GAW Report No. 246

Thirteenth Intercomparison Campaign of the Regional Brewer Calibration Center Europe

Lichtklimatisches Observatorium, Arosa, Switzerland
30 July to 10 August 2018

WORLD METEOROLOGICAL ORGANIZATION
GLOBAL ATMOSPHERE WATCH
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1. INTRODUCTION

This thirteenth campaign was a joint exercise of the Regional Brewer Calibration Center for Europe (RBCC-E) and the Regional Dobson Calibration Center (RDCC-E) with the support of MeteoSwiss and of the Global Atmosphere Watch (GAW) Programme of the World Meteorological Organization (WMO). The following operations were performed by the RBCC-E during the intercomparison:

- Ozone calibration against the RBCC-E travelling reference (B#185).
- Compilation of the calibration histories of the instruments.
- Evaluation of the Level 2 Eubrewnet ozone data for the period between intercomparisons.

During this intercomparison, the RBCC-E transferred its own absolute ozone calibration, obtained by the Langley method at the Izaña Observatory (IZO). A discussion about the calibration of the reference instrument (B#185) is presented in Section 2. All the participating instruments were provided with a provisional calibration at the end of the campaign, which can be considered final calibration constants for most of them. A detailed calibration report for each instrument is available online. A calibration history of the Brewers which have participated in previous campaigns is also included in this document. This allows an easy recalculation of the past ozone data. In addition, the travelling reference (B#158) operated by Kipp & Zonen (K&Z) experts will also participate in this intercomparison allowing participants to request its technical service for their instruments. A participant's list is presented in Table 1.

The initial Brewer comparison results (using the instruments' original calibration constants) indicates that all of the instruments present an ozone deviation lower than 1% with respect to the reference (see Fig. 2) if the SL correction is applied; note that the comparison is performed limiting the ozone slant column to 900DU , to exclude the observations affected by stray light. After the maintenance tasks in Brewer #044 and with the application of the determined stray light corrections, the agreement with respect to the reference was lower than 0.5% in all the instruments (Fig. 3).

Table 1. List of participants at Arosa 2018 Campaign

Institution	*IP*	*Brewer*	*Country*
York University	Tom McElroy		Canada
LKO MeteoSwiss	Herber Schill	#040	Switzerland
RPA	Vadim Shirotov	#044	Russia
LKO MeteoSwiss	René Stübi	#071	Switzerland
LKO MeteoSwiss	Herbert Schill	#072	Switzerland
LKO MeteoSwiss	Herbert Schill	#156	Switzerland
K&Z	Pavel Babal	#158	Netherlands
WRC	Luca Egli	#163	Switzerland
AEMET-IARC	Alberto Redondas	#185	Spain
K&Z	Erik Noort	#245	Netherlands

Figure 1. View of the Brewer spectrophotometers on Arosa Station terrace

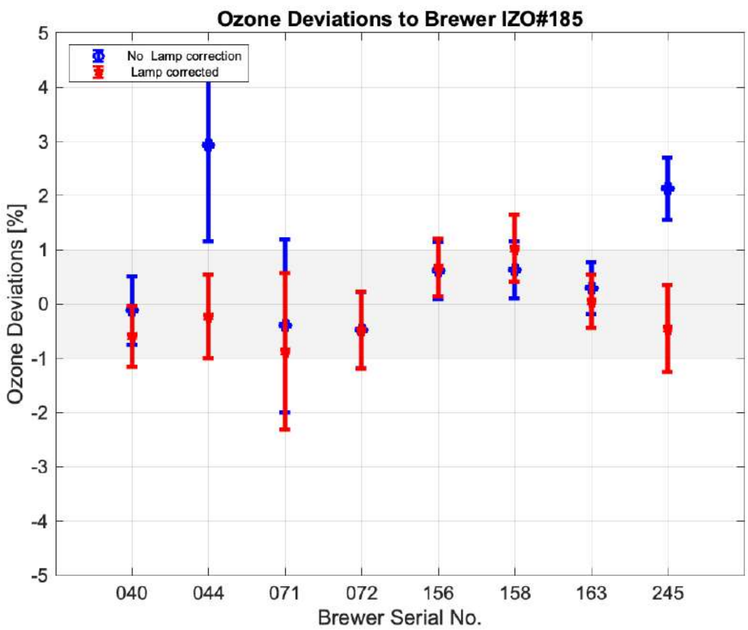


Figure 2. Ozone relative percentage differences of all Arosa 2018 participating instruments to RBCC-E travelling standard IZO#185. Ozone measurements collected during the blind period are reprocessed using the original calibration constants, the observations are limited to one with ozone slant column lower than 900 DU to exclude stray light effect, with (red symbols) and without (blue) standard lamp correction. Error bars represent the standard deviation.

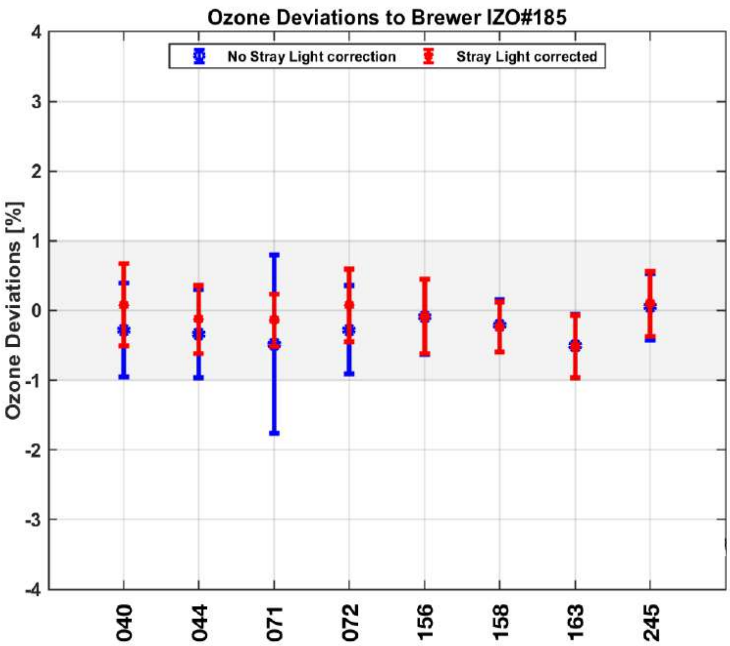


Figure 3. Ozone relative percentage differences of all Arosa 2018 participating instruments to RBCC-E travelling standard IZO#185. Ozone measurements collected during the final period are reprocessed using the proposed calibration constants, with (red) and without (blue) stray light correction. Error bars represent the standard deviation.

In the first part of the report a summary of the campaign is presented, including the comparison of the reference to the RBCC-E triad before and after the travel, and the detailed results of the blind and final comparison. In Section 3 each instrument is analysed in an individual summary.

2. SUMMARY

2.1 Weather conditions and campaign schedule

The weather conditions during the campaign at the Arosa Observatory (1860 m.a.s.l.) were good, allowing a minimum of 150 near-simultaneous direct sun ozone measurements with the reference instrument Brewer #185, which is enough to perform a reliable calibration for all instruments (Fig. 4). Moreover, the measurement routine schedule designed to maximize the number of ozone observations during the campaign, worked properly, reaching with all instruments a large percentage of potential near-simultaneous ozone measurements. As shown in Figure 5, most observations (≈ 75%) were within the 350-600 DU ozone slant column (OSC) range.

The actions carried out each day of the campaign are shown in Table 2. The first day is dedicated to the installation of the instrument. The next two-three days (depending on the weather conditions) will be "blind". During blind days any manipulation of the instrument that can produce a change on the initial calibration should be avoided. After that, the routine schedule can be interrupted to perform whatever maintenance tasks are needed to be done (Dispersion test, lamp calibrations, and so forth). In this campaign, the service of the Kipp & Zonen experts was required on the Brewer#044 because it had been inoperative since 2016. Moreover, during this campaign it was observed that it had humidity leaks. Finally, the programmed UV day measurements are considered as blind and final days for UV and ozone measurements, respectively.

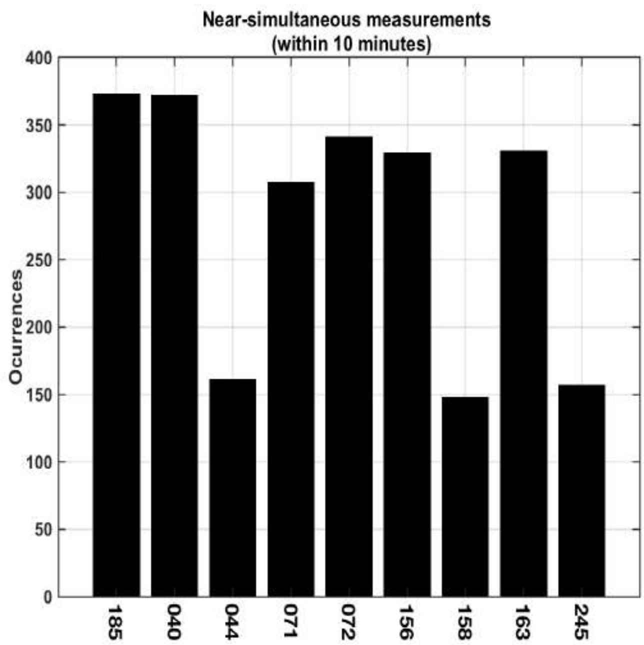


Figure 4. Statistics of the intercomparison conditions: number of near-simultaneous ozone measurements

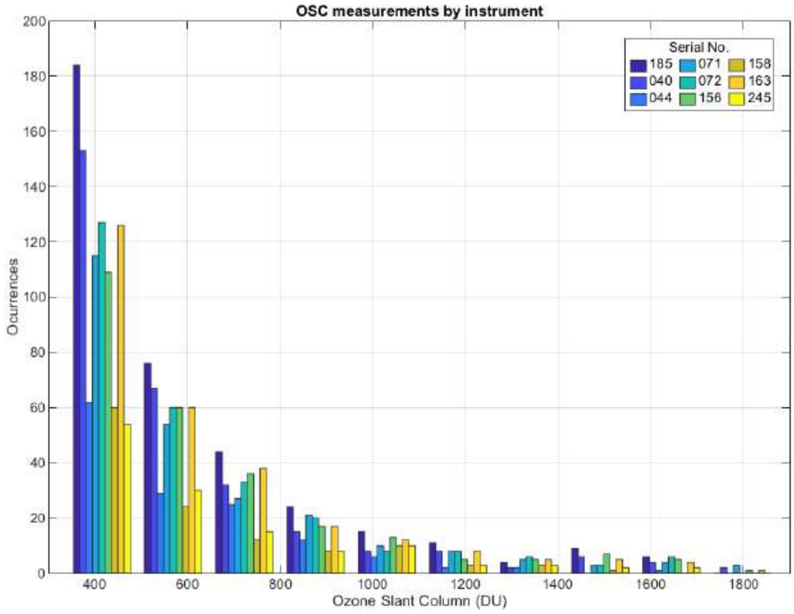


Figure 5. Statistics of the intercomparison conditions: frequency distribution of ozone slant column ranges

Table 2. Campaign schedule

Day	*Actions*	*Notes*
Saturday 28 July	Installation	
Sunday 29 July	Installation	Blind days
Monday 30 July	Installation	Blind days
Tuesday 31 July	O_3 measurements	Blind days
Wednesday 1 August	O_3 calibration / adjustments	Stray light characterization
Thursday 2 August	O_3 calibration / adjustments	Stray light characterization
Friday 3 August	O_3 calibration / adjustments	Stray light characterization
Saturday 4 August	O_3 calibration / adjustments	Ozone final calibration
Sunday 5 August	O_3 calibration / UV	Ozone final calibration
Monday 6 August	O_3 calibration / UV	Ozone final calibration
Tuesday 7 August	O_3 calibration / UV	Ozone final calibration
Wednesday 8 August	O_3 calibration / UV	Brewer / Dobson
Thursday 9 August	Packing	

2.2 RBCC-E Brewer reference spectrometer calibration

The RBCC-E was established at the Izaña Atmospheric Research Center in 2003. It comprises three MkIII Brewer spectrophotometers: a Regional Primary Reference (Brewers#157), a Regional Secondary Reference (Brewers#183) and a Regional Travelling Standard (Brewers#185). The calibration of the RBCC-E triad against the World Brewer Triad (WBT) was established by a yearly comparison with the travelling standard Brewer#017 operated and maintained by the International Ozone Services Inc. (IOS) and checked at the station by means of the Langley extrapolation method. In addition, during the RBCC-E Brewer intercomparison campaigns the travelling standard #185 is compared with other reference instruments when it is possible. These reference instruments are: IOS travelling reference #017, the Brewer #145, operated by Environment and Climate Change Canada (ECCC), and the Kipp & Zonen travelling reference #158. The first two instruments provide a direct link to the WBT a report of the comparison between references can be found in Redondas et al. (2018).

Since the beginning of 2012, due to the internal reorganization of the Spanish Meteorological Service (AEMET), the technical maintenance of the RBCC-E Brewer triad is performed by Kipp & Zonen, Brewer manufacturer, and the link to the WBT will be conducted directly in Toronto or by joint Langley campaigns at Mauna Loa or IZO stations. Due to the ECCC situation and the lack of funds of AEMET, this intercomparison has not been possible since 2014. As well, and because of the doubts about the maintenance of the WBT, the WMO Scientific Advisory Group (WMO-SAG) on Ozone authorized the RBCC-E to transfer its own ozone absolute calibration. The methodology used is described in Redondas (2003, 2018) and Ito et al. (2011). The current status and maintenance of the RBCC-E is discussed in Leon-Luis et al. (2018).

As a preliminary and subsequent task during all of the calibration campaign, the reference instrument (Brewer#185) is analysed in detail. So, their instrumental parameters – dead time (DT), temperature dependence, as well as its ozone absorption coefficient calculated from a dispersion test – are compared with the values recorded prior to the campaign.

However, the Langley technique is the best procedure to detect if the calibration of the instrument has changed. In this respect, the extraterrestrial constant (ETC) obtained from this method must be constant as a guarantee of the instrument calibration. Figure 6 shows the Langley values calculated before and after the campaign from the morning and afternoon observations made during this year. As it can be observed, the values obtained are situated around 1615, which is used as ETC operative for this instrument.

In addition, Table 3 shows the ETC values calculated from 1-point and 2-point methods when the Brewer#185 is calibrated from the other instruments that form part of the RBCC-E Triad (Brewer#157 and Brewer#183) which remain in the Izaña Atmospheric Observatory (IZO). The ETC and ozone coefficient and the operative values are compared with each other. Figure 9 shows the daily relative difference of the ozone observations between the three instruments before and after the Arosa Campaign which is around 0.25% with respect to the mean. Finally, a summary with the main parameters of Brewer#185 is presented in Table 4.

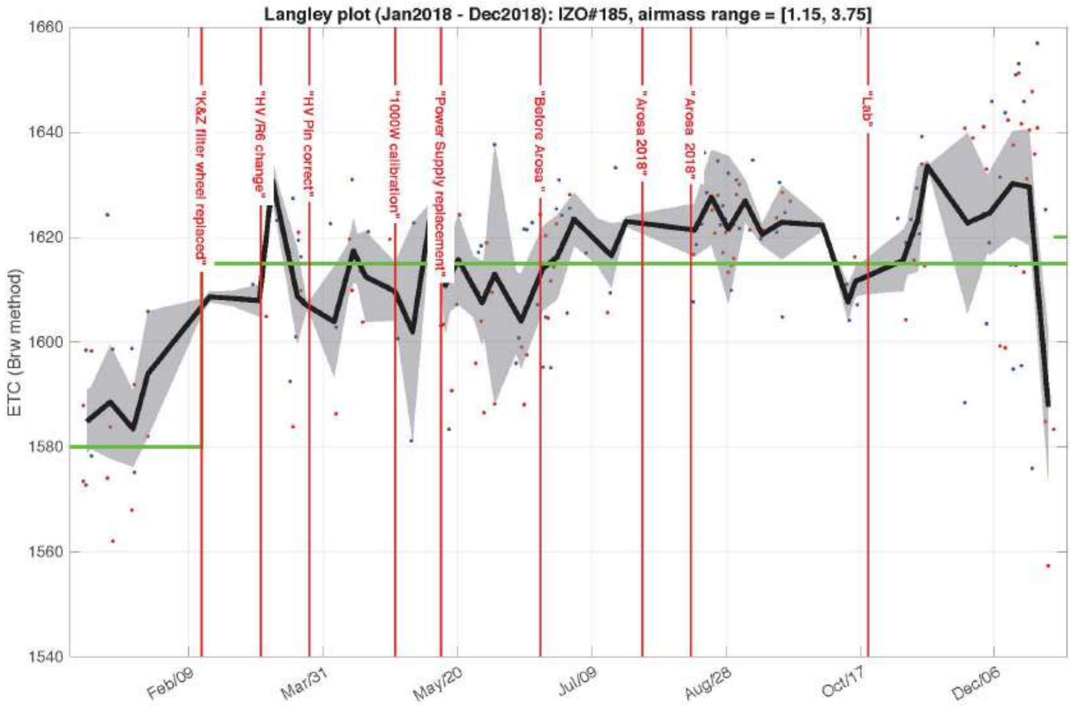


Figure 6. Langley ETC calculation for Brewer #185 during 2018. The blue (red) dots correspond to Langley results derived from AM (PM) data. The black line represents weekly means of both AM and PM Langley results, showing with dark and light grey shadows the standard error and the standard deviation of the mean, respectively. The vertical red lines indicate relevant events in the instrument's operation.

