GAW Report No. 224

# Ninth Intercomparison Campaign of the Regional Brewer Calibration Center Europe (RBCC-E)

(Lichtklimatisches Observatorium, Arosa, Switzerland, 14-26 July 2014)

World Meteorological Organization
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# Ninth Intercomparison Campaign of the Regional Brewer Calibration Center Europe (RBCC-E)

Lichtklimatisches Observatorium, Arosa, Switzerland

14-26 July 2014

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NINTH INTERCOMPARISON CAMPAIGN OF THE REGIONAL BREWER CALIBRATION CENTER EUROPE (RBCC-E), LICHTKLIMATISCHES OBSERVATORIUM, AROSA, SWITZERLAND, 14-26 JULY 2014

# 1. SUMMARY

This ninth intercomparison campaign was a joint exercise of the Regional Brewer Calibration Center for Europe (RBCC-E) and the Arosa Lichtklimatisches Observatorium (LKO) of MeteoSwiss during the period 14-26 July 2014. Six Brewers managed by 11 experts from four countries participated in the campaign (Table 1). The Brewer instruments were compared with the RBCC-E travelling reference Brewer #185 for ozone.


**Figure 1. Overview of the measurement platform at LKO Arosa with the participating Brewer spectrophotometers**

The RBCC-E transferred during this intercomparison its own absolute ozone calibration obtained by the Langley method at the Izaña Observatory (IZO). The calibration of the reference instrument, as well as the link to the world triad, is discussed in Section 2.1. 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. The individual calibration reports are also available online. A calibration history was introduced for those instruments present at previous campaigns, allowing an easy recalculation of the past ozone data.

**Table 1. List of participants at the Arosa 2014 campaign**

| *Institution* | *Name* | *Brewer* | *Country* |
|---|---|---|---|
| | | **Brewer** | |
| IOS | Martin Stanek<br>Volodya Savastiouk | #017-MKII | Canada |
| LKO | René Stübi<br>Herbert Schill<br>Werner Siegrist | #040-MKII<br>#072-MKII<br>#156-MKIII | Switzerland |
| K&Z | Alexander Visser<br>Pavel Babal | #158-MKIII<br>#212-MKIII | Netherland |
| AEMET-IARC | Alberto Redondas<br>Juan J. Rodríguez<br>Virgilio Carreño | #185-MKIII | Spain |
| INTA-UNEX | José M Vilaplana<br>Antonio Serrano | | Spain |

The initial Brewer comparison results (using the instruments' original calibration constants) were not good, with ozone deviation greater than 1% for half of the instruments (see Figure 2 and Figure 10). These include the references Brewer #017 and Brewer #158. The agreement was very good, within the 0.5% level on average, for all the instruments after the maintenance was done and using the final calibration constants (see Figure 11 and Figure 13). The comparison results are discussed in Section 2.2 and Section 2.3 for the blind and the final periods, respectively. A summary of individual calibration reports can be found in Section 2.4.

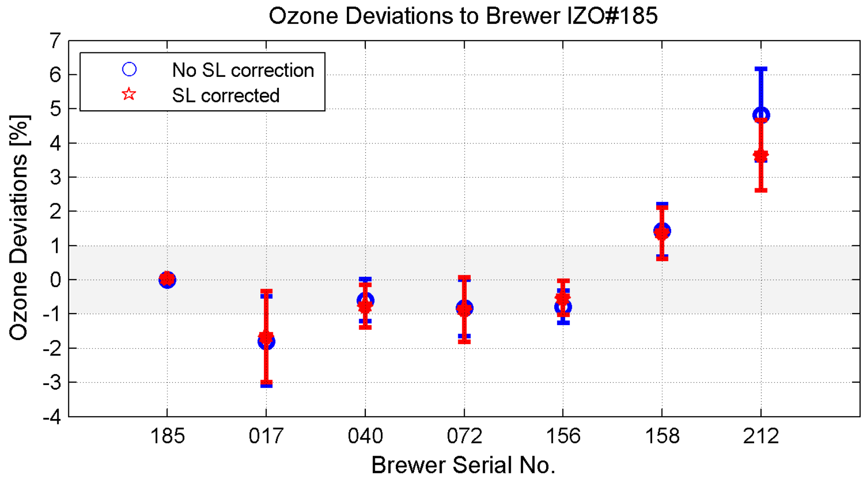



**Figure 2. Ozone relative percentage differences of all Arosa 2014 participating instruments to RBCC-E travelling standard #185. Ozone measurements collected during the blind period are reprocessed using the original calibration constants, with (red) and without (blue) SL correction. Error bars represent the standard deviation.**

## 1.1 Weather conditions and campaign schedule

The ozone calibration for Brewer requires clear skies. The weather conditions during the campaign at the Arosa Observatory (1860 m.a.s.l) was good, allowing enough direct sun ozone measurements so as to perform a reliable calibration for all instruments. The maintenance of the Brewer instruments was performed by the International Ozone Services company (IOS). Additionally to the routine tasks performed during the ozone intercomparison campaign, an experimental device designed to analyse the cosine response of the Brewer spectrophotometer was tested during this campaign. The Brewer calibration was performed using 350 near-simultaneous direct sun ozone measurements with the reference instrument Brewer #185. The measurement schedules, designed to maximize the ozone measurements during the campaign, worked properly, reaching with some instruments 80% of the potential near-simultaneous ozone measurements. The conditions during the campaign are summarized in Figure 3. Total ozone content at Arosa during the campaign ranged between 300 and 340 DU. Most of the measurements (≈ 60%) were within the 350-600 DU ozone slant column (osc) range. The internal instruments' temperature varied between 15ºC to 40°.

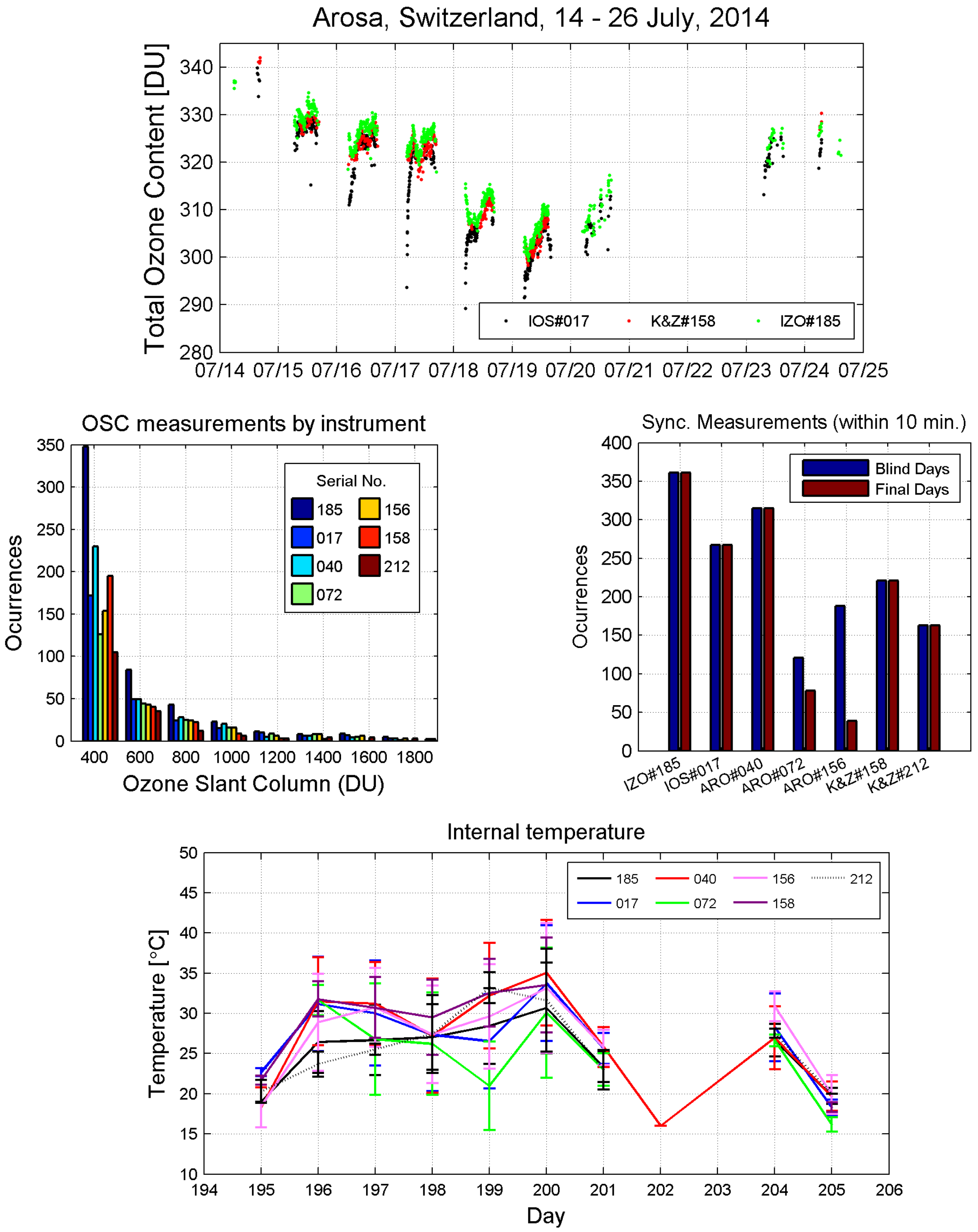



**Figure 3. Statistics of the intercomparison conditions: ozone total content (top), frequency distribution of ozone slant column ranges (middle panel, left) and number of near-simultaneous ozone measurements (middle panel, right) and internal temperature variability for all the participant instruments (bottom).**

# 2. RBCC-E BREWER SPECTROMETER REPORT

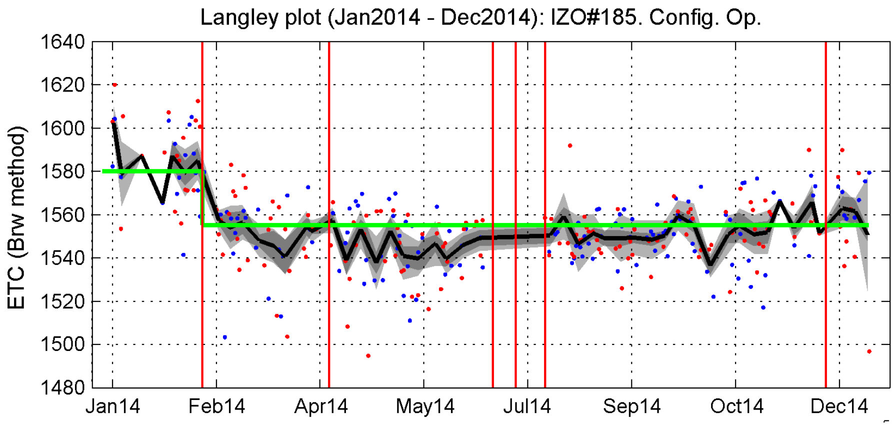
## 2.1 Reference calibration and checklist

The RBCC-E was established at the Izaña Atmospheric Research Centre in 2003. It comprises of three MkIII type 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) has been established by yearly comparison with the IOS travelling standard Brewer#017 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 possible. These reference instruments are: IOS travelling reference #017, the Brewer #145, operated by Environment Canada (EC), and the Kipp & Zonen travelling reference #158. The first two instruments provide a direct link to the world triad. The last world travelling reference triad to European reference triad calibration transfers was performed in July 2011. Since the beginning of 2012, due to 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 common Langley campaigns at Mauna Loa or IZO stations. Due to the EC situation and the lack of funds of AEMET, these options were not possible this year. As well, and because of the doubts about the maintenance of the WBT, the World Meteorological Organization (WMO) Scientific Advisory Group (SAG) authorized the RBCC-E to transfer its own ozone absolute calibration. The methodology used is described in Redondas, 2005, 2008 and Ito et al. 2011.

