A short comparison of the yearly TOC cycle at Diekirch (Luxembourg) and Uccle (Belgium)

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This paper is available as **annual_cycle.pdf** at https://meteo.lcd.lu/papers/

Summary

A comparison of the mean daily TOC measurements made at Diekirch (Luxembourg) with a Microtops II instrument for the period 2000-2018, and the mean monthly measurements at Uccle made by Brewer instruments for the period 1971-2018 shows that both series exhibit a sinus-shaped pattern. Modelling by a simple sinus function gives very close values for the amplitude and phase at both locations.

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1. The annual cycle of the total ozone column (TOC)

Since many years it is known that the total ozone column varies in an annual cyclical manner in both hemispheres, as for instance shown in this figure from Eleftheratos et al. [ref.1]:

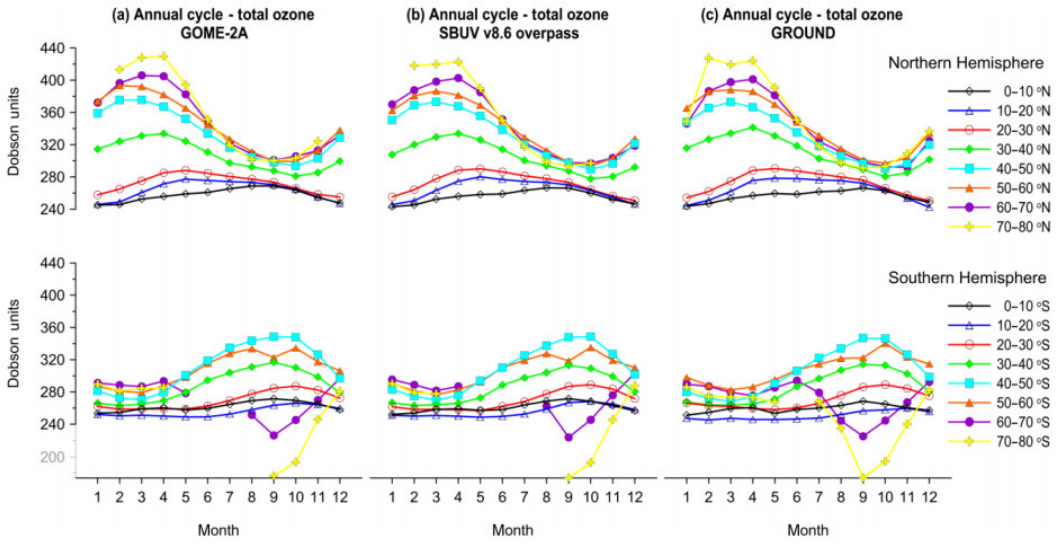

Fig.1. Annual TOC cycle measured by satellites (a,b) and ground observations [ref.1]

Clearly the variations in the two hemispheres are opposite in their phase, and the amplitudes increase continuously with latitude in the NH, whereas they are greatest in the SH at 40°- 50° South latitudes.
Shepherd [ref. 2] gives a clear explanation of the cause of this cycle. Between early fall and late spring upwelling air movements in the tropics and down-welling movements in the extra-tropics cause a migration of ozone from its production site (upper stratosphere in the tropics) to the extra-tropics lower stratosphere (Brewer-Dobson circulation). This transport is stronger in the NH than in the SH which explains why the maximum in the NH is higher than that in the SH. In early fall this circulation shuts down, so that ozone levels fall down to their photochemistry equilibrium. In simple terms: the annual pattern is caused by air dynamics, which increase the TOC above the equilibrium value which would exist in the absence of the Brewer-Dobson stratospheric circulation.
The next 3-D figure from [ref.3] shows this planetary pattern, with the added blue lines crossing at the approximate locations of Uccle (Belgium) and Diekirch (Luxembourg) and the month (April) of the maximum TOC measured at these stations.

