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Fifth International Comparison of Dobson Spectrophotometers Villa Ortúzar Observatory, Argentina, 4-22 March 2019

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Fifth International Comparison of Dobson Spectrophotometers

Villa Ortúzar Observatory, Argentina

4–22 March 2019

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EXECUTIVE SUMMARY

This report presents the background information, procedures and results of the Fifth Intercomparison of Dobson Spectrophotometers (IC/BUA-19) carried out at the Main Buenos Aires Observatory (Villa Ortúzar) of the Servicio Meteorológico Nacional (SMN) in Argentina, from 4–22 March 2019.

In this IC/BUA-19, the experts used the Dobson spectrophotometer D065 which is the World Secondary Standard to compare measured ozone column values and to calibrate individual instruments against it. The Dobson spectrophotometer D065 is maintained at the World Dobson Ozone Calibration Center operated by the Earth System Research Laboratory, Global Monitoring Division of the National Oceanic and Atmospheric Administration in Boulder, Colorado, United States of America (USA). The Regional Standard (R-III) also participated in the event and was calibrated.

Through this activity, the data obtained by individual Dobson spectrophotometers at different measurement sites will be standardized, and will be comparable locally, and globally.

Eleven Dobson spectrophotometers from different monitoring and research institutions in Latin America were calibrated at V International Comparison of Dobson Spectrophotometers of Region III.

The associated relative uncertainty of each Dobson was also estimated.

1 INTRODUCTION

The oldest and one of the most reliable instruments for measuring the Total Ozone Column (TOC) in the atmosphere is the Dobson spectrophotometer. The observations gathered by this instrument constitute the longest geophysical time-series (TOC over Arosa, Switzerland, since 1926) providing very useful information for ozone dynamics and its closely connected atmospheric variables. The data collected by the Dobson spectrophotometers are very useful for calibrating and validating satellite measurements of TOC, and other surface measurement techniques, such as the Brewer Spectrophotometer, and the PANDORA System.

The principle of operation of the Dobson instrument is based on comparison of the intensity of solar light at certain wavelength pairs. At one wavelength of each pair there is absorption by atmospheric ozone, and at the other wavelength there is no absorption. These pairs are selected in such a manner that the difference in the ozone absorption coefficient for each pair is as large as possible, while the difference between the corresponding wavelengths remains small.

This measured difference combined with the extra-terrestrial constant and the ozone absorption spectrum allows to derive the TOC. By using two pairs of wavelengths, the scattering effects can essentially be filtered out. For the selection of the particular wavelengths from the whole solar spectrum, the instrument uses two monochromators. The first one eliminates all of the radiation except for the selected pair and the second one rejects interfering scattered radiation.

The Dobson spectrophotometer can use five wavelength pairs. These pairs are coded as A, B, C, D and C´ (A: 305.5 and 325.4 nm; B: 308.8 and 329.1 nm; C: 311.4 and 332.4 nm; D: 317.6 and 339.8 nm; C´: 332.4 and 453.6 nm). The most frequently used are the pairs A and D, designated as AD, because they produce the most precise measurements. The accuracy of this mode of measurement also depends on the secant of the zenith angle, designated as μ. If μ is less than three, then the mode of measurement is called Direct Sun and produces the most accurate results.

The World Meteorological Organization (WMO), the Argentine SMN, the USA National Oceanic and Atmospheric Administration Earth System Research Laboratories Global Monitoring Division (NOAA/ESRL/GMD), and the University of Colorado's Cooperative Institute for Environmental Research (CIRES) organized the intercomparison of Dobson spectrophotometers (IC/BUA-19) from 4–22 March 2019.

While the primary purpose of the Intercomparison was to check the calibrations and perform maintenance on participating Dobson spectrophotometers operated within Region III of the WMO, the inclusion of two instruments from Region IV, transformed the IC/BUA-19 into a Latin-American event. Such intercomparison events are fulfilment of the Global Atmospheric Watch Programme of the World Meteorological Organization (WMO/GAW) Data Quality Objectives and traceability requirements set up by the GAW Scientific Advisory Group on Ozone and UV and, in turn, assures the good quality and intercompatibility of the total ozone data sets for global monitoring. Such observations are fundamental for the periodic Scientific Assessment of the state of the ozone layer in support of the Montreal Protocol and its Vienna Convention.

The Main Buenos Aires Observatory (OCBA) (34.052'24.09''S, 58.029'00''W, and 25 m a.s.l) is located in Villa Ortúzar town, Buenos Aires City. The OCBA belonging to SMN in Argentina has been recognized as the Regional Dobson Calibration Center (RDCC-BsAs) for Region III by WMO since 1999 and the technical and scientific staff of OCBA had regularly participated in previously organized intercomparisons.

2 INFORMATION ON REGION III REFERENCE STANDARD AND PAST INTERCOMPARISON ACTIVITIES

Detailed calibration history of the Regional Dobson reference standard and activities organized by the Region III Dobson Calibration Center are presented in chronological order below:

Dobson spectrophotometer D097 was acquired by SMN in 1964.

Dobson spectrophotometer D097 was installed and calibrated in Boulder, Colorado, USA, in 1977.

Dobson spectrophotometer D099 (initially installed in Marambio station) participated in an intercomparison campaign and was calibrated in Boulder, Colorado, USA, in 1992.

Dobson spectrophotometer D097 was calibrated in Izaña, Spain, in 1994.

Dobson spectrophotometer D097 was calibrated in Boulder, Colorado, USA, in 1998.

The following Dobson Intercomparison campaigns were previously held in WMO/GAW Region III:

I. Intercomparison of Dobson spectrophotometers was carried out in Buenos Aires, Argentina in 1999;
II. Intercomparison of Dobson spectrophotometers was carried out in Buenos Aires, Argentina in 2003;
III. Intercomparison of Dobson spectrophotometers was carried out in Buenos Aires, Argentina in 2006;
IV. Intercomparison of Dobson spectrophotometers was carried out in Buenos Aires, Argentina in 2010;
V. Intercomparison of Dobson spectrophotometers was carried out in Buenos Aires, Argentina in 2019.

