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Ozone distribution over India

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ABSTRACT. Using Dobson ozone spectrophotometer data from a network of six stations in India, the spatial and temporal distribution of total ozone over the country and its vertical distribution in the atmosphere during 1964-1969 have been studied. The study confirms earlier observations and shows that over stations north of 25°N the seasonal increase in total ozone is caused by a fractional increase in all layers from the ground to 28 km, the main contribution coming from the layers between 10 and 24 km. Above 28 km the concentration changes roughly in accordance with photochemical production. In lower latitudes south of 25°N an increase in total ozone amount during the annual cycle is caused by a gradual increase in all the layers from the ground to 36 km, above which the variation is negligible.

1. Introduction

The first measurement of the vertical distribution of ozone over Indian stations using the Umkehr method was made by Ramanathan and Karandikar (1949). They pointed out that the centre of gravity of ozone shifts downwards when the total ozone increases at a place. From the analysis of Umkehr observations made at three tropical stations, Rangarajan (1966) concluded that the main features of the vertical distribution of ozone over the tropics remain the same in all the seasons and a change in total ozone is brought out by a proportionate change throughout upto 30 km.

Regular ozone observations with the Dobson spectrophotometer have been made at a network of six stations in India, Srinagar (34°N), New Delhi (28°N), Varanasi (25°N), Ahmedabad (23°N), Dum Dum (22°N) and Kodaikanal (10°N) since 1963. A study of the spatial and temporal distribution of total ozone over India and its vertical distribution in the atmosphere has been made using the average of five years' data from 1964 to 1968 and the results are presented in the sections which follow.

2. Variation in total ozone over India

The main features of the annual variation of total ozone over India (Fig. 1) are well known. The higher values of the total ozone amount recorded at Kodaikanal during the summer (Indian monsoon) season give rise to a reversal of normal latitudinal gradient of ozone. Rangarajan (1966) explained this latitudinal anomaly as due to photolytic destruction of ozone over north India, and a secondary meridional-cum-vertical circulation with ascending air near New Delhi and descending air near Kodaikanal. The net ozone available in a vertical column of the atmosphere is the result of (*i*) photochemical production, (*ii*) the rate of transfer from the lower to the higher latitudes in the middle and upper stratosphere and (*iii*) the southward flux of ozone from higher latitudes in the lower stratosphere and the troposphere. The transfer mechanism is active during winter and is absent during summer in the northern hemisphere, while the photochemical production is higher during summer. This explains qualitatively the observed annual variation of ozone over Indian stations. Since the latitudinal gradient of total ozone is very small over Indian stations (Kulkarni *et al.* 1959) the time lag in the occurrence of maximum and minimum causes a reversal in the normal gradient.

Another anomaly in ozone distribution over India, evident from Fig. 1 is that over Ahmedabad (23°N) the total ozone is lower compared to Dum Dum (22° N) and even Kodaikanal (10° N). This is observed almost throughout the year. A detailed study of these anomalies will be possible after simultaneous observations of the vertical distribution of ozone by Indian ozonesondes from New Delhi and Kodaikanal become available in the future.

3. Vertical distribution of ozone from Umkehr observations

The vertical distribution of ozone in the atmosphere over India was studied using computed Umkehr data published in 'Ozone data for the world'. Since the number of observations in any one year, particularly during summer, was small, data

