POLAND

Ozone and UV monitoring and related research activities are conducted in the Institute of Meteorology and Water Management - National Research Institute (IMWM), and in the Institute of Geophysics of the Polish Academy of Sciences (IGFPAS). The ozone, UV-B monitoring, and research, carried on at both Institutes, are supported by the Chief Inspectorate for Environmental Protection; National Fund for Environmental Protection and Water Management; Ministry of the Environment, and the National Science Centre.

1. OBSERVATIONAL ACTIVITIES

1.1 Column ozone measurements and other gases and variables relevant to ozone Loss

1.1.1 Institute of Geophysics of the Polish Academy of Sciences

IGFPAS has been involved in the long-term monitoring of the ozone layer for over 60 years. Measurements of the total ozone content and ozone vertical profile by the Umkehr method at Belsk (51°50'N, 20°47'E) by means of the Dobson spectrophotometer No.84 started in 1963, long before the depletion of the ozone layer became the great challenge for research community and the policy makers. In 1991 the Brewer spectrophotometer No.64 (single monochromator) with a UV-B monitor was installed. The Brewer spectrophotometer No. 207 (double monochromator) was put into operation in 2010. The column ozone and ozone content in the Umkehr layers are measured simultaneously by 3 instruments that helps to determine precision of the ozone observations by each spectrophotometer. The surface ozone measurements with Monitor Labs, ML8810 meter started in 1991 (replaced by ML9811 in 2004 and Thermo 49i in 2010) and since 1992 NOx measurements have been done with Monitor Labs ML8841 meter (replaced by API200AU in 2004 and Horiba APNA 370 in 2019). The extended duration of the measurements and the high quality of the ozone data were essential for trend detection. Because the high quality of the ozone data is crucial subject in the analysis of the ozone variability the quality control and quality assurance of the ozone measurements is the major concern of the ozone research group. The Belsk ozone data were revaluated in 2020 on a reading-by-reading basis, accounting for the instrument drift, stray-light effect, and dependence on ozone absorption coefficient on temperature. The performance of the Belsk's ozone instruments was compared several times with the ground-based reference instruments (during international intercomparisons campaigns) and the satellite spectrophotometers (SBUV, TOMS, OMI, OMPS).

1.1.2 Institute of Meteorology and Water Management

Satellite monitoring of the total ozone over Poland and surroundings is based on ground receiving station equipped with dish located at Satellite Remote Sensing Department of IMWM in Krakow. Data from NOAA/TOVS/ATOVS were used since 1993, and since 2018 continued with the Ozone Mapping and Profiler Suite (OMPS) sensor on board the Suomi NPP meteorological satellite (S-NPP).
Since 2000, two NILU-UV spectral filter instruments installed at the IMMW station Legionowo measure total ozone.
Surface ozone measurements with Thermo Scientific™ Model 49i Ozone Analyzer are performed at 4 stations: Leba (54.75°N, 17.53°E) on the Baltic Coast, Warsaw (52.28°N, 20.96°E) and Jarczew (51.81°N, 21.98°E) located in the central Poland, Sniezka (50.73°N, 15.73°E) in Sudety Mountains.

1.2. Profile measurements of ozone

1.2.1 Institute of Geophysics of the Polish Academy of Sciences

The ozone content in selected layers in the stratosphere over Belsk is calculated using the Umkehr measurements by the Dobson spectrophotometer (since 1963) and the Brewer spectrophotometers (the Brewer No.64 since 1992 and Brewer No.207 since 2010). UMK04 algorithm is used both for to the Dobson and Brewer Umkehr data. From 2021 onwards, Dobson Umkehr observations were carried out less frequently (up to about 20 per year), only for comparison with the Brewer's results.

1.2.2 Institute of Meteorology and Water Management

IMWM has been involved in the long-term monitoring of the ozone profiles for over 40 years. The ozone soundings have been performed at Legionowo (52.40°N, 20.97°E) upper-air station since 1979. Up to May 1993 the OSE ozone sensor with the METEORIT/MARZ radio sounding system was used. Later on, the ECC ozone sensor and DigiCora/RS80/92/MWE41 radio sounding system of Vaisala is in use. The ozone soundings are launched regularly on each Wednesday, and since 1995 additional ozone soundings have been performed during expected ozone depletion episodes (Match campaigns). The Legionowo ozone profiles were also used in the validation procedures of ozone profiles derived from satellite projects: MIPAS, SCIAMACHY and OMI. Legionowo is a complimentary station of the global NDACC/NDSC ozone sounding network.

