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The solar cycle in the temperature of the tropical stratosphere

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RESUMEN

En este trabajo se busca una relación entre la anomalía de la temperatura estratosférica tropical a 10 hPa (~30 km), durante el período 1964-1996 y el flujo solar F10.7 cm. De las cuatro series estacionales y de la serie anual, se filtró la tendencia de largo plazo y la influencia de la oscilación de casi dos años (QBO). El coeficiente de correlación lineal r entre la temperatura y F10.7 para cada una de las cinco series está entre 0.02 y 0.31, lo que llevaría a pensar que la asociación entre la temperatura y el ciclo solar es débil. Sin embargo, si los datos de cada serie son agrupados de acuerdo con el ciclo solar al que pertenecen, la temperatura en función de F10.7 presenta un comportamiento no aleatorio, similar a una histéresis. El sentido de rotación, el eje y el área de cada histéresis varía segun el ciclo solar. El área, proporcional al desfasaje entre la temperatura y el F10.7, se hace más grande desde el ciclo 20 al 22. Para la serie anual r es 0.83 en el ciclo 20, decreciendo a 0.62 y 0.16 para los ciclos 21 y 22 respectivamente. La correlación entre la temperatura y F10.7 se hace progresivamente menos lineal desde el ciclo 20 al 22. Esto podría explicarse porque la temperatura estratosférica depende no sólo del flujo solar, sino de parámetros como O_3 y CO_2 y de los mecanismos de feedback entre ellos. A pesar de la pérdida de significancia estadística, el análisis de los datos agrupados por ciclo solar permitiría detectar cambios progresivos en una dada asociación.

PALABRAS CLAVE: Temperatura estratosférica, ciclo solar.

ABSTRACT

A search for a relationship between tropical stratosphere temperature anomalies at 10 hPa (~30 km), during 1964-1996 and the F10.7 cm solar flux has been carried out. The long-term trend and the Quasi-Biennial Oscillation influence over four seasonal and the annual temperature series were removed. The linear correlation coefficients, r, between temperature and F10.7 for the five series fall between 0.02 and 0.31, which suggests that the association between temperature and solar cycle is weak. However, when the data of each series are grouped according to solar cycle, temperature as a function of F10.7 shows a non-random behavior similar to a hysteresis loop. The sense of rotation, axis and area of a hysteresis loop are different for each solar cycle. The time shift between temperature and solar flux increases from cycle 20 to 22. The correlation between temperature and F10.7 becomes progressively lower from cycle 20 to 22. This suggests that the stratospheric temperature is determined not only by the solar flux, but also by parameters such as ozone and CO_2, and feedback mechanisms between them.

KEYWORDS: Stratospheric temperature, solar cycle.

INTRODUCTION

A direct relationship between the 11-year solar cycle activity and neutral atmospheric temperature was supported by several theoretical studies (Schwentek, 1971; Angell and Korshover, 1978; Quiroz, 1979, Brasseur and Simon, 1981 and García *et al*., 1984). Other studies showed that there was no significant influence of the 11-year solar cycle on stratospheric temperature (Angell and Korshover, 1983; Kokin *et al*., 1981; Devanarayanan and Mohanakumar, 1985). The 30hPa temperature at the North Pole during three solar cycles shows a correlation of 0.74 with solar activity when the data are grouped according to whether the QBO is in the westerly or easterly phase (Labitzke, 1987; Labitzke and Van Loon 1988; Labitzke and Chanin 1988). There is also some statistical evidence of the solar cycle influencing the heights and temperatures of the lower stratosphere in the Northern Hemisphere (Van Loon and Labitzke, 1990, 1993; Labitzke and Van Loon, 1992, 1997), and in the Southern Hemisphere (Van Loon and Labitzke, 1998).

Labitzke (2001) studied the vertical structure of the correlation between zonal average annual mean temperatures from 1000 to 10 hPa and the 11-year solar cycle. She found that the axis of high correlation (around 0.6) is at about 30º latitude; but over the polar region and into low latitudes, the vertical structure of the correlation was weak. In the tropical zone, at 10 hPa, the correlation was less than 0.4.

In this work we study the correlation between tropical stratospheric temperatures and the solar cycle with a new approach.

The stratospheric temperature is assumed to be controlled by absorption of solar UV radiation (200-300 nm) by ozone, balanced mainly by emission of infrared radiation at 15 mm by CO_2 (Houghton, 1997).

