

55

A comparative study on the variability and trend in total ozone in the northern and southern hemispheres

V H Annes & K Mohankumar

Department of Atmospheric Sciences, Cochin University of Science and Technology, Lakeside Campus,
Fine Arts Avenue, Cochin 682 016

Received 14 October 1996; revised 24 April 1997; accepted 17 July 1997

Using a statistical regression model, annual as well as seasonal trends in zonal mean total ozone in the northern and the southern hemispheric latitudes have been studied. The study is based on total ozone data measured by total ozone mapping spectrometer (TOMS) from 1978 to 1991. In the present regression model, quasi-biennial oscillation (QBO) is removed from the data by selecting the period as 26 and 30 months respectively, depending on the strength of amplitude of QBO at higher and lower latitudes. The trend in global total ozone is found to be about -4% over the 13-year period. At higher latitudes of both hemispheres, significant decreasing trend is observed during all seasons. It is insignificant at 65°N during winter, with maximum decrease at 45°N. Near equatorial latitudes of the northern hemisphere showed a slight increasing trend and the negative trend extended to a broad area (45°-65°N) during spring. In the southern hemisphere, the depletion is found to be between 35° and 65°S from summer to autumn, and it is higher during summer compared to other seasons between 35° and 45°S. (29 ref)

1 Introduction

During the last decade, considerable amount of depletion in total ozone in the earth's atmosphere has been reported by many researchers¹⁻⁵. These studies have shown the declining trend in the total amount of ozone over the Antarctic region, especially during southern hemispheric spring season. Further, Stolarski *et al.*^{4,5} observed that there is significant negative trend in total ozone over Arctic region. A regression analysis of ozone trend based on 14 years (1978-91) of data confirmed that there is a downward trend in the extratropics of the northern hemisphere during winter and spring⁶.

It is generally accepted that heterogeneous photochemical reactions and increased man-made pollutions are chiefly responsible for the depletion of ozone. In the present paper, we have attempted a comparative study on the variability and trend in total ozone in both the hemispheres using ozone data from total ozone mapping spectrometer (TOMS). A statistical regression model is used to eliminate short- and long-term oscillations to obtain the linear trend in the data. The study has

also been extended for different seasons. The results of the present study are compared with those of the earlier studies reported in the literature.

2 Data and analysis

The daily, zonal mean total ozone data (in Dobson Units) available for a period of 158 months, extending from 1 Nov. 1978 to 31 Dec. 1991 from the total ozone mapping spectrometer (TOMS) instrument onboard NIMBUS-7 satellite for 14 latitudinal zones in the northern and the southern hemispheres have been used to obtain the monthly means for the study. The latitude zones are from 65°S to 65°N with 10° latitude intervals. Latitude zones poleward of 70° are not included because of the lack of year-round data due to the polar night. The total ozone at the equator is obtained by averaging the zonal mean data at 5°S and 5°N as done by Bowman⁷. By integrating the data from 65°S to 65°N global data is calculated.

The monthly ozone data are represented as a function of time using the following statistical regression model,

$$O_3(t) = A + Bt + C \sin(2\pi t/12) + D \cos(2\pi t/12) + E \sin(2\pi t/6) + F \cos(2\pi t/6) + G \sin(2\pi t/132) +$$

$$H \cos(2\pi t/132) + I \sin(2\pi t/t_{(QBO)}) + J \cos(2\pi t/t_{(QBO)}) \dots (1)$$

where A is the mean value, t is the time in months which varies from 1 to 158, 12 and 6 are periods of annual and semi-annual oscillations, 132 is that for the 11-year solar cycle, $t_{(QBO)}$ represents the period of quasi-biennial oscillation, and B , C , D , etc. are constants.

The quasi-biennial oscillation in total ozone has been well documented by various authors⁸⁻¹⁵. Studies show that the period of QBO in ozone varies from 27 months at the equatorial region to 20 months at higher latitudes¹⁶. This variability in QBO period makes it difficult to filter out QBO in the ozone data¹⁷. It has been proved that the inter-annual variability and trend over equatorial region is positively correlated with the equatorial dynamical QBO (Refs 7 and 18). Earlier studies using linear regression techniques selected the period of QBO as 26 months throughout the globe¹⁹⁻²¹. A recent study²² showed that the period of QBO in global as well as equatorial region is characterized with a strong 30-month period oscillation. The study further showed that at the extratropics both 20- and 30-month periods of oscillation exist.

