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Variation of tropospheric ozone residue along the west coast region of India

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ABSTRACT

Tropospheric ozone is one of the key species in the atmosphere and it plays a vital role in the air quality, atmospheric chemistry, and climate change over a region. Being a secondary species produced from the photolysis of trace gases, ozone offers a good tracer to comprehend the atmospheric air quality. Economic liberalization in India began in early nineties which lead to a significant growth in industrial, energy and transport sectors in India. The advent of multinational industries in Indian cities could significantly increase the population. The rapid enhancement in industrial and anthropogenic activities in Indian cities could result a deterioration of air quality and this has influenced the rural areas as well. This work aims at the estimation of air quality in rural environment in Indian sub-continent before and after the economic liberalization in India. It shows an evidence of increase in tropospheric ozone over these hotspots lying along the coastal belt of the Arabian Sea which were mostly unpolluted prior to the period of liberalization.

Introduction

Tropospheric ozone plays an important role in atmospheric chemistry, as it is involved in all primary initiation of oxidation chains in the atmosphere. Ozone (O3) is produced in the troposphere by photochemical oxidation of methane (CH4), carbon monoxide (CO) and nonmethane volatile organic compounds (NMVOCs) in the presence of nitrogen oxides (NOx = NO + NO2). Anthropogenic emissions of NOx and methane have caused a large global increase of tropospheric ozone over the past century [1, 2] with consequences for the greenhouse effect on IPCC, 2007 [3] and surface air pollution. Ozone is also transported down from the ozone layer via stratospheric-tropospheric exchange. During the industrial era, human activities have changed the chemical composition of the atmosphere considerably. Increasing surface emissions of methane, carbon monoxide (CO), volatile organic compounds (VOCs) and nitrogen oxides (NOx=NO+NO2), produced by biomass burning and fossil-fuel combustion, have caused tropospheric O3 concentrations to increase significantly [1, 4, 5] The total amount of tropospheric O3 is estimated to have increased by 30% globally since 1750, which corresponds to an average positive radiative forcing of 0.35Wm^{-2} [6]. Measurements at several ground-based stations have indicated an increase in tropospheric ozone over the past decades, which may be an indication of increasing anthropogenic pollution. Future changes of tropospheric O3 will depend on how the emissions of ozone precursors change in the future and also on how the climate will change. Continuing emissions of NOx and VOCs are predicted to increase tropospheric O3, but the anticipated rise in temperature and humidity will likewise have an impact. Recently available satellite data have shown an increasing column concentration of nitrogen dioxide, a precursor to O3, over major industrial zones of India [7, 8] as well as over rural areas during the onset of rainy season [9]. Satellite observations (total column, stratospheric or tropospheric) offer the possibility to measure the distribution of ozone over large areas, and to study the temporal and spatial behaviour [9, 10, 11]. In this manuscript we analyze monthly tropospheric ozone residue (TOR) retrieved from Total Ozone Mapping Spectrometer (TOMS) and Solar Backscatter Ultraviolet (SBUV) measurements (TOMS/SBUV) between 1979–2005 to investigate temporal changes in tropospheric O_3 over Trivandrum, Cochin, Kannur, Mangalore and Go lying along the west coast region of India.

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Observation sites and general meteorology

Trivandrum

Trivandrum (76.95^{0}E, 8.51^{0}N) is the capital and most populous city of Kerala. It is located on the west coast of India near the extreme south of the mainland. The city has a tropical monsoon climate. As a result it does not experience distinct seasons. The mean maximum temperature is 34^{0}C and the mean minimum temperature is 21^{0}C. The humidity is high and will rise to about 90% during the monsoon season.

Trivandrum is the first city along the path of the south west moon and gets rain from the receding north east monsoons which hit the city on October. December, January and February are the coldest months while March, April and May are the hottest.

Cochin

Kochi (76.2^{0}E, 9.6^{0}N) is Kerala’s second largest city and is located on the southwest coast of India with spanning an area of 94.88 square kilometers. To the west lies the Arabian Sea, and to the east are estuaries drained by perennial rivers originating in the Western Ghats. Kochi features a tropical monsoon climate. Kochi's proximity to the equator along with its coastal location results in little seasonal temperature variation, with moderate to high levels of humidity. results in little seasonal temperature variation, with moderate to high levels of humidity. Annual temperatures range between 20 to 35 °C. From June through September, the south –west monsoon brings in heavy rains as Kochi lies on the windward side of the Western Ghats.

From October to December, Kochi receives lighter rain from the northeast monsoon, as it lies on the leeward side.

Kannur

Kannur is (75.4^{0}E, 11.8^{0}N) is the fourth largest urban agglomeration in Kerala after Cochin, Trivandrum, and Kozhikode and has an estimated population of 5, 74,876 in 2010. The city has a highly humid tropical climate with high temperature from March to May.

