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EMPIRICAL BACKGROUND TCO MODEL OVER BULGARIA

Petya Kaleyna, Plamen Mukhtarov, Nikolay Miloshev

National Institute of Geophysics, Geodesy and Geography, Acad. G. Bonchev Str., bl 3, Sofia 1113, Bulgaria

Abstract: A detailed analysis of the variations of the stratospheric and mesospheric ozone over Bulgaria, in the period 1996-2012, is presented in the article on the basis of ground and satellite measurements of the Total Column Ozone (TCO). The move of the most important components has been studied: yearly running mean values, amplitudes and phases of the first four harmonics of the seasonal cycle. Their mean values for the period and the existing long-term trends have been found. It has been studied the move of the most basic components of the seasonal course, the existing long-term trends in it and their relations to the stratospheric temperature and quasi-biennial oscillation (QBO). Based on these studies and analyses, an empirical model for daily forecast of TCO over Bulgaria has been created. The main aim of the model is monitoring of the ozone layer and, respectively, the biologically harmful ultraviolet radiation of the Sun related to it which has an effect on human health and life.

Key words: *ozone, modelling TCO, UV radiation, TCO over Bulgaria*.

INTRODUCTION

The purpose of the present work is to create an empirical functional model describing the variations of TCO over Bulgaria depending on the season while taking into account possible long-term variations. In this case, a suitable method is presenting of seasonal variations through a decomposition of the daily values in Fourier series with a sliding segment of one year (the decomposition is made up to the fourth harmonic).

The same approach was used by M. Antón et al. (2010) in the article *Temporal and spatial variabilities of total ozone column over Portugal*; however, the decomposition in Fourier series took part in the model only up to the first harmonic. Bekoryukov V. et al., (1987) used an analogous model; however, since the model with them was for the whole Earth, spheric functions were used. The statistical model of McCormick et al. (1992) contained quasibiennial, seasonal, and semiannual oscillations, a linear component and a first-order autoregressive noise process.

DATA ANALISYS

The move of the mean monthly values of TCO over Bulgaria, collected through satellite and ground measurements, is displayed on Fig. 1. The well-known seasonal cycle of the total ozone with a spring maximum and an autumn minimum is readily seen. The running trend of the mean annual value of the total ozone, presented on Fig. 2, shows three clearly expressed high sections in 1998, 2003-2007 and 2009-2010 and the respective low ones in 2000, 2007 and 2011. The running mean annual value, displayed with a dotted line, is 308.4 DU. A polynomial best fit of second degree as the most common characteristic of the trend change of the mean annual value is displayed which shows an upward trend in the first half of the period and changes into a downward trend in the second half.

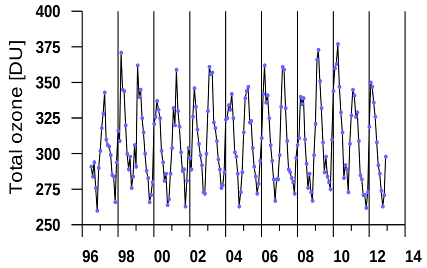

Fig. 1. Mean monthly values of TCO over Bulgaria in the period 1996-2012

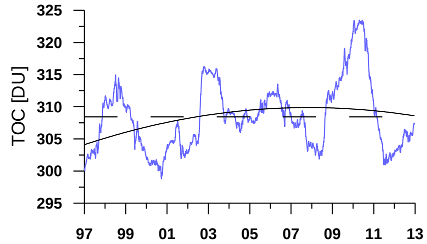

Fig. 2. Running mean annual values of TCO over Bulgaria in the period 1996-2012

The moves of a 12-month amplitude and phase are shown on Fig. 3 and 4. This is the strongest variation of the total ozone related to the seasonal cycle. The amplitude of the annual wave, in the observed period, shows a stable upward trend of about 30 to 40 DU. This means an increase of the maximal and a decrease of the minimal value over the year on condition that the mean annual value, as observed, has no significant upward or downward trend. The phase of the annual variability shows visible downward trend. The phase (that is, the maximum moment of the annual amplitude) is about the 98th day of the year (the beginning of April) as an average for the period. The negative linear trend is 0.9 days/year.

