551·510·534

Seasonal variation of atmospheric ozone in India and some ozone-weather relationships

S. RANGARAJAN

Meteorological Office, Poona

(*Received 7 March 1962*)

ABSTRACT. An analysis is made of the total ozone amounts determined at the four regular ozone stations in India during the period 1958 to 1960. While the ozone content at Srinagar and Delhi is relatively higher during January-April, that at Kodaikanal is relatively higher during June-September. A very interesting feature of the ozone distribution in India is the reversal of the latitudinal gradient of total ozone during the monsoon season which leads to higher ozone in the south than in the north. A possible mechanism to account for this reversal is suggested in terms of seasonal variations in the tropopause height. Good correlations are observed between day-to-day fluctuations in the ozone at Srinagar and changes in the 500-mb contour heights at Delhi caused by the movement of disturbances in the westerlies. A case study of an abnormal increase of ozone in association with a western depression in March 1960 is also discussed. The increase of ozone is apparently caused more by vertical descent of stratospheric ozone-rich air than by advection of northerly winds.

1. Introduction

The study of atmospheric ozone has become of considerable importance to meteorologists on account of the fact that ozone observations can provide valuable information on the physics and dynamics of the stratosphere. Though ozone is formed by the photochemical action of sunlight on the upper stratosphere, an appreciable fraction of the total ozone is stored in the lower regions of the stratosphere where the mean residence time is of the order of several days. Variations in the total amount of ozone are controlled mainly by the dynamical processes in the lower stratosphere and hence ozone serves as a natural tracer to study air movements. The total amount of ozone over a station is capable of being measured accurately from surface by spectrophotometric observations and the day-to-day variations, although small, reveal important information on the exchange of air between the lower and middle stratosphere and also between the lower stratosphere and the troposphere. For a complete understanding of the stratospheric circulation in relation to ozone amounts, a knowledge of the vertical distribution of ozone is also necessary. Umkehr observations being time-consuming and besides being dependant on favourable sky conditions for long periods are not determined regularly at ozone stations. From a few valuable relationships deduced by Ramanathan (1954) between the total ozone amounts and the patterns of vertical distribution, important conclusions can, however, be drawn from observations of total ozone alone.

2. Ozone observations in India

In India, the first series of determinations of ozone were those made at the Kodaikanal Observatory in 1929 as part of Dr. G.M.B. Dobson's famous World Ozone Survey. These observations which were made with the photographic spectrophotometer gave for the first time evidence of the relatively low amounts of ozone at low latitudes (Dobson 1930). The first observations using the improved photoelectric spectrophotometer were made by Ramanathan and his co-workers at Poona in 1940. During the post-war period ozone observations were made for limited periods at various locations in India