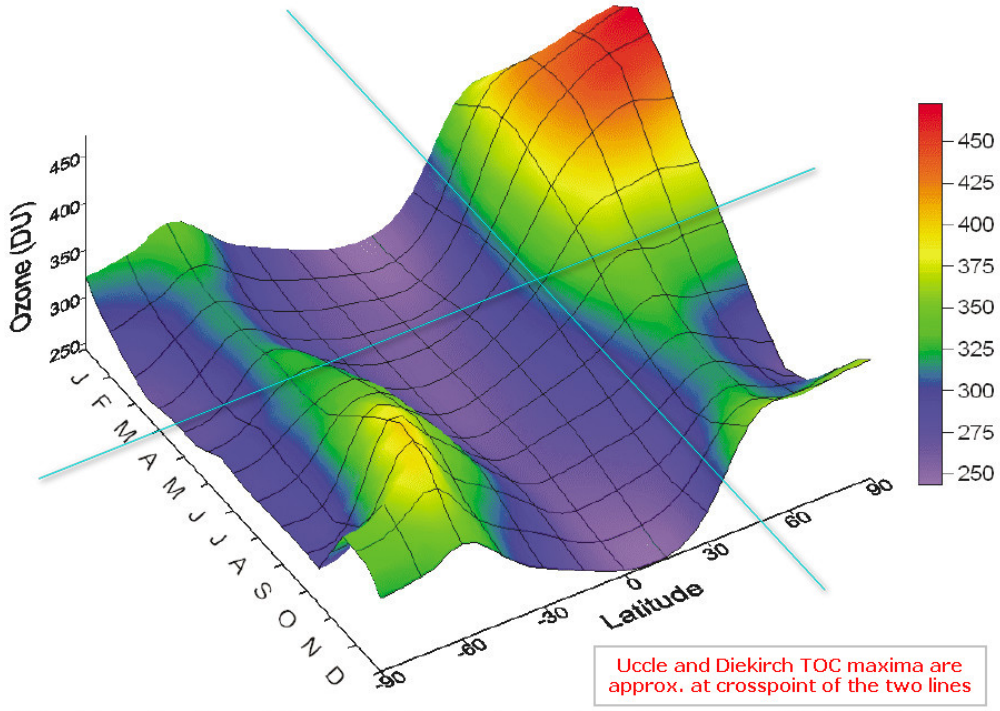

Fig. 2 Surface plot of zonal monthly mean total ozone as a function of latitude and month estimated from ground-based data for the period 1964–80.

Fig.2. 3-D plot of monthly mean TOC for 1964-1980 [ref.3]

2. The measurement of TOC at Uccle

The Royal Meteorological Institute (KMI-RMI) at Uccle (Belgium, 50°48' North, 4°21' East, 120 m asl.) is one of the stations having the longest uninterrupted record of TOC measurements in Europe, starting in 1971 [ref. 4]. The TOC is now measured by Brewer instruments (first instruments were Dobson spectrophotometers), both in direct sky (DS, i.e. the instrument points to the sun) and in zenithal sky (ZS) modes. All data are available at the WOUDC web-site, where Uccle is station 053 [ref. 5]. As an example: from the 676 daily measurements made in 2018, 504 were DS and 172 ZS measurements. The two types of measurements often give different results: for instance the 2nd June 2018 the DS measurement corresponds to 365.9 DU, whereas the ZS type measurements give 373.0 DU.
The daily measurements are published as a plot at the web-site ozone.meteo.be [ref. 6] and show the ongoing yearly evolution, together with the averages and the 2-sigma ranges from 1971 on. The next figure gives this image, as published the 3rd Nov. 2019.

