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RELATIONSHIP OF THE ANTARCTIC OZONE HOLE WITH INDIA AND OTHER REGIONS IN THE NORTHERN AND SOUTHERN HEMISPHERES AS DETERMINED FROM DOBSON DATA

R. P. Kane

A study of the monthly values of total ozone in the Indian region indicated long-term trends generally less than 5% in 13 years (1977-1989) and solar cycle effects also less than 5% (solar maximum to solar minimum). The quasibiennial oscillation (QBO) was at times as large as 10%. Simultaneously with the Antarctic ozone depletion of ~45% in October 1987, the Indian region showed 10-15% depletions in November and December 1987. Depletions were observed at other latitudes and longitudes also. However, the percentage depletions in low latitudes seem to be smaller than those at middle latitudes in both Southern and Northern Hemispheres. The changes observed in the Northern Hemisphere at high latitudes are most probably not related to the Antarctic ozone depletion but are, instead, caused by winter planetary waves. However, low latitudes, even in the Northern Hemisphere may have some effect of the Antarctic ozone hole.

Key words: Antarctic; Stratospheric ozone.

RELACIONAMENTO DO BURACO DE OZÔNIO DA ANTÁRTICA COM A ÍNDIA E OUTRAS REGIÕES NOS HEMISFÉRIOS NORTE E SUL, OBSERVADO EM DADOS DOBSON *Um estudo dos valores mensais de ozônio total na região indiana indicou tendências de longo prazo menores do que 5% em 13 anos (1977-1989) e efeitos do ciclo solar também menores do que 5% (máximo solar a mínimo solar). A Oscilação Quase-bienal (QBO) foi, por vezes, de até 10%. Simultâneamente com a depleção de ozônio na Antártica de ~45% em outubro de 1987, a região indiana mostra depleções de 10-15% em novembro e dezembro de 1987. Também foram observadas depleções em outras latitudes e longitudes. Entretanto, os percentuais de depleções em baixas latitudes parecem ser menores do que aqueles em latitudes médias em ambos os Hemisférios, Sul e Norte. As variações observadas no Hemisfério Norte em latitudes altas não são relacionadas à depleção de ozônio na Antártica, mas são causadas por ondas planetárias de inverno. Baixas latitudes, até no Hemisfério Norte, podem ter algum efeito do buraco de ozônio da Antártica.*

Palavras-chave: Antártica; Ozônio estratosférico.

Instituto Nacional de Pesquisas Espaciais
Caixa Postal 515 - 12201/970 - So José dos Campos, SP, Brasil

INTRODUCTION

The ozone level in the Antarctic stratosphere has been decreasing since 1976 (Farman et al., 1985). At Halley Bay (76°S, 27°W), the October values decreased from ~300 D.U. in 1976 to ~200 D.U. in 1985. Similar changes were reported for Syowa (69°S, 39°E) and for South Pole (Chubachi and Kajiwara, 1986; Komhyr et al., 1986; Bojkov, 1986a,b). Measurements by the polar orbitting Nimbus satellite showed similar decreases (Stolarski et al., 1986) in the Antarctic region and the depletion was mostly confined to 0-30°W longitudes (Chandra & McPeters, 1986). Sahai et al. (1987) showed that the depletion did not seem to extend to lower latitudes in the South American region. In October 1986, the ozone level recovered to ~15-30% above the October 1985 level. However, in October 1987, there was severe depletion again and the Antarctic ozone level dropped below the October 1985 level.

The cause of the Antarctic ozone depletion seems now to be well-established, viz. halogen chemistry (Anderson et al., 1991). Regarding the extension of the Antarctic ozone "hole" to lower latitudes, a three-dimensional chemical transport model for the stratosphere with linearized chemistry (Prather & Jaffe, 1990; Prather et al., 1990) indicated that measurable decreases (exceeding 1%) should be observable up to 30°S in austral summer. Satellite observations did show a detectable decline in column ozone throughout the year from the Antarctic as far as 50°S (Krueger et al., 1988). From ground-based Dobson spectrophotometers, Atkinson et al. (1989) reported that during Dec. 7-15, 1987, the ozone level in Australia and New Zealand decreased by several tens of D.U. (~30%) and the satellite TOMS data for the corresponding period showed that the decrease extended up to ~30°S. In a recent communication (Kane, 1991), it was shown from monthly values that the ~45% Antarctic ozone depletion in October 1987 (compared to October 1977) had a corresponding decrease of ~10% at Buenos Aires (35°S, 59°W) and only ~(1-2)% at Cachoeira Paulista (23°S, 45°W), Natal (6°S, 35°W) and Huancayo (12°S, 75°W) in the South American region. When data for individual days in October, November, December 1987 were examined, all these South American low latitude locations showed decreases from October to December. But a large part of these decreases was due to normal seasonal variations and, allowing for the same, the net decrease was almost zero at all these locations except at Huancayo, where a net residual depletion of ~5% was seen during December 1987. Incidentally, the depletions in the Australian region were also partly due to normal seasonal variations, so that the net residual depletions were only ~10% at Melbourne (37°S, 145°E) and ~5% at Perth (32°S, 116°E) in the latter half of December 1987 and very small at Brisbane (27°S, 153°E).

The International Ozone Trends Panel Report (UNEP-WMO, 1989) concluded that the Dobson data in tropics, subtropics and Southern Hemisphere were not adequate to determine trends. Since then, Bojkov et al. (1988) compared ground-based Dobson data with TOMS Nimbus 7 satellite data and identified more than 20 stations having excess variability and another dozen having long-term drifts and/or sudden changes. Bojkov et al. (1990) presented a trend analysis for revised Dobson data; but stations in India were not considered, probably because these data were considered unreliable. WMO (1991) & Stolarski et al. (1992) reported trend analysis for several individual locations. But, from India, only data for Ahmedabad were used. In this communication, we examine in detail the ozone level in the Indian region (10°N-35°N, 74°E-83°E) and compare the results with those at other latitudes and longitudes, and check whether the Indian data are really unreliable.

MONTHLY MEAN OZONE FROM 1977 TO 1989

Fig. 1 shows a plot of monthly mean values of total ozone at the Antarctic locations (a) South Pole and (b) Syowa and for the Indian locations (c) Kodaikanal, (d) Poona, (e) Varanasi (f) New Delhi and (g) Srinagar in the northern hemisphere. For the Antarctic locations, the spring (Sept.-Oct.) values dropped steadily from 1977 to 1984, more rapidly in 1985, partly recovering in 1986, decreasing largely in 1987, recovering considerably in 1988 and dropping again in 1989. For the Indian locations, there is a seasonal variation of ~(10-15)% range with maxima in late spring and summer and minima in winter. However, neither the maxima nor the minima seem to indicate a steady decline, except a noticeably low value for December 1987. To bring out the trends in monthly values more clearly, Fig. 2 shows a plot of monthly values separately (Jan., Feb. etc.) for total ozone at Srinager. The top curve (dashes) shows the annual sunspot numbers. To estimate the linear trend and sunspot cycle effect simultaneously, a multiple regression analysis was carried out using a formulation of the type:

$$y = A_0 + A_1 x + A_2 z + \text{Error}$$

where y = ozone, A_0 = constant base level of ozone, x = years, z = sunspot number, A_1 = ozone change per year, A_2 = ozone change per sunspot. In Fig. 2, the percentage linear changes in 13 years given by ($1300\ A_1/A_0$) are indicated for every month. These are also listed in Table 1 where the percentage solar cycle effects for a sunspot range 142 (maximum 155 in 1979, minimum 13 in 1986) obtained as (14200 A2/Ao) are also listed. In addition, estimates of the *maximum* QBO (Quasibiennial oscillation, percentage change from peak to trough) after correcting for long-term trend

