Assessment of Monthly Mean Total Ozone Distribution Changes With Regard to Atlantic Ocean Surface Temperatures Variations

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Summary: Taking into account monthly average surface temperatures changes of Atlantic water areas, which have a strong influence on monthly mean total ozone distribution above Poland, allows to imply their effective modeling and forecasting for several years. Prediction errors are at the maximum in June and rise as the forecast period increases. Nevertheless, when forecast is made for 1 – 2 years, their levels (modulo) do not exceed absolute error of total ozone measurements instrumentally based on the most exact of existing devices – Dobson spectrophotometer.
Key words: variability of total ozone distribution over Poland, surface temperatures, significant ocean areas, modeling, forecasting, statistical relationship, interaction of the troposphere and stratosphere.

INTRODUCTION

Variability of total ozone content (TOC) distribution in the atmosphere influences changes of UV solar radiation fluxes, which take part in creating tropospheric and surface ozone, growth of all land plants, animals and microorganisms, and affect human health as well. Therefore, improvement of the techniques of its monitoring is a topical problem of physical geography, meteorology and ecology.

Nowadays, since January 1979, variability and distribution of daily mean and monthly mean TOC have been researched by the means of global monitoring system. TOC values for different regions of the Planet which are not in the area of a pole night are measured by spectrophotometers TOMS (till 2013) and OMI. (2013 – present day) Such data go to the World ozone and ultraviolet data centre (Toronto), and are presented in the Internet for free access. Possibilities of these tools and data processing procedures provide resolution of 25 Dobson units (DU) with spatial grid 1.5°x1.5° [1].

Ground based TOC measuring stations are located in different cities; the most accurate device in use here is Dobson spectrophotometer, with measurement error around 5 DU. This allows to study the process peculiarities in more detail. Nevertheless, developing alternative monitoring techniques of TOC variability is of a great interest.

It has been established that changes of ozone depleting substances fluxes, entering different atmosphere segments, is one of the essential factors, causing TOC distribution changes in terrestrial atmosphere [2]. Such species of technogenic and natural origin are formed on ground surface and can be delivered by air streams to stratosphere, where mainly ozone is located. Within troposphere their transport is carried out by streams, which arise at various convectional and synoptic processes [3]. The mechanisms that allow such substances to enter stratosphere are not yet known with assurance. According to H.P. Pogosyan [4], the main role here is played by advection of tropospheric air through tropopause breakdowns, which are located above subtropical jet streams. Nevertheless, this mechanism does not explain how exactly such substances, which have gotten to the lower stratosphere, are distributed in steadily stratified upper layers, where ozone destruction occurs.

E.A. Zhadin [5] suggested, that the essential role in this process is carried out by planetary and gravity waves, which arise as a result of various interactions of atmosphere and the Earth's surface. They also can be generated by movement of cyclones and anticyclones, interaction of jet streams and orographic or pressure irregularities [6,7]. Being nonlinear and large-scale, such waves break at some distance from the source, as their wave profile transforms while spreading [8]. This results in turbulent rising air currents, which can transfer air to any heights in stratosphere.

An important role in generating pressure irregularities is played by exposure of the atmosphere to heat and water vapor fluxes which arise from the World ocean surface. Hence, a relation between surface temperature changes of some water areas and TOC over many world regions can exist.

The adequacy of such assumptions has been confirmed by many researchers [9]. This suggests a possibility of using surface temperature measurement results of some World ocean areas in the monitoring of TOC variations over the majority of the planet regions.

The Atlantic Ocean is the biggest and warmest part of the world oceans. This suggests a possibility of existence of such regions within it, whose surface temperature changes influence the ozonosphere state over Poland.

The occurrence was established of significant statistic relationships on coinciding time periods between TOC changes in the majority of atmosphere and surface temperature variations of many Atlantic water areas. On average, connections between these processes are weaker when the temporary shift between them grows [10].

Observations of surface temperature changes for the majority of Atlantic Ocean areas have been made for over 100 years. Their results in time series form are presented in the Internet. The data present the values of monthly mean anomalies calculated as an average of a segment, limited by parallels and meridians differing on 5° [11].

