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NOTA BREVE DE PESQUISA

SHORT RESEARCH NOTE

TRENDS IN THE STRATOSPHERE - A RE-ASSESSMENT (A NOTE)

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A re-examination of the data of Labitzke & van Loon (Adv. Space Res. 11, (3)21-(3)30, 1991) indicates that the geopotential heights and temperatures in the stratosphere for the last 25 years show distinct trends when 4-point running averages and 11-yearly running averages are examined. Trends are somewhat different at different altitudes and for different seasons and latitudes. In general, geopotential heights show downtrends up to 1975 and an upward trend from 1975 onwards up to date. Temperatures show a negligible or downward trend up to 1975, an upward trend during 1975-79, and a downward trend from 1979 up to date i.e. reverse to that of surface air temperature.

Key words: Stratosphere; Geopotential heights; Stratospheric temperatures.

TENDÊNCIAS NA ESTRATOSFERA - UMA REAVALIAÇÃO (BREVE NOTA) - *O reexame dos dados de Labitzke & Van Loon (Adv. Space Res. 11, (3):21-30, 1991) indica que as alturas do geopotencial e as temperaturas na estratosfera, nos últimos 25 anos, mostram tendências distintas, em termos de médias corridas de quatro pontos e de onze anos.As tendências são um tanto que discrepantes em diversas altitudes e para diferentes estações do ano e latitudes. Em geral, as alturas do geopotencial mostram tendências decrescentes até 1975 e crescentes a partir desta data. As temperaturas mostram uma tendência desprezízel ou decrescente até 1975, uma tendência ascendente no período 1975-1979, e uma tendência decrescente a partir de 1979, ou seja, o reverso do que ocorre com a temperatura do ar na superfície.*

Palavras-chave: *Estratosfera; Alturas do geopotencial; Temperaturas estratosféricas.*

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INTRODUCTION

Many stratospheric parameters exhibit a strong Quasi-Biennial Oscillation (QBO). When this is eliminated by evaluating running averages, some of the resulting series show solar cycle variations (10-12 years). In Kane (1992), it was shown that the 30mb stratospheric temperatures at the North Pole during winter months (November-February) showed an association with sunspot cycle. When further running averages over 11 consecutive years were evaluated, the resulting values for November-December showed a decline of about -3°C from 1962 to 1984 (22 years), yielding a negative trend of about 1.4K/decade, considerably larger than the earlier estimate of about -0.03K/decade at 80°N, reported by Labitzke et al. (1986). For January, there was a constant level from 1964 to 1976 and a drop of about 4°C thereafter. For February, there was no significant change. Thus, clear downward trends in some winter months were indicated.

Recently, Labitzke & van Loon (1991) reported in their article's Abstract that they could not find "an unambiguous, pervasive trend in the geopotential heights and temperatures of the 25 years when reliable daily analyses of the lower stratosphere were possible". This seems to be in contradiction with our results for the North Pole stratospheric temperatures. However, in their text, those authors have mentioned that for the area-weighted (10°N-90°N) mean temperatures for October-November, "there is an undeniable downward trend during the 25 years at 50, 30 and 10 mbar, but no trend at 100 mbar". Thus, some trends in some parameters for some seasons do seem to be indicated.

In this note, we examine their data for trends and compare with the North Pole results.

DATA AND ANALYSIS

Data were read from the various figures in Labitzke & van Loon (1991) and some were kindly supplied to us by Dr. Labitzke.

Let us examine the temperature values for October/November. Fig. 1(a) shows the plots for 10, 30, 50 and 100 mb temperatures, zonally averaged for the latitude belt 20°N-50°N, as given in Fig. 7 of Labitzke & van Loon (1991). As can be seen, there are large QBOs. In their analysis, these authors have obtained and illustrated 3-year running averages for some parameters. However, this procedure is not sufficient to eliminate the QBO; because, two-year oscillations (alternate year ups and downs) still persist. Hence, we evaluated further running averages over two successive values. In Fig. 1(a) the thick lines represent such averages. (Effectively, it is like applying a 4-point filter with weights 1, 2, 2, 1). In general, there are distinct downward trends at 10, 30, 50mb but virtually no trend at 100mb. However, the trends are not uniform. For 10mb, there was a sharper fall during 1970-78. For 30mb and 50mb, there was a fall during 1965-78 and an oscillatory level thereafter. Near 1982, all plots show an increase, probably due to the El Chichon volcanic eruption of 1982, marked with a triangle. The bottom curve shows sunspot activity which does not seem to be related with the temperature changes, though relationship with solar activity has been suggested earlier by Labitzke (1987), Labitzke & Chanin (1988) and Labitzke & van Loon (1988; 1989). Nevertheless, to minimize the 11-year solar cycle effects,

