Mausam, (1986), 37, 4, 471-482

551.510.534 : 551.588.7

Atmospheric ozone monitoring in the Indian network in view of possibility of damage to the biosphere due to distortion of ozone layer

KALIPADA CHATTERJEE

National Ozone Centre, Meteorological Office, New Delhi

(Received 18 March 1985)

सार — वायुमण्डलीय ओजोन जीवविज्ञान की दृष्टि से महत्वपूर्ण 300 नैनोमीटर क्षेत्र में तरंग दैर्ध्य के हानिकारक पराबैंगनी विकिरण से पृथ्वी पर जीवधारियों की रक्षा करता है। हाल के वर्षों में वायुमण्डलीय ओजोन के क्षेत्र में काम करने वाले बहुत से कर्मचारियों ने मानव उद्भूत कार्य कलापों द्वारा पैदा हुए नाइट्रोजन के आक्साइडों (NO_x), क्लोरीन के आक्साइडों (ClO_x) तथा हाइड्रल आक्साइडों (HO_x) के ओज़ोन परत पर होने वाले प्रभाव को उजागर किया है। हाल में अध्ययनों ने यह दर्शाया है कि नाइट्रोजन, क्लोरीन तथा हाइड्रोजन के ये मानव निर्मित आक्साइड, जो क्षोभमण्डल में औद्योगिकरण के कारण मिलते रहते हैं, निम्न क्षोभमण्डल में ये आक्साइड इसी दर से मिलते रहे तो स्पष्टतया समताप मण्डल में ओज़ोन को 5% तक कम कर देंगे। ओजोन की कुल मात्रा में यह कमी त्वचा के कैंसर के मामलों को बढ़ा सकती है। इसके अतिरिक्त, ऐसी भी सम्भावना हो सकती है कि पराबैंगनी विकिरण में होने वाले परिवर्तन वनस्पति जीवन समुद्री जीवन तथा अन्य पारिस्थितिक प्रणालियों को भी प्रभावित करें।

क्षोभमण्डल में उपस्थित ओजोन परत क्षोभमण्डल में ताप माप तथा पवनों को नियन्त्रित करती है तथा पृथ्वी पर सामान्य संचरण और जलवायु को भी बहुत प्रभावित करती है। मानव जनित गतिविधियों के कारण क्षोभमण्डल में ओज़ोन की मात्रा में कमी पृथ्वी की जलवायु पर विपरीत प्रभाव डालेगी। निदर्श गणनाओं से संकेत मिलते हैं कि अगली शताब्दी के पूर्वार्ध में ओज़ोन तथा अन्य ट्रेस गैसों का संयुक्त विकिरण प्रभाव वहीं होगा जो कार्बनडाइआक्साइड का होगा।

क्षोभ मण्डलीय ओजोन के क्षेत्र में किए गए हाल ही के अध्ययनों से संकेत मिलता है कि क्षोभ मण्डलीय विशेषकर औद्योगिक रूप से विकसित देशों में, ओजोन की मात्रा में मानव जनित गतिविधियों के कारण तीव्र वृद्धि की सम्भावना है। क्षोभमण्डलीय ओज़ोन की मात्रा में यह वृद्धि मानव स्वास्थ्य और वानस्पतिक जीवन विशेषकर वन संसाधनों पर विपरीत प्रभाव डाल सकती है।

इस लिए भूस्थापित और गुब्बारों पर लगे यंत्रों द्वारा तथा उपग्रह के मापों द्वारा समस्त भूमण्डलीय ओज़ोन का ठीक-ठीक मानीटरन बहुत आवश्यक हो गया है। वर्तमान लेख में कुल ओज़ोन और ऊर्ध्वाधर ओज़ोन के उमखेर व गुब्बारा सौन्दे द्वारा मापों के परिणाम व विश्लेषण प्रस्तुत करता है साथ ही भूआधारित तथा गुब्बारों पर लगे सौंदे द्वारा क्षोभमण्डलीय ओज़ोन मापो के परिमाण व विश्लेषण भी प्रस्तुत करता है। ये ओज़ोन माप भारतीय संजाल में पिछले दशक (1970-79) में किए गए थे। इस लेख में ओज़ोन प्रोफाइल्स तथा परिवर्तनों के विभिन्न पहलुओं तथा वर्षों से ओज़ोन परम्परा विश्लेषणों को प्रस्तुत किया गया है व उन पर चर्चा की गई है।

ABSTRACT. Atmospheric ozone protects life on the earth from harmful ultraviolet radiation of wavelengths in the biologically important 300 nanometre region. In recent years many workers in the field of atmospheric ozone have brought out the various effects of oxides of nitrogen (NO_x) Oxides of chlorine (ClO_x) and Hydroxyl radicals (HO_x) on the ozone layer due to man made activities. It has been demonstrated by recent studies that these man made chemicals like NO_x, ClO_x released in the troposphere due to industrializations may eventually deplete ozone in the stratosphere by as much as 5% at the present rate of discharge of these chemicals in the lower troposphere. This depletion of total ozone could cause an increase in the incident of skin cancer. Furthermore there are indications of the possibility that plant life and marine life and other ecological systems are also affected by the changes in ultraviolet radiation.

The ozone layer in the stratosphere controls the temperature & winds in the stratosphere and have a great influence in the general circulation & climate of the earth. Depletion of ozone in the stratosphere due to man made activities may, therefore, cause adverse effects on the earth's climate. Model calculations indicate that early next century the combined radiative effects of ozone and other trace gases would be of the same order as that calculated for CO_2.

Recent studies in the field of tropospheric ozone have indicated that due to man made activities there is a possibility of sharp increase in the tropospheric ozone particularly in the industrially developed countries. This increase in the tropospheric ozone could adversely effect human health and plant life particularly forest resources.

It has, therefore, become very important to accurately monitor atmospheric ozone on a routine and network basis over the entire globe by *insitu*, balloon borne and satellite measurements. The present paper brings out the results and analysis of total ozone, vertical ozone measurements by Umkehr and balloon sonde and tropospheric ozone measurements by ground based and balloon borne sondes made in the the Indian network during the last decade (1970-1979) and various aspects of ozone profiles and variations and ozone trend analysis over the years have been presented and discussed in this paper.

1. Introduction

Ozone whose total mass in the atmosphere is on the average 3.29×10^{9} tons or 0.64×10^{-6} of the whole atmospheric mass is only a minor constituent of the atmosphere with a maximum mixing ratio of about 10 parts per million, yet one of the most remarkable features of atmospheric ozone is that it prevents the penetration of biological damaging ultraviolet radiation to ground level and protects life on the earth from the harmful radiation of wavelength in the biologically important 300 nanometre region. In recent years many workers in the field of atmospheric ozone have brought out the adverse effect of oxides of nitrogen (NO_x), oxides of hydrogen (HO_x) & oxides of chlorine (ClO_x) on the ozone layer due to man made activities. Laboratory measurements and model calculations have estimated that these man made chemicals released in the troposphere due to industrialization can eventually deplete ozone in the stratosphere by as much as 3.3 to 5.5% of total ozone at the present rate of discharge of these chemicals in the lower troposphere. This depletion of total ozone could cause an increase in the incidents of skin cancer. Furthermore there are indications of the possibility that plant life and marine life and other ecological systems may also be affected by the changes in the ultraviolet radiations.

The ozone layer in the stratosphere controls the temperature and wind in the stratosphere and has a great influence in the general circulation and climate of the earth. Depletion of ozone in the stratosphere due to man made activities may, therefore, cause adverse effects on the earth's climate. In April 1983 the first meeting of the Co-ordinating Committee on the Ozone Layer (CCOL) of the UNEP was held in Geneva. Some of the findings of the Committee are that the distortion of the vertical ozone profile might become more important in studying possible climatic consequences than changes in the total amount and that calculations indicate, early next century the combined radiative effects of ozone and other trace gases would be of the same order as that calculated for CO_2 at that time.