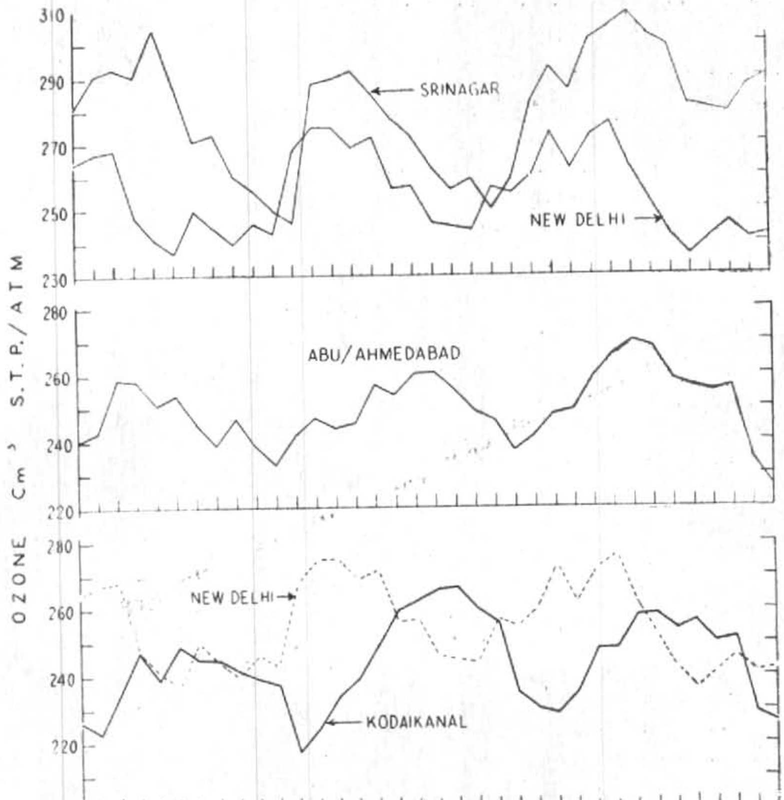

Fig. 1. Monthly mean values of total ozone at Srinagar, New Delhi, Kodaikanal and Abu/Ahmedabad during 1958-60

by Ramanathan and his collaborators. Some of the important results obtained have been discussed by Karandikar (1948), Ramanathan and Karandikar (1949) and Karandikar and Ramanathan (1949). Regular observations of ozone commenced at New Delhi, Mt. Abu and Srinagar from about 1955. The seasonal distribution and other features of ozone in north India have been discussed by Ramanathan (1954) and Kulkarni, Angreji and Ramanathan (1959). With the adoption of the Vigroux absorption coefficients for the routine evaluations from the beginning of 1958 and with the starting of a new ozone station at Kodaikanal from the same time, a homogeneous series of ozone values became available for four stations in India, *viz.*, Srinagar (Lat. 34°N), New Delhi (Lat. $28\frac{1}{2}$°N), Mt. Abu (Lat. 24° N)/Ahmedabad (Lat. 23°N) and Kodaikanal (Lat. 10°N). In the present paper, the important features of ozone distribution in India during the three-year period 1958 to 1960 are discussed. Some relationships between ozone and tropopause heights and between ozone and weather are also discussed. During this period, the determinations of total ozone were made at all the four stations on the direct sun using the C and C′ wavelengths (3112/3323 Å and 4536/3323 Å). On a few cloudy days, however, the observations were made on the zenith sky. Owing to heavy clouding, the observations from Kodaikanal and Mt. Abu were available on about

25-50 per cent of the days during the rainy season.

3. Seasonal and latitudinal variation of ozone

The mean monthly values of total ozone for the 3-year period are given in Fig. 1 separately for the four stations. It will be seen that except Srinagar, none of the Indian stations show a seasonal variation similar to the generally accepted pattern for the middle latitudes, *viz.*, a maximum in Spring and a minimum in Autumn. Even at Srinagar, there are significant changes from year to year. In 1959, the maximum occurred in March whereas in 1958 and 1960 the maximum was reached only in May. The seasonal variation at New Delhi is not similar to that at Srinagar, there being a minimum during the monsoon season at the former station. The time of attainment of the maximum both at Srinagar and New Delhi appears to be related to some extent on the activity of the western disturbances during the different months. With the movement of the western disturbances, horizonal as well as vertical movements of air take place leading to periodical surges of ozone. In general, the more the activity of the western disturbances during a month the more the average amount of ozone during that month. The decrease of ozone in summer and the monsoon months at New Delhi has been found to occur during all the three years. Kulkarni, Angreji and Ramanathan (1959) have drawn attention to the interesting fact that during the summer of 1957 the ozone amounts at Delhi did not undergo the usual decrease. It is relevant in this connection to observe that the monsoon of 1957 was peculiar in many respects. It set in over the country very late and withdrew early. Many parts of northwest India and West Pakistan experienced abnormal deficiency of monsoon rains. The upper trophospheric circulation of July and August 1957 also showed some singularities. As against the easterly winds predominating from 9 to 12 km over Delhi in normal years, westerlies were predominating during 1957. Apparently the lower stratospheric pattern was more of the pre-monsoon type. The ozone amount at Mt. Abu/Ahmedabad reaches a maximum in May or June and a minimum during November-December. At Kodaiknal, the most interesting feature is the seasonal variation which is nearly the opposite of that at New Delhi. The minimum occurs in January-February and the maximum during the monsoon period June to September. The amplitude of the seasonal variation amounting to about units 30-35 (cm^{-3} STP) is found to be appreciably higher than that found by Karandikar (1948). Compared with the other three stations, the seasonal variation at Kodaikanal follows a steadier pattern from year to year.