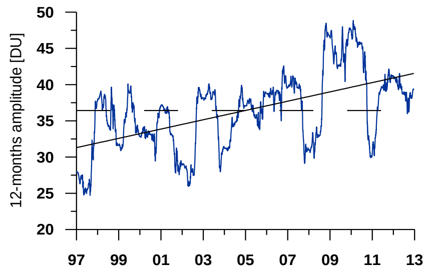

Fig. 3. 12-month amplitude

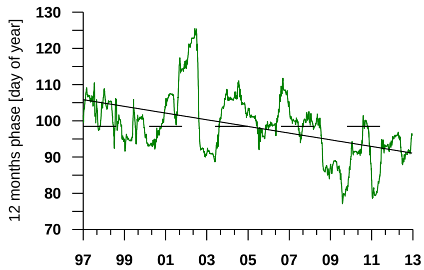

Fig. 4. 12-month phase

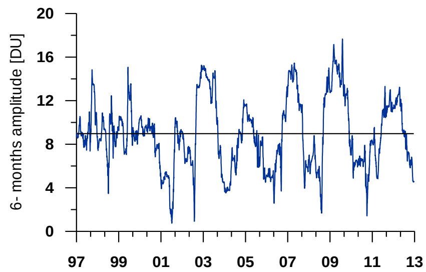

Fig. 5. 6-month amplitude

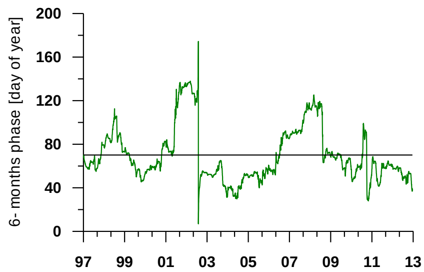

Fig. 6. 6-month phase

The amplitude and the phase of the semi-annual wave of the seasonal cycle of TCO do not show significant trends over the studied period (Fig. 5, 6). The amplitude varies over a wide range: from almost zero to about 16 DU while its average value is 9 DU. The mean value of the phase is the 70th day of the year. A quasi-biennial oscillation is readily seen in the period from 2001 to 2012. The values of the amplitudes of the other two components of the seasonal cycle, with periods of 3 and 4 months (the results are not shown), are close to the measurement error. Their variations are, most probably, of a random character. Bowman et Krueger, 1985, obtained values of the annual amplitudes of about 40 DU and of the semi-annual of about 5 DU, for 1978-1982, which were about the same values obtained in the present work.

INTERRELATION BETWEEN TCO AND STRATOSPHERIC TEMPERATURE AS WELL AS WITH QBO

Data have been used about the stratospheric temperature over Bulgaria from UK Met Office at isobaric level 68 hPa at 18 km altitude. This dataset is a result of assimilation *in situ* and of remotely collected data through a numerical model for analysis of the stratosphere and troposphere. The daily values of the stratospheric temperature over Bulgaria are decomposed in the same way as TCO.

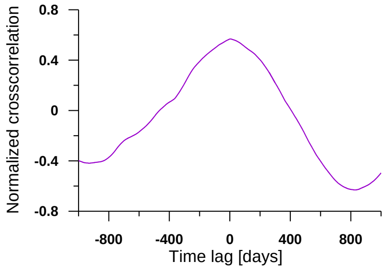

Fig. 7. Cross-correlation between temperature at 68hPa and running mean annual value of TCO

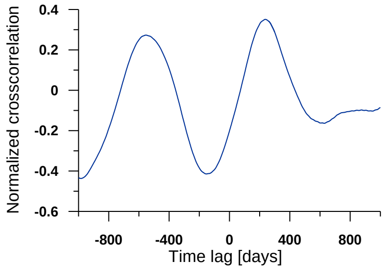

Fig. 8. Cross-correlation between QBO and a 12-month amplitude

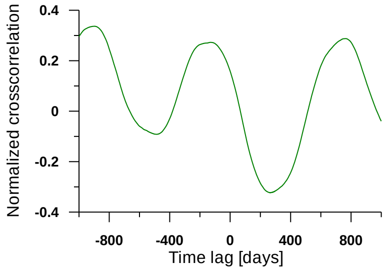

Fig. 9. Cross-correlation between QBO and a 12-month phase

The normalized cross-correlation function between the mean annual temperature and the mean annual TCO is displayed on Fig. 7. The maximal value of the correlation – 0.58 is observed by a positive day offset of five 24-hours. The ozone plays a significant role in the temperature regime of the stratosphere because it absorbs solar radiation but the observed delay shows that a reverse influence of the temperature over the concentration of ozone is also possible (Petzoldt et al., 1994).