2. Stratospheric ozone

The atmospheric ozone is produced in the upper stratosphere by the action of solar ultraviolet radiation with the wave lengths less than 242 nm upon molecular oxygen.

$$O_2+\text{Solar UV}\rightarrow O+O(\text{Shorter wave lengths than 242nm}) \qquad (1)$$

$$O+O_2+M\rightarrow O_3+M\ (M=\text{Stabilizing third body}) \qquad (2)$$

According to the classical theory developed by Chapman, ozone is destroyed through photodissociation by radiation in the visible and ultraviolet parts of the spectrum

$$O_3+\text{Solar radiation (visible)}\rightarrow O_2+O\ [\lambda<1140\text{ nm}] \qquad (3)$$

$$O_3+\text{Solar UV}\rightarrow O_2+O\ ('D)\ [\lambda<310\text{ nm}) \qquad (4)$$

and also by recombination with oxygen atoms

$$O_3+O\rightarrow O_2+O_2 \qquad (5)$$

In these reactions O and O_3 are known as species of odd oxygen. O and O_3 tend to be in equilibrium with each other through the rapid reactions (2) and (3). The main source of odd oxygen in the Chapman equation is reaction (1). The sink is reaction (5). It has been clear for sometime that reactions 1 to 5 cannot account for the observed average ozone distribution because reaction (4) in the Chapman equation is too slow. From the recent atmospheric ozone measurements by ground based, balloon and rocket borne instruments and from satellites, it has become clear that actual O_3 concentration in the atmosphere is smaller than that expected from the Chapman reaction. It has, therefore, been concluded by the workers in this field that there must be other reactions which provide odd oxygen and destroy ozone equivalent to reaction (4) and deplete ozone.

The abundance of ozone in the stratosphere is determined by a dynamic balance among processes that produce and destory it and transport it to the stratosphere. According to current understanding, the most important photochemical reactions regulating ozone, involve molecular and atomic oxygen and various radicals containing nitrogen, hydrogen and chlorine. All of these compounds have natural sources but their concentrations in the stratosphere can be significantly altered by human activities.

2.1. *Catalytic destruction of ozone in the stratosphere-Chlorine compounds*

Chlorine which is introduced into the stratosphere by the photodissociation of chlorofluromethanes (CFM) catalytically destroys odd oxygen species (O and O_3). The familiar ozone destruction cycle is

$$Cl+O_3\rightarrow ClO+O_2 \qquad (6)$$

$$ClO+O\rightarrow Cl+O_2 \qquad (7)$$

which has the net effect of

$$O+O_3\rightarrow 2O_2\ (\text{sink}) \qquad (8)$$

The CFM_s which are currently used are flurocarbon (F-11) $CFCl_3$ and flurocarbon (F-12) CF_2Cl_2,

which are widely used as refrigerants and aerosol propellents.

2.2. *Oxides of nitrogen*

The main controlling effect on the abundance of ozone in the natural atmosphere is probably exerted by the oxides of nitrogen (NO_x) through the following pair of catalytic reactions :

$$NO+O_3\rightarrow NO_2+O_2 \qquad (9)$$

$$NO_2+O\rightarrow NO+2O \qquad (10)$$

It has now been accepted that the earth's ozone shield could be affected by the release of nitrogen oxides in the stratosphere by high flying aircraft and space shuttles. In addition industrial and agricultural activities, through the ever increasing use of nitrogen fertilizer, may significantly enhance the input of nitrous oxide into the atmosphere, the oxidation of which would lead to large build up of ozone destroying oxides of nitrogen in the stratosphere.

2.3. *Hydroxyl radical* (HO_X)

Although very few measurements have been made of the concentrations of the HO_x radicals in the atmosphere it is nevertheless, clear that hydroxyl radicals play an important role in the chemistry of the atmosphere below 85 km. The important role HO_x in the chemistry of mesosphere was first discussed by Bates and Nicolet (1950) while Hampson (1964) drew attention to its importance in the chemistry of the stratosphere. The hydroxyl radical plays an important role in the odd oxygen balance of the atmosphere by a number of catalytic reactions as sh own below.

$$HO_2+O \rightarrow HO+O_2 \quad (11)$$

$$HO+O_3 \rightarrow HO_2+O_2 \quad (12)$$

$$\text{Net}: O+O_3 \rightarrow 2O_2 \quad (13)$$

and $$OH+O_3 \rightarrow HO_2+O_2 \quad (14)$$

$$HO_2+O_3 \rightarrow OH+2O_2 \quad (15)$$

$$\text{Net}: 2O_3 \rightarrow 3O_2 \quad (16)$$

Interactions occur :

$$HO+NO_2 \rightarrow HNO_3 \quad (17)$$

$$HO+HCl \rightarrow Cl+H_2O \quad (18)$$

$$ClO+NO_2 \rightarrow ClONO_2 \quad (19)$$

In reaction (17), OH ties up NO_2, decreasing the catalytic effectiveness of NO_x whereas in reaction (18), OH releases Cl, increasing the effectiveness of the ClO_x cycle in depleting O_3. Reaction (19) ties up both ClO_x and NO_x.

2.4. *Possible depletion of ozone*

The above discussion has demonstrated that the future 'health' of the earth's ozone layer under the influence of expanding industrial and agricultural activities may be adversely affected. This anticipated depletion of ozone will cause increase in skin cancer. In recent studies by the U.S. National Academy of Sciences it has been reasonably well established that a 5% decrease in total ozone could cause an increase in the incidence of skin cancer by more than 8000 or as many as 20,000-60,000 cases a year solely in the United States (U.S. National Academy of Sciences 1975). It is difficult to quantify other adverse effects on the biosphere due to the distortion in the ozone layer. However, it is believed that increase in ultraviolet radiation near 300 nm can reduce overall growth and photosynthesis rates in plants and this may imply reductions in the yields of certain agricultural crops. Solar ultraviolet radiation is able to penetrate to considerable depths (ten metre) in clear water, and the microscopic green plants which are the base of the equatic food chain are sensitive to ultraviolet radiation.

3. Tropospheric ozone

The troposphere contains, on the average, somewhat 10 per cent of the global ozone amount. Its fractional distribution varies with latitude. The classical view is that, ozone is transported from the stratosphere and destroyed at the surface at a rate less than 4.9×10^{10} molecules per cm^{-2} (Tiefenau & Fabian 1972). The observed ozone profiles over the globe, however, show lowest partial pressure of tropospheric ozone just below the tropopause. This fact is difficult to explain if one assumes that the only source of tropospheric ozone is from injections from the stratosphere.

In the stratosphere and mesosphere ozone is produced by the photodissociation of molecular oxygen and recombination of the oxygen atom with the oxygen molecule. The photo chemistry of ozone in the above mentioned regions of the atmosphere has been studied extensively. On the other hand, very few photochemical studies have been made of background ozone in the unpolluted troposphere.

3.1. *Tropospheric ozone chemistry*

Most studies of tropospheric ozone were concerned with the exchange process between the stratosphere and troposphere [Fabian *et al.* (1970)]. Levy (1971) indicated that OH is produced in the troposphere in the sunlit natural atmosphere by the interaction between ozone, ultraviolet light and water vapour and that it would influence substantially, tropospheric chemistry. The process begins with the photolysis of ozone into an oxygen molecule and two types atomic oxygen O $(3_p)$and O (1_D). Most photolitic destruction at of ozone wavelength less than 1100 nm in the troposphere produces ground state O (^3p) which ultimately recombines with O_2 to re-form ozone. Some of the ozone in the troposphere also photodissociates at wavelength less than 320 nm to produce additional metastable atomic $O(1_D)$ which, if not recombined with oxygen $O(3_p)$ and O_3 becomes available for odd oxygen reactions, which produce the OH radicals needed for various tropospheric reaction chain. Ozone may be generated in the troposphere by the oxidation of CO;

$$CO + OH \rightarrow H + CO_2 \quad (20)$$

$$H + O_2 + M \rightarrow HO_2 + M \quad (21)$$

$$HO_2 + NO \rightarrow HO + NO_2 \quad (22)$$

$$NO_2 + \text{Solar UV} \rightarrow NO + O \quad (23)$$

$$O + O_2 + M \rightarrow O_3 + M \quad (24)$$

$$\text{Net}: CO + 2O_2 + \text{Solar UV} \rightarrow CO_2 + O_3 \quad (25)$$

(Production)

Odd hydrogen (H, HO, HO_2 and H_2O_2) and NO_x act as catalysts in producing ozone from CO & O_2. The efficiency of this cycle depends on the concentrations of these species in the atmosphere.