**Table 2. RBCC-E Travelling Standard Checklist**

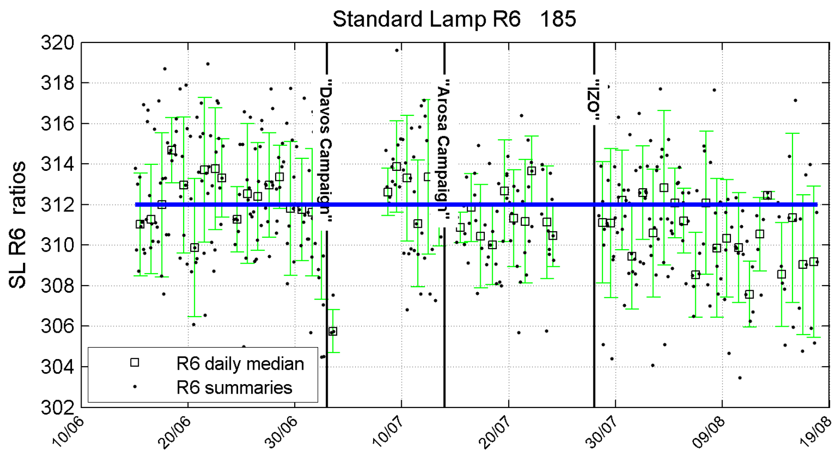
| Traveling standard Check list: Brewer#185 | Description | Y | N | Value | Comment |
|---|---|---|---|---|---|
| Calibration Data | 197-208. 2014 | | | | |
| Reference of the travelling (Triad, RBCC-E,...) | RBCC-E reference #185 | | | | Langley Cal. |
| Is travelling standard calibrated? | | Y | | | |
| %diff. before travel | | | | 0.0 ± 0.3 | 443 obs |
| %diff. after travel | | | | -0.1 ±-0.2 | 624 obs |
| Instrument operation: | | | | | |
| HP/HG | Hp/Hg tests repeatable within 0.2 steps | Y | | | |
| SH | SH shutter delay is correct | | | | NaN |
| RS | Run/Stop test within ±0.003 from unity for illuminated slits and between 0.5 and 2 for the dark count | Y | | | |
| DT | Dead time is between 28 ns and 45 ns for multiple-board Brewers and between 16 ns and 25 ns for single-board Brewers | | N | | DT on ICF, 29 ns |
| SL R6 | SL ratio R6 is within 5 units from calibration | Y | | 311 | Ref=312 |
| SL R5 | SL ratio R5 is within 10 units from calibration | Y | | 439 | Ref=440 |

During the Arosa 2014 campaign we transferred the ozone absolute calibration obtained at IZO. We can compare, at the same time and using the Brewer#017 as a link with the World Brewer Triad, our Langley calibration with the WBT. To assure the calibration of the RBCC-E Brewer triad, a weekly calibration is performed at IZO and the frequency of instrumental tests has been increased from a yearly to a monthly basis. Further, the measurement schedules have been adapted to maximize the Langley observations, reducing the spectral UV and Umkehr measurements. These routine calibrations are reported on the internal web showing the evolution of the instrumental performance of the RBCC-E triad. The status of the Brewer triad is also summarized on a public RBCC-E Checklist. As a result of this maintenance and continuous calibration work we have achieved a good long-term agreement between the instruments of the triad, with ozone deviation around 0.25% (see Figure 6).




| | Op. ETC | ETC (AM+PM) | std | N |
|---|---|---|---|---|
| "CSN chg. 1018 -> 1020 " | 1580 | 1585 | 18.4 | 35 |
| "K&Z maintenance" | 1555 | 1551 | 17.5 | 51 |
| "Lab" | 1555 | 1545 | 15.5 | 73 |
| "Davos Campaign" | 1555 | | | |
| "Arosa Campaign" | 1555 | | | |
| "IZO" | 1555 | 1552 | 12.4 | 134 |
| "Electronic Issue. SL chg." | 1555 | 1560 | 21.1 | 17 |

**Figure 4. Langley ETC calculation at IZO and for Brewer#185 during the 2014 year. 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 indicates relevant events in the instrument's operation, see Table in bottom panel.**




| | R6 Ref. | R6 | std | R5 | std | N |
|---|---|---|---|---|---|---|
| "Lab" | 312 | 312.3 | 1.17 | 440.7 | 2.21 | 18 |
| "Davos Campaign" | 312 | 311.7 | 2.59 | 439.5 | 4.15 | 7 |
| "Arosa Campaign" | 312 | 311.6 | 1.20 | 438.4 | 2.29 | 11 |
| "IZO" | 312 | 310.6 | 1.49 | 437.0 | 2.20 | 21 |

**Figure 5. Standard Lamp O3 R6 ratios: daily mean and standard deviation (squares) and individual tests (black dots). The solid blue line represents the SL R6 reference value used during the period of analysis. Vertical black lines mark the important events as concerns instrument's performance see Table in bottom panel.**

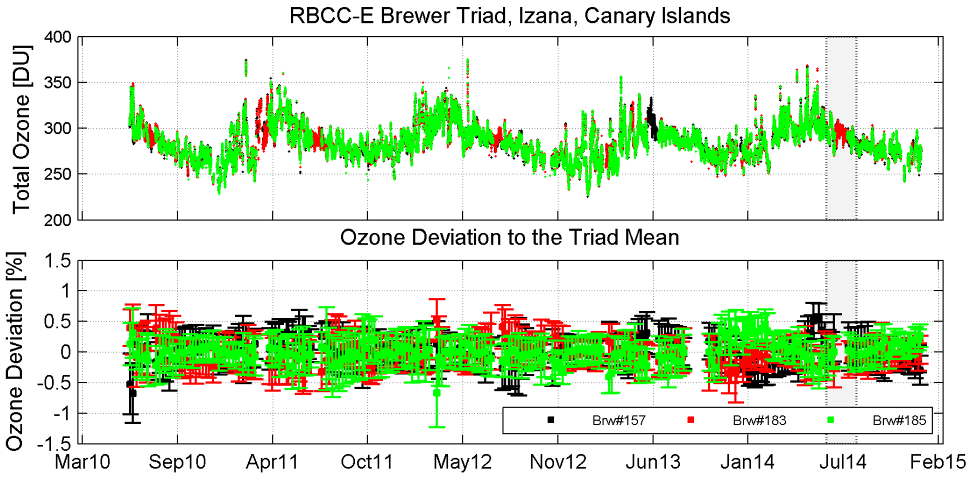



**Figure 6. Near-simultaneous (within 5 minutes) direct sun ozone measurements (top) and deviations of ozone values of individual RBCC-E triad Brewers from the mean of the three instruments (bottom) during the period from June 2010 to December 2014. Each point on the graph represents a weekly average. The shadowed area represents the period from 15th June (day of year 166) to 17th August (day of year 229), 2014.**

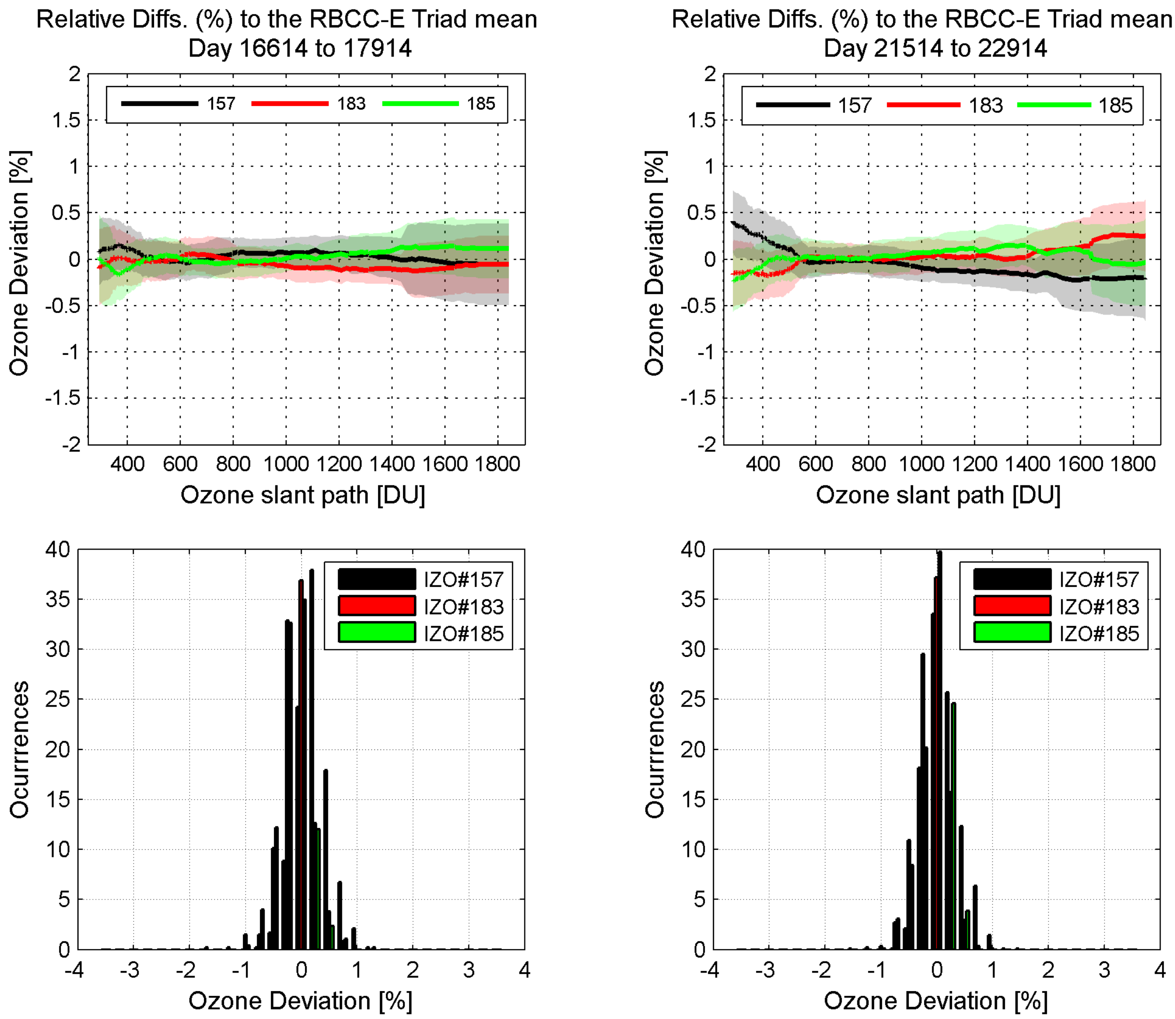



**Figure 7. Deviations of near-simultaneous ozone measurements of RBCC-E standard Brewer (serial no. #157, #183 and #185) to the triad mean. Before (left) and after (right) the Arosa 2014 intercomparison.**

## 2.2 Blind comparison

A blind comparison with the standard Brewer gives us an idea of the initial status of the instrument, i.e. how well the instrument performed using the original calibration constants (those operational at the instrument's station). Possible changes of the instrument response due to the travel can be detected through the analysis of internal tests performed before and after the travel.

The instruments are working during this period with their home calibration and the ozone is calculated using these calibration constants. The Standard Lamp (SL) test is an ozone measurement using the internal halogen lamp as a source. 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 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 Standard Lamp correction. Hence, it is reasonable to investigate if the observed R6 changes are related with similar changes in the calibration constant. If this would be the case, then the ETC constant should be corrected by the same change in SL R6 ratio as $ETC_{new} = ETC_{old} - (SL_{ref} - SL_{measured})$.

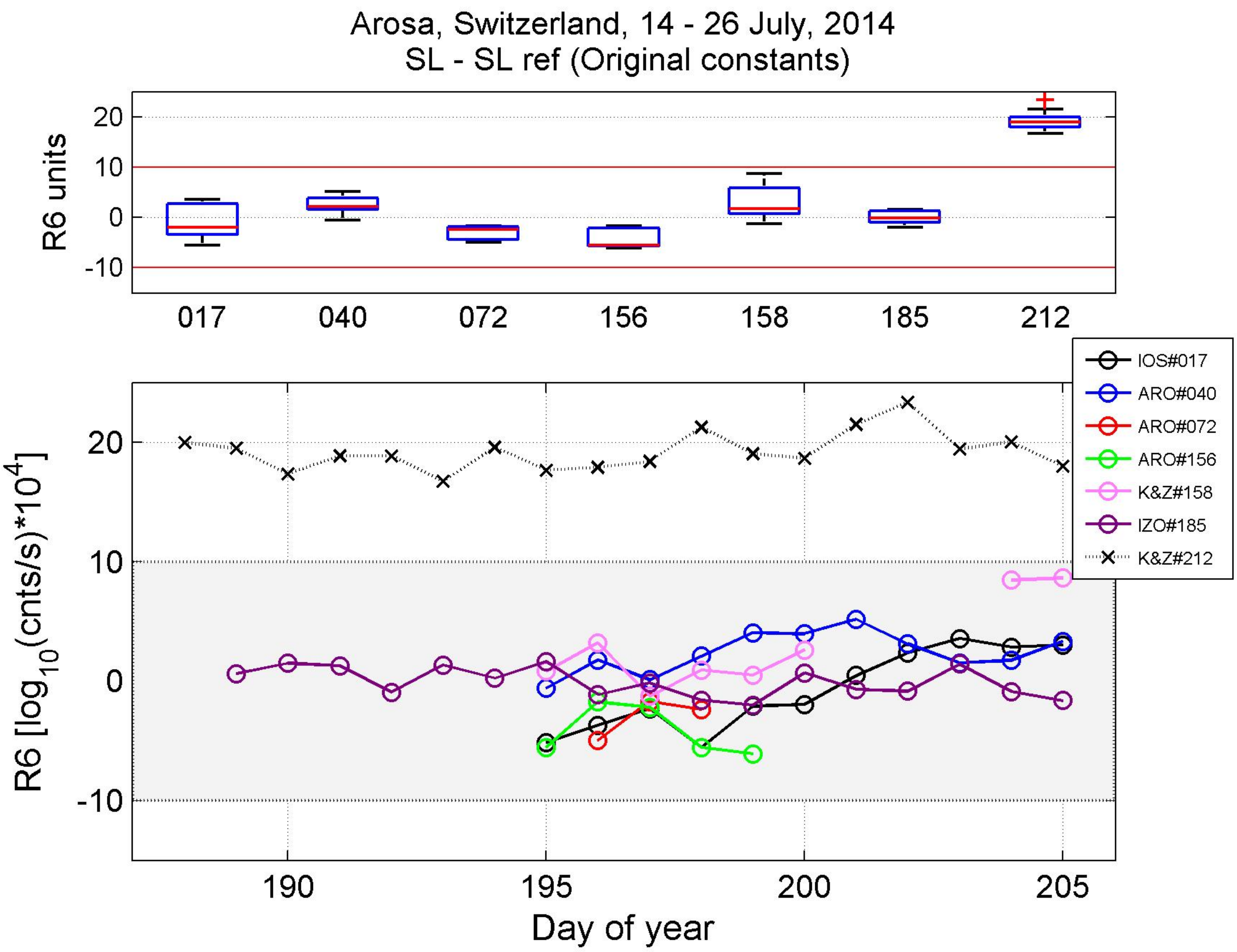
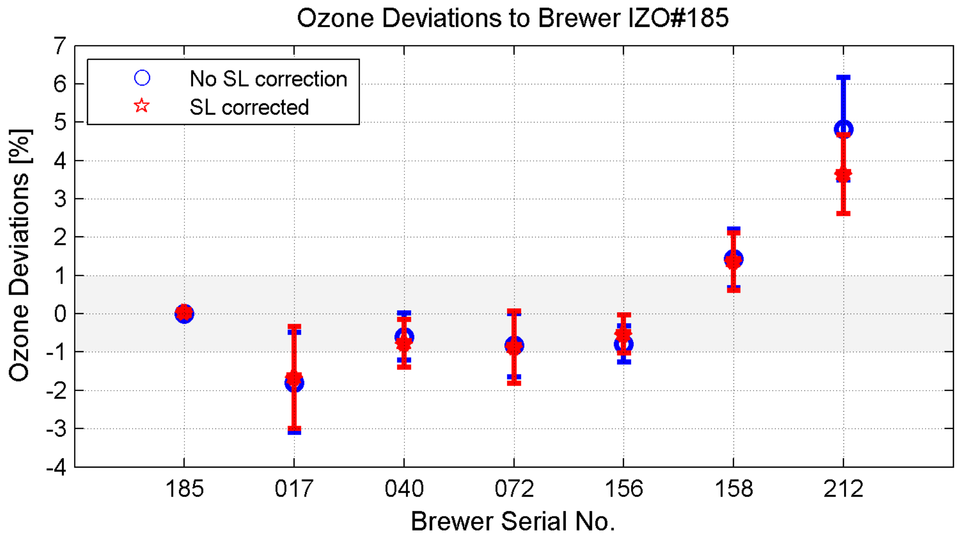



