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Internal consistency of the Regional Brewer Calibration Centre for Europe triad during the period 2005–2016

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The Standard Lamp (SL) test has not been included in the main part of this article but the values recorded by the RBCC-E triad are presented as supplementary information.

Generally, the SL value (so-called R6 value) is used to check the Brewer calibration since this parameter can mirror the changes of the relative spectral sensitivity. The differences between the SL record with respect to a reference value give an idea of how much the configuration of the instrument has changed. This variation can be taken into account in the ozone retrieval as follows:

$$O_3 = \frac{MS9 - ETC + (R6 - R6_{Reference})}{\alpha \cdot \mu} = \frac{MS9 - ETC}{\alpha \cdot \mu} + \frac{(R6 - R6_{Reference})}{\alpha \cdot \mu} \tag{S1}$$

where it is assumed that variation in the R6 value corresponds to a similar change in the Extraterrestrial constant (ETC). Therefore, the second term, $(R6 - R6_{Reference})/(\alpha \cdot \mu)$ represents the ozone correction by standard lamp. However, there are changes in the characteristics of the instrument that can be not detected with a SL test such as variations of the attenuation filters, iris and pointing. Therefore, the SL value does not represent the best indicator to check the calibration of our instruments. This justifies why the Brewers participate in the intercomparison campaign where their data are compared against a reference brewer.

The importance of having established the Regional Brewer Calibration Center in the Izaña Atmospheric Observatory is because this place presents ideal conditions for the Langley technique which allow us an absolute and independent derivation of ETC of each brewer. In this respect, the Langley method is the ideal calibration technique to check the state of an instrument and, hence, at the RBCC-E the SL correction does not usually apply to our instruments with some exceptions (see section Brewer#183). In general, the ETC detects the large changes in the calibration of an instrument while the smaller changes can be tracked with the SL records. Normally, when an instrument presents an irregular behavior, the SL allow us to track better the evolution of the instrument than the ETC calculation. This is due to the ETC being calculated from data obtained during several weeks of observation, a period where it is required that the instrument works uniformly.

Routinely since 2009, monthly calibrations are performed for the three instruments of the RBCC-E triad following the same procedure as described Redondas et al. (2018). This includes the instrument characterization (dead time, filter attenuation and temperature coefficients determination), the wavelength calibration and the ETC transfer. The ETC value are compared with the Langley calibration which is finally used. This calibration reports are available on the RBCC-E website (see for example León-Luis et al. (2016)), and the calibration of the travelling reference before and after the travels are part of the intercomparison reports (Redondas et al., 2015; Redondas and Rodriguez-Franco, 2016; Redondas and Rodríguez-Franco, 2015). During these routine calibrations a history of the calibrations is produced and the events which produce a change in the calibration (ETC) and/or Standard Lamp record are noted.

In the following figures and tables a calibration history of the RBCC-E Triad are shown, these events are identified with vertical lines in each figure and the dates on which these events have taken place are indicated in the corresponding table. Most of the changes are due to maintenance, hardware changes, testing and incidents on the instruments due to the storms which affect at the observatory. The figures show the calibration derived from the Langley technique and the ETC (Figures and Tables 1,3,5), and the Standard lamp corrections between calibrations (Figures and Tables 2,4,6).

Brewer#157

The Brewer#157 was installed at the observatory in 1998, since 2004 it shows small changes mostly due to maintenance as shown in Figure S1 and Table S1. From 1998 to 2010 Brewer#157 was calibrated yearly by were yearly calibrated by International Ozone Services (IOS), the comparison of the Langley calibration with the travelling shows a good agreement with difference lower than 0.5% (Redondas et al., 2013). Note that during this period IOS calibration and not Langley were used for the data evaluation. During the period 2013-2015 is when the instrument presented a more irregular behaviour as can be observed by the number of calibrations and the large changes in the ETC operative value. This unstable period is mirrored in the SL records, see Figure S2 and Table S2.

Brewer#183

On the record of the Brewer#183, we have to consider that this is our testing instrument where new routines and hardware changes are tested before being introduced on the Triad (Figure S3 and Table S3. This instrument were strongly affected by the Delta tropical Storm in November 2005 (Jorba et al., 2008) and we not considered stable until 2011, after that only small changes are noticed. A reprocessing of the calibration will improve the results during the 2006-2009 period, after the fixing of the instrument. Also, the SL record tracks this irregular period, especially in 2009. From 2012, the ETC has changed on numerous occasions. However, the R6 records and its reference value do not show large differences between them, see Figure S4 and Table S4. This is a sign of a stable behavior of the instrument from this date.

