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Results from the Indo–USSR ozonesonde intercomparison experiment

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Abstract. A total of seventeen vertical profiles of ozone were obtained during an Indo-USSR collaborative experiment on ozonesonde intercomparison conducted at Thumba during March 1983. The vertical distribution of ozone was measured using rocket-borne, balloon-borne as well as ground-based instruments. Four different rocket ozonesondes from India and USSR and the balloon ozonesonde were used to make *in situ* observations of ozone concentrations in addition to the Dobson spectrophotometric observations of total ozone and Umkehr. The rocket and the balloon launchings were effected in three salvos and measurements were made at different times of the day as well as during night. The results of all these measurements are used to obtain a mean ozone vertical distribution over Thumba for the spring equinoxial period. The mean profile shows the maximum ozone concentration at 27 km with a value of $(3{\cdot}86 \pm 0{\cdot}52) \times 10^{12}$ molecules per cc. Comparison of this mean profile with available satellite data for the equatorial regions shows that, in general, the Thumba values are lower by 10–15% at altitudes below 40 km and larger at altitudes above 50 km compared to the satellite results. The data also show evidence for a day-to-day variability and a possible day-to-night variability in the ozone vertical distribution with the night-time values higher than the daytime values at all altitudes above 35 km and the difference is found to increase with the increasing altitude.

Keywords. Ozone; intercomparison; vertical distribution; variability.

1. Introduction

A systematic programme of monitoring atmospheric ozone in the Indian zone has been in progress for quite some time with a Dobson spectrophotometer network of five stations at Kodaikanal (10°13′ N), Pune (18°31′ N), Varanasi (25°19′ N), New Delhi (28°35′ N) and Srinagar (34°08′ N) maintained by the India Meteorological Department and at Mt Abu (24°30′ N) that is being maintained by the Physical Research Laboratory, Ahmedabad. Regular balloon soundings for the measurement of ozone vertical profile are being conducted by the India Meteorological

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Department from Trivandrum (8°31′ N), Pune (18°31′ N) and New Delhi (28°35′ N) for more than a decade. The data from these programmes have been used in several studies of the low latitude ozone morphology as well as studies of short-term and long-term changes in ozone, their association with climatological features, solar and geophysical parameters etc. The balloon and the Umkehr data have recently been used to construct a reference ozonosphere for the Indian zone (Kundu 1982).

Vertical distribution of ozone, especially at altitudes above 30 km, is important for understanding the stratospheric chemistry as well as the ozone depletion problem. The Umkehr data is model-dependent, has poor vertical resolution and assumes that there are no temporal variations shorter than a few hours. This can give rise to some uncertainties in the upper levels where the photochemical time constants are small. Balloons used for regular ozone soundings rarely reach altitudes more than 30 km. *In situ* measurements with rockets and the satellite-borne sensors provide information on the vertical distribution of ozone at upper stratospheric and mesospheric levels. There are a few measurements available for mid-latitudes, especially from Wallops Island. These have been used to construct a model for the mid-latitude ozone distribution (Krueger and Minzner 1976). The vertical distribution in the tropics is expected to be different and there is not much of observational data from the tropical sites. With the advent of satellites, there has been a significant improvement and now there is a certain amount of data available even for the equatorial regions (McPeters *et al* 1984). While the satellite sensors give a large amount of data and provide a global coverage with better statistics, the vertical resolution is still poor, being of the order of 8 km and the satellite data reduction techniques depend largely on ground truth provided by Dobson and Umkehr data. *In situ* measurements with rockets have the disadvantage that they cannot provide a continuous data and the spatial and temporal frequency of soundings is limited. But they give height profiles with good vertical resolution. A resolution of 1 km or better can be achieved with most sensors. However, there is a need for an intercomparison of different rocket sensors if data from different sensors are to be used in morphological studies and to construct a global model. This need has been well appreciated and there have been several intercomparison experiments conducted in recent years.

A solar MUV photometer has been developed at the Physical Research Laboratory, Ahmedabad to measure the ozone concentrations at stratospheric and mesospheric levels and a few experiments have been conducted at the tropical site, Thumba, to study the vertical distribution of ozone in the tropics (Subbaraya and Shyam Lal 1981) and the transient changes produced during a solar eclipse (Lal and Subbaraya 1983). An instrument has also been developed at the National Physical Laboratory (NPL), New Delhi and flown from Thumba (Somayajulu *et al* 1981). The instrumentation for the IMD balloon ozonesonde has undergone significant improvements in recent years and the measurments made since 1980 are believed to be much more reliable than those made in earlier years. Further, there have been some shipboard rocket launches by the Soviet Union off the coast of South India for measurements of ozone concentration profiles over low latitudes. An Indo-USSR collaborative ozonesonde intercomparison experiment was conducted at Thumba during March 1983 with a view to intercompare these instruments. The experiment included all the rocket ozonesondes currently in use in India and the

Soviet Union, the Indian balloon ozonesondes as well as ground-based Dobson spectrophotometric observations, surface ozone measurements and filter photometer observations.