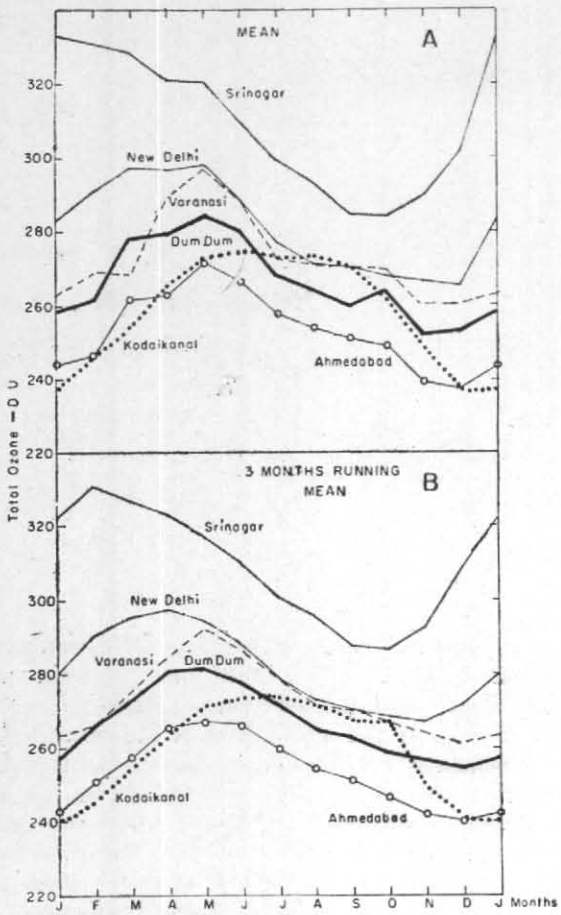

Fig. 1

Annual variation of total ozone at Srinagar, New Delhi, Varanasi, Ahmedabad, Dum Dum and Kodaikanal (1964-1968)

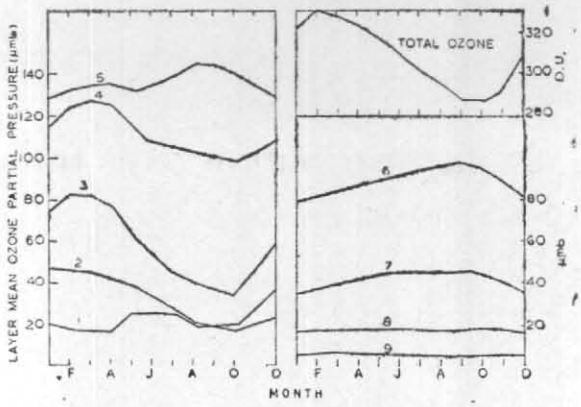

Fig. 2(a)

Layerwise distribution of ozone over Srinagar

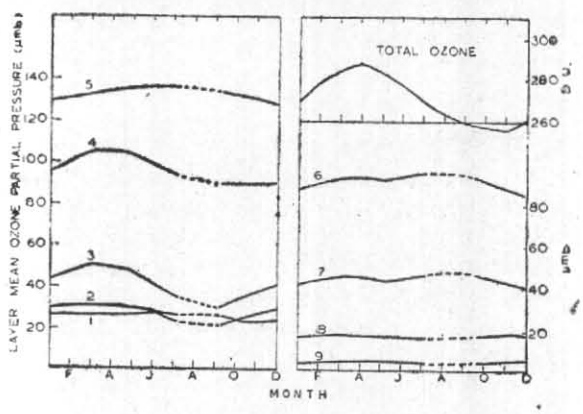

Fig. 2(b)

Layerwise distribution of ozone over New Delhi

for five years from 1964 to 1968 were used. Three months' overlapping means were calculated for each layer to eliminate irregular variations arising from the differences in the number of observations. Table 1 gives the number of Umkehr observations available for each station.

3·1. *Annual variation*

The annual variation of the mean ozone partial pressure in each layer over Srinagar is shown in Fig. 2 (a). The total ozone variation is also given for comparison. The ozone content in layer 1 (5·5-10·3 km) depends on the amount of destruction of ozone in the lower troposphere and does not show a significant correlation with total ozone changes, while layers 2, 3 and 4 (10·3-23·6 km) agree closely with the total amount curve. The concentration in these layers is the result of redistribution of ozone by atmospheric circulation. Layer 5 (23·6-28 km) shows two maxima, the first corresponding to the total ozone maximum in February-

TABLE 1

Number of Umkehr observations used for different stations (1964-1968)

	Srinagar	New Delhi	Varanasi	Ahmedabad	Dum Dum	Kodaikanal
Jan	7	25	45	49	13	23
Feb	9	23	48	54	21	31
Mar	15	22	71	53	16	13
Apr	10	27	56	34	12	4
May	6	41	67	26	2	1
Jun	9	4	17	15	1	—
Jul	8	1	1	4	—	—
Aug	20	—	—	5	—	—
Sep	15	21	17	16	—	—
Oct	13	59	53	25	4	—
Nov	19	48	35	26	9	2
Dec	11	24	35	36	13	18
Total	142	295	445	343	91	97