Brewer#185

The Brewer#185 is the travelling instrument and was the last instrument installed at the observatory. Figure S5 shows that the ETC values were stable between 2005-2010, except for a few months in 2008, see Table S5. Between the years 2011-2013, two abrupt changes in the ETC can be observed, in first place due to changes on the micrometer after a campaign in Huelva in 2011 and an optical focus reliagment in 2013. From 2013, the ETC has varied in a few units. The R6 has evolved similarly to ETC value, see Figure S5 and Table S6.

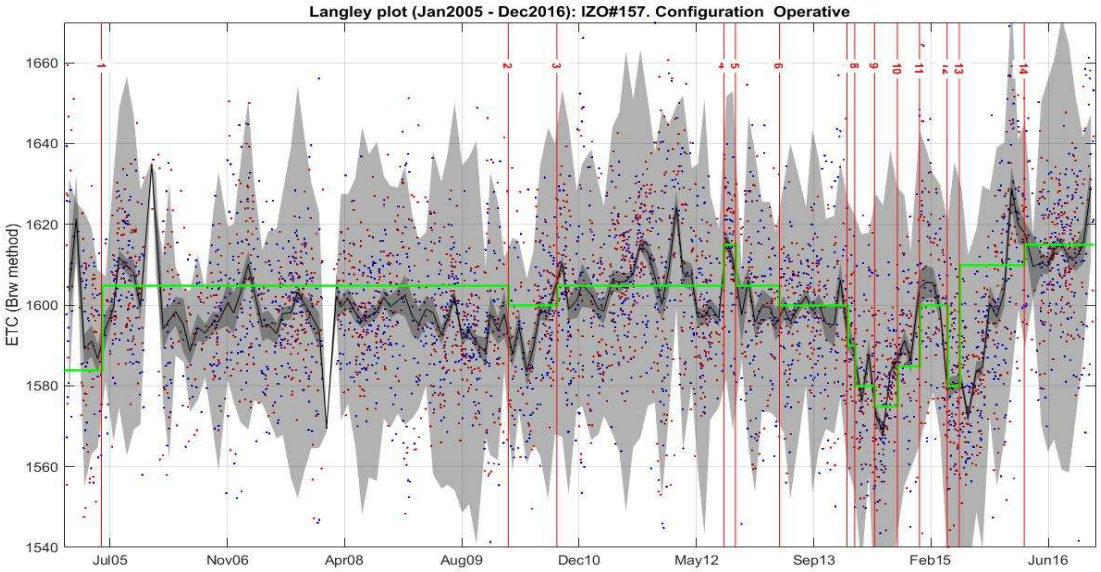

Figure S1. The vertical red lines correspond to events which have produced a change in the operative ETC configuration which is indicated with a horizontal green line. The red and blue dots denote the daily ETC values calculated by the Langley method before and after solar noon, respectively. The black line corresponds to the ETC weekly mean and the dark and light gray areas represent the 95% confidence interval and the standard deviation, respectively

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Table S1. ETC Reference values used in the Brewer#157 and events which have produced its change during the period 2005-2016.

Event	Date	ETC Operative	Event	Date	ETC Operative
1. SL Replacement	31/05/2005	1605	2. Storm	01/03/2010	1600
3. Maintenance IOS 2010	24/09/2010	1605	4. Hg replacement	05/09/2012	1615
5. Maintenance Kipp&Zonen	24/10/2012	1605	6. Hg replacement	30/04/2013	1600
7. Maintenance Kipp&Zonen	12/02/2014	1590	8. Wavelength Calibration	17/03/2014	1580
9. SL Shift	10/06/2014	1575	10. SL changed Storm	15/09/2014	1585
11. Hg replacement	18/12/2014	1600	12. Heating Issue	15/4/2015	1580
13. Maintenance IOS 2015	06/06/2015	1610	14. Maintenance Kipp&Zonen	09/03/2016	1615