All calibration intercomparison campaigns were jointly organized by the Regional Calibration Center (RDCC-BsAs) OCBA/SMN, the World Dobson Calibration Center, NOAA Climate Monitoring, and Diagnostics Laboratory (CMDL) in Boulder, Colorado, Colorado University, and WMO. The CMDL/NOAA maintains the world Primary (D083) and the Secondary Dobson (D065) Standard which is used to transfer ozone calibrations from the Primary Dobson Standard to Regional Dobson Standards and to Dobson instruments at GAW ozone observing stations. OCBA/SMN maintains the Regional Dobson Standard, which was initially D097, and is now D070. Dobson spectrophotometer D070 was automated and donated to the Region III GAW/WMO Dobson Calibration Center by Dr Koji Miyawaga from Japan.

3 PARTICIPATING DOBSON SPECTROPHOTOMETERS

The intercomparison was held at the SMN's Villa Ortúzar Observatory, site of the Regional Dobson Calibration Center, in Buenos Aires. Details on all participating instruments, the stations and countries where those instruments are making observations are presented in the table below.

Dobson Number	Country	Station
D065	USA	Boulder – World Secondary Standard
D067	Cuba	La Habana
D070	Argentina	Region III Standard
D087	Peru	Marcapomacocha
D093	Brazil	Sao Paulo
D097	Argentina	La Quiaca
D098	Mexico	Cd. De Mexico
D099	Argentina	Estación Antártica Marambio
D114	Brazil	Cachoeira Paulista
D131	Argentina	Ushuaia
D133	Argentina	Comodoro Rivadavia
D134	Uruguay	El Salto

Instrument D070 is fully automated with WinDobson system interface and software.

Instruments D093 and D114 read the position of the R-dial record using an encoder, but all other operations are performed manually.

4 TASK

4.1 Main Task

The intercomparison, instrument maintenance and lamp tests were carried out on daily schedules according to the weather conditions and with respect to the technical state of the individual instruments.

Technical support from SMN and NOAA/ESRL/GMD were essential in achieving the goals.

The activities which were part of this campaign are listed in chronological order:

- Perform any repairs necessary for instruments to operate during an initial intercomparison;
- Perform an intercomparison to determine the initial calibrations of all instruments and assess whether previous data should be reprocessed;
- Perform an internal inspection of all instruments and make repairs and adjustments;
- Determine new calibrations as needed;
- Provide instruction on the operation and routine calibration of Instruments;
- Perform a final intercomparison to ensure calibrations and repairs are correct and sufficient to bring instruments within 1% error.

Some instruments arrived late, which necessitated special treatment, but the overall agenda was as follows:

- Instrument unpacking, assembly, and visual inspection directly after arrival;
- Daily Standard Lamp (SL) and mercury (HG) lamp tests were performed to determine the operational condition of the instruments;
- An initial intercomparison against the secondary Standard instrument (D065) was performed to determine the existing calibration level;
- Determination of required adjustments and special tests needed for each instrument: wedge calibrations, replacement of mirrors, cleaning, and adjustment of the optics etc.;
- A final comparison against the secondary Standard (D065);
- New tables were provided to operators of instruments that required calibration adjustments;
- Instruments and other technical equipment were packed and prepared for shipment to home stations.

4.2 Detailed Task

Details of the service, maintenance, repair and calibration work performed on individual instruments is documented and saved by the scientific and technical experts, but a brief overview is provided below:

D065 World Secondary Standard. This instrument has been calibrated prior to the start of the campaign and was used to compare the measurements and performance of all other participating Dobson spectrophotometers. D065 was the reference standard for calibrating instruments that required maintenance, repair or had measured values with large differences compared to the Standard.

D067 Cleaned optics, replaced 67Q2 lamp with 67Q4, adjusted mirror M2. New calibration.

D070 Cleaned optics. Adjusted the holding current to Q2 stepper motor.

D087 Cleaned optics, Q2 stop repaired, sanded wedge slides.

D093 Cleaned optics, wedge calibration, power supply to R-dial encoder repaired. New calibration.

D097 Cleaned optics, repaired shutter motor roller, reinstalled cobalt filter, AC motor capacitor added.

D098 Cleaned optics, partial wedge calibration, replaced microammeter. New calibration.

D099 Cleaned optics, adjusted mirror M2. New calibration.

D114 Cleaned optics, replaced mirror M1, wedge calibration. New calibration.

D131 Cleaned optics, straightened S2/S3 shutter rod. New calibration.

D133 Cleaned optics, tightened R-dial axis screw, calibrated wedge. New calibration.

D134 Cleaned optics, replaced mirrors M1 and M2, repaired S2/S3 shutter rod. New calibration.

4.3 Other Activities in Villa Ortúzar during the IC/BUA-19

In addition to the Dobson intercomparison, the regional Brewer Ozone Spectrophotometer, and PANDORA spectrometer instruments by NASA were compared to Dobson World Secondary Standard as part of the intercomparison activities at Villa Ortúzar during this period. Special Umkehr observations on the zenith sky were made by all participating instruments on the morning of 21 March 2019 to create a reliable data set for the verification of different technologies used for the processing of these observations (see Chapter 5).

WinDobson Software was provided for the ozone data processing in all stations.

5 RESULTS

5.1 Reports of Individual Instruments

5.1.1 Instrument: D067

Havana, Cuba

Original calibration data:
N-tables and reference standard lamp values from the 2010 intercomparison with D070 in Buenos Aires. WinDobson information: PARA1011.067 and RtoN1011.067.

Initial condition:
The reference N values used differ slightly from those calculated in 2010 and can only conclude that we used slightly different RtoN tables. The reference values used here were calculated using RtoN1011.067.

The instrument arrived late due to a customs issue. The instrument operator was not able to attend and a staff member of SMN helped with the operation of this instrument.

A symmetry test was performed on 14 March. It showed a difference of about 1.5 degrees of Q values between the left and right side of the instrument.