Below a certain critical value of the ratio of (NO)/(O_3). 'Ozone loss' occurs through the following sequence :

$$HO_2 + O_3 \rightarrow HO + 2O_2 \quad (26)$$

$$CO + HO \rightarrow H + CO_2 \quad (27)$$

$$H + O_2 + M \rightarrow HO_2 + M \quad (28)$$

$$\text{Net}: O_3 + CO \rightarrow CO_2 + O_2 \quad \text{(sink)} \quad (29)$$

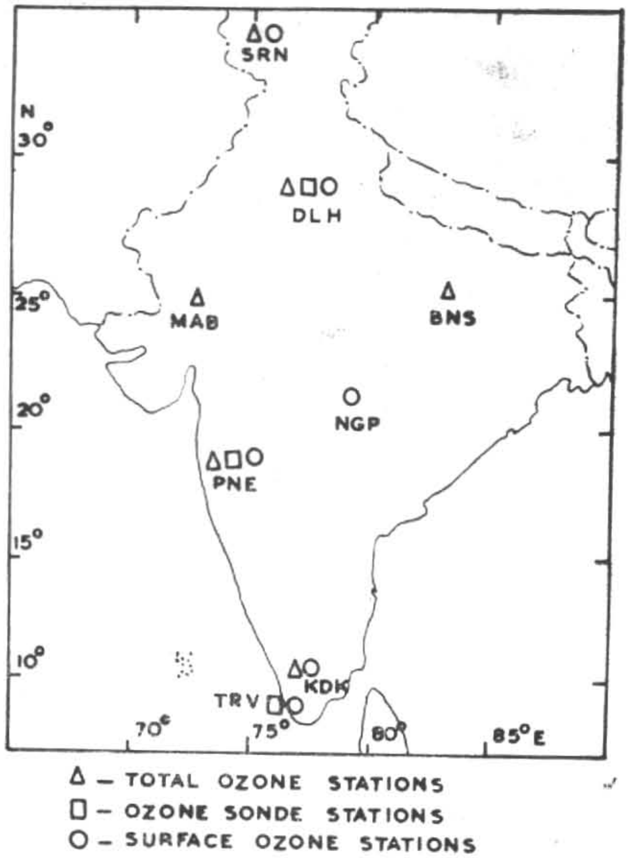


Fig. 1

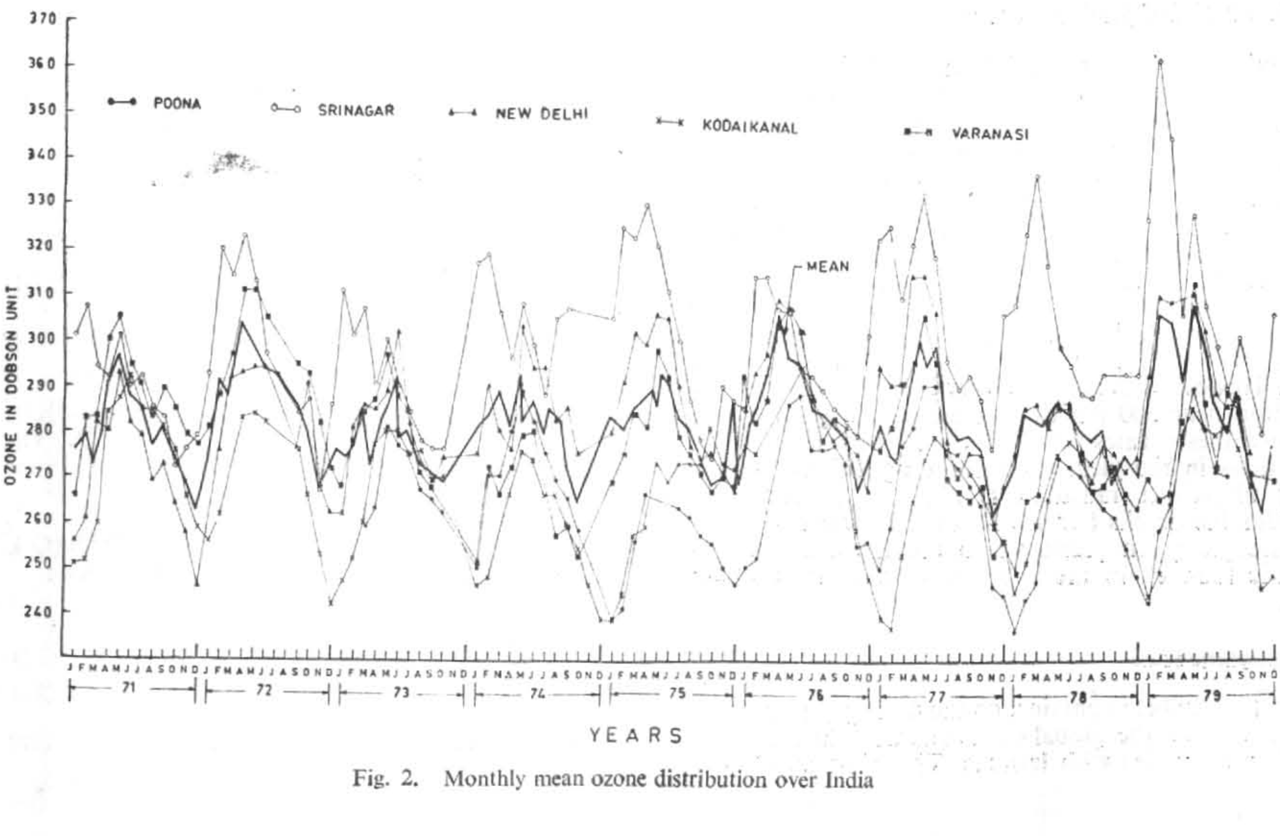


Fig. 2. Monthly mean ozone distribution over India

TABLE 1

Monthly latitudinal variation of ozone

Stations	1970		1971		1972		1973		1974		1975		1976		1977		1978		1979	
	Apr	Dec	Apr	Dec	Apr	Dec	Apr	Dec	Apr	Dec	Apr	Dec	Apr	Dec	Apr	Dec	Apr	Dec	Apr	Dec
Total ozone																				
Kodaikanal	272	255	284	259	283	242	277	254	266	239	259	272	—	248	265	256	—	—	279	248
Pune	—	—	—	—	—	—	263	258	280	239	266	246	—	256	281	244	265	246	277	—
Mt. Abu	277	241	267	240	277	232	254	253	272	235	267	248	289	259	286	247	272	254	295	—
Varanasi	308	268	300	277	311	272	287	282	295	257	281	268	203	280	295	256	282	263	—	269
New Delhi	292	245	288	246	292	262	285	274	276	270	299	267	309	280	314	268	291	274	317	272
Srinagar	303	286	292	279	323	286	290	294	296	—	330	287	307	301	321	305	316	292	305	305

For typical background ozone concentration photochemical loss by (29) dominates over production (25).

Ozone may be produced in the troposphere by photoxidation of Methane (CH_4) in presence of NO in the troposphere.

Model estimates of tropospheric ozone production depend critically on profiles of NO_x from natural, and man made sources. Besides, there is substantial production of NO_x by lightning discharges in the lower troposphere. In a report on lightning as source of NO_x in the troposphere. Kowalczyk and Bauer (1981) have summarised the finding of various workers in the field. Production rate of NO_x from an world average of 300 flashes per second consisting of approximately 20 per cent cloud to ground flashes and 80 per cent intracloud flashes with a production rate of 10^{26} NO_x/flash for ground flashes and 10^{25} NO_x/flash for cloud discharges yielding an annual global production rate of 5.7 T_g N/yr ($1T_g = 10^{12}$ grams) from lightning. The amount of NO_x produced by lightning has been measured *in situ*, simulated in the laboratory with spark discharges and numerically modelled by various methods. Most of the final estimates are between 0.6 to 4 $\times$ 10^{26} NO_x molecules produced per lightning flash. Since there are on the average about 300 lightning flashes each second over the earth, a considerable quantity of NO_x is being generated in the lower troposphere.