Although the quasi-biennial oscillation is a tropical phenomenon, it affects the stratospheric flow from pole to pole through an alteration of the effect of tropical waves. The influence of the quasi-biennial oscillation (Tung, K. K. et al., 1994) can be observed on the amplitudes and phases of the annual and semi-annual component of the seasonal cycle of TCO. The cross-correlations, displayed on Fig. 8 and Fig. 9, demonstrate correlation values of up to 50%, more significant in the amplitude than in the phase. A positive correlation with a delay of about 200 days and nights can be observed with the amplitude and a negative one with the same delay with the phase.

CONCEPT OF THE MODEL AND DETERMINING OF THE CONSTANTS

The functional dependency (1) which is taken as the basis of the proposed model represents a functional dependency of four of the seasonal cycle components: the running mean annual value, the amplitudes and phases of four harmonics of the basic period (one year) of the weather and a dependency of the temperature at 68 hPa and the values of the index QBO. A long-term trend of all the components, represented by a polynomial of second degree, is additionally introduced. For convenience, the amplitudes and phases of the sinusoidal components of the seasonal cycle are represented by a sine and a cosine component with a zero initial phase by which the functional dependency becomes a multi-linear regression.

$$
\begin{aligned}
&TOC(day) = a_{00} + a_{01}day + a_{02}T_{68}(day - t_t) + a_{03}QBO(day - t_q) + a_{04}day^2 + a_{05}T_{68}^2(day - t_t) + a_{06}QBO^2(day - t_q) + \\
&\sum_{n=1}^{4} a_{n0}\cos\left(n\frac{2\pi}{365.25}day\right) + \sum_{n=1}^{4} a_{n1}day\cos\left(n\frac{2\pi}{365.25}day\right) + \sum_{n=1}^{4} a_{n2}T_{68}(day - t_t)\cos\left(n\frac{2\pi}{365.25}day\right) + \sum_{n=1}^{4} a_{n3}QBO(day - t_q)\cos\left(n\frac{2\pi}{365.25}day\right) + \\
&\sum_{n=1}^{4} a_{n4}day^2\cos\left(n\frac{2\pi}{365.25}day\right) + \sum_{n=1}^{4} a_{n5}T_{68}^2(day - t_t)\cos\left(n\frac{2\pi}{365.25}day\right) + \sum_{n=1}^{4} a_{n6}QBO^2(day - t_q)\cos\left(n\frac{2\pi}{365.25}day\right) + \\
&\sum_{n=1}^{4} b_{n0}\sin\left(n\frac{2\pi}{365.25}day\right) + \sum_{n=1}^{4} b_{n1}day\sin\left(n\frac{2\pi}{365.25}day\right) + \sum_{n=1}^{4} b_{n2}T_{68}(day - t_t)\sin\left(n\frac{2\pi}{365.25}day\right) + \sum_{n=1}^{4} b_{n3}QBO(day - t_q)\sin\left(n\frac{2\pi}{365.25}day\right) + \\
&\sum_{n=1}^{4} b_{n4}day^2\sin\left(n\frac{2\pi}{365.25}day\right) + \sum_{n=1}^{4} b_{n5}T_{68}^2(day - t_t)\sin\left(n\frac{2\pi}{365.25}day\right) + \sum_{n=1}^{4} b_{n6}QBO^2(day - t_q)\sin\left(n\frac{2\pi}{365.25}day\right)
\end{aligned}
\qquad (1)
$$

The model is described by *9.6 = 54* constants plus the two time delays which makes a total of *56* constants. The constants of the model are determined according to the criterion of data best fit: the minimum of the variations squares' sum (the least squares best fit). All the constants take part linearly and can be determined through solving a system of linear equations except for the time delays to temperature and QBO.

A procedure is used to determine the time delays (under the criterion of the least squares best fir) which is based on trials and errors. The linear constants of the model are determined for all the possible combinations of the unknown time delay. The mean square deviation is calculated. The procedure of choosing of such delays is illustrated on Fig. 10. It can be readily seen that the mean square error shows a minimum by certain values of both time delays which gives ground to choose namely those two values as the most suitable for the model.

