EMPIRICAL BACKGROUND TCO MODEL OVER BULGARIA

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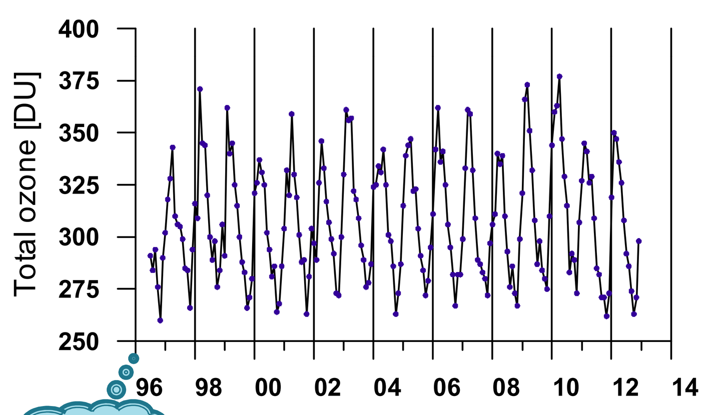
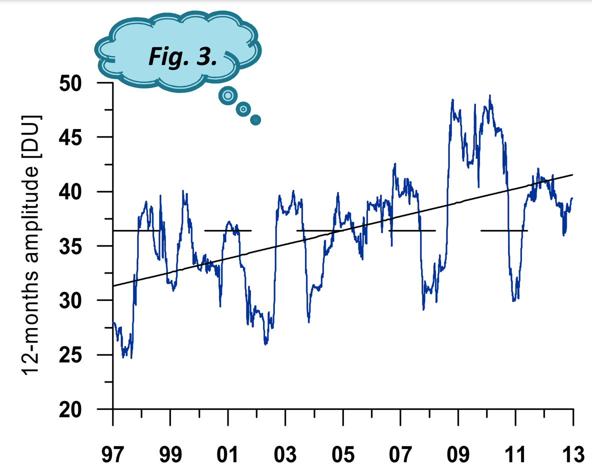
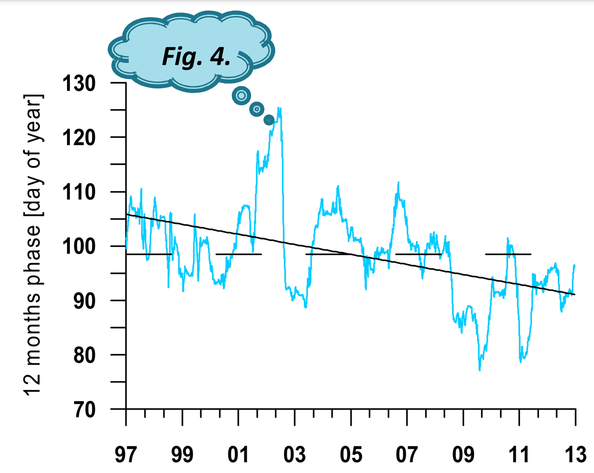
DATA ANALISYS



The move of the annual monthly values of TOC over Bulgaria for the period 1996-2012 on Fig. 1 shows:

- ✓A certain **seasonal cycle** of the total ozone with spring maximum and an autumn minimum;
- ✓ The initial value of **ozone** amounts to 305.4 DU;
- ✓Positive **trend** of 0.26 DU per year;
- ✓The ozone layer over Bulgaria is generally **stable**.

