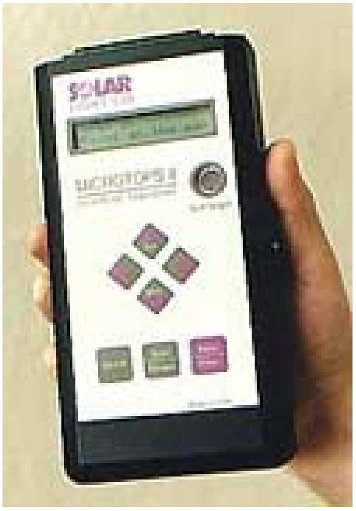

A comparison of the total ozone measurements done during 2012 with a Microtops II sun photometer and the Uccle Brewer #16 instrument

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Abstract:

Regular total ozone column measurements done during 2012 at the meteorological station of the Lycée classique Diekirch in Diekirch, Luxembourg are compared to the daily measurement series of the Brewer instrument #16 used by the RMI at Brussels, Belgium. Only direct sun measurements are compared, and this comparison is done for each of the three wave-length pairs used by the Microtops. Assuming the Brewer measurements correct, it is suggested **to apply a calibration factor of about 1.04** to the Microtops O3corr. readings of the instrument #5375. The correlations between TOC and various atmospheric parameters shows that only the solar zenithal angle and the precipitable water column have a statistically significant influence; the atmospheric optical thickness has none.

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1. The two measurement stations at Uccle and Diekirch

The following table shows the location and measurement procedures at both stations.

Uccle (Belgium) station 53 of the WOUDC	50°48' North 4°21' East altitude = 100m a.s.l.	**Brewer** spectrophotometer automatic measurements	zenith sky (ZS) measurements and direct sun (DS) measurements	measurement channels (nm): 303.2, 306.3,310.1, 313.5,316.8, 320,1 **[5]**
Diekirch (Luxembourg) station 412 of the WOUDC	49°52' North 6°10' East, altitude = 218m a.s.l.	**Microtops II** Sunphotometer manual measurements	only direct sun (DS) measurements	measurement channels (nm): 305.5, 312.5, 320

table 1. Station details

A notable difference between the measurement series of both stations is the following:

Uccle usually makes a more or less large number of observations over a time span of several hours (up to 28 measurements during up to 7 hours). The beginning, end and mean times are given, as well as the number of observations, the average, standard deviation and the measurement method as direct sun measurements (DS, the instrument points to the sun) or zenith sky measurements (ZS, the instrument points to the zenith). As the Microtops [2] instrument used at Diekirch measures exclusively by pointing to the sun, only.the DS readings are used for the main comparison. It should also be noted that besides days where both stations have measurements, there exist many days where Uccle has data and Diekirch has none, and a non negligible number where the opposite is true. From time to time, when instrument #5375 is unavailable, measurements were done at Diekirch with Microtops #3012 by operator Mike Zimmer. These data are multiplied by **0.908658** to make them comparable to the other instrument and are also given on the website http://meteo.lcd.lu/dobsonyy.html, with yy corresponding the the year. In this study, only readings made by instrument #5375 are used.

A second criterion to restrict the data ensemble is that only those readings will be taken as valid, where the time of measurement in Diekirch is inside the boundaries of the time-period (UTCbegin, UTCend) at Uccle or when outside, by less than 1 hour. A third still more stringent criterion "GOMEZOK" will be discussed in the text.

This leaves 87 readings for comparing the Microtops #5375 with the Brewer #16 if only DS measurements are retained, and 165 points if all DS and ZS (zenith sky) measurements from Uccle are to be used.

All the relevant data series can be found at the WOUDC website:

Uccle: ftp://ftp.tor.ec.gc.ca/Archive-NewFormat/TotalOzone_1.0_1/STN053/Brewer/

Diekirch: ftp://ftp.tor.ec.gc.ca/Archive-NewFormat/TotalOzone_1.0_1/STN412/Microtops/

A short explanation how access the data using an interactive mask at the WOUDC web site can be found at http://meteo.lcd.lu/woudc.html

The Microtops #5375 series used in this report are the raw data series as downloaded from the instrument; a few missing (NaN) or impossible measurements have been omitted. These raw data series are stored at the data archive of meteoLCD (http://meteo.lcd.lu/data/index.html)

2. Diurnal variability

It is often assumed **[3] [4]** that except at urban locations, the TOC (total ozone column) varies only little during the day. This is the reason why WOUDC retains only one single reading per day. This hypothesis remains questionable, as shown by the following table covering 5 selected days:of Microtops measurements.