The primary source of rain is the south west monsoon that sets in the first week of June and continues till September. The city also receives significant precipitation from the north east monsoon that sets in from the second half of October through November.

The average annual rainfall is 3,266mm. The weather is ideal towards the ends of the year from December and January until March when the sky is clear and the air is crisp.

Mangalore

Mangalore (74.84^{0}E, 12.88^{0}N) is situated on the west coast of India and it is the chief port city of Karnataka. Mangalore is bounded by Arabian Sea to its west and the Western Ghats to its east. Summer and winter months in Mangalore experience similar temperate conditions with the average temperature ranging from 27^{0}C to 34^{0}C.

The maximum average humidity is 93% in July and the average minimum humidity is 56% in January. Mangalore has a tropical monsoon climate and it is under the direct influence of the Arabian Sea branch of the south west monsoon. It receives about 90% of its total annual rainfall within a period of six months from May to October.

The annual precipitation in Mangalore is 4,242mm. The city experiences more precipitation than most urban centers in India, due to the Western Ghats.

Goa

Goa (73.94^0 E, 15.28^{0}N) is India's smallest state by area and is located in the south west region of India known as Konkan. Goa is bounded by the state of Maharashtra to the north and by Karnataka to the east and south, while the Arabian Sea forms its western coast.

Being in the tropical zone and near the Arabian Sea, Goa has a hot humid climate for most of the year. The month of May is the hottest coupled with high humidity. The monsoon rains arrive by early June and provide a much needed respite from the heat. Most of Goa's annual rain fall is received through the monsoon which last till late September. Goa has a short winter season between mid December and February.

The locations mentioned above are indicated in fig.1

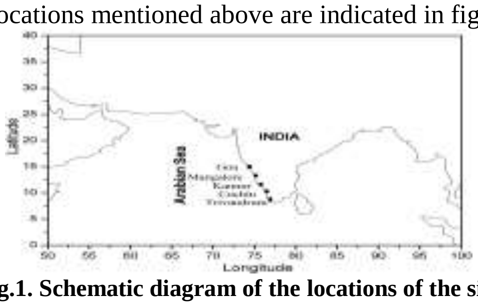

Fig.1. Schematic diagram of the locations of the site

DATA USED FOR THE STUDY

The ozone (TOMS/SBUV TOR) data over Trivandrum, Cochin, Kannur, Mangalore and Goa have been obtained from the web site http: //asd-www.larc.nasa.gov/TOR/data.html. Table 1 presents the details about the Tropospheric Ozone Residual (TOR) data used in the present analysis. The TOR data are obtained by empirically corrected tropospheric ozone residual technique and measured in Dobson Unit (DU). The derivation of the TOR data is a two steps process. First the empirically corrected stratospheric column ozone (SCO) is calculated from SBUV profiles using the Eq. (1) [12].

$SCO=SBUV\ Total\ O3-\gamma C^{*}-\beta B^{*}-A^{*}$------------ (1)

Where, SBUV Total O3 is the total O3 column derived from SBUV measurements, and _ lies between 0 and 1 and depends on the height of the tropopause, and C*, B* and A* are empirically corrected ozone layers using SBUV profile and Logan (1999) Climatology.

Second the TOR is derived using following equation,

$TOR=TOMS\ Total\ O3-SCO$ ------------- (2)

Parameter	Tropospheric ozone
Temporal coverage	Jan 1979 to Dec 2005
Temporal resolution	Monthly data
Data gap	57 Months, (Aug 1990, Mar 1991, May 1993 to Sep 1997 and Nov–Dec 1998)
Spatial coverage	50^{0}S to 50^{0}N
Spatial resolution	1.00^0 latitude by 1.25^0 longitude

Table1. Characteristics of Tropospheric Ozone Residual (TOR) dataset

Tropospheric ozone trend

India is the region of rapid development with faster growing number of industries and human population among all the developing countries in the world. Owing to the swift spread of multinational industrial groups in India witnessed a spontaneous increase in the industrial sectors over the country. This industrial revolution could result a deterioration in atmospheric air quality over India and this in turn affected the local climate. These uncontrolled emissions from the entire country caused a change in the climate. Thus to retrieve the role played by the emission of such pollutant gases an attempt is initiated to study the tropospheric ozone variation at different hotspots along the coastal belt of the Arabian Sea in South India. Surface ozone emission over the Indian region has been observed to be increasing in last few decades [13]. Accordingly, we have divided the total monthly Tropospheric Ozone Residue (during 1979–2005) data along the coastal belt of Arabian Sea in the Indian subcontinent into two parts; before economic liberalization (during 1979–1989) and from economic liberalization (during 1990–2005). In order to examine the substantial increase in tropospheric ozone during the period 1990–2005, the frequency distribution analysis of monthly tropospheric ozone has been carried out. Further, comparison of monthly tropospheric ozone between 1979–1989 and 1990–2005 were performed to evaluate the variation of tropospheric ozone residue. The following algorithm has been used to retrieve the tendency of tropospheric ozone in the hotspot regions.