1.3. UV measurements

1.3.1 Broadband and Narrowband Filter Instruments

1.3.1.1 Institute of Meteorology and Water Management

Broadband UV Biometers model SL 501 ver. 3 have been used for UV measurements at three IMWM stations: Leba (54.75N, 17.53E), on the Baltic Coast, Legionowo (52.40N, 20.97E), in central Poland, Zakopane 857m, in the Tatra Mountains (49.30N, 19.97E). Since 2000, two NILU-UV spectral filter instruments installed at the IMMW station Legionowo measure the UV-B, UV-A, and cloud transmission. Since 2017, a new version of NILU-UV instrument is installed at Warsaw (52.27°N, 20.96°E).

1.3.1.2 Institute of Geophysics of the Polish Academy of Sciences

Systematic measurements of ground level ultraviolet solar radiation (UV-B) with the Robertson- Berger meter were carried out at Belsk station in the period May 1975 – December 1993. In 1992 UV Biometer SL501A (replaced by the same type of the instrument in 1996) , and in 2005 Kipp and Zonen UVS-AE-T broadband radiometer were installed. The instruments have been operated continuously up to now. The UV monitoring was conducted at the Polish Polar Station at Hornsund, Svalbard (77°00'N, 15°33') in the period 1996-2001 by UV Biometer SL501A, and starting in spring 2006 by Kipp and Zonen UVS-AE-T (ended in 2022). Kipp & Zonen SUV-E radiometer was installed in 2017 and is currently calibrated using clear sky UV simulations from the TUV model with satellite total ozone and aerosols from CIMEL spectrophotometric measurements.

1.3.2 Spectroradiometers

The spectral distribution of UV radiation has also been monitored with the Brewer spectrophotometers at Belsk since 1992 (Brewer No.64) and in addition since 2010 (Brewer No.207). The spectra with 0.5 nm resolution for the range 290-325 nm and 286-363 nm have been calculated by the Brewer (No.64) and Brewer (No.207), respectively. Several spectra per hour are usually obtained for the solar zenith angles less than 85^0.

1.4. Calibration Activities

1.4.1 Institute of Meteorology and Water Management

IMWM uses six UV Biometers model SL 501 which are regularly calibrated at PMOD/WRC in Davos. Every year one or two instruments are sent for the calibration.
The Thermo Scientific™ Model 49i Ozone Analyzers are regularly (four times a year) compared against to Model 49i-PS Ozone Primary Standard. Ozone Primary Standard is calibrated every year at Czech Hydrometeorological Institute, Ambient Air Quality Calibration Laboratory in Prague.

1.4.2 Institute of Geophysics of the Polish Academy of Sciences

The Dobson and Brewer spectrophotometers are regularly calibrated. The latest calibrations of the Dobson instrument took place at the Hohenpeissenberg Observatory of DWD in summer 2021. As usual this year intercomparison will be carried out against the European substandard Dobson No.64.

The Brewer spectrophotometer No.64 was calibrated in 2020,2021 and 2023 against the reference instrument Brewer No.17 maintained by the International Ozone Services (Canada) at the Poprad-Ganovce Observatory (Slovak Hydrometeorological Institute) and at Belsk observatory (in 2020).
During the Brewer intercomparison campaigns both the total ozone and UV spectra were calibrated.
Surface ozone analyser is checked on regular basis against our ozone transfer standard; Model ME9811. Ozone Transfer Standard is calibrated every year at Czech Hydrometeorological Institute, Ambient Air Quality Calibration Laboratory in Prague.

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

2.1. Institute of Geophysics of the Polish Academy of Sciences

Four phases of the long-term total column ozone (TCO3) changes can be identified in the smoothed yearly mean data: constant level at 345 DU (1963-1980), decrease to 325 DU (1980-1996), increase to 330 DU (1996-2000), and constant level at 330 DU (2000-2023). The present level of the annual mean TCO3 is about 4.3% lower than its level before 1980 when only slight anthropogenic forcing on the ozone layer was expected. Based on the ozone recovery indices proposed by Krzyścin [2023], it could be estimated that about 20% of the TCO3 loss between 1980-1996 has been recovered up to now, i.e. only about half of that expected from ozone depleting substances changes. The long-term TCO3 changes appeared trendless at Belsk in the 21st century (Fig.1- left panel). Ozone content in the high stratosphere (above ~40 km, Fig.1- right panel) from the Umkehr observations showed statistically significant positive trend, i.e. about 4%/decade for the period 2000-2023 in the spring (March-April-May) Umkehr data. A statistically significant decreasing trend of ~ 2% per decade was revealed in the middle stratosphere, in summer (June-July-August) and annual (March-…-November) Umkehr data. Present level of the erythemal UV radiation is 14% larger than that in the mid-1970s but the levelling off in the yearly doses is observed since about 2000 (Fig.2 – left panel). Statistically significant negative (-5%/ 10 yr.) and positive (3%/ 10 yr.) trend are found in May and in summer, respectively. The yearly concentrations of surface ozone show an increase in the period 1992-2000, next decrease (2000-2010), and finally a slight increase (Fig.2- right panel). However, all these trends and the 2000-2023 trend are not statistically significant at 2 σ level.

