# OBSERVATIONS ABOUT THE TOTAL OZONE CONTENT IN THE ATMOSPHERE IN HIGH ARCTIC LATITUDES

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*Received June 30, 1994*

*Calculational results of the total content of atmospheric ozone at a high–latitude station on Heiss Island (81°N, 58°E) using a Brewer spectrophotometer are analyzed. The ground–based measurements in those latitudes during polar nights of 1989–1994 did not reveal any significant periods of any substantial decrease in the ozone content of the atmosphere. The summer observations of 1992 and 1993 indicate a substantial reduction of ozone compared to the climatic mean values. The maximum decrease of ozone (monthly mean is 16.7%) was observed in August, 1993, and the decrease of the total ozone content during April–September, 1993, was 13.2%.*

## 1. INTRODUCTION

Though an ozone hole has been discovered in Antarctic and different possible hypothesis on its origin have been considered, this phenomenon remains to be studied at length in the north latitudes. Over the past twenty years in the northern hemisphere the total ozone content (TOC) in the atmosphere has been decreasing. It became particularly noticeable during the past several years. It should be noted that the strongest negative trend of TOC occurs in winter period.

The estimates of trends are usually carried out only for latitudes up to 60 to 65°N since a number of ground–based stations in high latitudes and observations at them are insufficient. The extraction of information on ozone from spaceborne measurements is bounded in time and space to large solar zenith angles when twilight sets in the polar region. As a consequence, there are many uncertainties in estimating real trends of atmospheric ozone in arctic latitudes particularly in winter.

In recent years several publications appeared on extremely low content of ozone observed at ground–based stations and with spaceborne instrumentation in midlatitudes of the northern hemisphere. Based on the analysis of satellite data Gleason et al.[1] reported on extremely low TOC in 1992 for a latitude belt of 65°N to 65°S. In Ref. 2 the authors describe the measurement results of ozone using an instrument SBUV/2 onboard a NOAA–11 satellite for the 25–60°N zone. They indicate low TOC starting in late in summer of 1992, which was also observed in summer of 1993. Though the situation with extremely low TOC is not clear enough it may be caused by volcanic aerosol occurring in the atmosphere after the powerful Pinatubo eruption in June, 1991.

Extremely low content of ozone was also observed at many ground based ozonometric stations in the northern hemisphere. The USA network of stations equipped with Dobson spectrometers recorded the ozone reduction by 12.6%, on the average, in January–April, 1993 (Ref. 3). Low TOC was observed in 1992 and 1993 over the vast areas of North America, Europe, and Siberia[4] where, between 45 and 65°N, the ozone deficit reached 11–13% as compared to the climatic mean level. An extremely low TOC were observed in Canada with a set of Brewer instrumentation in the latitude interval between 44 and 75°N covering a 80° longitudinal zone. Here the TOC values decreased by 11 to 17% too. The results of simultaneous analysis of ozone–zonde data on the ozone vertical distribution[5] revealed the ozone deficit in the lower stratosphere between 40 and 200 mbar level (at the same altitudes an enhanced aerosol layer was observed after the Pinatubo eruption) and the maximum ozone losses at the 100 mbar level attaining 30% of the norm. The ozone–zonde measurements in Greenland[6] showed a 12% decrease of TOC from the end of January, 1993. The ozone concentration reduction was observed at the heights between 14 and 20 km.

The calculations of TOC variations made in Ref. 7 using a two–dimensional model allowing for the processes of heterogeneous chemistry on aerosol surface estimated based on SAGE–II data show that the maximum ozone reduction in the northern hemisphere occurred in winter of 1992–1993. If the heterogenous mechanism is the chief reason for low level of ozone in 1992 and 1993, then the ozone concentrations are expected to restore in 1994.

In this paper we discuss the results of ground–based spectrophotometric observations about the total content of atmospheric ozone in high latitudes of European sector of Arctic Regions over Heiss Island (81°N, 58°E) which complete the general picture of the atmospheric ozone field of the northern hemisphere prior to and after the Pinatubo eruption which seems to be the most powerful eruption in the present century. At the same time we consider variations in TOC during the polar night of 1989–1994 winters and analyze the observational results of the total ozone content during summers of 1990–1993.

## 2. INSTRUMENTATION AND QUALITY OF THE OZONE OBSERVATIONAL RESULTS

To extract information about the state of the Arctic atmosphere, the high–precision measurements of the total ozone content have been started on Heiss Island in 1989. The Brewer spectrophotometer capable of measuring ozone by either sunlight or moonlight under polar night conditions was used in the measurements. In winter of 1988–1989 we undertook an expedition observations and in May, 1990, the Brewer instrument of new modification MK–IV was installed for regular ozonometric measurements within the framework of joint research

0235-6880/95/6 451-04 $02.00 

program of Russian and Canadian specialists from the Environment Protection Service of Canada.