Figure 7. Setup of the instruments at Arosa Observatory

Figure 8. Dobson Calibration Center and Brewer participants at Arosa

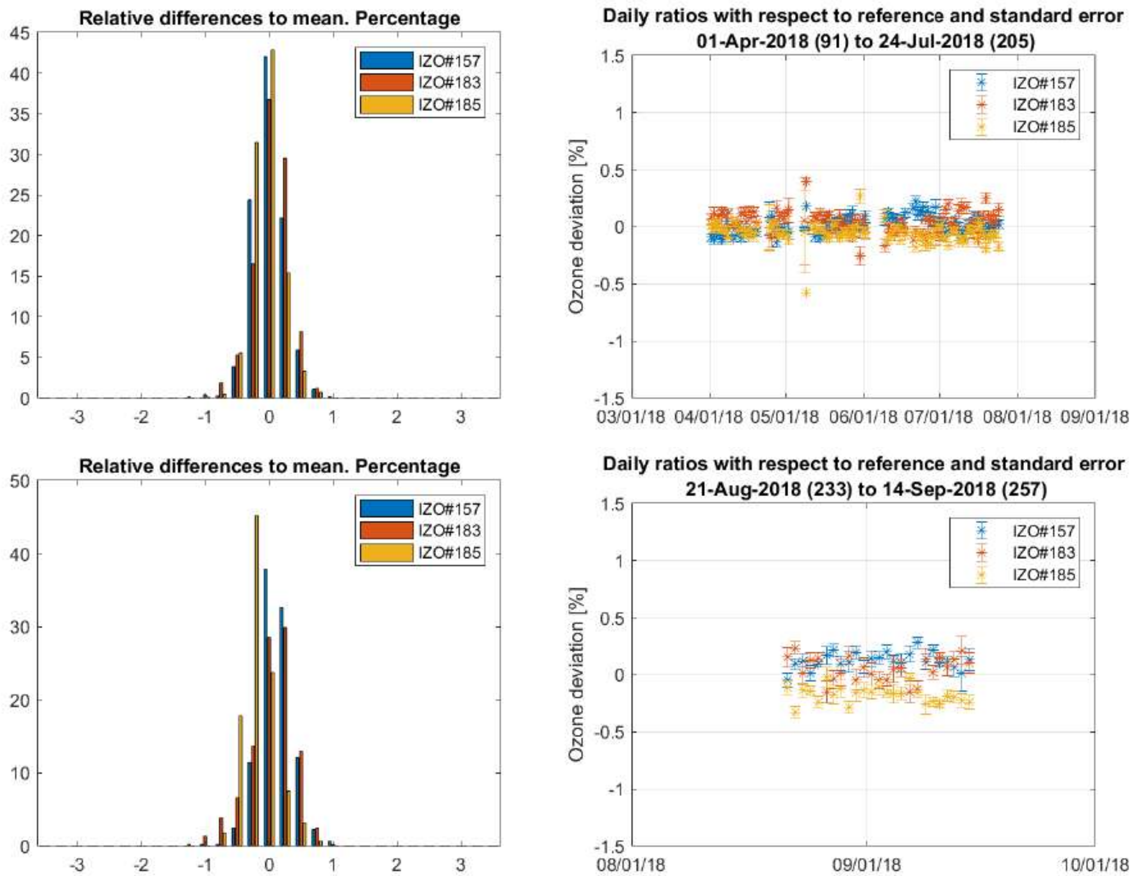


Figure 9. Percent **d**eviations of near-simultaneous ozone measurements of RBCC-E standard Brewer (serial no. #157, #183 and #185) to the triad mean (left) and temporal evolution of daily mean deviation of near-simultaneous ozone measurements with the error bars representing the standard error (right). Data before (top) and after (bottom) the Arosa 2018 intercomparison are presented.

Table 3. ETC values calculated from comparison between the RBCC-E instruments

Comparison of RBCC-E instruments before the Arosa campaign						
Brewer calibrated	*Brewer reference*	*$ETC_{Operative}$ (Langley)*	*$O_{3\ Operative}$*	*ETC_{1P}*	*ETC_{2P}*	*$O_{3\ 2P}$*
185	157	1615	0.341	1614	1616	0.341
185	183	1615	0.341	1615	1624	0.339
Comparison of RBCC-E instruments after the Arosa campaign						
Brewer calibrated	*Brewer reference*	*$ETC_{Operative}$ (Langley)*	*$O_{3\ Operative}$*	*ETC_{1P}*	*ETC_{2P}*	*$O_{3\ 2P}$*
185	183	1615	0.342	1611	1618	0.340
185	157	1615	0.342	1615	1631	0.338

Table 4. Calibration and instrument checklist of Brewer#185

Reference Check list: B#185	*Step description*	*Passed?* *Yes*	*No*	*Value*	*Comments*
Calibration data					
Reference of the travelling	RBCC-E B#185				Own Langley
Is travelling standard calibrated?		Y			
% difference before travel?				-.05%	
% difference after travel?				-.17%	
Instrument operation					
HP/HG	Hp/Hg tests repeatable to within 0.2 steps	Y			
SH	SH shutter delay is correct		NaN		
RS	Test within +/- 0.003 from unity for illuminated slits and between 0.5 and 2 for the dark count	Y			
Dead time	It is between 28 ns and 45 ns for multiple-board Brewers and between 16 ns and 25 ns for single-board Brewers		N	29	
Standard lamp	SL ratio R6 is within 5 units from calibration	Y		365	
Standard lamp	SL ratio R5 is within 10 units from calibration	Y		581	

2.3 Blind comparison

During the blind period the instruments are working with their home calibration and the ozone is calculated using these calibration constants. An initial comparison with the reference Brewer gives us an idea of the initial status of the instrument, that is, how well the instrument performed using the original calibration constants (those operational at the instrument's station). Moreover, it is possible to detect changes of the instrument response due to the travel from internal tests, as standard lamp (SL), performed before and after the travel.

The SL test is an ozone measurement using the internal halogen lamp as a source. In the local station, this test is performed routinely to track the spectral response of the instrument and therefore the ozone calibration. A reference value for the SL R6 ratio is provided as part of the calibration of the instrument. The ozone measurement is routinely corrected assuming that deviations of the R6 value from the reference value are the same that changes in the extraterrestrial constant (ETC). This is the so-called SL correction. Hence, it is reasonable to investigate if the observed R6 changes are related with similar changes in the calibration constant. If this were the case, then the ETC constant should be corrected by the same change in SL R6 ratio as $ETC_{new} = ETC_{old} - (SL_{ref} - SL_{measured})$. Figure 10 shows the difference between the calculated and reference R6 values, and as it can be observed only the Brewer#044 and Brewer#245 have a difference larger than 10 units. The first instrument because it was inoperative since 2016 and the second one because the cal step was changed just before the campaign. The rest of the instruments presented variations ± 10, units which suggests that the instruments have remained stable from their last calibration.

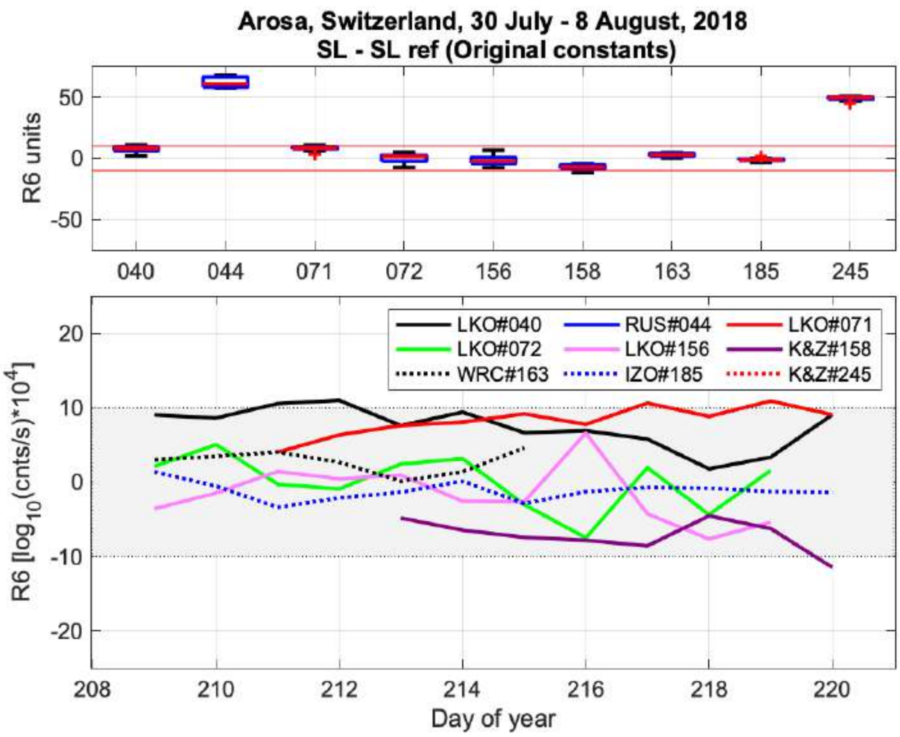


Figure 10. Standard lamp R6 difference to R6 reference value from last the calibration during the blind days, before the maintenance. Variations within the ± 10 range (≈1% in ozone) are considered normal, whereas larger changes would require further analysis of the instrument performance.

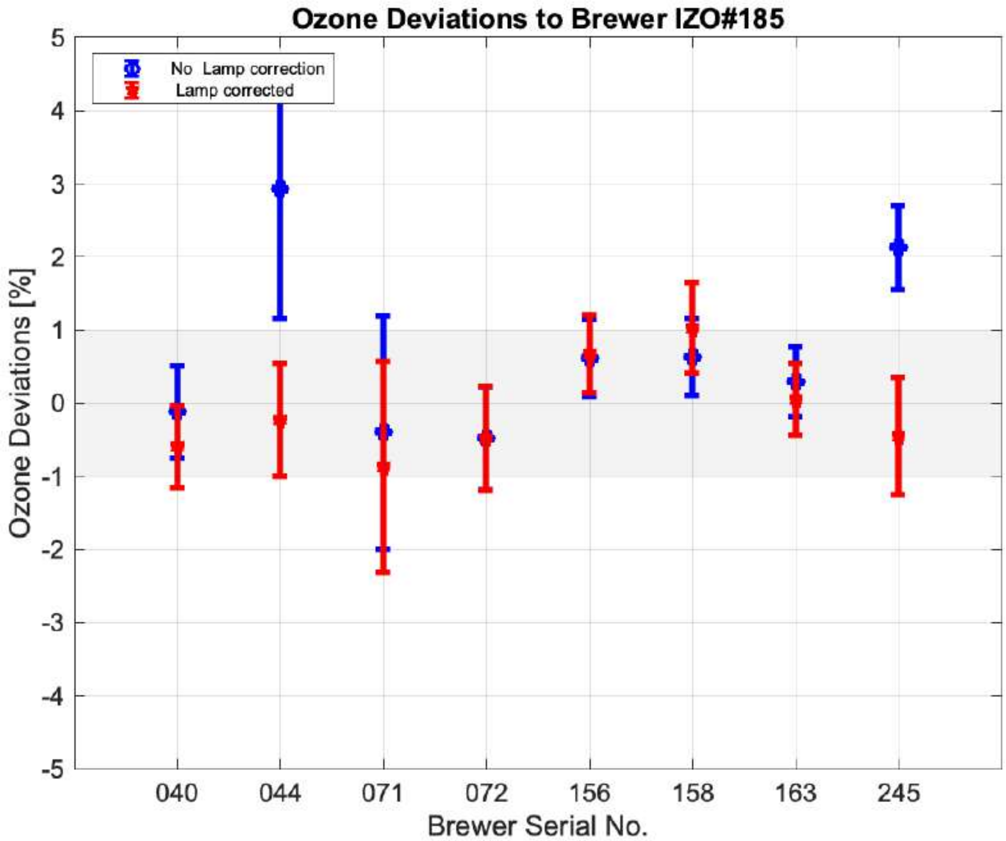


Figure 11. Ozone relative percentage differences of all Arosa 2018 participating instruments to RBCC-E travelling standard IZO#185. Ozone measurements collected during the blind period are reprocessed using the original calibration constants, with (red) and without (blue) standard lamp correction. Error bars represent the standard deviation.

However, the comparison with a reference instrument is the only way to assess whether the SL measurements properly track changes on the calibration constants or if the change observed is due to an emission spectrum change.

The results of the blind comparison with the reference instrument Brewer#185 showed very satisfactory results for some instruments (Brewer#040, Brewer#072, Brewer#156, Brewer#158 and Brewer#163) with ozone deviations lower than 1%, see Figure 11. This includes the reference Brewer K&Z#158 which is used to transfer the ozone calibration worldwide by Kipp & Zonen. Given the observed differences SL_{ref} - $SL_{measured}$, see Figures 12 and 13, applying the SL correction to the ETC constant has little effect for all the participating instruments, with the exception of the Brewer#044 and Brewer#245. Moreover, in Figure 12 the stray light effect is observed in the single Brewers with a marked ozone slant column dependence in ozone measurements, especially the Brewer#071. In Section 3, an individual stray light correction for each instrument is presented.

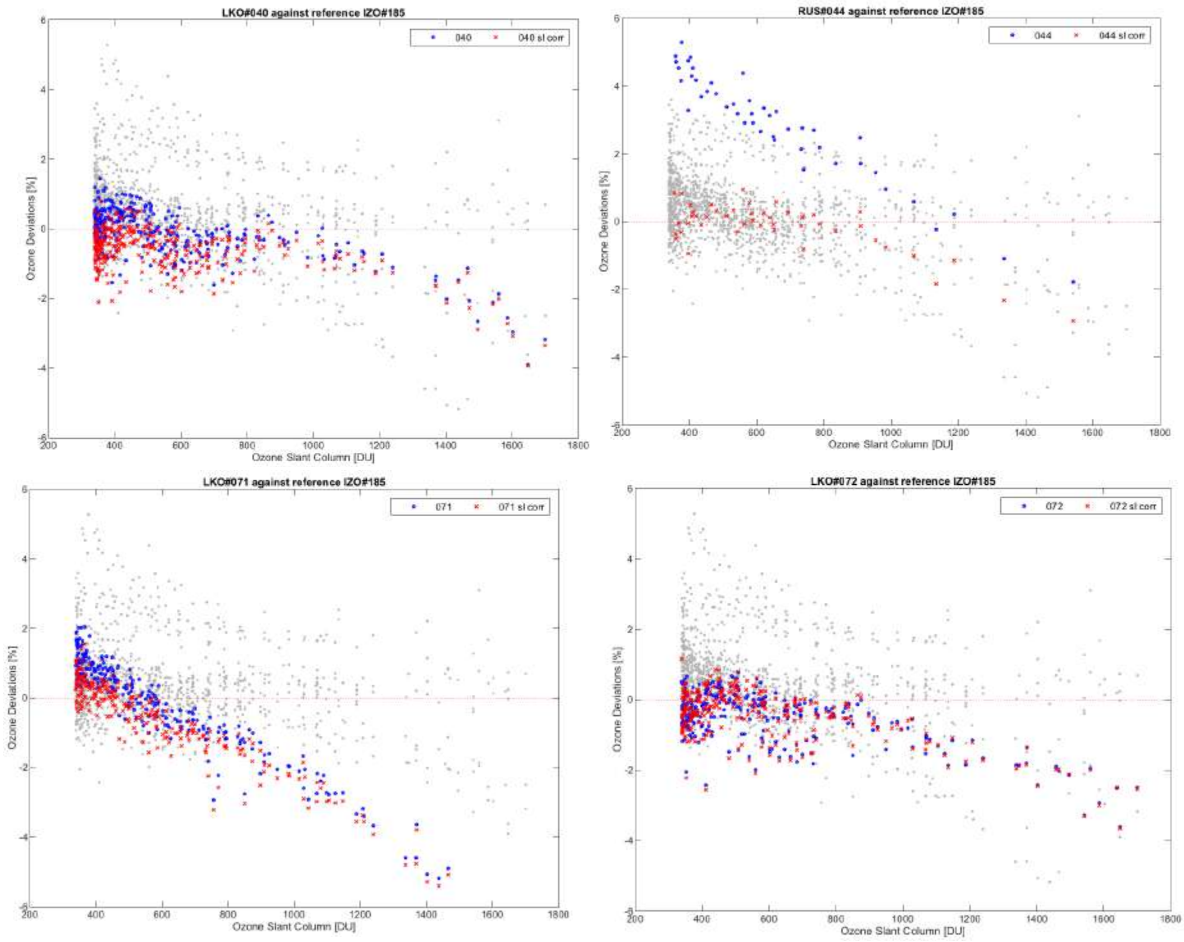


Figure 12. Blind-days ozone relative differences (percentage) of Arosa 2018 single Brewer instruments to RBCC-E travelling standard Brewer #185. Ozone measurements collected during the blind period (before the maintenance) were reprocessed using the original calibration constants, with (red stars) and without (blue stars) standard lamp correction. Grey dots mean ozone deviations for all participating instruments.