DATE	TIME	N	SZA	TEMP	WATER	AOTLOW	AOTHI	TOCAVG	TOCSTD	TOCoverlap
12-May-12	8:56:50	3	44.20	20.40	0.62	0.086	0.276	322.13	0.55	
12-May-12	11:57:21	9	31.96	22.10	0.49	0.030	1.951	331.67	1.07	**no**
1-Jul-12	9:57:12	4	33.45	20.90	1.67	0.369	0.432	304.08	4.28	
1-Jul-12	11:24:16	2	26.97	21.60	1.31	0.458	1.058	304.70	0.14	yes
1-Jul-12	12:24:00	5	26.97	21.60	1.31	0.145	0.247	306.78	2.20	yes yes
1-Jul-12	12:30:23	12	28.43	24.70	1.41	0.032	0.055	276.73	1.18	**no no no**
10-Jul-12	10:41:14	5	30.12	21.20	1.68	0.042	0.056	317.76	0.76	
10-Jul-12	11:27:56	9	27.85	23.40	1.48	0.035	1.861	318.47	3.22	yes
19-Sep-12	10:13:32	4	51.24	19.60	0.72	0.032	0.035	307.50	1.28	
19-Sep-12	11:13:01	4	48.76	22.10	0.63	0.034	0.325	308.08	1.27	yes
21-Oct-12	10:30:44	4	61.73	22.00	1.99	0.114	0.675	242.93	2.34	
21-Oct-12	12:19:51	4	62.19	22.90	2.10	0.191	0.245	238.95	1.01	yes

table 2. Diurnal variablity: The column TOCoverlap shows "no" if the 2-sigma intervals do not overlap, i.e. if the difference of the TOC measurements are statistically significant.

It can easily seen that same-day differences go from less than 1 DU to well over 27 DU, especially when done at very different times. When there is 1 hour or less between the measurements as for example for the 10 July and 19 September), the differences are indeed small.

The Uccle measurement may start early in the morning, for instance at 06:00 and go to 16:00, so one could expect strong diurnal changes. A telling example is the file with July 2013 data from Uccle which shows daily standard deviations in the range of [0; 19.0].

For the whole month of July the average TOC is 340.1 DU and the standard deviations 14.9. This gives a calculated 2*sigma interval of [310.3; 369.9] to be compared to the spread [306.3; 372.0] of the measurements ; thus these intervals are very close. Let us accept the same for the daily variations: the 2*sigma interval for the 1rst July is [305.2; 381.2], an absolutely huge variation of ~11% with respect to the mean. The conclusion is that using this daily average from Uccle to calibrate versus an average from a series of consecutive measurements done at a specific time in Diekirch may be problematic. In [3] the authors discuss this problem (see chapter 4), and (prudently!) conclude than at non-urban sites the variation may expected be be negligible.

This seems to be a question waiting for a more definitive answer.

The last column "TOCoverlap" compares the [average-2σ; average+2σ] intervals for an overlap; if there is an overlap. the difference between the averages is not statistically significant. Out of the 10 possible comparisons, 4 are statistically different.

3. The correlation of the TOC with other parameters.

In this chapter we will shortly check the correlations between some parameters like solar zenithal angle (SZA), water column (WATER), temperature (TEMP), atmospheric optical depth (AOT) and the different TOC masurements. To select "acceptable" days, we will apply separately two criteria:

1. the "acceptable" criterion is that the time of the Microtops measure is not more than one hour outside the boundaries [UTCbegin, UTCend] of the Brewer series.
2. as a supplementary condition the "GOMEZOK" criterion will be applied (see [5]): only Microtops data where the error of the channels is less than 2% and the standard deviation of the AOT is less than 0.015 will be retained. The percentage error is the number (average - stdev)/average*100.

Correlations (Uccle_Diekirch_allcommonDSacceptable_2012.sta)
Marked correlations are significant at p < .05000
N=83 (Casewise deletion of missing data)