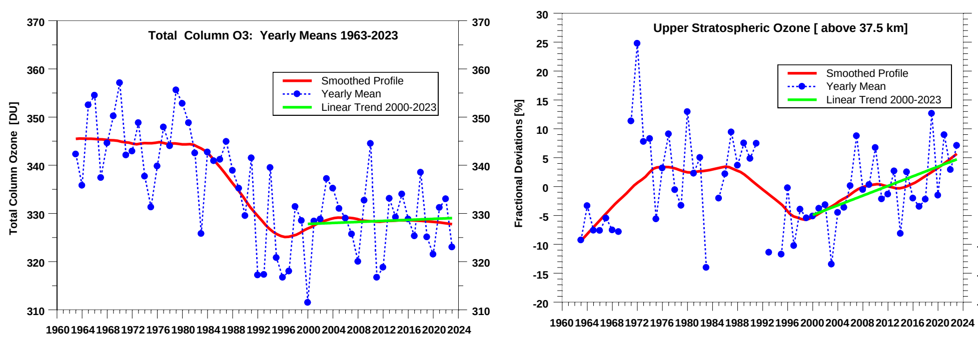

Figure 1. (left panel) Annual means (1963-2023) of total ozone at Belsk, Poland, from the Dobson spectrophotometer measurements. (right panel) Fractional deviations of the spring (Mar.-Apr.-May) mean of ozone content in the upper stratosphere (above 37.5km) in percent of the 1963-2023) mean.

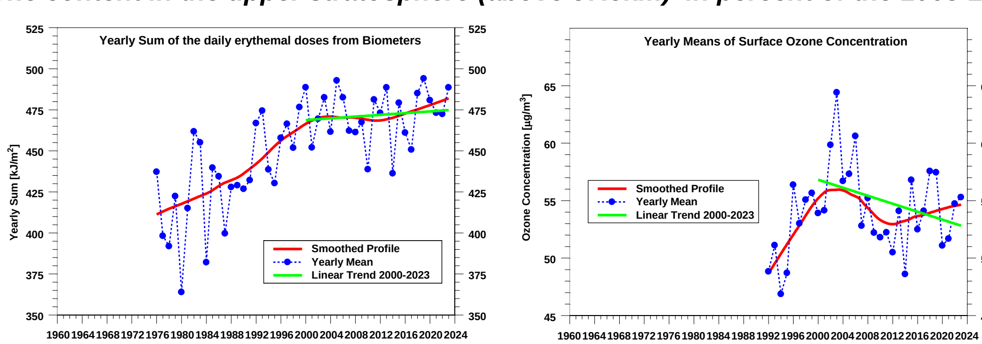

Figure 2. (left panel) Yearly sum [kJm^{-2}] the daily erythemal doses at Belsk in the period 1976-2023. (right panel). Yearly means (1992-2023) of the concentration of surface ozone at Belsk.

2.2. Institute of Meteorology and Water Management

The long-term study of ozone profiles over Poland, dating back to 1979 with the BM series, has revealed significant negative trends, particularly during winter and spring months in the lower stratosphere, reflecting a period of accelerated global ozone depletion. Continued observations using ECC 5A/6A ozone sondes, supplemented by additional measurements during Match campaigns since 1995, have provided valuable insights into ozone variability. Following the SPARC-IGACO-IOC initiative on "Past Changes in the Vertical Distribution of Ozone" (SI2N) since 2010, aiming to reduce uncertainty in the measurements from 10-20% down to 5-10%, homogenized ozone sonde data sets have been obtained for most EU ozone sonde stations, including Legionowo. Continued efforts to maintain high-quality DQA ozone sonde data are essential for calibrating satellite measurements and ensuring accurate trend assessments, despite challenges such as residual biases (Fig.3).