Taking the above factors into account we used 30 months as the period of QBO [$t_{(QBO)}$] in Eq. (1) for near equatorial region and global data. An average of 26-month period is considered for other latitudinal zones. The constants A to J in Eq. (1) were obtained using the method of least squares. The time series plotted using this approach fits the data better over equatorial region compared to that obtained using 26-month QBO period. Using Eq. (1), the linear trend is retained in the time series after removing the seasonal cycles, QBO and 11-year period oscillations. The seasonal and annual mean data for various latitudinal zones and the equator are calculated.

The seasons considered in the northern hemisphere are winter (December, January, February), spring (March, April, May), summer (June, July, August), and autumn (September, October, November), and in the southern hemisphere are winter (June, July, August), spring (September, October, November), summer (December, January, February), and autumn (March, April, May). The trends in different

seasons are estimated by plotting the best fit line using the method of least squares. From the monthly mean data yearly mean values are calculated (since the data for the year 1978 are only for two months, November and December, hence this year is excluded). The major limitation of the present study is that the linear trend in total ozone is estimated based on data for a short period (13 years). Hence, the trend has been tested using the Mann-Kendall and Spearman rank statistic method²³. However, the study seems to provide indications about the nature of the ozone variations at different latitudes in the northern and the southern hemispheres during the last decade.

3 Results and discussion

The observed and predicted data for equatorial, middle and higher latitudes of both hemispheres as well as for the global data are plotted in Figs 1 and 2 respectively. From Figs 1 and 2, it is seen that the predicted curves fit well for global total ozone data and for different latitudinal zones. The TOMS data also contain El-Nino Southern Oscillation (ENSO)-type variations, but they are less apparent in the zonal mean fields⁶ and therefore not included in the model.

Annual mean values of total ozone at every 10° latitude intervals between 65°S and 65°N latitude zone of both the hemispheres for the period 1979 to 1991 are plotted (Fig. 3). The total ozone in the two hemispheres is found to have more or less the same magnitude in the tropical region. Beyond 35° latitude, the total ozone in the northern hemisphere has steadily increased and reached the maximum of the order of 370 DU at 55°-65°N latitude. In the southern hemisphere, the rate of increase with latitude is relatively lower than that of the northern hemisphere, the maximum amount of ozone attained at 55°S is of the order of 340 DU, and thereafter it decreases.

The difference in total ozone in the two hemispheres is found to be larger at 65° latitude region, of the order of 50 DU. Poleward of 55° latitude, the ozone in the northern hemisphere is found to be increasing gradually, whereas in the southern hemisphere a sharp decrease is observed.

Between 35°S and 35°N the annual trend is not significant (Fig. 4), but considerable amount of depletion is observed between 45° and 65°N and S