Variable	SZAAVG	TEMPAVG	OZ12AVG	OZ23AVG	OZONAVG	WATERAVG	AOTAVG	ColumnO3
SZAAVG	1.00	-0.29	-0.38	-0.45	-0.34	-0.41	-0.13	-0.48
TEMPAVG	-0.29	1.00	-0.16	-0.09	-0.19	0.40	0.01	-0.10
OZ12AVG	-0.38	-0.16	1.00	0.98	0.99	-0.29	-0.03	0.95
OZ23AVG	-0.45	-0.09	0.98	1.00	0.95	-0.22	-0.11	0.95
OZONAVG	-0.34	-0.19	0.99	0.95	1.00	-0.33	0.01	0.93
WATERAVG	-0.41	0.40	-0.29	-0.22	-0.33	1.00	-0.08	-0.21
AOTAVG	-0.13	0.01	-0.03	-0.11	0.01	-0.08	1.00	-0.04
ColumnO3	-0.48	-0.10	0.95	0.95	0.93	-0.21	-0.04	1.00

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table 3. Correlation table computed from the "acceptable" days (AVG means average)

There are N = 83 valid days. Statistically significant correlations are printed in red.

Obviously, both Microtops (all channels!) and Brewer readings are inversely correlated to the solar zenithal angle SZAAVG: a solar disc low on the horizon (= large SZA) tends to give lower TOC readings from both instruments. The TOC is inversely correlated to the precipitable water column WATERAVG, but the correlation is only significant for the 3 channels of the Microtops. The Brewer (ColumnO3) nevertheless comes very close with -0.21 (under the assumption that the water column at Uccle is comparable to that measured in Diekirch).

All Microtops channels are very strongly correlated to the Brewer readings.

No significant correlation exists with the temperature of the Microtops optical block.

Finally, and this might come as a surprise, there is no statistically significant correlation between the three Microtops channels and the atmospheric turpitude (AOTAVG); the very small numbers show that statistically speaking the AOT has no impact on the TOC readings of the Microtops. So the only parameter having a possible influence on the TOC measurements by both instruments are the solar zenithal angle and the precipitable water column.

	Correlations (Uccle_Diekirch_allcommonDSacceptable_2012.sta) Marked correlations are significant at p < .05000 N=61 (Casewise deletion of missing data) Exclude condition: GOMEZOK = 0							
Variable	SZAAVG	TEMPAVG	OZ12AVG	OZ23AVG	OZONAVG	WATERAVG	AOTAVG	ColumnO3
SZAAVG	1.00	-0.31	-0.32	-0.41	-0.26	-0.43	-0.12	-0.43
TEMPAVG	-0.31	1.00	-0.10	-0.03	-0.14	0.38	0.02	-0.06
OZ12AVG	-0.32	-0.10	1.00	0.98	0.99	-0.32	-0.06	0.94
OZ23AVG	-0.41	-0.03	0.98	1.00	0.94	-0.23	-0.13	0.95
OZONAVG	-0.26	-0.14	0.99	0.94	1.00	-0.37	-0.02	0.92
WATERAVG	-0.43	0.38	-0.32	-0.23	-0.37	1.00	-0.02	-0.23
AOTAVG	-0.12	0.02	-0.06	-0.13	-0.02	-0.02	1.00	-0.10
ColumnO3	-0.43	-0.06	0.94	0.95	0.92	-0.23	-0.10	1.00

table 4. Correlation table computed from the "acceptable" + "GOMEZOK" days

Table 4 shows the correlations if the supplementary GOMEZOK condition is enforced; this reduces the number of days to 61 but the significant correlations remain essentially the same. In the following, we will use the series of 83 days.

4. Comparing the Microtops #5375 channels to the DS and ZS Brewer #16 measurements.

There are 100 data points which allow a comparison, but two points (11 Dec and 16 Dec) from the Microtops series must be discarded, having impossible high channel 3 readings (530.1 and 481.5); figure 1 shows the plot of the Uccle (DS and ZS) measurements versus the Microtops readings.