The sky conditions during the initial intercomparison were cloudy and the instrument could only be evaluated between μ = 1.2 – 2.0. (Figure 1)

Initial calibration results: 14 March 2019
(Adjustments based on the results of Standard Lamp tests included.)

d_Na:+1.0 d_Nc:+1.2 d_Nd:-0.8 d_Nad:+1.8

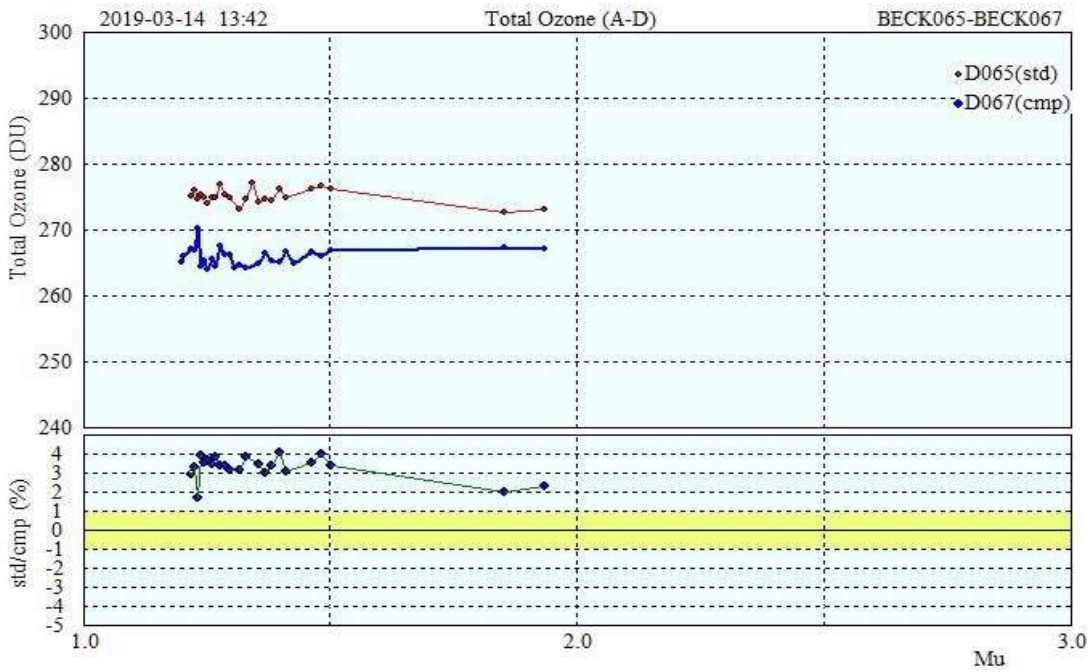


Figure 1: Initial comparison of std (D065) vs cmp (D067). Top plot represents direct comparison, with red line corresponding to std, and blue line to cmp. Bottom plot represents the relationship in percentage.

The d_Nad value implies an average **-2.5% error** in calculated ozone value, μ = 1 to 2, Total Ozone = 300 Dobson Units.

Work performed:

- Optics cleaned;
- 067Q2 lamp is damaged and 067Q4 lamp is provided;
- M2 was adjusted and marginally improved the Q1 Q2 symmetry, but some difference remains.

Final intercomparison: 18 March 2019
Using RtoN1903.067 showed very good results. The average difference was 0.1% at 300DU. New N-tables and reference SL values were defined from this intercomparison. (Figure 2)

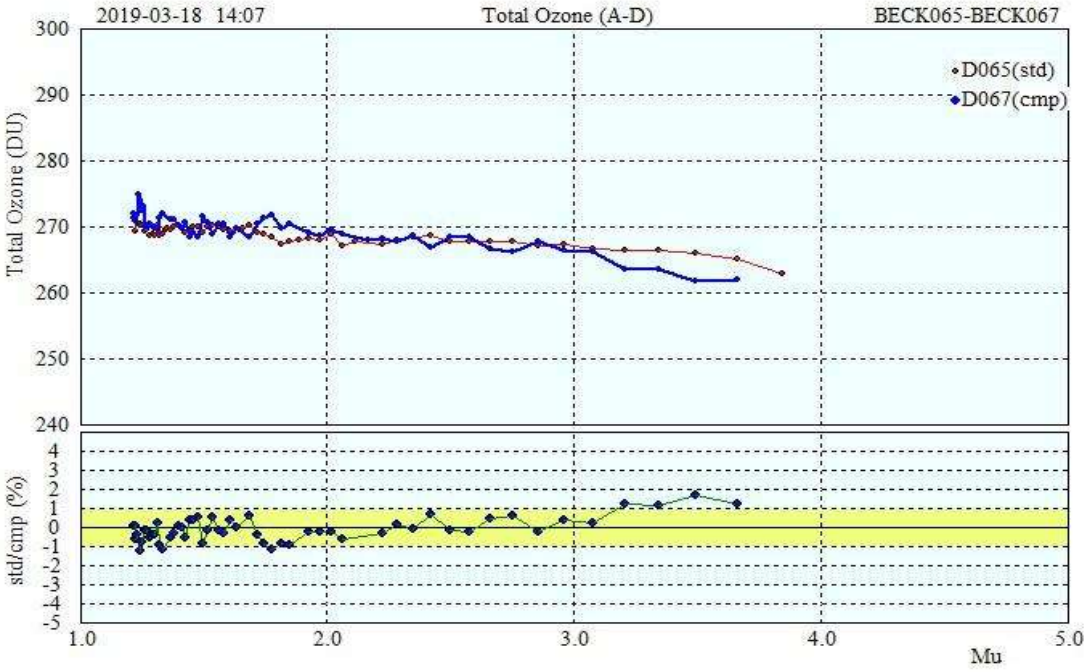


Figure 2: Final comparison of std (D065) vs cmp (D067) after adjusting. Top plot represents direct comparison with red line corresponding to std, and blue line to cmp. Bottom plot represents the relationship in percentage.

