

Global Distribution of the Residual Ozonosphere Field Based on TOMS Satellite Data 1979–1992

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The residual ozone field (ROF), i.e., the global distribution of the total ozone content (TOC) after subtracting the contribution of calm solar energy, was constructed. Only the experimental Total Ozone Mapping Spectrometer (TOMS) Nimbus 7 data (1978–1993) were used in [1, 2]. In order to suppress temporal variations, the daily TOC values were first averaged over a 1-yr period for each year of the TOMS data and then averaged over the entire 14-year period. Annual and general charts of TOC were plotted. For each version, the global mean TOC meridional profile was plotted by averaging meridional profiles. Differences between the meridional TOC distribution in this chart and the global mean meridional distribution of this parameter make up elements of the ROF. The ROF value is expressed in Dobson units (DU) with a sign. It is positive if the TOC value at the current point exceeds the global mean value at the same latitude and is negative if the relation is the opposite. The ROF charts clearly demonstrate the following global division of the Earth's surface into two regions with the distribution of ROF elements of only one sign. The existence of anomalies confined to one field of the same type is a regional peculiarity. The only distortion is a negative anomaly over North America located in the positive ROF region. The ROF morphology is stable. The standard deviation between the ROF distribution in individual TOMS years and the ROF distribution averaged over 14 years varies within 2.6–5.4 DU. Two segments of the zero contour line, which spread from the North Geographic Pole to the South Geographic Pole demonstrate a similarity in their configuration, which is associated with their probable splitting. If these lines are displaced along latitude, they coincide with a high accuracy. The standard deviation between the elements of segments elongated in the latitudinal direction is 387 km. According to the paleomagnetic

data, the breakdown of Pangaea and the motion of continents [3] can be considered as mechanisms responsible for the division of the ROF into two regions.

All processes of the formation of the ozonosphere structure occur in the near-Earth space. Both geophysical and space fields function in this space. Within the multitude of fields existing in the ozonosphere, it is reasonable to analyze the set of energy sources in which the Sun would be the most powerful among them, but only as one of the components.

The reason to seek for the Earth's influence on the ozonosphere is confirmed by the TOC charts. The charts show that vast ozone-rich regions with size comparable with that of continents are located between the polar and mid-latitudes. These regions are marked by maximal values of the following two parameters: (i) the total strength of the geomagnetic field and (ii) the rigid magnetic cutoff of cosmic rays [4, 5]. In the course of time, these regions contract and expand in the meridional and latitudinal directions, respectively. The content of ozone varies within their limits, but its confinement to the regions is retained. The time variability is associated with the ozone-forming energy from outside. However, the confinement to specific regions indicates terrestrial mechanisms and sources. The search for energy sources of ozone is a pressing issue. Recent investigations indicate variations in the TOC against the background of its global-scale depletion since 1980. Statistically reliable positive trends suggesting the possible restoration of ozone content in the atmosphere have not been recorded thus far [6].

METHOD

The analysis in this work is only based on the experimental TOC values recorded by the TOMS Nimbus 7 in the years 1978–1993 [1, 2]. The TOC value includes the contribution of all ozone-forming sources. The Sun is the most powerful one among them. In order to estimate the role of terrestrial sources, we have to exclude the contribution of the Sun as a prominent latitudinal

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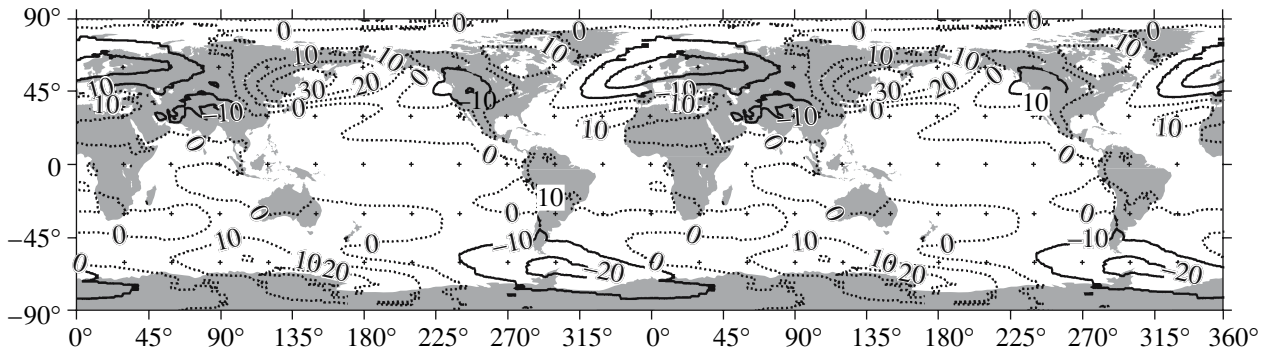


Fig. 1. Residual ozone field based on the TOMS data (average over the entire period 1979–1992). Zero dashed contour line denotes the boundary between positive and negative global ROF regions; dashed contour lines with numerals, regional positive ROF anomalies; solid lines, negative anomalies.