2. The ozonesonde intercomparison experiment at Thumba

The experiment involved the launching of thirteen rocket ozonesondes, six contributed by the Central Aerological Observatory of USSR including three optical ozonometers for day-time measurements and three chemiluminescent ozonesondes for night-time measurements. India contributed seven ozonesondes, three photometers for day-time measurements and one for night-time measurements from Physical Research Laboratory (PRL) Ahmedabad and three optical ozonesondes from the National Physical Laboratory, New Delhi for day-time measurements. In addition to these rocket flights, three meteorological rockets and eleven balloon ozonesondes from IMD were also launched during the programme. The rocket and balloon launchings were supported by onsite Dobson spectrometer observations of both total ozone and Umkehr by IMD, filter photometer observations made by the Indian Institute of Tropical Meteorology, Pune, as well as surface ozone observations made by IMD. The rocket and balloon launchings were effected in three salvos on 23 March 1983, 28/29 March 1983 and 31 March 1983. Near simultaneous measurements were made by different rocket and balloon sensors during morning hours, afternoon hours as well as night-time periods. The details of the measurement programme and the results of a study on intercomparison of different sensors are reported by Acharya *et al* (1984). However, the experiment yielded a data set of eleven rocket profiles, five balloon profiles in addition to the Umkehr data, all collected within a reasonably short time of eight days. In this study an attempt has been made to delineate from the data collected during the intercomparison experiment, the basic features of the vertical distribution of ozone and construct a reference ozone profile for the tropical site, Thumba.

3. Experimental results

Rocket data

Figure 1 shows the data obtained from three day-time flights of the PRL optical ozonesonde flown on 23 March at 9.15 hr and 15.45 hr IST and on 28 March at 15.30 hr IST respectively. The night-time launch of the PRL lunar MUV photometer made at 23.35 hr IST on 28 March failed to give any data due to a malfunction of the onboard electronics. The day-time optical ozonesonde was a four-channel instrument working at 250 nm, 280 nm, 310 nm and 450 nm respectively and yielded data typically in the altitude region of 16 km to 60 km. The inset in figure 1 illustrates the accuracy of measurements. The uncertainties which are mostly due to random errors are partly due to errors in the measurement of the sensor current and partly due to uncertainties in the estimation of the rocket attitude and the consequent correction factors to be applied. The net uncertainty in

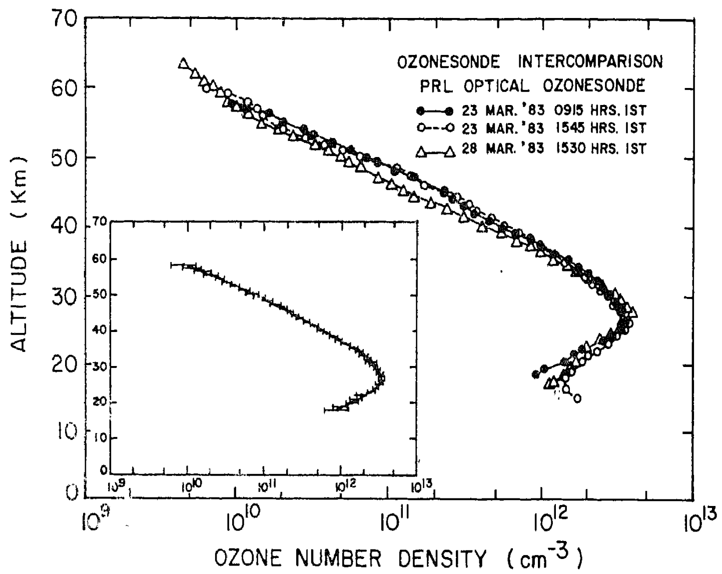

Figure 1. Ozone concentration profiles from the three PRL rocket ozonesondes flown on 23 and 28 March 1983. The inset shows typical uncertainties in the ozone concentration estimates.

the estimation of ozone concentration is of the order of ±25% at 20 km, decreases to ±10% in the altitude range of 30 to 35 km and ±5% in the altitude range of 35 to 45 km. At altitudes above 45 km the errors increase rapidly with the increasing altitude reaching a value of ±20% at 50 km and ±50% at 60 km. The larger uncertainties in the altitude region above 50 km are mostly due to the change in the rocket attitude in this region and the resulting uncertainties in the aspect correction employed. The instrument in principle is capable of measuring the ozone concentrations of the order of 1×10^{10} molecules per cm^3 with an uncertainty of ±20% or less. The data of figure 1 show that the ozone concentration peak is attained at an altitude of 27 km with number densities ranging between 3·2 and $3{\cdot}6 \times 10^{12}$ per cc. The ozone concentration values are, in general, lower by about 30% on 28 March 1983 than on 23 March 1983 in the entire altitude region of 30 to 60 km. This will be discussed in greater detail later.

Measurements are available from two of the three flights that were conducted with the NPL optical ozonesonde. The measurements were made in the afternoon hours, at 16.10 hr IST on 29 March 1983 and 15.53 hr IST on 31 March 1983 respectively. The data are shown in figure 2. The instrument was a two-channel photometer operating at wavelengths of 255 and 290 nm and was expected to yield ozone concentrations in the altitude range of 30 to 60 km. Since the instrument suffered from a delayed door ejection on both the flights, the data collected during the descending portion of the rocket trajectory had to be used for analysis. The rocket executes a large coning motion during its descent and the aspect corrections that have to be applied are generally large. The data shown in figure 2 are the result of smoothing the original data and the error bars amounting to ±20% on the flight of 29 March 1983 and ±30% on the flight of 31 March 1983 represent the spread