Recommendations and comments:

- Existing data set does require re-evaluation;
- Para1903.067 and RtoN1903.067 should be used for processing all future data;
- SL Reference values (067Q1, 067Q2, 067Q3 and 067Q4) were defined;
- There were slight changes to the SLs immediately following the final calibration. Those results are shown in the following table.

Special observations:
An intercomparison of the measurement of the Umkehr effect was made on the evening of the 21 March 2019. These measurements were made as part of an effort to further understand the characteristics of this instrument.

The result is an ozone profile. Figure 3 shows the profile calculated from the measurements made with D065 and D067.

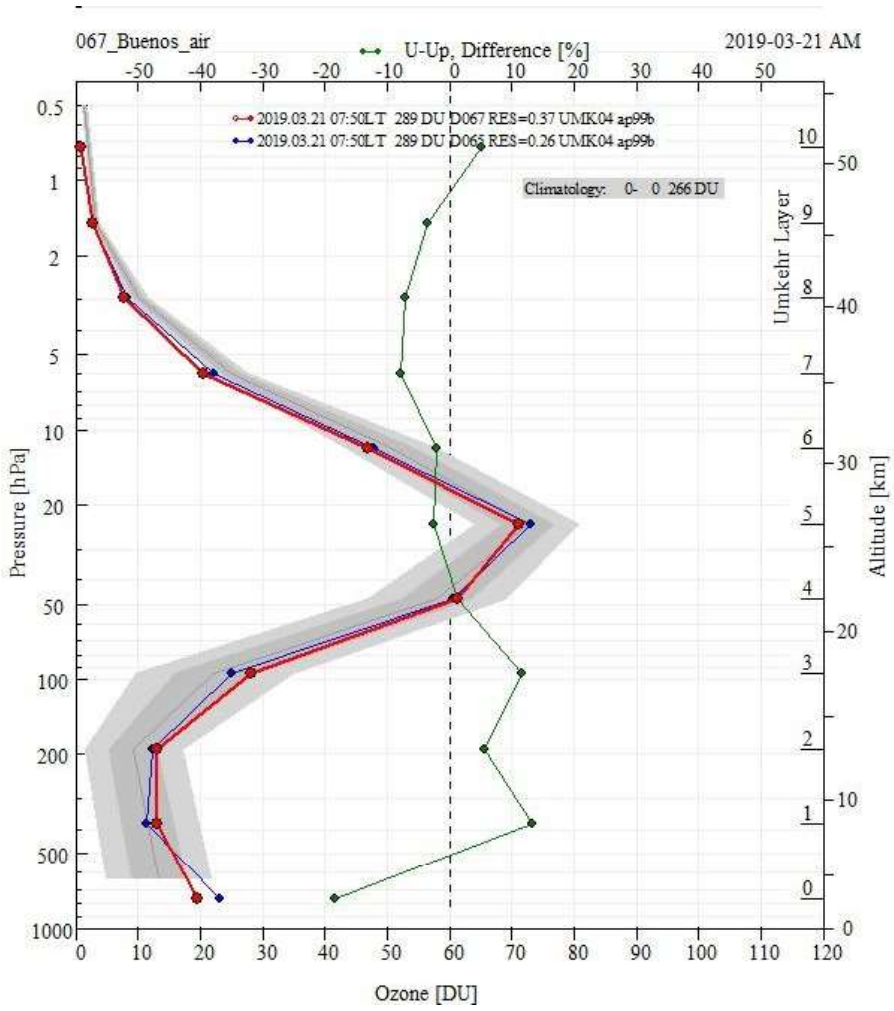


Figure 3: Comparison of Umkehr measurements of std D065 (blue line) vs cmp D067 (red line). The green line corresponds to the differences in percent, the light grey shadow represents the climatology in Buenos Aires.

5.1.2 Instrument: D070

Region III Standard Instrument Report on re-calibration March 2019 at Buenos Aires, Argentina

Original calibration data:
N-tables and reference SLs values from September–November 2013 intercomparison with D083 in Boulder, Colorado USA. WinDobson information: PARA1310.070 and RtoN1310.070

History:
This instrument was automated with the WinDobson system. It was donated to Region III in 2010 and began its operation in Buenos Aires as the Regional Reference Instrument.

Initial condition:
A symmetry test performed on 10 March gave satisfactory results. (Figure 4)

Initial Intercomparison: 10 March 2019
Adjustments based on the results of SL tests were included.

d_Na:-0.9 d_Nc:-0.3 d_Nd:-0.2 d_Nad:-0.7

The d_Nad value implies an average **+1.0% error** in calculated ozone value, μ = 1 to 3, Total Ozone = 300 Dobson Units.