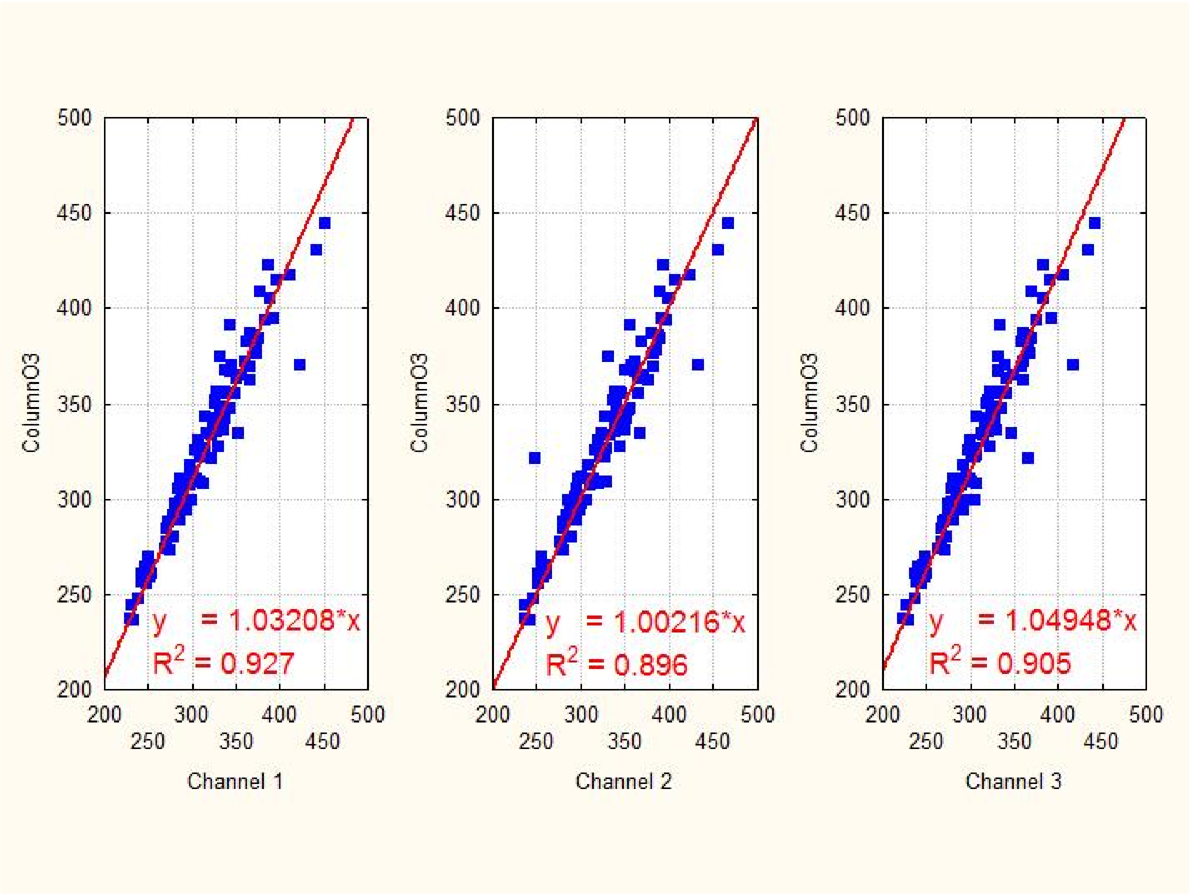

fig. 1 Uccle DS & ZS versus the 3 Microtops channels (N = 98 data points)

The linear model (= regression line forced through the origin) suggests the calibration factors of 1.032, 1.00 and 1.049 (rounded to the 3rd decimal) by which the Microtops channel readings should be multiplied. All R^2 are very good; channel 1 shows the least scatter.

5. Comparing the Microtops #5375 channels to the DS only Brewer #16 measurements.

As said above, a sensible comparison should be limited to measurements done under the same conditions, i.e. Microtops readings should only be compared to Uccle DS. The next figure shows these comparisons with the regression lines forced through the origin.