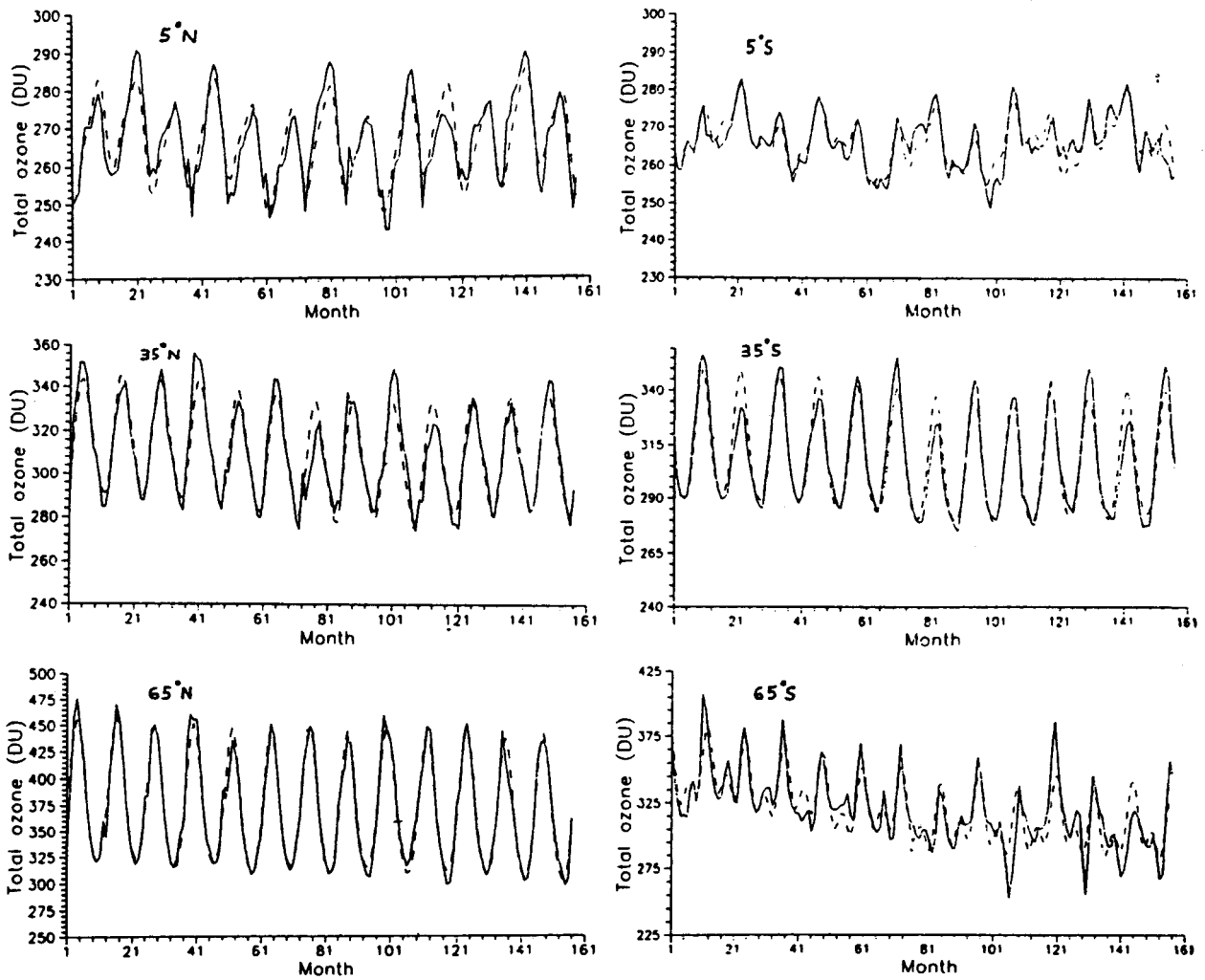


Fig. 1—Observed (solid curve) and predicted (dashed curve) total ozone for different latitudes of both hemispheres.

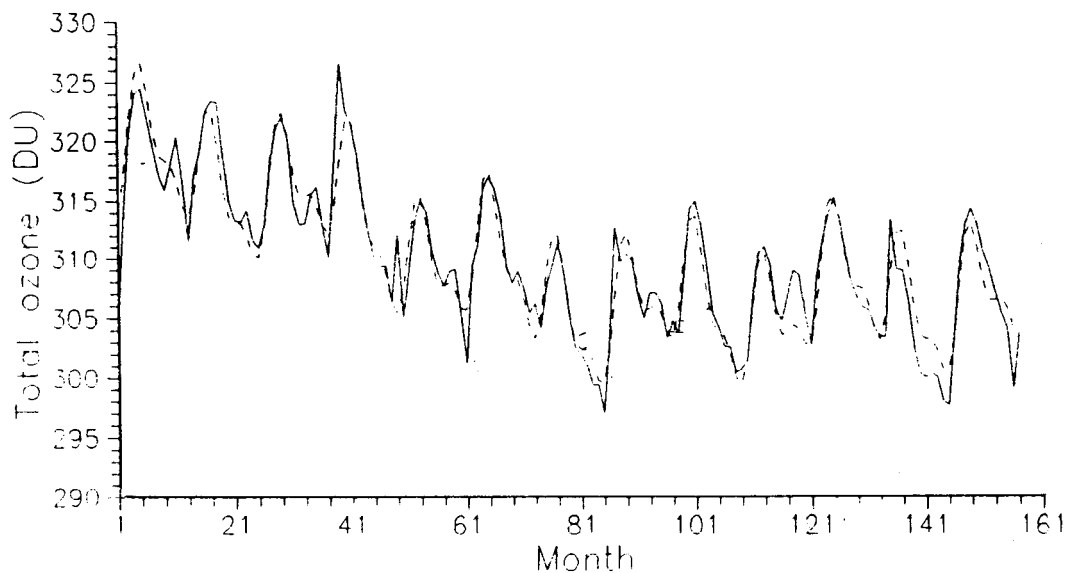


Fig. 2—Observed (solid curve) and predicted (dashed curve) global total ozone using the regression model.