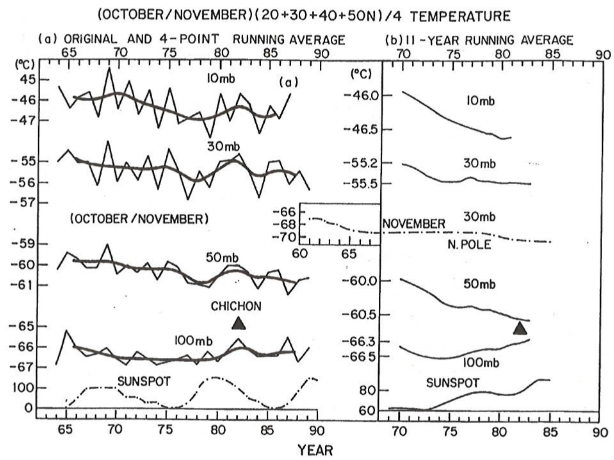

Figure 1 - October/November temperatures (Labitzke & van Loon, 1991, Fig. 7) for latitudes (20°+30°+40°+50°N)/4: (a) original values and 4-point running averages; (b) 11-year running averages. The middle plot is for North Pole 30mb temperatures for November (dashed line). The bottom plots are for sunspots. The triangle indicates El Chichon volcanic eruption of 1982.

Figura 1 - *Temperaturas em Outubro/Novembro para latitudes 20°+ 30°+40°+50°N/4 (Labitzke & Van Loon, 1991) : (a) valores originais e médias corridas de 4 pontos; (b) médias corridas de onze anos. A curva do meio é para temperaturas (30 mb) de novembro (linha tracejada) no Polo Norte; as curvas inferiores são para manchas solares; os triângulos indicam a erupção vulcânica de El Chicon de 1982.*

further running averages over 11 successive yearly values were obtained. These are shown in Fig. 1(b). As can be seen, the downward trends are now clearly seen for 10, 30, 50mb temperatures; but the magnitudes and natures are different. For 10 and 50mb, the trends are almost linear with gradients of about -0.5 K/decade. For 30mb, there was a sharp fall of about 0.3° from 1970 to 1974 (4 years only) and a steady level thereafter. However, all these are "undeniable downward trends" as mentioned by Labitzke & van Loon (1991) and thus, there is no difference of opinion. For 100mb, the trend is mixed viz. a fall of about 0.2° from 1970 to 1974 and a rise of about 0.3° from 1974 to 1983. For both 30mb and 100mb, there seems to be a transition (trend change) near 1973-75. It is interesting to note that the 11-year running averages of the sunspot numbers (Fig. 1b, bottom plot) are not constant. There is a slightly rising trend from 1973 onwards. Thus, 11-year averages do not necessarily guarantee that all solar cycle effects would be eliminated.

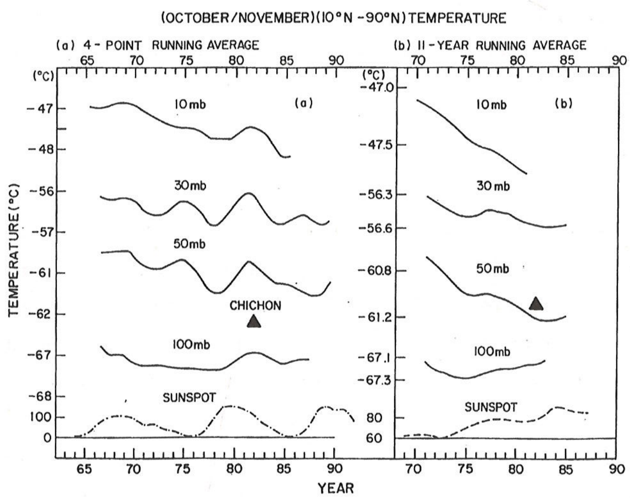

Figure 2 - October/November area-weighted mean temperatures (Labitzke & van Loon, 1991, Fig. 8) for latitudes 10°N-90°N: (a) 4-point running averages; (b) 11-year running averages. Bottom plots are for sunspots. Triangle indicates El Chichon eruption of 1982.