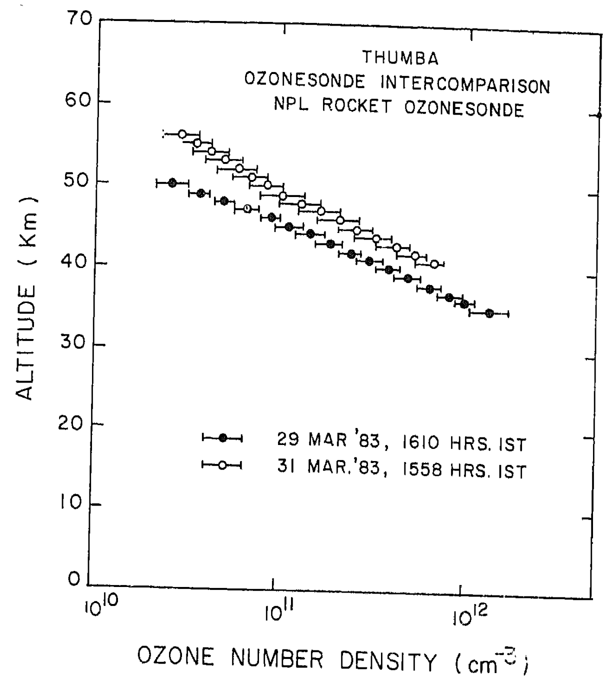

Figure 2. Ozone profiles from the two NPL ozonesonde rocket ozone-flights on 29 and 31 March 1983.

around this smoothed line. The data show that the ozone concentrations were, in general, lower on 29 March 1983 than on 31 March 1983 and the differences in the region of overlap amounting to 50–60% are qualitatively similar to the result from the PRL instrument.

Figure 3 shows the three profiles obtained by the Soviet optical ozonometer, two on 23 March at 08.20 hr IST and 16.50 hr IST respectively and the third on 31 March at 17.20 hr IST. The instrument was a two-channel photometer working at 260 nm and 300 nm respectively and the measurement errors are typically of the order of 25% at 20 km and are much smaller in the 30 to 45 km altitude region (Brezhgin 1982). Maximum ozone concentrations are in the range of $3{\cdot}2$–$4{\cdot}2 \times 10^{12}$ molecules per cc. While the three profiles show very good agreement in the range of 35 to 50 km, at lower altitudes they show a larger spread. The profile obtained at 08.20 hr on 23 March 1983 shows a double-peaked structure. The afternoon profile of 23 March 1983 shows maximum ozone at 22 km which is quite unusual. None of the previous measurements at Thumba show an ozone maximum at such a low altitude. This could be due to the large slant optical path that solar rays had to traverse before reaching the detector and the consequent uncertainties/inaccuracies in the air mass correction used. The solar zenith angle at the time of launch was 61°.

Figure 4 shows the data obtained from the three Soviet chemiluminescent ozonesondes flown on 23, 28 and 31 March 1983 respectively. All the three were flown in the early part of the night. Data are obtained during the downward part of the rocket trajectory starting from a height of about 60 km and the lower limit is set by the signal dropout. In principle, ozone concentrations can be measured down to

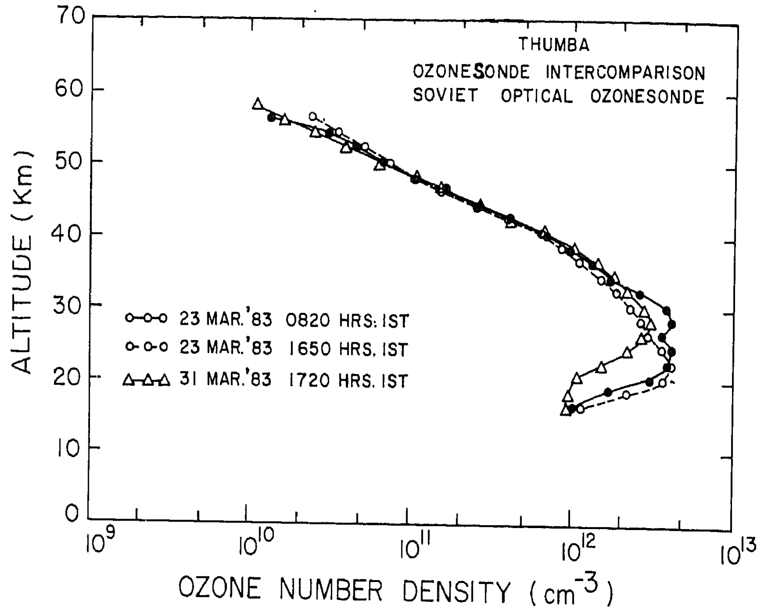

Figure 3. Ozone concentration profiles obtained from the three Soviet optical rocket ozonometers flown on 23 and 31 March 1983.

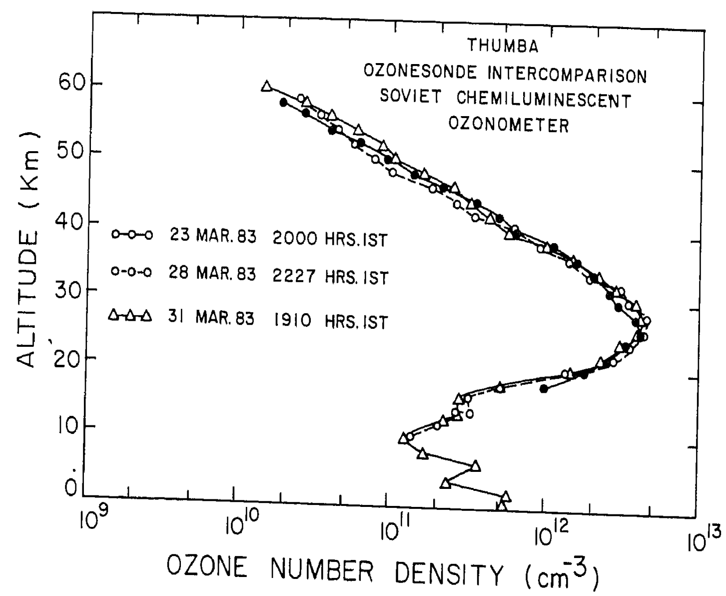

Figure 4. Ozone concentration profiles obtained from the three Soviet chemiluminescent rocket ozonesondes flown on 23, 28 and 31 March 1983.

