

Statistical Analysis of Surface Ozone and Black Carbon over Distinct Regions of India

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ABSTRACT

Since India has different climatology, statistical analysis of trace gases over distinct regions is very important to take necessary actions to control the pollutants. A network of stations has been initiated by Indian Space Research Organization in India to retrieve data on atmospheric trace gases. However, only few studies have been done on statistical analysis of trace gases on distinct regions of India. In this paper discussed statistical behavior of surface ozone (O₃) and black carbon (BC) mass concentration in different regions of India like rural, semi-urban, urban, and hill stations. The diurnal variation of rate of change of O₃ is used to analyze trace gases chemical environments of various locations. Results showed that surface ozone at Anantapur is similar to Kannur, and lower than that at Dayalbagh, an urban site; Darjeeling and Port Blair, a high altitude and hill site. In India, some locations reported lower surface ozone mixing ratios than Anantapur like Dibrugarh, a semi-urban location; Kullu, Pantnagar, semi-urban; Hyderabad, an urban site; Trivendrum, a coastal site; Chennai, an urban site; and Joharapur, a rural site. High concentrations of black carbon were observed at Kanpur, an urban site (6-20 µg/m³) followed by Hyderabad, an urban site (1.5-11.2 µg/m³), and Ahmedabad (0.2-10.2 µg/m³). Results showed that Mohal-Kullu, and Darjeeling reported high BC compared with other hill stations like Ooty and Nainital, and semi-arid rural stations also reported substantial BC.

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Introduction

Since past decades the emission of trace gases (O₃, NO, NO₂, CO, SO₂, CH₄ and NMHCs etc.) has been increasing in the lower troposphere due to globalization and industrialization. The increase in mixing ratios of these trace gases substantially modulates the Earth's climate because of their competence to modify the radiation and energy balance of the earth-atmosphere-system [1]. Surface ozone is an important constituent of lower atmospheric trace gases in troposphere; they are low in amount but they play a vital role in the greenhouse effect, radiative forcing, and atmospheric chemistry. Surface O₃ is not directly emitted into the air, but is produced by chemical reactions between volatile organic compounds (VOC) and oxides of nitrogen (NO_x). The main sources of O₃ precursors are carbon monoxide (CO), methane (CH₄), VOCs, etc. are generated from fossil fuel combustion, biomass burning, and other anthropogenic activities. Surface O₃ plays a central role in tropospheric photo-oxidation, thereby regulating their lifetime and directly changes in the photolysis rate constant and indirectly by the NO_x and HO_x budget. Black carbon (BC) aerosol particles are one of the most variable components of the Earth's atmosphere and directly affect the Earth's radiative balance by scattering and absorbing solar radiation [2]. Also, aerosol particles play an important role in atmospheric chemistry and so affect the concentration of

other minor atmospheric constituents like ozone [3]. Black carbon aerosols have the potential to absorb solar radiation at visible and near-infrared wavelengths that might lead to positive and negative radiative forcing [4-5]. High concentrations of O₃ and BC have a negative impact on human health, regional hydrological cycle, and agricultural productivity [6-7].

A network stations has been initiated by Indian Space Research Organization in India to retrieve the data of atmospheric trace gases at various regions in the Indian subcontinent and various groups are being vigorously involved in the long-term measurements of surface O₃ and its precursors [8-10]. The study showed that trace gases follow distinct seasonal and temporal variations and suggested long term measurements are essential to analyze its budget at different regions. In this paper discussed statistical behavior of O₃ and BC mass concentration in different regions of India like rural, semi-urban, urban, and hill stations.