The disposition of water areas, influencing TOC distribution variations over one or other world region the most, (which we will further call 'significant'), is not clearly understood. It does not allow to use connections between the mentioned processes in modeling and forecasting TOC changes over such regions.

On this basis, the object of the research was monthly mean TOC distribution changes over Poland and monthly mean surface temperatures of various Atlantic Ocean areas.

The subject of the research was elaboration of monthly mean TOC distribution changes monitoring with regard to surface temperatures variations of the Atlantic Ocean significant areas on the example of Poland.

The purpose of the work was to identify the Atlantic Ocean significant areas, modeling accuracy assessment and TOC distribution variations forecasting over Poland.

To attain these ends the following tasks were solved:

1. Identification of Atlantic Ocean areas, whose monthly mean surface temperature inter-annual changes significantly influence (in coinciding time periods) monthly mean TOC variations over the majority of Poland's regions.
2. Identification of interannual TOC changes predictive models over the Poland's territory.
3. Developing TOC distribution changes forecasts over the Poland's territory and their adequacy assessment.

METHODOLOGY AND DATA

One of the most universal mathematical modeling methods of stochastic processes is a multiple regression method [12]. It is also applied for their prediction if the factors, considered as arguments, are connected with the studied process. Proving existence of stochastic connections between such natural process as TOC changes over Poland and other natural processes is really hard, in many cases – impossible. It is much easier to establish an existence of statistical connection between them.

The application of factors, connected statistically with the studied process, as factors in multiple regression model, does not guarantee its practicality in the forecasting tasks. But the possibility is the higher, the stronger the statistical connections considered in modeling are. Hence, the application of this method in developing forecasting techniques of studied process was accepted as admissible.

The mentioned technique included two stages.

At the first stage the first task was solved with the use of correlation analysis. Among all the Atlantic Ocean areas (5x5°) the ones were identified whose surface temperature inter-annual changes were significantly correlated with TOC in one or other atmosphere segment (1x1°) over Poland's territory. As a quantity measure of connection between the studied processes a pair correlation coefficient was used. The latter, with due regard to freedom degrees of corresponding time series, was accepted significant when exceeding 99% by Student's t-test. Further, among such water areas the significant ones were established. Their temperature changes were significantly connected with TOC variations at coinciding time periods in not less than 75% of atmosphere segments over the studied territory.

At the second stage the models' monthly mean TOC inter-annual changes , corresponding to each atmosphere segment over Poland, were identified.

Linear multiple regression was used as a predictive model:

$$\mathrm{Y}(t) = c_0 + c_1 x_1(t) + c_2 x_2(t) + \ldots + c_N x_N(t), \qquad (1)$$

here: c_i – constants, which were chosen so that the sum of deviation squares $z(t) = Y(t) - y(t)$ for all the time periods *t* was minimal;

$y(t)$ – time series for each predictable process during the 1979–2008 period;

$Y(t)$ – its model;

$x_i(t)$ – state in a time moment t of some process, which is significantly statistically connected with $y(t)$.

As model arguments (1) the time series of monthly mean surface temperatures of significant world oceans areas were used. They correspond to the 1979 – 2008 period in some time moments *t* coinciding with the studied processes.

Forecasting was made for 2009 and 2010, since there are results of satellite TOC monitoring for these years over Poland so their comparison can be made.

It was suggested that the number of model arguments (1) was equal to the number of significant areas – N . Time series for each of them contained M members ($M = 2N$). Then model coefficients (1) were calculated as components of ($N+1$)-vector $\underline{\tilde{N}}$, which is a solution to vector-matrix equation:

$$\underline{B} = A * \underline{C}, \qquad (2)$$

where:

$\underline{\tilde{N}} - N+1$-vector

$$B = \begin{Bmatrix} \sum_{i=1}^{M} y_i \\ \sum_{i=1}^{M} y_i x_{i,1} \\ \ldots \\ \sum_{i=1}^{M} y_i x_{i,N} \end{Bmatrix},$$