**Figure 8. Standard lamp R6 difference to R6 reference value from last calibration during the blind days, before the maintenance. Variations within the ± 10 range (≈1% in ozone) are considered normal, whereas larger changes would require further analysis of the instrument performance.**

During the Arosa 2014 intercomparison campaign all the instruments agreed on average with the corresponding R6 reference value within ±10 units, which is about 1% in ozone, with the exception of Brewer K&Z#212. This instrument showed deviations of R6 values to the reference value of the order of 20 units (see Figure 8). The comparison with a standard instrument is the only way to assess whether the SL measurements properly track changes on the calibration constants or the change observed is just due to changes of the lamp's spectral emission. In the case of Brewer K&Z#212 the SL correction slightly improved the comparison, as can be seen in Figure 9 and Figure 10. From this we deduced that changes in the SL ratios are related to changes in the instrument's response to light.




| | No SL corr. | SL corr. |
|---|---|---|
| **IOS#017** | -1.4+/-0.59 | -1.2+/-0.61 |
| **ARO#040** | -0.6+/-0.56 | -0.8+/-0.57 |
| **ARO#072** | -0.6+/-0.63 | -0.6+/-0.67 |
| **ARO#156** | -0.7+/-0.48 | -0.4+/-0.50 |
| **K&Z#158** | 1.6+/-0.65 | 1.5+/-0.64 |
| **K&Z#212** | 5.1+/-1.09 | 3.8+/-0.87 |

**Figure 9. Ozone relative percentage differences of all Arosa 2014 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 plots) and without (blue plots) SL correction. Error bars represent the standard deviation. The table below the graph shows deviations of ozone values to the reference Brewer IZO#185 for ozone slant path below 900 DU, with and without applying the SL correction.**

Results of the blind comparison with the standard instrument Brewer IZO#185 were rather poor, with ozone deviations greater than 1% for half of the instruments (see Figure 2 and Figure 10). This includes the standard Brewer IOS#017 and Brewer K&Z#158, which are used to transfer the ozone calibration worldwide. Given the observed differences $SL_{ref}$ - $SL_{measured}$ (see Figure 8), the SL correction to the ETC constant has little effect for all the participating instruments, with the exception of the aforementioned Brewer K&Z#212. Due to the stray light rejection in single Brewers (single monochromator), marked ozone slant column dependence in ozone measurements is observed for these instruments (Brewers #017, #040 and #072, see Figure 10). We will analyse individual instruments in Section 1.3.

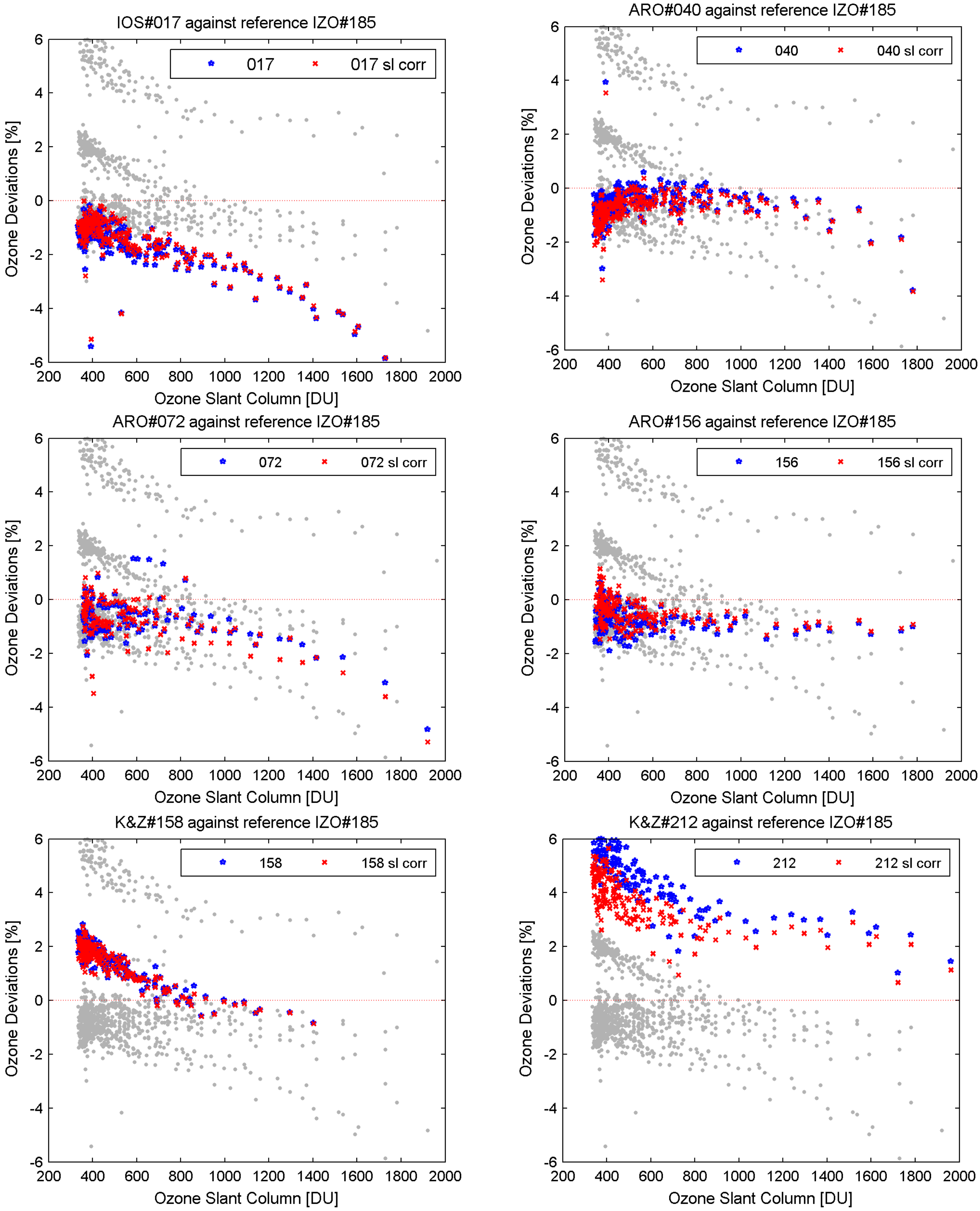



**Figure 10. Blind-days ozone relative differences (percentage) of Arosa 2014 participant instruments to RBCC-E travelling standard Brewer#185. Ozone measurements collected during the blind period (before the maintenance) were reprocessed using the original calibration constants, with (red stars) and without (blue stars) standard lamp correction. Grey dots mean ozone deviations for all participating instruments.**

## 2.3 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 to not 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.

We show in Figure 11 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, with the exception of Brewer K&Z#158 during the last 2 days. We will analyse this instrument in more detail in Section 2.4.6.

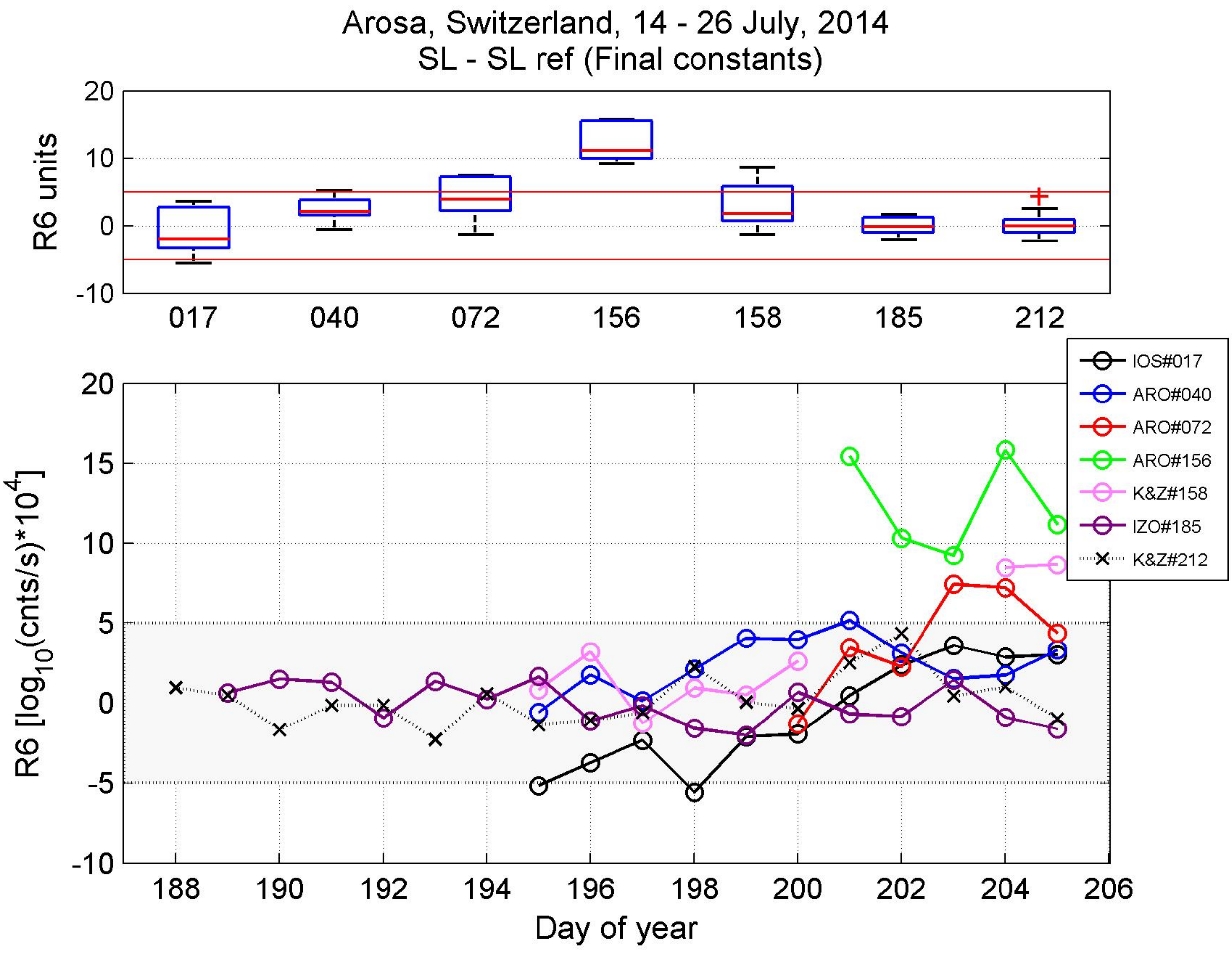
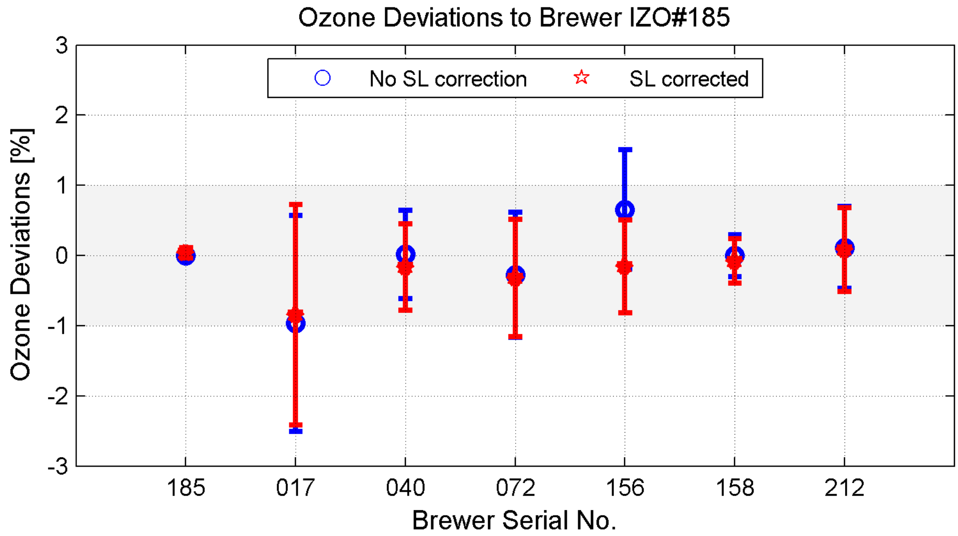



**Figure 11. Standard lamp R6 ratio to R6 reference from last calibration differences during the final days grouped by Brewer serial number (above) and as a function of time (below). The shadow area represents the tolerance range (±5 R6 units).**

Deviations of ozone values for all the participating instruments to the RBCC-E travelling standard Brewer IZO#185 are shown in Figure 12. We have recalculated the ozone measurements using the final calibration constants, with and without SL correction. All Brewers were calibrated using the one parameter ETC transfer method, i.e. 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 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.