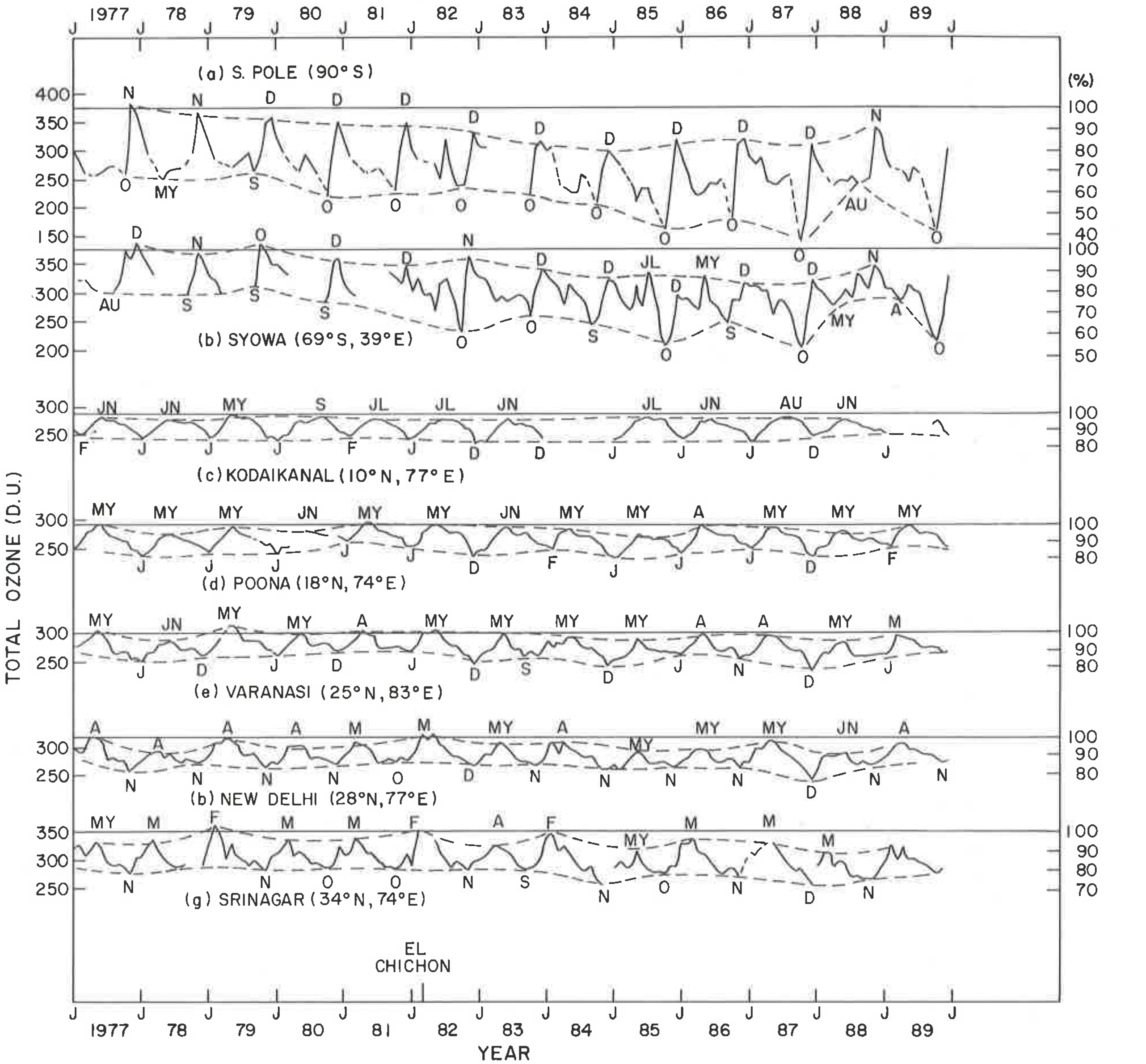

Figure 1- Plots of the monthly values of total ozone from 1977 to 1989 for (a) South Pole, (b) Syowa in the Antarctic region and the Indian stations (c) Kodaikanal, (d) Poona, (e)Varanasi, (f) New Delhi and (g) Srinagar. J = January, F = February, M = March, A = April, MY = May, JN = June, JL = July, AU = August, S = September, O = October, N = November, D = December. The right side vertical scale shows ozone variations as percentages of the 1977-78 level.

***Figura 1**- Gráfico de valores mensais de ozônio total de 1977 a 1989 para (a) Pólo Sul, (b) Syowa na região da Antártica e para as estações da Índia, (c) Kodaikanal, (d)Poona, (e)Varanasi, (f)Nova Delhi e (g)Srinagar. J = Janeiro, F = Fevereiro, M = Março, A = Abril, MY = Maio, JN = Junho, JL = Julho, AU = Agosto, S = Setembro, O = Outubro, N = Novembro, D = Dezembro. A escala vertical do lado direito mostra as variações de ozônio em percentagem em comparação com o nível durante 1977-78.*

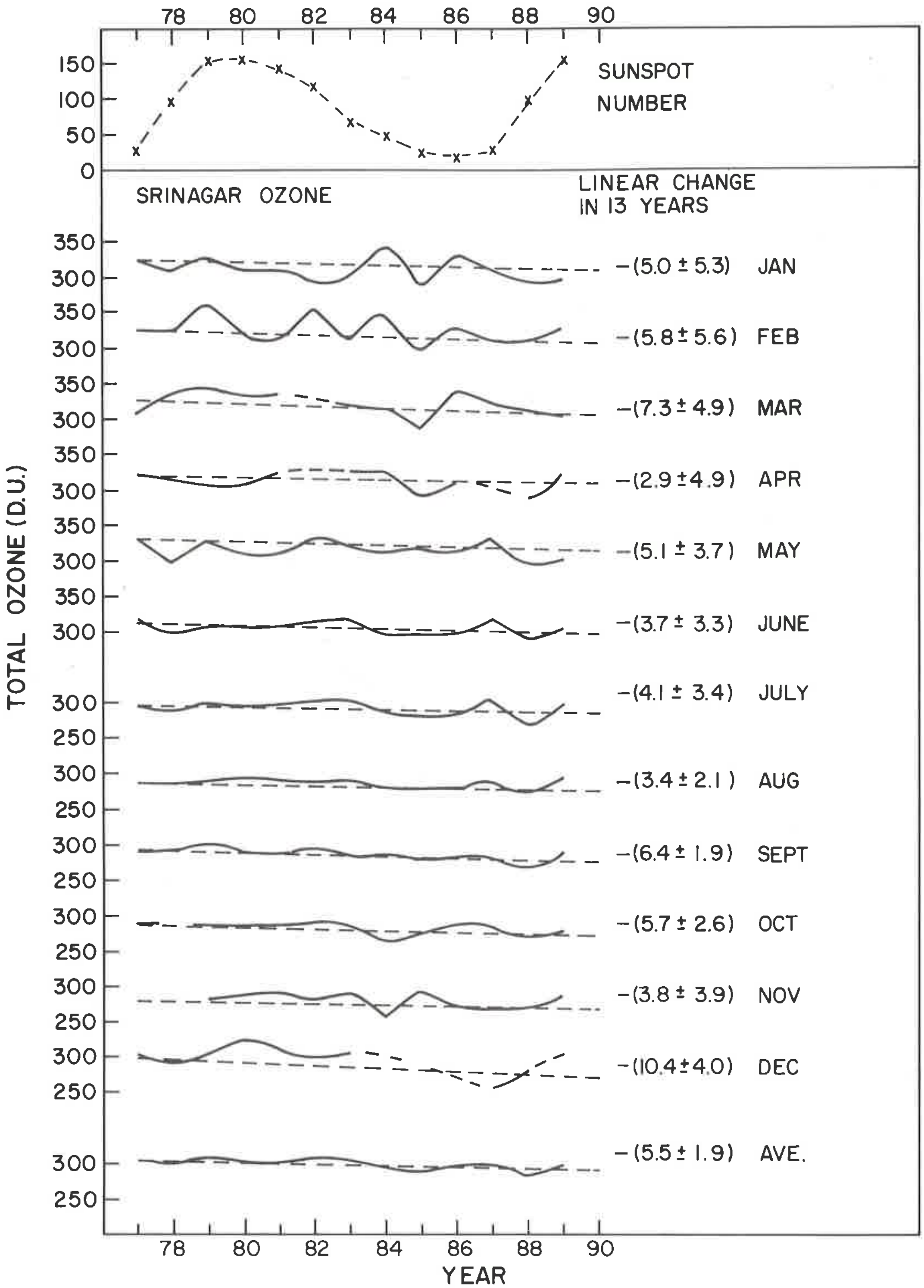

Figure 2 - Plots for 1977-89 for annual sunspot numbers (top plot) and monthly mean values of ozone at Srinagar, India, for different months and for the yearly average (bottom plot). The dashed lines represent the long-term linear trends and the numbers indicate percentage change in 13 years (1977-89).