3.2. *Effect of increase in the tropospheric ozone*

The above studies in the field of tropospheric ozone have demonstrated that there is a possibility of considerable increase in the tropospheric ozone particularly in the industrially developed countries. This increase in ozone near the earth's surface may adversely effect human health and plant life particularly forest resources.

4. Importance of monitoring of atmospheric ozone in the Indian network

In view of the possibility of distortion of ozone layer in the stratosphere and in the troposphere and their adverse effects on the human health, plant life, marine life and other ecological systems, and long term effects on earth's climate, it has become very important to accurately monitor atmospheric ozone on a routine and and net work basis over the entire globe by *in situ*, balloon borne and satellite measurements. The present paper brings out the results and analysis of total ozone, vertical distribution of ozone and tropospheric ozone both near the ground and upto tropopause as obtained by atmospheric ozone monitoring and measurements over the Indian network made during the last decade 1970-1979, and various aspects of ozone profile variations and ozone depletion trend analysis over the years have been presented and discussed. Some recent ozone data and that of earlier period (sixties) have also been presented and discussed.

5. Data and analysis

5.1. The India Meteorological Department is operating a network of stations in India at Srinagar, New Delhi, Varanasi, Pune and Kodaikanal for total ozone measurements, at New Delhi, Pune and Trivandrum for measurement of vertical distribution of ozone and at Srinagar, New Delhi, Pune, Nagpur, Trivandrum and Kodaikanal for measurement ozone near the earth's surface (Fig. 1). The present status of ozone measurements in India has been described earlier by Alexander and Chatterjee (1980).

Chatterjee *et al.* (1982) have also described some of the interesting features of ozone distribution over India during the total solar eclipse of 16 February 1980.

5.2. *Total ozone and vertical distribution of ozone*

5.2.1. *Total ozone*

5.2.1.1. *Total ozone distribution*

Fig. 2 depicts the monthly mean ozone distribution over India for the period 1971-1979. Examination of the Fig. 2 and Table 1 reveals that total ozone is highest during March-April and lowest during winter months. Other important features of monthly mean distribution of ozone over India are :

(1) Ozone distribution exhibits considerable month to month variability. The range of this variation over India between the maximum (365 D.U.) and the minimum (236 D.U.) ozone is of the order 129 D.U.

(2) The monthly latitudinal variation as has been tabulated (Table 1) clearly depicts that ozone amount

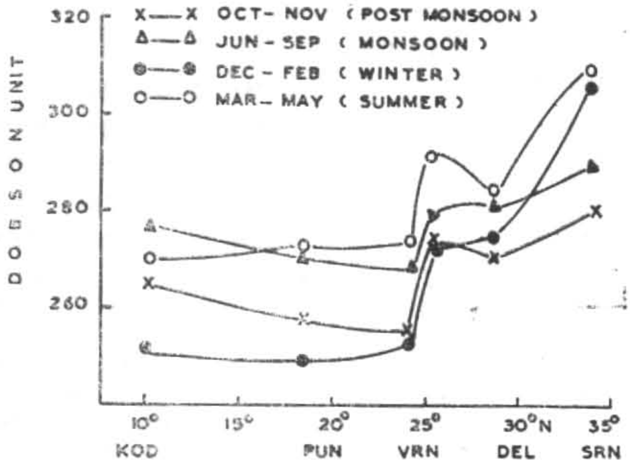
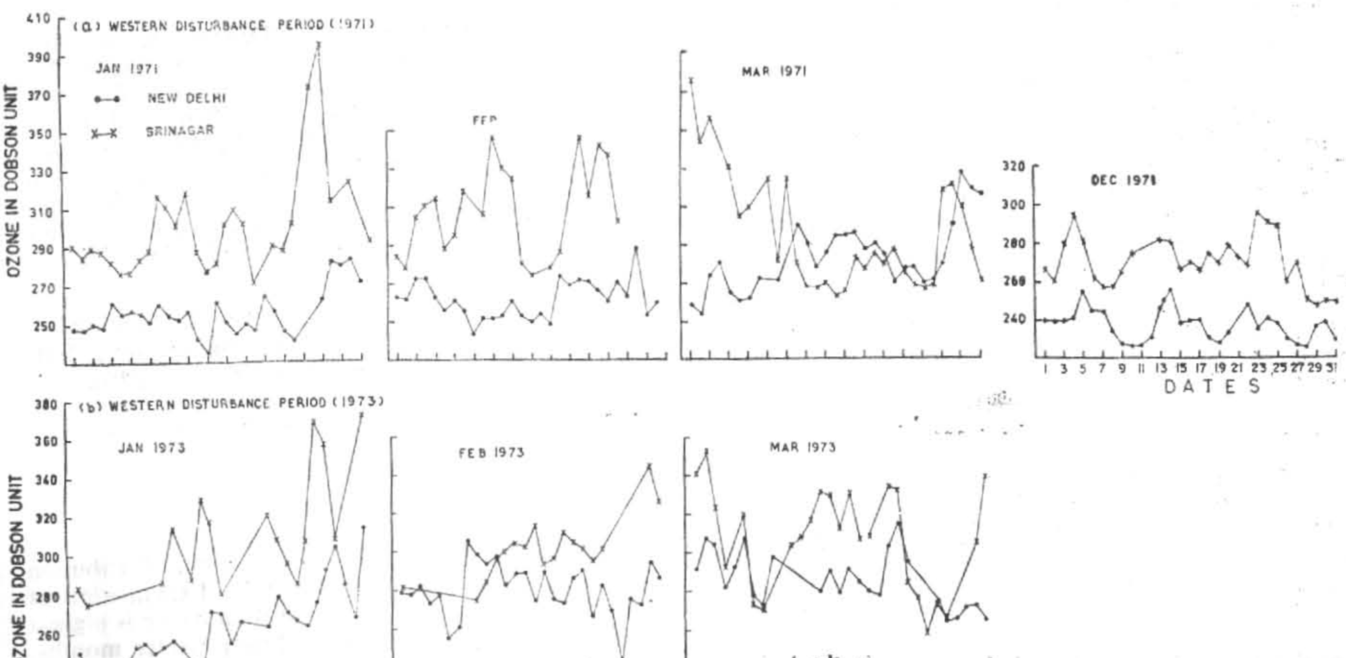


Fig 3. Latitudinal distribution of mean ozone in different seasons



Figs. 4(a & b). Day-to-day variation of ozone during western disturbances period : (a)1971 & (b) 1973

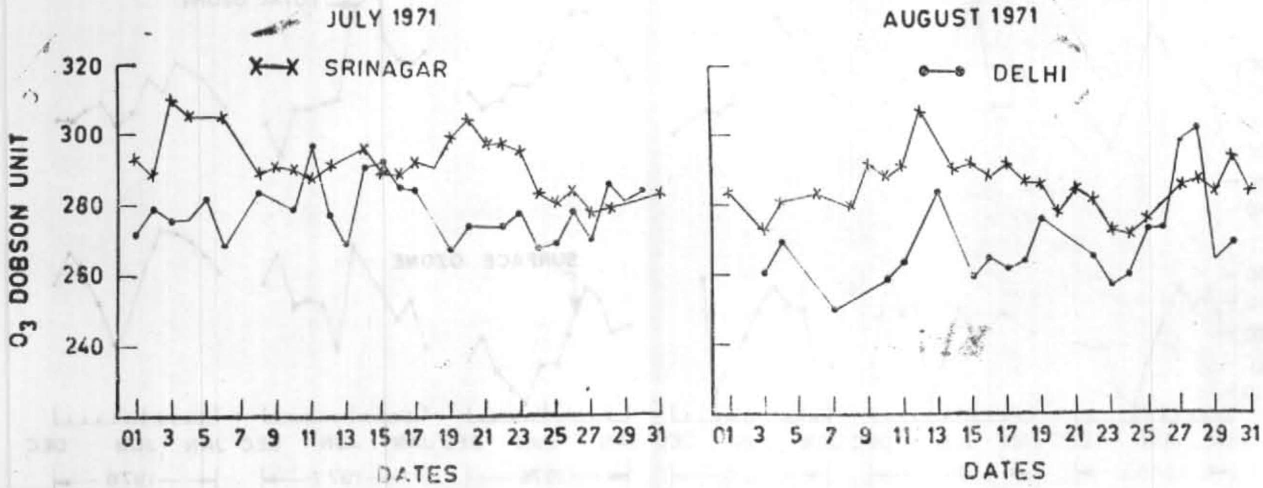


Fig. 5. Day-to-day variation of ozone during monsoon period (1971)