We achieved a good agreement with the reference instrument Brewer IZO#185 using the final calibration constants, within the range ±0.5% (see Figure 12). Note that anomalous low total ozone deviations are frequent in the case of single monochromator Brewers, corresponding to high ozone slant values where stray light effect is large (see Figure 13).




| | No SL corr. | SL corr. |
|---|---|---|
| **IOS#017** | -0.4+/-0 .72 | -0.3+/-0.74 |
| **ARO#040** | 0.1+/-0.52 | -0.1+/-0.51 |
| **ARO#072** | 0.0+/-0.56 | 0.0+/-0.49 |
| **ARO#156** | 0.8+/-0.80 | -0.1+/-0.63 |
| **K&Z#158** | 0.0+/-0.29 | -0.1+/-0.31 |
| **K&Z#212** | 0.1+/-0.59 | 0.1+/-0.60 |

**Figure 12. Ozone relative percentage differences of all Arosa 2014 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) SL correction. Error bars represent the standard deviation. The table below the graph shows deviations of ozone values to the reference Brewer IZO#185 for ozone slant path below 900 DU, with and without applying the SL correction.**

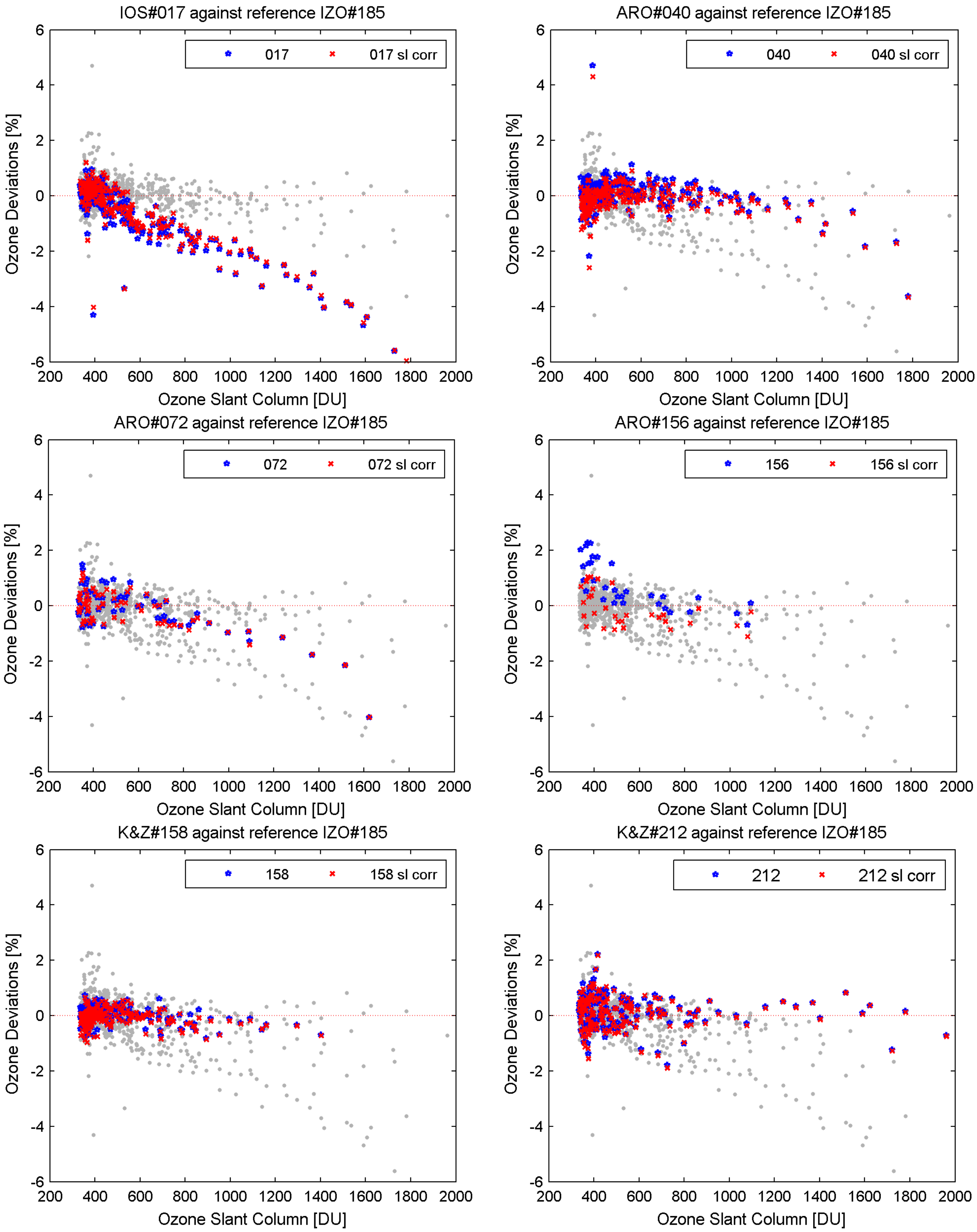



**Figure 13. Final-days ozone relative differences (percentage) of Arosa 2014 participant instruments to RBCC-E travelling standard Brewer#185. Ozone measurements collected during the final period (after the maintenance) were reprocessed using the proposed calibration constants, with (red stars) and without (blue stars) standard lamp correction. Grey dots mean ozone deviations for all participating instruments.**

## 2.4 Ozone Brewer Reports

### *2.4.1 Brewer IOS#017, Travelling standard*

Brewer IOS#017 participated in the campaign from 14 to 24 July 2014. The instrument's foreoptics was disassembled on 18th July (natural day 199) to be used on Brewer ARO#072. We did not detect any significant change in the instrument's performance during the campaign days. We used the same ozone data set to evaluate the instrument's initial status as well as for final calibration purposes (310 near-simultaneous direct sun ozone measurements).

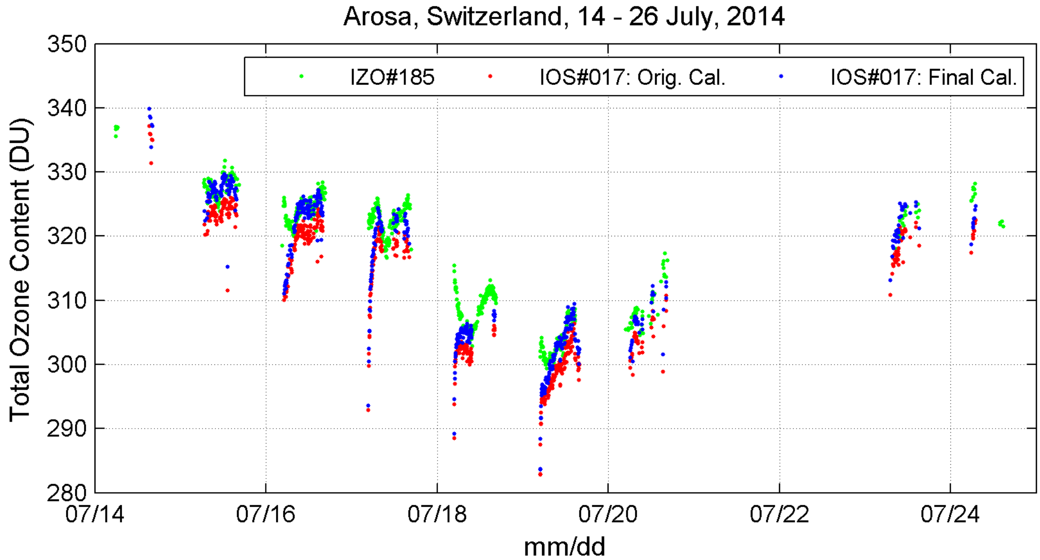



**Figure 14. Brewer Intercomparison Arosa 2014**

**Original calibration**

The updated calibration constants provided by the instrument operator were icf19714.017 and reference value 2100 for the standard lamp R6 ratio.

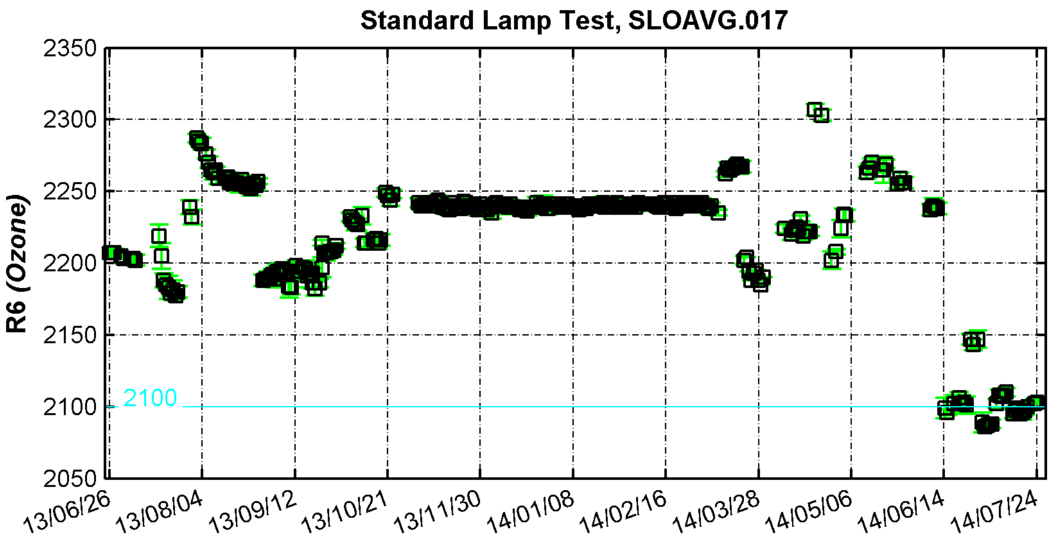



**Figure 15. Standard Lamp test R6 (Ozone) ratio**

## Historical analysis

The standard lamp (SL) test results from IOS#017 have been very unstable since the last RBCC-E intercomparison (El Arenosillo, June 2013, see Figure 15). R6 ratios stabilized around values 2100 during the campaign days. This is the new reference value proposed. All the other parameters analysed (Dead Time constant, Run / Stop test, Hg lamp intensity, CZ and CI scans) were normal.

## Initial comparison

The original calibration constants performance was not good enough, with ozone deviations around -1% for low ozone slant path values (osc<600 DU, see Figure 16). Correcting for the SL change did not improve significantly the comparison with the reference instrument IZO#185. It is worth noting that both the Cal-Step number (CSN) and the ozone Extraterrestrial constant (ETC) were updated on the second day of the campaign (from 862 to 860 and from 3287 to 3300, respectively).

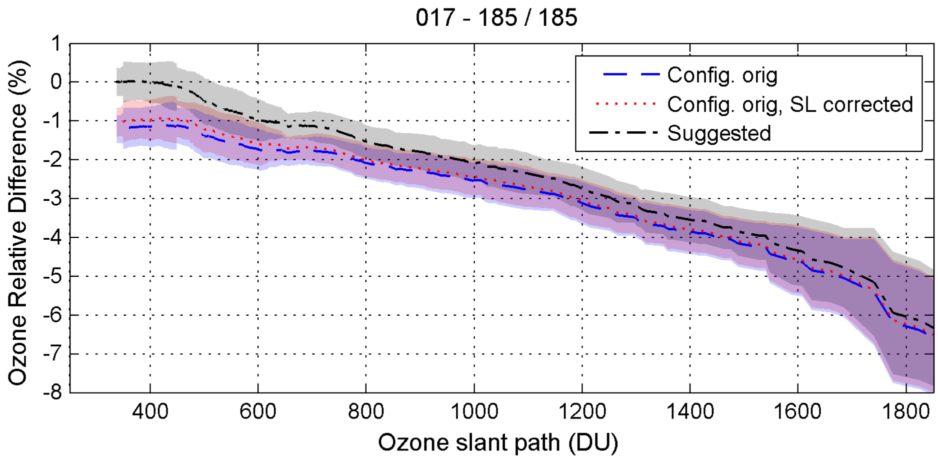



**Figure 16. Ozone deviation to the reference instrument as a function of ozone slant path. The shadow areas represent standard deviation.**

## Final calibration

We achieved a good agreement against the RBCC-E traveling standard using the proposed calibration constants, with ozone deviations within the 1% range up to ozone slant path 600 DU (see Figure 17, blue dashed line). We advise to check the effect of the SL correction before that date.

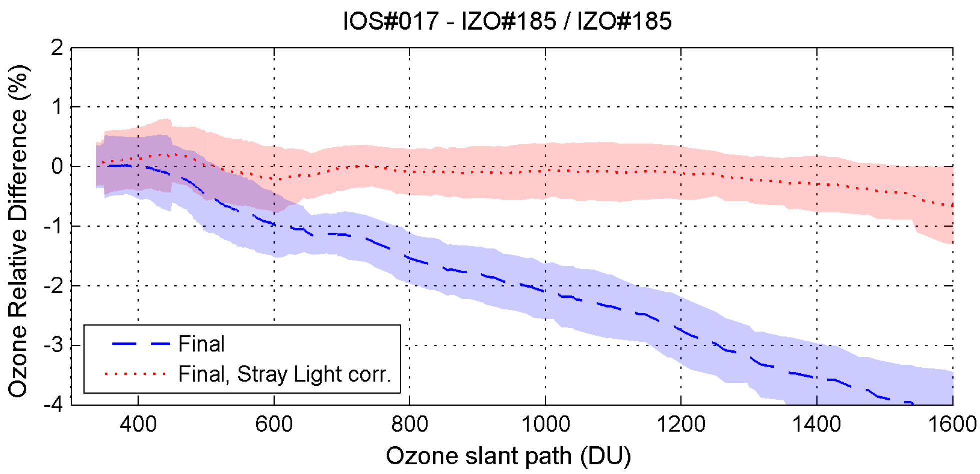



**Figure 17. Ozone deviation to the reference instrument as a function of ozone slant path. The shadow areas represent standard deviation.**

**Stray light**

This single Brewer shows large stray light rejection, leading to total ozone being underestimated up to around 1% at ozone slant path 600 DU. This is greatly improved after the stray light correction is applied (see Figure 17, red dotted line).