Tendency (%) = % of rel. frequency (1979-1989) - % of rel. frequency (1990-2005) --- (3)

The relative frequencies were taken in an interval of 2DU. The output of this algorithm is recorded for tropospheric ozone concentration at various locations and is shown in figure 2. If the output of the algorithm (Tendency %) is positive, then it has a tendency to increase, whereas the negative values show a percent decrease in respective frequency interval. Figure 2 reveals that all the five locations show general tendency of increase in number of months with higher (36-41DU) tropospheric ozone values during 1990–2005 period (with corresponding decrease in lower (24-26DU) tropospheric ozone values. It is observed that the percentage change of tropospheric ozone in the number of months at Trivandrum is found to be negative below 32DU and it is positive above 32DU. This is clearly indicating that tropospheric ozone below 36DU is found to be decreasing while above 36 DU is increasing at Trivandrum.

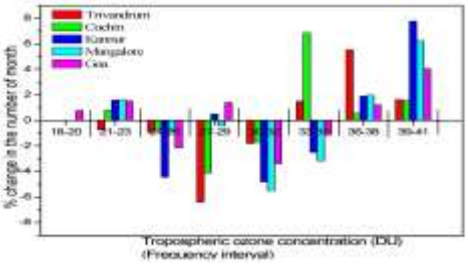

Fig.2. Frequency distribution of percentage change in the number of months of tropospheric ozone concentration with frequency interval of 2DU over the locations

The percentage change in the number of months at Cochin is negative between 24 to 32 DU and is positive in the range 21-23DU and 32-41DU. Hence it is observed a decrease in percentage change of tropospheric ozone in the middle order (24-32DU) while an increase in the lower and higher levels. Similarly the percentage change in the number of months at Kannur is negative between 24 to 35DU and is positive in the range 21-23DU and 36-41DU. Hence it is observed that a decrease in percentage change of tropospheric ozone in the center order (24-35DU) values and an increase in the lower and higher levels. Also the percentage change in the number of months over Mangalore is negative between 24- 35DU and is positive in the range 21-23DU and 36-41DU. In the case of Goa, the percentage change is negative between 24- 26DU and 30- 35 DU, whereas it is in positive for low tropospheric ozone value (18-20DU) and higher values above 36DU. Except Trivandrum, all other locations have a general tendency to increase the percentage change between 21- 23DU.

Fig 3 shows a histogram of tropospheric ozone concentration at a frequency interval of 2DU over all locations. It is observed that Trivandrum and Kannur are the two locations affected by maximum ozone concentration in the frequency range 30-32DU. But at Cochin and Mangalore, the maximum ozone concentration are found to be in the frequency range of 33-35DU. In Goa, the maximum frequency of ozone concentration is in the range of 36-38DU. In general, the concentration of tropospheric ozone ranges between 24-38DU along the coastal belt of the Arabian Sea.

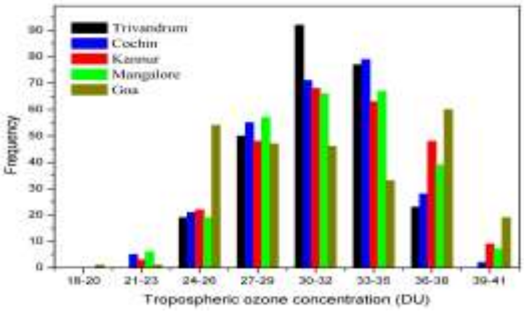

Fig.3.Histogram of tropospheric ozone at frequency interval of 2DU

Seasonal variation of tropospheric ozone

To study the decadal changes in the tropospheric ozone, we compare the tropospheric ozone residue between 1979-1989 and 1990-2005 over the study locations. It shows little evidence of long-term changes in the tropospheric ozone over the locations.

Figure 4 and 5 shows the annual variations in averaged tropospheric ozone over Trivandrum, Cochin, Kannur, Mangalore and Goa. A comparison of tropospheric ozone Trivandrum shows an increase in ozone during 1990-2005 for all months except June and August. Similarly the ozone concentrations have a tendency to increase over Cochin during 1999 – 2005 for all months except monsoon period (Jun, July August). Also at Kannur, the tropospheric ozone shows a noticeable increasing tendency during 1990- 2005in all seasons.