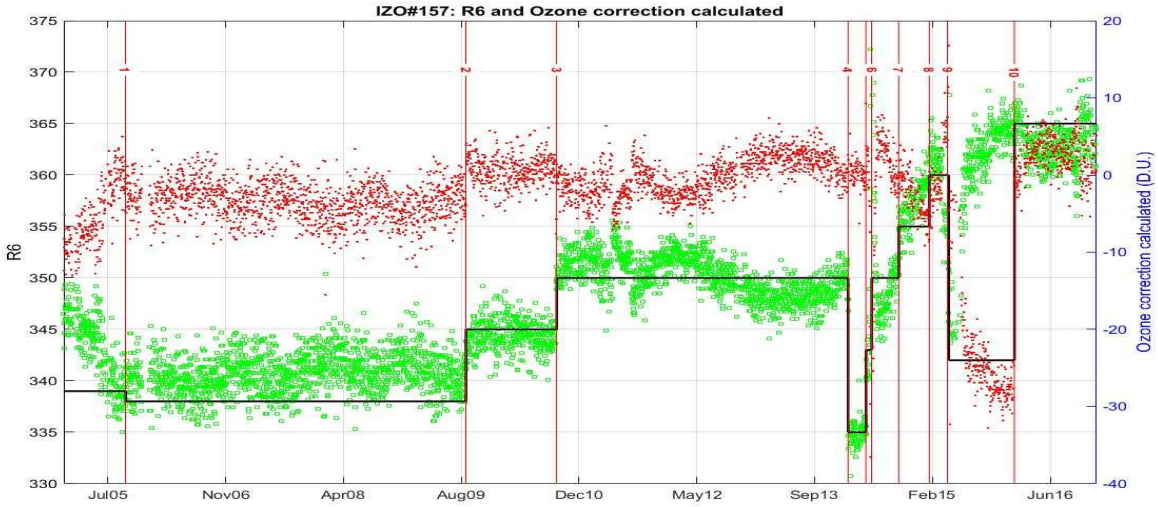

Figure S2. The vertical red lines indicate events which have produced a change in the R6 Reference value which is indicated with a horizontal black line. The green dots are the R6 value measured by the Brewer#157. In contrast, the red dots represents the ozone correction value calculated from the difference R6-R6 Reference, assuming a ozone absorption coefficient and an airmass equal to 0.3995 and 2, respectively.

Table S2. R6 Reference values used in the Brewer#157 and events which have produced its change during the period 2005-2016.

Event	Date	R6 Reference	Event	Date	R6 Reference
1. Maintenance IOS 2005	20/09/2005	338	2. Maintenance IOS 2009	05/09/2009	345
3. Maintenance IOS 2010	24/09/2010	345	4. Maintenance Kipp&Zonen	12/02/2014	350
5. Laboratory	29/04/2014	335	6. Temp. Controler off	23/05/2014	350
7. SL change Storn	15/09/2014	355	8. Maintenance Kipp&Zonen	23/01/2015	360
9. Temp. Controler ON	15/04/2015	342	10. Hg replacement	19/01/2016	365