**Calibration constants summary: IOS#017**

| | *Last Cal.* | *Initial (blind)* | *Final* |
|---|---|---|---|
| O3 ETC constant | 3300 | | 3285 |
| SL R6 reference value | 2100 | | 2100 |
| change SL R6 ratio /ETC | 3 / 0 | | <10 / <10 |
| DT Constant (ns) | 34 | | 34 |
| Temp. Coeffs. | | | No change |
| Cal Step Number | 860 | | 860 |
| Ozone Abs. Coeff. | 0.3416 | | 0.3416 |
| Stray Light factors (F0 / k / s) | 3379/ -64.2/ 2.72 | | 3292 / -81 / 2.33 |
| Calibration File recommended | Icf19714.017 | | Icf19014_rbcce.017 |

**Recommendations and comments**

- The standard lamp test results from Brewer IOS#017 have been very unstable during the last 2 years. R6 ratios stabilized around 2100 units during the campaign days. This is the proposed reference value. All the other diagnostics analysed (DT, RS, AP records, CZ scans ...) were normal.
- We did not detect any appreciable temperature dependence in the ozone or the standard lamp observations, which indicates the correct choice of the temperature coefficients. We did not apply any correction factor to neutral density filters.
- Both the Cal Step and the ozone absorption coefficients were confirmed through analysis of sun scans and dispersion test performed during the campaign days. No change is suggested.
- The instrument's performance was quite stable during the campaign days. Ozone deviations to the reference instrument were of the order of -1% using the original calibration constants and for ozone slant path range below 600 DU.
- Ozone deviations were within the 1% range (for ozone slant path values lower than 600 DU) after the final calibration constants were applied. We advise to check carefully the effect of the standard lamp correction to re-evaluate historical ozone data.
- This single Brewer shows large stray light rejection, leading to total ozone being underestimated up to around 1% at ozone slant path 600 DU.

**Calibration report**

*http://www.iberonesia.net/archives/reports/Aro2014/CALIBRATION_017.pdf*

### *2.4.2 Brewer ARO#040, Station: Arosa, Switzerland*

Brewer ARO#040 operates normally at the Arosa station. The instrument UV focus was checked and the photon counter board was changed as part of the maintenance work on 17th July (Julian day 198). We did not detect any significant change in the instrument's performance due to these actions, and, accordingly, we used 424 near-simultaneous direct sun ozone measurements from days 14 to 24 July for calibration purposes as well as for evaluation of the instrument's initial status.

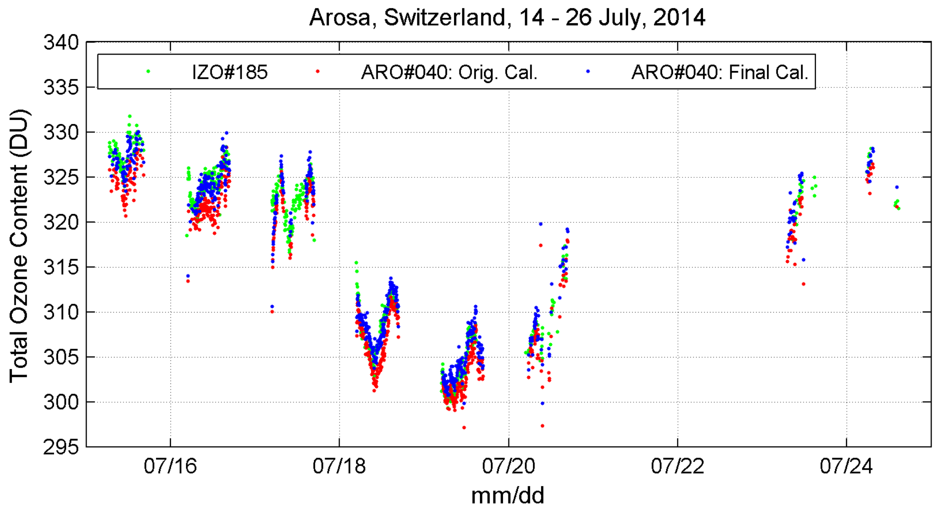



**Figure 18. Brewer Intercomparison Arosa 2014**

**Original calibration**

The instrument operates with the configuration file icf20412.040 and reference value 1740 for the standard lamp R6 ratio. These calibration constants were obtained after the 2012 intercomparison at Arosa, Switzerland, but they did not match the calibration constants suggested by the RBCC-E.

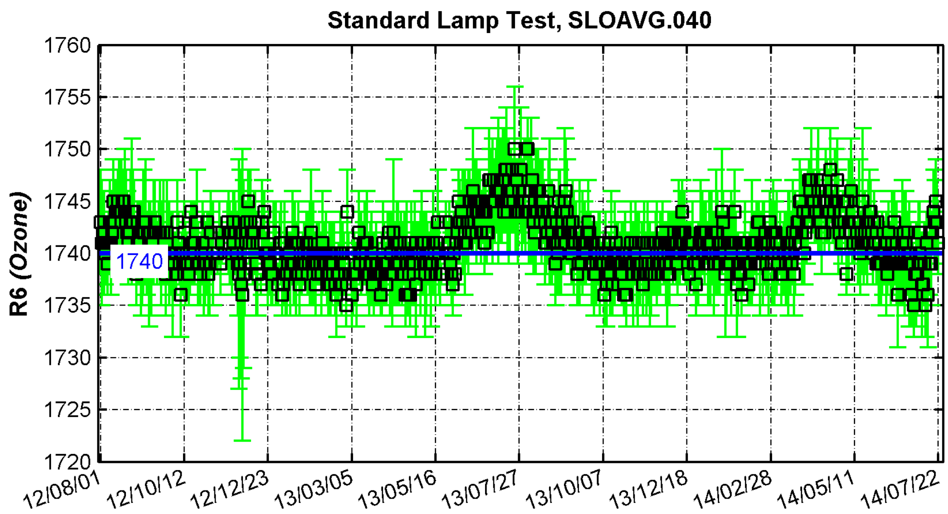



**Figure 19. Standard Lamp test R6 (Ozone) ratio**

### Historical analysis

As concerns to historical data analysis we will consider the period since the last Brewer intercomparison (July 2012). The standard lamp R6 ratio has been quite stable during this period and in close agreement, within +/-5 units, with the provided reference value (1740). The same R6 reference value would be valid from July 2014 onwards. All the other parameters analysed were normal, except for CZ scans performed on internal Hg lamp wavelength 296.728 nm: we found discrepancies of the order of 0.025 nm between the calculated line peak and the nominal values. Although this do not affect to the ozone calibration, UV data should be corrected from the observed wavelength shift.

### Initial comparison

The original calibration constants performed reasonably well during the campaign days, with ozone deviations lower than 1% as compared to the reference instrument IZO#185 and for ozone slant path values lower than around 1300 DU (see Figure 20). Correcting for the SL change did not affect significantly to the comparison.

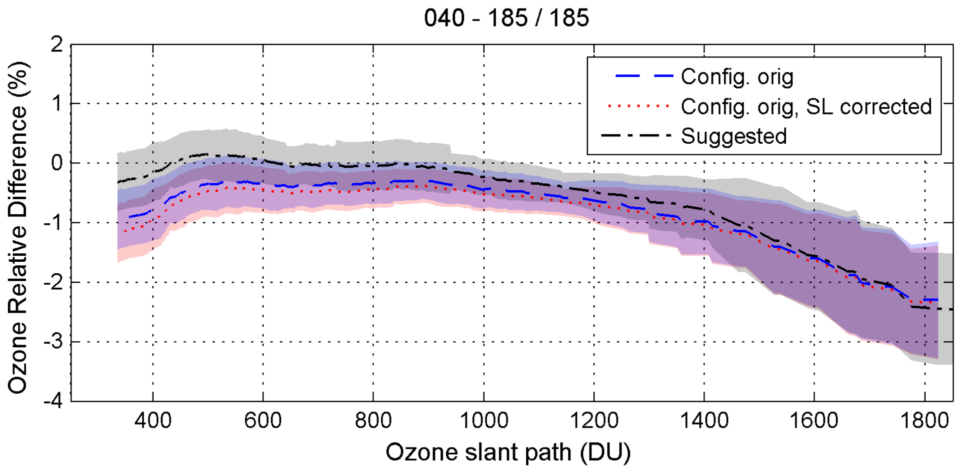



**Figure 20. Ozone deviation to the reference instrument as a function of ozone slant path. The shadow areas represent standard deviation**

### Final calibration

The calculated Extraterrestrial constant (ETC) was around 10 units lower than the operational value (2970 against 2980). Overall, we achieved a good agreement with the RBCC-E reference IZO#185 using this new constant (see Figure 20, black dashed line), with ozone deviations lower than 0.25% up to ozone slant path 1200 DU.

### Stray light

This single Brewer shows a low stray light rejection, with 1% underestimated ozone at around ozone slant path 1400 DU (see Figure 21, red dotted line).

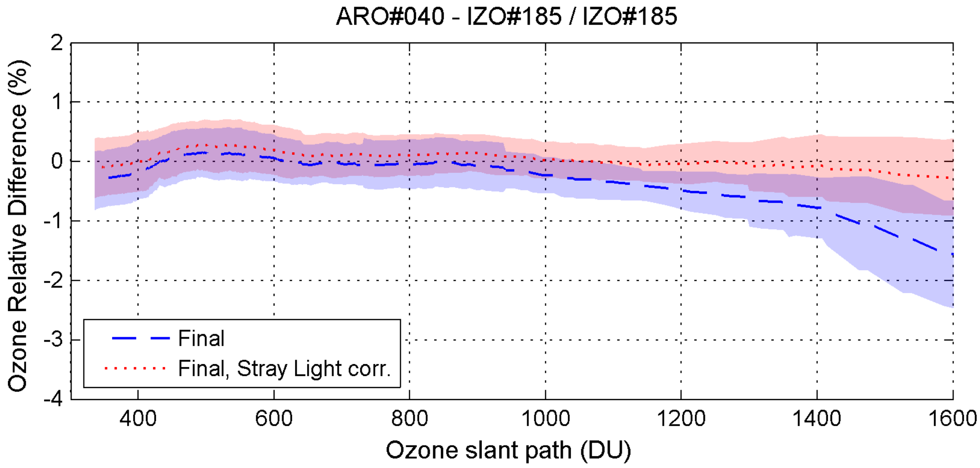



**Figure 21. Ozone deviation to the reference instrument as a function of ozone slant path. The shadow areas represent standard deviation.**

### Calibration constants summary: ARO#040

| | *Last Cal.* | *Initial (blind)* | *Final* |
|---|---|---|---|
| O3 ETC constant | 2980 | 2980 | 2970 |
| SL R6 reference value | 1740 | 1740 | 1740 |
| change SL R6 ratio /ETC | | <5 / <5 | <5 / <5 |
| DT Constant (ns) | 38 | 38 | 38 |
| Temp. Coeffs. | | No change | No change |
| Cal Step Number | 943 | 943 | 943 |
| Ozone Abs. Coeff. | 0.3335 | 0.3335 | 0.3335 |
| Stray Light factors (F0 / k / s) | 2986 / -8.56 / 4.97 | 2986 / -8.56 / 4.97 | 2972 / -5.33 / 5.44 |
| Calibration File recommended | Icf20412.040 | Icf20412.040 | icf219514.040 |

### Recommendations and comments

- The standard lamp test results have been very stable during the last 2 years, with mean value 1740 +/- 5 units for R6 ratio, although with some seasonal cycle. All the other diagnostics analysed (DT, RS, AP records ...) were normal, except for scans performed on internal Hg lamp (wavelength 296.728 nm). UV data should be corrected from the observed wavelength shift. Alternatively, a new dispersion relation (dcf file) could be used.

- We did not detect any appreciable temperature dependence in the ozone or the standard lamp observations, which indicates the correct choice of the temperature coefficients

- Some anomalous neutral density filter ND\#3 performance was observed, affecting to the total ozone retrievals in the ozone slant path range from 300 to 500 DU. However, we think that this is unlikely due to some filter correction needed. In any case, the correction factor deduced for neutral density filter ND\#3 was of the order of 5 units. No correction is suggested.

- We calculate a Cal-Step number 2 steps lower (941) as compared to the operational value (943). A similar discrepancy (2 micrometer steps) has been found between the calculated (0.3361) and the operational (0.3335) ozone absorption coefficient. Because of the uncertainty in the CSN constant, we have not updated the ozone absorption coefficient in the final configuration file (icf19514.040).

- The instrument performed well after the final calibration constants were applied, with ozone deviations lower than 0.5% for ozone slant path values lower than 1200 DU. The proposed SL R6 ratio reference is the same as the original one, R6=1740.

