Statistical relationship of the NO2 slant column densities over Stara Zagora station and the solar F10.7 flux with consideration of the QBO phase

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Abstract. By means of the GASCOD spectrometer at Stara Zagora station (42.8 N, 26.1 E), data series were obtained of monthly NO2am (at sunrise) and NO2pm (at sunset) slant column densities (SCD), covering the interval from September 1999 to the end of 2006. After removing the seasonal cycle, relationships between the NO2am and F10.7 solar flux and NO2pm and F10.7 were sought. The monthly deseasonalized NO2am show a positive statistical significant correlation with F10.7 having r = 0.41 at level p = 0.01. No statistical significant correlations were found between monthly NO2pm and F10.7 unless the QBO phase was taken into consideration. The original data series of the quasi-biennial oscillations (QBO) at the level of 30 h Pa have been used to study the relation between the NO2 and the F10.7 taking into account the QBO phase. The data have been separated into two different groups – positive (westerly) and negative (easterly) QBO phase. As a result, during the negative QBO phase, the monthly NO2pm show a negative correlation with F10.7 (r = - 0.37 and p = 0.01). During the positive QBO phase, the monthly NO2pm show no correlation with F10.7 (r = 0.02). The separation of NO2am into two groups according to the sign of the QBO phase practically does not change the results – the correlation coefficient remains between 0.40 and 0.43 at level p = 0.01. The statistical significance of the found relationships was determined by means of Student's t-test.

Keywords: nitrogen dioxide, F10.7, quasi biennial oscillation phase

1. Introduction

The influence of the phase of the Quasi Biennial Oscillation (QBO) on some stratospheric parameters has been shown in [1], where it has been found that more major stratospheric mid-winter warmings occur when the equatorial wind is easterly (negative QBO phase).

It has been shown in [2] that the global total ozone does not show any evident connection with 10.7 cm solar flux ($F_{10.7}$). However, when the data are separated according to the east or west QBO phase, it has been found positive correlation with the solar cycle when the QBO is in west (positive) phase. The opposite holds for the east phase of the QBO.

In [3] it has been shown that the highest statistically significant correlations between the total column ozone observed by TOMS and the 11-yr sunspot cycle were found in subtropical regions. This suggests that the association between the Sun and the ozone is not a direct, radiative one, but that is due to solar induced changes in the transport of ozone.

The connection between one of the important ozone-destructing trace gases, namely the nitrogen dioxide (NO_2), and the solar cycle is less studied. Monthly averaged stratospheric NO_2 slant column measurements at 45 S show that, there was small but significant long-term reduction in the NO_2 slant column densities from solar maximum to solar minimum [4]. Eighteen years of NO_2 measurements in Lauder, New Zealand show weak correlation with the solar cycle [5].

In the present paper we seek relationships between the NO_2 and $F_{10.7}$ solar flux, obtained by means of the GASCOD spectrometer at Stara Zagora station (42.8 N, 26.1 E).

2. Data

The 10.7 cm solar flux measurements $F_{10.7}$ [6] are used as an indicator of solar cycle activity, which gives a reasonably good indication of the shape of solar UV flux activity at wavelengths absorbed in the stratosphere [7].

By means of the GASCOD type spectrometer at Stara Zagora station, data series were obtained of daily NO_2am (at sunrise) and NO_2pm (at sunset) slant column densities (SCD). The measurements cover an interval from September 1999 to the end of 2006, which is longer than three QBO cycles. The raw NO_2am and NO_2pm data series are shown in Fig. 1. The spectrometer and the Differential Optical Atmospheric Spectroscopy (DOAS) method, used for retrieval of NO_2, are described in detail in [8]. The DOAS spectrometry by means of GASCOD type spectrometer allows retrieving slant column amount of NO_2 and O_3 at zenith angle 90^0, i.e. at sunrise (NO_2am) and at sunset (NO_2pm). The differences between sunrise and sunset measurements are mainly the result of photochemical processes in stratosphere, and are partially due to the atmospheric