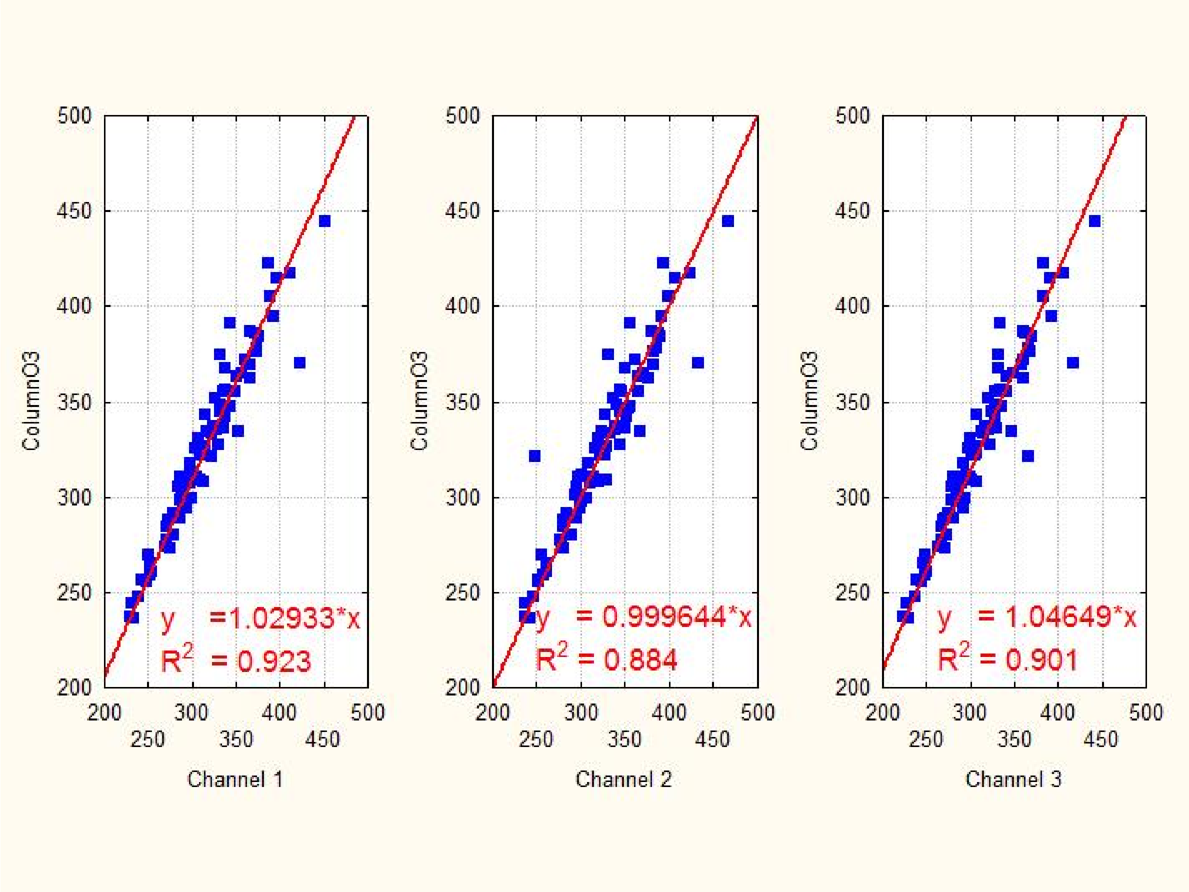

fig. 2 Uccle DS versus the three Microtops channels (N = 84 data points)

The calibration factors and R^2 parameters are nearly the same as in the comparison using both the Brewer DS and ZS measurements. As in the previous case, channel 1 has the lowest scattering around the regression line. Table 5 resumes these findings and also gives the elementay statistics.

Brewer Obscode	N	Brewer #16	channel 1	channel 2	channel 3
ZS & DS	98	329.28 +/- 46.83	318.59 +/- 46.93	327.88 +/- 49.14	313.19 +/- 46.50
			R^2 = 0.927	R^2 = 0.896	R^2 = 0.905
calibration factor			1.03208	1.00216	1.04948
DS	84	326.84 +/- 45.2	317.10 +/- 45.64	326.29 +/- 47.73	311.76 +/- 45.38
			R^2 = 0.923	R^2 = 0.884	R^2 = 0.901
calibration factor			1.02933	0.99964	1.04649

table 5. Average +/- standard deviation of the different measurements, together with the R^2 and the calibration factors

Clearly the channel 1 readings have the least scattering versus the Uccle measurements; so if this is the criterion for a choice, using the channel 1 would be the answer. This is exactly what Gómez-Amo et al. [3] have found in their paper. What's surprising is that the restriction to DS measurements for the comparison does not give much better results; on the contrary the different R^2's are very slightly worse. The differences between the averages of the three channels and that of the Brewer nevertheless diminish by -8.9%. -39.3% and -6.3% when one imposes the restriction to DS readings only. This is a very good argument for using exclusively the DS measurements when computing.a calibration factor.

6. The differences during 2012.

The following graph shows the series of the differences of readings from the start to end of the year. The axis axis is not a time scale, but gives the running number of the measurement; the time interval between measurements is not a constant!