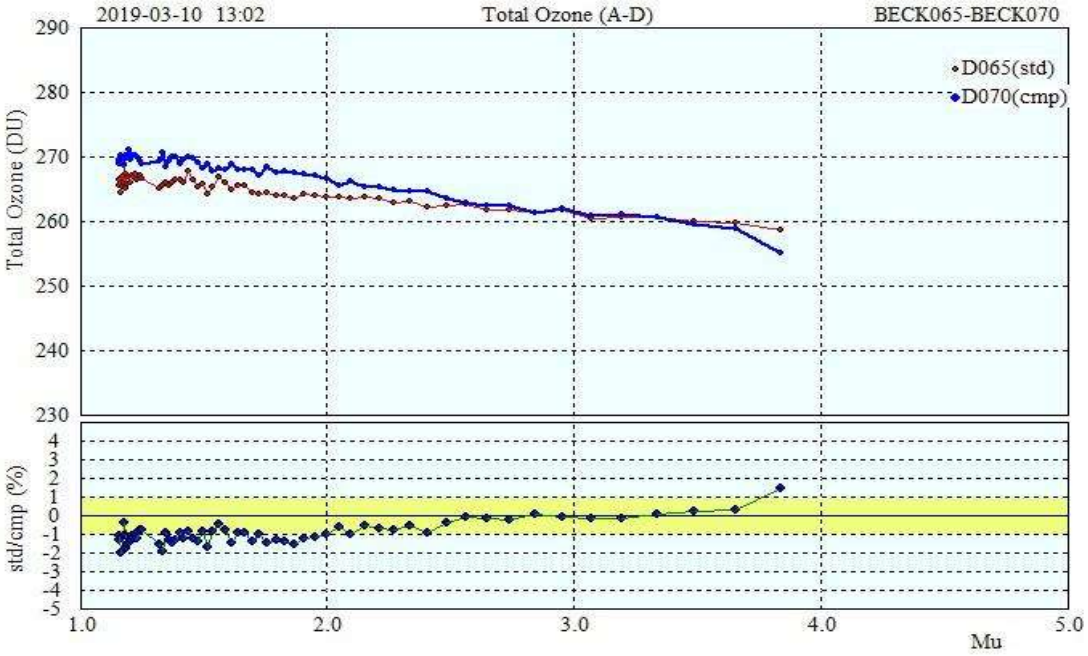


Figure 4: Initial comparison of std (D065) vs cmp (D070). Top plot represents direct comparison with red line corresponding to std, and blue line to cmp. Bottom plot represents the relationship in percentage.

Work performed:

- Optics cleaned;
- Operation of the Q2 lever was initially unstable. This was corrected by adjusting the holding current of the Q2 stepper motor.

Final intercomparison: 18 March 2019
There was zero percent error following the second intercomparison. New N-tables and reference SL values were defined from this intercomparison. (Figure 5)

Recommendations and comments:

- Existing data set does not require re-evaluation;
- New SL reference values (070Q3, 070J1, 070J3 and UQ09A) were defined.

Special observations:
An intercomparison of the measurement of the Umkehr effect was made on the evening of the 21 March 2019. These measurements were made as part of an effort to further understand this process. The result is an ozone profile. Figure 6 shows the profile calculated from the measurements made with D065 and D070.

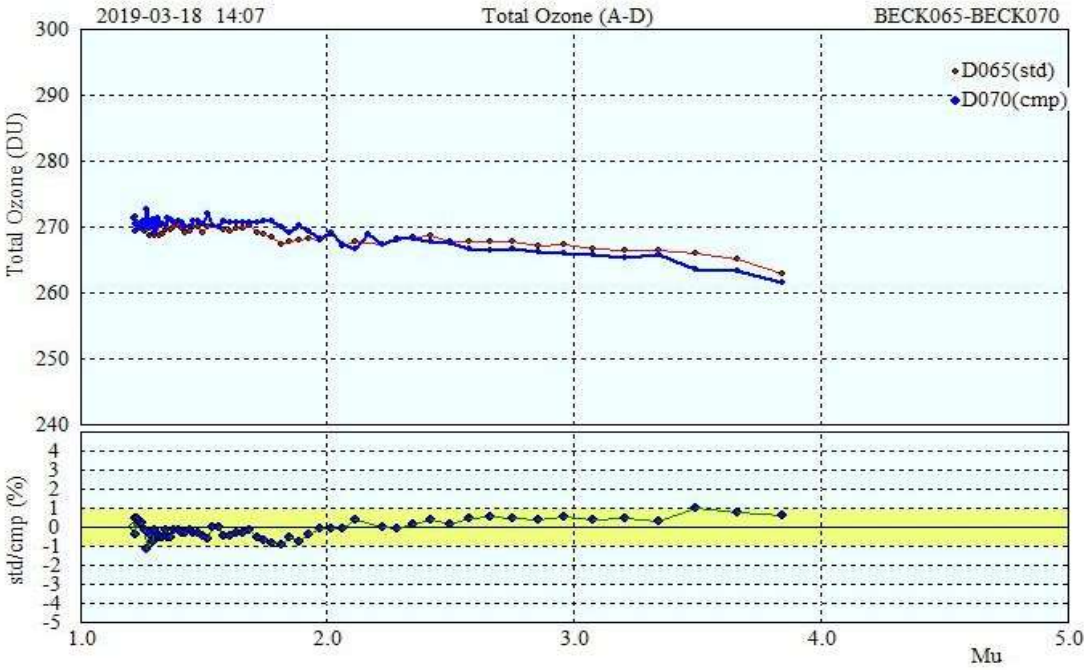


Figure 5: Final comparison after adjusting D070, std (D065) vs cmp (D070). Top plot represents direct comparison with red line corresponding to std, and blue line to cmp. Bottom plot represents the relationship in percentage.