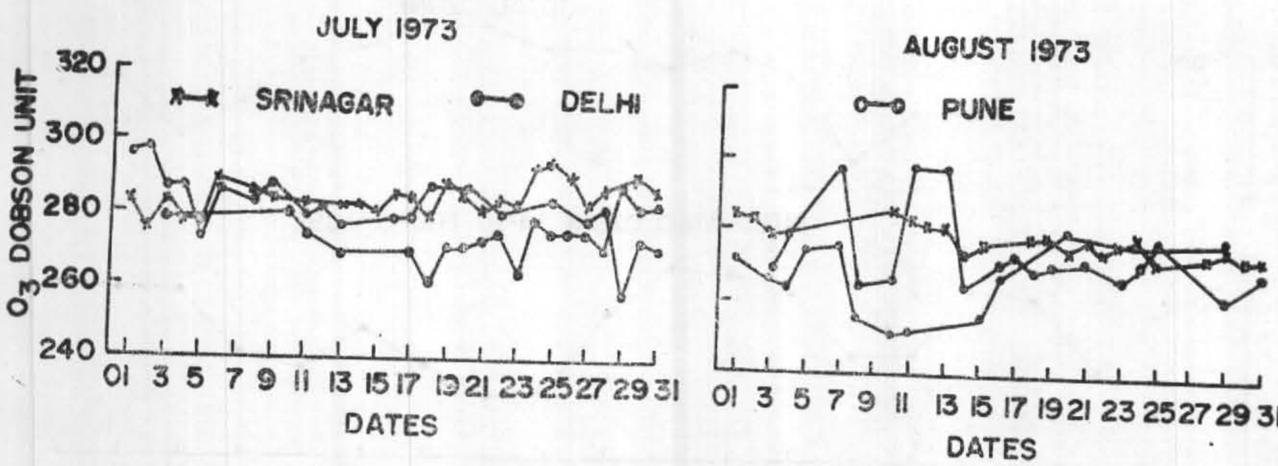


Fig. 6. Day-to-day variation of ozone during monsoon period (1973)

increases from lower to higher latitude. This can be attributed to the fact that the height of the tropopause gradually lowers with the increase of latitude and thus increase the depth of ozone layer and increasing total ozone. That corroborates the findings of Ramanathan (1956).

(3) The variation of ozone with the change of months (season) is a more or less regular and most characteristic feature for all the stations. The variation of ozone over the Indian stations for the period 1970-1979 (10 years) as shown in the Table 1 exhibits similar trends. Ozone amount over the Indian stations is highest in March-April and lowest in November-December. Exceptions are, however, noticed on occasions of Western Disturbances (WDs) over north India when ozone amount over a station suddenly increased with the passage of W.D.

5.2.1.2. *Latitudinal distribution of total ozone*

Ramanathan (1956) had brought out the outstanding features of the latitudinal and seasonal variation of ozone. The study showed a steep increase in ozone amount to the north of 30° and discontinuity in the latitudinal variation of ozone at about 30°. He concluded that this steep rise of ozone beyond 30° is associated with the steep lowering of tropopause in the same direction.

In this present study a similar attempt has been made to study the latitudinal variation of ozone during the decade 1970-1979 over India.

Fig. 3 depicts certain typical features of the latitudinal and seasonal variations of ozone computed from the long period averages of the Indian Stations (1970-1979). The steep increase in ozone amount to the north of 25° and again further steep rise to the north of 30° are two very important features of O_3 variations over India as revealed in the present study. The steep rise of O_3 beyond 25°N and again beyond 30° may be attributed to the lowering of the tropopause heights.

5.2.1.3. *Variation of total ozone in association with western disturbances over India*

Day to day variations of total ozone during western disturbance (W.D) months January-March 1971

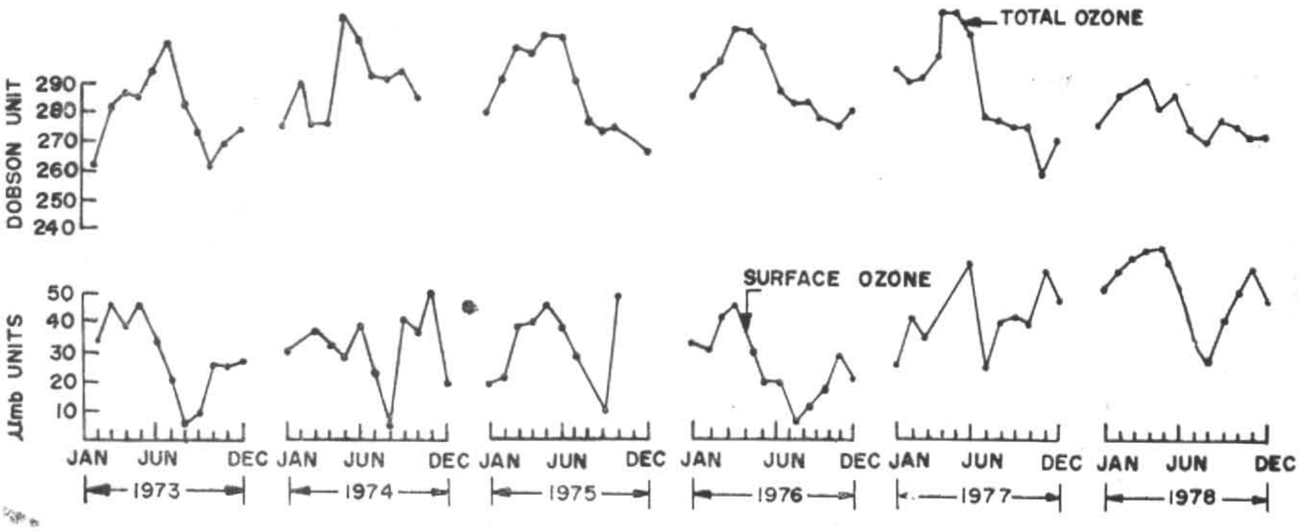
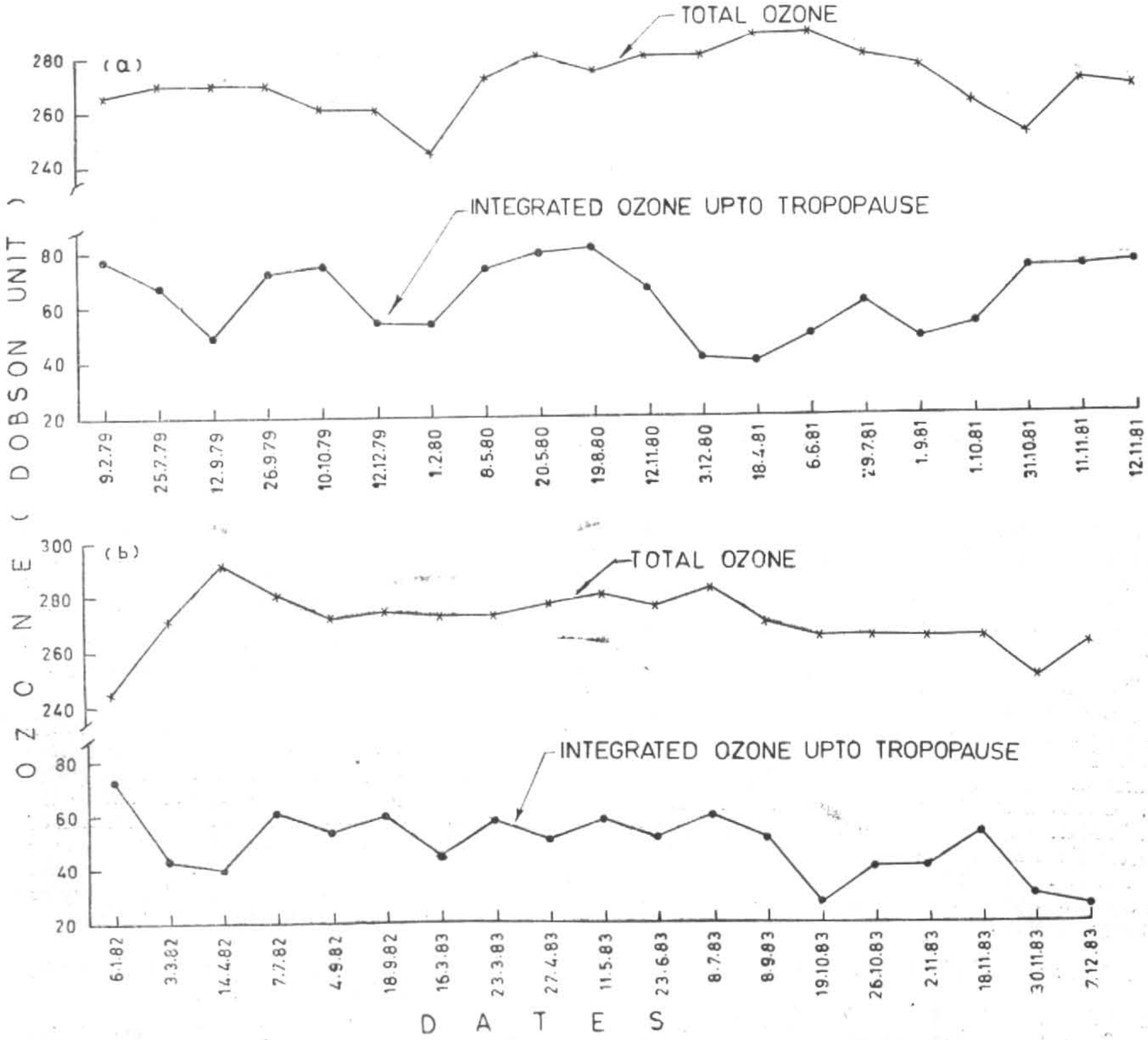