Figura 2- *Gráfico para o período de 1977-89 do número de manchas solares anuais (superior) e médias mensais e anuais de ozônio em Srinagar, Índia, para meses diferentes e médias anuais (gráfico inferior). As linhas quebradas representam a longa duração e os números indicam mudanças em percentagem em 13 anos (1977-89).*

and solar cycle effects are also given in Table 1. As can be seen, the linear trends show in 13 years ~1-3% decline for Kodaikanal and Poona, ~1-5% decline for Varanasi and N. Delhi and ~3-10% decline for Srinagar, though the December values for Srinagar are often missing. Also, statistical errors are large. Table 2 lists the *decadal* trends during 1977-89 for the Indian stations for winter (Dec.-March), summer (May-August) and for whole year. For comparison, similar values obtained by WMO (1991) and by Stolarski et al. (1992) for Ahmedabad and for the tropical region (30°N-14°S) are also given. For Srinagar (34°N), the trends are significantly negative and the values (-3 to -5%) are comparable to those of some of the mid latitude stations in Europe. At New Delhi and Varanasi, the trends are slightly negative (-2%), but not statistically significant at a 2σ level. At locations near equator, the trends are almost zero, in agreement with WMO (1991) and Stolarski et al. (1992). Thus, the Indian data may not be as unreliable as WMO assumed and seem to show trends appropriate to their latitudes. The total solar cycle effect is small (less than ~5% for a 142 sunspot range). The QBO range is highly variable. QBO seems to be present in some years and almost absent in some other years but can be occasionally as large as 10%. The *average* values would be in the range 1-5%, same as those reported by Zerefos et al. (1992) for low to high latitudes.

Month	Total linear Change (%) During 1977-89					Solar Cycle Effect (%) (Peak to trough, 142 sunspots)					QBO effect (%) Peak to through				
	Srinagar	N. Delhi	Varanasi	Poona	Kodaikanal	Srinagar	N. Delhi	Varanasi	Poona	Kodaikanal	Srinagar	N. Delhi	Varanasi	Poona	Kodaikanal
	(13 years)	(13 years)	(13 years)	(13 years)	(13 years)										
Jan	-(5.0±5.3)	-(5.0±3.3)	-(3.5±4.0)	+(3.0±3.5)	-(1.5±2.7)	+(3.1±4.2)	+(0.7±2.6)	+(0.7±3.1)	-(3.2±2.6)	-(1.2±2.0)	12	8	12	5	3
Feb	-(5.8±5.0)	-(3.7±4.3)	-(4.0±3.0)	-(1.6±2.9)	+(0.9±1.8)	-(4.6±4.3)	-(3.3±3.3)	-(1.3±2.3)	-(2.6±2.2)	-(2.3±1.4)	12	12	8	5	3
Mar	-(7.3±4.9)	-(2.3±4.1)	-(1.3±4.7)	+(0.7±4.7)	-(0.7±1.5)	-(4.8±3.8)	-(7.4±3.1)	-(4.6±3.6)	-(0.9±3.6)	-(1.3±1.1)	10	12	10	10	5
Apr	-(2.9±4.9)	-(4.2±3.0)	-(2.1±3.0)	+(2.8±4.1)	+(2.3±1.9)	-(0.5±3.8)	-(2.0±2.8)	-(3.1±2.7)	-(0.1±3.1)	-(2.1±1.4)	8	10	10	10	5
May	-(5.1±3.7)	-(3.2±3.5)	-(4.7±2.7)	+(0.7±3.1)	-(0.8±1.2)	+(3.2±2.8)	+(0.3±2.9)	-(0.8±2.0)	-(1.0±2.3)	-(1.0±0.9)	8	8	8	4	3
June	-(3.7±3.3)	-(2.6±2.6)	-(3.7±1.9)	-(0.6±2.4)	-(0.5±0.9)	-(0.3±2.5)	-(1.4±2.0)	-(2.6±1.4)	-(1.3±1.9)	+(0.6±0.7)	7	5	5	3	2
July	-(4.1±3.4)	+(1.6±3.1)	-(2.3±2.3)	-(1.5±1.7)	-(3.3±1.4)	-(1.9±2.6)	-(2.4±2.4)	-(2.3±1.8)	-(1.2±1.3)	-(0.5±1.1)	7	8	5	3	3
Aug	-(3.4±2.1)	-(0.1±2.4)	-(2.2±2.2)	-(0.4±1.7)	-(2.5±1.4)	-(3.2±1.6)	-(2.1±1.9)	-(2.9±1.7)	-(1.8±1.3)	-(0.5±1.1)	5	5	5	3	4
Sept	-(6.4±1.9)	+(0.4±1.5)	-(1.2±2.4)	+(1.0±2.2)	-(2.2±1.9)	-(1.9±1.4)	-(2.5±1.2)	-(4.7±1.9)	-(1.0±1.7)	-(0.1±1.5)	5	4	5	3	4
Oct	-(5.7±2.6)	-(1.5±1.0)	-(2.5±2.0)	+(2.4±1.7)	+(0.1±1.9)	-(0.5±2.0)	-(0.7±0.8)	-(3.1±1.5)	-(2.0±1.3)	-(0.6±1.5)	8	3	3	3	5
Nov	-(3.8±3.9)	+(0.6±2.0)	-(1.4±2.0)	+(0.5±3.2)	-(1.3±1.9)	-(4.0±3.0)	-(3.9±1.5)	-(5.5±1.5)	-(6.0±2.4)	+(0.8±1.4)	10	6	4	8	7
Dec	-(10.4±4.0)	-(1.1±3.5)	-(1.8±4.4)	-(1.7±4.2)	-(1.2±2.6)	-(10.0±3.1)	-(4.9±2.7)	-(5.8±3.3)	-(3.8±3.3)	+(1.4±2.0)	8	8	10	8	7
Annual	-(5.5±1.9)	-(1.7±1.8)	-(2.7±1.7)	+(0.5±1.9)	-(0.8±0.6)	-(1.9±1.4)	-(2.4±1.4)	-(2.9±1.3)	-(1.9±1.5)	-(0.6±0.5)	5	5	5	3	3

Table 1 - Estimates of percentage linear trends during (1977-89), percentage solar cycle effects (peak to trough, 142 sunspots) and percentage QBO (peak to trough, largest value, not average value) at various locations for different months and for the annual averages.

Tabela 1 - *Estimativas de percentagens de deriva linear durante (1977-89), percentagens de efeito de ciclo solar (pico a mínima, 142 manchas solares) e percentagem de QBO (pico a mínima, valores máximo, valor não médio) em vários locais para os meses diferentes e para médias anuais.*

Ozone Decadal trends in India (1977-89)

	Lat.	Dec.-March	May-August	Year-round
Srinagar	34°N	-5.5±2.5	-3.2±1.7	-4.3±1.5
New Delhi	28°N	-1.9±2.0	-0.8±1.5	-1.3±1.4
Varanasi	25°N	-2.0±2.0	-2.5±1.2	-2.1±1.3
Ahmedabad	23°N	-0.3±2.4	-2.3±1.5	
Poona	18°N	+0.1±2.0	-0.4±1.0	+0.4±1.5
Kodaikanal	10°N	-0.5±2.2	-1.0±0.6	-0.6±0.5
Average (WMO, 1991)	30°N to 14°S	+0.1	+0.2	-

Table 2 - Ozone decadal trends in India (1977-89).