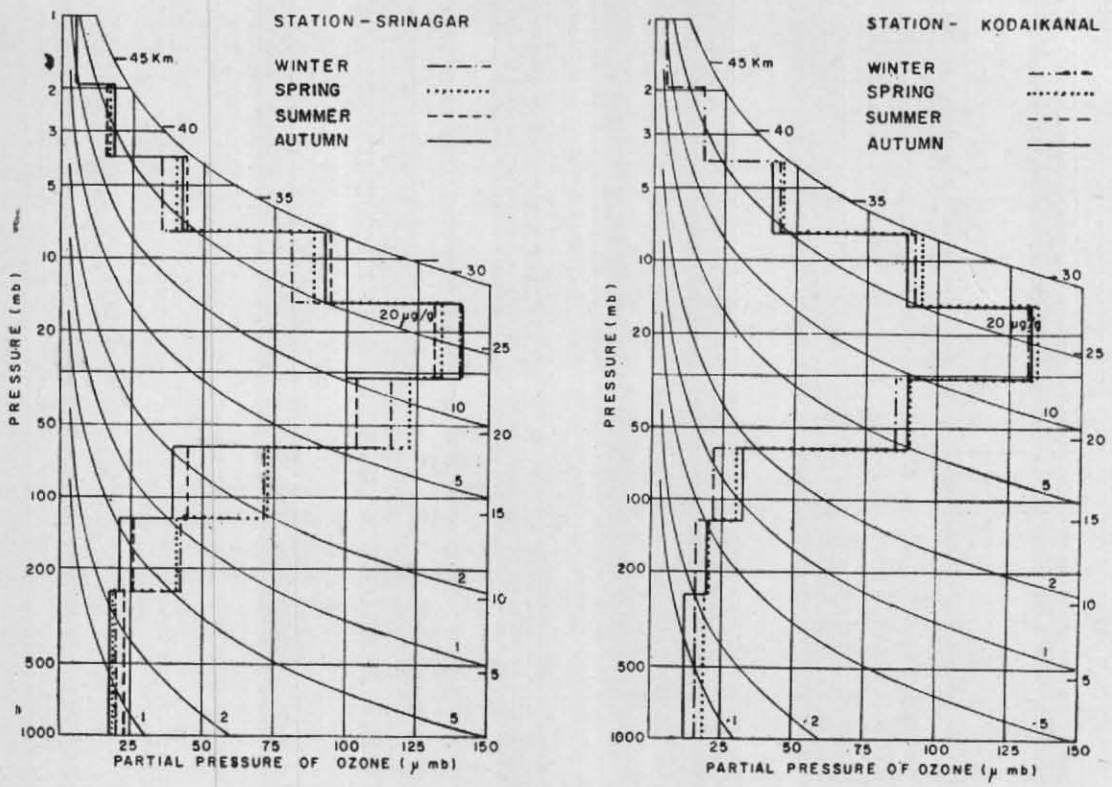

Fig. 3

Seasonal variation of ozone in different layers over Srinagar and Kodaikanal

March and the second which is even more pronounced in August-September, when the total ozone is nearly at its minimum.

The circulation during the southwest monsoon season is characterised by the migration of the equatorial trough to as far north as 20-25° N, a broad and strong westerly current upto 700 mb to the south of trough, overlaid by a strong easterly current south of the Himalayas with its core, the easterly jet stream, established at an altitude of 100-150 mb positioned near 15°N. The subtropical jet stream over northern India found during winter is absent during summer. Thus the complete circulation over the Indian sub-continent is reversed during the southwest monsoon season and the sub-continent is cut off from the northern latitudes (Koteswaram 1958). The presence of strong easterly current near the tropopause along with the increased photochemical production during the period appears to induce the secondary maximum in layer 5.