By far the most interesting feature of the ozone distribution in India is the reversal of the latitudinal gradient of total ozone which occurs during the monsoon season leading to higher ozone amount in the south than in the north. In all the three years studied, the ozone content at Kodaikanal has been found to exceed that at New Delhi during most days of the monsoon season. This type of reversal persisting for a whole season does not appear to have been reported elsewhere. The ozone climatology of India appears to have important peculiarities and calls for more detailed investigation by the establishment of more ozone stations.

4. On the possible causes for the reversal of latitudinal gradient

It is now fairly well established that the total amount of ozone over any location is made up of two components—

(*i*) the daily equilibrium amount produced by the photochemical action of sunlight on the upper stratosphere, and,

(*ii*) the accumulated ozone below the region of photochemical equilibrium.

The seasonal changes in the first component are probably not large enough to account for the observed features. On the other hand, the second component could undergo changes from season to season, depending on conditions

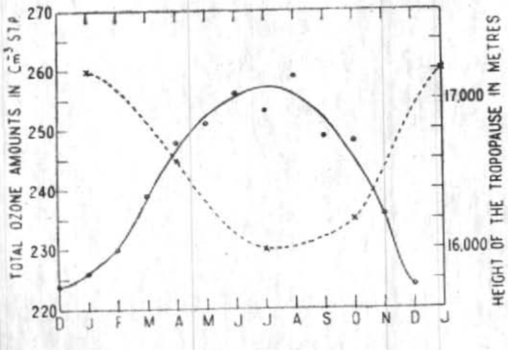

Fig. 2

o—o—o Mean monthly ozone amounts based on data 1958-60 (Kodaikanal)

x..x..x Height of tropopause near Kodaikanal estimated from mean tropopause maps

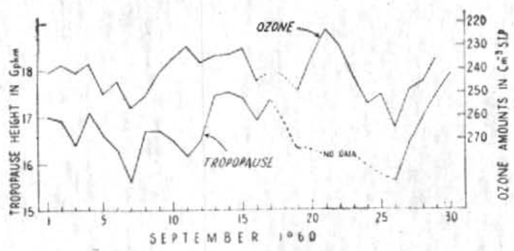

Fig. 3. Day-to-day variations in tropopause height and ozone amounts at New Delhi

Ordinates of ozone inverted

in the lower stratosphere and the upper troposphere. The great thermal stability of the tropical stratosphere does not promote the generation of any large-scale vertical movement and a region of horizontally stratified ozone content develops with the ozone-mixing ratio increasing upwards. The lower the tropopause, the greater will be the ozone-holding capacity of the stratosphere and thus any seasonal change in the height of the tropopause could affect the seasonal total ozone content to some extent. Although the data on tropopause heights are somewhat meagre in India, certain important features of the tropical tropopause are known. During the monsoon season, the tropopause height is a minimum in the south being about 14-15 km and a maximum in the north with a value of 17-18 km. The annual variation of the tropopause height in the south is such that the minimum (14-15 km) occurs in July and a maximum (16-17 km) in January. It appears probable that at least a part of the seasonal variation of ozone at Kodaikanal might be related to the tropopause height as shown in Fig. 2. The reversal of the latitudinal gradient of ozone over India during the monsoon also appears to be connected with the occurrence of a higher tropopause in the north. A fairly close connection between the tropopause height and the total ozone at New Delhi during September 1960 is shown by Fig. 3. Adequate data on the tropopause is not available to examine the situation at other locations. In addition to the effect of tropopause height, there might as well be other contributory causes for the observed seasonal changes. For example, the rather abrupt decrease of total ozone at Kodaikanal occurring in December-January in all years might be due to a reduction in the equilibrium amount in the upper stratosphere in association with the seasonal decrease of sun's elevation angle. It is of interest to observe that the abrupt fall of total ozone at Mt. Abu/Ahmedabad occurs at the same time as at Kodaikanal. A part of the rather sudden increase of ozone at Kodaikanal during March-April might be due to thunderstorm activity. This aspect of thunderstorm influencing the ozone amount is being studied.