The individual differences, with and without applying the SL correction, with respect to the reference instrument plot in Figures 12 and 13 has been averaged. The results are summarized in Table 5.

2.4 Final calibration

We defined the final days as those available after the maintenance work was finished for each participating instrument. These days are used to calculate the final calibration constants, so we tried not to manipulate the instruments during this period. As well, the SL R6 value recorded during the final days is normally adopted as the new reference value. It is also expected that this parameter will not vary more than 5 units during the same period.

Figure 14 shows the differences between the daily standard lamp R6 ratio and the proposed R6 reference value during the final days. As expected, the recorded SL values did not vary more than 5 units during this period.

Table 5. Ozone deviation in % with respect to the reference calculated with the home calibration

	No standard lamp correction		*Standard lamp corrected*		*Best comparison*	
	mean	*std*	*mean*	*std*	*mean*	*std*
LKO#040	-0.01	0.55	-0.51	0.50	-0.01	0.55
RUS#044	3.36	1.13	0.05	0.42	0.05	0.42
LKO#071	0.17	0.98	-0.35	0.85	0.17	0.98
LKO#072	-0.34	0.57	-0.33	0.59	-0.33	0.59
LKO#156	0.61	0.52	0.64	0.55	0.61	0.52
K&Z#158	0.75	0.54	1.18	0.63	0.75	0.54
WRC#163	0.28	0.44	0.01	0.44	0.01	0.44
K&Z#245	2.22	0.60	-0.65	0.68	-0.65	0.68

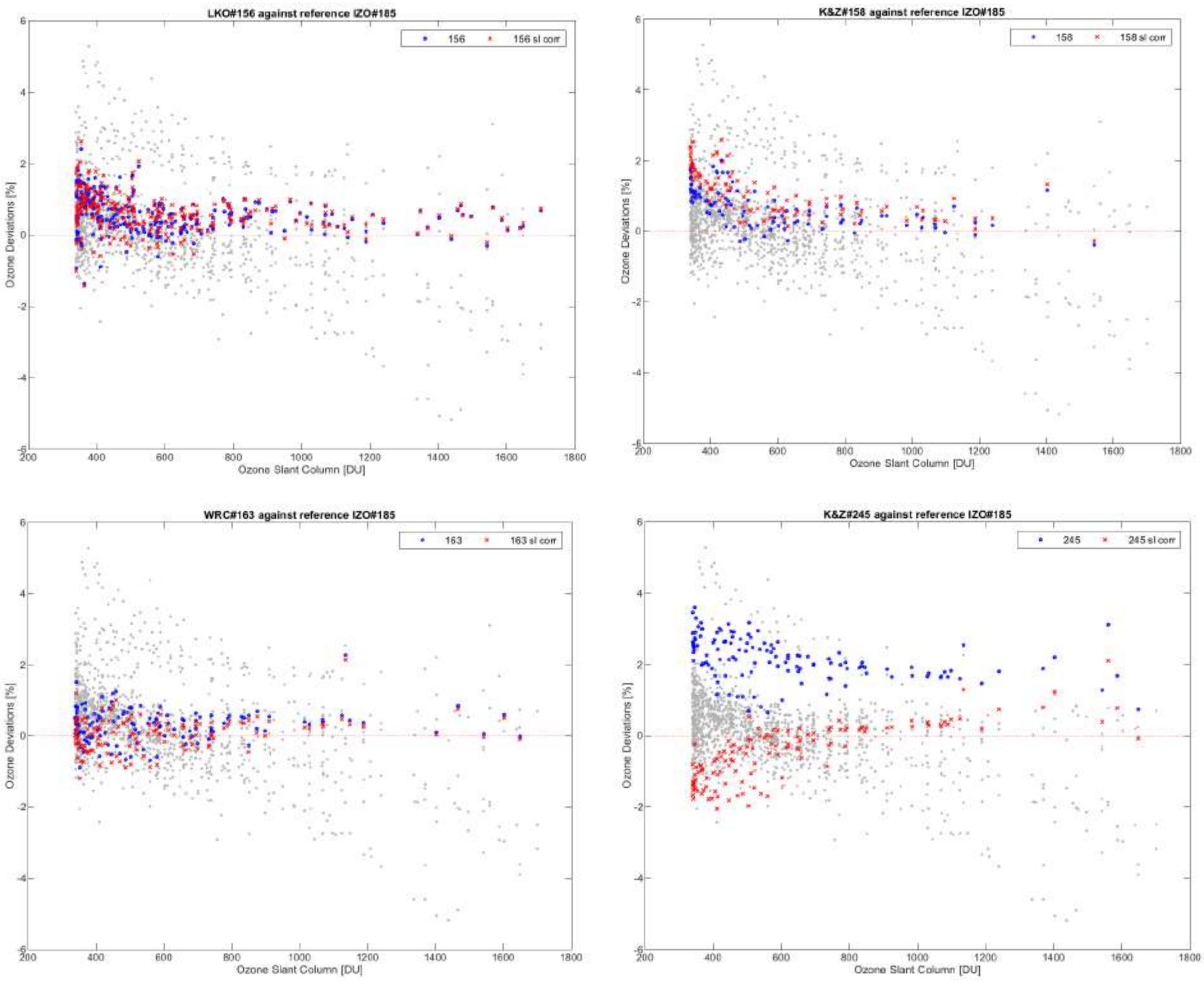
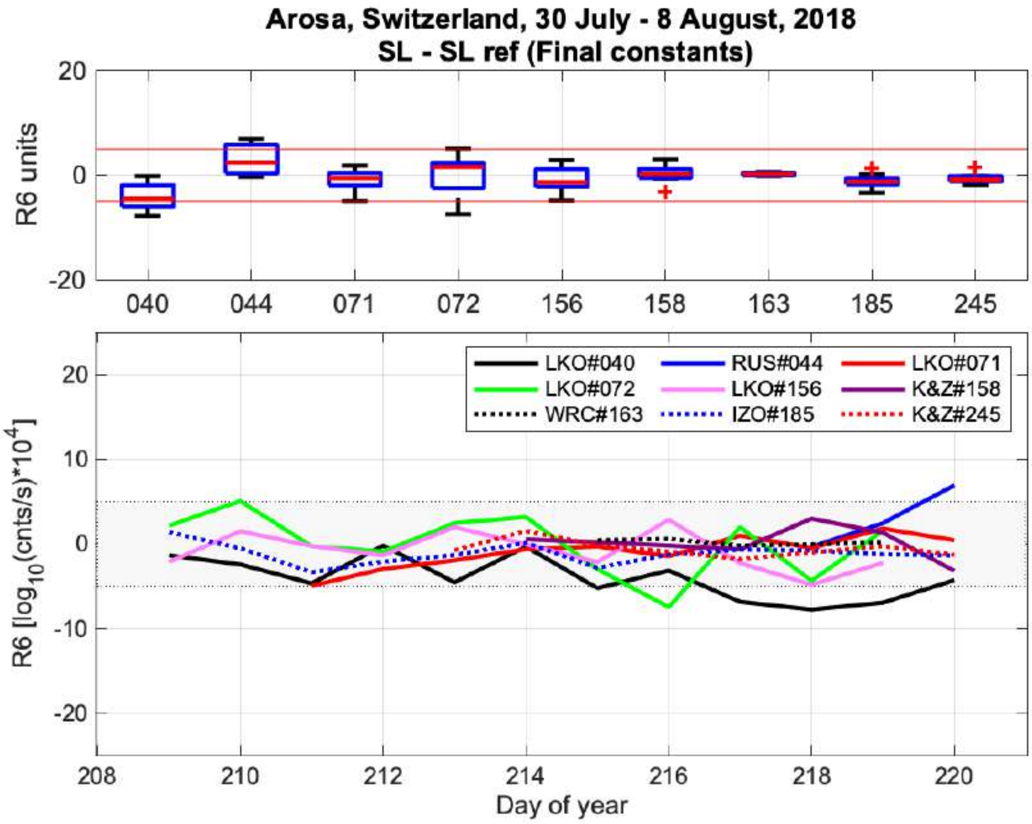


Figure 13. Blind-days ozone relative differences (percentage) of Arosa 2018 double Brewer instruments to RBCC-E travelling standard Brewer #185. Ozone measurements collected during the blind period (before the maintenance) were reprocessed using the original calibration constants, with (red stars) and without (blue stars) standard lamp correction.



Grey dots mean ozone deviations for all participating instruments.

Figure 14. Standard lamp R6 ratio to R6 reference from last calibration differences during the final days grouped by Brewer serial number (above) and as a function of time (below). The shadow area represents the tolerance range (±5 R6 units).

Deviations of ozone values for all the participating instruments from the RBCC-E travelling standard Brewer IZO#185 are shown in Figure 15. We have recalculated the ozone measurements using the final calibration constants, with and without stray light correction in the case of single Brewers. The ozone underestimation due to the effect of the stray light in single Brewers and the correction applied by the model is depicted in Figure 16, details of these corrections are found in (Redondas et al., 2018)

All Brewers were calibrated using the one parameter ETC transfer method, that is, the ozone absorption coefficient was derived from the wavelength calibration (dispersion test) and only the ozone ETC constant is transferred from the reference instrument. The two parameters calibration method is also used as a quality indicator. For all the instruments both the one parameter and the two parameters ETC transfer methods agreed with each other within the limits ±5 units for ETC constants and ±0.001 atm/cm for the ozone absorption coefficient (one micrometer step), which is a very good indication of the quality of the calibration provided. With these tolerance limits, a good agreement with the reference instrument Brewer#185 using the final calibration constants, within the range ±0.5%, was achieved.

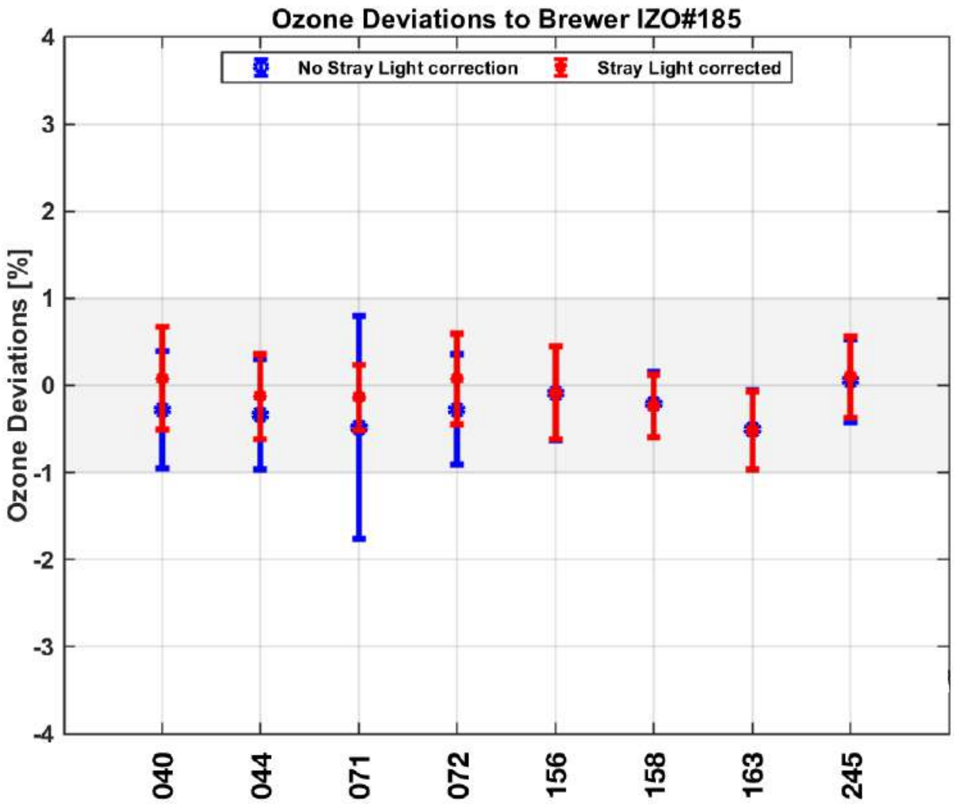


Figure 15a. Ozone relative percentage differences of all Arosa 2018 participating instruments to RBCC-E travelling standard IZO#185. Ozone measurements collected during the final period are reprocessed using the proposed calibration constants, with (red plots) and without (blue plots) stray light correction. Error bars represent the standard deviation.

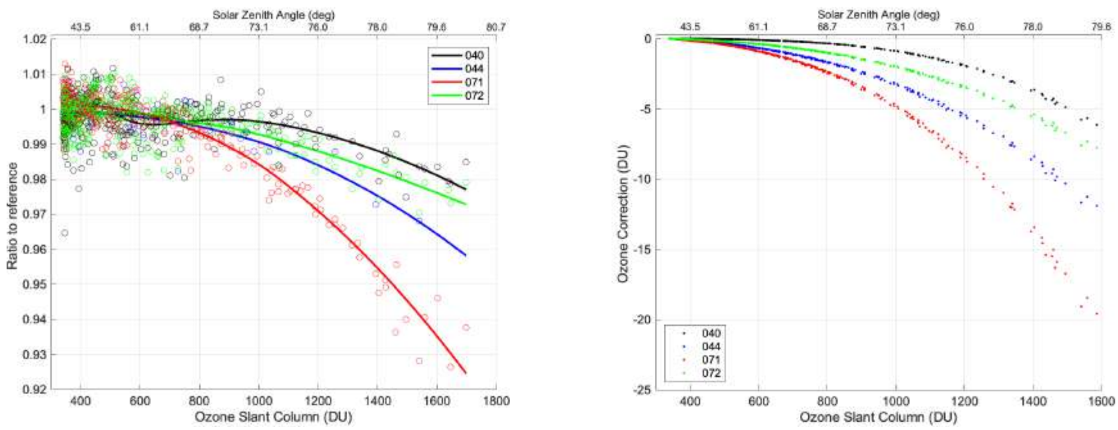


Figure 15b. Ozone relative percentage differences of single Brewers at Arosa 2018 participating instruments to RBCC-E travelling standard IZO#185, showing the underestimation of the Ozone measurements for solar Zenith angle above 70º (left) and the correction applied by the model in Dobson Units.

In Table 6, the mean differences are summarized with and without applying the stray light correction, respect to the reference instrument. The ozone was calculated using the final calibration of the instrument.

Table 6. Ozone deviation in % respect to the reference calculated with the final calibration

	No stray light correction		*Stray light corrected*	
	mean	*std*	*mean*	*std*
LKO#040	-0.31	0.63	-0.06	0.66
RUS#044	-0.46	0.78	-0.56	0.73
LKO#071	-0.61	1.42	-0.96	1.34
LKO#072	-0.34	0.68	-0.27	0.73
LKO#156	-0.16	0.54	-0.16	0.55
K&Z#158	-0.14	0.46	-0.15	0.45
WRC#163	-0.55	0.52	-0.56	0.52
K&Z#245	0.00	0.46	0.05	0.44

3. OZONE BREWER REPORTS

3.1 Brewer LKO#040, Station: Arosa, Switzerland

Brewer LKO#040 is a single instrument which operates normally at the Arosa station. The last calibration was made by IOS after a maintenance task in 2017. This instrument participated in the campaign during the period from 28 July to 10 August 2018 (Julian days 209–220). During this period, no maintenance tasks were performed, so the same dataset was used to evaluate the initial status of the instrument as well as for final calibration purposes.