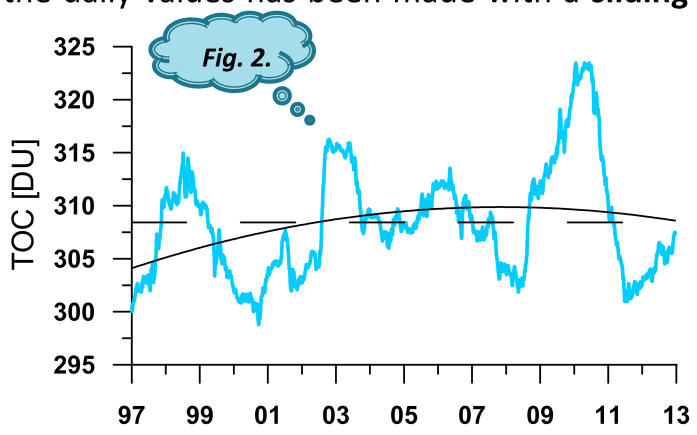


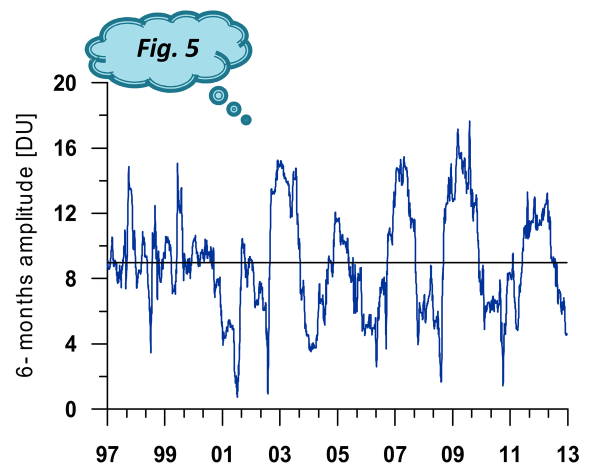


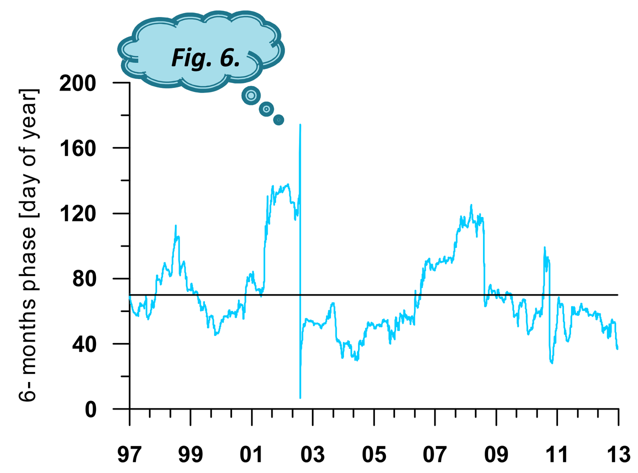
The amplitude on Fig. 3 of the annual oscillation shows a steady upward trend in the studied period (line). The mean value for the period is 36.4 DU (dotted line). **The phase** of the annual oscillation shows a distinctive downward trend. (line). It is about the 98th day of the year as an average for the period - dotted line (Fig. 4).

A detailed study of the behavior of the total ozone was made on the basis of the components of the seasonal cycle over the studied period. A decomposition of the daily values has been made with a **sliding time segment** of a year with a step of one day (Fig. 2).

- ✓**Maximums**: 1998 , 2003-2007 and 2009-2010;
- ✓**Minimums**: 2000, 2007 and 2011;
- ✓**The mean value** *:* 308.4 DU (dotted line);
- ✓**Polynomial best fit***:* upward trend in the first half of the period that changes to a downward trend In the second half (line).