the ground as illustrated by the data of 31 March 1983. On the flights of 23 and 28 March 1983 data could be obtained down to 18 km and 10 km respectively. The ozone number densities are obtained by first integrating the rocket profile and comparing the integrated ozone amount with the total ozone content for that day as given by the Dobson spectrophotometer. A height-independent correction factor is then applied to the rocket data to obtain the final ozone number density profile. The accuracy of measurements is determined by various factors. The errors are mostly due to a height-dependent factor used to convert the measured photometer current into ambient ozone mixing ratios and random errors in measurement of photometer currents. Absolute errors in the calibrating factor due to possible day-night variations in total ozone are likely to be small. These errors are in the range of 7–15% upto about 40 km and increase to much higher values at altitudes above 40 km (Kononkov *et al* 1982). The data of figure 4 show that the maximum ozone level is situated in the 26–28 km region with peak values ranging between 4·1 and $4{\cdot}7 \times 10^{12}$ molecules/cc. These values are larger than the maximum ozone concentrations of $3{\cdot}2 - 4{\cdot}2 \times 10^{12}$ molecules/cc estimated by the day-time optical ozonesondes. Further, the 31 March 1983 profile shows marked structures in the troposphere. This is an unusual feature, not generally seen on the balloon profiles. This particular rocket flight took place under thunderstorm conditions and there is evidence that the rocket trajectory intercepted the region of thunderclouds and lightning. It is believed that lightning produces NO_x in the tropical troposphere which enhances the ozone concentration (Ko *et al* 1986).

3.2 *Balloon data*

Eight successful balloon ascents were made with the IMD electrochemical-ozonesondes from Trivandrum during the period 4 March 1983 to 5 April 1983. The data from these flights are shown in figure 5. The balloon reached a peak altitude of 25–26 km or less on many of the flights and only in a few cases did the balloon penetrate the peak of the ozone layer which has been revealed to lie in the altitude range of 26–28 km from the rocket data. The procedure for obtaining absolute values of ozone concentrations involves converting the instrument signals into ozone mixing ratios using laboratory calibration of the instrument and obtaining a

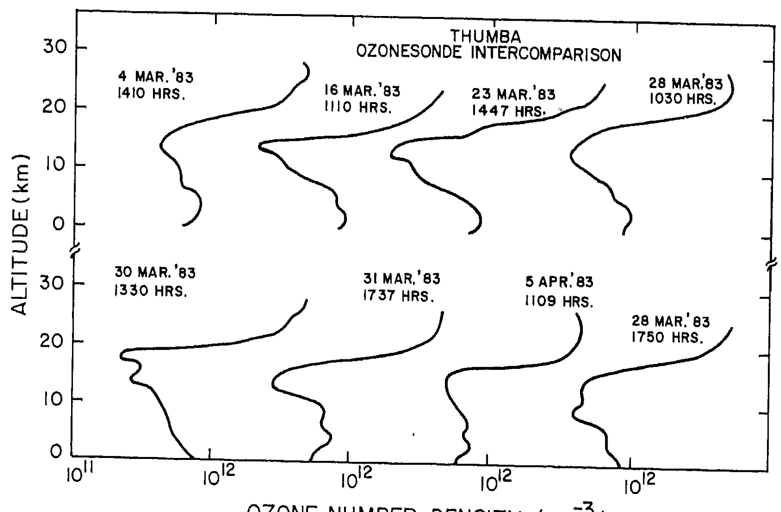

Figure 5. Balloon ozonesonde data obtained at Thumba during the intercomparison experiment.

first order ozone profile which is integrated to obtain the total ozone content. It is assumed that ozone maintains a constant mixing ratio above the peak. The resulting total ozone content is then compared with the Dobson spectrophotometer data for total ozone and a blanket height-independent correction factor is applied to give the final ozone profile. If the balloon does not penetrate the peak ozone level and ascend at least a few kilometers higher, this procedure can give rise to significant errors in the estimation of ozone concentrations. A significant fraction of the total ozone amount is contained in the region ± 5 km around the peak Ozone chemistry in this region is quite complex and ozone concentrations in the first 5 to 10 kms above the peak level do not maintain a constant mixing ratio. The situation becomes critical at tropical/equatorial stations where the peak of the ozone concentration profile is higher than at middle or higher latitudes. The anomalies that can arise are illustrated in table 1 which shows the maximum height attained by the balloon, the maximum ozone level as detected by the balloon ozonesonde and the maximum ozone concentration value for the eight balloon ascents conducted during the intercomparison period.

A careful examination of the data of table 1 shows that when the balloon measurements are available beyond the ozone maximum, the detected level of maximum ozone nearly coincides with that obtained by rocket ozonesondes. However, when the balloon does not penetrate the ozone maximum and the measured profile is extrapolated upwards on the assumption of a constant mixing ratio above the balloon burst level the recorded value of the peak ozone density becomes larger than the actual values. At a tropical site like Trivandrum, unless the balloon reaches a peak altitude of about 30 km, it is not possible to make a proper assessment not only of the level of maximum ozone but also of the absolute values of the ozone concentrations from the balloon data. The Umkehr data for Trivandrum always shows maximum ozone in layer 5 which corresponds roughly to the altitude region of 24 to 28 km and never at lower levels. The maximum ozone concentrations obtained from the Umkehr analysis (figure 6) are in agreement with

Table 1. Balloon ozonesonde data—peak level and maximum ozone number densities.