TOC evolution, because many details of ozone distribution are not manifested against this background.

The problem is solved by constructing the ROF. With this in mind, first, annual mean values are estimated from the daily TOMS data on TOC. Then, the values averaged over the total period of 1979–1992 are considered. Based on the average TOC values, annual charts and the general chart for 1979–1992 are compiled. For each chart, the global mean meridional TOC profile is calculated by averaging the meridional profiles for the whole globe.

It is important to take into consideration that the distribution of solar energy over a strict period of one year would be the same over each meridian. If we subtract the global mean value of the meridional TOC profile from individual meridional profiles, we would get the ROF, which is free from the contribution of the calm Sun (Fig. 1). The aforesaid can be presented in an analytical form. The TOC value at a current point on the Earth’s surface ($\Omega_{\phi\lambda}$) sums up the ozone content over all heights (1). Then, using the commonly accepted notations, the ROF value at this point can be presented as (2)

$$\Omega_{\phi\lambda} = \sum_h [O_3]_{\phi\lambda h}, \quad (1)$$

$$\Omega_{R\phi\lambda k} = \frac{1}{365} \sum_1^{365} \left\{ \sum_h [O_3]_{\phi\lambda hk} - \frac{1}{360} \sum_{\lambda=1}^{360} \sum_h [O_3]_{\phi\lambda hk} \right\}, \quad (2)$$

where Ω is the total ozone content, $[O_3]_h$ is the ozone concentration (indices h , ϕ , and λ designate height, latitude, and longitude, respectively), R is the residual value, and the index k denotes year in the TOMS experiment (1, 2, ..., 14 designate year 1979, 1980, ..., 1992, respectively). The residual ozone field is the distribution of the TOC deviation at the current point from the

mean TOC value at the given latitude averaged over one year or over the total period of k years.

MORPHOLOGY OF THE RESIDUAL ATMOSPHERIC OZONE FIELD

The ROF has characteristic features of both planetary and regional scales. The planetary features of the ROF are as follows:

1. The regions of the ROF of opposite signs are separated in space. The zero contour line divides the entire surface of the globe in the NW–SE direction into two regions, each of which includes elements of the field of only one sign (Fig. 1). From here on we shall call them the positive and negative regions of the ROF. There are no cases when the values of ROF of one sign would be found within the field of the opposite sign. In Fig. 1, the ROF chart is shown in a double opening version for convenience of viewing.

2. The boundary between the ROF regions has large-scale bends strongly elongated in the latitudinal direction.

3. The outlines of two segments of the separating line, each of which stretches from the North Geographic Pole to the South Geographic Pole, are clearly similar.

The regional features of the ROF are as follows:

1. Regions with extreme ROF values (ROF anomalies) exist over the Earth’s surface. Their power increases from the equator to the geographic poles. Anomalies with an amplitude of 5–10 DU are found predominantly in the equatorial and mid-latitudes. Large-scale anomalies with sizes comparable with those of continents are located between the polar and mid-latitudes, where the amplitude reaches ± 50 DU (Fig. 1).

2. The regional ROF anomalies are superimposed on the planetary regions of the same sign. The positive planetary region incorporates three positive anomalies located (1) at the North Magnetic Pole, (2) near the South Magnetic Pole, and (3) over East Siberia and Sea of Okhotsk. Regional negative anomalies located over