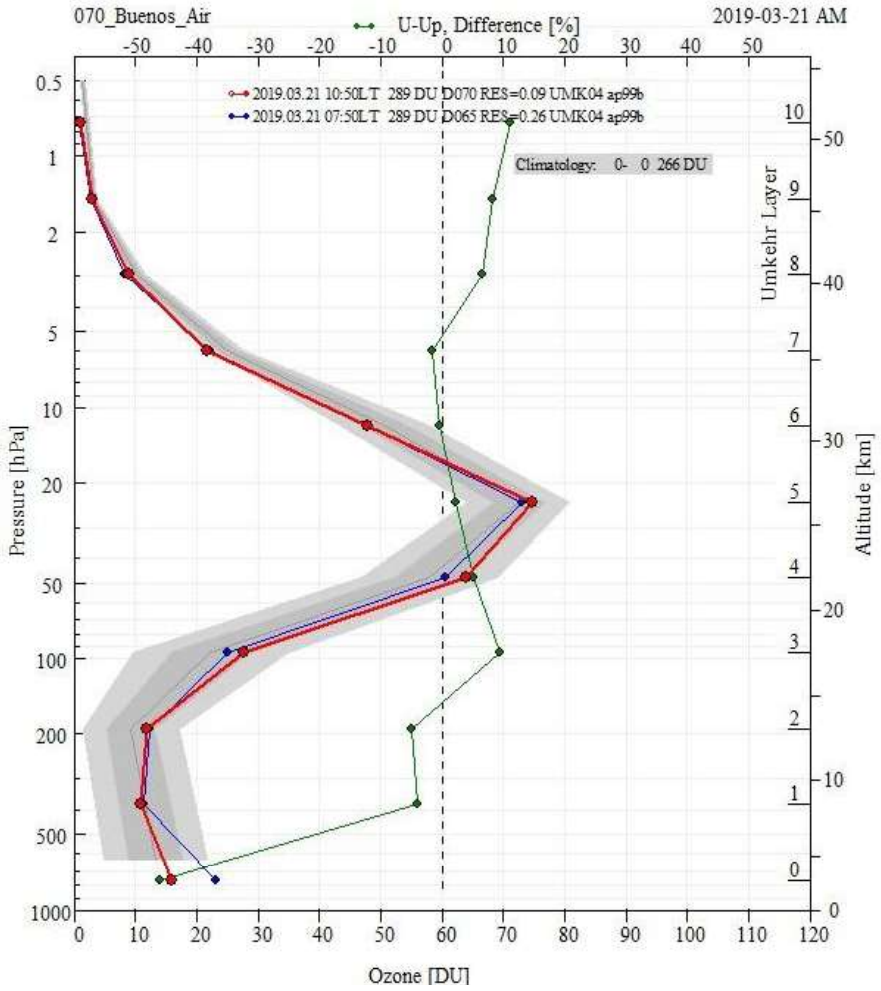


Figure 6: Comparison of Umkehr measurements of std D065 (blue line) vs cmp D070 (red line). The green line corresponds to the differences in percent, the light grey shadow represents the climatology in Buenos Aires.

5.1.3 Instrument: D087

Marcapomacocha, Peru

Original calibration data:
N-tables and reference SLs values from 28 November 2010 intercomparison with D070 in Buenos Aires, Argentina. WinDobson information: PARA1011.087 and RtoN1011.087

Initial condition:
The N differences for 87R63 are large and should be ignored initial intercomparison:
10 March 2019 (Figure 7).

Adjustments based on the results of SL tests were included.

d_Na:-0.2 d_Nc:+0.6 d_Nd:-0.8 d_Nad:+0.6

The d_Nad value implies an average **-0.8% error** in calculated ozone value, μ = 1 to 3, Total Ozone = 300 Dobson Units.

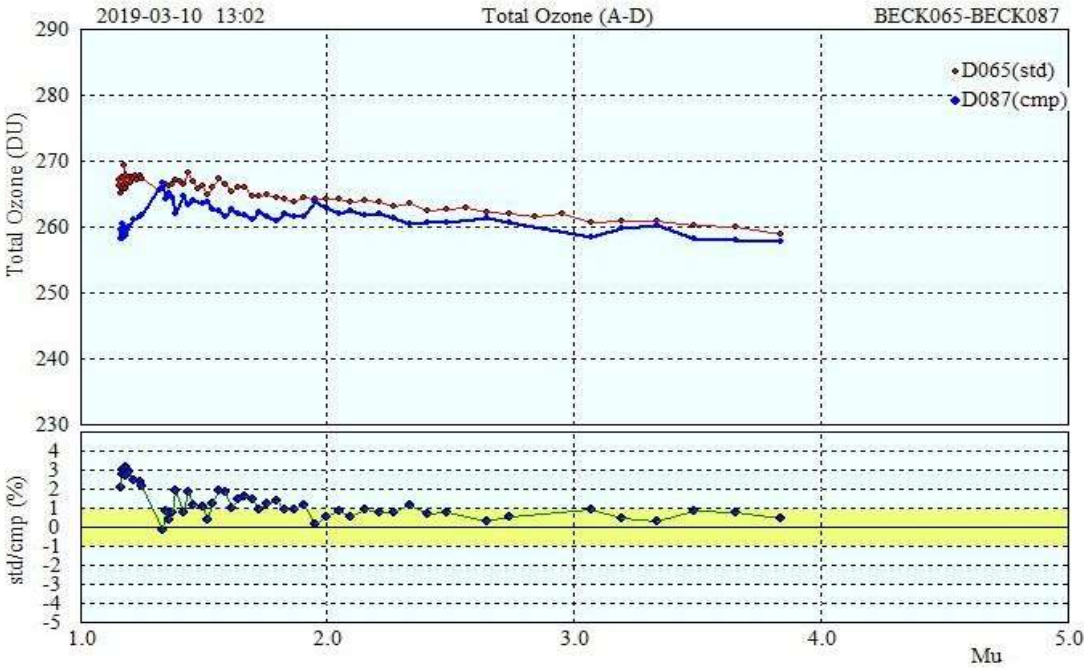


Figure 7: Initial comparison of std (D065) vs cmp (D087). Top plot represents direct comparison with red line corresponding to std, and blue line to cmp. Bottom plot represents the relationship in percent.

Work performed:

- Optics cleaned;
- Q2 lever stop repaired;
- Wedge slides were lightly scraped to make the operation of the R-dial smoother at high readings.

Final intercomparison: 18 March 2019

New N-tables and reference SL values were defined from this intercomparison. (Figure 8)