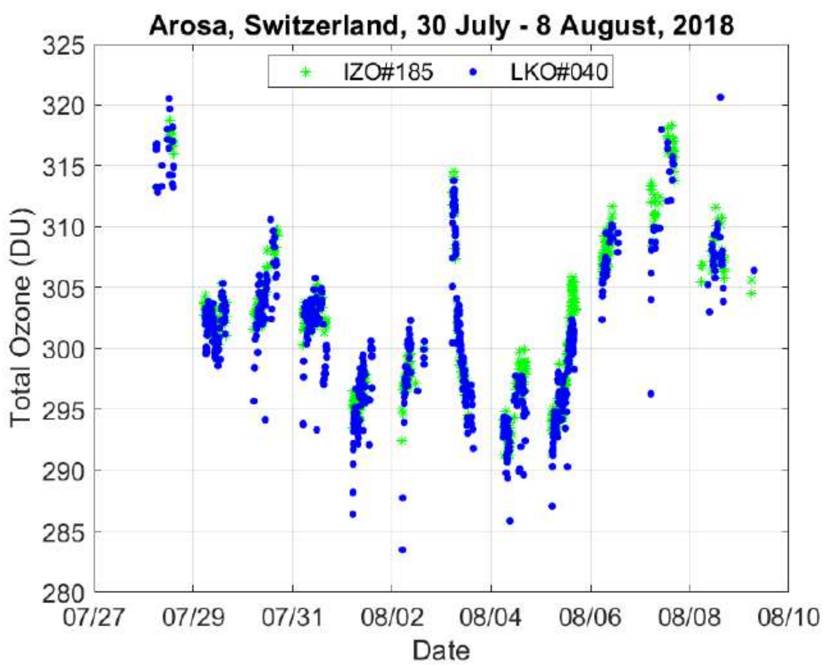


Figure 16. Total ozone Brewer Intercomparison Arosa 2018. Reference Brewer#185 and Arosa Brewer#040.

Original calibration
The instrument operates with the configuration file icf19817.040 and reference value for the standard lamp R6 ratio 1742. These calibration constants were provided by IOS during their maintenance tasks in 2017.

Historical analysis
The SL test results have been very stable during the last two years, although a small seasonal dependence can be appreciated, as it is shown in Figure 17. This dependence suggests that a new temperature coefficient set must be provided with our calibration. During the campaign days, the SL tests were stabilized around values 1738 and 3275 for R6 and R5 ratios, respectively. These values were calculated taking into account the new temperature coefficients and dead time calculated in this campaign. All the other parameters analysed (Run/Stop test, Hg lamp intensity, CZ & CI files) were good.

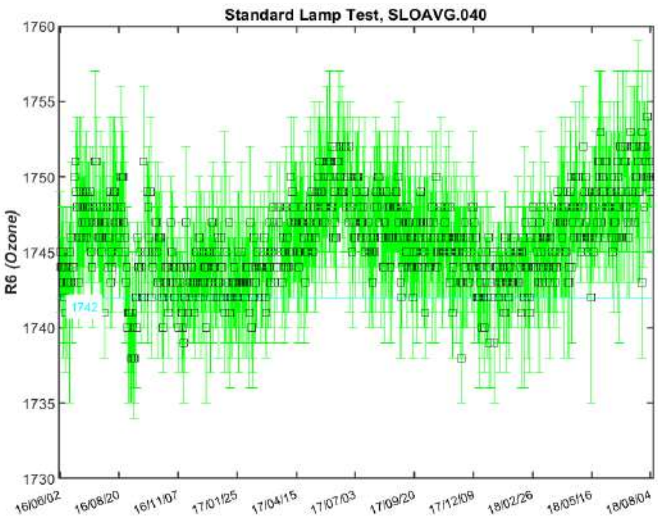


Figure 17. Standard lamp test R6 (ozone)ratio

Initial comparison
For the evaluation of the initial status of Brewer LKO#040 we used the period from days 209 to 220, which corresponds with 445 near-simultaneous direct sun ozone measurements. As Figure 18 shows the current ICF (Instrument Configuration File) produces ozone values with a good agreement respect to the reference. However, when the ETC is corrected taking into account the difference between the SL and R6 reference (SL correction), the results get worse. Therefore, it is not recommended to use this correction to recalculate the previous ozone values.

Final calibration and stray light
In this campaign, a new DT and temperature coefficients have been provided, hence, a new ETC must be calculated for the final calibration. In the final calibration, we used 688 simultaneous direct sun measurements from days 209 to 220. The new ETC (2963) is 13 units lower than the current one (2976). Therefore, we recommend using this new ETC, and the new SL reference ratio R6 1738. On the contrary, the cal step and the ozone absorption coefficients have not been changed in the new calibration, see Table 7.

As Figure 18 shows the final calibration performed well with error near zero for OSC<1000 and an underestimation of 1% at 1300 OSC which is very good for a single Brewer. The empirical stray light model fits pretty well with coefficient values: k=-10.2, s=5.21, ETC=2960 agrees perfectly with the reference for the full range of OSC.

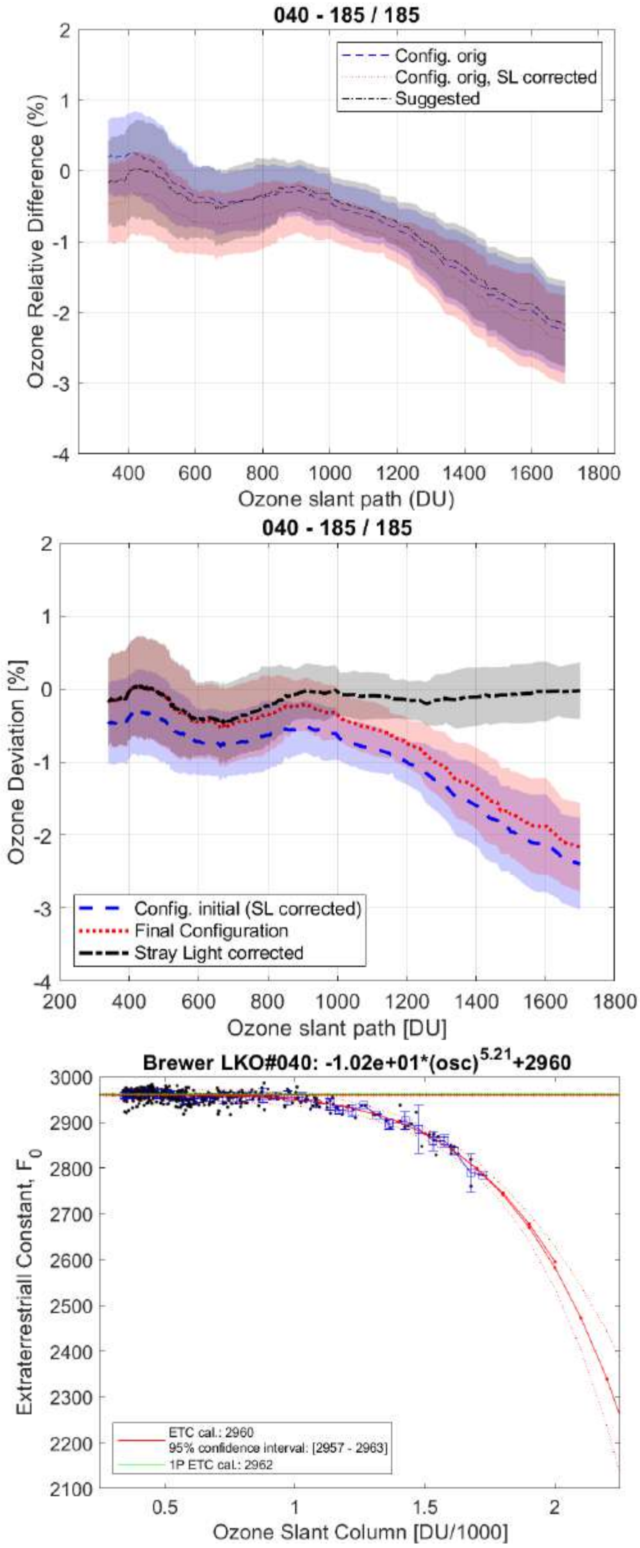


Figure 18. (Top) Ratio respect to the reference used the initial configuration with and without SL correction. (Middle) Initial and final configuration without and with stray light correction. (Bottom) Stray light empirical model determination.

Recommendations and comments

1. New reference values are given in this campaign for R6=1738 and R5=3275.

2. All the other diagnostics analysed (RS, AP records ...) were normal, except the measurement of the DT which is 1ns lower than the reference value.

3. We suggest using a DT constant of 37ns, which is one unit less than proposed during the last intercomparison (IOS 2017). Several studies suggest that a difference of around one nanosecond is admissible for a single Brewer.

4. The neutral density filters have an excellent behaviour and, hence, no correction factor is suggested.

5. We have adopted new temperature coefficients.

6. The Sun-scan tests are conclusive enough to analyse the optical position 940. However, the final ICF used was 943.

7. The instrument performed very well after the calibration constants were applied, with minimal ozone deviations when the stray light correction was used. We recommend the use of the stray light correction.

Calibration report

http://rbcce.aemet.es/svn/campaigns/aro2018/latex/040/CALIBRATION_040.pdf

Table 7. Calibration constants summary

Parameters	*Initial Configuration*	*Final Configuration*
O_3 ETC constant	2976	2963
SL R6 reference value	1742	1738
Change SL R6 ratio/ETC		<10
DT constant (ns)	38	37
Temp. coefficients	Old TC	New TC
Cal step number	943	943
Ozone abs. coeff.	0.335	0.335
Stray light factors Arosa 2018	2960-10.2*(OSC)^5.21	
Calibration file	icf19817.040 (IOS)	Icf21018.040 (RBCC-E)

3.2 Brewer RUS#044, Station: RPA, Russia

Brewer RUS#044 participated in the campaign during the period from 30 July to 10 August 2018 (Julian days 209–221). It is important to note that this instrument was stopped since 2016 and it was repaired by Kipp & Zonen during this campaign. Therefore, it has been considered as a new instrument for this campaign. The maintenance task (prism orientation, humidity leaks) finished on day 218, also the wavelength calibration was modified (cal step constant was updated to a new value 141). For the evaluation of the initial status, we used 134 simultaneous direct sun ozone measurements from days 216 to 220, whereas days 218 to 220 were used for final calibration purposes.

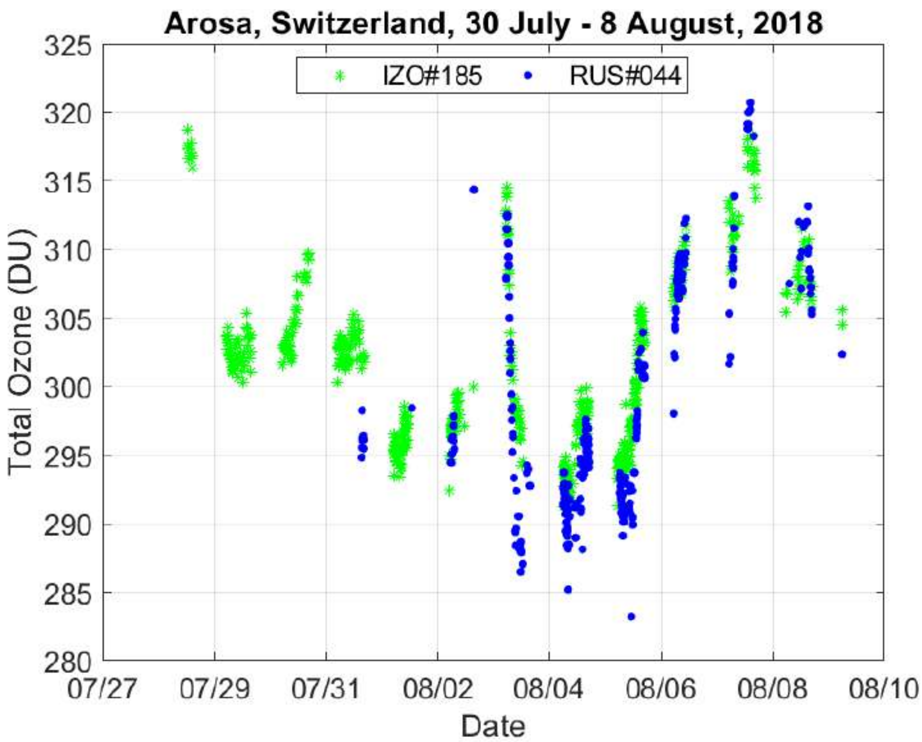


Figure 19. Brewer Intercomparison Arosa 2018

Original calibration

The instrument operates with the configuration file icf15315.044 and reference value for the standard lamp R6 ratio 2012. These calibration constants were obtained after the 2015 RBCC-E Intercomparison campaign at El Arenosillo (Huelva, Spain).

Historical analysis

After the maintenance tasks, this Brewer is considered as a new instrument and hence, it hasn't any available historic data. Figure 20 shows current R6 value calculated with the ICF provided in this campaign. The other parameters analysed (Run/Stop test, Hg lamp intensity, CZ & CI files) were ok, except for the DT value. This parameter showed a small difference between both the original and recorded values, around 1 unit. The neutral density filters didn't show nonlinearity in the attenuation spectral characteristics which indicated that it is not necessary to apply any correction to filters.

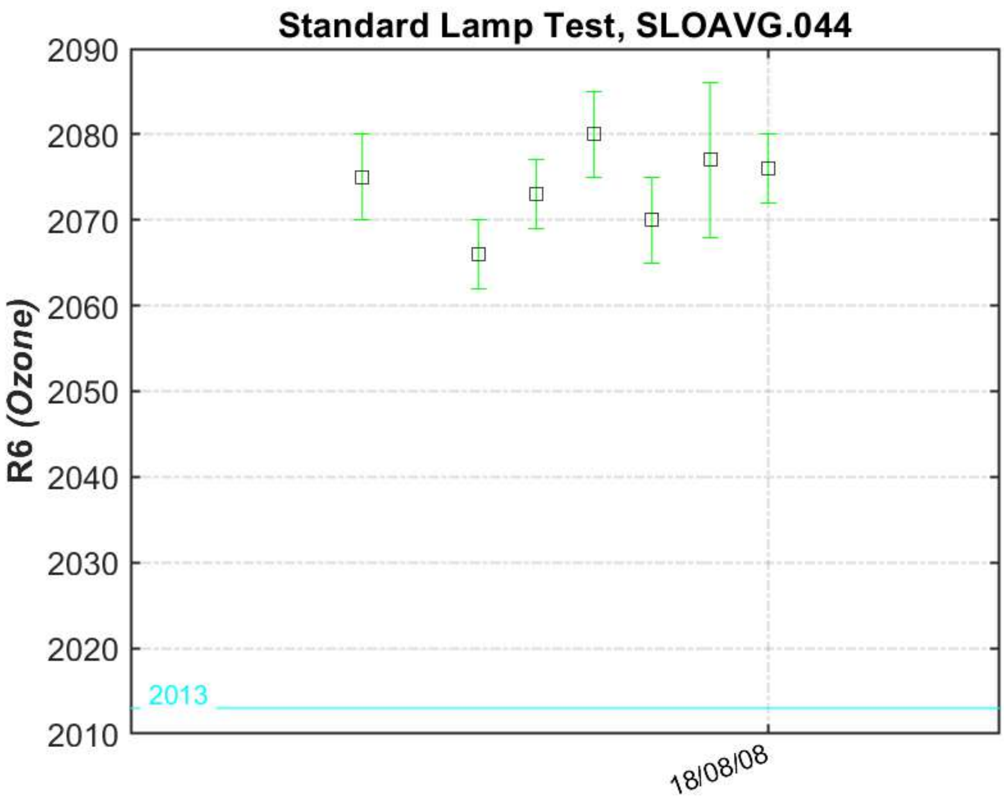


Figure 20. Standard lamp test R6 (ozone) ratio

Initial comparison
For the evaluation of the initial status of Brewer RUS#044 we used the period from days 216 to 220, which corresponds with 134 near-simultaneous direct sun ozone measurements. As shown in Figure 21, the current calibration constants produced greater ozone values than the reference instrument (+2%, on average). Moreover, when the ETC was corrected taking into account the difference between the SL and R6 reference (SL correction), the results got better.

Final calibration and stray light
Due to the difference with the reference Brewer and also taking into account the maintenance tasks, a new ETC value was calculated using 207 simultaneous direct sun measurements from days 218 to 220. The new value (3220) is 52 units greater than the current ETC value (3168). Therefore, we recommend using this new ETC, together with the new proposed SL reference ratios R6 2070. It is important to note that the ETC has been calculated taking into account the new dead time provided, see Table 8.

As Figure 21 shows the final calibration performed well with error near zero for low OSC and an underestimation of 1% at 800 OSC which is very good for a single Brewer. The empirical stray model fits pretty well with coefficient values: s=2.70, k=-4.20, ETC=3221, which agrees perfectly with the reference for the full range of OSC.