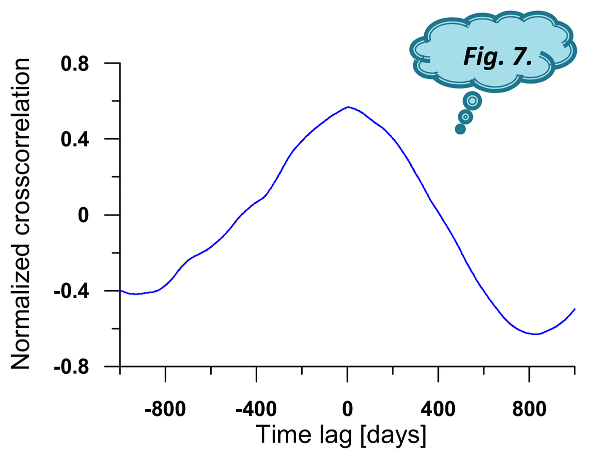




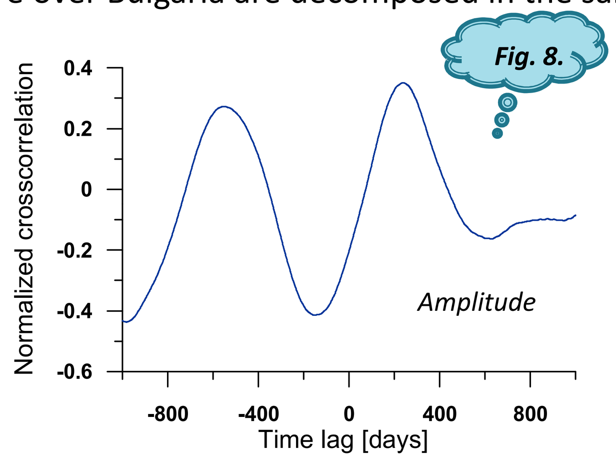
The amplitude and **the phase** of the semi-annual oscillation of the seasonal cycle of TOC (Fig. 5, 6) do not show significant trends for the studied period. The amplitude varies from 0 to 16 DU, the mean value is 9 DU. The mean value of the phase is the 70th day.

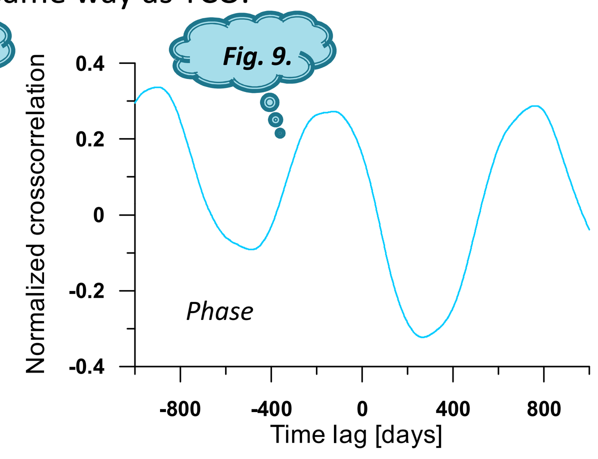
INTERRELATION BETWEEN TCO AND STRATOSPHERIC TEMPERATURE AS WELL AS WITH QBO

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.



Cross-correlation between temperature at 68hPa and running mean annual value of TCO on Fig. 7. shows maximal value of the correlation – 0.58 is observed by a positive day offset of five 24-hours. The observed delay shows that a reverse influence of the temperature over the concentration of ozone is possible.