Figura 2 - *Temperaturas médias ponderadas (área) em Outubro/Novembro para latitudes 10° - 90° N (Fig. 8 de Labitzke & Van Loon, 1991) : (a) médias corridas de 4 pontos; (b) médias corridas de onze anos. As curvas inferiores referem-se às manchas solares. Os triângulos indicam a erupção vulcânica de El Chicon de 1982.*

For North Pole, we had data for 30mb for Nov. Dec. Jan. Feb. Mar. Apr. only. In Fig. 1(b), the middle plot (dashed curve) is for N. Pole 30mb temperatures (11-year running averages) for November only. As can be seen, there was a drop of about 2° from 1962 to 1966 (4 years), an almost constant level from 1966 to 1978 and a fall of about 1.5° from 1978 to 1985. Overall, there was a downtrend of about 3.5° in 25 years yielding a gradient of about 1.4°/decade, much larger than the gradient for the (20°N-50°N) stratospheric region. Naujokat (1981) mentioned that the stratospheric trends are not necessarily the same in all latitude belts. Labitzke & van Loon (1991) have also given the plots for October/November for a wider area viz. whole area north of 10° (i.e. 10°N-90°N) for 10, 30, 50 and 100mb. These are reproduced in our Fig. 2. Fig. 2(a) shows the 4-point running averages. El Chichon effect for 1982 is probably there. But 30 and 50mb plots indicate a possible 5-6 year periodicity. Fig. 2(b) shows the 11-year running averages and the characteristics are the same as for Fig. 1(b), with roughly similar gradients.

These results refer to October/November only and, as remarked by Labitzke & van Loon (1991), are not representative of other months or of the whole year. Let us examine now the results for all months for the 30mb geopotential heights. Fig. 3(a) shows the plots for two-month means (JF, MA, MJ, JA, SO, ND) as also the annual means. As mentioned by Labitzke & van Loon (1991), the most dominant effect is the 10-12 year wave, almost parallel to the solar cycle, which had a maximum in 1979-80 while the geopotential heights are maximum a year or two later, probably coinciding with the El Chichon eruption of 1982. Fig. 3(b) shows the 11-year running averages. As can be seen, there are clear upward trends in all months, though the gradients are different (larger) in the summer months. Again, the trends are not always uniform. There is a tendency of negligible or downward trend from 1970 up to about 1975 and a rising trend thereafter up to date. Since the 11-year running averages of sunspot number also show a steady level up to about 1973 and a rising tendency thereafter, it would be tempting to associate the two. Labitzke & van Loon (1991), though in general sceptical about detecting a long-term trend when such a strong solar cycle effect is involved, have noted this peculiar structure and have offered an explanation in terms of a possible association with the annual mean surface air temperature over the Northern Hemisphere (Jones et al., 1986; Hansen & Lebedeff, 1988) which showed a downward trend from

1938 to 1976 and a rise thereafter. In Fig. 3(a) and (b), the crosses on the annual curves show the surface air temperature variation and the two seem to be parallel. Thus, the rising trend in the 11-year average from 1972 to 1983 could be due to increase in surface temperature as well as increase in sunspot number.