Fig. 7. Monthly mean ozone variation over New Delhi



Figs. 8 (a & b). Tropospheric ozone over Pune

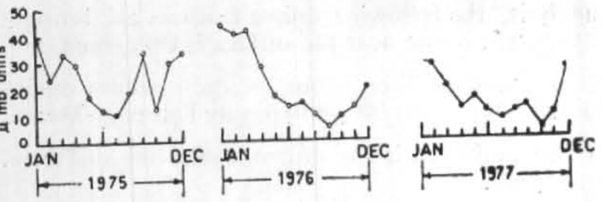


Fig. 9. Monthly mean surface ozone variation over Trivandrum

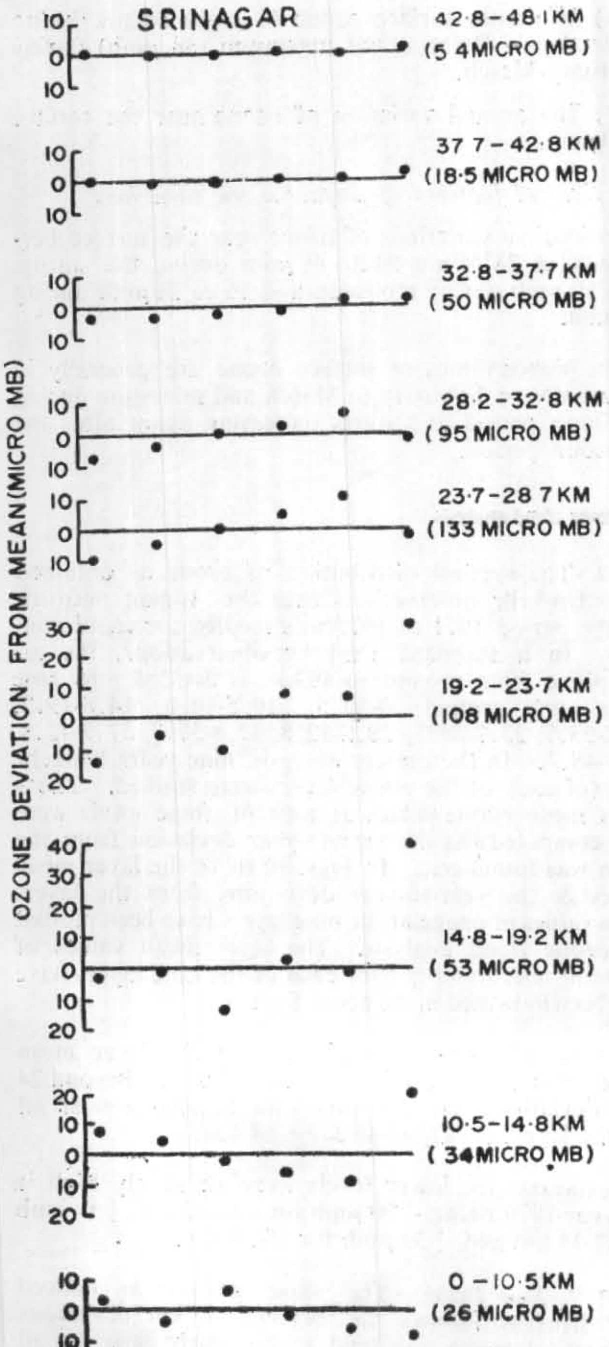


Fig. 10

and December 1971 and January-March 1973 over New Delhi and Srinagar have been depicted in the Figs. 4 (a & b) respectively to demonstrate the effects of W.D. on the atmospheric total ozone content over the northern part of the country. Though day to day variability of total ozone over Srinagar and New Delhi is considerable as seen from Fig. 4(a) but in association with W.D. the total ozone over Srinagar increased from about 290 D.U. on the 23 January 1971 to 400 D.U. on 25 January 1971—an increase of 110 D. U. On 31 January 1971, the total ozone over Srinagar became 290 D.U. again. During the same epoch, while examining total ozone variation over New Delhi, few interesting features are brought out. They are, (*i*) the total ozone started falling from 260 D.U. on 21 January to 240 D.U. on 24 January. The total ozone then started rising from 240 D.U. on 24 January to about 280 D.U. on 28 January, (*ii*) there is a lag of about 24 hours between the rise of total ozone over Srinagar and New Delhi due to the effect W.D. and (*iii*) the effect of W.D. on the increase of total ozone over New Delhi is not considerable as compared to the effect on the total ozone due to W.D over Srinagar. On examining the day-to-day variation of total ozone over Srinagar and New Delhi during the months of February, March and December 1971 it is seen that the effect of W.Ds on the total ozone over the northern parts of India is not very striking, though the variation show similar trends as was noticed during January 1971.

On examining the day-to-day variation of total ozone over New Delhi and Srinagar during the W.D. period January to March 1973 (Fig. 4b) it is seen that the variability due to the effect W.D on the total ozone distribution over the northern part of India is quite appreciable during these months, but is more pronounced over Srinagar. The trends in the total ozone distribution showed similar features as discussed earlier for Srinagar and New Delhi for the W.D. period — January to March 1971.

5.2.1.4. *Variation of total ozone during the monsoon over India*

Figs. 5 and 6 depict a flat day-to-day variability of total ozone during the monsoon months of July and August 1971 and 1973 over the northern part of India. The total ozone values during these two monsoon months varied between 250 and 310 D.U.—minimum occurring over New Delhi (250 D.U.) during August and maximum occurring over Srinagar (310 D.U.) during July.