Tabela 2 - *Deriva de dez anos de ozônio na Índia (1977-89).*

OZONE VARIATIONS DURING OCT.-DEC. 1987

To study the specific effect of the ozone hole in the Antarctic during Oct.-Dec. 1987, Fig. 3 shows a plot of daily values of total ozone. As shown in the bottom part, the ozone level in October dropped to ~150 D.U. in the Antarctic region and remained low almost up to the middle of November. Whereas South Pole shows almost steady levels, Syowa shows large variations indicating that the ozone hole did not extend up to Syowa all the time. By November end, recovery started and was complete by mid-December. For the Indian locations, the full triangles (joined by dashes) represent the pre-ozone-hole seasonal variations obtained as average monthly values for about 7 years prior to 1985. The standard deviation of these means is about the height of the triangles ($\sigma = \pm 2\%$). The thick lines represent 5-day averages. As can be seen, all locations except Kodaikanal show large depressions (5-10%) in mid-November and all locations show large depressions (5-15%) in the first half of December for Kodaikanal and Poona and in almost whole of December for the other locations, even after allowing for the seasonal variations. This result is very surprising indeed as these magnitudes for these locations in the Northern Hemisphere are larger than those for Australian locations in the Southern Hemisphere shown in Fig. 4 where depressions are seen in early November also. Here again, as also in Figs. 5, 6, 7, the standard deviations of the means are equal to the height of the triangles ($\sigma = \pm 2\%$). For Australia and New Zealand, Atkinson et al. (1989) reported a decrease of several tens of D.U. (~30%) during Dec. 11-12, 1987. As can be seen from Fig. 4, a large part of the 30% decrease in December is due to the 20% seasonal variation (full triangle), leaving, thus, only a few percent as probable ozone hole effect. However, Atkinson et al. (1989) confirmed this decrease from TOMS data, which showed that the effect could extend up to 30°S and also conducted a trajectory analysis. Our Fig. 3 shows similar depressions, but with larger negative magnitudes and it is tempting to claim that the Antarctic ozone hole effect extended right up to Srinagar. However, this result needs to be considered with great caution. Firstly, these fluctuations could be natural variations driven by *winter* planetary waves (one could not raise the same doubt for Fig. 4 as there, Oct.-Dec. are *summer* months!). Secondly, as seen in Fig. 1, even *before* the Antarctic ozone hole, i.e. in 1979-1982, the Nov., Dec., Jan. values at the Indian locations are low, almost two months after the natural austral spring (Sept. Oct.) low in the Antarctic. Thus, this may be indicative of a natural dynamic relationship between the two, unconnected with the Antarctic ozone hole that developed in later years. Thus, whereas the relationship between the Nov. Dec. 1987 depressions at Indian locations and the 1987 Antarctic ozone hole could be because of other reasons, a probable relationship with Antarctic ozone hole should be considered as an open question, to be studied further in more details.

Fig. 5 shows similar plots for several other low latitude stations in the *Northern* Hemisphere. The right-hand scale is percentage (100% = October level). Station names are above the 100% line and geographic coordinates are below the 100% line. In the far-eastern sector, Manila (14°N), Naha (26°N) and Kagoshima (31°N) show depressions of ~10% in late November, but Tateno (36°N) does not show any similar depression. On the other hand, Kagoshima shows another depression of ~10% by December end and Tateno also shows a similar depression. If it is assumed that isolated parcels of ozone-poor air from the Antarctic moved slowly northwards and extended up to middle latitudes in the north in the far-eastern sector, these parcels seem to have missed Singapore (1°N, 140°E). However, it may as well be that all these are driven by winter planetary waves and are unrelated to Antarctic ozone hole.

In Fig. 5, the sixth plot is for Quetta, Pakistan (30°N, 67°E), at a latitude similar to New Delhi, India but about 10° west. A small depression of ~8% is seen at the end of December at Quetta. If the effect is due to ozone-poor air parcels, the air parcel passing over India did not extend much westward in Pakistan. This is also indicated by the plots of Mahe (4°S, 55°E) (top plot in Fig. 10), where no depressions are seen. Again, all these could be planetary wave phenomena.

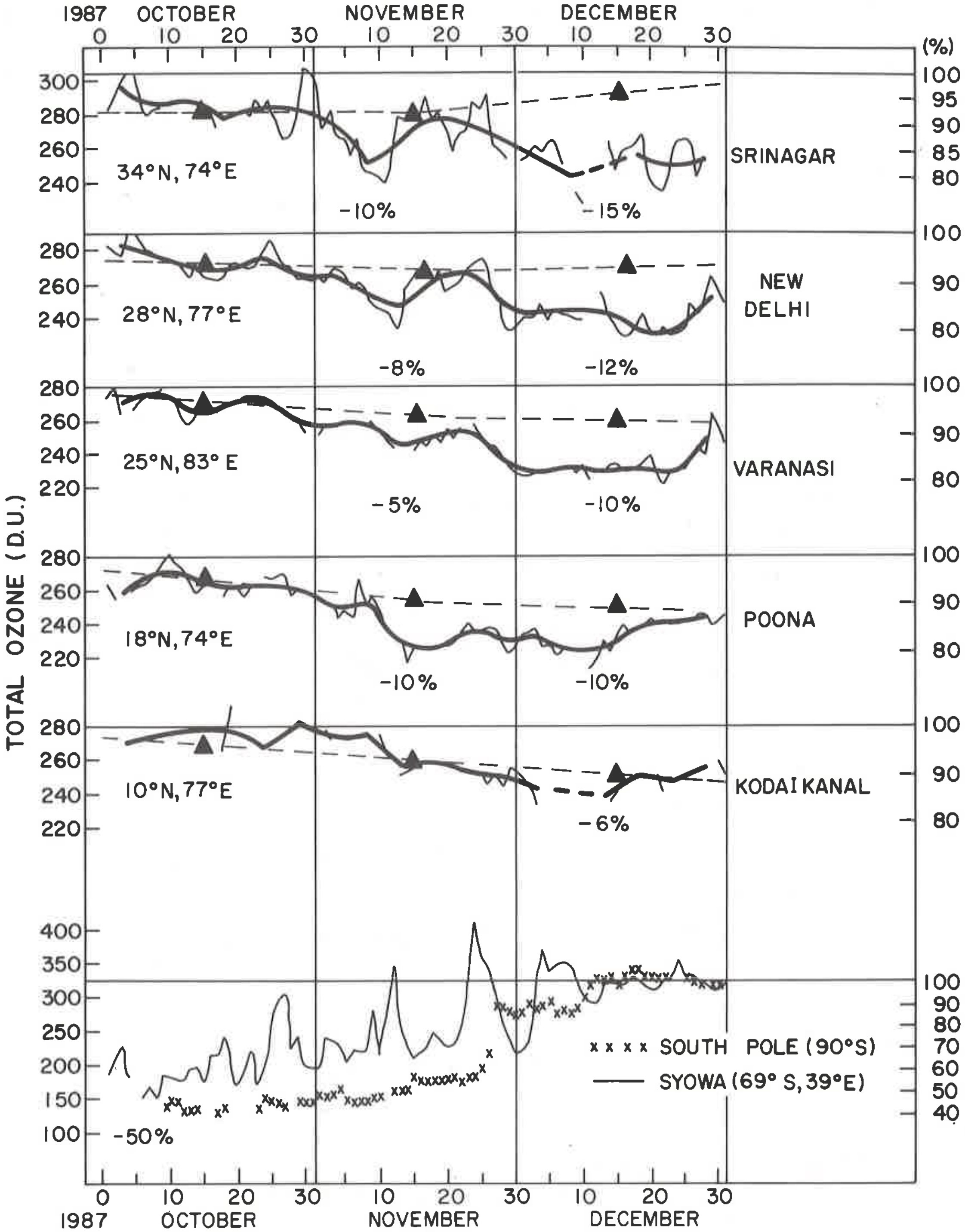

Figure 3 - Plots of daily values of total ozone for the 3 months October, November, December, 1987 for Srinagar, New Delhi, Varanasi, Poona and Kodaikanal in India and South Pole (crosses) and Syowa (full lines) in the Antarctic. The thick lines represent 5-day averages. The triangles joined by dashed lines represent average values for October, November and December, obtained from data for about 7 years prior to 1985.