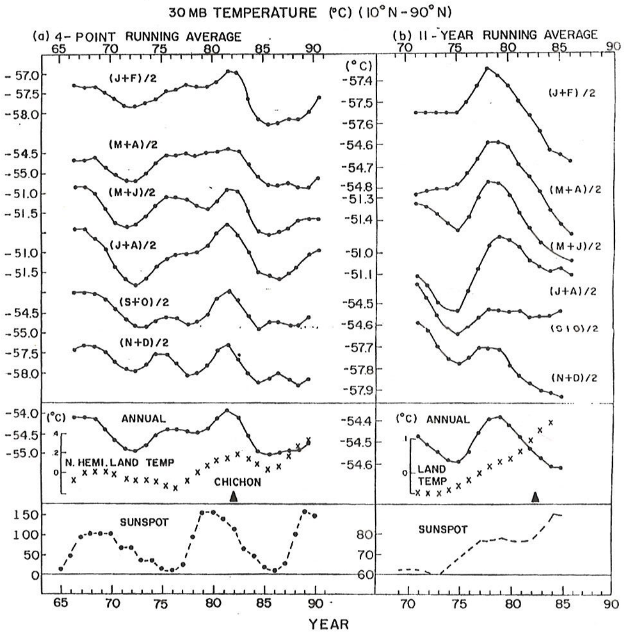

Figure 3 - Area-weighted (10°N-90°N) 30mb geopotential heights (Labitzke & van Loon, 1991, Figs. 9-10) for Jan./Feb., Mar./Apr., May/Jun., Jul./Aug., Sep./Oct., Nov./Dec. and the whole year (annual): (a) 4-point running averages; (b) 11-year running averages. On the annual curves (full lines), the crosses represent surface air temperature for the Northern Hemisphere (Jones et al., 1986; Hansen & Lebedeff, 1988). Bottom plots are for sunspots. Triangle indicates El Chichon eruption of 1982.

Figura 3 - *Médias ponderadas (área) das alturas do geopotencial (30 mb) para latitudes 10° - 90° N (Figs. 9 - 10 de Labitzke & Van Loon, 1991) em Jan./Fev., Mar./Abr., Mai./Jun., Set./Out., Nov./Dez., e o ano inteiro (anual): (a) média corrida de 4 pontos; (b) média corrida de onze anos. Nas curvas anuais (linha sólida), as cruzes representam a temperatura do ar na superfície para o Hemisfério Norte (Jones et al., 1986; Hausen & Lebedeff, 1988). As curvas inferiores referem-se às manchas solares. Os triângulos indicam a erupção vulcânica de El Chicon de 1982.*

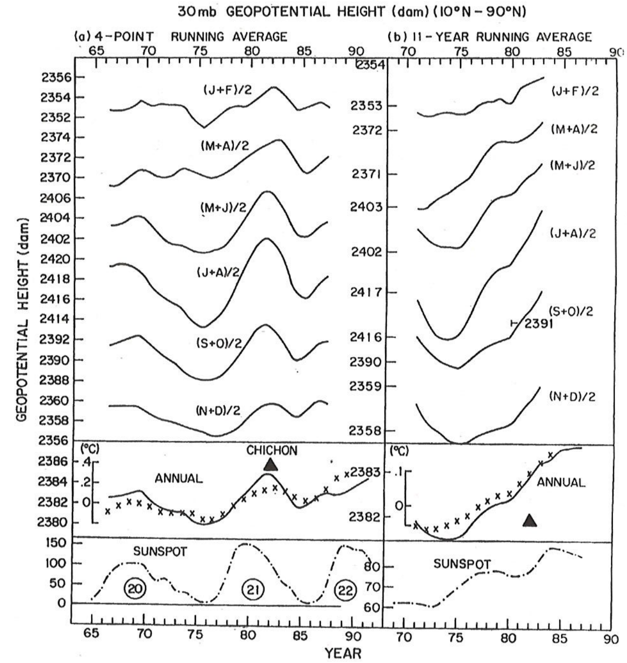

Figure 4 - Same as Fig. 3, for (10°N-90°N) 30mb temperatures (Labitzke & van Loon, 1991, Figs. 9-10).

Figura 4 - *O mesmo da Fig.3, para temperaturas (30mb) entre 10°N-90°N (Figs. 9-10 de Labitzke & van Loon, 1991).*

Fig. 4 shows plots for the 30mb temperatures. Fig. 4(a) shows the 4-point running averages for two-month means. In 1982, there was a prominent maximum in all months, coinciding with the El Chichon eruption and 1 or 2 years later than the 1980 sunspot maximum. There was a maximum in 1966-68, slightly earlier than the solar maximum of 1969-70. Thus, some parallelism with solar activity is indicated. But, there is an indication of an additional in-between peak in 1975 (6-7 year periodicity), coinciding with the solar minimum of 1975. This peak is very prominent in Oct. Nov. Dec. (see Fig. 2a also). Thus, something besides the solar activity is involved. Fig. 4(b) shows the 11-year running averages. The trends differ considerably for the different months and a clear downward trend is seen only for November/December, though, even here, there is a peak during 1975-80. In Fig. 1(b) and 2(b) also, the 30mb plots had a small peak during 1975-80. Thus, the downward trend is restricted to the early winter period only. In other months, there are no unique uniform linear trends, but instead, there are oscillatory structures. Up to 1975, there were negligible or downward trends. From 1975 to 1978-79, there were sharp upward trends. Thereafter, there are clear downward trends. It is not possible to say whether the negative trend from 1978 onwards up to date in Fig. 4b will continue negative or will revert upwards in near future. For the North Pole 30mb temperatures, the trends were negative only for November (see Fig. 1b) and December. In January, the trend was negative only after 1975 and in February, the trend was slightly positive (Kane, 1992). In March and April, there were positive trends. Thus, different trends in different months are indicated.