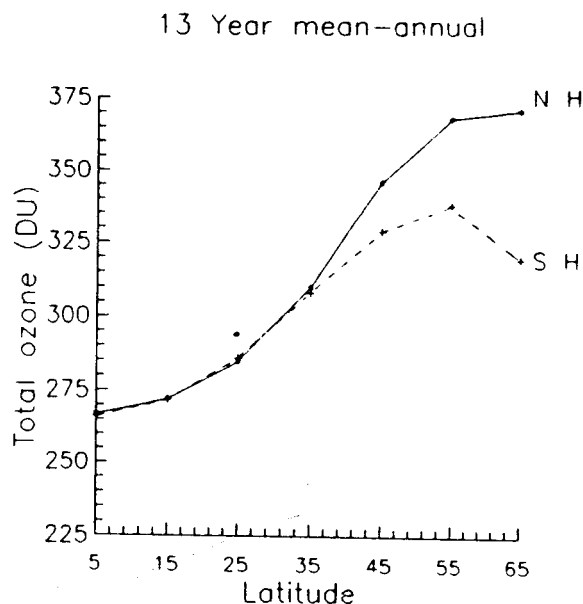


Fig. 3—Latitudinal variation in mean annual total ozone for the northern and the southern hemispheres.

regions. The trend in global total ozone obtained from the present study [term B in Eq. (1)] is about -0.965 DU per year or $-0.312\%/year$. It is comparable to the $-0.26\%/year$ trend in the 11.6 year data analysed by Stolarski *et al.*⁴ and the -0.8 DU/year trend reported by Tung and Yang²². The difference in trend in between the present study and that of Tung and Yang²² is because the latter did not remove the effect of QBO. In all seasons the total ozone at higher latitudes of the two hemispheres showed significant negative trend (Fig. 5, Tables 1 and 2). This trend extends from $35^\circ N$ to $55^\circ N$ with maximum at $45^\circ N$ during winter (Table 1), but in the southern hemisphere the trend shifts poleward and found between 45° and $65^\circ S$ latitude belt (Table 2). The highest negative trend (-4.348 DU/year) noted at $65^\circ S$ is significant at 99% level (Table 2), while the trend at $65^\circ N$ (-0.428) is insignificant (Table 1). The study by Stolarski *et al.*⁴ showed significant negative trend from 30° to $60^\circ N$ with maximum at $40^\circ N$.

A northward shift of significant trend in the northern hemisphere is observed from winter to spring, and it shrinks to 45° - $65^\circ N$ region during spring season. The trend in the southern hemisphere shifts southward and it is not significant at $45^\circ S$ compared to that at $45^\circ N$ (Tables 1 and 2). It is seen that during spring the

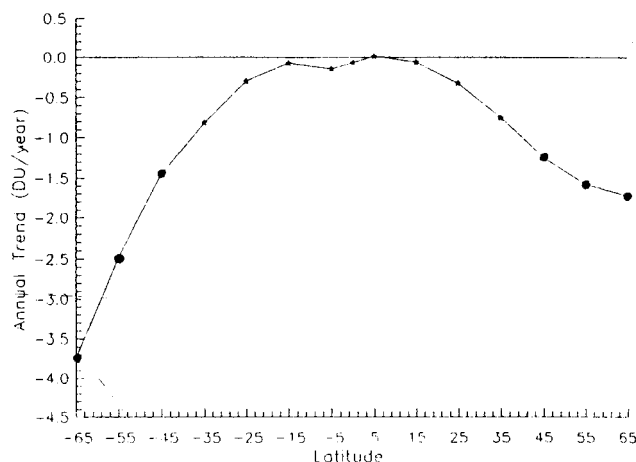


Fig. 4—Latitudinal variation of annual trend in total ozone (•, Significant at 99% level).

depletion of ozone extends to a larger area in the northern hemisphere than in the southern hemisphere.