Above the level of the ozone maximum, layers 6 and 7 show a summer maximum and winter minimum. These are the transition layers where the ozone concentration seems to be mainly governed by photochemical processes, with circulation effects superimposed on it. Above these, atmospheric ozone is totally governed by sun's radiation but over the Indian region no appreciable change is observed from month to month.

The layerwise distribution over New Delhi is very similar to that observed over Srinagar, except that in layer 5 only a single maximum is observed in the months May-July (Fig. 2 b).

The layerwise distribution over Varanasi, Ahmedabad and Dum Dum is also similar to that over New Delhi. The concentration in layer 2 is quite low over Varanasi and Dum Dum and does not appear to contribute much to the total ozone amount. The vertical distribution over Kodaikanal is still poorly understood, since no Umkehr observations are available between May and November due to overcast skies.

3.2. *Seasonal variation*

The ozone concentration in various layers was averaged for four seasons, winter (December-February), spring (March-May), summer (June-August) and autumn (September-November).

The vertical distribution of ozone over Srinagar for the four seasons is shown in Fig. 3 (a). The ozone concentration in layers 1, 2 and 3 is nearly the same in winter and summer and the

sharp increase in total ozone from autumn to winter is contributed by a steep rise in layers 2, 3 and 4. During summer when the total ozone amount decreases, there is general decrease up to the 4th layer, whereas in the higher layers there is an increase. The main contribution to total ozone increase or decrease comes from the layers below the ozone maximum, above which the photochemical processes assume prominence.

The seasonal variation in ozone concentration over New Delhi is similar to that at Srinagar, but the order of variation is much smaller. At Varanasi, the values of ozone, in the lower layers show no sharp variations in autumn and winter and hence the minimum ozone occurs in winter. In spring, when the total ozone attains a minimum value, a gradual increase is observed at all levels followed by a decrease below the 5th layer during summer. The difference in the vertical distribution of ozone over New Delhi and Varanasi is to be attributed to the existence of the tropopause break between these two stations.

Seasonal variations over Ahmedabad and Dum Dum are indentical with those at Varanasi.

At Kodaikanal where the maximum total ozone occurs during summer and the minimum during winter the distribution is different from that at all the other stations (Fig. 3 b). However, no Umkehr observations are possible throughout summer due to overcast skies and the vertical distribution in summer is not known. From winter to summer, the increase in total ozone is contributed to by a proportionate increase in all the layers upto the 7th layer (38 km).

3.3. *Latitudinal distribution*

In order to study the nature of the vertical distribution as one proceeds from higher to lower latitudes over the Indian region the average distributions for Srinagar (34°N), New Delhi (28° N) and Kodaikanal (10° N) were compared.

In winter, Srinagar shows a steep rise just above the sub-tropical tropopause at 250 mb, followed by another increase above the tropical tropopause. Over New Delhi which falls at the region of the tropopause break and is characterised by a double tropopause, the profile shows slight increase in the second layer but the real increase takes place only above the tropical tropopause. In the first layer, the ozone concentration over New Delhi is always higher than that over Srinagar, presumably due to higher destruction in the lower levels over Srinagar. Over Kodaikanal the tropospheric values are quite low and steady upto the tropical tropopause and the increase in ozone concentration starts only above 16 km. Above the level of the ozone maximum, the concentration over Kodaikanal is higher and that over Srinagar is lower, in agreement with photochemical processes. The normal latitudinal gradient in total ozone is maintained by the higher concentration in the lower layers, due to the redistribution of ozone by atmospheric circulation in the lower stratosphere.

During summer, the lower level concentration over Srinagar and New Delhi decreases considerably, presumably due to the absence of a circulation bringing ozone from the production region to the higher latitudes. The concentration in the higher layers continues to increase and records highest value during this season.

In autumn the decrease in ozone in the lower layers over Srinagar and New Delhi continues due to leakage and destruction in the troposphere. Also in the higher layers the ozone value decreases with the retreat of the sun thus giving the minimum total ozone during this period. Over Kodaikanal the distribution below the ozone maximum level is nearly same as over New Delhi but in the higher layers it is in disagreement with what is to be expected according to photochemical considerations. This result, however, depends only on two observations in November and requires a confirmation by more observational data.

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