For many of the plots showed so far, there are indications of non-uniformity in the trends. Recently (Kane, 1996), we noticed that such an uniformity has occurred in many other atmospheric parameters in the troposphere, stratosphere and mesosphere and, trends before and after 1970-75 are often different. The most famous example of a non-uniform trend is that of total ozone. Till about 1970, ozone level was steady and thereafter, a downward trend started. However, the level has decreased faster in recent years. Hence, workers now adopt what is known as a "hockey stick model" viz. a steady ozone level up to 1969, a smaller downward gradient up to ~1980 and a larger downward gradient thereafter (Stolarski et al., 1992). Incidentally, such non-uniformities can be detected only from plots of running averages as illustrated above and would remain hidden if only statistical regression analyses are used. In a recent publication, Pawson et al. (1993) have mentioned these variations (non-uniformities) in the trends and also refer to four major external influences viz. QBO (Quasi-biennial Oscillations), TTO (Ten-to-Twelve year Oscillations), ENSO (El Nino-Southern Oscillation) and VE (Volcanic errruptions). For example, the high temperatures in the beginning of all these series (early 60's) could be due to volcanic errruptions (Newell, 1970; Labitzke & Naujokat, 1983). Running averages over 4 years eliminate or minimise the QBO, ENSO and VE effects and only TTO remains. The 11-year averages may not eliminate variable TTO. An alternative way of estimating long-term trends in the presence of TTO would be to use the function $y=a_0+at+bS$ where y = any one of the atmospheric parameters, (at) would represent the linear trend and bS the sunspot (S) effect, and conduct a Bivariate Regression Analysis to estimate a, b and their standard errors. In recent years, Dr. Labitzke has kindly supplied us data for more recent years and some are given in Pawson et al. (1993) and used by us (Kane, 1995) for studying the seasonal dependence of trends. In the present paper, Figs. 1-4 show data as much updated as possible and the updating may be different for different parameters. For analysis, we chose the common period 1966-1988 and used 4-point running averages for all parameters as well as for sunspot numbers. Table 1(a) shows the results of Multiple Correlation Coefficient and the regression coefficients a,b with their

Table 1(a) for monthly values

Parameters	Multiple Correlation Coefficient	a, linear gradient	b, sunspot effect
Temperatures		(°C)/decade	(°C)/100 sunspots
Oct.-Nov. (20°N-50°N)			
10mb	0.57	-0.36*±0.12	0.10±0.20
30mb	0.43	-0.20*±0.10	0.10±0.17
50mb	0.81	-0.45*±0.07	0.02±0.13
100mb	0.35	+0.08 ±0.07	0.16±0.12
Oct.-Nov. (20°N-50°N)			
10mb	0.92	-0.57*±0.06	0.22*±0.10
30mb	0.57	-0.21*±0.08	0.17 ±0.13
50mb	0.77	-0.44*±0.08	0.02 ±0.14
100mb	0.26	-0.04 ±0.06	0.10 ±0.10
30mb (10°N-90°N)			
Jan.-Feb.	0.65	-0.21*±0.10	0.56*±0.18
Mar.-Apr.	0.49	-0.11 ±0.10	0.37*±0.17
May-June	0.54	-0.27*±0.12	0.33 ±0.20
Jul.-Aug.	0.63	-0.17 ±0.13	0.73*±0.22
Sep.-Oct.	0.66	-0.22*±0.09	0.43*±0.15
Nov.-Dec.	0.63	-0.29*±0.09	0.22 ±0.15
Geopotential Heights		(dam)/decade	(dam)/100 sunspots
30 mb (10°N-90°N)			
Jan.-Feb.	0.51	+0.41 ±0.30	1.21*±0.51
Mar.-Apr.	0.80	+1.36*±0.27	1.53*±0.46
May-June	0.76	+0.63 ±0.38	3.27*±0.65
Jul.-Aug.	0.78	+0.56 ±0.54	5.05*±0.92
Sep.-Oct.	0.67	+0.34 ±0.41	2.91*±0.69
Nov.-Dec.	0.31	+0.21 ±0.37	0.91 ±0.64

Table 1(b) for annual means

Values in parentheses are from Pawzon et al. (1993).