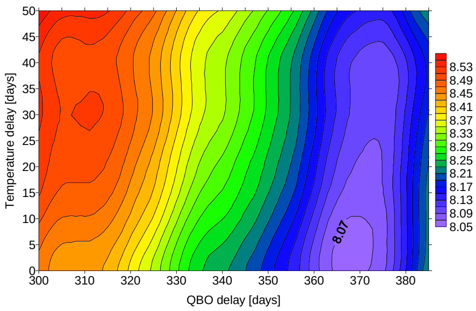

Fig. 10. The dependency of the mean square error of the model from the introduced delays within the respective range

Table. 1. Empirically obtained delays, mean square deviation and mean square error of the model.

Delay Temp	3
Delay QBO	368
RMS	8.058
Mean error	0.000

RESULTS

The data for TCO (light blue) with which we dispose are presented on Figure 11 compared to the results obtained from the model (dark blue). As it can be seen, the oscillation of TCO over the years is satisfactorily represented. It can be noted that the model renders an account of the alterations by sharp rises of the concentration even though with far more smoothed values (for example the middle of 1998 and the beginning of 2010).

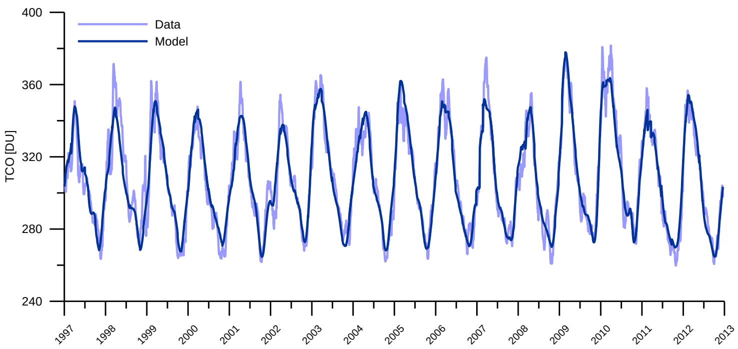

Fig. 11. A comparison of the data with the model values

VERIFICATION OF THE MODEL

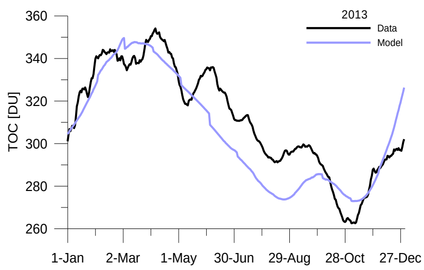

Fig. 14. Data and model for 2013

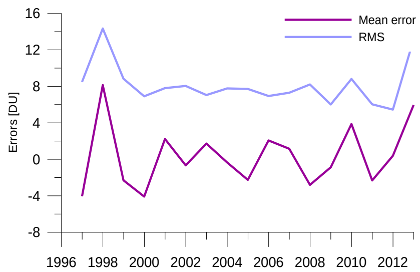

Fig. 15. Mean error and RMS of the model by years

The data trend and the trend of the model values of TCO, for 2013, is displayed on Fig. 14 which year has not been used by the synthesis of the model. The purpose of this is to make an evaluation of the model quality by prognosticating of the values of TCO. More significant deviations of the model from the data can be observed for the period May – August.

The mean error and RMS, for 2013, is bigger that the respective values for the whole period 1997-2012 but it does not surpass the biggest error for the separate years (in 1998). One of the possible reasons is the violation of the trend of the seasonal cycle of TCO's components which are put in the model for 2013 purely empirically. Another possible reason is a deviation of the TCO trend from the general regularities introduced in the model in 2013 in particular, like the situation in 1998.

CONCLUSION

The presented empirical model of the daily values of TCO over Bulgaria describes satisfactorily the general regularities of the TCO trend related to the seasonal changes in the atmosphere as well as the influence of the temperature and the dynamics in the stratosphere in particular while the resulting errors are in the range of the data measurement error. The long-term trends of the components of the seasonal cycle obtained by the analysis and included in the model are described through parabolic dependencies which poses a certain risk of increases in the error by using of the model beyond the time range for which it has been synthesized. An attempt is made to describe the trends not with a polynomial of second degree but with linear functions (the results are not presented). The errors for the period of time 1997-2012 are a little bit bigger than the presented results of the parabolic approximation but are smaller for 2013. The parabolic approximation is nevertheless preferred since it better describes the trend of TCO over the studied period. A further perfection of the model is possible by the accumulation of a longer data row. The presented model can be used to control the condition of the ozone layer over Bulgaria and to prognosticate whether there is any hazard of dangerous increases of the ultraviolet radiation of the Sun for people's health.

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