higher by 2 to 5 Dobson units than that over urban locations in the eastern and north eastern states of India like West Bengal, Jharkhand, Assam and Arunachal pradesh comprising of mangrove, teak, pine,

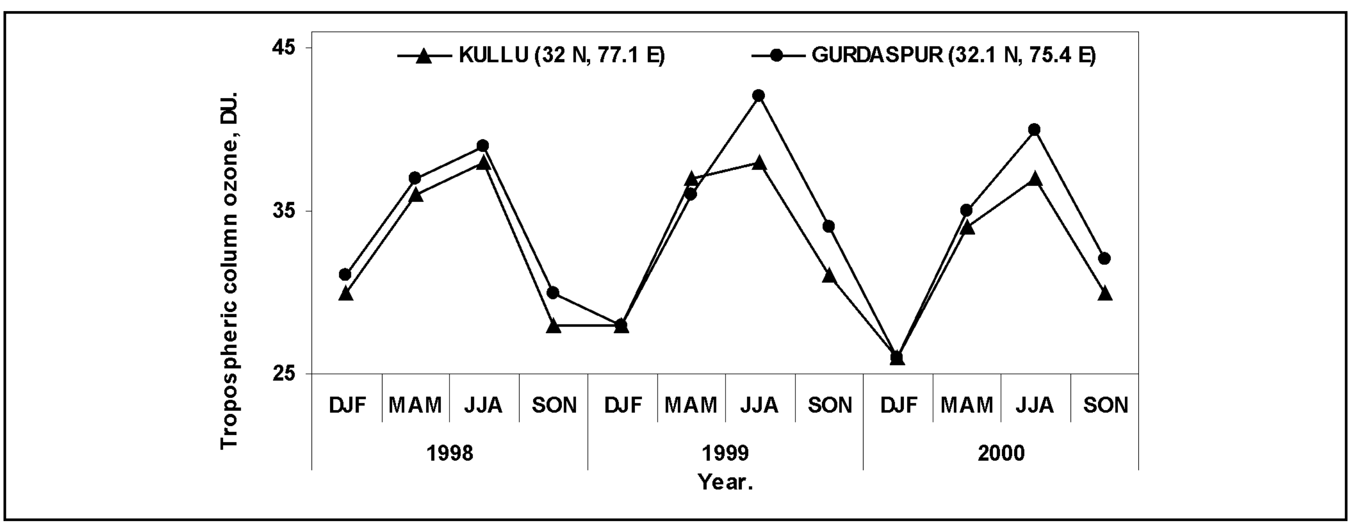

Figure 6. Tropospheric column ozone (DU) in Himalayan region.