Result and Discussion

Surface ozone concentration

We selected different geographical locations such as urban, semi-urban, rural, semi-arid, and coastal locations for surface ozone analysis in India and results were shown in Table 1. Surface ozone concentration at Anantapur is similar to ozone concentrations in Kannur (50.83 ppbv), Delhi (51.7 ppbv), Udaipur (51.7 ppbv), and Pune (54.6 ppbv). The observed O₃ at Anantapur and Kannur

is lower than that measured in other locations like Dayalbagh, an urban site (75 ppbv); Darjeeling (63 ppbv), a high-altitude site; and Port Blair (60 ppbv), a hill area. In India some locations reported lower surface ozone mixing ratios than Anantapur like Dibrugarh (24 ppbv), a semi-urban location; Kullu (40 ppbv), a hill site; Pantnagar (39.3 ppbv), a semi-urban; Hyderabad (43 ppbv), an urban site; Trivendrum (47.5 ppbv), a coastal site; Chennai (41 ppbv), an urban site; and Joharapur (44 ppbv), a rural site. This variation is mainly attributable to local sources, long range transport, and meteorology. Hill areas reported higher ozone mixing ratios like Port Blair (60 ppbv), Ooty (61 ppbv), and Darjeeling (63 ppbv), due to regional transport from urban regions [11]. Study revealed that in India most of the locations (urban, semi-urban, and rural) have surface ozone day time build-up. In contrast, the diurnal pattern of ozone did not show any day time build up in Nainital and Ooty [12-13]. In Thumba, a tropical coastal site, distinct diurnal variations of surface ozone were found, mainly attributed to the wind pattern from sea breeze to land breeze. Polluted air from land is being moved towards marine regions and significantly increasing ozone levels [14].

Table 1: Surface ozone concentration at different locations in India

Location	Site description	O ₃ (ppbv)	Reference
Anantapur (14.60 N, 77.60E)	Semi-arid rural	18-55.8	[15]
Delhi (28.70N, 77.20E)	Urban	30-51.7	[16]
Udaipur	Semi-arid Urban	5-53	[17]
Port Blair (11.04 N, 92.45 E)	Hill area	5-60	[18]
Dibrugarh (27.30N, 94.60E)	Semi-urban	8-24	[19]
Kannur (11.90N, 75.40E)	Rural	15.76-50.83	[20]
Mohal-Kullu (31.90N, 77.120E)	High altitude	40	[10]
Ooty (11.20N, 76.430E)	High altitude	17-61	[13]
Pantnagar (29.00N, 79.50E)	Semi-urban	10.8-39.3	[21]
Hyderabad (17.470N, 78.580E)	Urban	20-43	[22]
Dayalbagh (27.10N, 780E)	Urban	10-75	[9]
Trivendrum (8.50N, 770E)	Tropical coastal	15.7-47.5	[23]
Pune (18.540N, 73.810E)	Tropical semi-urban	12.2-54.6	[24]
Darjeeling (27.10N, 88.70E)	High altitude	18-63	[25]
Chennai (13.040N, 80.230E)	Urban	15-41	[26]
Joharapur (19.30N, 75.20E)	Rural	15-44	[11]
Gadanki (13.50N, 79.20E)	Rural	18.1-33.6	[27]

Rate of change of surface ozone

Table 2 shows the average rate of change of ozone during morning and evening hours for different locations in India. The average rate of change of ozone in morning was more (6.08 ppbv h⁻¹) than change in evening (-3.15 ppbv h⁻¹) at Anantapur. Results indicate that the rate of change of ozone is similar in many rural and semi-urban locations in India namely Mohal, Gadanki, Pune, and Kanpur (Table 1). The average rate of increase of ozone over Mohal, Ahmedabad, Pantnagar, and kannur was 7.3, 5.9, 5.6, and 4.9 ppbv h⁻¹, suggesting the fast production of ozone by freshly emitted of its anthropogenic precursors. The average rate of change of O₃ in morning and evening hours at Anantapur is higher than in Agra, Gadanki, Pune, Kanpur and Dayalbagh, indicating the more photochemical oxidation and titration process. In contrast, the average rate of increase of ozone during morning hours was less than evening hours on urban location in India like Delhi, Udaipur, Ahmedabad, and Pantnagar, mainly due to the high emissions of NO_x and fast titration with ozone during evening.