A – matrix $(N+1)\times(N+1)$

$$A=\begin{Bmatrix} M & \sum_{i=1}^{M}x_{i,1} & \sum_{i=1}^{M}x_{i,2} & \dots & \sum_{i=1}^{M}x_{i,N} \\ \sum_{i=1}^{M}x_{i,1} & \sum_{i=1}^{M}x_{i,1}x_{i,1} & \sum_{i=1}^{M}x_{i,2}x_{i,1} & \dots & \sum_{i=1}^{M}x_{i,N}x_{i,1} \\ \sum_{i=1}^{M}x_{i,2} & \sum_{i=1}^{M}x_{i,1}x_{i,2} & \sum_{i=1}^{M}x_{i,2}x_{i,2} & \dots & \sum_{i=1}^{M}x_{i,N}x_{i,2} \\ \dots & \dots & \dots & \dots & \dots \\ \sum_{i=1}^{M}x_{i,N} & \sum_{i=1}^{M}x_{i,1}x_{i,N} & \sum_{i=1}^{M}x_{i,2}x_{i,N} & \dots & \sum_{i=1}^{M}x_{i,N}x_{i,N} \end{Bmatrix}$$

The mentioned solution would look like:

$$\underline{C}=A^{-1}*\underline{B}, \qquad (3)$$

here: A^{-1} is an inverse matrix to A. Vector $\underline{C}$ was identified for each considered Poland's region. The forecasting was made by substitution in equation (1) time series of arguments, corresponding to 2009 and 2010 yy. TOC values were calculated for each month and each Poland's region. For each of them prediction accuracy was estimated.

As data time series of monthly mean surface temperatures, anomalies of all the Atlantic Ocean areas (5x5°) were used. They were obtained from [11]. In doing so, only time series with no gaps during 1979 – 2010 were used. As ozone variability data, time series were taken of monthly mean TOC values over each Earth surface square 1°x1°, limited by parallels 55°N and 49°N and meridians 14°E and 24°E, received from [1]. Such atmosphere segment completely covers the whole Poland's territory and some regions of Germany, Ukraine and Belarus.

RESULTS AND DISCUSSION

With the use of the mentioned technique, significant areas of Atlantic Ocean for all the months were identified. The smallest amount of such regions (15) occurred in June. Coordinates of the established significant areas of Atlantic Ocean are tabulated in Table 1.

Locations of such regions are presented in Figure 1.

As is seen from Table 1 and Figure 1, the mentioned regions are located in the area where a strong interaction of Gulf Stream and Labrador Current is found. So, here the most contrastive pressure gradients are observed. Their interplay with jet streams makes the last ones vertically oscillate. This arises planetary and gravitation waves, tropopause breakdown and allows ozone depleting species enter the stratosphere.

When solving the second task for each month, the TOC changes models (1) were identified for all the considered atmosphere segments.

With the use of these models, TOC values were predicted for various parts of Poland in June 2009 and 2010. These forecasts, as well as the fact values of TOC over various regions of Poland in June 2009 are tabulated in Table 2.

Table 1. Coordinates of the regions' centers of Atlantic Ocean, which were significant in modeling TOC changes above Poland in June

# №	latitude (°)	longitude (°)	# №	latitude (°)	longitude (°)	# №	latitude (°)	longitude (°)
1	57.5N	42.5W	6	52.5N	42.5W	11	37.5N	42.5E
2	57.5N	37.5W	7	42.5N	47.5W	12	37.5N	37.5W
3	52.5N	57.5W	8	42.5N	42.5W	13	32.5N	67.5W
4	52.5N	52.5W	9	37.5N	52.5W	14	32.5N	37.5E
5	52.5N	47.5W	10	37.5N	47.5W	15	27.5N	72.5W