***Figura 3** - Gráfico de valores diários de ozônio total para os três meses de outubro, novembro e dezembro de 1987 para Srinagar, Nova Delhi, Varanasi, Poona e Kodaikanal na Índia e Pólo Sul (cruzes) e Syowa (linha inteira) na Antártica. As linhas grossas representam médias de cinco dias. Os triângulos ligados com as linhas quebradas representam valores das médias para outubro, novembro e dezembro obtidos de dados de sete anos antes de 1985.*

In Fig. 5, the plots for middle-east (Cairo and Aswan) show no large depressions, only small depressions of ~5% in late November. At Mexico City (19°N, 99°W), data are insufficient, but no depression is indicated. At Mauna Loa (20°N, 156°W), a depression of ~8% by December end is indicated. If these are Antarctic ozone hole effects, great longitudinal differences would be indicated. More likely, these would be different planetary wave effects.

Fig. 6 shows similar plots for *low* latitude stations in the *Southern* Hemisphere. No depressions are seen at Mahe, St. Helena, Natal, Cachoeira Paulista, very little (~3%) at Buenos Aires, ~5% at Huancayo and ~8% at Samoa, all in the end of December 1987. Samoa shows an additional depression (~5%) in November end. These results are consistent with the assumption that Antarctic ozone holes would not extend to very low latitudes!

Fig. 7 shows plots for *some middle and high* latitude locations in the *Northern* Hemisphere, farthest away from the Antarctic. Surprisingly, many locations show depressions of ~(5-10%) in mid-November and mid-December. Some show

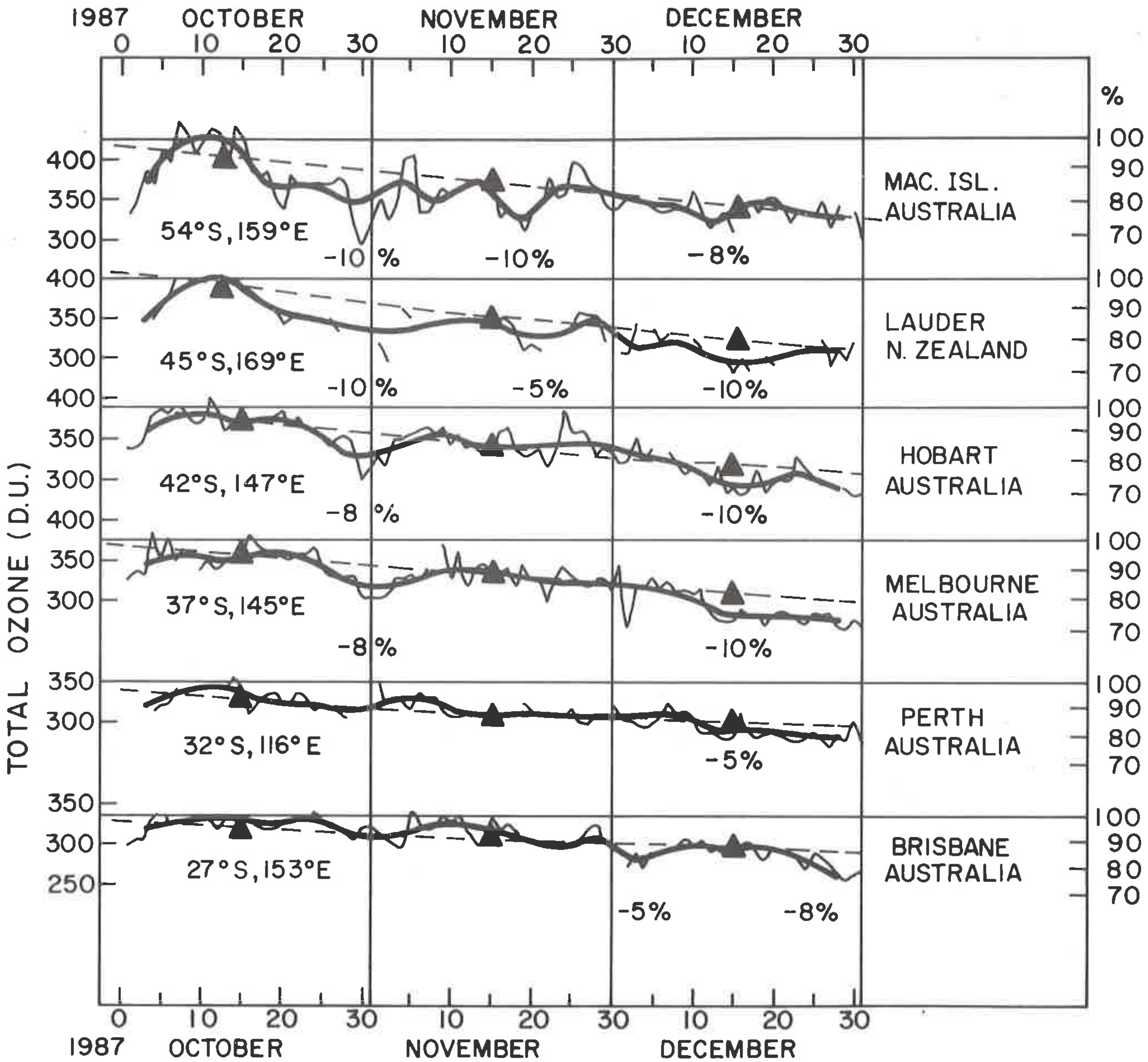

Figure 4 - Same as Fig. 3, for locations in the *far-eastern sector* in the Southern Hemisphere (Australia and New Zealand).

***Figura 4** - Mesmo que na Fig. 3, para os locais no setor bem a leste do Hemisfério Sul (Austrália e Nova Zelândia).*

depressions even in mid-October (e.g. Cagliari, Bismarck). These could not possibly be related to the Antarctic ozone hole as some occur in October, too early for the ozone hole to spread up to the Northern Hemisphere. Also, most of the plots have wavy structures with periods of ~(10-30 days), which could be a natural routine behaviour for these latitudes and would show depressions as well as increases relative to the mean seasonal change (full triangles joined by dashed lines). To examine this aspect in detail, it would be necessary to study the behaviour before and after the ozone hole