Table 2: Observed rates of change of ozone at different locations in India

Sites	(08:00-11:00 hrs) ppbv h ⁻¹	(17:00-19:00 hrs) ppbv h ⁻¹	References
Anantapur	6.0	-3.1	[15]
Delhi	4.7	-5.5	[28]
Udaipur	3.7	-4.5	[17]
Ahmedabad	5.9	-6.4	[27]
Mohal	7.3	-5.9	[10]
Agra	2.5	-2.4	[9]
Kannur	4.9	-6.4	[8]
Gadanki	4.6	-2.6	[27]
Pune	4.8	-2.6	[29]
Panthnagar	5.6	-8.5	[21]
Kanpur	3.3	-2.6	[30]
Dayalbag	2.2	-2.3	[9]

Black carbon concentration

The scientific studies showed that high concentrations of black carbon were observed at Kanpur, an urban site (6-20 $\mu\text{g}/\text{m}^3$), followed by Hyderabad, an urban site (1.5-11.2 $\mu\text{g}/\text{m}^3$), and Ahmedabad (0.2-10.2 $\mu\text{g}/\text{m}^3$). The high hill stations reported very low BC as Ooty (0.6 $\mu\text{g}/\text{m}^3$), Nainital (1.36 $\mu\text{g}/\text{m}^3$), and results showed that Mohal-Kullu (4.6 $\mu\text{g}/\text{m}^3$), and Darjeeling (5.6 $\mu\text{g}/\text{m}^3$) reported high BC compare with other hill stations. The semi-arid rural stations also reported substantial BC as Anantapur (3.03 $\mu\text{g}/\text{m}^3$) and Udaipur (5.6 $\mu\text{g}/\text{m}^3$).

Table 3: Black carbon mass concentration at different regions in India

Station	Site description	Concentration ($\mu\text{g}/\text{m}^3$)	Reference
Anantapur	Semi-arid, rural	3.03	[31]
Udaipur	Semi-arid	5.6	[32]
Pune	Urban	4.1	[33]
Kanpur	urban	6-20	[34]
Hyderabad	urban	1.5-11.2	[35]
Bhubaneswar	Urban	5.2	[36]
Thivandrum	Costal, urban	0.5-8	[37]
Ahmedabad	Urban	0.2-10.2	[38]
Delhi	Urban	3-27	[39]
Ooty	High altitude	0.6	[40]
Kullu	High altitude	4.6	[5]
Darjeeling	High altitude	5.6	[41]
Nainital	High altitude	1.36	[42]

Conclusions

In this paper analyzed statistical behavior of surface ozone (O_3) and black carbon (BC) mass concentration over distinct regions of India. We selected different geographical locations such as urban, semi-urban, rural, semi-arid, and coastal locations for better understanding across India. Results showed that the hill areas reported high ozone mixing ratios like Port Blair (60 ppbv), Ooty (61 ppbv), and Darjeeling (63 ppbv), due to regional transport from urban regions. The observed O_3 at Anantapur and Kannur is lower than that measured in other locations like Dayalbagh, an urban site; Darjeeling, a high-altitude site; and Port Blair, a hill area. Dibrugarh, a semi-urban site, was reported to have less O_3 . In India most of the location have surface ozone day time build-up. In contrast, the diurnal pattern of ozone did not show any day time build up in Nainital and Ooty. Results elucidated that the rate of change of ozone is similar in many rural and semi-urban locations in India namely Mohal, Gadanki, Pune, and Kanpur. The average rate of increase of ozone during morning hours was less than evening hours on urban location in India like Delhi, Udaipur, Ahmedabad, and Pantnagar. Studies showed that high concentrations of black carbon were observed at Kanpur, an urban site, followed by Hyderabad, and Ahmedabad. Results showed that Mohal-Kullu, and Darjeeling reported high BC compared with other hill stations like Ooty and Nainital, and semi-arid rural stations also reported substantial BC. The present study revealed that rural and hill sites also reported significant pollutant trace gases budget; hence government has to initiate necessary actions to control pollution besides urban sites.

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