5. Ozone and Weather

The day-to-day variability of ozone in India during the monsoon season is found

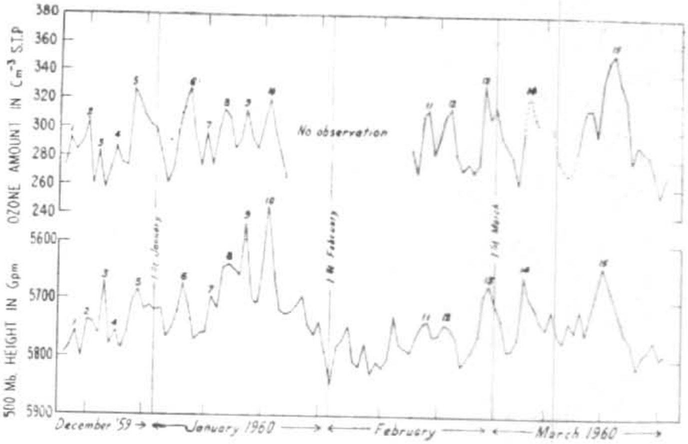

Fig. 4. Daily variation of ozone at Srinagar and New Delhi correlated with 500-mb height values at New Delhi during 16 December 1959 to 31 March 1960

to be small. Due to heavy clouding and rain, ozone observations were also not available on many days from Kodaikanal and Mt. Abu. It was, therefore, not possible to study ozone variations in relation to monsoon weather systems. In the winter season, however, significant fluctuations of ozone amount take place at Srinagar and to a lesser extent at New Delhi in association with the passage of western disturbances. It was, therefore, possible to study this feature in some detail. The western disturbances that affect north India are essentially phenomena in the middle and upper troposphere and are hence not always revealed by surface meteorological parameters. After some trials, it was found that an objective way of tracing these disturbances is by following the day-to-day values of the 500-mb contour heights. When the daily values of the 500-mb contour height at New Delhi or Amritsar were plotted, the passage of the western disturbances could be easily identified by the depressions in the contour values. In Fig. 4 are plotted the sequence of daily 500-mb height values of New Delhi for the period 16 December 1959 to 31 March 1960 together with the total ozone amounts observed at Srinagar during the same period. To bring out clearly the increase of ozone associated with a decrease in the 500-mb height value, the ordinates of the latter have been inverted. The correspondence between the two parameters is striking, well-marked peaks of ozone being invariably associated with a drop in the 500-mb height value. (The peaks have been numbered). From the point of view of time sequence, it is of interest to note that an ozone maximum tends to coincide with the passage of a 500-mb trough rather than follow it. The New Delhi ozone values also showed some correlation but not to the same extent and these have not been shown. The additional ozone brought into the upper troposphere by the disturbances does not persist for any length of time as it is destroyed by various factors, like photochemical decomposition in presence of water vapour, dust, etc. The increase in the ozone can possibly be brought about by the two processes—

(*i*) either by the downward transport from the ozone-rich regions of the stratosphere, or,

(*ii*) by the advection of northerly winds from higher latitudes where the normal ozone content is higher (Taba 1961).

In view of the paucity of upper wind data from near Srinagar, it was not possible to check which one of the two processes is more effective in the case of western disturbances.