From spring to summer and autumn the highly significant trend in the northern hemisphere is shifting further northward, while in the southward hemisphere the shifting is further to lower latitudes. In the southern hemisphere, highly significant trend is between 35° and $65^\circ S$ and it is from 55° to $65^\circ N$ in the northern hemisphere during summer and autumn. The present study shows considerable depletion in total ozone in the northern hemisphere during autumn, especially in the 55° - $65^\circ N$ zonal belt.

Solomon *et al.*² and Stolarski *et al.*³ observed that the spring time ozone depletion over Antarctic region is due to heterogeneous photochemical reactions associated with chloroflouro carbons (CFCs) and other pollutants which are transported into the stratosphere from the lower atmosphere. The significant negative trend in total ozone during spring in the northern hemisphere extends to middle and higher latitudes (45° - $65^\circ N$). This suggests that ozone destruction due to photochemical reactions affects extensive area of the northern hemisphere also.

In the lower stratosphere the transporting mechanism is a combination of quasi-horizontal eddy mixing and vertical advection caused by diabatic heating²⁴. Recent studies propose many reasons for the observed middle latitude trend outside the polar vortex of the northern and the

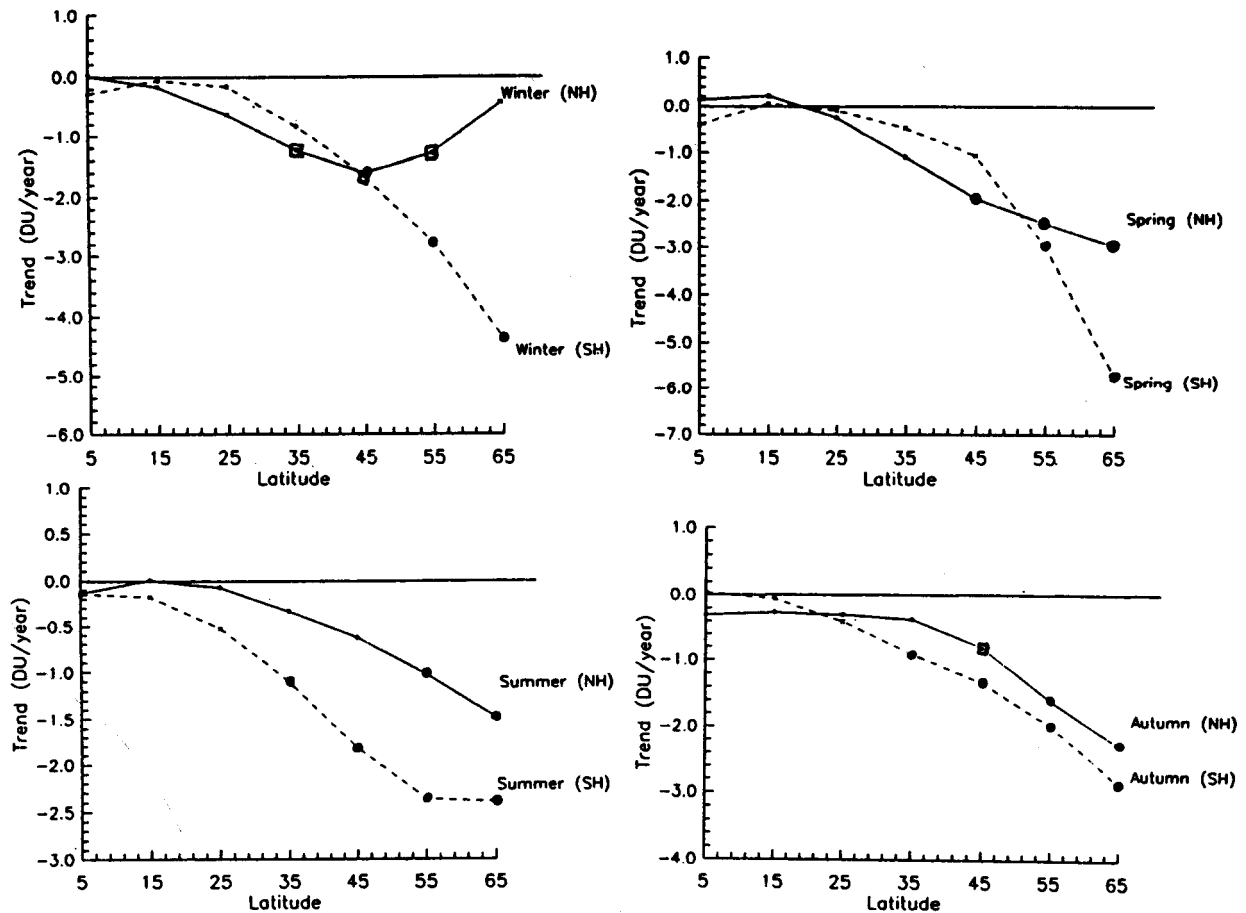


Fig. 5—Seasonal and spatial variation in total ozone trend (●, Significant at 99% level; □, Significant at 95% level).

Table 1—Linear trend in annual and seasonal total ozone in the northern hemisphere

Latitude deg	Ozone trend (DU/year)				
	Winter (D, J, F)	Spring (M, A, M)	Summer (J, J, A)	Autumn (S, O, N)	Annual
5	+0.010	+0.134	−0.135	−0.304	+0.014 (+0.005)
15	−0.167	+0.209	+0.004	−0.259	−0.056 (−0.021)
25	−0.640	−0.253	−0.074	−0.289	−0.315 (−0.111)
35	−1.235 [†]	−1.092	−0.331	−0.361	−0.751 (−0.247)
45	−1.612*	−1.950*	−0.626	−0.798 [†]	−1.243* (−0.359)