The Brewer spectrophotometer MK–IV produced by the SCI–TEC Company (Canada) is a modification of the Brewer instrument of the MK–II model and enables one to carry out automated measurements of the total content of atmospheric ozone, $SO_2$, $NO_2$, and observations about the levels of UV solar radiation.

The standard procedure for calculating TOC from radiation measurements at four wavelengths in the 310–320 nm range accepted for the Brewer spectrophotometers was used to obtain the values of the total ozone content. The observational data on TOC during winter period were obtained from the spectrophotometric measurements of moon radiation. The summer results which are analyzed in this paper are the TOC measurements based on the direct solar radiation.

To check the quality of ozone measurements, the Brewer spectrophotometer was compared to the other ozonometers when observing TOC based on the direct solar radiation including the reference to the standard triad with the Brewer ozonometer in Toronto and the comparison was also made with the Dobson No. 107 spectrophotometer calibrated in 1988 based on the USA standard Dobson spectrophotometer. Disagreement in the daily mean values of ozone did not exceed 1% for the measurement interval of atmospheric ozone mass between 1.6 and 3.2. Long–term stability of the Brewer spectrophotometer used on Heiss Island was tested by indicators of standard halogen lamp built–in in the ozonometer. The analysis of four–year series of counts from the standard lamp (from May, 1990, till March, 1994) revealed good agreement between their values and those set originally within ±0.5% is indicative of normal operation of the instrument during such a long period.

Additional observations about the dependence of the Brewer instrument data on the value of solar zenith angle were made and the random components of the error in the TOC measurements by sunlight and moonlight were considered to assess the quality of the total ozone content observations over Heiss Island. The TOC observations by direct solar radiation were usually carried out for optical mass of the atmosphere, $m$, not exceeding 3.2. When it is substantially higher there appeared a regular measurement error which resulted in false underestimation of the ozone content. The error was related to both the decreased level of the recorded direct solar radiation, increased contribution from the light scattered inside a single monochromator from longer wavelengths and an increased portion of the radiation scattered in the atmosphere.

The results of our observations show that the limit of admissible value of optical air mass of the atmosphere, when there is no underestimation in the Brewer spectrophotometer data on ozone, is $m = 4.2$ and decreases to $m = 3.8$ in hazes and observations through thin clouds in the atmosphere. When $m$ increases, a systematic measurement error appears which grows to minus 3% for $m = 5.5$. A random component of the error in the TOC individual observation by the direct sun under favorable atmospheric conditions is lower than 1% when $1.3 < m < 3.5$ and it increases to 2% when $m = 5$. For observations using moonlight, when $1.6 < m < 3.5$, its value varies from 2 to 3% and rapidly increases to 5% for $m = 3.6$.

To obtain qualitative data, when observing TOC the upper limit of air mass was chosen to be $m = 3.2$ for measurements in moonlight and $m = 3.8$ for direct solar measurements taking into account the aforementioned relations. Therefore the summer period of solar TOC observations was confined from early in April till the middle of September. The polar–night measurements of the total ozone content were carried out from late in October till late in February taking into account the fact that the Sun rise after polar night at the latitude of Heiss Island starts on February 23 and the moon observations of ozone in March are hampered due to the sunlight illumination of the sky.

Since during the polar day the Sun constantly occurs above the horizon it is possible to carry out a great number of direct solar measurements of TOC and the results of these observations in May–August represent the most realistic situation of annual summer variations of ozone in this high–latitude region of European section of Arctic Regions.