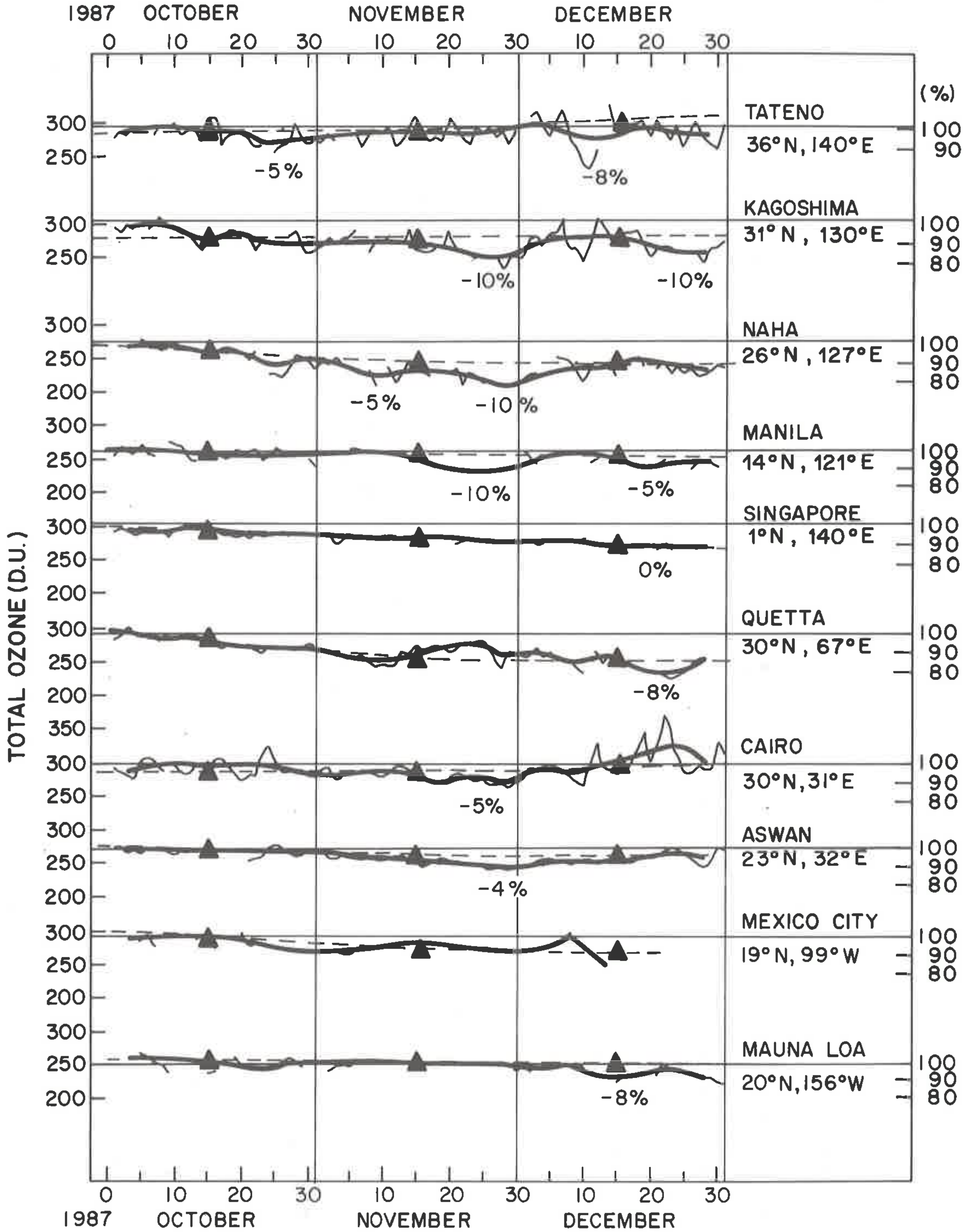

Figure 5 - Same as Fig. 3, for locations in the *Northern* Hemisphere *low* latitudes (0-36°) in various longitudes.

Figura 5 *- Como na Fig. 3, para locais de baixas latitudes do Hemisfério Norte (0-36°) em várias longitudes.*

interval, i.e. before October and after December. The next section shows the results of such a study.

OZONE VARIATIONS BEFORE AND AFTER OCTOBER-DECEMBER 1987

Fig. 8 shows plots of daily values of total ozone for a few selected locations during August-September, 1987. In the left half, the top plot is for Syowa (Antarctic) and shows that a first depression started by about September 15. No other location shows any depressions at this time, except Bismarck (46°N, 15°E) and Edmonton (53°N, 113°E), which show depressions of ~10%, far beyond statistical errors. It is unlikely that the Antarctic depression could have reached these locations (if at all) so early. We conclude, therefore, that depressions of this type at high northern latitudes should be due to other causes, probably winter planetary waves.

Fig. 9 shows plots for January-February, 1988. In the top plot of the left half, Syowa shows recovery from the

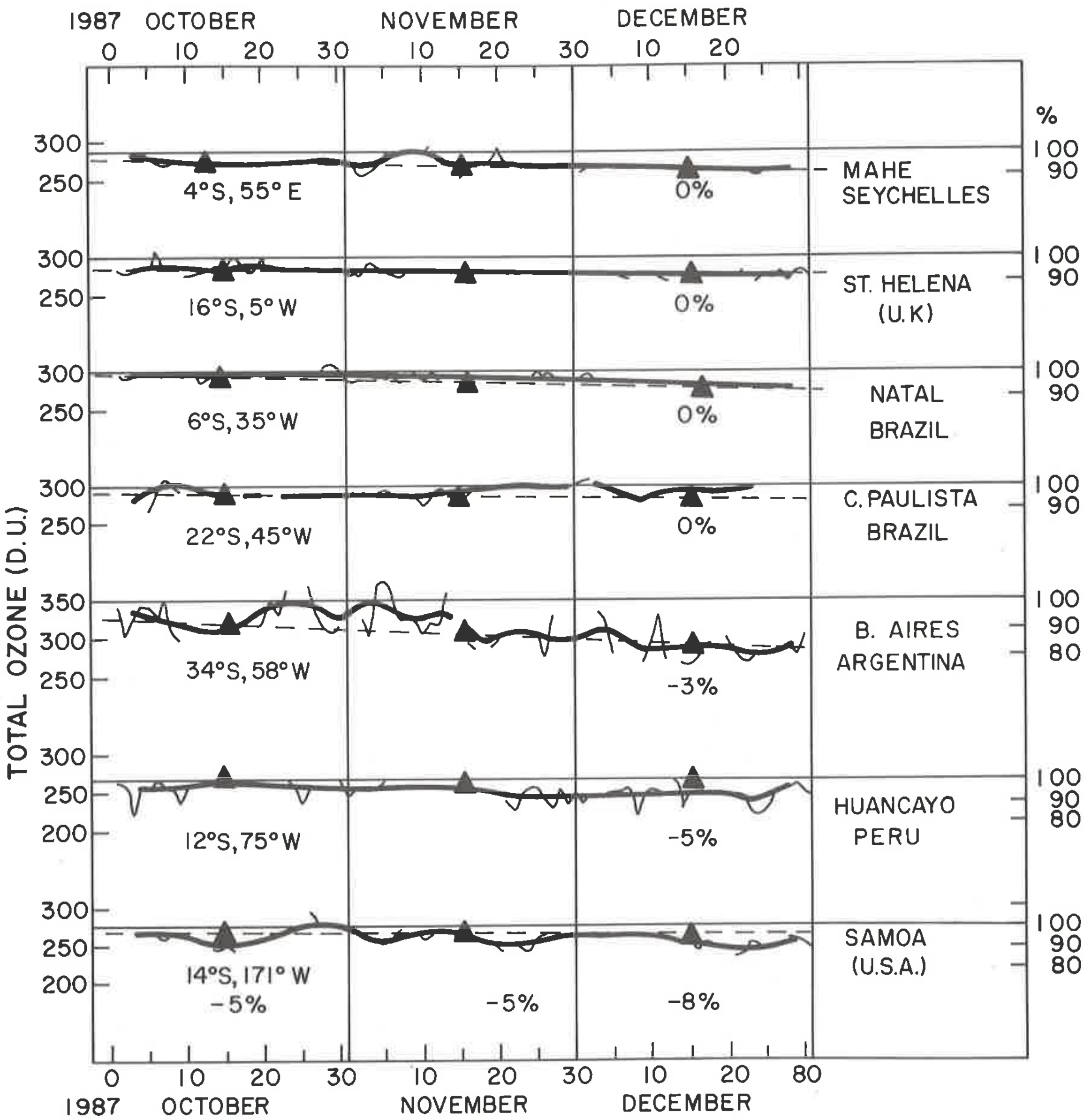

Figure 6 - Same as Fig. 3, for locations in the *Southern* Hemisphere *low* latitudes (0-34°) in various longitudes.