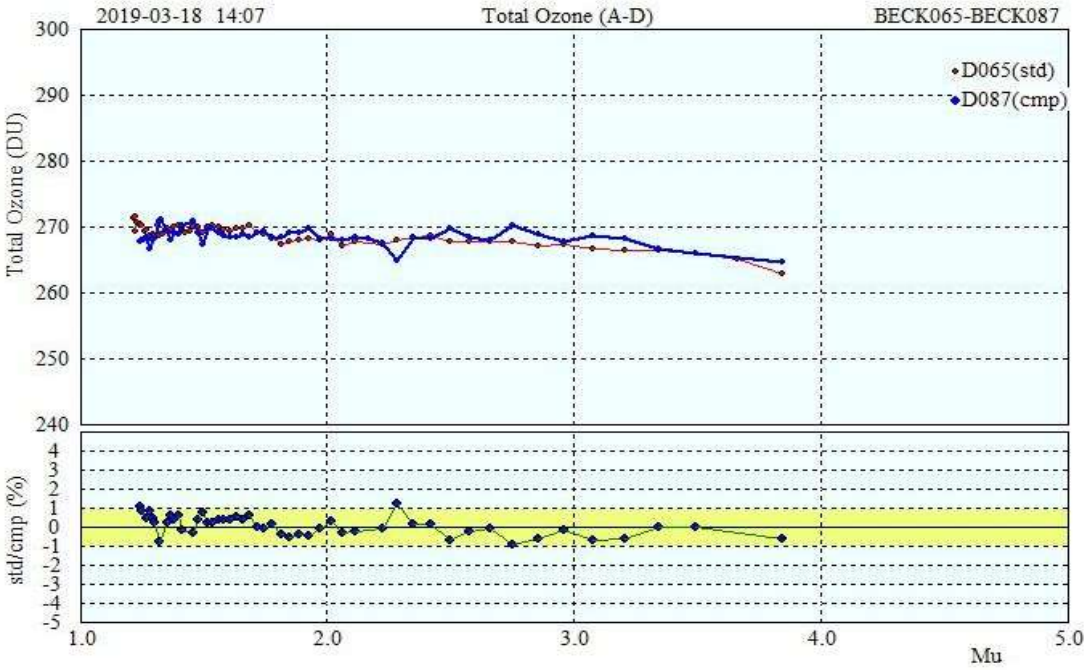


Figure 8: Final comparison of std (D065) vs cmp (D087) after adjusting D087. Top plot represents the direct comparison with red line corresponding to std, and blue line to cmp. Bottom plot represents the relationship in percent.

Recommendations and comments:

- Para1903.087 and RtoN1903.087 should be used to process all data after 1 April 2019;
- Existing data from this station requires no reprocessing. But it is better to re-calculate;
- This instrument is operated at one of the few near equatorial stations, and the data from this station is especially important;
- Only 087Q5 lamp should be used for reprocessing existing data;
- New SL reference values (087Q3, 087Q5, 087Q7 and 087R63) were defined.

Special observations:

An intercomparison of the measurement of the Umkehr effect was made on the evening of the 21 March 2019. These measurements were made as part of an effort to help characterize the instrument. The result is an ozone profile. Figure 9 shows the profile calculated from the measurements made with D065 and D087.

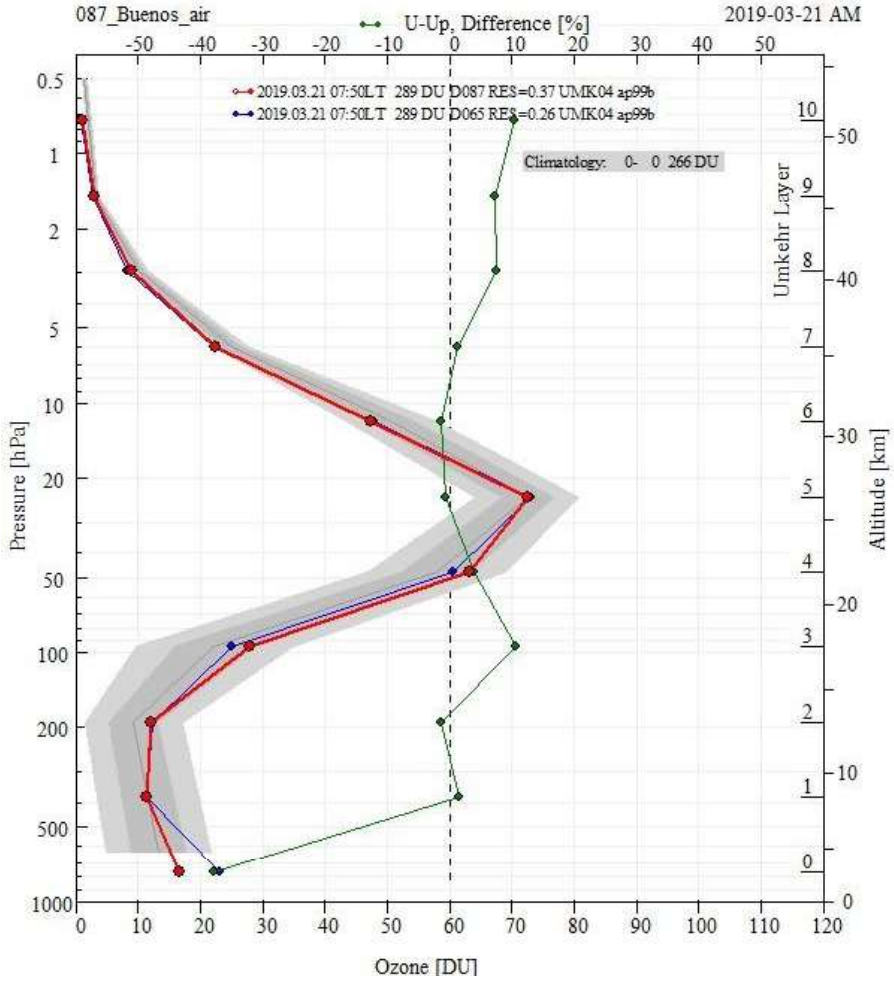


Figure 9: Comparison of Umkehr measurements of std D065 (blue line) vs cmp D087 (red line). The green line corresponds to the differences in percent, the light grey shadow represents the climatology in Buenos Aires.

5.1.4 Instrument: D093

Natal, Brazil

Original calibration data:
N-tables and reference SLs values from 23 November 2010 intercomparison with D070 in Buenos Aires, Argentina. WinDobson information: PARA1011.093 and RtoN1011.093

Initial calibration results: 10 March 2019
Adjustments based on the results of SL tests were included and are shown on figure 10.

d_Na:+0.8 d_Nc:-0.8 d_Nd:-1.5 d_Nad:+2.3

The d_Nad value implies an average **-3.2% error** in calculated ozone value, μ = 1 to 3, Total Ozone = 300 Dobson Units.