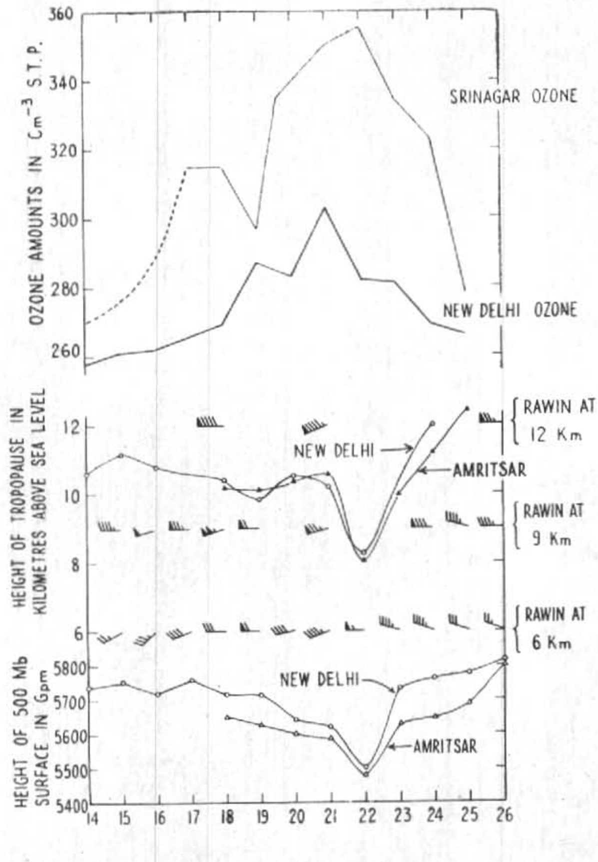

Fig. 5. Variation of ozone at Srinagar and New Delhi in association with the movement of a western depression during March 1960

However, an examination of radiowind data of Delhi revealed that sharp rises in ozone amount are not usually associated with northerly component of winds but only with a fall in the height of the tropopause. Advection by northerly winds appears to play a subordinate role only.

6. A case study of an abnormal increase of ozone at Srinagar and New Delhi

A phenomenal increase in the ozone amounts at Srinagar and New Delhi took place between 20 and 23 March 1960 in association with the movement of an active extra-tropical depression across the northern parts of the country. The peak value of ozone amouting to 355 units (cm^{-3} STP) occurred on the 22nd at Srinagar and a peak value of 303 units occurred on the 21st at New Delhi An examination of the aerological data showed that an abnormal lowering of the tropopause took place at Amritsar and New Delhi in association with the depression. The tropopause (of the extra-tropical type) came down to as low a height as 8 km on the 22nd. Fig. 5 illustrates the sequence of— (*a*) ozone amounts at Srinagar, (*b*) ozone amounts at New Delhi, (*c*) heights of the tropopause at New Delhi and Amritsar, (*d*) the heights of the 500-mb surface at New Delhi and Amritsar and (*e*) the radiowinds over New Delhi at 6, 9, and 12 km a.s.l. for the period 14 to 25 March 1960. It is seen that the occurrence of the ozone maximum coincides with the height minimum of the 500-mb surface as well as the attainment of the minimum height by the tropopause. It is also of interest to note that the ozone maximum is not associated with any northerly component of wind at New Delhi. The upper winds continued to be W or WSW until the occurrence of the ozone maximum on the 21st-22nd and the northerly component set in only later. It would, therefore, appear that in the typical example studied, advection was not responsible for the increase in the ozone associated with the disturbance. In other cases too, the same type of mechanism might be operating. The location of New Delhi is very close to the region of transition between the tropical and extra-tropical tropopauses in the winter season and the frequency of occurrence of the extra-tropical tropopause there, is over 50 per cent. Ramanathan (1954) has suggested a mechanism to account for the occurrence of an abrupt increase in the ozone amounts to the north of the sub-tropical tropopause break-line. He visualises a gradual leakage of ozone from the stratosphere to the north of the break-line to the troposphere to the south of the break-line. It is very probable that this mechanism is operative at the time of movement of western disturbances in bringing about an increase of ozone. The important use of ozone value as a tracer in studying large scale movement in the upper troposphere and the lower stratosphere will be evident from the above study.

7. Acknowledgement

The author is grateful to Prof. Dr. K. R. Ramanathan, for kindly going through the manuscript and his encouragement. He is also thankful to Shri N.R. Patole for assistance in preparing the diagrams.

REFERENCES

Dobson, G. M. B.	1930	*Proc. Roy. Soc.*, 129. A, 411.
Korandikar, R. V.	1948	*Proc. Ind. Acad. Sci.* A, 28, 63.
	1952	*Ibid.*, A, 35, 290.
Karandikar, R. V. and Ramanathan, K. R.	1949	*Ibid.*, 29, 330.
Kulkarni, R. N., Angreji, P. D. and Ramanathan, K. R.	1959	*Pap. Met. Geophys.*, Tokyo, **10**, 85.
Ramanathan, K. R. and Karandikar, R. V.	1949	*Quart. J. R. met. Soc.*, **75**, 257.
Ramanathan, K. R.	1954	*Sci. Proc. Int. Assoc. Met.*, Rome, Presidential Address.
Taba, H.	1961	*W. M. O. Tech. Note*, 36.