Ozone concentration has been decreasing and CO_2 has been increasing over the last decades (Mann *et al.*, 1998; Brasseur *et al.*, 1988). Ozone concentration depends on UV solar flux in the 200-240 nm band, also affected by CO_2 variations (Rind *et al.*, 1998). Due to the ozone and CO_2 variations and the feedback between solar radiation, ozone and CO_2 (Rind *et al.*, 1998; Shindell *et al.*, 1998), the physical system is not the same for different periods. In different solar cycles, the atmospheric conditions will be different. Thus despite a decrease of statistical significance, it may be better to analyze the data grouped in periods of solar cycles in order to detect a possible correlation between temperature and solar flux.

DATA

We consider the deviation of seasonal tropical stratospheric temperatures from the 1961-1990 mean (STST) at 10 hPa for the interval 1964-1996, and the solar flux proxy, F10.7. At a height of 30 km the ozone mixing ratio is a maximum (Peixoto and Oort, 1992).

The temperature data from NOAA include all available soundings recorded at 10 stations of the tropics (5 in the northern subtropics and 5 in the equatorial zone), within the longitude band from Ascension Island (7ºS, 345º7E) to Singapore (1ºN, 104ºE).

The seasons centered in January (DJF), April (MAM), July (JJA) and October (SON) and the annual series (ATST) were used.

The data show a long-term trend from general cooling of the stratosphere over the past three decades (Dunkerton *et al.*, 1998; Golitsyn *et al.*, 1996). The rate of decrease is about 0.6º/decade in average. This trend was filtered, and the detrended series was called STST Anomaly (STSTA) in the seasonal case, and ATST Anomaly (ATSTA) in the annual case.

The high-frequency oscillation (between 2 and 3 years period), possibly connected to the QBO (Holton, 1992), was removed applying a 3-year moving average to each series. The resulting series was called STSTAma and ATSTAma.

For the interval 1964 -1996 the linear correlation coefficients, r, between $STSTA_{ma}$ and the seasonal mean F10.76* of F10.7, are 0.02, 0.26, 0.31 and 0.09 for DJA, MAM, JJA and SON respectively. For the annual series, shown in Figure 1, r is 0.30. The significance level (probability of r = 0) of all r values is greater than 25%.

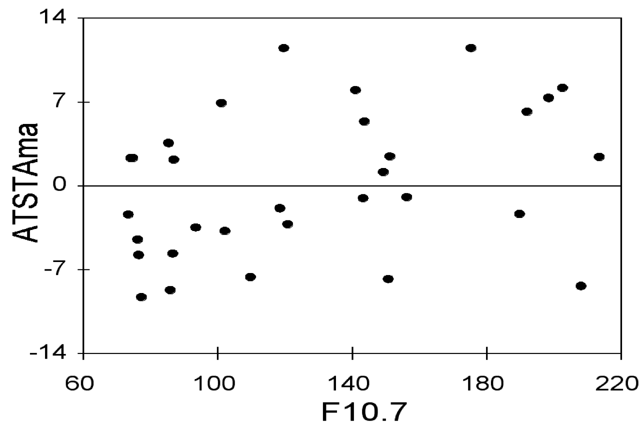

Fig. 1. Annual tropical stratospheric temperature anomaly after a 3-year running mean, ATSTAma, in terms of F10.7 for solar cycles 20, 21 and 22.

If temperature and F10.7 are plotted against time (Figure 2), both curves coincide for cycle 20 and are out of phase in cycles 21 and 22; the temperature lags behind in cycle 21 and is ahead in cycle 22, as referred to F10.7.

The time evolution of the five series is shown in Figure 3, where the points of Figure 1 are linked by chronological order. The seasonal series present a similar pattern. The points are not randomly distributed: the temperature in terms of solar flux follows an orderly pattern which correspond to a hysteresis loop, the area of which increases from cycle 20 to 22, by increasing solar activity. The hysteresis area (A) of the five series, normalized with respect to the minimum, yields $1 \leq A \leq 2.5$ for cycle 20; $2 \leq A \leq 7$ for cycle 21 and $7 \leq A \leq 10$ for cycle 22.

The sense of rotation and axis of the hysteresis loop differ for each solar cycle. The r values for 15 series grouped in solar cycles 20, 21 and 22 are indicated in Table 1.

DISCUSSION AND CONCLUSIONS

The tropical stratosphere temperature at 10 hPa shows a long-term oscillation with a period similar to that of the solar cycle. During solar cycle 20, temperature and F10.7 are in phase, as expected theoretically (Schwentek, 1971; Angell and Korshover, 1978; Quiroz, 1979, Brasseur and Simon, 1981 and García *et al.*, 1984). But during cycles 21 and 22, temperature and F10.7 are out of phase. The phase difference (for the annual and almost all the seasonal data) is negative in cycle 21 and positive in cycle 22. When the whole period of temperature data is considered, a large dispersion is observed when temperature is plotted against F10.7, with low r values.