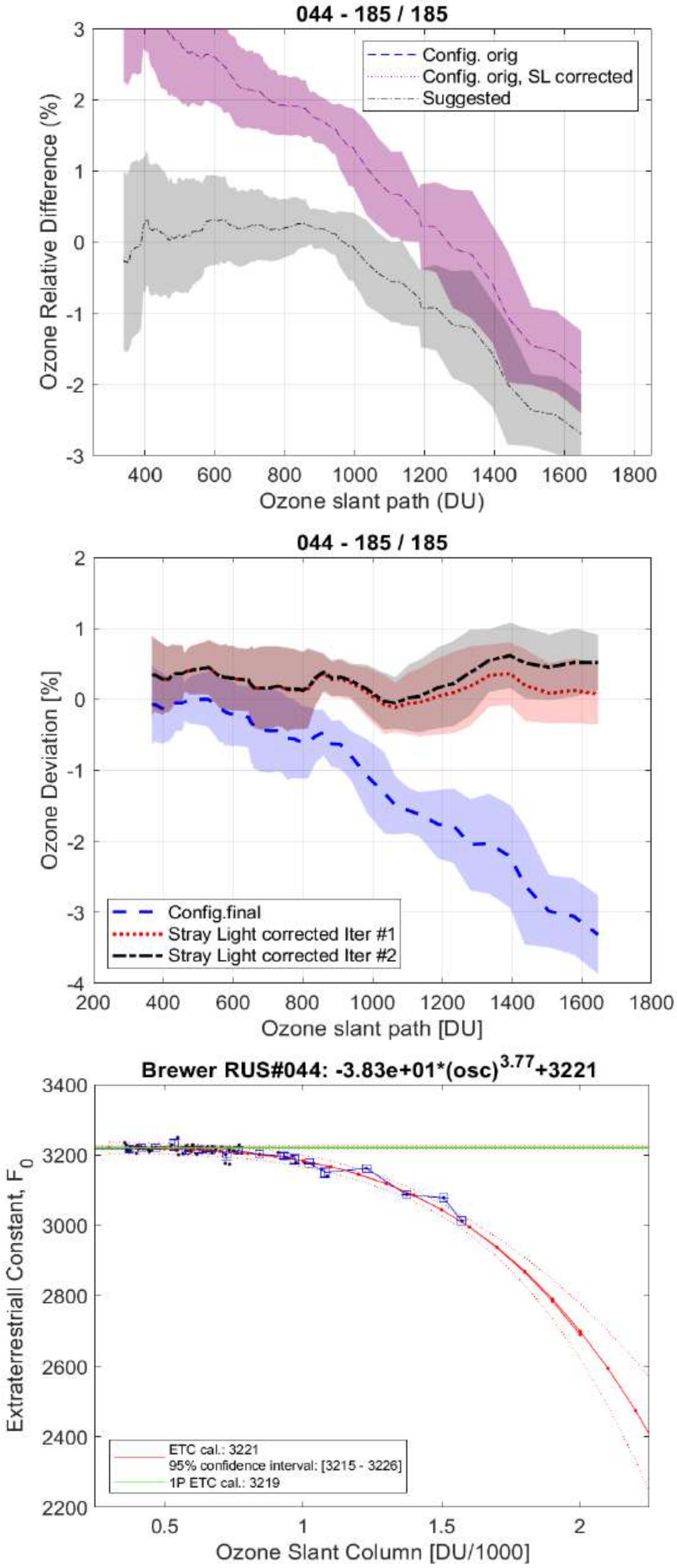


Figure 21. (Top) Ratio respect to the reference used in the initial configuration with and without SL correction. (Middle) Initial and final configuration without and with stray light correction. (Bottom) Stray light empirical model determination.

Table 8. Calibration constants summary

Parameters	*Initial Configuration*	*Final Configuration*
O_3 ETC constant	3168	3220
SL R6 reference value	2012	2075
Change SL R6 ratio/ETC		>50
DT constant (ns)	40	39
Temp. coefficients	Old TC	Old TC
Cal step number	137	141
Ozone abs. coeff.	0.342	0.3438
Stray light factors Arosa 2018	3221-38.3*(OSC)^3.77	
Calibration file	icf15315.044 (RBCC-E)	Icf21518.044 (RBCC-E)

Recommendations and comments

1. In this campaign new R6 2075 and R5 3698 reference values are given.

2. All the other diagnostics analysed (RS, AP records ...) were normal.

3. We suggest using a DT constant of 39ns, which is one unit lower than proposed during the last intercomparison. Several studies suggest that a difference of around one nanosecond is admissible for a single Brewer.

4. The neutral density filters have an excellent behaviour and, hence, no correction factor is suggested.

5. We have not adopted new temperature coefficients.

6. The sun-scan (SC) tests performed during the campaign suggested that a new cal step number (CSN) must be used. It was updated to a new value (141) on day 218.

7. The instrument performed very well after the calibration constants were applied, with minimal ozone deviations when the stray light correction was used. We recommend the use of the stray light correction.

Calibration report

http://rbcce.aemet.es/svn/campaigns/aro2018/latex/044/CALIBRATION_044.pdf

3.3 Brewer LKO#071, Station: Arosa, Switzerland

Brewer LKO#071 participated in the campaign during the period from 30 July to 10 August 2018 (Julian days 209–221). For the evaluation of the initial status, we used 354 simultaneous direct sun ozone measurements from days 211 to 220. The same period was used for final calibration purposes (542 simultaneous measurements).

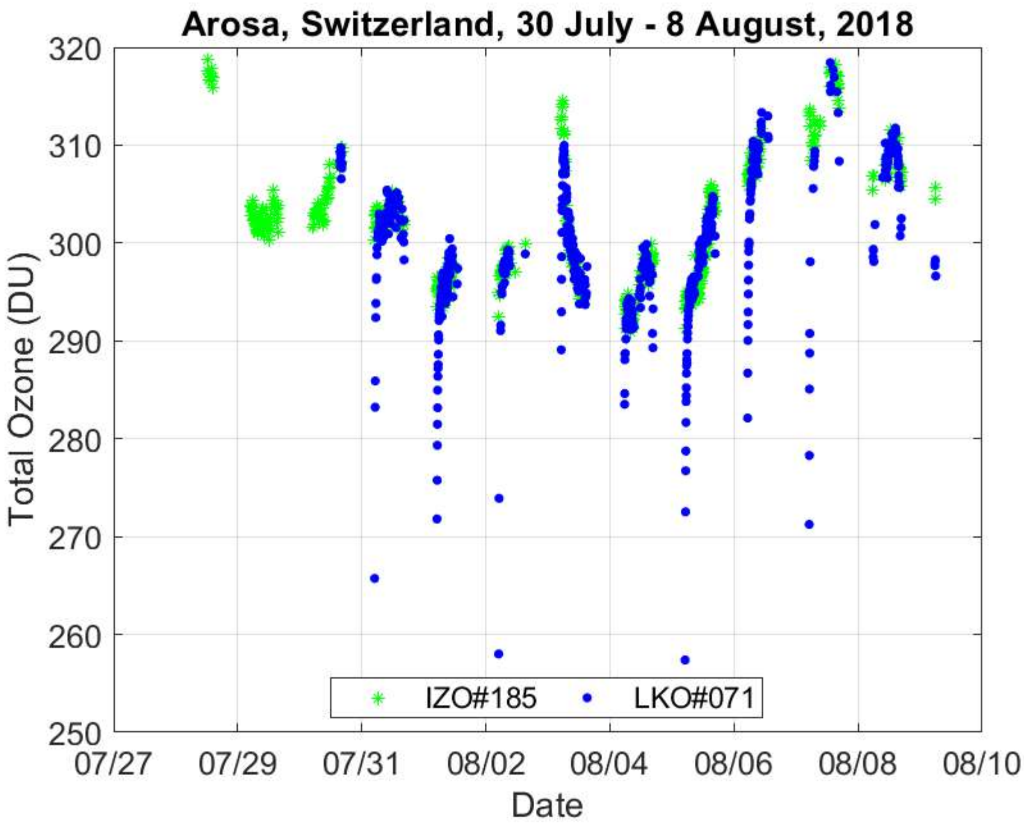


Figure 22. Brewer Intercomparison Arosa 2018

Original calibration

The instrument operates with the configuration file icf16818.071 and reference value 1878 for the standard lamp R6 ratio. These calibration constants have been obtained recently, in May 2018 by IOS. This calibration was necessary because the $NISO_4$ filter was changed in the instrument.

Historical analysis

Due to the replacement of $NISO_4$ filter, the historic data starts from this event. Therefore, in this campaign it was considered as a new instrument. During the campaign days the SL ratios stabilized around values 1880 and 3525 for R6 and R5 standard lamp ratios, respectively (see Figure 23). The other parameters analysed (Run/Stop test, Hg lamp intensity, CZ & CI files) are inside the tolerance limits, except for the DT. This parameter showed a small difference between both the original and recorded values of 1 unit.

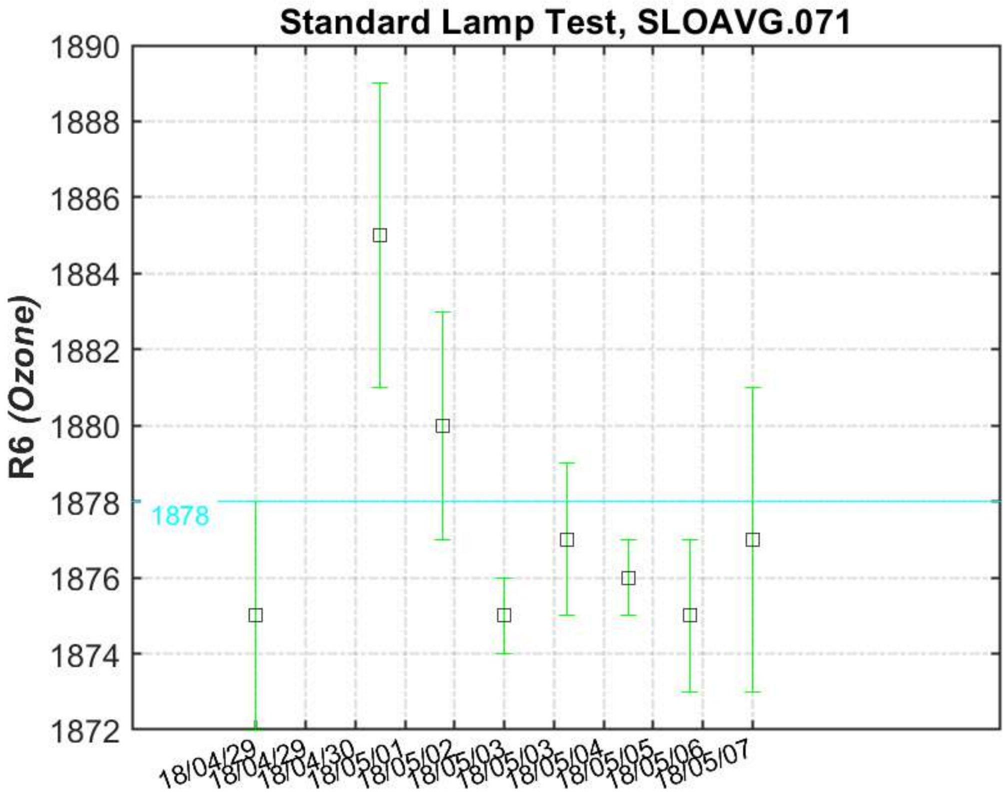


Figure 23. Standard lamp test R6 (ozone) ratio

Initial comparison

For the evaluation of the initial status of Brewer LKO#071 we used the period from days 211 to 220, which corresponds with 354 near-simultaneous direct sun ozone measurements. As shown in Figure 24, this instrument has a strong ozone slant path dependence and its current calibration overestimates the ozone concentration for low slant path (OSC<600). Applying the SL, a small improvement in the result is observed.

Final calibration and stray light

In the final calibration, we used 542 simultaneous direct sun measurements from days 211 to 220. The new ETC (3065) is 5 units lower than the current one (3070). Therefore, we recommend using this value, together with the new proposed SL reference ratio 1885 for R6. The final ETC was calculated taking into account the new dead time and absorption coefficient calculated during the campaign, see Table 9.

The final calibration performed well with error near zero for low OSC and an underestimation of 1% at 900 OSC which is very good for a single Brewer. The empirical stray model fits pretty well with coefficients values: k=-57.6, s=4.10, ETC=3068 which agrees perfectly with the reference for the full range of OSC.

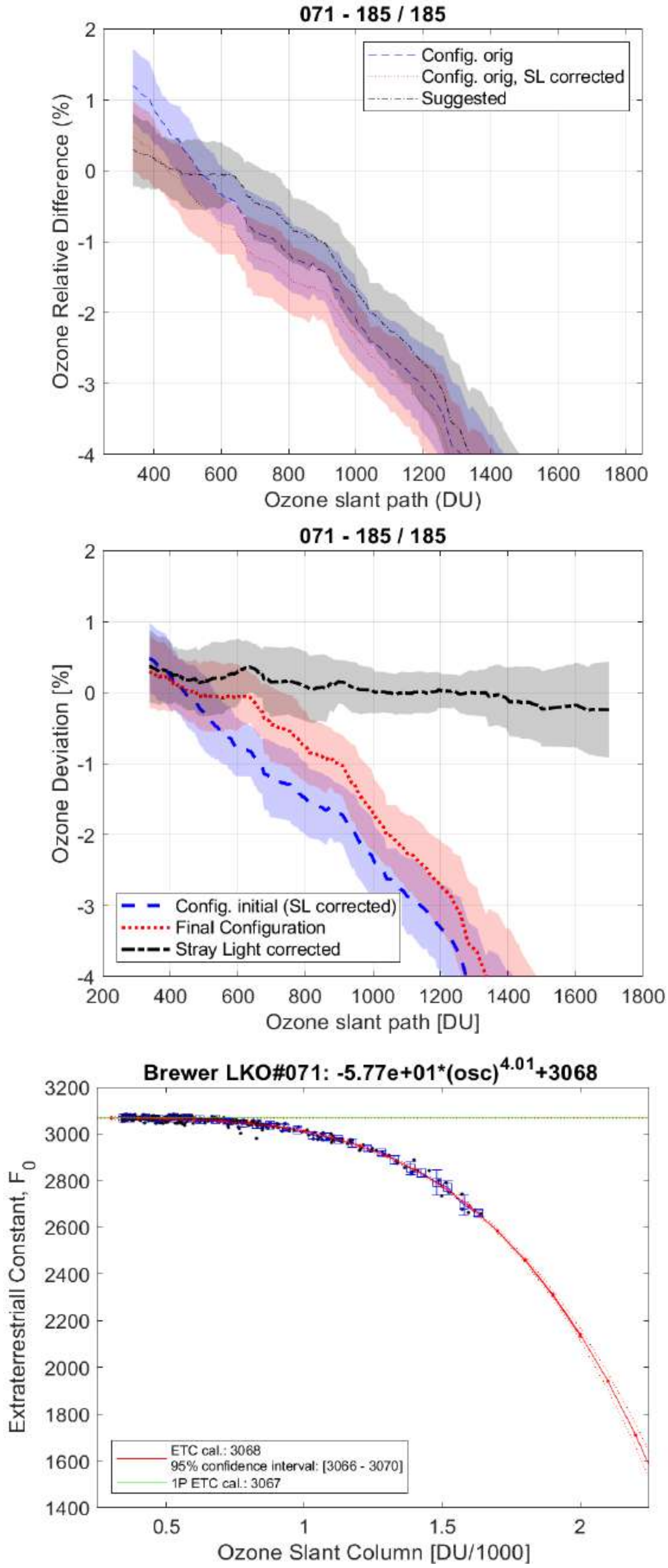


Figure 24. (Top) Ratio respect to the reference used in the initial configuration with and without SL correction. (Middle) Initial and final configuration without and with stray light correction. (Bottom) Stray light empirical model determination.

Recommendations and comments

1. New reference values are given in this campaign for R6=1885 and R5=3525.

2. All the other diagnostics analysed (RS, AP records ...) were normal, except the measurement of the DT.

3. We suggest using a DT constant of 35ns, which is one unit less than proposed during the last calibration (IOS 2018). Several studies suggest that a difference of around one nanosecond is admissible for a single Brewer.

4. The neutral density filters have an excellent behaviour and, hence, no correction factor is suggested.

5. We have not adopted new temperature coefficients.

6. The Sun-scan tests are conclusive enough to analyse the optical position of the CSN.

7. The instrument performed very well after the calibration constants were applied, with minimal ozone deviations when the stray light correction was used. We recommend the use of the stray light correction.

Calibration report

http://rbcce.aemet.es/svn/campaigns/aro2018/latex/071/CALIBRATION_071.pdf

Table 9. Calibration constants summary

Parameters	*Initial Configuration*	*Final Configuration*
O_3 ETC constant	3070	3065
SL R6 reference value	1878	1885
Change SL R6 ratio/ETC		>5
DT constant (ns)	36	35
Temp. coefficients	Old TC	Old TC
Cal step number	942	942
Ozone abs. coeff.	0.3431	0.342
Stray light factors Arosa 2018	3068-57.7*(OSC)^4.01	
Calibration file	Icf11618.071 (IOS)	Icf21518.071 (RBCC-E)

3.4 Brewer LKO#072, Station: Arosa, Switzerland

Brewer LKO#072 participated in the campaign during the period from 30 July to 10 August 2018 (Julian days 209–221). For the evaluation of the initial status, we used 421 simultaneous direct sun ozone measurements from days 209 to 219. The same days were used for final calibration purposes (579 simultaneous measurements).