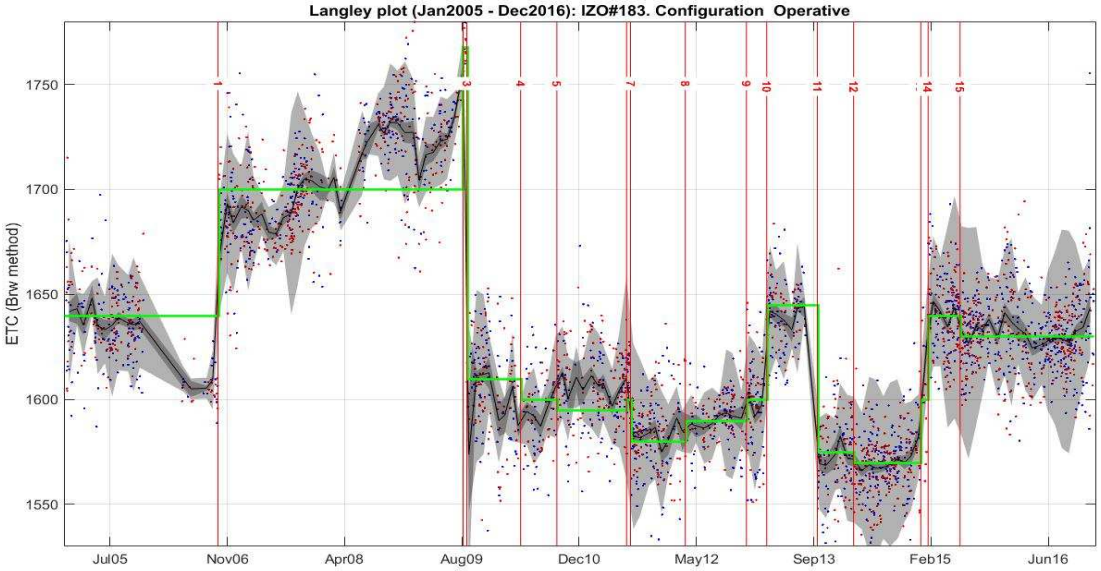

Figure S3. The vertical red lines correspond to events which have produced a change in the operative ETC configuration which is indicated with a horizontal green line. The red and blue dots denote the daily ETC values calculated by the Langley method before and after solar noon, respectively. The black line corresponds to the ETC weekly mean and the dark and light gray areas represent the 95% confidence interval and the standard deviation, respectively

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Table S3. ETC Reference values used in the Brewer#183 and events which have produced its change during the period 2005-2016.

Event	Date	ETC Operative	Event	Date	ETC Operative
1. Maintenance IOS 2006	10/10/2006	1700	2. SL replacement	20/08/2009	1768
3. Maintenance IOS 2009	05/09/2009	1610	4. Wavelength calibration	22/04/2010	1600
5. Maintenance IOS 2010	24/09/2010	1595	6. Maintenance IOS 2011	18/07/2011	1600
7. Wavelength calibration	04/08/2011	1580	8. Wavelength calibration	24/03/2012	1590
9. SL replacement	10/12/2012	1600	10. Slitmask issue	07/03/2013	1645
11. Old board test	09/10/2013	1575	12. Hg replacement	12/03/2014	1570
13. Slitmask issue	24/12/2014	1600	14. Maintenance Kipp&Zonen	24/11/2015	1640
15. Maintenance IOS 2015	09/06/2015	1630			

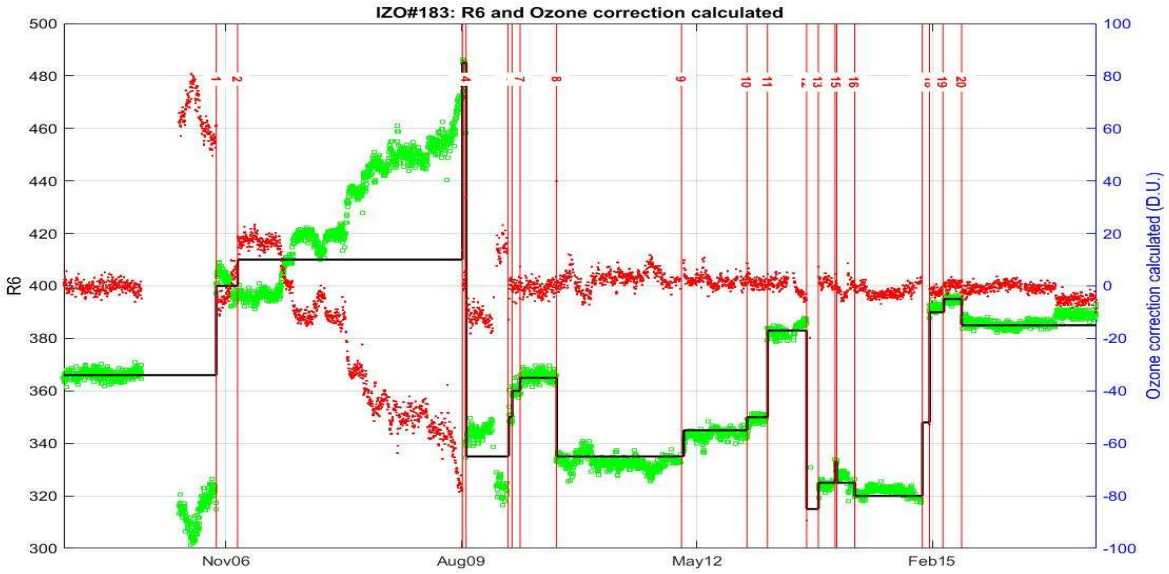

Figure S4. The vertical red lines indicate events which have produced a change in the R6 Reference value which is indicated with a horizontal black line. The green dots are the R6 value measured by the Brewer#183. In contrast, the red dots represents the ozone correction value calculated from the difference R6-R6 Reference, assuming a ozone absorption coefficient and an airmass equal to 0.3995 and 2, respectively.