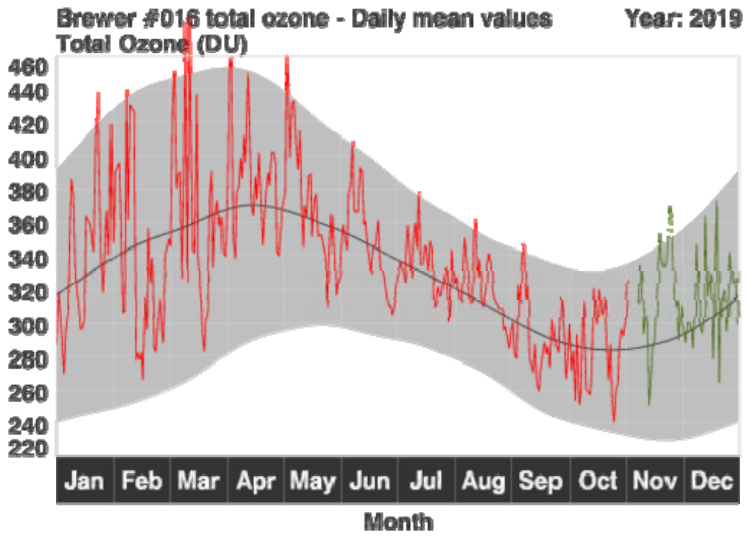

Fig.3. Total ozone plot by RMI at Uccle (3rd Nov. 2019)

The figure shows that the TOC can vary enormously in a very short time, but the overall daily averages over the full period starting in 1971 are clearly close to a simple sinus function. The grey region corresponds to the 2-sigma region containing about 95% of all observations; in the early part of 2019, quite a lot of days had TOC's exceeding the upper limit.
By manually reading the bi-monthly values of the average curve, one gets the sequence of blue dots in the next figure 4. Fitting a sinus-curve gives an excellent good fit ($R^2 = 0.99$), so that this simple sinus function represents an excellent model for the annual cycle. The spring maximum is close to mid-April, and the autumn low between mid- and end of October.

A Fourier analysis (not shown here) suggests a total of three harmonics, but the amplitude of the second and third are only 18% resp. 13% of that of the first harmonic, so following Occam's razor we accept the simple sinus curve as a valid model for the annual cycle.

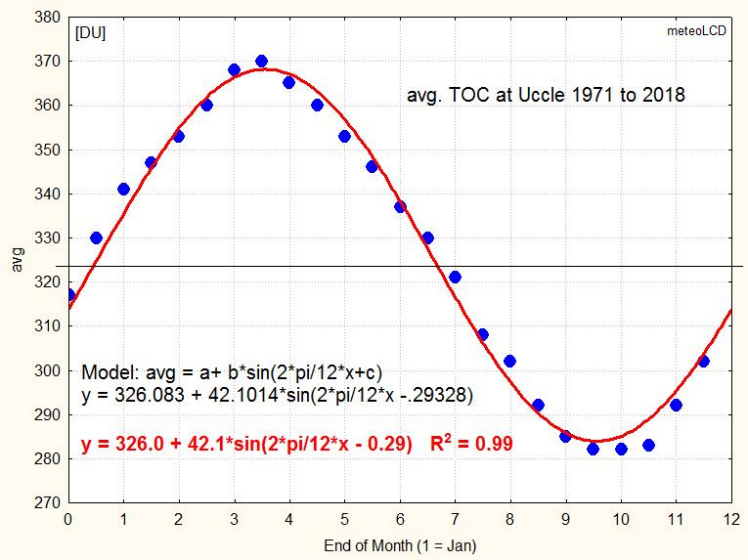

Fig.4. Sinus pattern of TOC at Uccle from grey curve at fig.3

3. The measurement of TOC at meteoLCD, Diekirch.

Regular TOC measurements began in 1997 at the meteorological station of the Lycée classique Diekirch (LCD) in Luxembourg (49°52' North, 6°10' East, 218 m asl.). The instrument used was a handheld Microtops II ozone monitor from Solar Light Inc. During the first years most measurements were made by F. Massen with instrument # 3012A pointing to the sun (DS measurement type), and a small subset by the late Marcel Thilmany, a technician from the informatics department. Starting 2003, a second Microtops #5375 was used most of the time until today. Mike Zimmer used instrument #3012 to make measurements in the absence of F. Massen from Nov. 2009 on, and the readings of this instrument are multiplied by a calibration factor to make them comparable to those of #5375, which represents the reference at meteoLCD (see for instance comments at https://meteo.lcd.lu/mikezimmer/dobson19.html). The meteoLCD Dobson and UVB measurements are uploaded to the WOUDC as station 418.
In this paper only meteoLCD daily TOC measurements (by definition all are of the DS type) from 2000 to 2018 will be used.