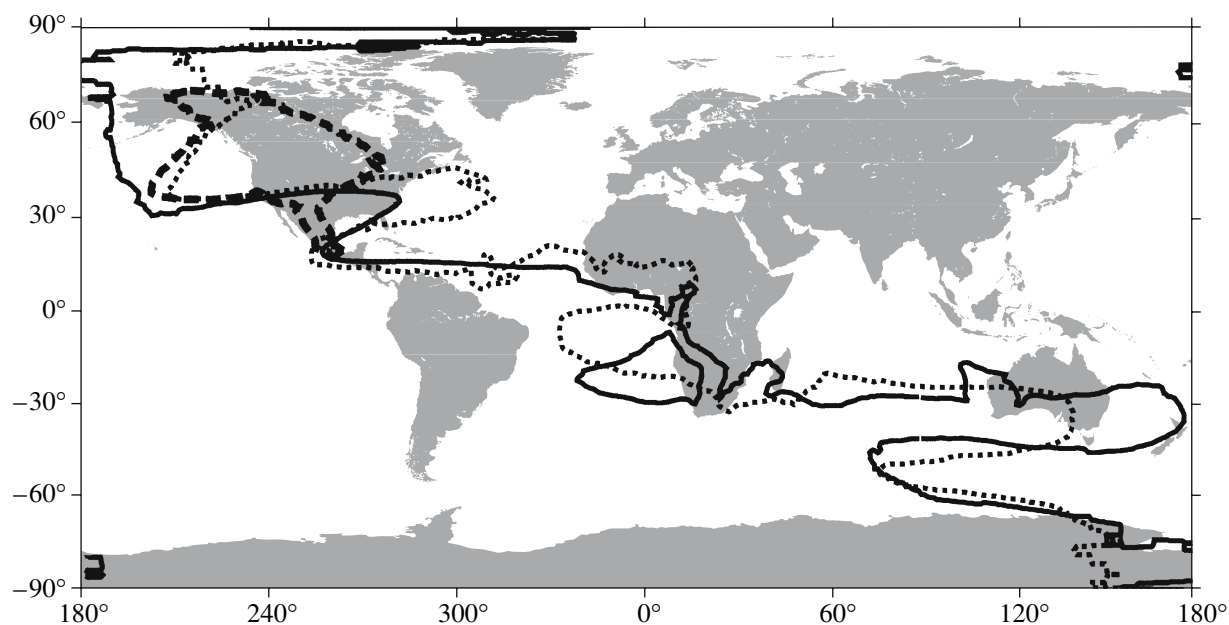


Fig. 2. Joining of two segments of the zero contour line. Solid and dashed lines denote the western and eastern boundaries, respectively, of the positive region. Heavy dashed line denotes negative anomaly over North America.

Scandinavia, North Atlantic, South Asia, South America, and Antarctica do not spread beyond the negative planetary region.

The only exception is the negative anomaly over North America. It is located in the positive ROF region.

SCENARIO OF THE EVOLUTION OF THE RESIDUAL OZONE FIELD

The ROF morphology suggests a scenario of its development in time. The similarity in the configuration of two segments of the zero contour line is associated with the possible division of the ROF and further splitting of the interface in the latitudinal direction. The reality of this scenario can be tested by realizing it in the reverse time scale. This means that the boundaries of the field would move along the latitude opposite to each other until they merge. On the basis of the shape of the restored initial positions of the separation line, one can judge whether or not the suggested scenario is correct. Figure 2 demonstrates the following facts:

(1) Segments of the zero contour line converge to a high accuracy. The weighted mean deviation between all merged fragments elongated in the latitudinal direction is equal to 387 km. On the global scale, such deviation is negligibly small. A significant deviation of ~1500 km falls on the southwestern part of Africa and adjacent oceans.

(2) The restored position of the fracture is located in the World Ocean basin.

The reality of the ROF splitting is confirmed by the analysis of the evolution of our planet. It is necessary that both processes would develop simultaneously in

the same space. From this point of view, the timing of separation of the joint block of North America and Eurasia from the ancient Pangaea continent is very important [2]. Subsequently, the block was separated into two continents that drifted to their present locations. Gondwanaland left after Pangaea was subject to further splitting and only Africa retained its position. This fact should be reflected in the ROF. Indeed, if we displace boundaries of the positive ROF region together with the associated real continents in the Southern Hemisphere up to the point of the convergence of boundaries, South America and Australia should converge with Africa from the west and east, respectively. Thus, pieces of the split Gondwanaland return to the initial positions.

In the Northern Hemisphere, the outlines of the ROF negative anomaly over North America mimic the contours of the real continent, but they are displaced to the west of the continent. Even the isthmus between North and South Americas is retained. At a certain stage of convergence, the negative anomaly over North America merges with the global negative ROF region, while the continent closely approaches Eurasia. After this, the boundary of the field would pass along the western contour of the anomaly. During the further convergence, the boundaries merge and the positive ROF part disappears (Fig. 2). Thus, this scenario explains why the negative ROF anomaly over North America appeared in the field of the opposite sign and makes up the only exception in the ROF morphology. This is the result of fragmentation and further pull-apart motion of the continents.