Figura 6 *- Como na Fig. 3, para locais de baixas latitudes do hemisfério sul (0-34°) em várias longitudes.*

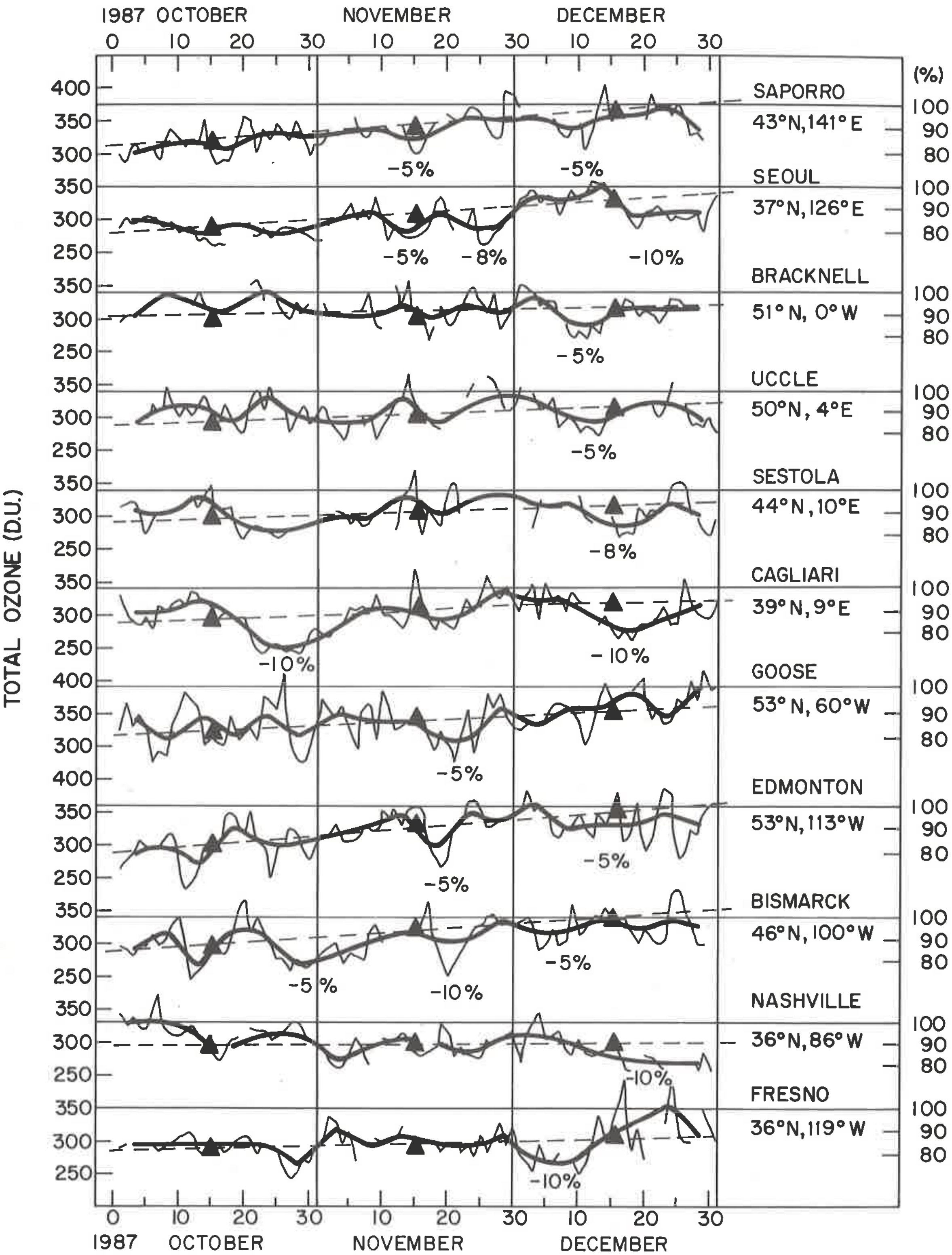

Figure 7 - Same as Fig. 3, for locations in the Northern Hemisphere middle and high latitudes in various longitudes.

Figura 7 - *Como na Fig. 3, para locais de médias e altas latitudes do Hemisfério Norte em várias longitudes.*

ozone hole in January but a fresh depression seems to have occurred by January end (~10%) and a large depression by February end (~15%). At Bismarck and Edmonton, very large oscillations are seen, ~10-20%, far beyond statistical errors. The magnitudes are larger than those seen for these locations in October-December, 1987. Obviously, all these large oscillations (15-50%) could not be due to ozone-poor air parcels arriving all the way from the Antarctic and must be due to strong, local effects. In Europe (Cagliari) and middle east (Cairo, Aswan) also, oscillations are seen, with depressions in January end. In view of the quiet levels seen in Fig. 8 (prior to ozone hole), it is tempting to attribute the variations in Fig. 9 to a delayed effect of the October ozone hole. But the magnitudes are too large and relationship with Antarctic ozone hole should be ruled out at least for high latitudes. In the Indian region, Kodaikanal, Poona, Varanasi show quiet levels, while New Delhi shows depressions (~10%) in late January and early February. Tateno also shows depressions (~10%) in mid-January and mid-February. Singapore and Perth show quiet levels. In all these plots, an interesting feature is that the *percentage changes are smaller near the equator* and larger at middle latitudes, even in the northern hemisphere. This by itself probably indicates that the Antarctic ozone hole effects peter out much before reaching the equator. However, we want to keep the possibility open that oscillations seen at *low* latitudes in the northern hemisphere could be due to local causes such as winter planetary waves, as also partly due to changes in the Antarctic.

