

# 30 years of total ozone and AOD measurements using the Brewer spectrophotometer in Poprad-Gánovce, Slovakia



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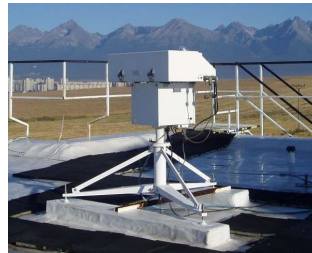
**Introduction:** the first measurements of total atmospheric ozone in Slovakia began at the Poprad-Gánovce station with the Brewer ozone spectrophotometer in August 1993. As a result, a 30-year series of measurements was completed in 2023. The main goal of my contribution is to present the calculated values of total atmospheric ozone and aerosol optical depth (AOD) which come from measurements using the same Brewer. Also presented are interesting trends of two key parameters that affect the amount of solar UV radiation reaching the Earth's surface. The obtained results fit quite well into the well-known mosaic of recent years atmospheric development in the wider regional space of Eastern Europe. The total ozone trend in this region is determined by both atmospheric dynamic and ozone-depleting substances (ODS) related effects. An acceleration of the Brewer-Dobson circulation and other atmospheric changes due to increasing amounts of greenhouse gases are probably beginning to manifest itself, but differently in individual months of the year. Social and industrial changes in the region have caused a significant decrease in anthropogenic air pollution. As a result, there has been a gradual decline in AOD in recent decades.

## Measurement site



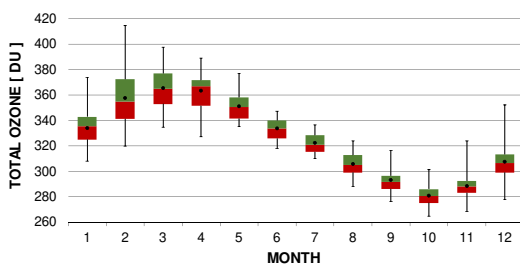
The Brewer is placed on the roof of the building of Aerological and Solar Radiation Center Poprad-Gánovce of the Slovak Hydrometeorological Institute. Its coordinates are 49.03 °N, 20.32 °E and it has an altitude of 709 m above sea level. The site is located in the Podtatranská basin, which is part of a larger geomorphological unit called the Carpathians. There are mountain units of different heights around. Gerlachovský štít (2654 m above sea level), the highest peak of the Carpathians, is located only 20 km from the station. Among the more important local aerosol sources are the products of burning solid fuel, mainly wood in the surrounding villages and agriculture. In the presence of a larger pressure gradient, the location is relatively windy. The prevailing wind directions are west, north and south-east. The proximity of the city of Poprad (approx. 1.5 km) with approximately 50 000 inhabitants and various industrial activities also plays a role. In spite of the proximity of the mentioned city, the area can generally be deemed rural with respect to the anthropogenic impact.

## Instrument and method

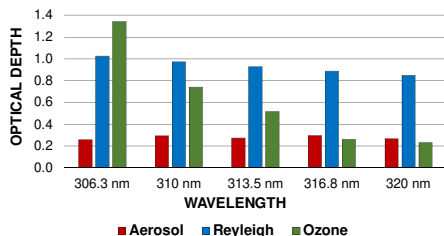
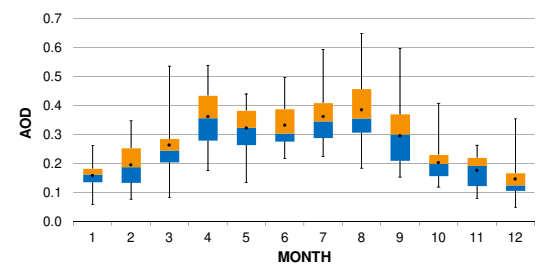


The Brewer ozone spectrophotometer # 97, model MKIV (single monochromator) has been working at the Poprad-Gánovce station since August 18, 1993. It focuses mainly on the measurement of total atmospheric ozone and the spectrum of global solar UV radiation. Measurements of direct sunlight for wavelengths of 306.3 nm, 310 nm, 313.5 nm, 316.8 nm and 320 nm were also used to determine AOD. Since the beginning of the measurements, the device has undergone regular 2-year calibration and daily tests using internal lamps. The instrument is calibrated by International Ozone Services Inc. according to the global reference group (Brewer Triad), maintained at Environment Canada, through a travel reference instrument. Measurements can be considered as homogeneous from a technical point of view. Only Direct Sun (DS) measurements were used for total ozone analysis. AOD was determined by using extraterrestrial constants (changed after each calibration) obtained by the Langley plot method. The calculation takes into account the corrections for diffuse radiation, the stray-light effect and polarization. The methodology follows the work of Hrabčák, 2018, but it is improved.