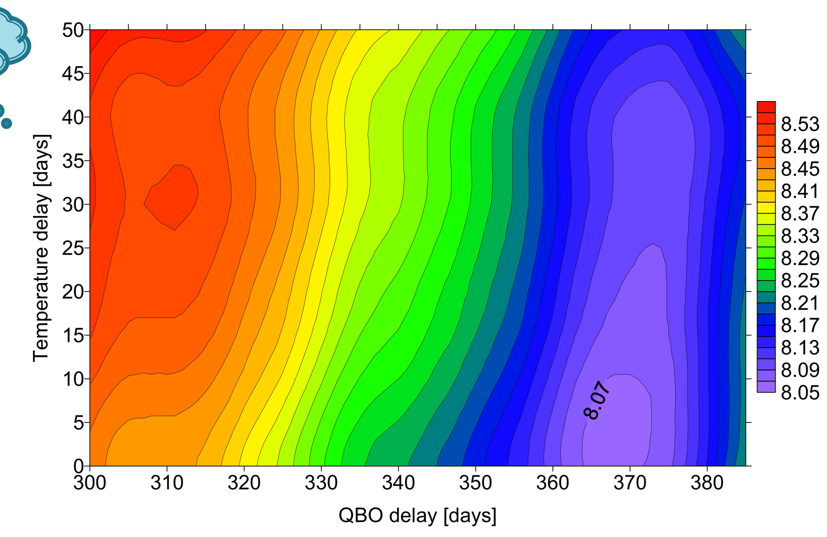


The influence of the quasi-biennial oscillation can be observed on the amplitudes and phases of the annual and semi-annual component of the seasonal cycle of TCO. The cross-correlations, displayed on Fig. 8 and Fig. 9, demonstrate correlation values of up to 50%, more significant in the amplitude than 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

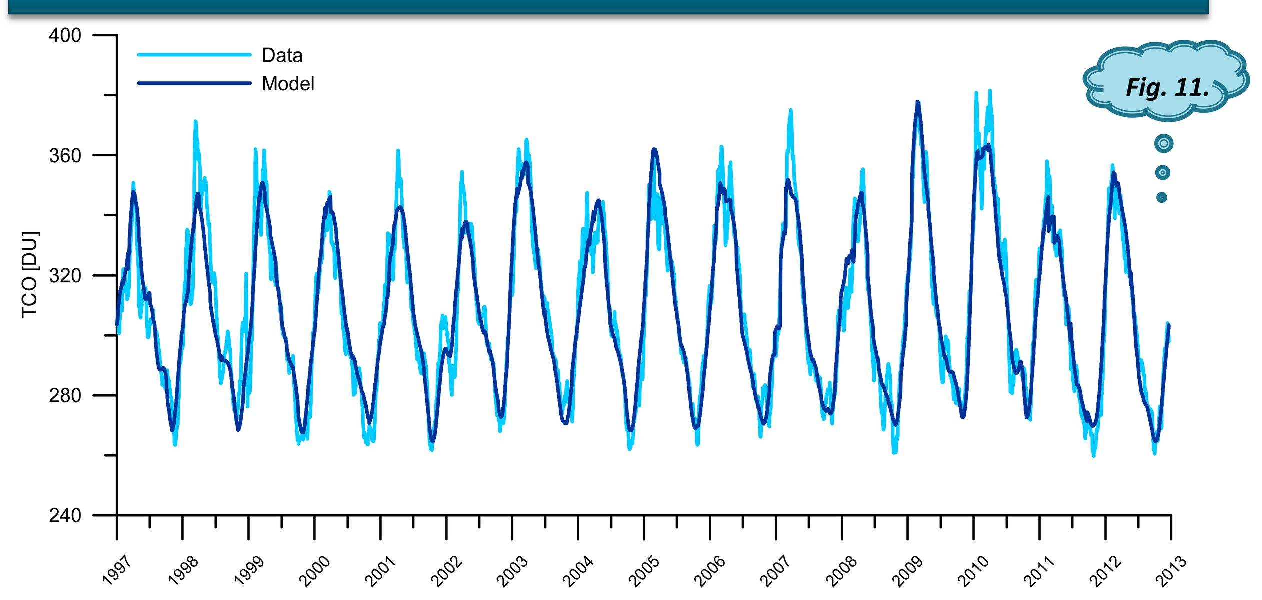
The functional dependency which is taken as the basis of the proposed model represents a functional dependency of four of the seasonal cycle components: the running mean annual value, the amplitudes and phases of four harmonics of the basic period (one year) of the weather and a dependency of the temperature 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. The model is described by 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. All the constants take part linearly and except for the time delays to temperature and QBO.