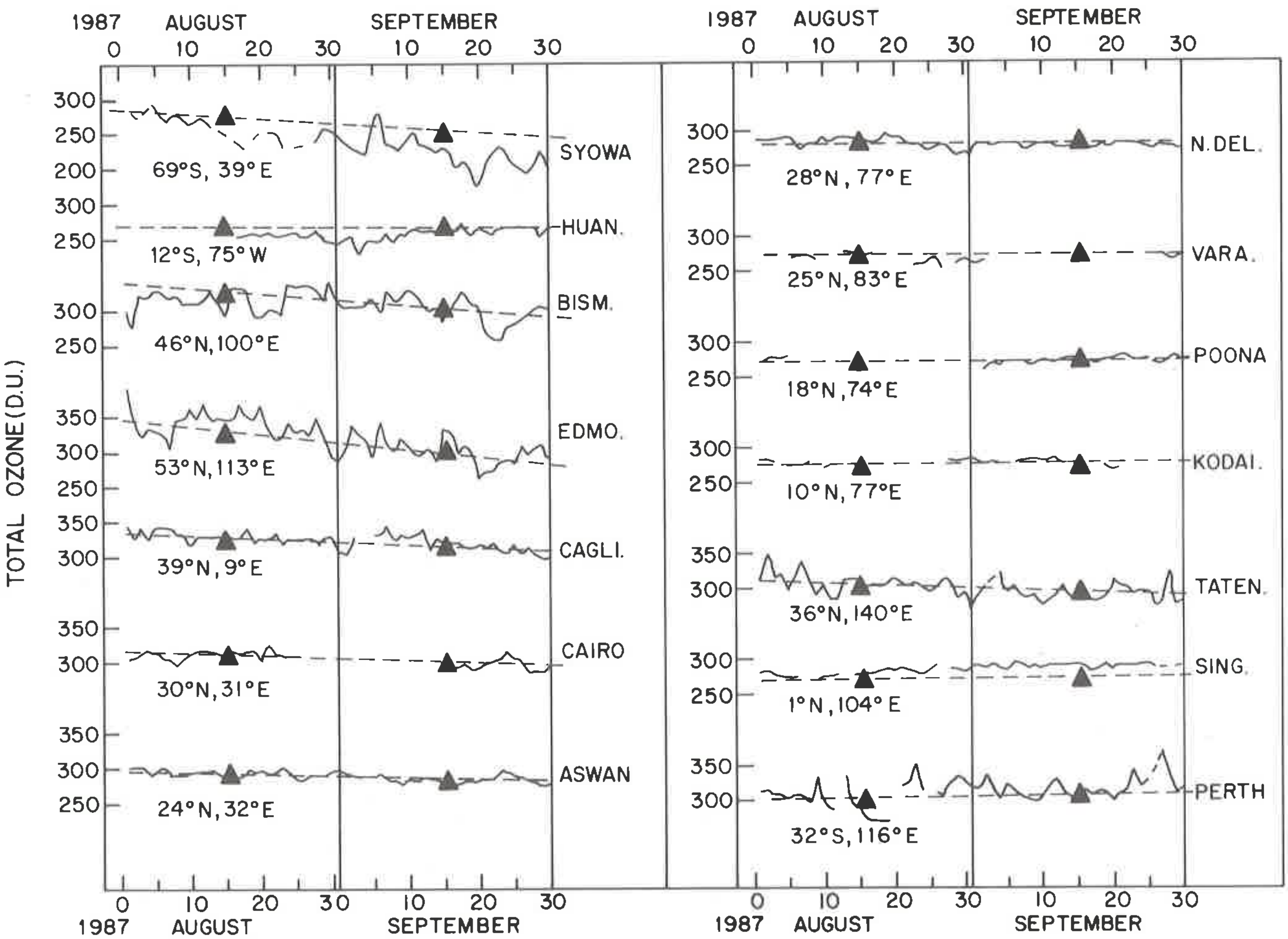

Figure 8 - Plots of daily values of total ozone for August and September, 1987 for a few selected stations. The triangles joined by dashed lines represent average values obtained from data for 7 previous years.

Figura 8 - *Gráfico de valores diários de ozônio total para agosto e setembro de 1987 para algumas estações selecionadas. Os triângulos ligados com as linhas quebradas representam valores médios obtidos de dados dos sete anos anteriores.*

CONCLUSIONS

(1) For the Indian region (10°N-35°N, 74°E-83°E), a study of the monthly mean column ozone values showed that for low latitudes, the long-term linear trends over 13 years (1977-1989) were generally small (less than 5%, for some months very much less). The solar cycle effects, i.e. decreases of ozone from solar maximum to solar minimum were also small, 5% or less. This is in rough agreement with the assessment report of Watson et al. (1988), and subsequent WMO (1991) report. The Quasibiennial oscillation (QBO), though not always present, could be occasionally as large as ~10%.

(2) The 45% Antarctic ozone depletion in October 1987 seems to have spread to lower latitudes and it is tempting to speculate that it penetrated even in the Northern Hemisphere, with different velocities and intensity in different longitudes. The Indian region showed large depletions (10-15%) in November and December 1987. At other longitudes also, depletions were noticed up to 30°N and even beyond in some cases. However, the percentage depletions were smaller at or near equator and larger on both sides (northern and southern). This by itself probably indicates that the Northern Hemisphere oscillations may have an altogether different origin, e.g. winter planetary waves. However, we want to leave the possibility open that, at least for low latitudes, the effect of the Antarctic ozone hole may reach the Northern Hemisphere. This needs further detailed investigation, specially using satellite data.

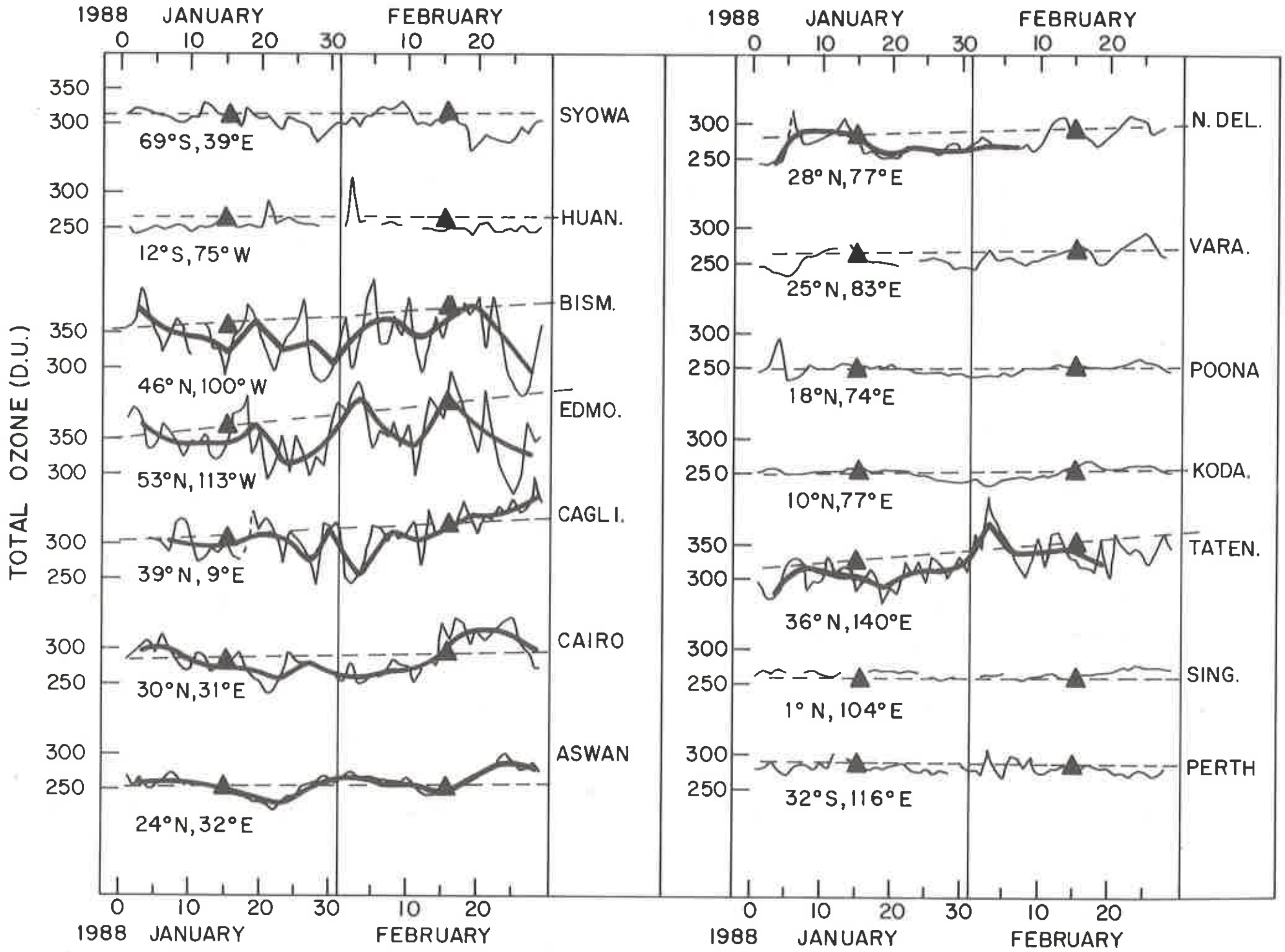

Figure 9 - Plots of daily values of total ozone for January, February, 1988 for a few selected stations. The full lines represent 4-day averages. The triangles joined by dashed lines represent average values obtained from data for 7 previous years.

Figura 9 - Gráfico de valores diários de ozônio total para janeiro, fevereiro de 1988 para as estações selecionadas. As linhas inteiras representam médias de quatro dias. Os triângulos ligados com as linhas quebradas representam valores obtidos de dados dos sete anos anteriores.

Model predictions by Prather and Jaffe, (1990) and Prather et al. (1990) envisage distinct parcels of ozone-poor air spreading from the Antarctic region out to low latitudes, when the final stratospheric warming starts and the southern circumpolar vortex breaks (Bojkov, 1986b). However the spread extends to only about 40°S during austral summer (Dec. Jan.) and, one year later, only 30% of the original depletion remains, mostly poleward of 30°S. Thus, penetration into the Northern Hemisphere would seem to be ruled out. However, this needs further scrutiny.

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