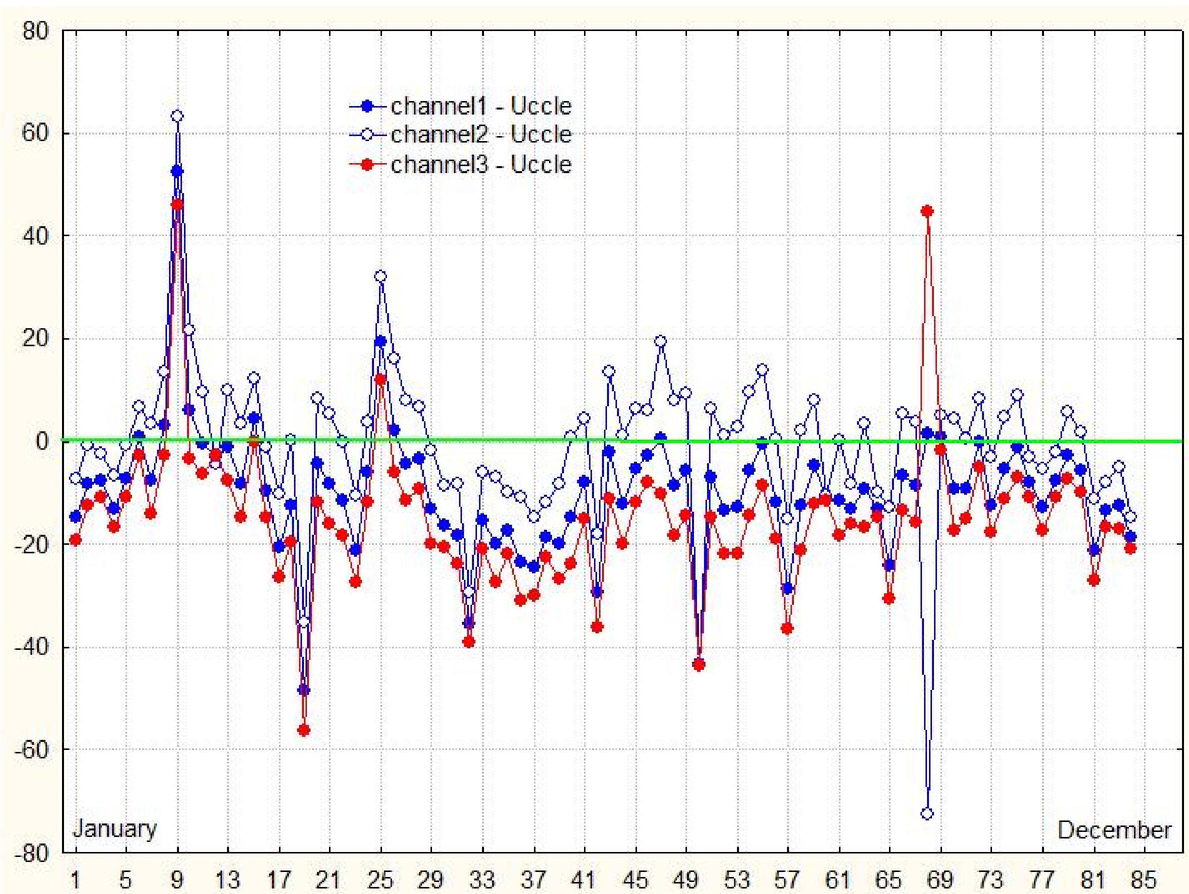

fig. 5 Differences (channel x - Uccle) during 2012. Time interval between successive points is variable!

Obviously the channel 3 readings (red dots) which are the numbers given on the meteoLCD website (http://meteo.lcd.lu/, link at DOBSON (total O3)) are most of the times lower than the Uccle measurements. There are two visible outliers at measurement number 47. Removing this single point (measurement point 47) has the following result:

number of observations = 53	mean	standard deviation	calibration factor	R^2
Uccle Brewer #16, DS only	333.2	46.1		
Microtops #5375, channel 1	325.1	47.3	1.023400	0.962
Microtops #5375, channel 2	336.0	48.6	0.990361	0.959
Microtops #5375, channel 3	318.8	46.7	1.043500	0.961

table 6: Calibration factors for the 3 Microtops channels (channel #3 are the O3corr reading shown at http://meteo.lcd.lu/dobsonyy.html, yy = year)

The R^2 factor is now virtually the same, so a preferential choice becomes somewhat moot. The channel 2 series corresponds to a calibration factor that is closest to 1.