Fig.5 shows a scatterplot of all the 2857 measurements, the x-axis corresponding to the day of the year (1st January = day 1); during leap-years the 365th day is December 30 and the 31st December is ignored.

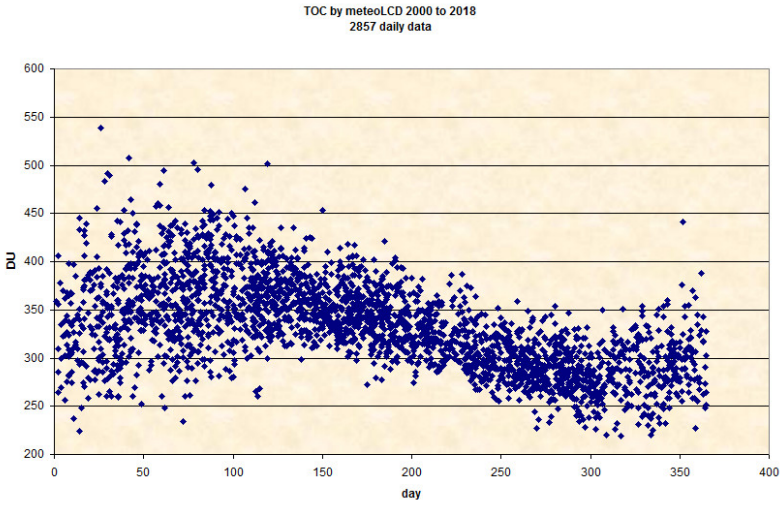

Fig.5. Scatterplot of all daily TOC measurements at meteoLCD from 2000 to 2018.

It should be noted that for the 19 years, the number of data available per day of the year vary strongly (similar to the Uccle series), from a minimum of 1 to a maximum of 14; the average is 7.8 measurements per day. Fig. 6 shows the averages for each day of the year and the 2 sigma range. As in the previous figure 5, the greater spread of the measurements during the first part of the year is clearly visible.

Fig. 7 represents the averages per day of the year together with a sinus-fit. The coefficient of determination $R^2 = 0.82$ is quite acceptable, and the parameters of the model close to those at Uccle.

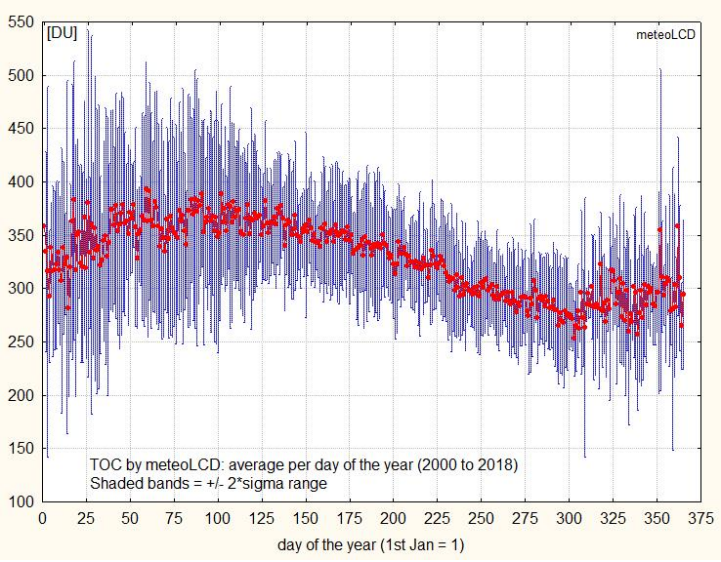

Fig. 6. Average per day and 2-sigma range of TOC at meteoLCD (2000 – 2018)