**Calibration report**

*http://www.iberonesia.net/archives/reports/Aro2014/CALIBRATION_040.pdf*

### *2.4.3 Brewer ARO#072, Station: Arosa, Switzerland*

Brewer ARO#072 participated in the campaign for the period from 14-24 July 2014. The UV focus was updated on 18th July (natural day 199) as part of the maintenance provided to this instrument. The instrument's response to light changed significantly because of this. Accordingly, we used days 14 to 18 July for evaluation of the instrument's initial status (156 near-simultaneous direct sun measurements), whereas days 19 to 24 July were used for final calibration purposes (65 near-simultaneous direct sun ozone measurements).

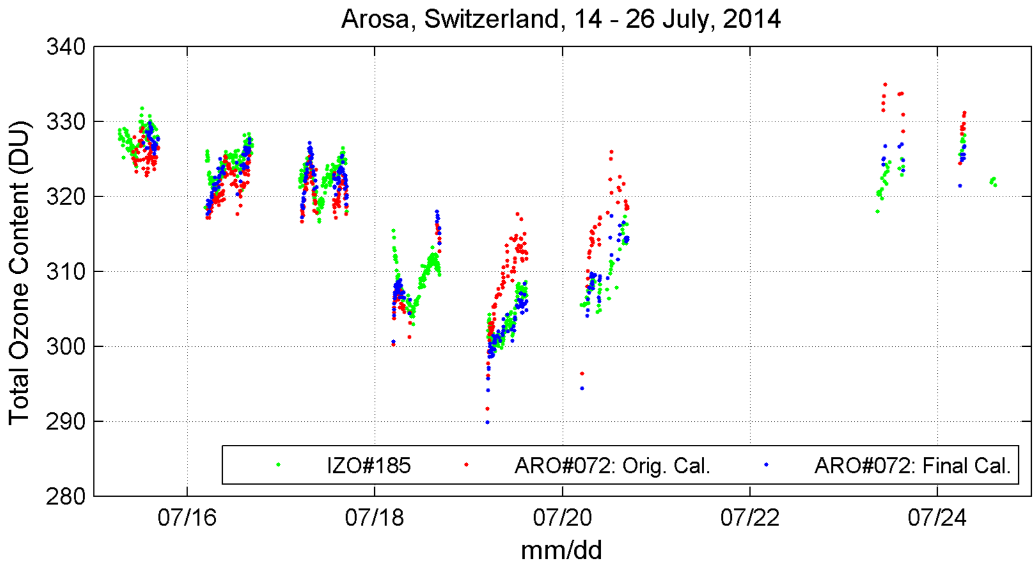



**Figure 22. Brewer Intercomparison Arosa 2014**

**Original calibration**

The instrument operates with the configuration file icf20312.072 and reference value 1925 for the standard lamp R6 ratio. These calibration constants were obtained after the last intercomparison campaign (Arosa 2012), but they did not match the calibration constants suggested by the RBCC-E.

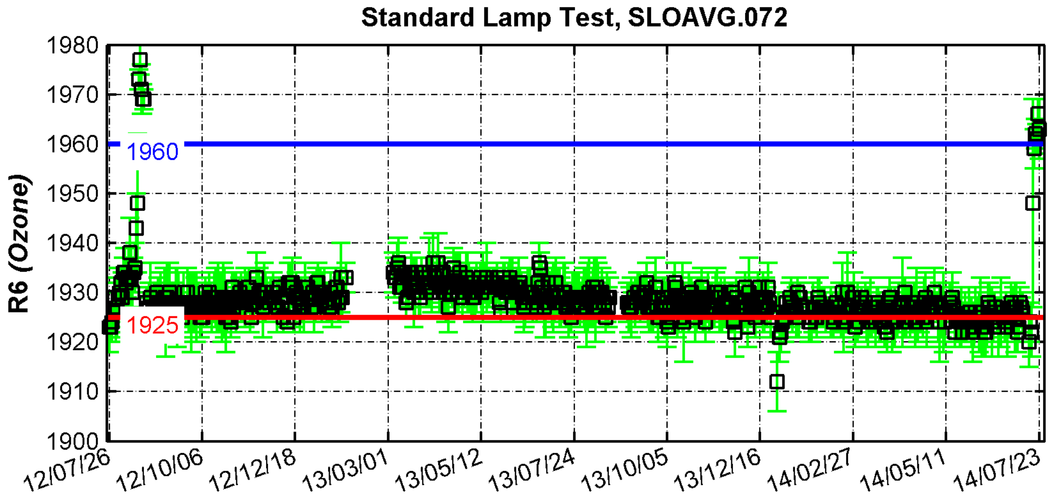



**Figure 23. Standard Lamp test R6 (Ozone) ratio**

## Historical analysis

The standard lamp tests have been very stable during the last 2 years, except for 2 remarkable events during this same period (see Figure 23): the first one just after the 2012 campaign, with a significant SL R6 ratios increasing (+50 units) and then recovering to its normal values (1925 units), and the second one after the UV focus was improved during the current intercomparison, with R6 ratio changing from 1925 to 1960. This last value is the proposed R6 ratio reference value. All the other diagnostics analysed (Dead Time constant, Run / Stop ratios, AP records ...) were normal.

## Initial comparison

The initial comparison with reference IZO#185 showed ozone deviations of the order of -1%. Correcting thee calibration constants for the SL change did not improve the comparison (see Figure 24). We suggest using the calibration constants ETC = 3180 and $R6_{REF}$ = 1925 to be applied from 24 August 2012, after the observed change in R6 ratio.

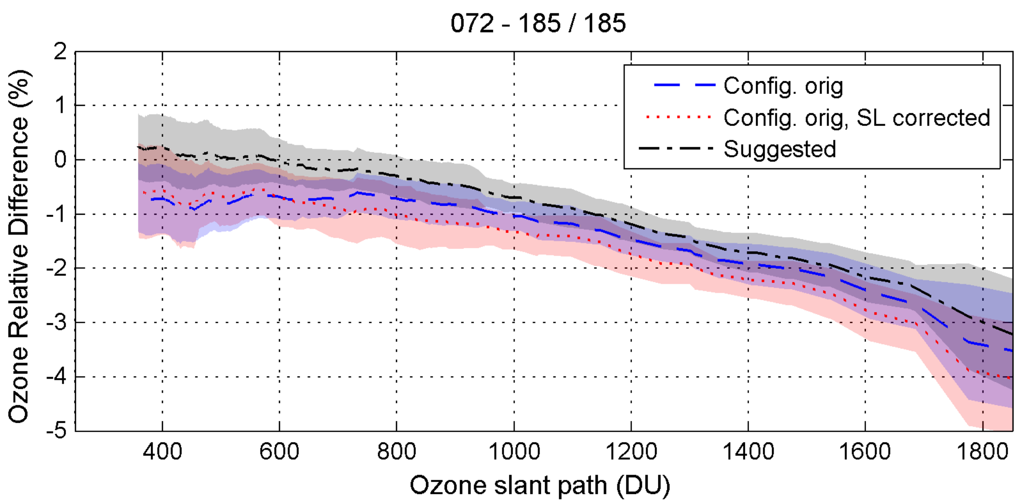



**Figure 24. Ozone deviation to the reference instrument as a function of ozone slant path. The shadow areas represent standard deviation.**

**Final calibration**
A notable change in the instrument's response was observed after maintenance was performed on this instrument. We have used an updated Dead Time constant to transfer the final extraterrestrial constant (ETC). We achieved a good agreement against the RBCC-E traveling standard using the new calibration constants (instrument's configuration file icf19914.072 and R6 reference value 1960), with ozone deviation within 0.5% up to ozone slant path around 900 DU (see Figure 25, blue dashed line).

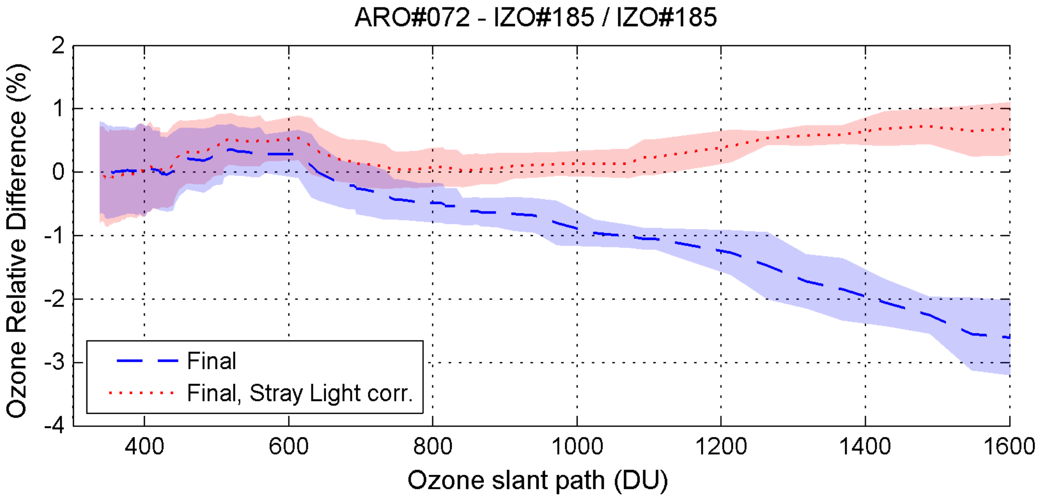



**Figure 25. Ozone deviation to the reference instrument as a function of ozone slant path. The shadow areas represent standard deviation.**

**Stray light**
This single Brewer shows a moderate stray light rejection, with ozone underestimated by around 1% at ozone slant path 900 DU. This is improved after the power-law stray light correction is applied (see Figure 25, red dotted line).

**Calibration constants summary: ARO#072**

| | *Last Cal.* | *Initial (blind)* | *Final* |
|---|---|---|---|
| O3 ETC constant | 3188 | 3180 | 3223 |
| SL R6 reference value | 1925 | 1925 | 1960 |
| change SL R6 ratio / ETC | | <5 / <10 | 35 / 40 |
| DT Constant (ns) | 38 | 38 | 39 |
| Temp. Coeffs. | | No change | No change |
| Cal Step Number | 915 | 915 | 915 |
| Ozone Abs. Coeff. | 0.3377 | 0.3377 | 0.3377 |
| Stray Light factors (F0 / k / s) | 3192 / -29.4 / 3.27 | 3182 / -25.1 / 4.08 | 3226 / -36.5 / 3.84 |
| Calibration File recommended | icf20312.072 | Icf23712.072 | Icf19914.072 |

**Recommendations and comments**

- ARO#072 SL R6 ratio has been quite stable during the two last years and in close agreement with the provided reference value (1925). However, it is worth noting two main events related to R6 ratio performance: just after the Arosa 2012 intercomparison and after maintenance was carried out during the current intercomparison.

- We have updated the Dead Time constant to a new value 39 ns in final configuration file.

- We did not detect any appreciable temperature dependence in the ozone or the standard lamp observations, which indicates the correct choice of the temperature coefficients. We did not apply any correction factor to neutral density filters.

- The calculated Cal-Step Number (CSN) was 2 steps lower (913) than the operational value (915). This difference was even greater after the UV focus was improved (5 steps difference, calculated 910 against operational 915). The CSN number has not been changed in final configuration.

- The original constants corrected for the SL change resulted in averaged ozone deviation of -1%. We recommend the calibration constants ETC = 3150 and $R6_{REF}$ = 1900 to re-evaluate Brewer ozone measurements 03 February 2012. The original constants should perform fine before that date.

- A re-evaluation of the historical ozone observations is recommended: we propose a new set of calibration constants (icf23712.072, R6=1925) to be applied from 24 August 2012. The original calibration constants (those operational, icf20312.072) should work before that date.

- We achieved a good agreement with the standard instrument using the final calibration constants set, with ozone deviations within 1% up to ozone slant path 900 DU.

**Calibration report**

*http://www.iberonesia.net/archives/reports/Aro2014/CALIBRATION_072.pdf*

### *2.4.4 Brewer ARO#156, Station: Arosa, Switzerland*

Brewer ARO#156 operates normally at the Arosa station. Major modifications were carried out on this instrument during the maintenance work: among others, attenuation filters ND#3 and ND#4 were replaced on day 19 July (natural day 200). Brewer operative software was also updated, allowing a cubic dispersion relation (a new DCF file was adopted). It is expected these last changes not to modify the ozone calibration. Unfortunately, there were not enough ozone observations after these changes so as to provide reliable ozone for this instrument. The calibration constants provided here were transferred from collocated instrument ARO#040 using a number of direct-sun ozone measurements collected after the campaign.

**Original calibration**

The instrument operates with the configuration file icf20312.156 and reference value for the standard lamp R6 ratio 445. These calibration constants were obtained after the last RBCC-E intercomparison campaign (July 2012), but they did not agree the calibration constants proposed by the RBCC-E team.