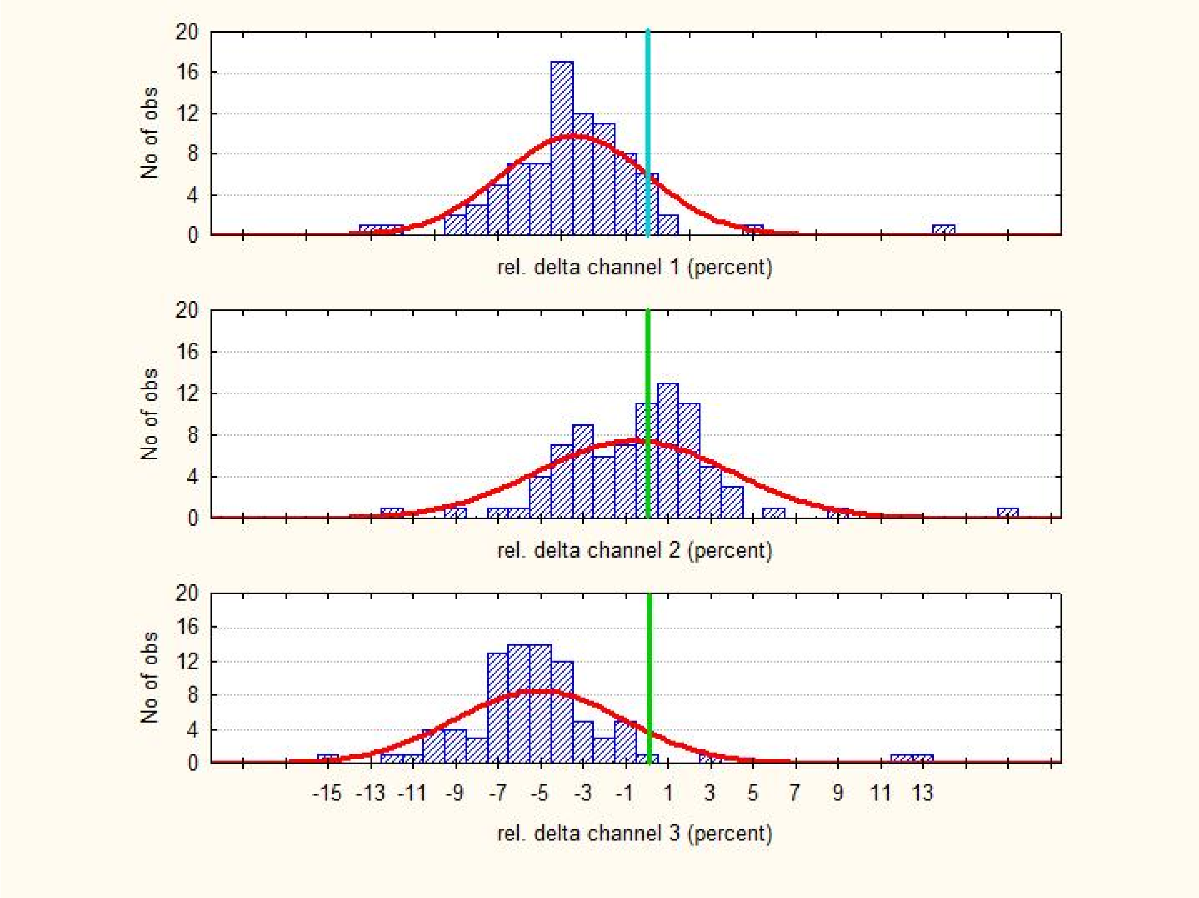

fig.6. Histogramm of the differences (ch.1 to ch.3 from top to bottom)

Fig.6 shows the distribution of the three differences series (from top to bottom: ch. 1 to 3). The red curve is a fit to a normal distribution; series 1 and 3 are reasonably close to that distribution, only series 2 shows a slight skew.

7. Conclusion

Fig. 6 shows an over-plot of the two graphs published on the websites of Uccle and meteoLCD at the end of the year 2012. The blue curve representing the channel #3 readings of the Microtops are most of the time below the red curve of the Brewer measurements (ZS and DS readings).

It is remarkable that the Microtops measurements can be calibrated against the Uccle Brewer #16 by a multiplier of 1.04 that is very close to 1. The inter-comparison done on the 2011 measurements gave an inter-Brewer calibration factor of 1.06 between Brewer #16 and Brewer #178, greater than that we find here for the Microtops versus Brewer#16.

This report once again confirms the excellent behavior of this instrument, first documented in [1], and which may be considered a valuable replacement to the much more expensive Brewer instruments (and possibly even to satellite measurements during field observations , as shown in [3]).