		Maximum		Detected ozone peak		
Launch date in 1983	Time IST (hr)	Level reached (mb)	Height attained (km)	Level (mb)	Height (km)	No. density $n(O_3)cm^{-3}$
4 March	1410	16	27·8	18	27·2	4·49 (12)
16 March	1110	22	25·8	≤24	≥25·4	5·09 (12)*
23 March	1447	24	25·4	≤24	≥25·4	5·37 (12)*
28 March	1030	15	28·5	20	26·4	4·29 (12)
28 March	1750	26	24·8	≤26	≥24·8	5·15 (12)*
30 March	1330	15	28·5	18	27·2	4·75 (12)
31 March	1737	19	26·8	≤26	≥24·8	4·59 (12)*
5 April	1109	16	27·8	≤24	≥25·4	4·13 (12)*

* The values of the peak number density are estimated using the standard procedure recommended by WMO for analysis of the ozonesonde data. Since the balloon did not penetrate the peak of the ozone layer, these values are uncertain (refer discussions in §3.2).

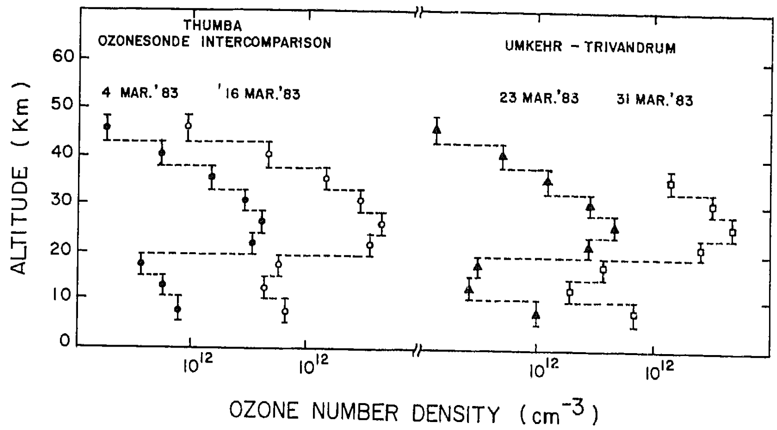

Figure 6. Umkehr data obtained at Thumba during the inter-comparison experiment.

the rocket ozonesonde values within 10%. This shows much better agreement than between the rocket and the balloon ozonesondes.

4. Mean distribution for the intercomparison period

A preliminary study of the data from the March 1983 experiment aimed at an intercomparison of the different sensors was published earlier (Acharya *et al* 1984) where all sensors were given equal weightage and no single sensor was considered to be more standard than the others. Since a number of different sensors have been used, it is realized that the present data set of seventeen ozone profiles consisting of 11 profiles from rocket ozonesondes which includes 8 optical ozonesonde data and 3 chemiluminescent ozonesonde data, 4 balloon profiles and 2 Umkehr profiles represents a significant amount of data, all collected in three salvos within a reasonably short period of eight days from one location and should give an average picture of the vertical distribution of ozone over Thumba accurately and unaffected by individual instrument biases. Further, such a large amount of data from a tropical site has been obtained for the first time. This data set is used to obtain a mean ozone distribution for the Thumba site representing the tropical reference profile. Although this mean distribution cannot represent all seasons of the year, it can be considered as a reference profile for the spring equinox.

The mean vertical distribution of ozone number density is obtained by taking the average of all 17 measurements made on 23 March, 28/29 March and 31 March respectively. The mean ozone number density and the standard deviation ($\pm\sigma$) are shown in figure 7 and the values tabulated in table 2. The tropospheric ozone values are mainly the mean of balloon and rocket chemiluminescent measurements and Umkehr observations since the optical ozonesonde data become available only above 16 km. The distribution shows a minimum in the troposphere in the 12–14 km region with number density of $2{\cdot}8\times10^{11}$ molecules/cc and the ozone maximum is obtained at an altitude of 27 ± 1 km with a concentration of $3{\cdot}86\times10^{12}$ $\pm0{\cdot}52\times10^{12}$ molecules/cc. Above the peak the ozone concentrations decrease steadily and at altitudes above 40 km the profile can be represented by a scale

Table 2. The mean vertical distribution of ozone over Thumba for the spring equinox period of March 1983.