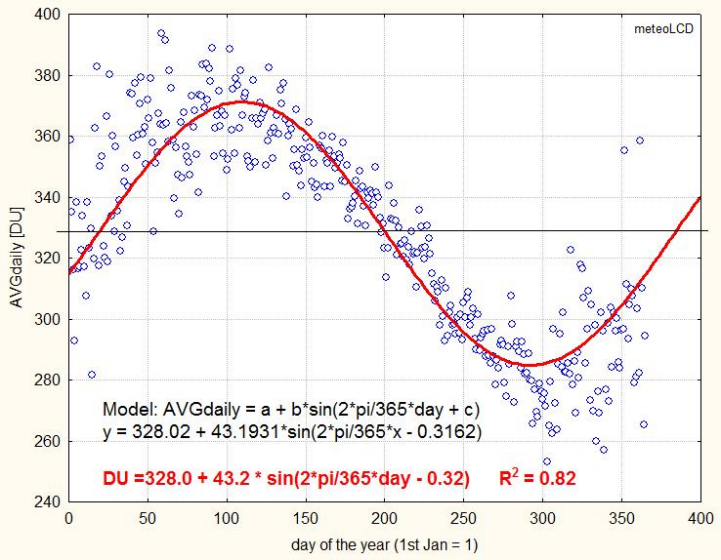

Fig.7. Sinus-fit to the daily average of TOC at meteoLCD

The following table summarizes the most important parameters of the two sinus models from Uccle and Diekirch:

Location	model	zero - day	max - day	min - day
Uccle 120 asl. 50°48' North 4°21' East	326+42.1*sin(0.0172*day-0.29)	16.86 16 January	108.18 18 April	290.83 17 October
Diekirch 218 asl. 49°52' North 6°10' East	328+43.2*sin(0.0172*day-0.32)	18.60 18 January	109.93 19 April	292.58 19 October

The concordance of all parameters (baseline, amplitude, phase) is surprisingly good, keeping in memory the huge difference in complexity and cost between the equipments in use at Uccle and Diekirch.

4. Conclusion

The 19 year long measurements of the total ozone column at Diekirch show clearly a sinus-pattern for the daily mean value, as do the measurements by the RMI at Uccle for the period 1971 to 2018.
The parameters of a sinusoidal fit are very close for the 2 locations. This is a good argument that using a relative inexpensive Microtops II instrument for these TOC measurements has merit, keeping in mind the enormous difference in price and complexity of the Brewer instruments used at Uccle.

References:

[1] K. Eleftheratos et al. (2019) : The use of QBO, ENSO and NAO perturbations in the evaluation of GNOME-2 MetOp A total ozone measurements. Atmos. Mes. Tech, 12, 987-1011. https://doi.org/10.5194/amt-12-987-2019

[2] T.G. Shepherd (2008) : Dynamics, stratospheric ozone, and climate change, Atmosphere-Ocean, 46:1, 117-138, https://doi.org/10.3137/ao.4601036

[3] V.E. Fioletov (2008) : Ozone climatology, trends and substances that control ozone, Atmosphere-Ocean, 46:1, 39-67, https://doi.org/10.3137/ao.460103

[4] R. Van Malderen et al. (2009): Revision of 40 years of ozone measurements at Uclle, Belgium (poster). http://ozone.meteo.be/publication/Roeland.V.M/2009EGUVienna.pdf

[5] WOUDC, World Ozone and UV radiation Data Center, https://woudc.org/data/explore.php

[6] Plot of daily TOC measurements at ozone.meteo.be http://ozone.meteo.be/meteo/view/en/113200-ajaxcontroller.html/1569014/image.jpg