The importance of the splitting process is determined by the following facts:

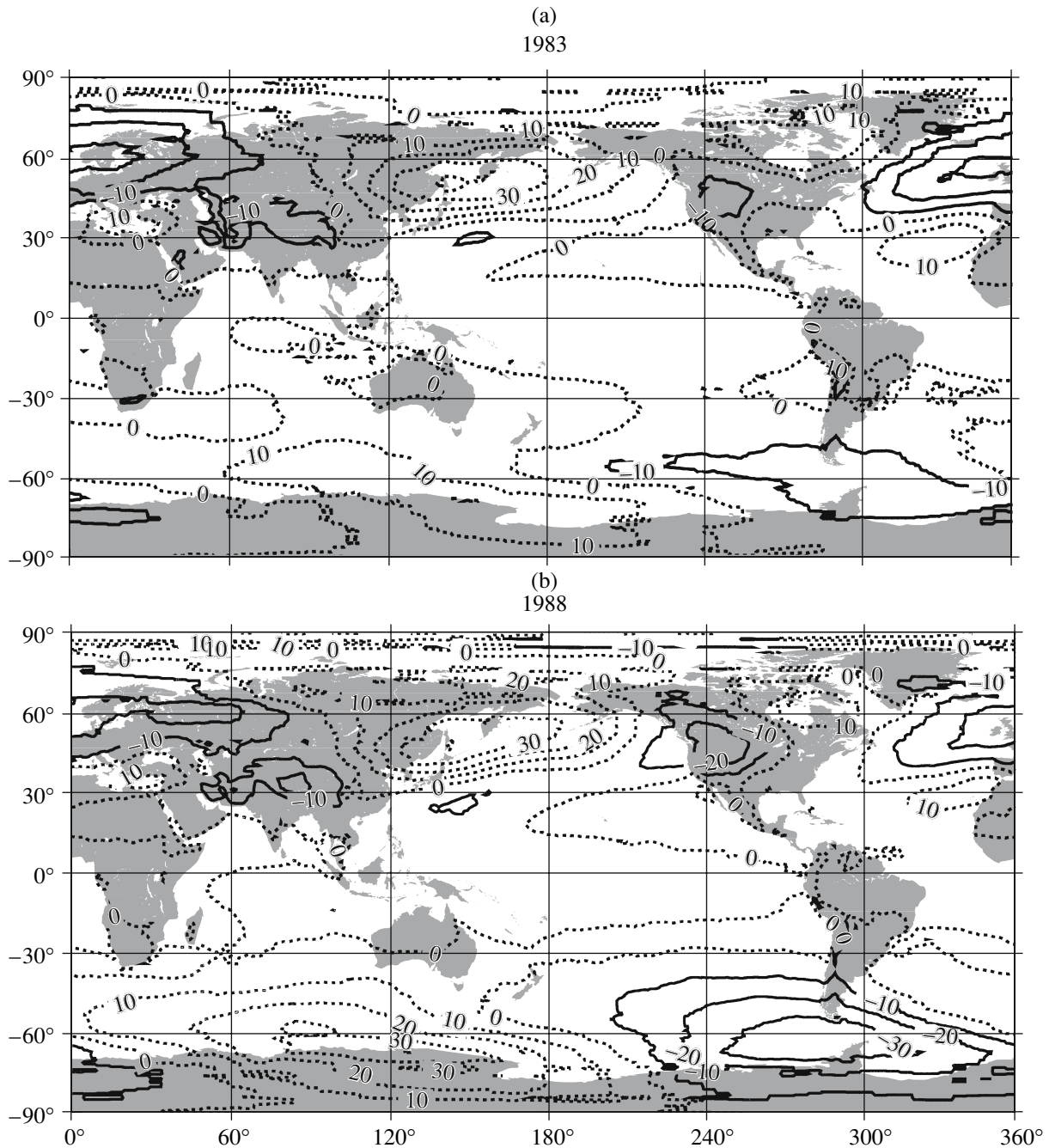


Fig. 3. Annual mean ROF in (a) 1983 and (b) 1988 located on the falling and rising branches of the solar activity cycle.