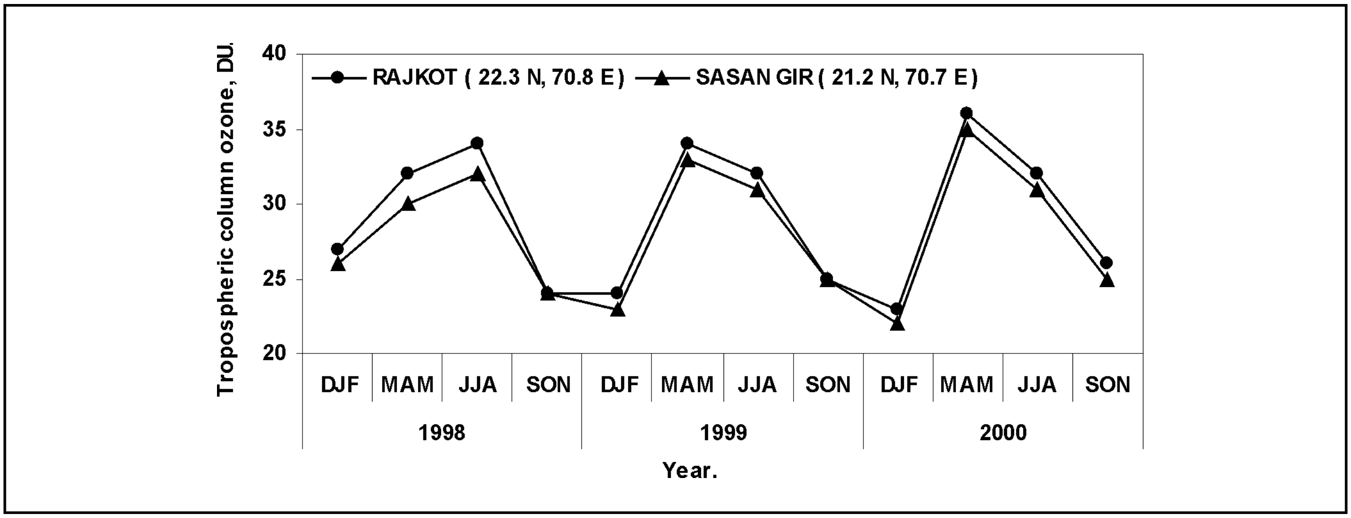

Figure 7. Tropospheric column ozone (DU) in Gujarat.

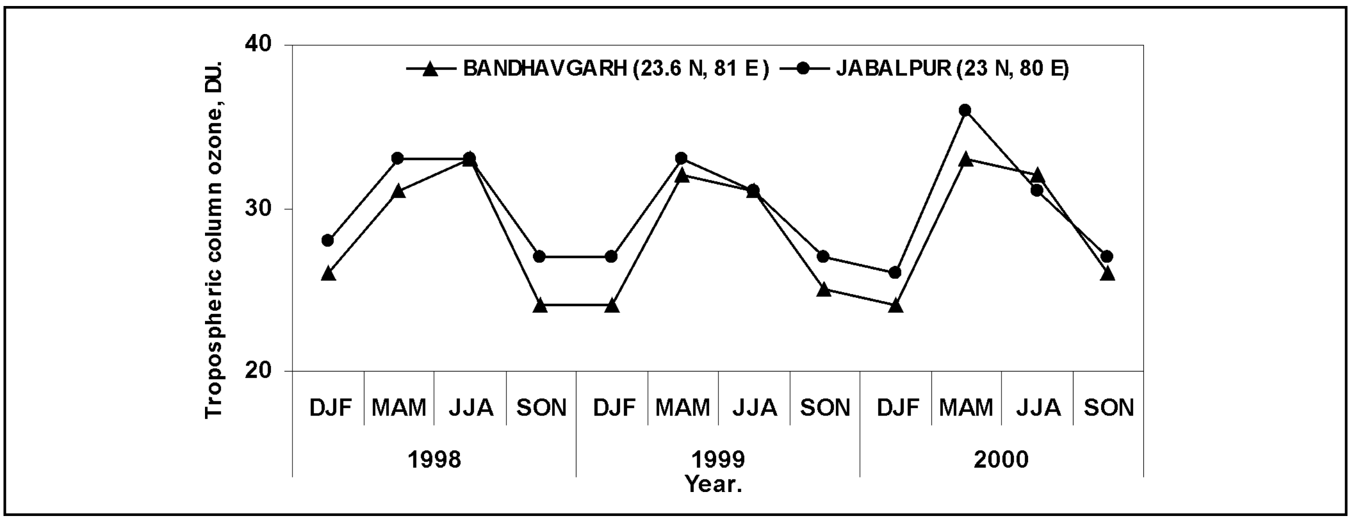

Figure 8. Tropospheric column ozone (DU) in Madhya Pradesh.

alpine and bamboo forests. On the other hand, the urban locations in the western, central, and northern states of India like Gujarat, Madhya Pradesh and Himachal Pradesh, which comprise mainly of pine, deodar, oak, fir, pipal, sal, dhak and bahera forests, have 2 to 5 Dobson unit higher ozone concentration than that found in the forests. It is also observed, that in general, the ozone concentration in forest areas of northern and northeastern states of India like Himachal pradesh, Arunachal Pradesh and Assam are comparatively higher than that found in the forests of remaining parts of India. However, since ozone produced in the forests is constantly transported to the cities along with the wind, it is difficult to estimate the exact amount of ozone which is produced due to isoprene and monoterpene emission, from satellite measurements.