55	−1.279 [†]	−2.481*	−1.022*	−1.589*	−1.582* (−0.429)
65	−0.428	−2.964*	−1.478*	−2.266*	−1.736* (−0.467)

*Significant at 99% and 95% levels

[†]Significant at 95% level only

Note: Values in brackets are trends in %/year

Table 2—Linear trend in annual and seasonal total ozone in the southern hemisphere

Latitude deg	Ozone trend (DU/year)				
	Winter (J, J, A)	Spring (S, O, N)	Summer (D, J, F)	Autumn (M, A, M)	Annual
5	-0.286	-0.397	-0.144	+0.031	-0.137 (-0.052)
15	-0.063	+0.044	-0.175	-0.052	-0.065 (-0.024)
25	-0.166	-0.094	-0.524	-0.398	-0.293 (-0.102)
35	-0.831	-0.475	-1.103*	-0.898*	-0.812 (-0.264)
45	-1.656†	-1.070	-1.817*	-1.324*	-1.442* (-0.439)
55	-2.765*	-2.956*	-2.362*	-1.967*	-2.475* (-0.733)
65	-4.348*	-5.716*	-2.392*	-2.864*	-3.739* (-1.171)

*Significant at 99% and 95% levels

†Significant at 95% level only

Note: Values in brackets are trends in %/year.

southern hemispheres. The possible causes are: transport of chemically processed polar vortex air associated with polar stratospheric clouds (PSCs) and their outward flow to middle latitudes²⁵⁻²⁸, *in situ* depletion due to chemically processed air, etc. In the present study, it is observed that significant depletion takes place in the northern and the southern hemispheres throughout the year. From the calculated cross-vortex exchange rate, Randel and Wu²⁹ conclude that the possibility of transport of chemically processed air out of the vortex is less. Since the present study shows year-round depletion in TOMS data in the southern as well as in the northern hemispheres, these processes may be responsible for the large negative trend throughout the year. The quasi-horizontal eddy mixing by waves play important role in the distribution of ozone²⁵. An intense wave activity in the northern hemispheric winter can transport ozone into the polar vortex. This can be one of the reasons for the insignificant trend noted beyond the 55°N latitude zone during winter.