1. The evolution of the ozonosphere followed the scenario of increase in the TOC value. Splitting of the continents facilitated the release of deep energy needed for ozone formation. According to [7], the average amount of thermal flux directed from the Earth's interior to the surface in the continents and ocean is equal to 65 and 101 mW m⁻², respectively [8]. This energy is sufficient to supply 4 · 10¹² of new ozone molecules per second to the atmospheric column with an area of 1 cm². As a result, drift of split boundaries promoted expansion of the ozone-rich space.

2. The epoch of separation of North America from Eurasia can be estimated in the following way. Let us assume that the velocity of the mutual convergence of boundaries is 4 cm/yr, which corresponds to the velocity of the pull-apart motion of the Mid-Atlantic rift. The anomaly is located at a distance of approximately 45° by longitude from the eastern boundary. The equivalent distance of 5000 km at the equator can be passed at the specified velocity in 125 Ma. According to the paleomagnetic data, America was separated from Eurasia in the early Mesozoic, i.e., 125 Ma ago. Since data on the

Standard and maximal deviations of the annual ROF values from the mean ROF values over the entire period of the TOMS experiment (1979–1992)

Year	Standard deviation, DU	Maximal deviation, DU	Longitude east, deg	Latitude, deg
1979	3.0	16.0	0.5	16.5
1980	3.6	16.4	315.5	86.5
1981	2.7	-12.4	15.5	84.4
1982	3.2	18.5	35.5	76.5
1983	3.2	-14.7	318.0	52.5
1984	3.0	17.3	185.5	87.5
1985	5.0	-19.7	63.5	-67.5
1986	3.5	-15.7	65.5	77.5
1987	3.1	17.9	50.5	72.5
1988	5.4	-22.2	250.5	-67.5
1989	3.5	19.1	347.5	66.5
1990	3.5	19.6	318.5	66.5
1991	3.3	16.0	10.5	87.5
1992	3.9	17.0	173.5	-63.3

initial velocity are lacking, the exact chronological coincidence of the two processes is not a strict factor, but chronological coincidence by the order of magnitude is an important argument in favor of the reality of ROF splitting.

3. The general ROF splitting occurred much earlier than the separation of the North American continent from Eurasia.

4. A hypothesis is put forward about the nature of the Siberian–Sea of Okhotsk ROF anomaly. The general orientation of the ROF global regions is determined by two positive anomalies located (1) over East Siberia and the Sea of Okhotsk and (2) near the South Magnetic Pole. Furthermore, both regional anomalies together with a third anomaly located near the North Magnetic Pole are localized in the regions with extreme values of TOC, full strength of the geomagnetic field, and sharp geomagnetic cut-off of cosmic rays [4]. It is known from paleomagnetic data that the North Magnetic Pole shifted from the region of present-day Australia to the region of the Sea of Okhotsk at the beginning of the Devonian. It remained there until the beginning of the Triassic and then shifted to the present-day Polar region. The Siberian–Sea of Okhotsk anomaly, the most powerful among all anomalies, is now located at the site of the localization of the past North Magnetic Pole. It is not excluded that this anomaly is a result of geomagnetic field evolution. An alternative explanation is possible because the anomaly is located in the zone of high tectonic activity [9].

STABILITY OF THE PARAMETERS OF THE RESIDUAL OZONE FIELD

Annual mean charts of the ROF for each year of the TOMS experiment were plotted to estimate variability of the ROF in time (Fig. 3). All morphological features typical of the chart averaged over the entire TOMS period are retained in each of the charts (Fig. 1). The table shows standard deviations between the distributions of the residual ozone on annual charts and on the chart averaged over the entire period. Their values vary from 2.7 DU (1981) to 5.4 DU (1988). Charts for 1983 and 1988 show that differences in the annual ROF distribution are manifested in the solar activity cycle. These years correspond to the falling and rising branches, respectively, of the solar cycle activity.

CONCLUSIONS

Geophysical processes were identified with the terrestrial mechanisms, which can stimulate ozone formation in the atmosphere. The ROF without the contribution of the direct solar energy points to its terrestrial origin. The analysis showed that two processes (global splitting of the Earth's surface and evolution of the geomagnetic field) are reflected in the ROF morphology. The timing and localization of both processes are consistent with paleomagnetic data. It is difficult to explain the global-scale structure of the ozonosphere and forecast its evolution without consideration of the ROF morphology.

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