The columnar tropospheric NO_2 values measured by GOME in the year 2000 indicate that the NO_2 levels in the forests of western India are less compared to those over eastern and northeastern India (Fig.9). The pollution levels observed in some major Indian cities from the reports of central pollution control board in the years 1998 - 2000 is indicated in Table 1. It is observed that the pollution levels due to NO_2 in $\mu g/m^3$ are higher in eastern India compared to western and northern India which is in agreement with the observations from GOME.

Table 1. Industrial Pollution Level of NO_2 ($\mu g/m^3$) in Indian States from 1998 to 2000 according to the reports of central pollution control board, Ministry of Environment & Forests, New Delhi, India.

STATE / CITY	1998	1999	2000
Jamshedpur (Bihar)	42.50	54.80	47.00
Chandigarh	9.80	14.80	Inadequate Data
Bhilai (Chattisgarh)	34.90	34.50	32.30
Ahmedabad (Gujarat)	24.40	31.10	35.20
Paonta Sahib (Himachal Pradesh)	6.30	6.20	6.40
Bhopal (Madhya Pradesh)	26.30	25.10	26.00
Dehradun	14.50	17.70	18.30
Haldia (West Bengal)	59.00	Not Available	77.00

Yearly mean isoprene levels in different Indian forests for the year 1990, which has been obtained from the global model by Guenther et al (1995) indicates a lower isoprene level in the forests of western and central India, compared to those in eastern and north eastern India (Fig.10).

Dew point is the temperature to which air must be cooled before it becomes saturated and dew or liquid water will drop out of it. Closer the temperature and dew point, higher is the humidity of air. The difference between air temperature and dew point observed in the cities of northern, central and western India are comparatively higher than those observed in the cities of eastern and north eastern states (Fig.11). This means that the humidity level is higher in the eastern and northeastern states of India compared to the northern, central and western states.

Thus the NO_2 , isoprene and humidity levels in northeastern India are found to be high. This may be the one of the reasons why the ozone concentration observed in the forests of north eastern India are higher compared to those observed in the remaining parts of India.

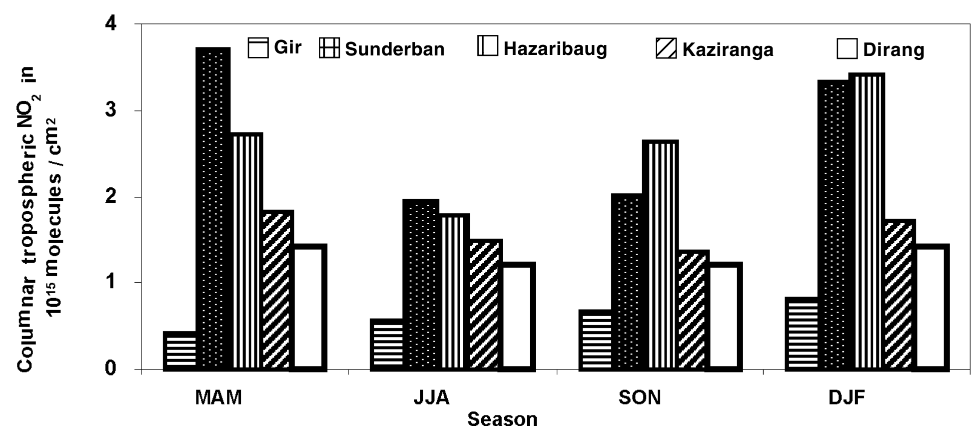

Figure 9. Columnar tropospheric NO_2 measured by GOME over Indian forests.