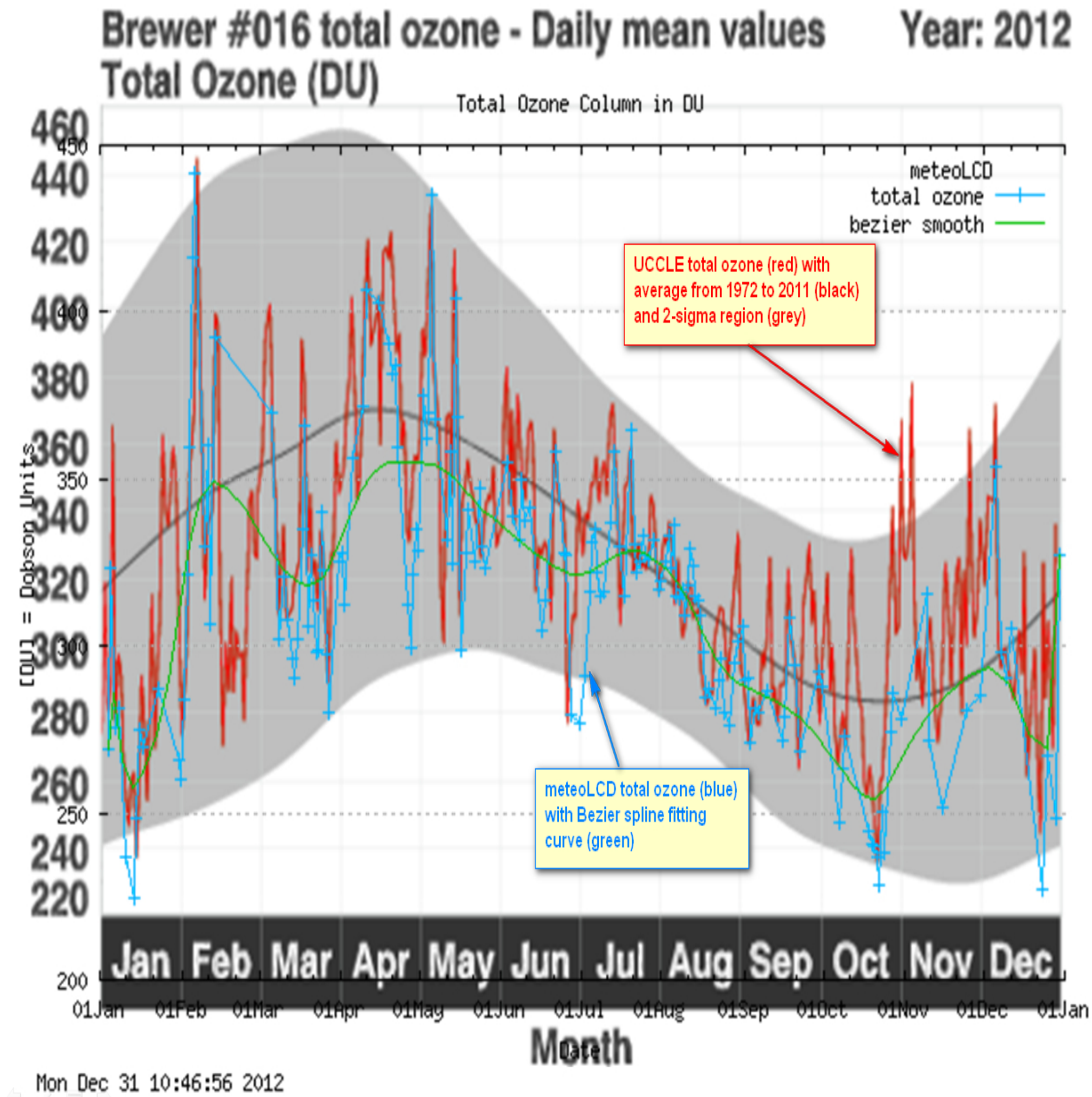

fig. 7. Overplot of the website plots of the Uccle and Diekirch TOC measurements at the end of the year 2012. The grey area corresponds to the 2-sigma region around the averagesat Uccle from 1971 on.

References:

[1] Massen, F. : A comparison of the total ozone measurements done with the Microtops II sun photometer and the Uccle Brewer spectrophotometer. 2005 http://meteo.lcd.lu/papers/ozone/uccle/index.html and

[2] Solar Light: http://www.solarlight.com/products/sunphoto.html

[3] Gómez-Amo et al: A comparison of Microtops II and satellite ozone measurements in the period 2001-2011. Journal of Atmospheric and Solar-Terrestrial Physics. (94) 2013, 5-12.

[4] Kerr & McElroy Total ozone measurements made with the Brewer ozone spectrphotometer during STOC 1989. Journal of Geophysical Research 116.

[5] Gómez-Amo et al: Operational considerations to improve total ozone measurements with a Microtops II ozone monitor. Atmospheric Measurement techniques, 5, 759-769, 2012.

History:

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