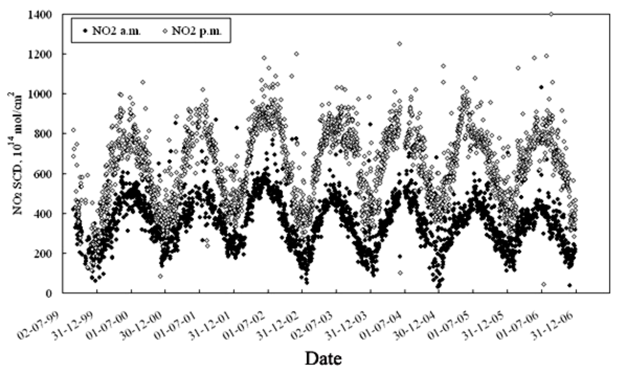

Fig. 1. The raw daily NO_2am and NO_2pm data series in Stara Zagora.

circulation. At present, it is not clear whether the long term destruction of ozone is different at sunrise to sunset.

By averaging the daily values, monthly mean NO_2am and NO_2pm have been obtained. The latter are presented in Fig. 2. Next, the monthly values for each month have been averaged for the interval of observations 1999-2006, and the seasonal means has been obtained. Finally, the seasonal means has been subtracted from monthly data series. Thus the seasonal cycle has been removed and the deseasonalized monthly NO_2am and NO_2pm values have been obtained.

The original data series of the quasi-biennial oscillations (QBO) at the level of 30 hPa [9] have been used to study the relation between the NO_2 and the $F_{10.7}$ taking into account the QBO phase. The solar flux $F_{10.7}$ and 30 hPa zonal wind (QBO) are shown in Fig. 3. The positive sign corresponds to the westerly QBO phase and negative sign corresponds to the easterly QBO phase.

3. Results

After removing the seasonal cycle, relationships between the NO_2am and $F_{10.7}$ solar flux and NO_2pm and $F_{10.7}$ were sought. The monthly deseasonalized NO_2am show a positive statistical significant correlation with $F_{10.7}$ having $r = 0.41$. The statistical significance of the found relation was determined by means of Student's t-test and it exceeds level $p = 0.01$. The positive relation can be seen in Fig. 4, which represents descending courses of NO_2am and $F_{10.7}$ during the observation period. These courses support the results obtained in [4]. Contrariwise, the monthly NO_2pm do not show any statistical significant correlation with $F_{10.7}$, since the correlation coefficient is very low ($r = 0.16$).

The data have been separated into two different groups – positive (westerly) and negative (easterly) QBO phase. As a result, during the negative QBO phase, the monthly NO_2pm show a negative correlation with $F_{10.7}$ ($r = -0.37$ and $p = 0.01$). During the positive QBO phase, the monthly NO_2pm show no correlation with $F_{10.7}$ ($r = 0.02$). Fig. 5 demonstrates the negative correlation with $F_{10.7}$ (ascending course of NO_2 pm) during the negative QBO phase and a break-up of the correlation during the positive QBO phase. Most probably, the positive correlation of NO_2am and $F_{10.7}$ and the negative correlation of NO_2pm and $F_{10.7}$ in negative QBO phase result from the global and regional transport of NO_2, although the mechanism is yet unclear. This could be the subject of our future investigations.

The separation of NO_2am into two groups according to the sign of the QBO phase practically does not change the results – the correlation coefficient remains between 0.40 and 0.43 at level $p = 0.01$. The statistical significance of the found relationships was determined by means of Student's t-test.

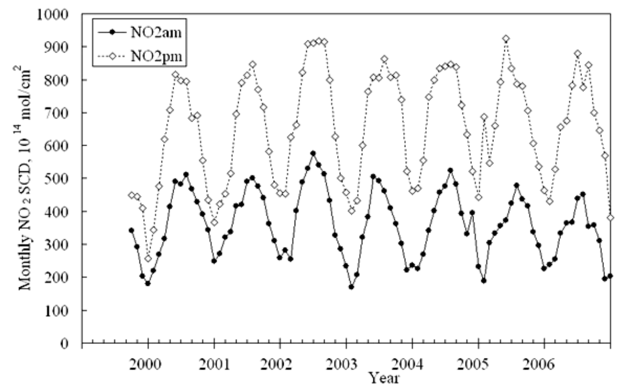

Fig. 2. The monthly NO_2am and NO_2pm data series in Stara Zagora.