4 Conclusions

The comparative study of the total ozone trend

using the regression model for different latitudes shows that throughout the year ozone is decreasing in the northern and the southern hemispheres. All the tropical latitudes showed insignificant trend with a positive trend at 5°N. It is found that the negative trend between 35° and 45°S is higher in summer, compared to other three seasons. The global trend in total ozone is found to be -0.312%/year. In the northern hemisphere, winter trend is more at middle latitudes and is maximum at 45°N. At 65°N the trend is statistically not significant. This is attributed to the ozone transport by planetary waves, which increase the ozone content inside the vortex. The significant trend in the northern hemisphere shifts toward north from winter to spring and autumn. Significant trend extends up to 35°N in winter. A southward shift of highly significant trend is noted in the southern hemisphere from winter to spring and equatorward from spring to summer and autumn. The possible cause of the middle latitude trend during winter may be due to the flow of chemically processed and less ozone-containing air out of the polar vortex or processes which take place at the middle latitudes.

Acknowledgement

One of the authors (VHA) would like to thank the Council of Scientific and Industrial Research (CSIR), New Delhi, for providing Research Fellowship to him.

References

- 1 Farman J C, Gardiner B G & Shantklin J D, *Nature (UK)*, 315 (1985) 207.
- 2 Solomon S, Garcia R R, Rowland F S & Wuebbles D J, *Nature (UK)*, 321 (1986) 755.
- 3 Stolarski R S, Krueger A J, Schoeberl M R, McPeters R D, Newman P A & Alpert J C, *Nature (UK)*, 322 (1986) 808.
- 4 Stolarski R S, Bloomfield P, McPeters R D & Herman J R, *Geophys Res Lett (USA)*, 18 (1991) 1015.
- 5 Stolarski R S, Bojkov R, Bishop L, Zerefos C, Staehelin J & Zawodny J, *Science (USA)*, 256 (1992) 342.
- 6 Randel W J & Cobb J B, *J Geophys Res (USA)*, 99 (1994) 5433.
- 7 Bowman K P, *J Atmos Sci (USA)*, 46 (1989) 3328.
- 8 Funk J P & Garnham G L, *Nature (UK)*, 14 (1962) 378.
- 9 Ramanathan K R, *Q J R Meteorol Soc (UK)*, 89 (1963) 540.
- 10 Angell J K & Korshover J, *J Atmos Sci (USA)*, 21 (1964) 479.
- 11 Angell J K & Korshover J, *Mon Weather Rev (USA)*, 101 (1973) 426.
- 12 Oltmans S J & London J, *J Geophys Res (USA)*, 87 (1982) 8981.
- 13 Hasebe F, *J Meteorol Soc Jpn (Japan)*, 58 (1980) 104.
- 14 Hasebe F, *J Geophys Res (USA)*, 88 (1983) 6819.
- 15 Wilcox R W, Nastrom G D & Belmont A D, *J Appl Meteorol (USA)*, 16 (1977) 290.
- 16 Hilsenrath E & Schlesinger B M, *J Geophys Res (USA)*, 86 (1981) 12087.
- 17 Chandra S, *J Geophys Res (USA)*, 89 (1984) 1373.
- 18 Grey L J & Dunkerton T J, *J Atmos Sci (USA)*, 47 (1990) 2429.
- 19 Keating G M, Lake L R, Nicholson III J Y & Natarajan M, *J Geophys Res (USA)*, 86 (1981) 9873.
- 20 Reber C A & Huang F T, *J Geophys Res (USA)*, 87 (1982) 1313.
- 21 Kundu N & Jain M, *Geophys Res Lett (USA)*, 20 (1993) 2881.
- 22 Tung K K & Yang H, *J Atmos Sci (USA)*, 51 (1994) 2699.
- 23 World Meteorological Organization, *Technical Note, No. 79* (1966).
- 24 Mahlman J D, Levy II H & Moxim W J, *J Atmos Sci (USA)*, 37 (1980) 655.
- 25 Atkinson R J, Matthews W A, Newman P A & Plumb R A, *Nature (UK)*, 340 (1989) 290.
- 26 Prather M J, Garcia M M, Suenzo R & Rind D, *J Geophys Res (USA)*, 95 (1990) 3449.
- 27 Webster C R, May R D, Toohey D W, Avallone L M, Anderson J G, Newman P, Lait L, Schoeberl M R, Elkins J W & Chan K R, *Science (USA)*, 261 (1993) 1130.
- 28 Mahlman J D, Pinto J P & Umscheid L J, *J Atmos Sci (USA)*, 51 (1994) 489.
- 29 Randel W J & Wu F, *Geophys Res Lett (USA)*, 22 (1995) 683.