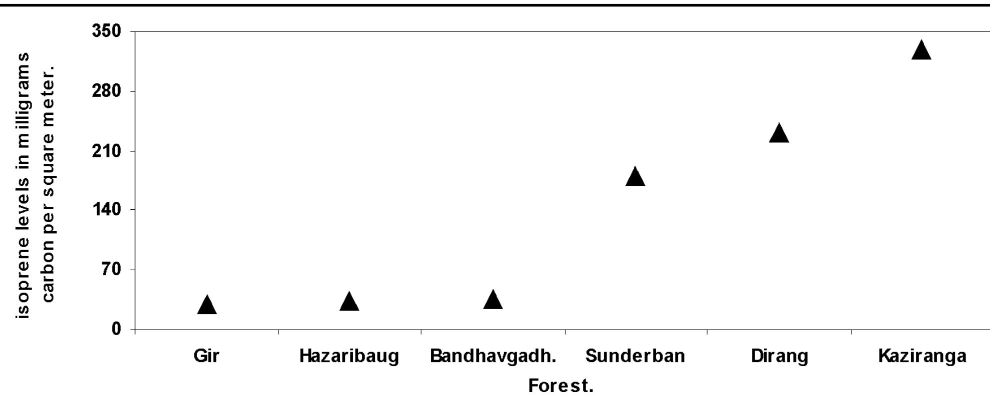

Figure 10. Yearly mean isoprene levels for different Indian forests.

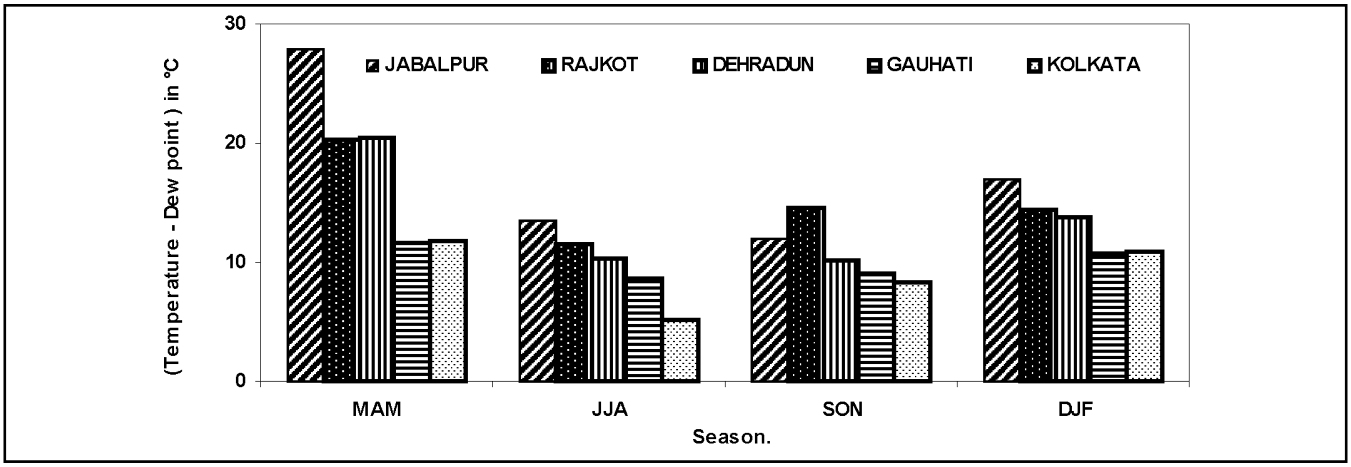

Figure 11. Seasonal variation of relative humidity observed in different Indian cities.

CONCLUSIONS

The tropospheric ozone concentration for a few Indian States have been studied using the data obtained from the Tropospheric Ozone Residual (TOR) method for urban sites and forests located nearby to determine the impact of forest canopy on atmospheric ozone and the importance of plant emissions to our climate.

The impact of forest canopy on tropospheric ozone concentration depends on factors like the amount of isoprene and monoterpene emitted by the plants, the type and area of forests, humidity and background NO_x levels. The NO_2, isoprene and humidity levels in northeastern India are found to be high. This may be one of the reasons why the ozone concentration observed in the forests of north eastern India is also higher compared to that observed in the remaining parts of India.

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