5.3. *Tropospheric ozone over India*

Figs. 8(a & b) depict the tropospheric ozone variation over Pune as obtained from balloon ozone soundings. The tropospheric ozone upto tropopause over Pune varies between 25-27 Dobson Units during the period of the study (February 1979 to December 1983). This shows that the tropospheric ozone accounts for about 10% of the total ozone in the atmosphere. The variation of total ozone does not show any similarity with the variation of integrated total ozone.

Ozone near the earth's surface

Over New Delhi — In Fig. 7 the monthly mean ozone variation of both total and surface ozone over New Delhi for the period from 1973-1978 have been depicted.

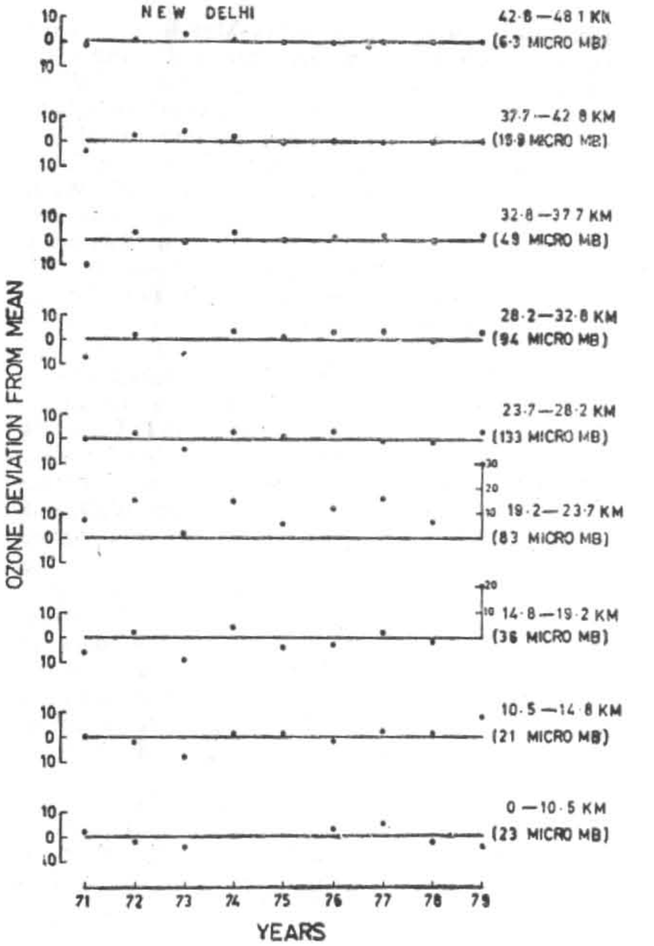


Fig. 11.

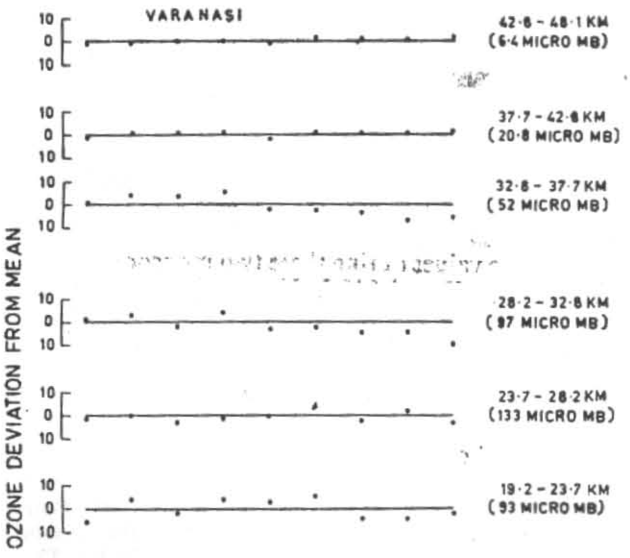


Fig. 12

On analysis, the following salient features are brought out as regards ozone near the surface is concerned :

(1) Minimum surface ozone (6 μmb) occurs during August and maximum (48 μmb) during February-March.

(2) The annual variation of ozone near the surface is about 42 μmb.

Over Trivandrum — In Fig. 9 the monthly mean ozone variation over Trivandrum for the period 1975-77 have been depicted and on analysis the following salient features are brought out :

(1) Minimum surface ozone (8 μmb) occurs during September — October and maximum (38 μmb) during February-March.

(2) The annual variation of ozone near the surface is 30 μmb.

General features of surface ozone variations

Latitudinal variations of ozone near the surface between 8° & 28°N are 34 to 48 μmb during the spring, 8 to 18 μmb during monsoon and 16 to 28 μmb during autumn.

The higher values of surface ozone are generally in the months of February to March and minimum during monsoon period and starts increasing again after the monsoon period.

6. Ozone trend analysis

6.1. The vertical distribution of ozone as obtained from Umkehr observations over the Indian network for the period 1971 to 1979 was studied for trend analysis. In a standard Umkehr observations, the atmosphere from ground to 48 km is divided into nine layers (*viz*, ground) 0-10.5, 10.5-14.8, 14.8-19.2, 19.2-23.7, 23.7-28.2, 28.2-32.8, 32.8-37.7, 37.7-42.8, 42.8-48.1. In the present analysis, nine years Umkehr data (of each of the above layer) were studied. The 9 years mean ozone values at each of these levels were first computed and the year-to-year deviation from the mean was found out. In Figs. 10 to 14 the layer mean values & the year-to-year deviations from the layers mean values of ozone at the nine layers have been plotted for ozone trend analysis. The layer mean values of ozone in micro millibar for each of the nine layers have also been indicated in the above figures.

6.1.1. *Srinagar* — Deviations from the layer mean values was maximum in the lower levels. Beyond 24 km, deviations fell abruptly and became almost nil for the layers 36-42, 42-48 & 48-54 km.

Deviations for lower levels were strikingly high in the year 1979 being +20 μmb for 6 to 12 km, +40 μmb for 12-18 km and +30 μmb for 18-24 km.

6.1.2. *New Delhi* — The same pattern as noticed over Srinagar follows, *i.e.*, beyond 24 km deviations gradually decrease and tend to be nearly zero for all the years. However, deviations in the lower levels are not too high as compared to Srinagar. The maximum deviation was at the level 18-24 km in the years 1972, 1974 & 1977 and was of the order of about 15 μmb.

6.1.3. *Varanasi* — Deviations are much less as compared to Delhi & Srinagar. Maximum deviation range is from + 5 to —5 μmb.