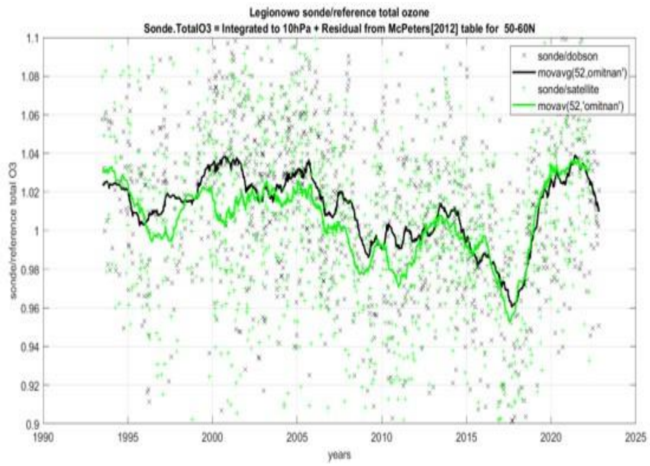

Figure 3. Comparison of the homogenized total ozone from sondes to reference total ozone measurements

The IMWM has been conducting UV-B irradiation measurements for over thirty years, initially with sporadic international calibrations. Currently, one or two detectors are regularly sent each year for calibration at PMOD/WRC in Davos. Therefore, data homogenization is necessary to estimate trends. Erythemal UV-B measurement series were homogenized using total ozone and aerosol data from MERRA2 reanalysis, simultaneous actinometric measurements at stations, and modeling using the libRadtran solar radiation transfer model. Positive trends in erythemal UV-B are observed for three IMWM stations, with statistical significance noted only for Łeba (Fig.4).

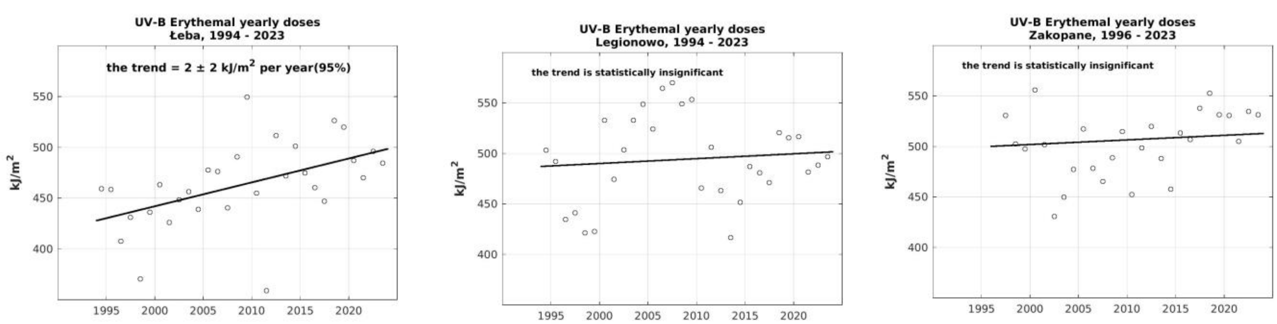

Figure 4. The yearly doses of erythemal UV-B at Łeba and Legionowo for 1994-2023, and Zakopane for 1996-2023.

3. THEORY, MODELLING, AND OTHER OZONE RELATED RESEARCH

3.1. Institute of Meteorology and Water Management

The research achievements since the previous Report (2020) could be summarized as follow:

- In 2023 UV Index forecast was updated. New ozone forecast algorithm was elaborated and included. Additionally, the last five years of aerosol from MERRA2 reanalysis was used.

3.2. Institute of Geophysics of the Polish Academy of Sciences

The main research achievements since the previous report are as follow:

- re-evaluation of all (1963-2019) Dobson total ozone measurements on a reading-by-reading basis accounting for the instrument drift, stray-light effect, and dependence on ozone absorption coefficient on temperature
- specific weather conditions (low total ozone on warm days in April) may increase the incidence of skin cancer (melanoma) in Europe
- indicators are proposed to monitor the stage of total column recovery in relation to stratospheric concentration of the ozone depletion gases
- the statistical properties of extreme day-to-day changes of in the NH mid-latitudinal total column ozone remained unchanged throughout the observation period (1980-2020)

4. DISSEMINATION OF RESULTS

4.1 Data reporting

The ozone data taken at Belsk are regularly submitted (every month) to the World Ozone and Ultraviolet Radiation Data Centre (WOUDC) in Toronto. The mean daily values of total ozone are also submitted operationally (every day) to WOUDC and the Laboratory of Atmospheric Physics, Aristotle University of Thessaloniki, Greece. The results of total column measurements by the Belsk's Brewer spectrophotometer are sent to EUBREWNET data base. The ozone sounding data from Legionowo are submitted to the World Ozone and Ultraviolet Radiation Data Centre in Toronto regularly on a monthly schedule, and operationally to the data base at NILU (Norway).