## Results

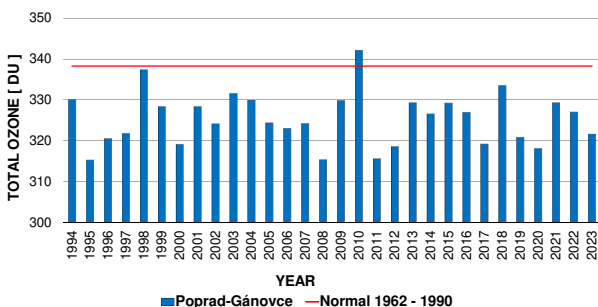
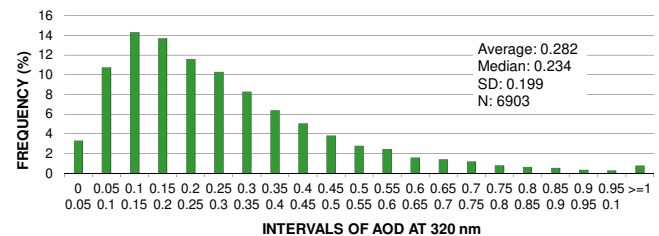


The graphs illustrate the long-term monthly characteristics of total ozone (left side) and AOD at 320 nm (right side) for Poprad-Gánovce obtained over the 30-year period (1994 - 2023). Solid points represent mean values, the border between the boxes represents the median, the lower and upper limits of the boxes portray the first (25%) and the third (75%) quartiles respectively and the lower and upper whiskers account for minimum and maximum respectively.



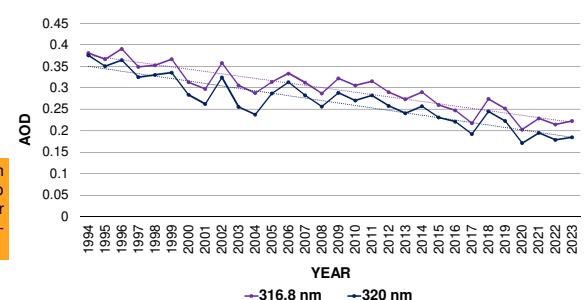
The left-side graph shows the 30-year averages (1994 - 2023) of optical depth values at five wavelengths for aerosol, Rayleigh scattering and total ozone.

The right-side histogram illustrates the relative occurrence of daily averages of AOD at 320 nm for Poprad-Gánovce in the 30-year period (1994 - 2023).



The left graph shows the annual averages of total ozone for Poprad-Gánovce for the 30-year period (1994 - 2023) compared with the normal (1962 - 1990) measured at the nearby Hradec-Králové station.

The right graph shows the comparison of annual averages of AOD at the two longest wavelengths and their linear trend for Poprad-Gánovce for the 30-year period (1994 - 2023).



The tables show the statistical characteristics of the linear trend for the period from 1994 to 2023 in the case of individual months for total ozone values (left-side) and AOD at 320 nm (right-side).

MONTH	1	2	3	4	5	6	7	8	9	10	11	12
TREND [ DU ]	13.3	-4.7	7.0	-7.5	4.0	-1.3	-2.0	-10.3	-8.2	-2.1	6.5	0.1
SD OF TREND	9.8	14.2	9.7	9.4	7.2	5.1	4.7	5.3	6.7	5.6	6.6	9.8
TREND/SD	1.4	-0.3	0.7	-0.8	0.6	-0.2	-0.4	-1.9	-1.2	-0.4	1.0	0.0

MONTH	1	2	3	4	5	6	7	8	9	10	11	12
TREND	-0.06	-0.13	-0.20	-0.25	-0.19	-0.17	-0.18	-0.24	-0.20	-0.15	-0.11	-0.09
SD OF TREND	0.03	0.04	0.04	0.05	0.03	0.04	0.05	0.05	0.05	0.03	0.03	0.04
TREND/SD	-2.3	-3.5	-4.5	-5.2	-6.1	-4.5	-3.7	-4.5	-4.0	-5.4	-4.4	-2.6

**Summary:** the long-term 30-year average (1994 - 2023) of total ozone reached the value of 325.4 DU, which is 3.8% less than the normal value of 338.3 DU measured at the nearby Hradec-Králové station. The lowest annual average was measured in 1995 at 315.3 DU (-6.8% compared to normal). The highest annual average was measured in 2010 at 342.2 DU (+1.1% compared to normal). The linear trend for the period 1994 - 2023 is statistically insignificant and reached the value of  $-0.4 \pm 4$  (SD) DU. In the case of months, the most interesting trends were observed in January ( $13.3 \pm 9.8$  DU) and August ( $-10.3 \pm 5.3$  DU). The historically lowest daily average was measured on January 1, 1998 at 202.6 DU and the highest on February 24, 1999 at 509 DU. The long-term 30-year average of AOD acquired the following values: 0.257 at 306.3 nm, 0.293 at 310 nm, 0.273 at 313.5 nm, 0.298 at 316.8 nm and 0.267 at 320 nm. The Ångström exponent takes on a negative value for some pairs of wavelengths. The relative occurrence of daily averages of AOD at 320 nm showed a left-side skewed distribution and the most frequent occurrence of values in the range from 0.1 to 0.15. The linear trend for the period from 1994 to 2023 is statistically significant for all wavelengths and reached the following values:  $-0.17 \pm 0.1$  at 306.3 nm,  $-0.15 \pm 0.1$  at 310 nm,  $-0.17 \pm 0.1$  at 313.5 nm,  $-0.16 \pm 0.1$  at 316.8 nm and  $-0.17 \pm 0.1$  at 320 nm. Decreasing trends in AOD were observed for all wavelengths and months of the year. It is noteworthy that the lowest annual average of AOD for all 5 wavelengths was measured in 2020, during the first year of COVID-19 pandemic.

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**Reference:** Hrabčák, P.: Comparison of the optical depth of total ozone and atmospheric aerosols in Poprad-Gánovce, Slovakia, Atmos. Chem. Phys., 18, 7739-7755, <https://doi.org/10.5194/acp-18-7739-2018>, 2018.