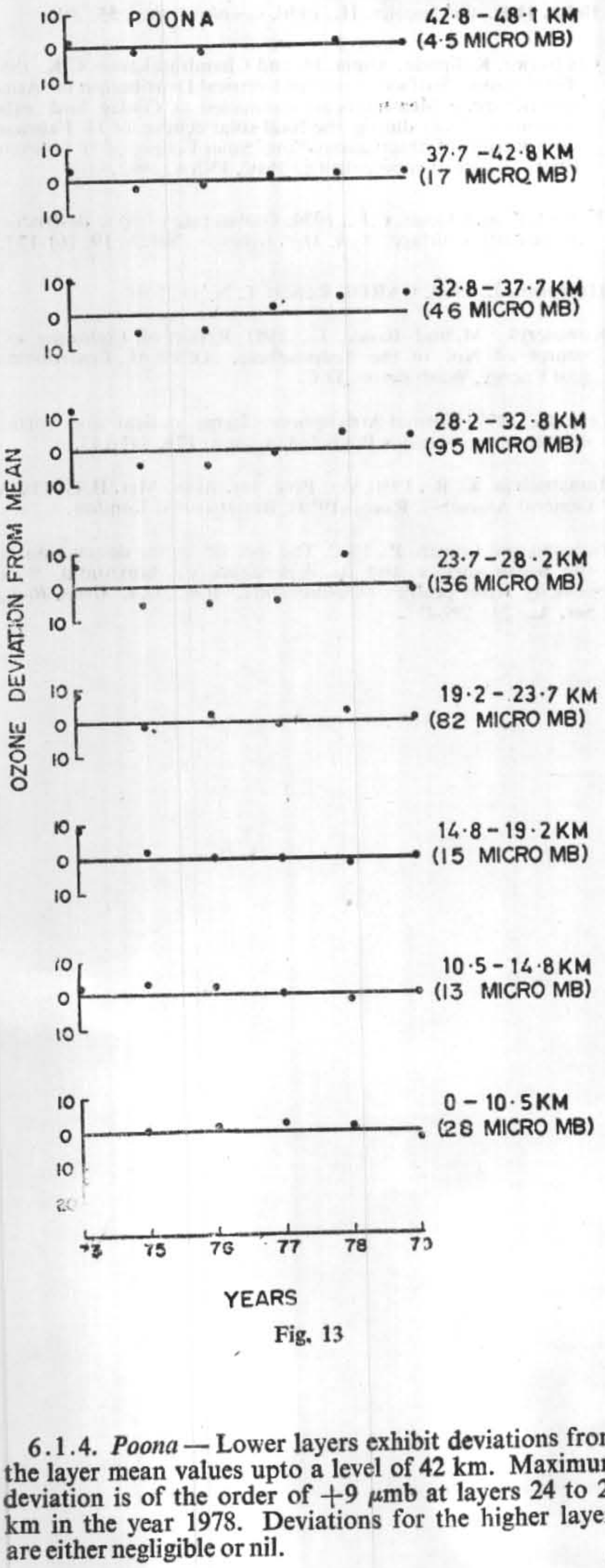


Fig. 13

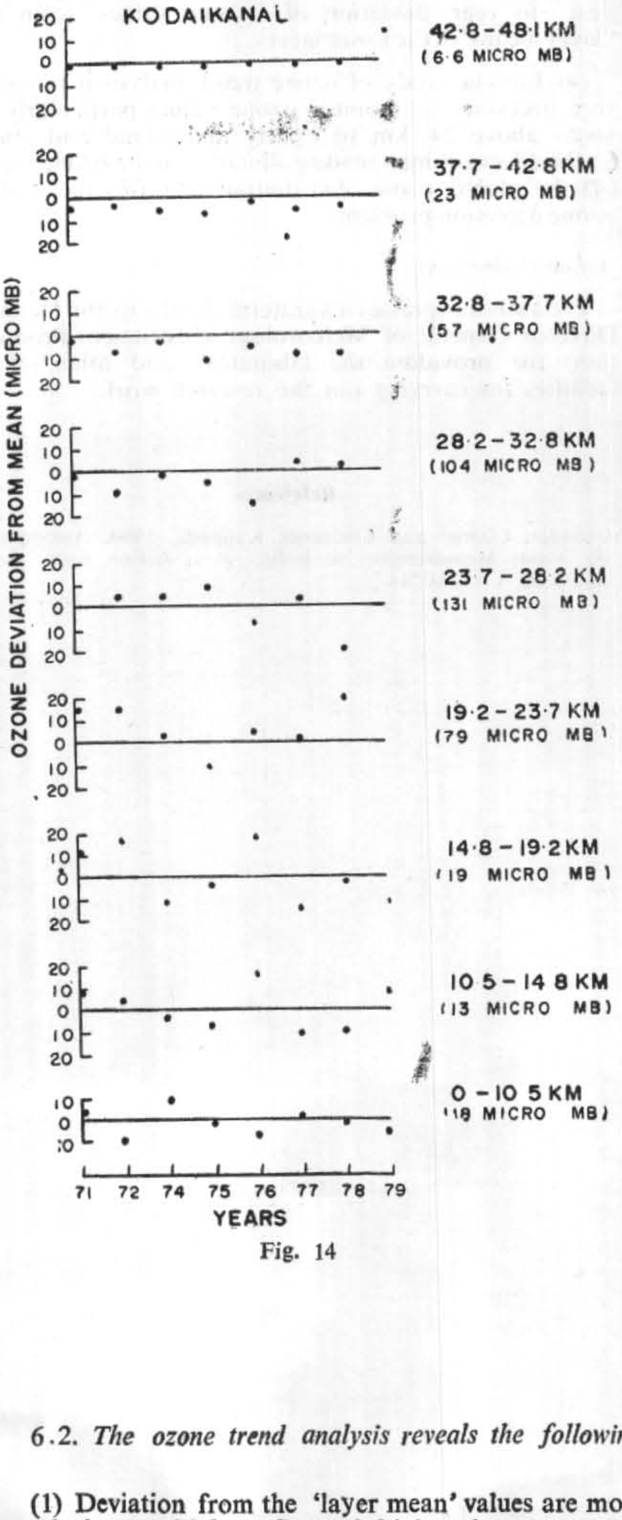


Fig. 14

6.1.4. *Poona* — Lower layers exhibit deviations from the layer mean values upto a level of 42 km. Maximum deviation is of the order of $+9$ μmb at layers 24 to 28 km in the year 1978. Deviations for the higher layers are either negligible or nil.

6.1.5. *Kodaikanal* — Deviations are particularly high for the layers 6-12, 12-18, 18-24, 24-30, 30-36 km, the values ranging from $+20$ μmb to -20 μmb. The deviation is *positive maximum* ($+$ 20 μmb) at the layer 18-24 km in 1978 and at 12-18 km layer in 1976. It is negative maximum (-20 μmb) at 24-30 km layer in 1978.

6.2. *The ozone trend analysis reveals the following*

(1) Deviation from the 'layer mean' values are more marked upto 24 km. Beyond 24 km the year-to-year deviations from 'layer means' or ozone variability are not appreciable.

(2) The year-to-year variability of ozone in the troposphere and in the lower stratosphere may be attributed to the effect of weather and wind circulation in these height ranges.

(3) Presence of aerosols and other suspended materials in the troposphere also may be responsible year to year deviation of ozone values from the 'layer means' in the lower layers.

(4) For the study of ozone trend analysis it is therefore necessary to monitor ozone values particularly at levels above 24 km to clearly understand and study (*i*) the effects of man made pollutants on the ozone layer, (*ii*) the global ozone distribution and (*iii*) the global ozone depletion problems.

Acknowledgement

The author expresses his grateful thanks to the Deputy Director General of Meteorology (Instrument Production) for providing the laboratory and other office facilities for carrying out the research work.

References

Alexander, George and Chatterjee, Kalipada, 1980, Atmospheric ozone Measurements in India, *Proc. Indian natn. Sci. Acad*; **46**, A 3, 234-244.

Bates, D.R. and Nicolet, H., 1950, *Geophys. Res.*, **55**, 301.

Chatterjee, Kalipada, Ahuja, H. and Chandrasekaran, C.K, 1982, Total ozone, Surface ozone and vertical Distribution of Atmospheric ozone Measurements conducted at Gadag and other stations in India during the total solar eclipse of 16 February 1980-Results of observations-Total Solar Eclipse of 16 February 1980—A special supplement to Proc. INSA, 1982.

Fabian, P. and Junge, C.E., 1970, Global rate of zone destruction at the earth's surface, *Arch. Met. Geophys.*, Ser.A, **19**, 161-172.

Hampson, J., 1964, CARDE Report T. N. 1627/64.

Kowalczyk, M. and Bauer, E., 1981, Report on Lightning as a source of No_x in the Troposphere, Office of Environment and Energy, Washington, D.C.

Levy, H., 1971, Normal Atmosphere: Large radical and formal dehyde concentrations Predicted, *Science*, **173**, 141-143.

Ramanathan, K. R., 1956, Sci. Proc. Int. Assn. Met. IUGG 10th General Assembly, Rome (1954), Butterworks, London, 3-24.

Tiefenau and Fabian, P., 1972, The specific ozone destruction at the ocean surface and its dependence on horizontal wind velocity from profiles measurements, *Arch. Met. Geop. Biok.*, Ser. A., 21, 399-412.