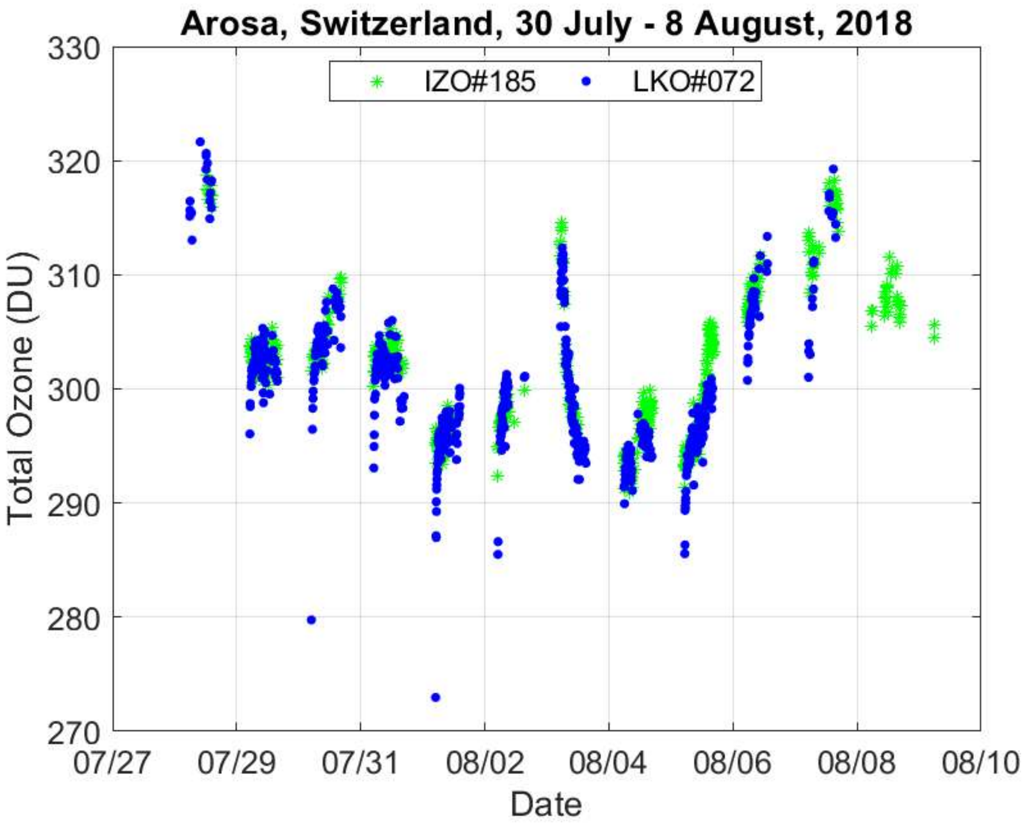


Figure 25. Brewer Intercomparison Arosa 2018

Original calibration
The instrument operates with the configuration file icf19817.072 and reference value for the standard lamp R6 ratio 1960. These calibration constants were obtained after the maintenance tasks carried out by IOS in 2017.

Historical analysis
The lamp test results from Brewer LKO#072 presented a jump in July 2017, but it has been very stable since then. During the campaign days the SL ratios stabilized around values 1960 and 3740 for R6 and R5. From historic data and those obtained during the campaign, a new dead time was provided in the final calibration. Together, new R6 and R5 references values.

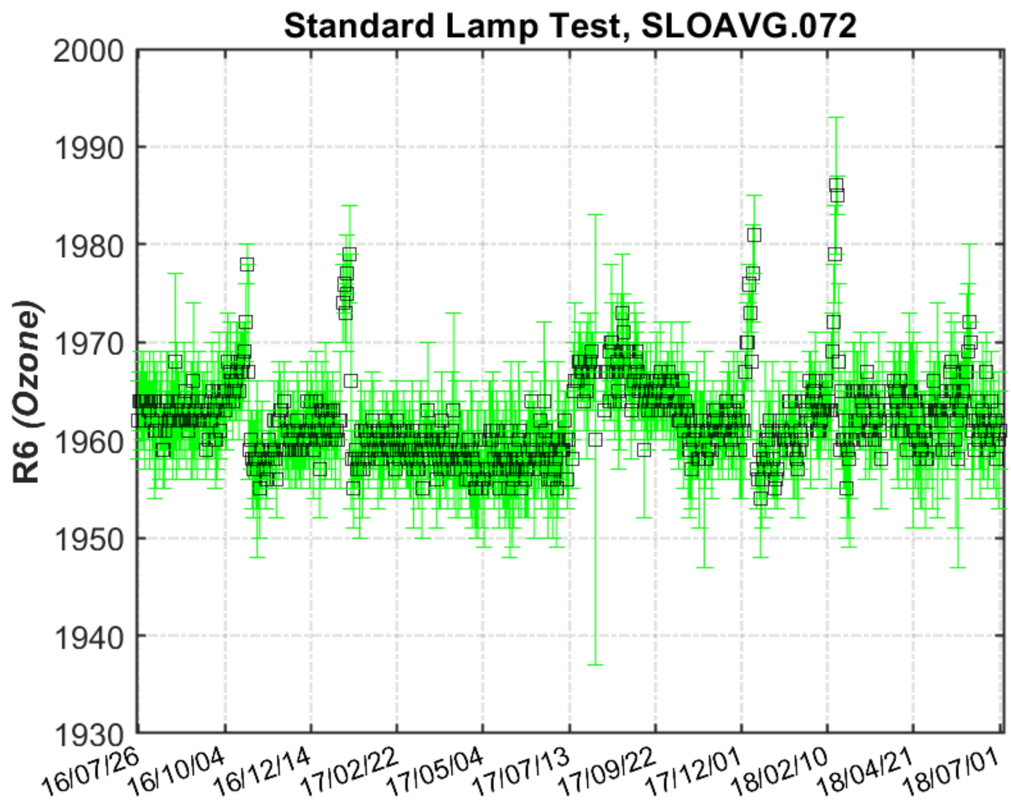


Figure 26. Standard lamp test R6 (ozone) ratio

Initial comparison

For the evaluation of the initial status of Brewer LKO#072 we used the period from days 209 to 219, which corresponds with 421 near-simultaneous direct sun ozone measurements. As shown in Figure 27, the current calibration constants produce ozone values lower than the reference instrument ones (-1.5%). Moreover, for this instrument, when the SL correction is applied, the results are similar without any significant improvement.

Final calibration

Due to the difference with the reference Brewer, a new ETC value was calculated using 579 simultaneous direct sun measurements made during days 209 to 219. The new value (3215) is 6 units lower than the current one. Therefore, we recommend using this together with the new SL reference ratio R6 1960. The ETC was calculated taking into account the new dead time.

Stray light

Figure 27 shows that the final calibration performs well with error near zero for low OSC and an underestimation of 1% at 1000 OSC which is very good for a single Brewer. The empirical stray model fits pretty well with coefficients values: k=-23.8, s=3.92, ETC=3215 which agrees perfectly with the reference for the full range of OSC.

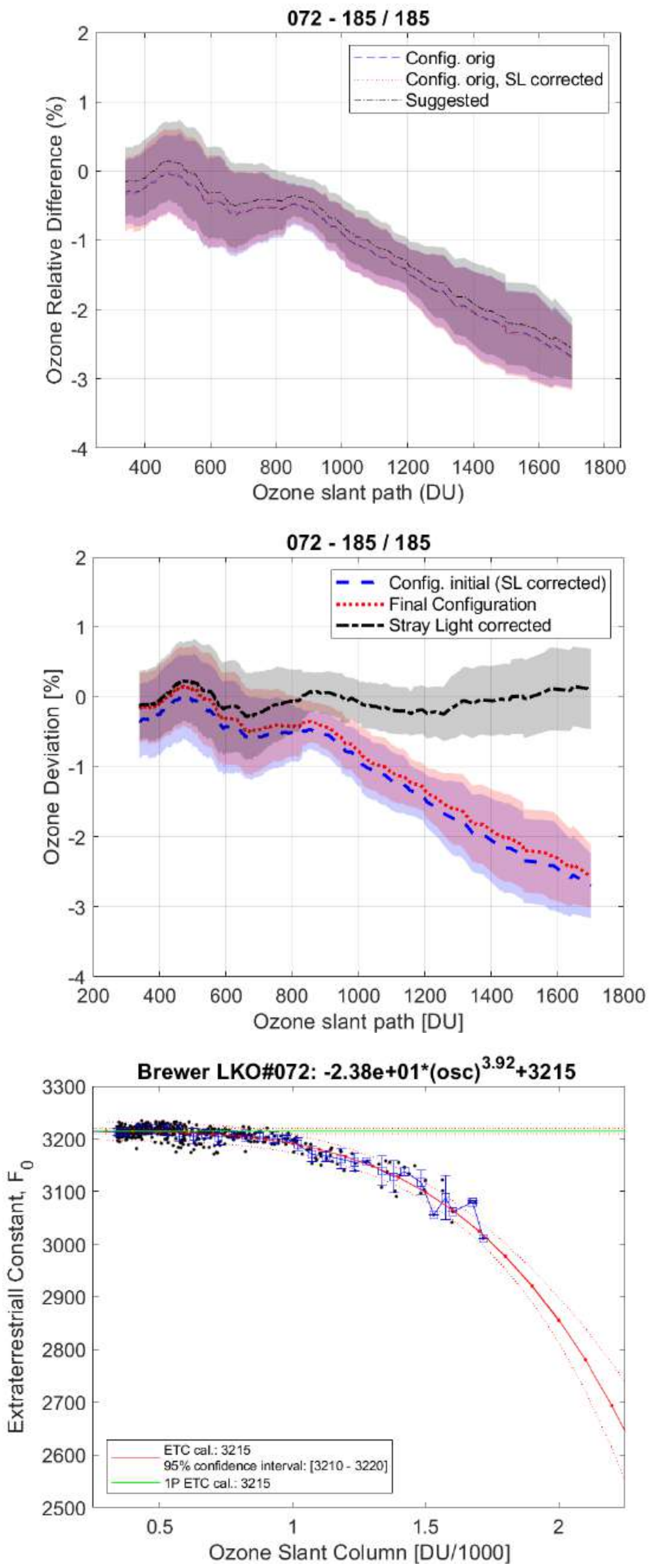


Figure 27. (Top) Ratio respect to the reference used in the initial configuration with and without SL correction. (Middle) Initial and final configuration without and with stray light correction. (Bottom) Stray light empirical model determination.

Recommendations and comments

1. New reference values are given in this campaign for R6=1960 and R5=3740.

2. All the other diagnostics analysed (RS, AP records ...) were normal, except the measurement of the DT.

3. We suggest using a DT constant of 37ns, which is one unit lower than proposed during the last intercomparison. Several studies suggest that a difference of around one nanosecond is admissible for a single Brewer.

4. The neutral density filters have an excellent behaviour and hence, no correction factor is suggested.

5. The current temperature coefficients present a good behaviour.

6. The Sun-scan test are conclusive enough to analyse the optical position of the CSN.

7. The instrument performed very well after the calibration constants were applied, with minimal ozone deviations when the stray light correction was used. We recommend the use of the stray light correction.

Calibration report

http://rbcce.aemet.es/svn/campaigns/aro2018/latex/072/CALIBRATION_072.pdf

Table 10. Calibration constants summary

Parameters	*Initial Configuration*	*Final Configuration*
O_3 ETC constant	3221	3215
SL R6 reference value	1960	1960
Change SL R6 ratio/ETC		<5
DT constant (ns)	38	37
Temp. coefficients	Old TC	Old TC
Cal step number	915	915
Ozone abs. coeff.	0.3377	0.3377
Stray light factors Arosa 2018	3215-23.8*(OSC)^3.92	
Calibration file	Icf19817.072 (IOS)	Icf21018.072 (RBCC-E)

3.5 Brewer LKO#156, Station: Arosa, Switzerland

Brewer LKO#156 participated in the campaign during the period from 30 July to 10 August 2018 (Julian days 209–221). For the evaluation of the initial status, we used 470 simultaneous direct sun ozone measurements from days 209 to 219, the configuration of the instrument didn't change during the campaign so the same period was used for the final calibration.

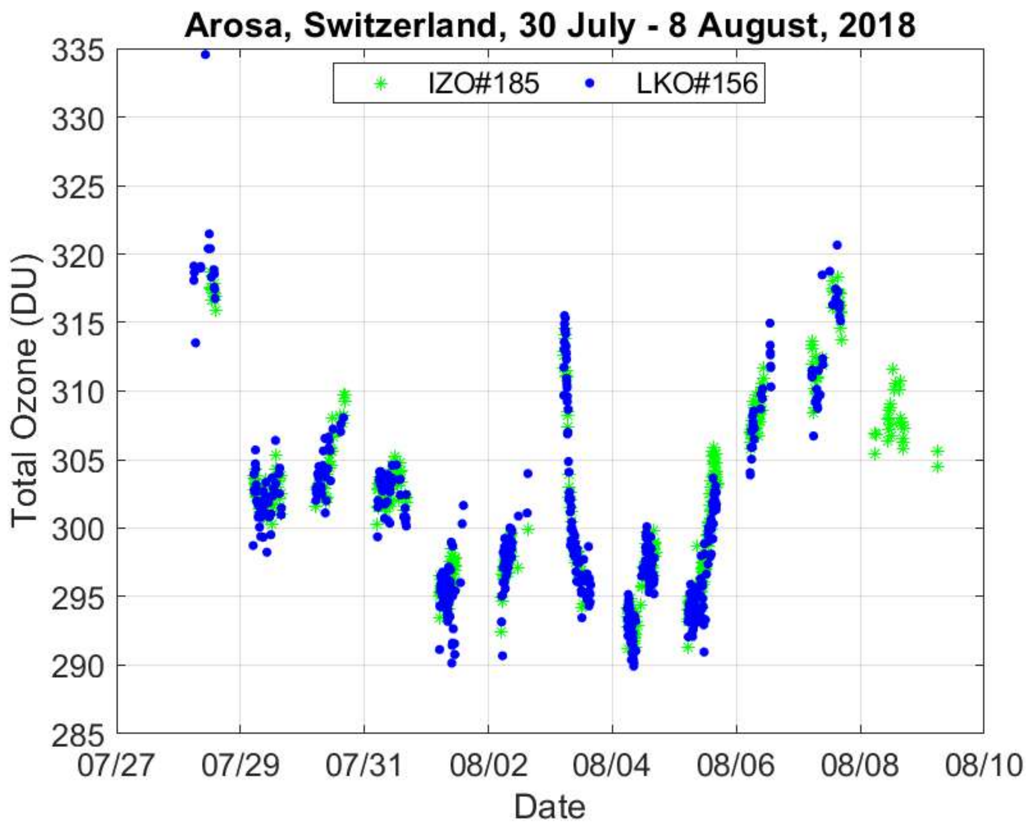


Figure 28. Brewer Intercomparison Arosa 2018

Original calibration

The instrument operates with the configuration file icf19817.156 and reference value 460 for the standard lamp R6 ratio. These calibration constants were obtained after the maintenance tasks carried out by IOS in 2017.

Historical analysis

During the last 2 years, the lamp tests recorded presented a stable behaviour but a clear seasonal dependence, which indicates that a new temperature coefficient must be provided in the final calibration, see Figure 29. During the campaign days, the SL ratios stabilized around values 445 and 1130 for R6 and R5, respectively. Moreover, the historic data indicated that the dead time must be changed.