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



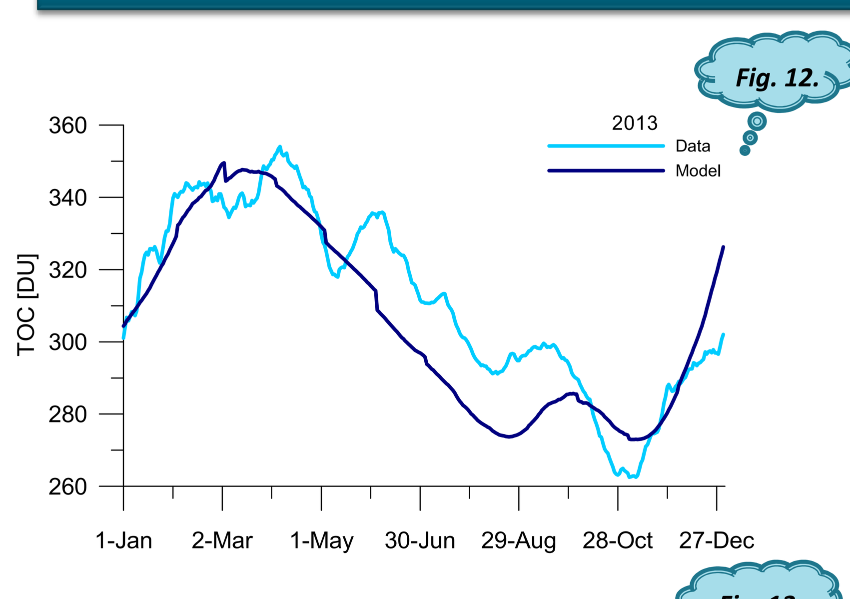
The linear constants of the model are determined for all the possible combinations of the unknown time delay. The procedure of choosing of such delays is illustrated on Fig. 10. It can be readily seen that the mean square error shows a minimum by certain values of both time delays which gives ground to choose namely those two values as the most suitable for the model.

RESULTS

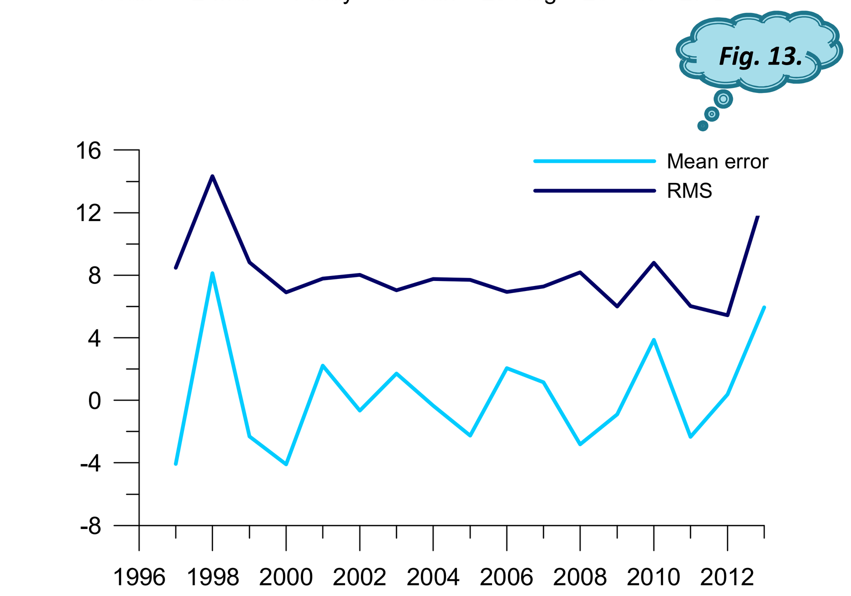


The data for TCO (light blue) is presented on Fig. 11 compared to the results obtained from the model (dark blue). As it can be seen, the oscillation of TCO over the years is satisfactorily represented. It can be noted that the model renders an account of the alterations by sharp rises of the concentration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

VERIFICATION OF THE MODEL



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.



The mean error and RMS, for 2013 shown on Fig. 13., 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 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.

ACKNOWLEDGEMENT

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