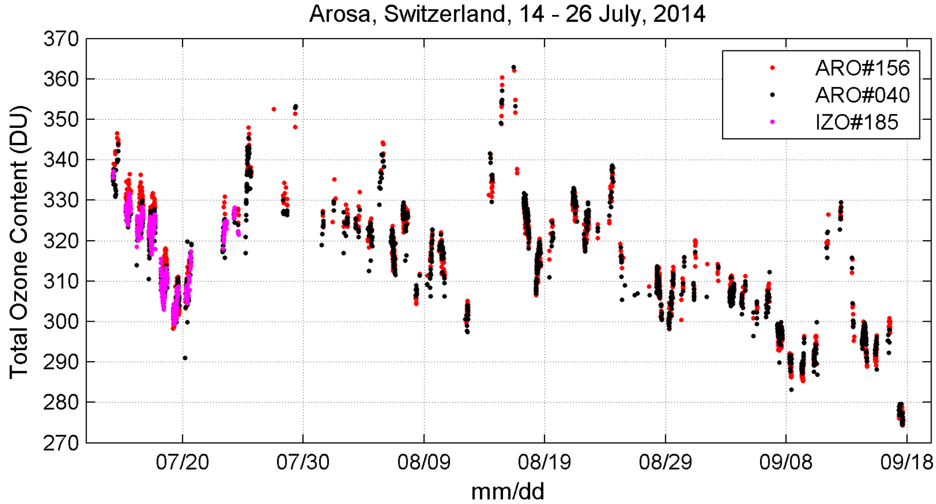



**Figure 26. Brewer Intercomparison Arosa 2014**

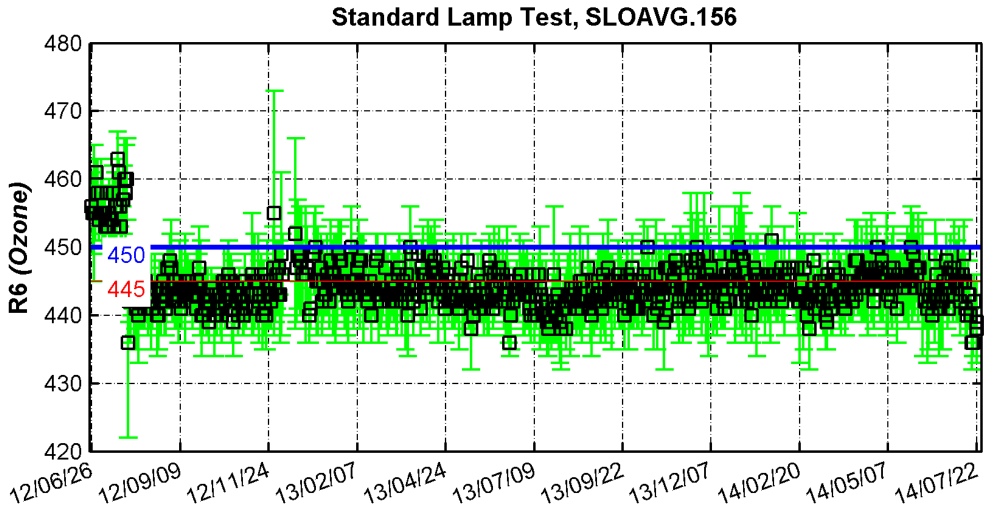



**Figure 27. Standard Lamp test R6 (Ozone) ratio**

### Historical analysis

ARO#156 has shown very good stability based on its SL ratios during the two last years, except for the observed change (around 15 units in R6 ratio) in July 2012 just after the last intercomparison. This SL change was due to temperature coefficients being updated on configuration file, thus not related to instrument's response changes. The R6 ratio stabilized around 450 during the campaign days. This is the proposed reference value. All the other parameters analysed are within the tolerance limits, with the exceptions of the Dead Time constant and CZ scans performed on internal Hg lamp wavelength 3341.48 nm. We believe that it is no necessary to change the DT constant, whereas the CZ issue was fixed by updating the dispersion relation. The instrument is now operating with a cubic dispersion relation.

### Initial comparison

Ozone deviations to the reference standard IZO#185 of the order of -1% were observed during the blind days. Correcting for the SL change did not improve the comparison results. Although the SL R6 ratio was updated from the value 445 to 458 in October, the ETC constant was kept the same as the one provided during the last Arosa 2010 intercomparison. From this and from the good agreement observed during the initial campaign days we conclude that SL R6 ratio changes seemed not to be related to changes in the instrument's response. Accordingly, we recommend not applying the standard lamp correction to this instrument.

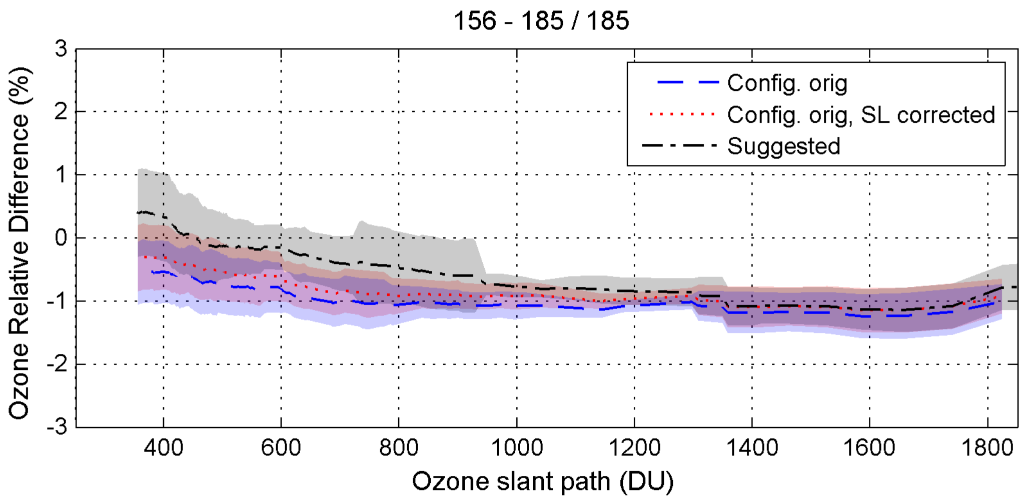



**Figure 28. Ozone deviation to the reference instrument as a function of ozone slant path. The shadow areas represent standard deviation.**

### Final calibration

We have used updated A1 and CSN constants for the final calibration. All other instrumental calibration constants remained the same. We achieved a very good agreement against the RBCC-E traveling standard using this calibration set, with ozone deviation lower than 0.25% up to ozone slant path 1600 DU.

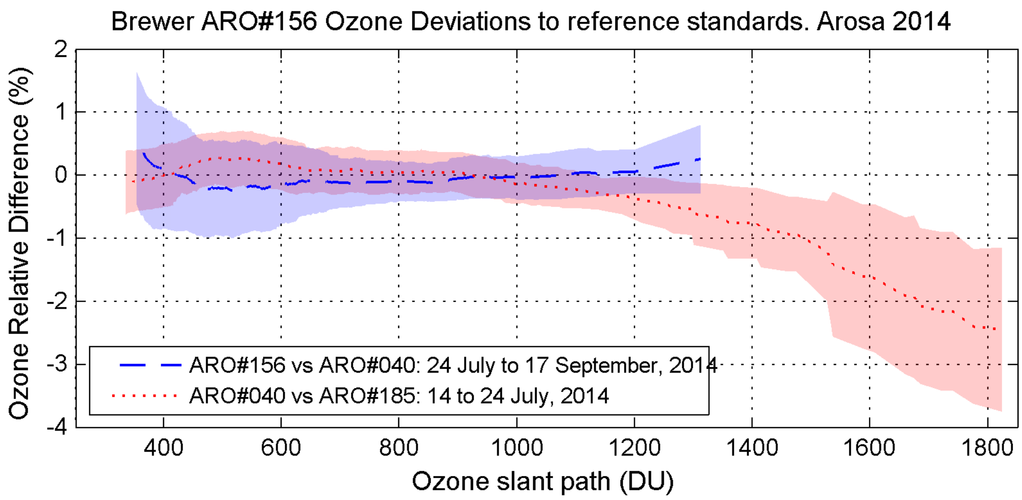



**Figure 29. Ozone deviation to the reference instrument as a function of ozone slant path. The shadow areas represent standard deviation.**

### Stray light

No stray light rejection (double monochromator).

**Calibration constants summary: ARO#156**

| | *Last Cal.* | *Initial (blind)* | *Final* |
|---|---|---|---|
| O3 ETC constant | 1750 | 1735 | 1746 |
| SL R6 reference value | 445 | 440 | 440 |
| change SL R6 ratio /ETC | | 5/15 | 0/10 |
| DT Constant (ns) | 24 | 24 | 24 |
| Temp. Coeffs. | | Change | Change |
| Cal Step Number | 1022 | 1022 | 1022 |
| Ozone Abs. Coeff. | 0.3402 | 0.3390 | 0.3390 |
| Stray Light factors (F0 / k / s) | | | |
| Calibration File recommended | Icf20312.156 | | ICF |

**Calibration report**

*http://www.iberonesia.net/archives/reports/Aro2014/CALIBRATION_156.pdf*

### *2.4.5 Brewer K&Z#158, Station: Delft, The Netherlands*

Brewer K&Z#158 participated in the campaign from 14 to 24 July 2014. This instrument is using new electronics since June 2014, so we did not provide any evaluation of the initial status. We will analyse historical data just from June 2014. The instrument had some problems with the slits mask assembly during the last days of the intercomparison, affecting to the instrument's response (the SL R6 ratio changed 10 units after this event). Although we didn't get enough observations after that to confirm the change in the calibration constants, we believe that the SL change is related to real changes in the instrument's response.

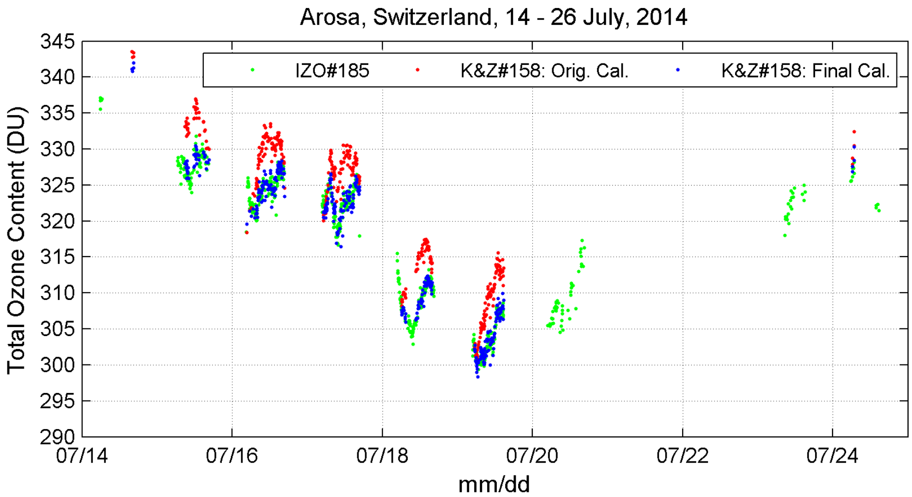



**Figure 30. Brewer Intercomparison Arosa 2014**

**Original calibration**

The instrument operates with the configuration file icf16714.158. No reference value for the standard lamp R6 ratio was provided.

**Historical analysis**

We analysed just data collected during the campaign days. The standard lamp R6 ratio was quite stable except for some increasing (around 10 units) in the last 2 days, due to slits mask misalignment. All the other diagnostics data (Dead Time constant, Run / Stop ratios, CI & CZ scans, AP records …) analysed were within the accepted tolerance range.

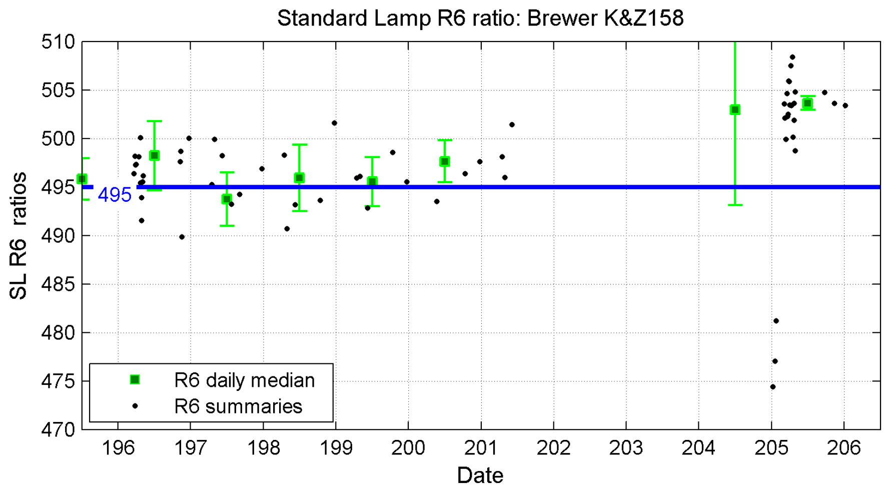



**Figure 31. Standard Lamp test R6 (Ozone) ratio**

## Initial comparison

We did not provide any evaluation of the initial status for Brewer K&Z#158 (see final calibration) as it not change during campaign.

## Final calibration

The initial comparison with reference IZO#185 was found to be poor, showing an average ozone deviation of 1% for low ozone slant path (<500 DU). Correcting the ETC by the standard lamp ratio change did not improve significantly the comparison. We have used updated DT constant and temperature coefficients for the final calibration. Note that, and because we have reprocessed the SL ratios using these new constants, the suggested reference value for R6 (468) does not match the values plotted in Figure 1. We achieved a very good agreement against the RBCC-E traveling standard using this calibration set, with ozone deviation lower than 0.25% up to ozone slant path 1600 DU. This calibration is only valid after PMT tube replacement in June.