4.2 Information to the public

UV Index forecast for Poland has been available from May to September on IMWM web pages since 2000. The forecast was extended for two days since 2017. Since 2006 UV Index (UVI), real time measurements and daily course forecast from the IMWM network has been published on IMWM web pages (http://www.pogodynka.pl). IGFPAS has been provided 24-h forecast of UVI over Poland with hourly resolution since 2016. Since 2019, the UVI nowcasting every 15-minute (actual UV index values with a forecast for the rest of the day) has been issued together with the maximum allowed sunbathing duration. IGFPAS forecasts ended in October 2023.

4.3. Relevant scientific papers

4.3.1 Institute of Meteorology and Water Management

Steinbrecht, W., et al. (including Kois B.) (2021). COVID-19 crisis reduces free tropospheric ozone across the Northern Hemisphere. Geophysical Research Letters, 48, e2020GL091987. https://doi.org/10.1029/2020GL091987

4.3.2 Institute of Geophysics of the Polish Academy of Sciences

Krzyścin, J.W. Indicators of the ozone recovery for selected sites in the Northern Hemisphere mid-latitudes derived from various total column ozone datasets (1980-2020), Atmospheric Chemistry and Physics, 2023, 23(5), pp. 3119–3132.

Krzyścin, J.W. , *Atmospheric Environment*, *2023, 295, 119543.*
Czerwińska, A.E., and Krzyścin, J.W. Exposure to solar UV radiation of Polish teenagers after the first COVID-19 lockdown in March–April 2020, International Journal of Biometeorology, 2022, 66(10), pp. 2021–2032.
Krzyścin et al. Total column ozone measurements by the Dobson spectrophotometer at Belsk (Poland) for the period 1963-2019: Homogenization and adjustment to the Brewer spectrophotometer, *Earth System Science Data*, *2021, 13(9), pp. 4425–4436.*
Krzyścin, et al. Short-term variability of total column ozone from the Dobson spectrophotometer measurements at Belsk, Poland, in the period 23 March 1963–31 December 2019, Tellus, Series B: Chemical and Physical Meteorology, 2021, 73(1), pp. 1–10.
Krzyścin, J. Is the Antarctic ozone hole recovering faster than changing the stratospheric halogen loading?, *Journal of the Meteorological Society of Japan*, *2020, 98(5), pp. 1083–1091.*
Czerwińska, A.E., and Krzyścin, J.W. Numerical estimations of the daily amount of skin-synthesized vitamin D by pre-school children in Poland. *Journal of Photochemistry and Photobiology B: Biology*, 2020, 208, 111898.
Czerwińska, A.E., Krzyścin, J.W. Climatological aspects of the increase of the skin cancer (melanoma) incidence rate in Europe, *International Journal of Climatology*, *2020, 40(6), pp. 3196–3207.*
Krzyścin et al. Improvement of the 24 hr forecast of surface UV radiation using an ensemble approach. Meteorological Applications, 2020, 27(1), e1865.

5. PROJECTS AND COLLABORATION, TWINNING AND CAPACITY BUILDING

- 2021-2022 funding from Chief Inspectorate of Environmental Protection under agreement no GIOŚ/19/2021/DMŚ/NFOŚ
- 2022-2023 funding from Chief Inspectorate of Environmental Protection under agreement no GIOŚ/31/2023/DMŚ/NFOŚ
- 2021-2022 funding from Chief Inspectorate of Environmental Protection under agreement no GIOŚ/30/2021/DMŚ/NFOŚ
- 2023-2025 funding from Chief Inspectorate of Environmental Protection under agreement no GIOŚ/13/2023/DMŚ/NFOŚ

6. IMPLEMENTATION OF THE RECOMMENDATIONS OF THE 11TH OZONE RESEARCH MANAGER MEETING

According to the recommendations, IMWM and IGFPAS continue monitoring of the ozone and UV radiation on several national ground-based stations. The quality control procedures are routinely applied to have the data homogenized. Trends (in the column and profile data) are regularly updated. Factors affecting UV radiation at the surface (i.e. ozone, clouds, and aerosols) are of special interest. An impact of the resulting changes in UV radiation on human health and recommendations to get maximum health profit when staying outdoor are under study.

7. FUTURE PLANS

- finding differences between measured and re-analysed (ERA5, MERRA-2, MSR) total column ozone in terms of proposed ozone recovery stage indicators (IGFPAS).
- monitoring various biological effective irradiances by means of measurements with standard erythema biometers – software applicable anywhere in the world (IGF PAS)

8. NEEDS AND RECOMMENDATIONS

IMWM and IGF PAS recommend closer international collaboration on interactions between the ozone and climate changes to determine the ozone recovery date and evolution of policy instruments to reduce greenhouse gases.