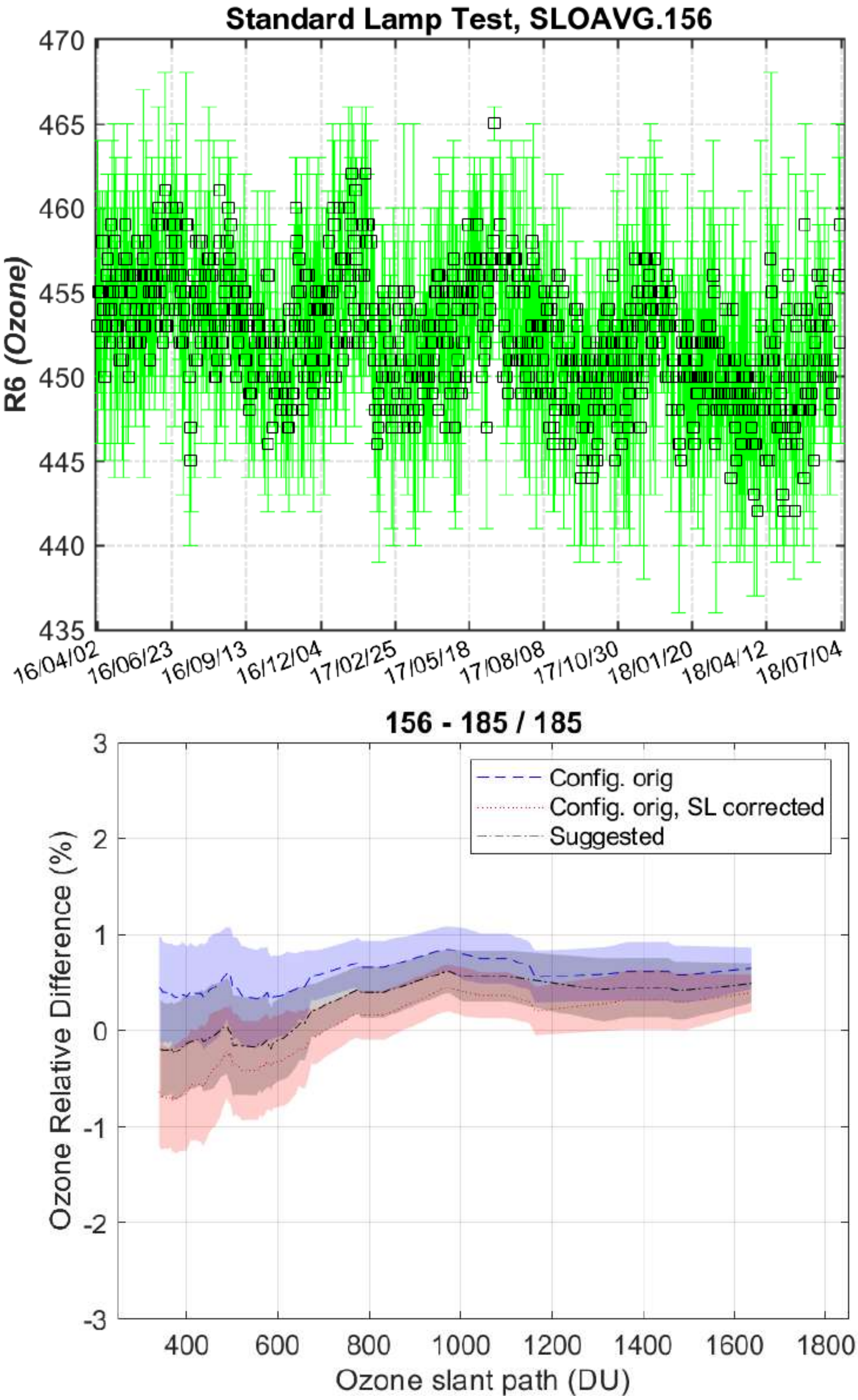


Figure 29. (Top) Standard lamp test R6 (ozone) ratio. (Bottom) Ratio respect to the reference used in the initial configuration with and without SL correction and final configuration.

Initial comparison

For the evaluation of the initial status of Brewer LKO#156 we used the period from days 209 to 219, which corresponds with 470 near-simultaneous direct sun ozone measurements. As shown in Figure 29, the current calibration constants produce ozone values lower than the reference instrument (0.5%). However, when the ETC is corrected taking into account the difference between the SL and R6 reference (SL correction), the results improved only in the observations made at large ozone slant path.

Final calibration

Due to the difference with the reference Brewer and taking into account the new temperature coefficient and dead time proposed in this campaign, a new ETC was calculated from the 470 simultaneous direct sun measurements made between days 209 to 219. The new ETC (1743) is 16 units lower than the current ETC value (1759). Also, the ozone absorption coefficient was updated. Therefore, we recommend using this and the new proposed SL reference ratio R6 440, see Table 11.

Recommendations and comments

1. New reference values are given in this campaign for R6=445 and R5=1130.

2. All the other diagnostics analysed (RS, AP records ...) were normal, except the measurement of the DT.

3. We suggest using a DT constant of 27ns which is three units less than proposed during the last intercomparison.

4. The neutral density filters have an excellent behaviour and, hence, no correction factor is suggested.

5. We have adopted new temperature coefficients.

6. The Sun-scan test is conclusive enough to analyse the optical position of the CSN.

Calibration report

http://rbcce.aemet.es/svn/campaigns/aro2018/latex/156/CALIBRATION_156.pdf

Table 11. Calibration constants summary

Parameters	*Initial Configuration*	*Final Configuration*
O_3 ETC constant	1759	1743
SL R6 reference value	460	445
Change SL R6 ratio/ETC		<5
DT constant (ns)	30	27
Temp. coefficients	Old TC	New TC
Cal step number	705	705
Ozone abs. coeff.	0.339	0.341
Calibration file	Icf19817.156 (IOS)	Icf21018.156 (RBCC-E)

3.6 Brewer K&Z#158, Station: Delft, Netherlands

Brewer K&Z#158 participated in the campaign during the period from 30 July to 10 August 2018 (Julian days 209–221). For the evaluation of the initial status, we used 176 simultaneous direct sun ozone measurements from days 213 to 220. The same period was used for final calibration purposes (159 simultaneous measurements).

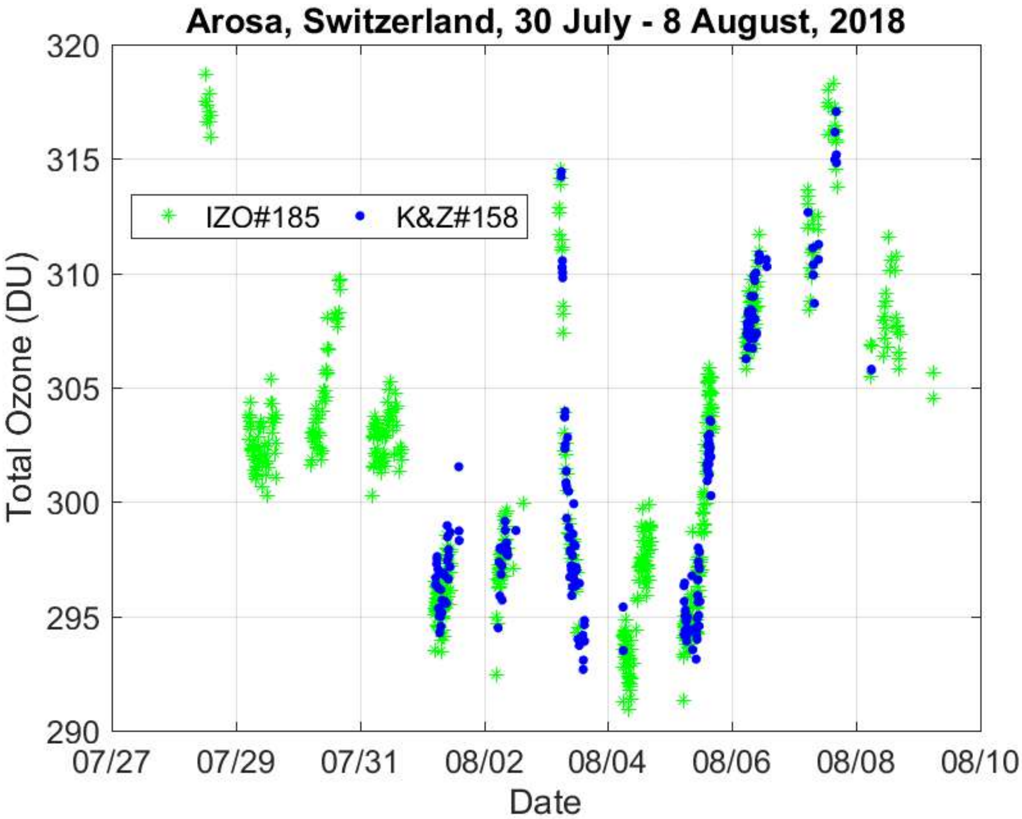


Figure 30. Brewer Intercomparison Arosa 2018

Original calibration
The instrument operates with the configuration file icf29017.158 and reference value 565 for the standard lamp R6 ratio. These calibration constants were obtained in Izaña Atmospheric Observatory (IZO) in October 2017.

Historical analysis
During the campaign days the SL ratios stabilized around values 558 and 853 for R6 and R5, respectively. However, these values are very different from those given as a reference in 2017. Moreover, the historic data indicates that other parameters analysed (Run/Stop test, Hg lamp intensity, CZ & CI files) were ok, except for DT value. This parameter shows a small difference between both the original and recorded values, around 1 unit.

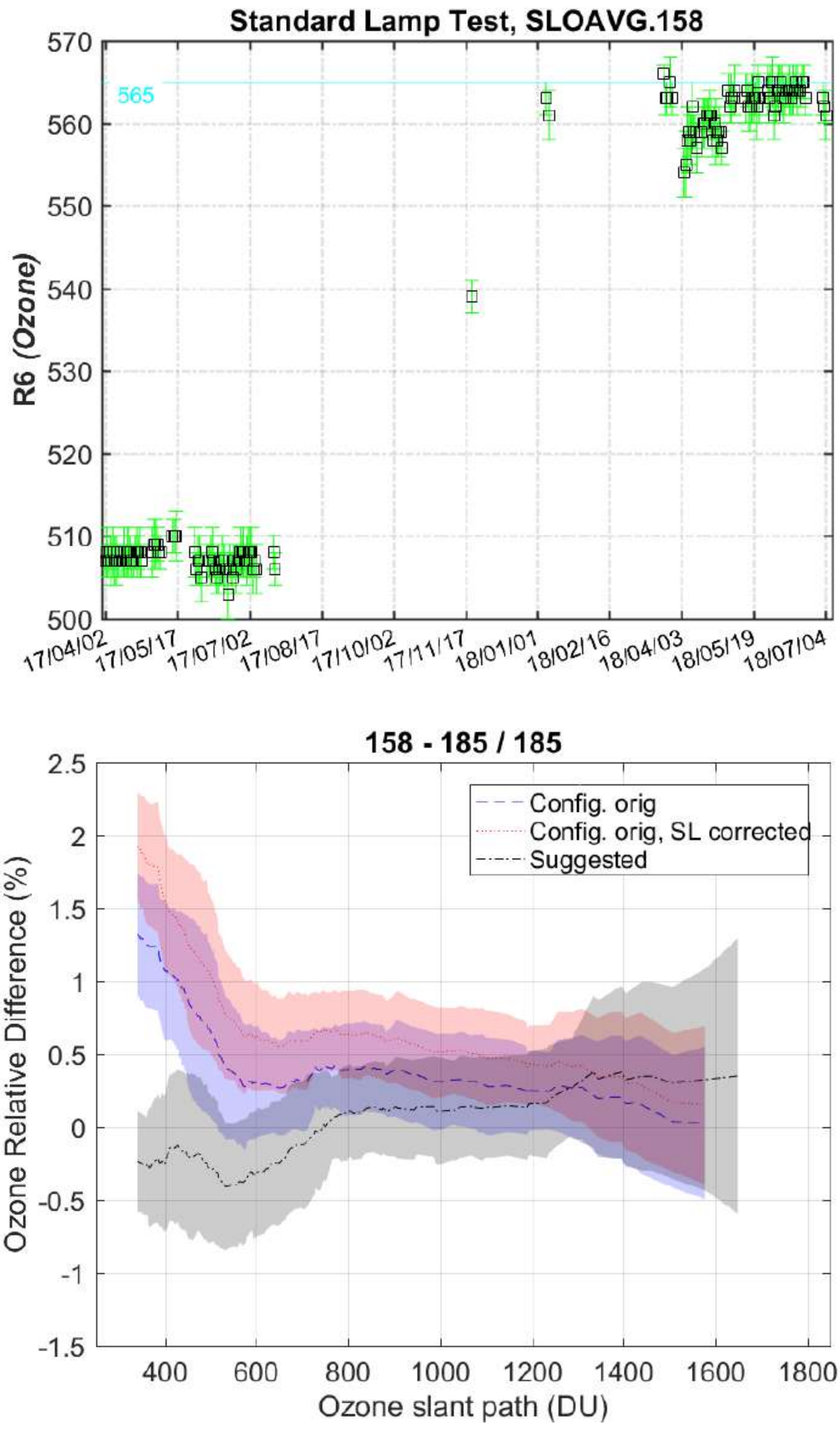


Figure 31. (Top) Standard lamp test R6 (ozone) ratio. (Bottom) Ratio respect to the reference used in the initial configuration with and without SL correction and final configuration.

Initial comparison

For the evaluation of the initial status we used days 213 to 220, which corresponds with 176 near-simultaneous direct sun ozone measurements. As shown in Figure 31, the current calibration constants produce ozone values greater than the reference instrument (+0.75%, on average). However, when the ETC is corrected taking into account the difference between the

SL and R6 reference (SL correction), the results got slightly worse, with a difference of around +1.25%, on average.

Final calibration

Due to the difference with the reference Brewer, a new ETC value was calculated taking into account the new dead time proposed. For the final calibration, we used 159 simultaneous direct sun measurements from days 214 to 220. The new ETC (1820) is 25 units greater than the current one (1795). Therefore, we recommend using this new ETC, together with the new proposed SL reference ratio, 558 for R6. Moreover, a new ozone absorption coefficient was provided in the final calibration.

Recommendations and comments

1. New reference values are given in this campaign for R6=558 and R5=853.
2. All the other diagnostics analysed (RS, AP records ...) were normal, except the measurement of the DT which was really low.
3. We suggest using a DT constant of 28ns, which is one unit greater than proposed during the last intercomparison.
4. The neutral density filters have an excellent behaviour and hence, no correction factor is suggested.
5. The current coefficients are enough to reduce the temperature dependence.
6. The Sun-scan test are conclusive enough to analyse the optical position of the CSN.

Calibration report

http://rbcce.aemet.es/svn/campaigns/aro2018/latex/158/CALIBRATION_158.pdf

Table 12. Calibration constants summary

Parameters	*Initial Configuration*	*Final Configuration*
O_3 ETC constant	1795	1820
SL R6 reference value	565	558
Change SL R6 ratio/ETC		<5
DT constant (ns)	27	28
Temp. coefficients	Old TC	Old TC
Cal step number	1015	1015
Ozone abs. coeff.	0.3435	0.3415
Calibration file	Icf29017.158 (RBCC-E)	Icf21018.158 (RBCC-E)

3.7 Brewer WRC#163, Station: Davos, Switzerland

Brewer WRC#163 participated in the campaign during the period from 30 July to 10 August 2018 (Julian days 209–221). For the evaluation of the initial status, we used 334 simultaneous direct sun ozone measurements from days 209 to 215. Whereas, days 215 to 219 were used for final calibration purposes (192 simultaneous measurements). We only used these days to obtain the final calibration because we detected a small change in the instrument after the 200W calibration (day 215).

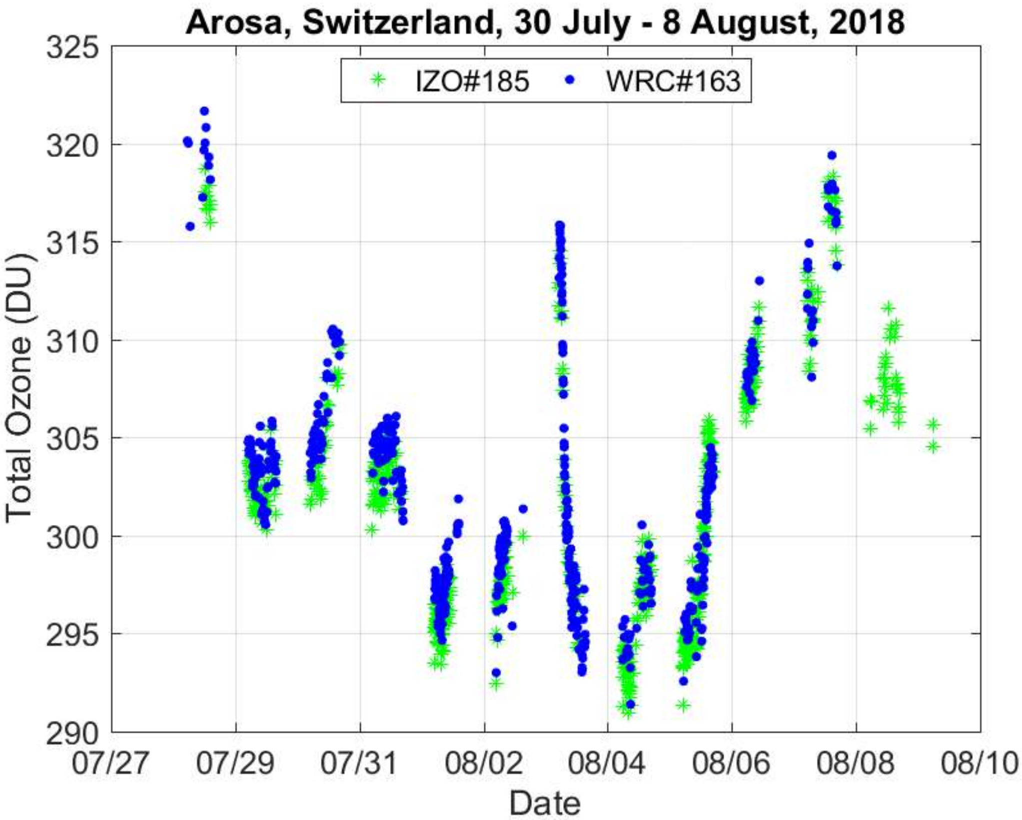


Figure 32. Brewer Intercomparison Arosa 2018

Original calibration

The instrument operates with the configuration file icf15017.163 and reference value 270 for the standard lamp R6 ratio. These calibration constants were obtained after the 2017 Intercomparison at El Arenosillo (Huelva, Spain).