Temperatures		(°C)/decade	(°C)/100 sunspots
(10°N-90°N)			
30mb	0.64	-0.25*±0.07 (-0.19)	0.38*±0.13
50mb	0.74	-0.34*±0.06 (-0.29)	0.19 ±0.11
100mb	0.35	-0.08 ±0.05 (-0.12)	0.07 ±0.08
Geopotential Heights		(dam)/decade	(dam)/100 sunspots
(10°N-90°N)			
30mb	0.72	+0.38 ±0.28 (-0.24)	2.16*±0.50
50mb	0.78	+0.75*±0.24 (+0.34)	1.73*±0.42
100mb	0.87	+0.78*±0.13 (+0.68)	0.89*±0.23

* Indicates significance at a 2 (95% confidence) level or more.

Table 1 - Multiple correlation coefficient and the regression coefficients a and b (and their standard errors) used in $y=a_0+at+bS$, where y = atmospheric parameter, a = linear gradient, and b = coefficient relating y to sunspots S, using 4-point averages of y and S.

Tabela 1 - *Coeficientes de correlação múltipla e de regressão a e b (e desvios padrão) usado em $y = a_0 + at + bS$, onde y = parâmetro atmosférico, a = gradiente linear, e b = coeficiente que relaciona y às manchas solares S, usando médias corridas de 4 pontos.*

standard errors. The following may be noted:

(i) The multiple correlation coefficient is not always high, indicating that in some cases, there are other causes of variability besides a linear trend and a solar cycle effect.

(ii) The asterisks (*) indicate significance better than 2s (95% confidence level). For Oct.-Nov. temperatures, 10, 30, 50mb have significant down trends for both (20°N-50°N) and (10°N-90°N). However, for 100mb, trends are doubtful. It is interesting to note that the 11-year averages in Fig. 1(b) convey the same information. The solar cycle effects are, in general, insignificant, indicating that the various peaks are not matching with sunspot peaks.

(iii) For 30mb (10°-90°N) temperatures (Fig. 4), the linear trends are significantly down for almost all months and the solar cycle effects are also significant. Multiple correlations are not always high, indicating other effects (e.g. 5-6 year periodicities).

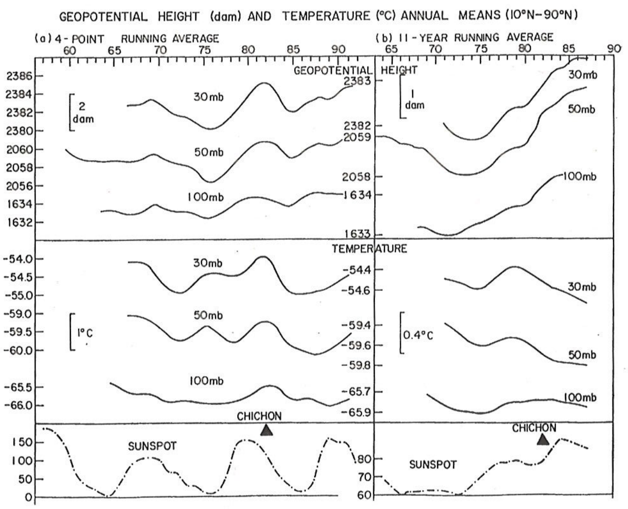

Figure 5 - Area-weighted (10°N-90°N) geopotential heights (upper portion) and temperatures (middle portion) for 30, 50, 100mb levels (Labitzke & van Loon, 1991; Figs. 10-11): (a) 4-point running averages; (b) 11-year running averages. Bottom plots are for sunspots. Triangle indicates El Chichon eruption of 1982.

Figura 5 - *Médias ponderadas (área) das alturas do geopotencial (parte superior) e temperaturas (no meio) para níveis de 30, 50, e 100 mb (Figs. 10 -11 de Labitzke & Van Loon, 1991) : (a) médias corridas de 4 pontos; (b) médias corridas de onze anos. As curvas inferiores são das manchas solares. Os triângulos indicam a erupção vulcânica de El Chicon de 1982.*

(iv) For 30mb ((10°-90°N) geopotential heights (Fig. 3), the gradients are significantly positive only for March-April; but solar cycle effects are significant for all months except Nov.-Dec. This indicates predominance of solar cycle effect and doubtful linear gradients.