Table S4. R6 Reference values used in the Brewer#183 and events which have produced its change during the period 2005-2016.

Event	Date	R6 Reference	Event	Date	R6 Reference
1. Maintenance IOS	10/10/2006	400	2. Maintenance IOS	09/01/2007	410
3. UV Calibration	20/08/2009	485	4. Maintenance IOS 2009	05/09/2009	335
5. Storm	02/03/2010	350	6. Micrometer issue	19/03/2010	360
7. New micrometer	22/04/2010	365	8. Maintenance IOS 2010	24/09/2010	335
9. New board replacement	07/03/2012	345	10. SL replacement	10/12/2012	350
11. Slitmask issue	07/03/2013	383	12. Inoperative	20/08/2013	315
13. Operative old board	09/10/2013	325	14. SL Replacement	19/12/2013	333
15. Prism Alignment	26/12/2013	325	16. Hg replacement	12/03/2014	320
17. Slitmask issue	24/12/2014	348	18. Maintenance Kipp&Zonen	24/01/2015	390
19. Storm	22/03/2015	395	20. Maintenance IOS 2015	09/06/2015	385

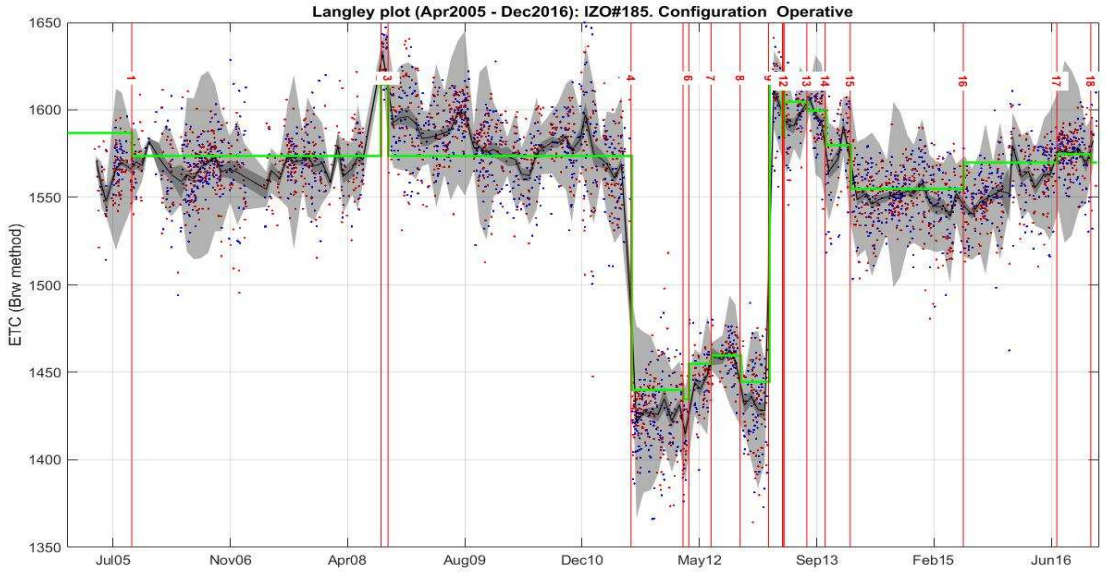

Figure S5. The vertical red lines correspond to events which have produced a change in the operative ETC configuration which is indicated with a horizontal green line. The red and blue dots denote the daily ETC values calculated by the Langley method before and after solar noon, respectively. The black line corresponds to the ETC weekly mean and the dark and light gray areas represent the 95% confidence interval and the standard deviation, respectively

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Table S5. ETC Reference values used in the Brewer#185 and events which have produced its change during the period 2005-2016.