Altitude (km.)	Ozone concentration molecules/cm^3	Standard deviation	Ozone mixing ratio PPMV	Standard deviation
0	0·6825E+12	0·1121E+12	0·2834E−01	0·4653E−02
1	0·7600E+12	0·1541E+12	0·3454E−01	0·7000E−02
2	0·7675E+12	0·1011E+12	0·3838E−01	0·5056E−02
3	0·7775E+12	0·9323E+11	0·4286E−01	0·5137E−02
4	0·7450E+12	0·7141E+11	0·4546E−01	0·4356E−02
5	0·7125E+12	0·8539E+11	0·4824E−01	0·5782E−02
6	0·6300E+12	0·1042E+12	0·4748E−01	0·7856E−02
7	0·5625E+12	0·1464E+12	0·4719E−01	0·1228E−01
8	0·6215E+12	0·2698E+12	0·5802E−01	0·2518E−01
9	0·5083E+12	0·1787E+12	0·5283E−01	0·1857E−01
10	0·3769E+12	0·1878E+12	0·4367E−01	0·2176E−01
11	0·3294E+12	0·1318E+12	0·4259E−01	0·1705E−01
12	0·2894E+12	0·9829E+11	0·4242E−01	0·1442E−01
13	0·2811E+12	0·7499E+11	0·4587E−01	0·1217E−01
14	0·2794E+12	0·6417E+11	0·5101E−01	0·1156E−01
15	0·3300E+12	0·8864E+11	0·6942E−01	0·1886E−01
16	0·7108E+12	0·4432E+12	0·1696E+00	0·1087E+00
17	0·8424E+12	0·4669E+12	0·2410E+00	0·1355E+00
18	0·1159E+13	0·5738E+12	0·3941E+00	0·1993E+00
19	0·1631E+13	0·6988E+12	0·6750E+00	0·2920E+00
20	0·2207E+13	0·9104E+12	0·1134E+01	0·4825E+00
21	0·2725E+13	0·9041E+12	0·1681E+01	0·5801E+00
22	0·3173E+13	0·9915E+12	0·2318E+01	0·7516E+00
23	0·3473E+13	0·9487E+12	0·3005E+01	0·8608E+00
24	0·3597E+13	0·8772E+12	0·3696E+01	0·9630E+00
25	0·3757E+13	0·6861E+12	0·4537E+01	0·8989E+00
26	0·3834E+13	0·5264E+12	0·5419E+01	0·7174E+00
27	0·3858E+13	0·5196E+12	0·6393E+01	0·7983E+00
28	0·3783E+13	0·5817E+12	0·7422E+01	0·1072E+01
29	0·3477E+13	0·5556E+12	0·7904E+01	0·1174E+01
30	0·3168E+13	0·5081E+12	0·8481E+01	0·1245E+01
31	0·2820E+13	0·4364E+12	0·8740E+01	0·1255E+01
32	0·2427E+13	0·3907E+12	0·8774E+01	0·1384E+01
33	0·2082E+13	0·3242E+12	0·8738E+01	0·1309E+01
34	0·1755E+13	0·2583E+12	0·8667E+01	0·1230E+01
35	0·1468E+13	0·2290E+12	0·8398E+01	0·1295E+01
36	0·1232E+13	0·2003E+12	0·8210E+01	0·1270E+01
37	0·1034E+13	0·1810E+12	0·7950E+01	0·1348E+01
38	0·8577E+12	0·1532E+12	0·7602E+01	0·1371E+01
39	0·7000E+12	0·1308E+12	0·7263E+01	0·1386E+01
40	0·5568E+12	0·9951E+11	0·6758E+01	0·1301E+01
41	0·4675E+12	0·1080E+12	0·6491E+01	0·1417E+01
42	0·3742E+12	0·8918E+11	0·6032E+01	0·1385E+01
43	0·3096E+12	0·7650E+11	0·5723E+01	0·1439E+01
44	0·2508E+12	0·6445E+11	0·5329E+01	0·1419E+01
45	0·2056E+12	0·5496E+11	0·4953E+01	0·1362E+01
46	0·1632E+12	0·4616E+11	0·4421E+01	0·1234E+01
47	0·1348E+12	0·3953E+11	0·4131E+01	0·1189E+01

Table 2. (*Contd.*)

Altitude (km.)	Ozone concentration molecules/cm^3	Standard deviation	Ozone mixing ratio PPMV	Standard deviation
48	0·1053E+12	0·3099E+11	0·3624E+01	0·1039E+01
49	0·8577E+11	0·2591E+11	0·3322E+01	0·9796E+00
50	0·6900E+11	0·2052E+11	0·3052E+01	0·8798E+00
51	0·5764E+11	0·1938E+11	0·2856E+01	0·9097E+00
52	0·5050E+11	0·1565E+11	0·2806E+01	0·7693E+00
53	0·4167E+11	0·1438E+11	0·2596E+01	0·7977E+00
54	0·3365E+11	0·1243E+11	0·2371E+01	0·7874E+00
55	0·2775E+11	0·1110E+11	0·2212E+01	0·8061E+00
56	0·2260E+11	0·9395E+10	0·2037E+01	0·7760E+00
57	0·1925E+11	0·1048E+11	0·1965E+01	0·9811E+00
58	0·1572E+11	0·8725E+10	0·1823E+01	0·9355E+00
59	0·1650E+11	0·7365E+10	0·2066E+01	0·9115E+00
60	0·1300E+11	0·5292E+10	0·1858E+01	0·7539E+00

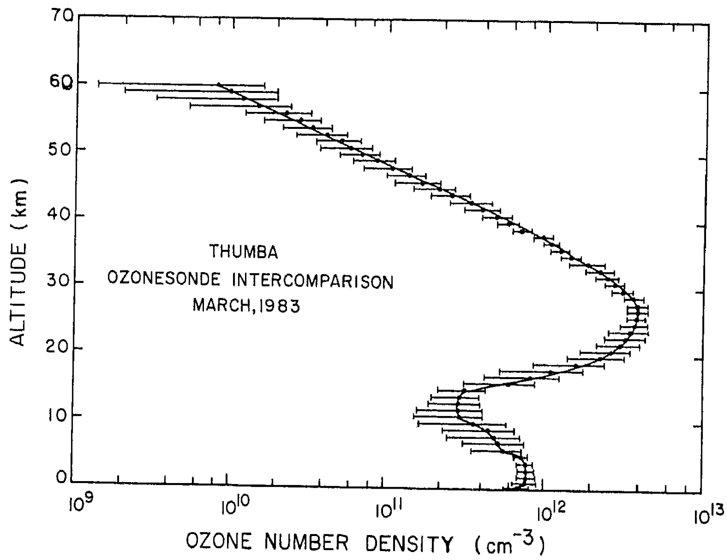

Figure 7. Mean ozone concentration profile obtained from the March 1983 ozone intercomparison experiment at Thumba. The bars denote the ± one σ standard deviations from the mean.