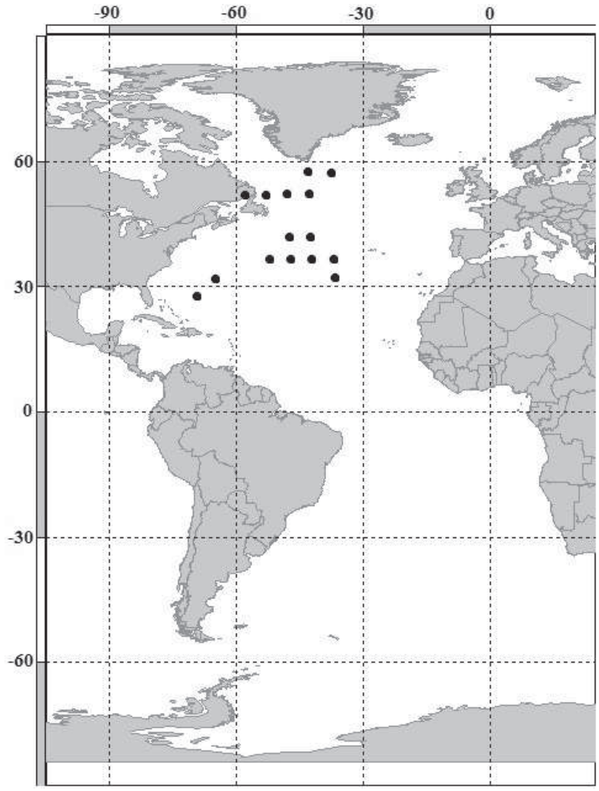


Fig. 1. Location of the regions' centers of Atlantic Ocean, whose surface temperature changes were significant in modeling TOC changes above Poland in June

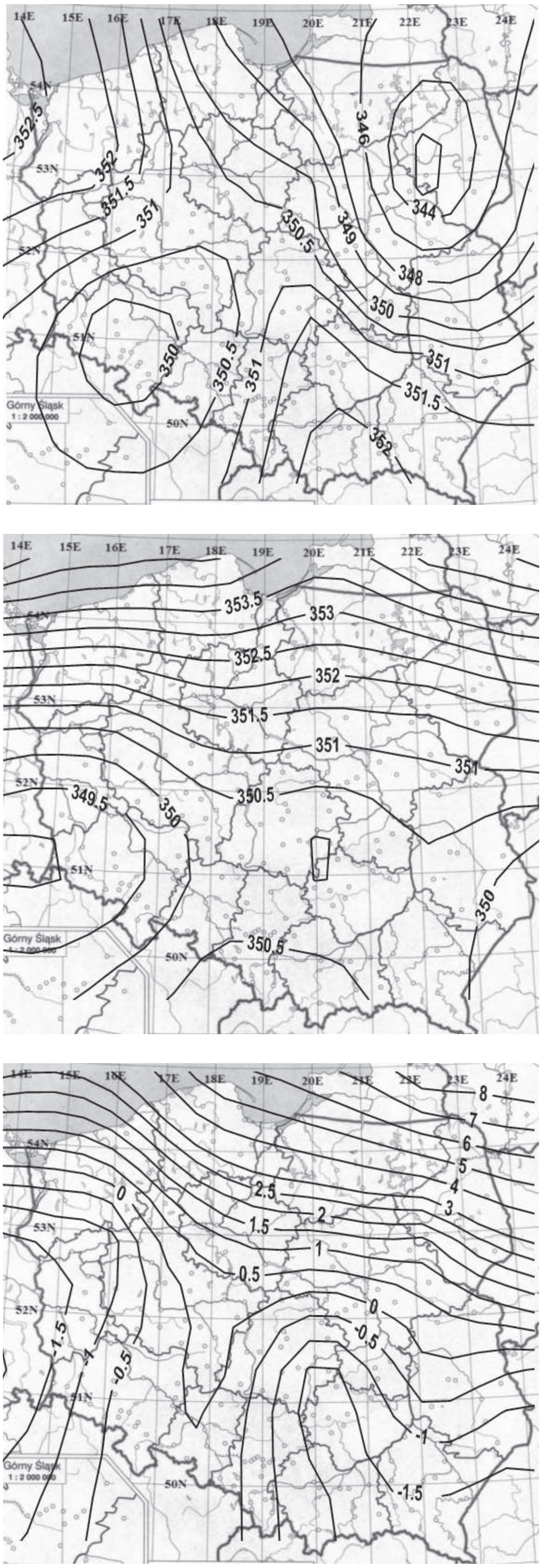
Table 2. Fact and forecasted TOC values over the Poland regions in June 2009