Event	Date	ETC Operative	Event	Date	ETC Operative
1. Maintenance IOS 2005	24/09/2005	1574	2. Maintenance IOS 2008	22/08/2008	1615
3. Slitmask issue	21/09/2008	1574	4. Maint. 2011. Hg line changed	24/07/2011	1440
5. Wavelength calibration	02/03/2012	1435	6. Wavelength Calibration	27/03/2012	1455
7. Changed Langley	30/06/2012	1460	8. Storm	31/10/2012	1445
9. Packing Kipp&Zonen.Focus align.	02/03/2013	1616	10. Wavelength calibration	30/04/2013	1585
11. Wavelength calibration	05/05/2013	1620	12. Zero update to 1730	07/05/2013	1605
13. UV calibration	12/08/2013	1600	14. Hg replacement	29/10/2013	1580
15. Maintenance Kipp&Zonen	13/02/2014	1555	16. Maintenance IOS 2015	10/06/2015	1570
17. Calibration	13/07/2016	1575	18. Storm	05/12/2016	1570

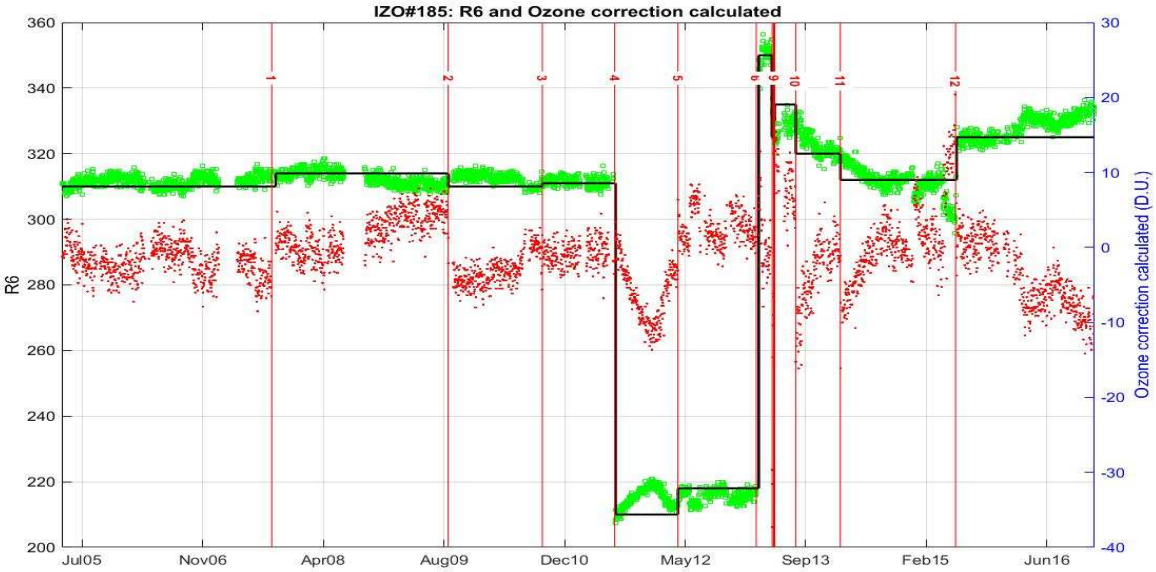

Figure S6. The vertical red lines indicate events which have produced a change in the R6 Reference value which is indicated with a horizontal black line. The green dots are the R6 value measured by the Brewer#185. In contrast, the red dots represents the ozone correction value calculated from the difference R6-R6 Reference, assuming a ozone absorption coefficient and an airmass equal to 0.3995 and 2, respectively.

Table S6. R6 Reference values used in the Brewer#185 and events which have produced its change during the period 2005-2016.

Event	Date	R6 Reference	Event	Date	R6 Reference
1. Maintenance IOS 2007	02/09/2007	314	2. Maintenance IOS 2009	02/09/2009	310
3. Maintenance IOS 2010	27/09/2010	311	4. Maintenance IOS 2011.Hg replac.	24/07/2011	210
5. Laboratory	11/04/2012	218	6. Focus alignment	02/03/2013	350
7. Zero update to 1730	07/05/2013	325	8. Zero update to 1733	13/05/2013	330
9. Mix Fixed	17/05/2013	335	10. Laboratory	12/08/2013	320
11. Maintenance Kipp&Zonen	13/02/2014	312	12. Maintenance IOS 2015	10/06/2015	325

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