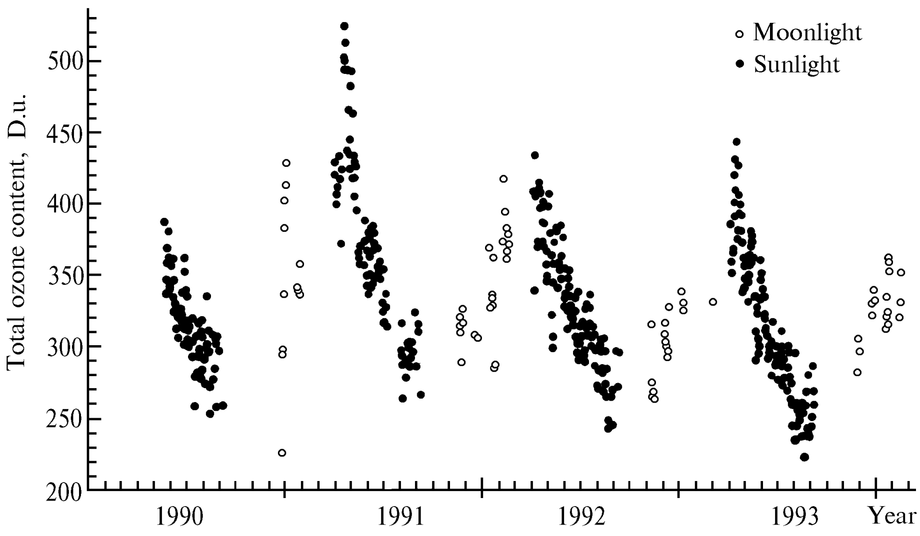


*FIG. 1. Measurement results on the total ozone content at Heiss Island in 1990–1994.*

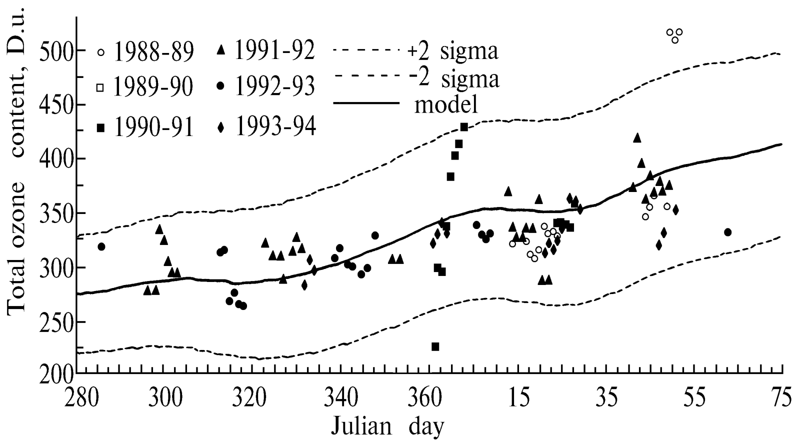


*FIG. 2. Observational results on the total ozone content during winter of 1989–1994 and data of the TOC empirical model for Heiss Island.*

## 3. RESULTS OF OBSERVATIONS AND DISCUSSION

The observational results of the total content of ozone over Heiss Island (81°N, 58°E) are represented in Fig. 1.

The TOC values considered above have been corrected for the entire period of observations according to ozone absorption coefficients of Bass and Paur.[9] The annual cycle of ozone measurements at 81°N is typical for high latitudes of the northern hemisphere. The large values of TOC, larger than 400 D.u. (Dobson units), are observed between late winter and early spring depending on the start of rise in stratospheric temperature. Minimum TOC are usually observed here in winter months, October and November, and during the polar day late in summer. In 1992–1993 the total ozone content reached an extremely low levels in July and August. The monthly mean value of TOC in August, 1993, was 249 D.u. which was the lowest monthly mean of ozone content for the entire five–year period of observations in this Arctic Region. The maximum TOC values were observed in spring of 1991 when the total ozone content in the atmosphere increased to 528 D.u. on April 24. The lowest value 226 D.u. was recorded in December 27, 1990.

## 4. TOTAL OZONE CONTENT DURING THE POLAR NIGHT

The total ozone content over Heiss Island during the polar nights of 1984–1994 was sufficiently stable. This period is characterized by a relatively stable state of ozonosphere when during some months, particularly in November–January, ozone except for a one–week period between late in December, 1990, and early in January, 1991, varied insignificantly and its month variations did not exceed 10%. Thus in January and the first half of February, 1989, the values of TOC varied slightly between 310 and 350 D.u. In January, 1991, there were also no substantial variations in TOC. It varied between 340 and 360 D.u. In the lower stratosphere at the 50 mbar level in the second half of January, 1991 the temperature was fairly stable and did not fall below –80°C. In the January series of ozone observations of 1989 it often dropped down to –85°C, the TOC values were much lower and TOC variations over Heiss Island coincided with temperature variations in the lower stratosphere.[10,11] As a rule, during the temperature decrease we observed decreased values of the total ozone content in the atmosphere which were recorded by the spectrophotometer. These periods are characterized by unperturbed dynamics of the stratosphere. The results of spectrophotometric measurements during winter, 1992–1994, did not reveal any sharp variations in TOC as compared to the previous winter periods.