Historical analysis

The lamp tests results from Brewer WRC#163 have been very stable during the last 2 years. During the campaign days, the SL ratios stabilized around values 274 and 465 for R6 and R5, respectively. These values have been calculated taking into account the new dead time proposed in this campaign. This parameter showed a small difference between both the original and recorded values, around 2 units. All the other parameters analysed (Run/Stop test, Hg lamp intensity, CZ & CI files) were stable.

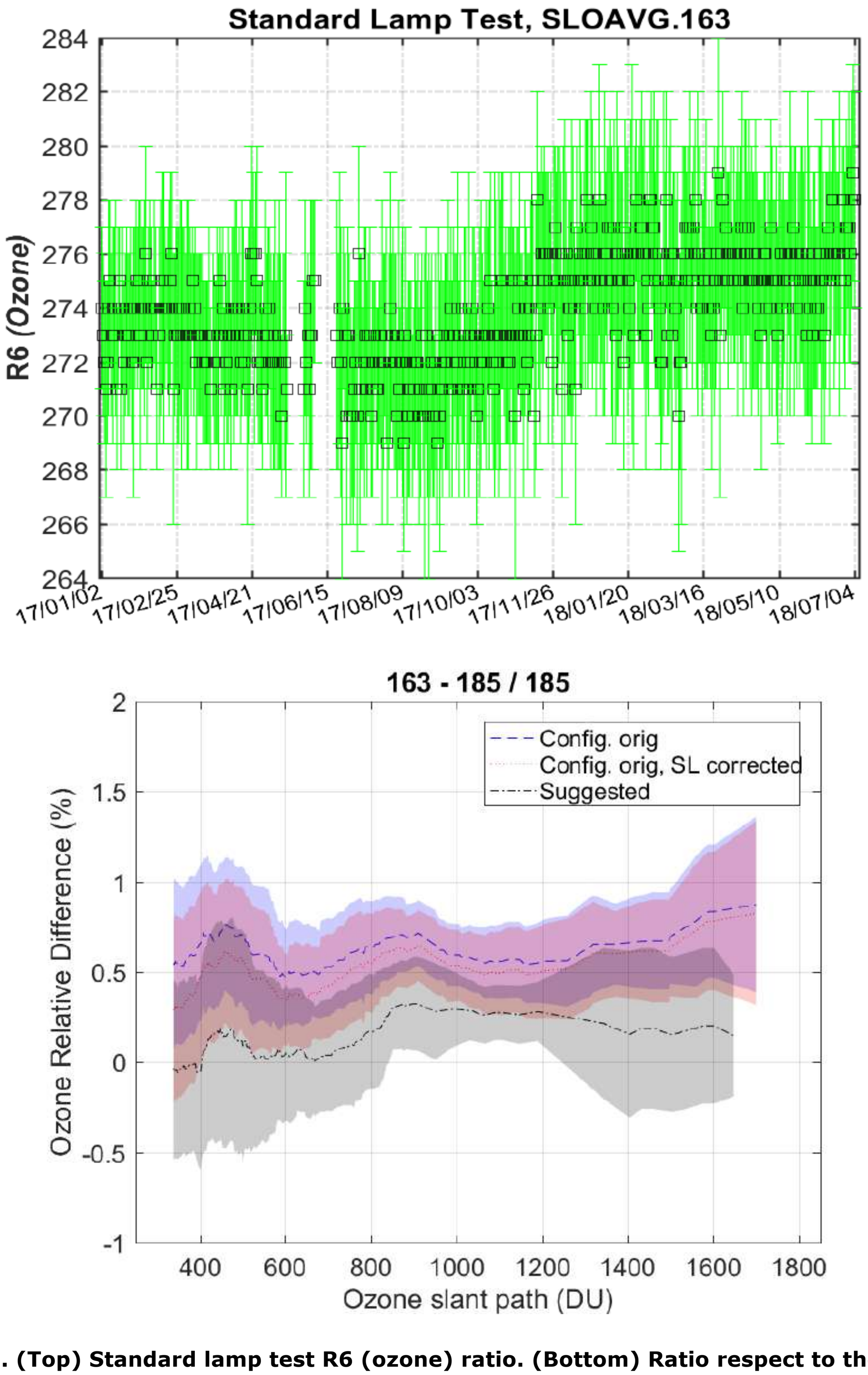


Figure 33. (Top) Standard lamp test R6 (ozone) ratio. (Bottom) Ratio respect to the reference used in the initial configuration with and without SL correction and final configuration.

Initial comparison

For the evaluation of the initial status we used the period from days 209 to 215, which corresponds with 334 near-simultaneous direct sun ozone measurements. As shown in Figure 33, the current calibration constants produce ozone values greater than the reference instrument (+0.5%). Moreover, when the ETC was corrected applying the SL correction the results got slightly better (+0.4%).

Final calibration
A new ETC value was calculated using 192 simultaneous direct sun measurements made during days 215 to 219. The new ETC (1490) is approximately 10 units greater than the current ETC value (1480). Therefore, we recommend using this together with the new proposed SL reference ratio R6 274. Table 13 shows a summary with the new parameters.

Recommendations and comments

1. New reference values are given in this campaign for R6=274 and R5=465.

2. All the other diagnostics analysed (RS, AP records ...) were normal, except for the measurement of the DT.

3. We suggest using a DT constant of 28ns, which is two units less than proposed during the last intercomparison.

4. The neutral density filters have an excellent behaviour and hence, no correction factor is suggested.

5. The old temperature coefficients are enough to reduce the dependence with this parameter.

6. The Sun-scan test are conclusive enough to analyse the optical position of the CSN and the results suggest a new cal step. However, the current one guarantees a good agreement with the reference.

Calibration report

http://rbcce.aemet.es/svn/campaigns/aro2018/latex/163/CALIBRATION_163.pdf

Table 13. Calibration constants summary

Parameters	*Initial Configuration*	*Final Configuration*
O_3 ETC constant	1480	1490
SL R6 reference value	270	274
Change SL R6 ratio/ETC		<5
DT constant (ns)	30	28
Temp. coefficients	Old TC	Old TC
Cal step number	1021	1021
Ozone abs. coeff.	0.3405	0.341
Calibration file	Icf15017.163 (RBCC-E)	Icf21018.163 (RBCC-E)

3.8 Brewer K&Z#245, Station: Delft, Netherlands

Brewer K&Z#245 participated in the campaign during the period from 30 July to 10 August 2018 (Julian days 209–221). For the evaluation of the initial status, we used 209 simultaneous direct sun ozone measurements from days 213 to 220. The same days were used for final calibration purposes (206 simultaneous measurements). This instrument has not participated in any previous calibration campaigns. Therefore, its initial calibration was provided by Kipp & Zonen. Moreover, it has only been working for two months before this campaign.

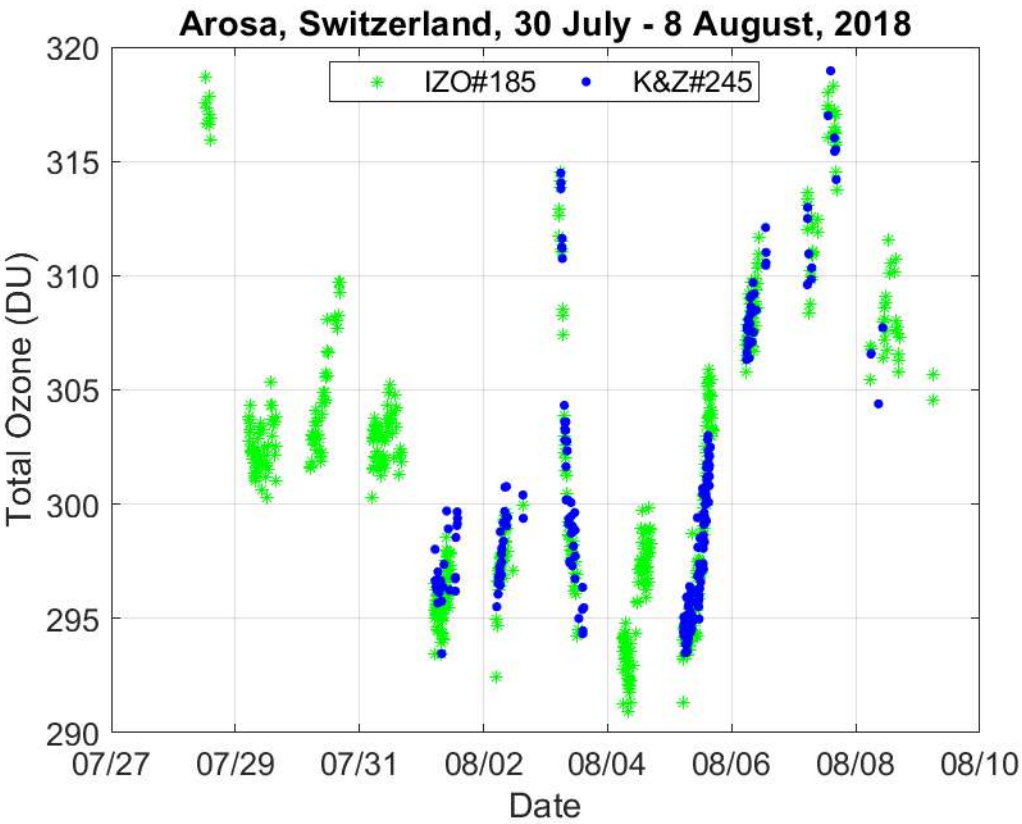


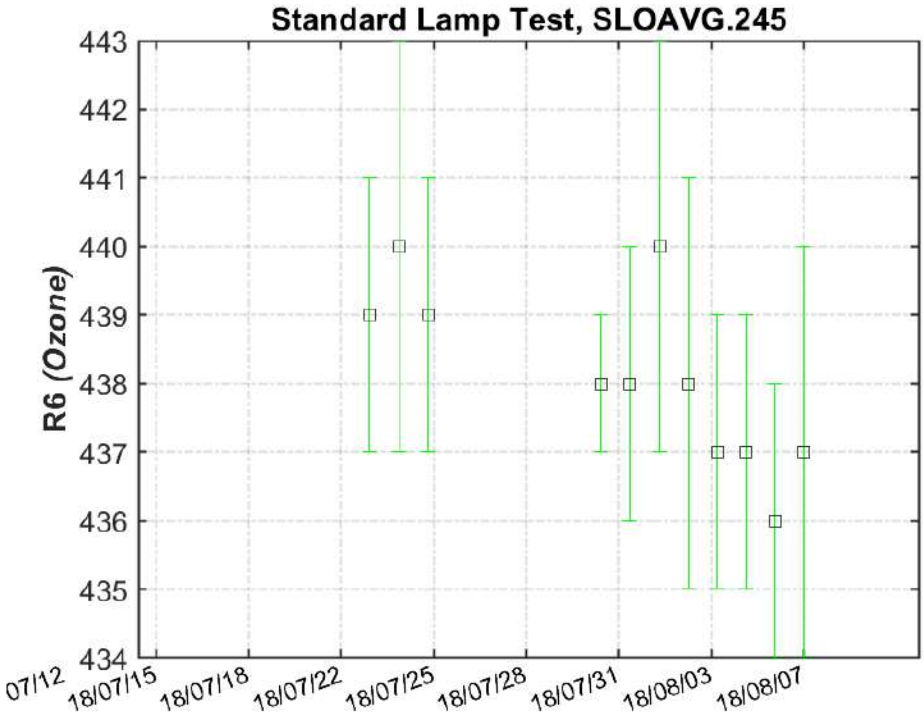
Figure 34. Brewer Intercomparison Arosa 2018

Original calibration

The instrument operates with the configuration file icf18618.245 and reference value 377 for the standard lamp R6 ratio. These calibration constants were provided by Kipp & Zonen as the initial configuration of this instrument.

Historical analysis

During the campaign days the SL ratios stabilized around values 438 and 580 for R6 and R5, respectively (see Figure 35). These values are very different from those given as a reference initially by Kipp & Zonen. This is due to the cal step position been changed a few days before the campaign. Moreover, the historic data suggests that the dead time and temperature coefficient must be provided for the final calibration. All the other parameters analysed (Run/Stop test, Hg lamp intensity, CZ & CI files) were stable.



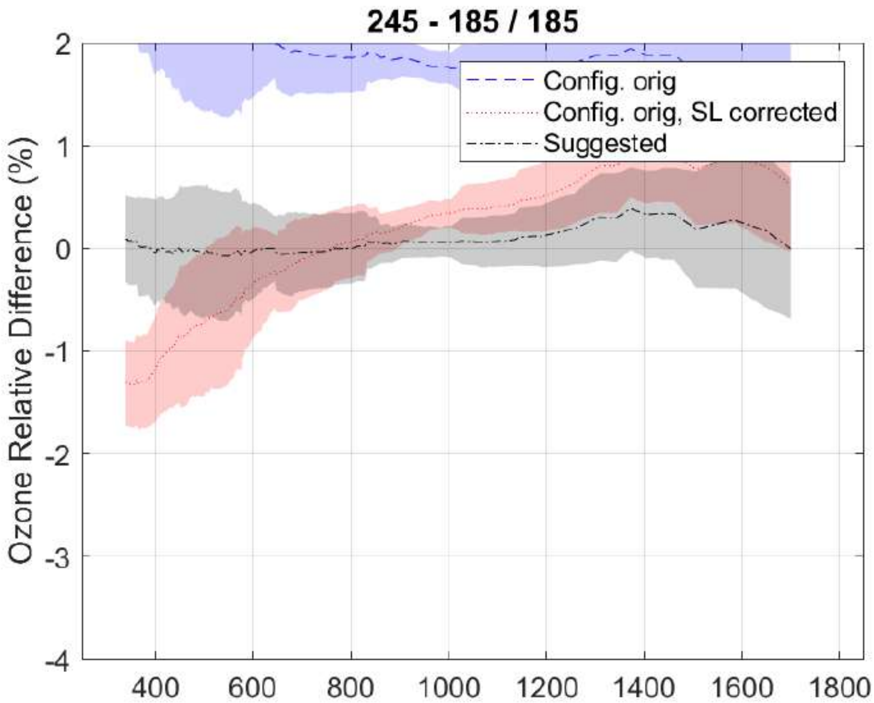


Figure 35. (Top) Standard lamp test R6 (ozone) ratio. (Bottom) Ratio respect to the reference used in the initial configuration with and without SL correction and final configuration.

Initial comparison

For the evaluation of the initial status we used the period from days 149 to 155, which corresponds with 209 near-simultaneous direct sun ozone measurements. As Figure 35 shows, the current ICF produces ozone values with a difference around +2% (on average) with respect to the reference. When the SL correction is applied, the results improved significantly, with a difference of around +0.5% (on average).

Final calibration

Due to the difference with respect to the reference Brewer, a new ETC was calculated using 207 simultaneous direct sun measurements made between days 213 to 220. The new ETC (1820) is 33 units greater than the current one (1587). Therefore, we recommend using this new ETC, together with the new proposed SL reference ratio R6, 438. We updated the new calibration constants in the ICF provided, see Table 14. It is important to note that the new ETC was calculated taking into account the new set of temperature coefficient, dead time and ozone absorption coefficient.

Recommendations and comments

1. New reference values are given in this campaign for R6=438 and R5=580.

2. All the other diagnostics analysed (RS, AP records ...) were normal, except for the measurement of the DT, which was really low.

3. We suggest using a DT constant of 25ns, which is three units lower than the current reference.

4. The neutral density filters have an excellent behaviour and hence, no correction factor is suggested.

5. We have adopted new temperature coefficients.

6. The Sun-scan tests are conclusive enough to analyse the optical position of the CSN.

Calibration report

http://rbcce.aemet.es/svn/campaigns/aro2018/latex/245/CALIBRATION_245.pdf

Table 14. Calibration constants summary

Parameters	*Initial Configuration*	*Final Configuration*
O_3 ETC constant	1587	1620
SL R6 reference value	377	437
Change SL R6 ratio/ETC		<5
DT constant (ns)	28	28
Temp. coefficients	Old TC	New TC
Cal step number	1020	1026
Ozone abs. coeff.	0.3428	0.3466
Calibration file	Icf18618.245 (Kipp & Zonen)	Icf21018.245 (RBCC-E)

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