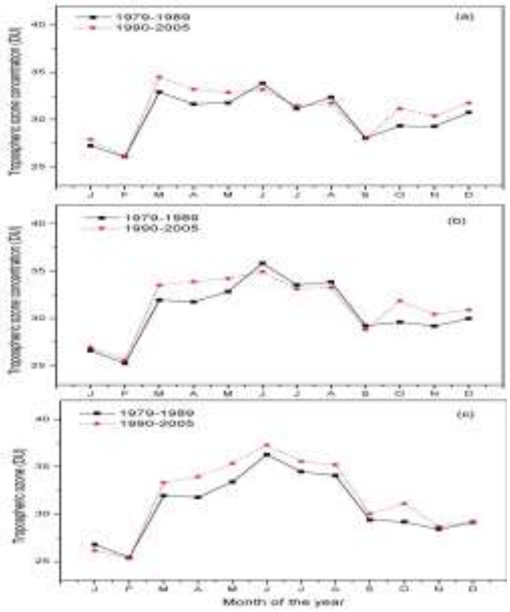

Fig.4. Annual variation in averaged TOR over (a) Trivandrum, (b) Cochin, (c) Kannur for the period 1979–2005

In the case of Mangalore tropospheric ozone concentrations shows a noticeable increase during 1990-2005 in all seasons with huge increase in summer months (March, April, May, June). In Goa, tropospheric ozone concentration shows an increasing tendency mainly during summer months (March, April, May) and post monsoon periods (September, October, November) in the period 1990-2005.

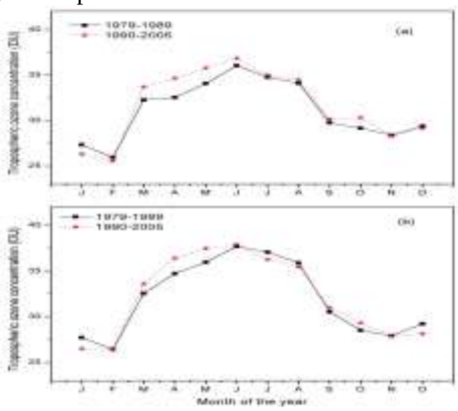

Fig.5. Annual variation in averaged TOR over (a) Mangalore, (b) Goa for the period 1979–2005

From the observations, it is found that tropospheric ozone residue exhibit an increasing trend during the period of observation. Figures 4 and 5 clearly reveals that tropospheric ozone values over the study locations significantly increased during 1990-2005 compared to 1979- 1989. The percentage of seasonal increase in the concentrations of tropospheric ozone residue over the study locations are tabulated in Table 2.

The four seasons considered are winter from December, January February; summer from March, April, May; monsoon from June, July, August and post-monsoon from September, October, November. During winter months there is an increase of TOR is noticed over Trivandrum Cochin and Mangalore and a decrease in trend is observed over Kannur and Goa. In summer and post monsoon months over all the locations, the percentage of change in TOR is positive .During monsoon season there is a slight decrease in TOR is observed over Trivandrum, Goa whereas the trend over Kannur and Mangalore is positive The increase in trend is believed to be a result of increased anthropogenic emissions in these location and the neighboring megacities. Beig and Brasseure [14] noticed that CO emission from Hyderabad and Bangalore has increased by approximately 25% and 20% respectively between 1991 and 2001 [15]. Similarly NOx emission in Bangalore has been increased by 65% [16].

Seasons	Percentage of change in TOR concentration (1979-89) to (1990-2005)				
	Trivandrum	Cochin	Kannur	Mangalore	Goa
Winter	1.92	1.93	-0.81	1.99	-2.69
Summer	4.23	4.98	5.4	5.04	3.91
Monsoon	-1.04	-1.8	2.99	1.29	-0.92
Post Monsoon	3.18	3.35	3.2	1.62	1.32

Table.2. Percentage of seasonal increase of tropospheric ozone residue over the locations

Thus work on this direction revealed the enhancement of tropospheric ozone over major Indian cities [15] and the transport of pollution to the rural areas are a serious concern.

Conclusion

The tropospheric ozone residual data from 1979–2005 have been precisely analyzed to examine the changes in tropospheric ozone before and after 1990 over the hotspot region along the coastal belt of the Arabian Sea in the Indian Subcontinent. A frequency distribution of data before and after 1990 shows that there is noticeable tendency of increase in the higher tropospheric values after 1990. Further, a comparison of tropospheric ozone climatology before and after 1990 over these cities shows evidence of increase in the tropospheric ozone after 1990. The primary reason for the enhancement of tropospheric ozone beyond 1990 is due to the enriched anthropogenic activities due to the advent of globalization in India. Subsequently, a rapid increase in the number of vehicles added a momentum to the pollution levels at these locations. This work essentially endow with a fingerprint of the variation of tropospheric ozone over this region which was relatively unpolluted compared to other regions in India.

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