height of about 5 km. The distribution above the peak is dominated by the rocket data and upto 56 km they represent the mean of 10 profiles and are statistically significant without any individual instrumental bias.

The integrated ozone amount corresponding to the profile of figure 7 amounts to 249 DU. Dobson spectrophotometric observations made at Thumba during the intercomparison period gave the average daily values ranging from 252 DU to 260 DU for the period 23 March to 31 March 1983 with an average value of 256·7 and a standard deviation of ±2·6 DU. Hence the mean profile of figure 7 gives a total ozone amount which is less than the Dobson value by 3·1%. While the difference is within the uncertainties of the Dobson estimates, it is noted that there have been earlier studies dealing with a comparison of Dobson data with satellite data (Lovill and Ellis 1983) suggesting that the Dobson instrument overestimates the total ozone content by a few per cent. This is considered by some researchers to be due to contamination by other absorbing gases in the atmosphere (e.g. Komhyr and Evans 1980). Further, Klenk *et al* (1985) show that the revised ozone aborption coefficient data of Bass and Paur (1985) would give 4% less total ozone. Hence the above discrepancy might be due to the incorrect use of ozone absorption coefficient for the Dobson data.

The ozone number density profiles observed over Thumba are converted into mixing ratio profiles and the mean of all is compared with other measurements. In order to obtain mixing ratios, air density values obtained from the meteorological rocket flights on 23, 28 and 31 March are used and the individual ozone concentration profiles are converted into mixing ratio profiles. These data are plotted in figure 8 along with other published values for the equatorial region, viz (1) the SBUV measurement of NIMBUS-7 for March 1979 by McPeters *et al* (1984), (2) the ozone number density values from the solar maximum mission (SMM) by Aikin *et al* (1984) for the fall equinoctial period of 1980 converted into mixing ratios using the mean of the above meteorological data and (3) the BUV measurement on the Atmospheric Explorer-E (AE-E) satellite reported by Frederick *et al* (1978) for the March 1976 period.

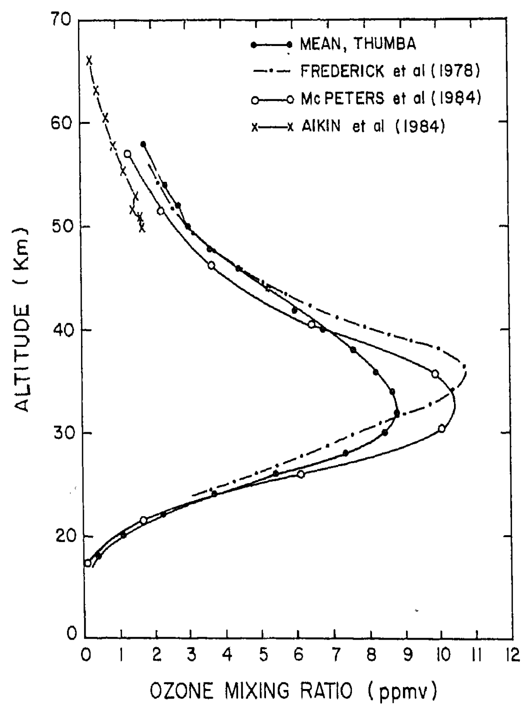

Figure 8. Comparison of the Thumba mean ozone mixing ratio profile with available satellite data for the tropical region.

Figure 8 shows that at altitudes below 20 km the present rocket values are larger than the NIMBUS-7 data, the difference being of the order of 15%. The mean Thumba profile crosses the NIMBUS-7 profile at 24 km and at higher altitudes the NIMBUS-7 values are larger than the Thumba mean values. In the entire region of 25 km to 35 km the NIMBUS-7 profile shows values larger by about 15%. The Thumba profile crosses the NIMBUS-7 profile again around 40 km and above this altitude the Thumba values are consistently larger than the NIMBUS-7 values. The discrepancy lies in the range of 20% to 30% in the 45–55 km altitude region. The AE-E satellite data for the March equinox period of 1976, reported by Frederick *et al* (1978) show lower values for altitudes below 30 km and higher values in the altitude region of 30 to 45 km. This is also seen as a difference in the peak levels with the AE-E data showing the peak about 4 km above the rocket data. However, at altitudes above 45 km the two sets of data agree within a few per cent. The data from the SMM satellite show lower ozone values in the limited region of data overlap and the difference is about 40%. The possibility of a systematic bias in the satellite data depending on the altitude and length of the integration time has been considered by some workers earlier (e.g. Herman 1979) due to the fact that the satellite instruments look through different local times and altitudes. Further, the satellite data represent global averages for a given latitude belt whereas the present data refers to one location. This aspect needs special consideration at mesospheric altitudes where the ozone concentrations are sensitive to water vapour and temperature.