Until 1989 there were no winter observations on Heiss Island, therefore there are no data with which we could compare the results of 1989–1994. In Ref. 12 an empirical model of the TOC field for the northern hemisphere was proposed. It was constructed based on the data of the ground–based ozonometric net obtained during 1974–1984 and allowed one to extrapolate the TOC values and their rms deviations for diurnal data to high latitudes. Figure 2 shows that all winter observations of TOC are in good agreement with the model and there is no sharp decrease of TOC over Heiss Island in November–February.

Thus, during the polar nights of 1989–1994 in the absence of solar radiation in the lower stratosphere we did not detect any significant periods with distinct reduction of the total ozone content.

## 5. TOTAL OZONE CONTENT DURING THE POLAR DAY

Figure 3 depicts a plot of variations of monthly mean values of the total ozone content over Heiss Island for summer periods between April and September, 1990–1993. Given here for comparison are the monthly mean values of TOC obtained from the empirical model. It is clearly seen from the plot that in 1992 and 1993 the values of TOC are lower than those in 1990 and 1991. The decrease of the total ozone content in the atmosphere over Heiss Island during April–September, 1992, was 8.3% compared to the long–term mean value. The data of 1993 support the fact of summer ozone decrease. In 1993 the ozone content decreased by 5.3% more as compared to that of 1992. The maximum level of reduction of the total ozone content over Heiss Island was recorded in August, 1993. The ozone content during this month reduced by 16.7%.

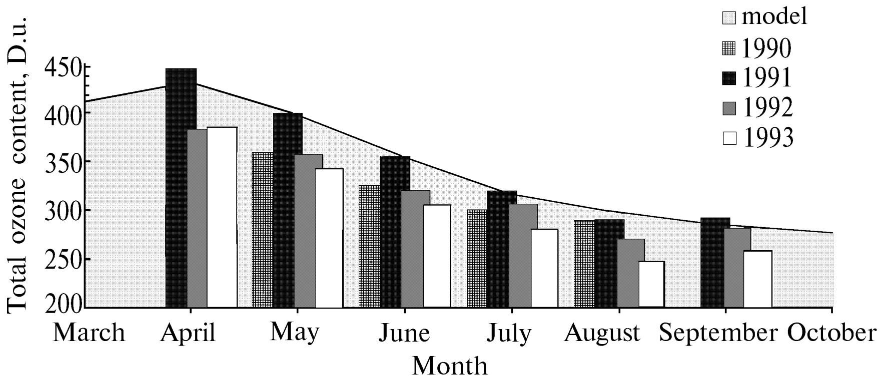


*FIG. 3. Monthly mean values of TOC on Heiss Island compared to the summer model of 1990–1993.*

The results of observations about TOC obtained over Heiss Island during the polar day of 1992 and 1993 coincide with the general situation of decreased TOC values during 1992 and 1993 in midlatitudes of the northern hemisphere and show that the extremely low values of TOC in the atmosphere are also characteristic of high polar latitudes of the Eastern Arctic Region at 81°N. The decrease of the TOC level in April–September of 1993 was 13.2%. This substantial reduction of TOC in 1992 and 1993 is not yet understood, though many authors try to relate them to the powerful Pinatubo eruption. Further observations about the ozone content will allow one to adjust possible mechanism of TOC decrease during this period.

## REFERENCES

1. J.F. Gleason, et al., Science, No. 260, 523–526 (1993).
2. W.G. Planet, et al., GRL **21**, 205–208 (1994).
3. W.D. Komhyr, et al., GRL **21**, 201–204 (1994).
4. R.D. Bojkov, et al., GRL **20**, 1351–1354 (1993).
5. J.B. Kerr, D.I. Wardle, and D.W. Tarasick, GRL **20**, 1979–1982 (1993).
6. T.S. Jorgenson, et al., Annales Geophysical **12**, Suppl. 3, 597 (1994).
7. J.M. Rodrigues, et al., GRL **21**, 209–212 (1994).
8. J.B. Kerr, et al., in: *Atmospheric Ozone* (G.S. Zerefos and A. Ghazi, eds) (D. Reidel Publ. Co., 1985), pp. 346–401.
9. A.M. Bass and R.J. Paur, in: *Atmospheric Ozone* (G.S. Zerefos and A. Ghazi, eds) (D. Reidel Publ. Co., 1985), pp. 605–610.
10. V.M. Dorokhov, Atm. Opt. **3**, No. 1, 89–94 (1990).
11. V.M. Dorokhov, V.È. Fioletov, and V.I. Sitnikova, Meteorol. Gidrol., No. 6, 54–59 (1992).
12. T.V. Kodygrova and V.È. Fioletov, in: *Atmospheric Ozone* (Gidrometeoizdat, Moscow, 1990), pp. 89–96.