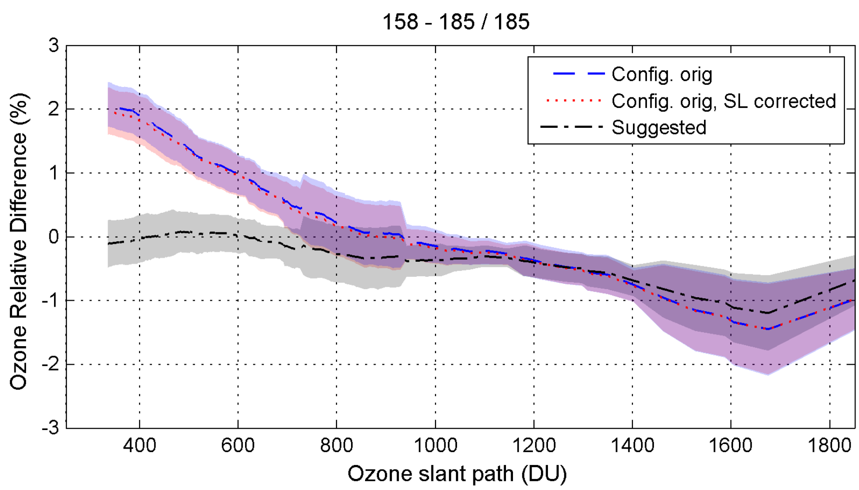



**Figure 32. Ozone deviation to the reference instrument as a function of ozone slant path. The shadow areas represent the standard deviation.**

**Stray light**
No stray light rejection (double monochromator).

**Calibration constants summary: K&Z#158**

| | *Last Cal.* | *Initial (blind)* | *Final* |
|---|---|---|---|
| O3 ETC constant | 1738 | | 1775 |
| SL R6 reference value | 495 | | 495 |
| change SL R6 ratio / ETC | | | <10 / <10 |
| DT Constant (ns) | 31 | | 31 |
| Temp. Coeffs. | | | No change |
| Cal Step Number | 1017 | | 1017 |
| Ozone Abs. Coeff. | 0.3432 | | 0.3400 |
| Stray Light factors (F0 / k / s) | Double Monochr. | | Double Monochr. |
| Calibration File recommended | icf16714.158 | | icf19514.158 |

**Recommendations and Comments**

- This instrument is using new electronics since June 2014, so we did not provide any evaluation of the initial status.
- We did not detect any appreciable temperature dependence in the ozone or the standard lamp observations, which indicates the correct choice of the temperature coefficients. No correction factors to be applied to attenuation filters are needed.
- The sun-scan (SC) tests performed during the intercomparison confirmed the operational Cal-Step (CSN) setting. We updated the ozone absorption coefficient in the final configuration file.
- The instrument performed well after the final calibration constants were applied, but negative ozone deviations to the reference instrument IZO#185 at high ozone slant column conditions are observed.
- The SL R6 ratio changed around 10 units during the last days of the intercomparison. We believe that this is related to real changes in the instrument’s response, so the calibration constant should be corrected by the SL change. Our recommendation is to compare with the Brewer K&Z#212 at the same station to confirm this change.

**Calibration report**

*http://www.iberonesia.net/archives/reports/Aro2014/CALIBRATION_158.pdf*

### *2.4.6 Brewer K&Z#212, Station: Delft, The Netherlands*

Brewer K&Z#212 participated in the campaign for the period from 14-24 July 2014. Both Brewer K&Z#212 and RBCC-E travelling standard IZO#185 participated in the UV campaign hosted by the World Radiation Center (PMOD/WRC), 7-16 July 2014. No change is observed due to transportation from Davos to Arosa, and hence, the results described in this report are valid also for that campaign. We use the same ozone data set to evaluate the initial status of the instrument as well as for final calibration purposes (209 near-simultaneous direct sun ozone measurements).

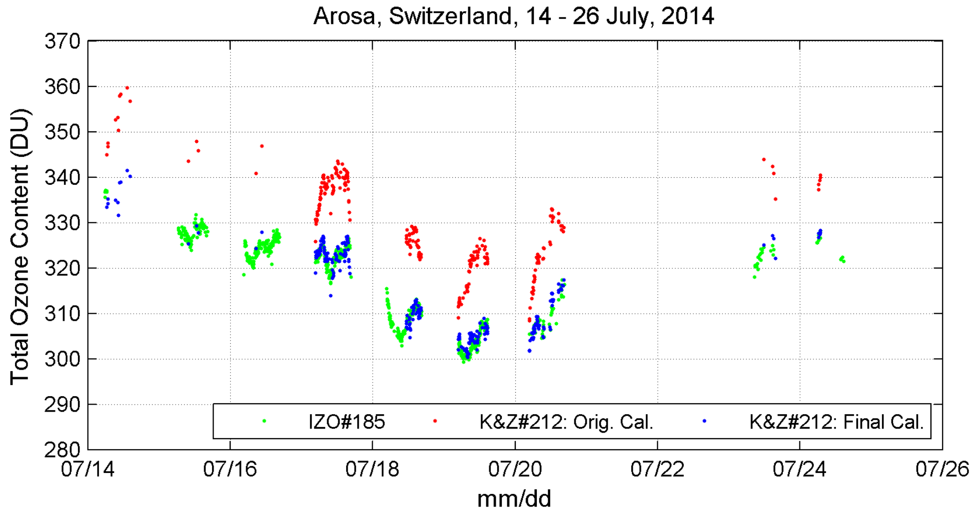



**Figure 33. Brewer Intercomparison Arosa 2014**

## Original calibration

The instrument operates with the configuration file icf23213.212 and reference value for the standard lamp R6 ratio 495.

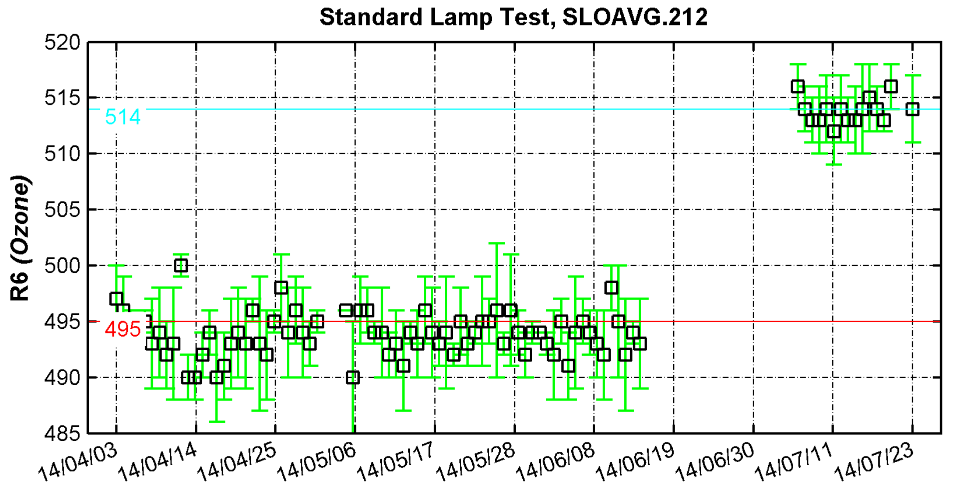



**Figure 34. Standard Lamp test R6 (Ozone) ratio**

## Historical analysis

As concerns to historical data analysis, we will consider just the period from April 2014. The SL R6 ratio changed from 495 to 514 during the travel to the Davos UV intercomparison. No change was observed when moving the instrument from Davos to Arosa stations. The new proposed SL R6 ratio reference value is 514. All the other analysed instrumental parameters were within the tolerance range, with the exception of the dispersion relation: it was completely off for both longer and shorter wavelengths. This issue was fixed after a new dispersion relation was adopted (dcf19114.212).

**Initial comparison**
The original calibration constants performance was not good; ozone deviations above 3% were observed. Correcting for the SL change did not improve significantly the comparison. We recommend using a new set of constants (icf19114.212 and R6=514) to re-evaluate historical ozone data.

**Final calibration**
We have used updated ozone absorption coefficient constant for the final calibration days. The resulting Extraterrestrial constant was around 1760. A very good agreement against the RBCC-E standard IZO#185 is observed after using these new calibration constants, with ozone deviation around 0.25% up to ozone slant path 1800 DU (see Figure 35, black dashed line).

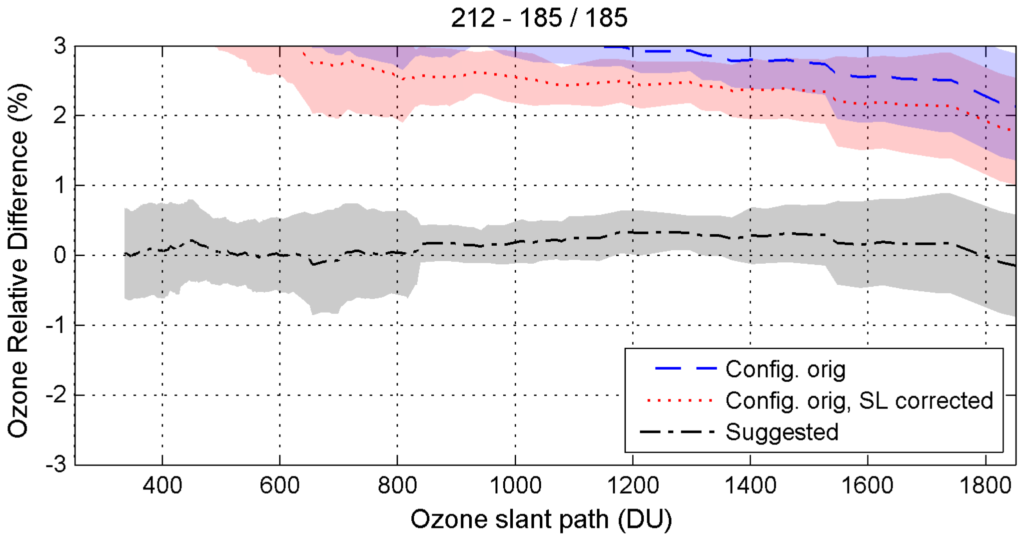



**Figure 35. Ozone deviation to the reference instrument as a function of ozone slant path. The shadow areas represent standard deviation.**

**Stray light**
No stray light rejection (double monochromator).

**Calibration constants summary: K&Z#212**

| | *Last Cal.* | *Initial (blind)* | *Final* |
|---|---|---|---|
| O3 ETC constant | 1705 | 1760 | 1760 |
| SL R6 reference value | 495 | 514 | 514 |
| change SL R6 ratio / ETC | | 20 / 55 | <5 / <5 |
| DT Constant (ns) | 30 | 30 | 30 |
| Temp. Coeffs. | | No change | No change |
| Cal Step Number | 1020 | 1020 | 1020 |
| Ozone Abs. Coeff. | 0.3391 | 0.3437 | 0.3437 |
| Stray Light factors (F0 / k / s) | Double Monochr. | Double Monochr. | Double Monochr. |
| Calibration File recommended | Icf23213.212 | icf19114.212 | icf19114.212 |

**Recommendations and comments**

- The SL R6 ratio changed around 20 units after the travel to the Davos UV intercomparison. However, it remained stable until the end of the Arosa campaign, one week later. We propose R6=514 as the new SL R6 ratio reference value.

- We did not detect any appreciable temperature dependence in the ozone or the standard lamp observations, which indicates the correct choice of the temperature coefficients. No correction factors to be applied to attenuation filters are needed.

- The sun-scan (SC) tests performed during the campaign days confirmed the operational Cal-Step (CSN) setting. The ozone absorption coefficient has been updated in final configuration file. A new dispersion relation is provided.

- The instrument performed quite well after the final calibration constants were applied. The SL change observed after the travel to Davos station is not related to changes in the instrument's response (ETC change=55 units, R6 change=20 units). We recommend using a new set of constants (icf19114.212 and R6=514) to re-evaluate historical ozone data.

**Calibration report**

*http://www.iberonesia.net/archives/reports/Aro2014/CALIBRATION_212.pdf*

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Ito, M. et al., 2014: *Observation of total ozone and UV solar radiation with Brewer Spectrophotometers on the Norikura mountains, Northern Japanese Alps*, from 2009). *http://www.jma-net.go.jp/kousou/information/journal/2014/pdf/72_45_Ito_et.pdf*

Redondas A., 2003: *Izana atmospheric observatory, ozone absolute calibration, Langley regression method*. The Eight Biennial WMO Consultation on Brewer Ozone and UV Spectrophotometer Operation, Calibration and Data Reporting. (*http://old.woudc.org/bdms/meetings/BRWKSH2003/brwksh2003_workshop_e.html*)

WMO, 2008a: *The Ninth Biennial WMO Consultation on Brewer Ozone and UV Spectrophotometer Operation, Calibration and Data Reporting*, GAW Report No. 175, (Delft, The Netherlands, 31-May-3 June 2005) (WMO TD No. 1419), 69 pp.

WMO, 2008b: *The Tenth Biennial WMO Consultation on Brewer Ozone and UV Spectrophotometer Operation, Calibration and Data Reporting,* GAW Report No. 176, (Northwich, United Kingdom, 4-8 June 2007) (WMO TD No. 1420), 61 pp.

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## LIST OF RECENT GLOBAL ATMOSPHERE WATCH REPORTS*

149. Comparison of Total Ozone Measurements of Dobson and Brewer Spectrophotometers and Recommended Transfer Functions (prepared by J. Staehelin, J. Kerr, R. Evans and K. Vanicek) (WMO TD No. 1147).

150. Updated Guidelines for Atmospheric Trace Gas Data Management (Prepared by Ken Maserie and Pieter Tans (WMO TD No. 1149).

151. Report of the First CAS Working Group on Environmental Pollution and Atmospheric Chemistry (Geneva, Switzerland, 18-19 March 2003) (WMO TD No. 1181).

152. Current Activities of the Global Atmosphere Watch Programme (as presented at the 14th World Meteorological Congress, May 2003). (WMO TD No. 1168).

153. WMO/GAW Aerosol Measurement Procedures: Guidelines and Recommendations. (WMO TD No. 1178).

154. WMO/IMEP-15 Trace Elements in Water Laboratory Intercomparison. (WMO TD No. 1195).

155. 1st International Expert Meeting on Sources and Measurements of Natural Radionuclides Applied to Climate and Air Quality Studies (Gif sur Yvette, France, 3-5 June 2003) (WMO TD No. 1201).

156. Addendum for the Period 2005-2007 to the Strategy for the Implementation of the Global Atmosphere Watch Programme (2001-2007), GAW Report No. 142 (WMO TD No. 1209).

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