For the annual series r is 0.30, in agreement with Labitzke (2001) for the period 1968-1998.

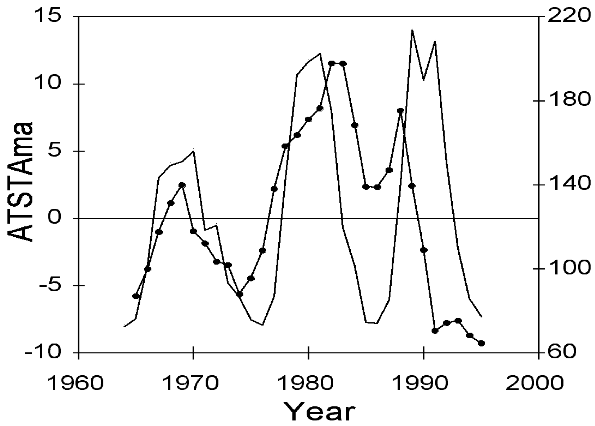

Fig. 2: Annual tropical stratospheric temperature anomaly after a 3-year running mean, ATSTAma (circles), and F10.7 (solid line) for the period 1964-1996 in terms of time.

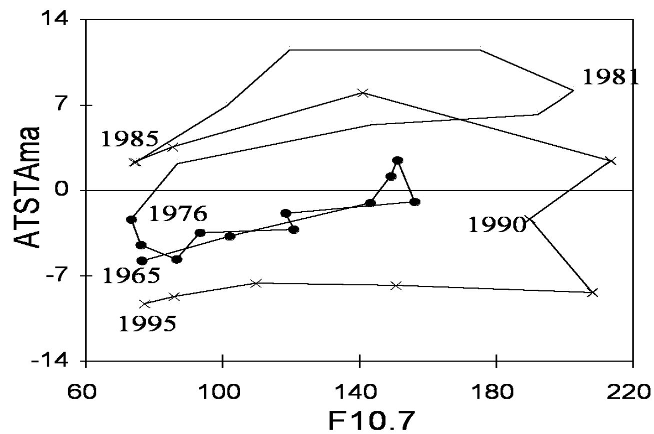

Fig. 3. Annual tropical stratospheric temperature anomaly after a 3-year running mean, ATSTAma, in terms of F10.7 for solar cycles 20 (circles), 21 (solid line) and 22 (line with crosses).

Table 1

Correlation coefficient, r, between temperature and F10.7 for the annual and seasonal series for the whole period (1964-1996) and solar cycles 20, 21 and 22.

	Annual	DJF	MAM	JJA	SON
Whole period	0.30	0.02	0.26	0.31	0.09
Solar Cycle 20	0.83	0.52	0.88	0.40	0.35
Solar Cycle 21	0.62	0.81	0.70	0.54	0.20
Solar Cycle 22	0.16	0.19	0.13	0.43	0.17

A time-lagged cross-correlation between the temperature series and F10.7, in both directions, shows that he highest correlation, 0.4, corresponds to the one-year lag. For the original temperature data series, the highest correlation is 0.42 (at a 1% significance level), for a two-year lag.

When the data series are grouped according to solar cycles the scatter plot of temperature against F10.7 shows a non-random behavior. Despite the decline of statistical significance, there is correlation between temperature and F10.7, but it progressively decreases from cycle 20 to 22 (see Table 1). These results suggest that the stratospheric temperature is determined not only by the solar flux, but also by ozone and CO_2 that vary in time, plus feedback mechanisms between them.

Stratospheric aerosol injection by volcanic eruptions also influences temperature by warming the lower stratosphere through the enhanced absorption of solar long-wave radiation. The radiative forcing produced by a single volcanic eruption lasts for only a few years (IPCC, 1995). The two major injections during the time period analyzed in this work, El Chichón in 1982 and Pinatubo in 1991 (major volcanic eruption of the century), do not show a clear signature in our temperature data.

Ionospheric parameters show a similar modulation of that of the tropical stratospheric temperature. Solar EUV radiation in the range 10–102.6 nm is the prime cause of ionization in the ionospheric F region. The maximum ionospheric electron density in the F region, NmF2, and the corresponding peak height , hmF2, against F10.7, show variable phase lags (Rao and Rao, 1969; Smith and King, 1981; Ortiz de Adler *et al*, 1993; Ortiz de Adler and Manzano, 1995). This modulation has also been observed in galactic cosmic ray (GCR) intensity. The cross-plots of the annual mean sunspot number against the annual mean intensity of GCR for solar cycles 19, 20, 21, and 22 show hysteresis, always counterclockwise (Van Allen, 2000).

It would be interesting to analyze other time series in the same way, grouping the whole data set in different periods, in order to determine the relevance of omitted variables.

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