Fact	14°E	16°E	18°E	20°E	22°E	24°E
55°N	355.3	354.7	354.6	353.7	354.7	355.2
53°N	350.9	350.9	351.7	351.5	351.6	352.1
51°N	348.8	348.9	350.2	349.8	350.5	349.8
49°N	349.9	350.3	350.9	350.8	350.2	349.7
Outlook						
55°N	352.6	351.8	348.8	346.8	345.9	346.0
53°N	352.5	352.2	350.6	350.0	340.0	348.5
51°N	350.9	349.5	350.0	351.8	350.6	350.7
49°N	350.9	350.6	350.9	352.3	351.9	351.8
Forecast error						
55°N	2.7	2.9	5.8	6.8	8.9	9.1
53°N	-1.6	-1.3	1.0	1.5	1.6	3.5
51°N	-2.1	-0.5	0.2	-2.0	-0.1	-0.9
49°N	-1.1	-0.3	-0.1	-1.4	-1.7	-2.0

As is seen from Table 2, the maximum forecast errors (9.1 DU) correspond to Poland region with center coordinates 55°N, 24°E. Average error value over the whole Poland territory for a one-year forecast measures 1.44 DU, which is less than TOC measurement error, obtained on Dobson spectrophotometer.

Related comparisons for 2010 have shown, that prediction mean error, made for 2 years, measures 4.6 DU. If the forecast for 2010 is made with the use of model (1), factor changes in 1980 – 2009 period (i.e. the forecast for one year), mean error value measures 2.64 DU. In other months the amount of significant Atlantic Ocean areas is greater, and the TOC forecasts mistakes over Poland are fewer.

A) B) C)



Pic. 2. Distribution over Poland territory of forecasted (A) and fact (B) TOC values in June 2009, and prediction errors (C)

CONCLUSIONS

1. There are Atlantic Ocean areas whose surface temperature inter-annual changes significantly influence the TOC variations over Poland in coinciding time periods. It supports the adequacy of hypothesis about wave nature of the distribution mechanism in the stratosphere of ozone depleting substances.
2. Prediction errors of TOC distribution changes over Poland are maximal in June and increase when forecast is made on greater time shifts. Nevertheless, when forecast is made for 1 – 2 years, their levels (modulo) do not exceed absolute error of total ozone measurements instrumentally based on the most exact of existing devices – Dobson spectrophotometer. This reinforces application efficiency of predicting technique in the studied forecasting process.

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OCENA ZMIAN MIESIĘCZNEJ ŚREDNIEJ CAŁKOWITEJ DYSTRYBUCJI OZONOWEJ W ASPEKCIE WAHAŃ TEMPERATURY WÓD POWIERZCHNIOWYCH OCEANU ATLANTYCKIEGO

Streszczenie: Biorąc pod uwagę średnie miesięczne zmiany temperatury powierzchni w wodach Atlantyku, które mają silny wpływ na miesięczną średnią całkowitej dystrybucji ozonowej nad Polską, można sugerować ich skuteczne modelowanie i prognozowanie przez kilka lat. Błędy przewidywania są najwyższe w czerwcu i rosną wraz ze wzrostem okresu prognozowania. Niemniej jednak, gdy prognoza jest robiona na 1–2 lata ich poziom (modulo) nie przekracza błędu absolutnego sumy pomiarów ozonu w oparciu o najbardziej dokładne z istniejących urządzeń – spektrofotometr Dobsona.
Słowa kluczowe: zmienność całkowitego rozkładu ozonu nad Polską, temperatury powierzchniowe, znaczące obszary oceaniczne, modelowanie, prognozowanie, statystyczny związek, interakcja troposfery i stratosfery.