Fig. 5(a) shows the 4-point running averages of the mean geopotential heights (upper portion) and temperature (middle portion) for 30, 50 and 100mb for 10°N-90°N. The variations are similar for 30 and 50mb and somewhat different for 100mb. In particular, the 1975 peak in temperature, seen in 30 and 50mb plots, is absent at 100mb.

Fig. 5(b) shows the 11-year running averages. For geopotential heights, the pattern seems to be a downward trend up to about 1975 and an upward trend thereafter for all levels. (30, 50, 100mb). For temperature for 30, 50 and 100mb, there was a downtrend up to 1975. Thereafter, 30 and 50mb show an uptrend for the next 4 years (up to 1979) and then a steep decrease. For 100 mb, the uptrend is lessened but still positive up to date.

Table 1(b) shows the results of a regression analysis. For temperatures at 30 and 50mb, there are significant (better than 2s) down-trends, roughly matching with those reported by Pawson et al. (1993) (shown in parentheses) from a simple regression analysis. For temperature at 100mb, the multiple correlation is low and trend is downward but less certain. Since the surface temperatures have an uptrend for the same interval (Hansen & Lebedeff, 1988; Jones et al., 1986), the transition from an uptrend at the surface to a down trend in the stratosphere should be somewhere below 100mb level. For geopotential height, all the 3 levels (30, 50, 100mb) show uptrends. Those for 50 and 100mb are highly significant; but for 30mb, the significance is much lesser and Pawson et al. (1993) report a negative trend of poor significance.

DISCUSSION AND CONCLUSIONS

In conclusion, one could summarize as follows:

a) The geopotential heights and temperatures in the stratosphere show distinct trends. However, these are not always monotonically upward or downward and are different at different altitudes (mb levels) and in different seasons and latitudes. For example, North Pole temperature changes are much larger.

b) The 30mb geopotential heights have a very strong solar cycle effect (larger values at sunspot maximum) and probably an increase associated with the 1982 El Chichon volcanic eruption. When these effects are minimized by evaluating 11-year running averages, the resulting plots show upward trends in January, February, March and April throughout. For other months, there are downward trends up to about 1975 and upward trends thereafter up to date. Since the maximum sunspot numbers in cycle 21 and 22 were larger than those in cycle 20, the 11-year running averages of sunspot also show a similar pattern viz. downward trends up to about 1973 and a rising trend thereafter. Also, the Northern hemisphere surface air temperature shows a similar pattern.

Bivariate regression analysis shows significant uptrends.

c) The 30mb temperature shows a more complex pattern. An association with sunspot maxima (1969 and 1980) is discernable, though the latter may be mixed up with El Chichon (1982) effect also. However, there is an additional peak near 1975 (a solar minimum). Specially in November/December, this peak, in conjunction with the peaks in 1968-70 and 1982, gives an appearance of a 6-7 year periodicity. The 11-year running averages show a negligible or downward trend up to 1975, an upward trend during 1975-79 and a downward trend thereafter up to date. However, this pattern has strong variations from season to season. For example, in October/November/December, the trend is largely downward all through. For September/October, the recent downtrend is negligible. These patterns have no resemblance with sunspot numbers and are <u>opposite</u> to surface temperature, thus confirming that stratospheric temperature changes are opposite to those of lower (tropospheric) levels.

d) For geopotential heights, the rising trend after 1975 is seen at 30, 50 as well as 100mb. For temperature, trend at 100mb is smaller. At 30, 50mb, the temperatures trend is downwards from 1978-79 onwards. Thus, the transition from uptrends in lower levels to down trends in stratospheric temperatures seems to be near 100mb and is in agreement with theoretical predictions (Ramanathan, 1988).

It seems, therefore, that, contrary to the scepticism expressed by Labitzke & van Loon (1991), there are distinct trends in geopotential heights and temperatures in the stratosphere. However, their conclusion that several more periods of the low frequency wave are necessary before one can determine if trends of even lower frequency (periods exceeding 11 years) exist, also deserves due respect. Because, in geophysical research, short term trends have often turned out to be parts of longer oscillatory waves. Incidentally, in a recent publication (Pawson et al., 1993), Dr. Labitzke and her group have indicated some trends significant at a better than 95% confidence level.

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