5. Day-to-day and day-night variations

The mean vertical distribution of ozone obtained for the three individual salvos on 23, 28/29 and 31 March shows existence of a day-to-day variability at different altitudes. This is demonstrated in figure 9 which shows percentage deviation of mean ozone concentration at different altitudes from one salvo to another. The percentage deviation lies within 10% in the altitude region of 25 to 35 km, but it is larger at other heights. The differences below 25 km are random in nature and are considered to be the manifestation of the dynamical process. Such short-term variations in this height region are well known (Dutsch 1980). At altitudes above 35 km, the ozone concentration values obtained from the 28/29 March salvo are systematically lower than those obtained on the other two days. The difference is 25–30% around 40 km and is of the order of 40–50% in the altitude region of 40 to 55 km. This feature is shown not only in the mean distribution, but also in the data from individual instruments. From figure 1 it can be seen that the ozone values obtained from PRL ozonesonde on 28 March are lower than those of 23 March. Figure 2 shows that the NPL ozone values for 29 March are lower than those for 31 March. The night-time chemiluminescent ozonesonde values are also lower on 28 March when compared to the values of 23 and 31 March in this altitude region. Hence it does appear that ozone concentration in the 30–50 km altitude were really lower on 28/29 March when compared to 23 and 31 March. This altitude region is photochemically dominated. The solar and geophysical data reported for this period show no anomalies. But the temperature data for three days obtained from the Thumba M-100 met. rocket sounding shows a warmer stratosphere on 28 March in the entire altitude region of 30 to 55 km, warmer by 5–10°K as compared to 23

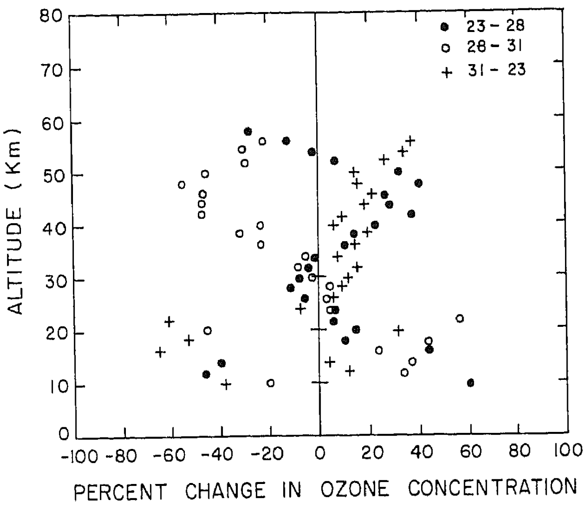

Figure 9. Day-to-day variability in the vertical distribution of ozone indicated by the rocket data of the inter-comparison experiment.

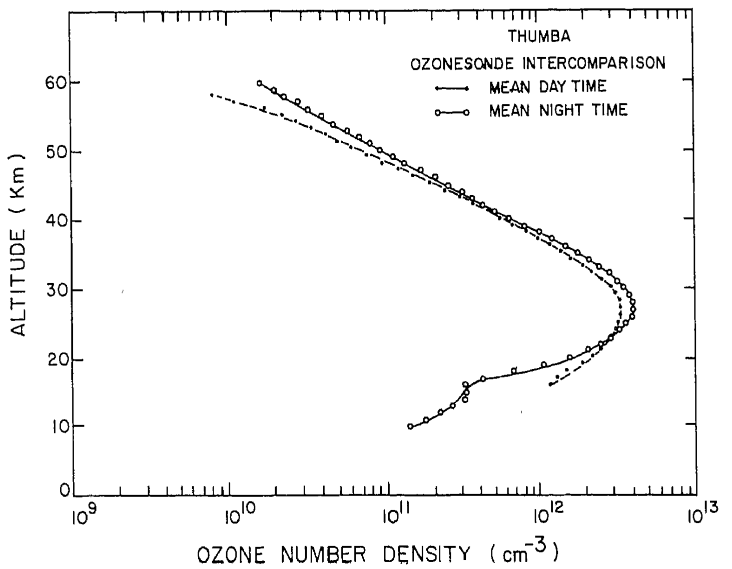

Figure 10. Day-night variations in ozone concentrations at different altitudes from the data of the Thumba March 1983 experiment.

and 31 March. Also, the temperature maximum around stratopause is broader on this day. Since temperature and ozone concentrations are anti-correlated in this height region, the observed decrease in ozone concentration on 28 March can be qualitatively attributed to this temperature increase.

The data from the March 1983 experiment gave an opportunity to see the variations in the ozone concentration values from day to night since there was one successful night-time flight in each of the three salvos. The mean of the three Soviet chemiluminescent rocket flights conducted during night-time is compared with the mean of the daytime values in figure 10. The night-time values are higher than daytime values at all altitudes above 22 km, but are lower at altitudes below. The differences between the night-time and daytime values are within the standard deviations upto 42 km. However, above this altitude, the differences are more than the standard deviation limit showing a statistically significant day to night increase in the ozone concentration. The increase in night-time is by an amount of 28% at 45 km, 32% at 50 km, 45% at 55 km and 56% at 60 km. The same feature is apparent when the data for the same day and same night is compared. Although this is qualitatively in agreement with the earlier rocket data from Thumba (Subbaraya *et al* 1985) and theoretical predictions, quantitatively the observed increases are much larger. Whether this increase is partly or wholly due to a systematic bias between the two sets of instrumentation, since all the three night-time profiles are from chemiluminescent sonde and all the daytime data in this altitude region come from optical ozonesondes or the differences represent a genuine day-night variations, needs to be established.

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