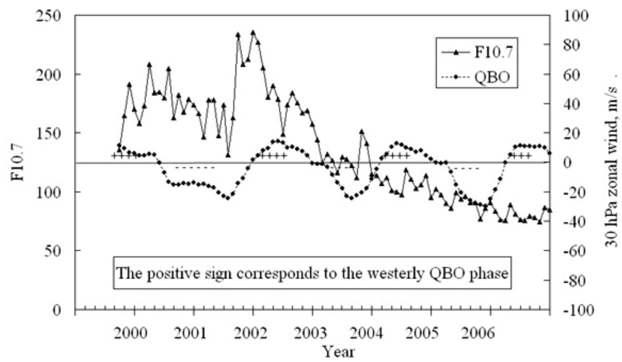

Fig. 3. The $F_{10.7}$ solar flux and 30 hPa zonal wind (QBO).

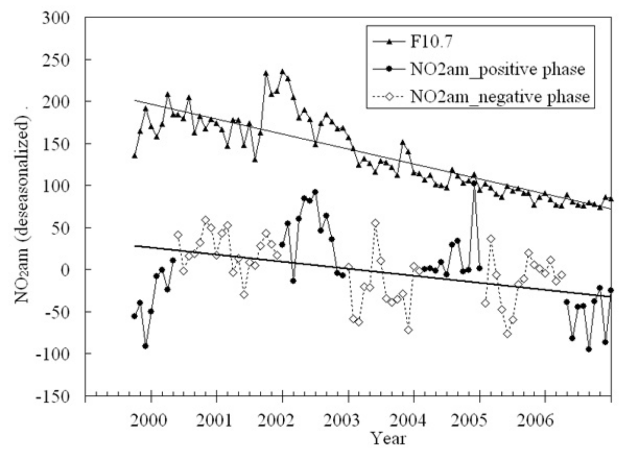

Fig.4. The descending courses of $F_{10.7}$ solar flux and deseasonalized NO_2am in Stara Zagora.

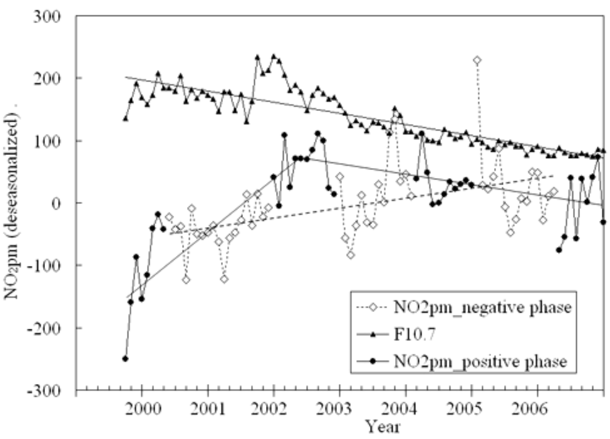

Fig. 5. The ascending course of deseasonalized NO_2pm in Stara Zagora during the negative QBO phase and the correlation break-up during the positive QBO phase.

4. Conclusions

After removing the seasonal cycle, relationships between the NO_2am and $F_{10.7}$ solar flux and NO_2pm and $F_{10.7}$ were sought. The monthly NO_2am show a positive statistical significant correlation with $F_{10.7}$ having $r = 0.41$ at level $p = 0.01$.

No statistical significant correlations were found between monthly NO_2pm and $F_{10.7}$ unless the QBO phase was taken into consideration. The data have been separated into two different groups – positive (westerly) and negative (easterly) QBO phase. As a result, during the negative QBO phase the relationship between NO_2pm and $F_{10.7}$ becomes negative ($r = -0.37$) and statistically significant at level $p = 0.01$. The dependence of sign of correlation of NO_2 and $F_{10.7}$ from QBO phase supports influence of the correlation from atmospheric circulation and NO_2 transport.

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