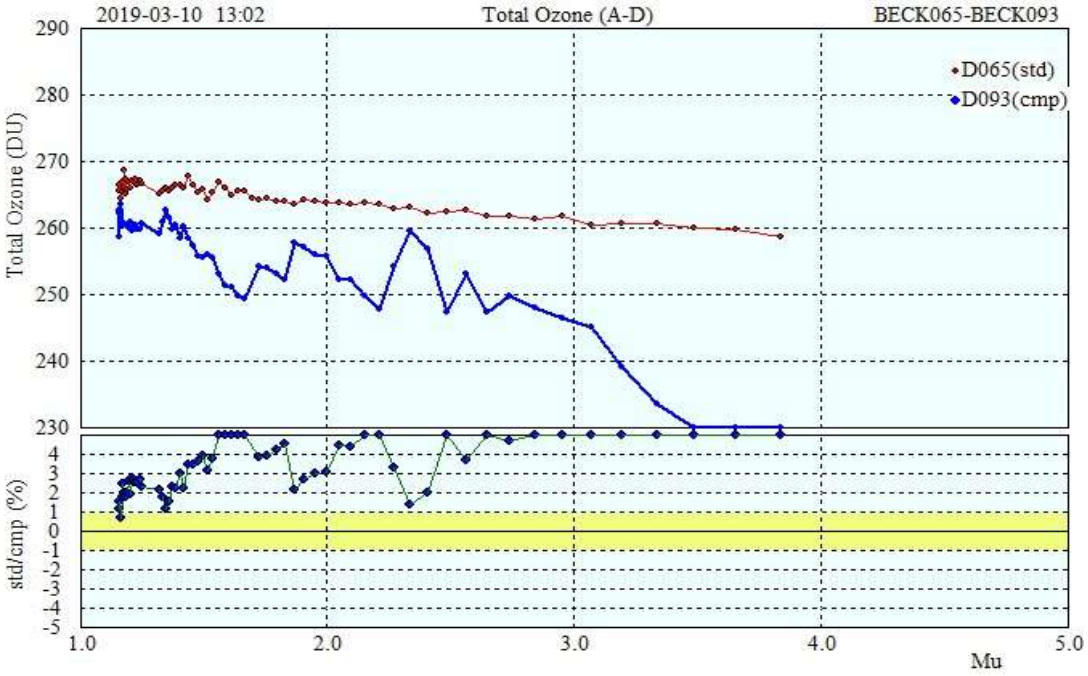


Figure 10: Initial comparison of std (D065) vs cmp (D093). Top plot represents direct comparison with red line corresponding to std, and blue line to cmp. Bottom plot represents the relationship in percent.

Work performed:

- Optics cleaned;
- The power supply for R-dial encoder had a noise;
- Performed wedge calibration.

Final intercomparison: 18 March 2019
New N-tables and reference SL values were defined from this intercomparison. (Figure 11)

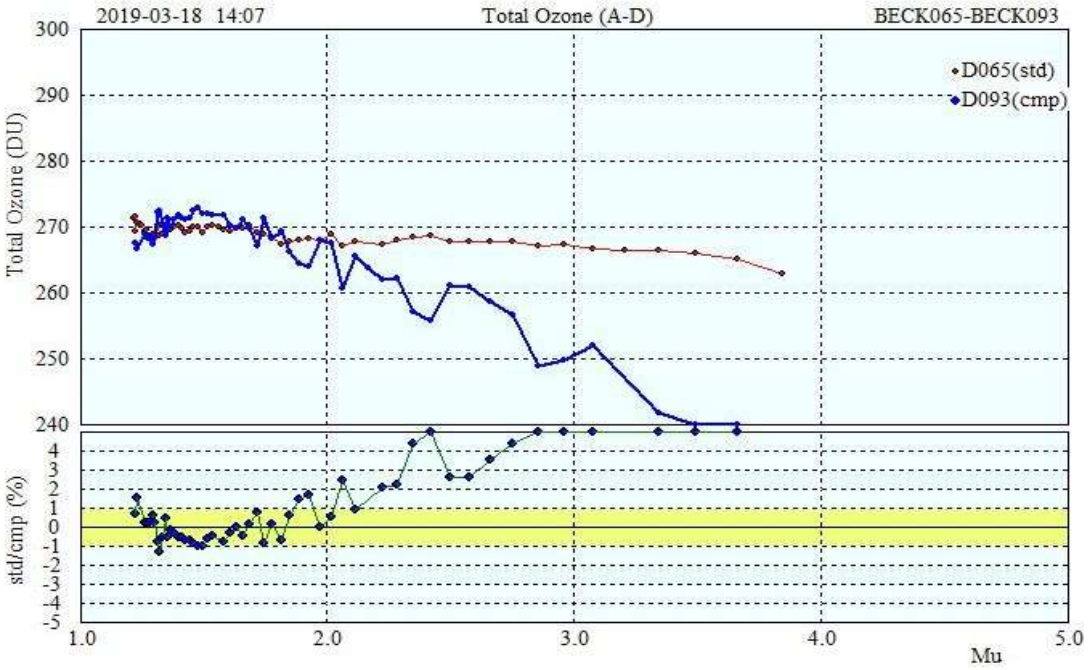


Figure 11: Final comparison of std (D065) vs cmp (D093) after adjusting D093. Top plot represents direct comparison with red line corresponding to std, and blue line to cmp. Bottom plot represents the relationship in percent.

Recommendations and comments:

- A new calibration (N-tables and reference SL values) was defined, based on the intercomparison of 18 March 2019. This new calibration should be used to process all data after 1 April 2019;
- The existing data set from this instrument should be reprocessed and republished;
- This instrument shouldn't be used for measurements greater than $\mu = 2.0$;
- There was considerable noise on this instrument and a sharp jump between positions of the selector switches. It was suggested to replace the selector switches to see if performance improves and to consider the upgrade of the electronics in general;
- New SL reference values (093Q2, 093Q6 and 093Q7) were defined.

Special observations:
An intercomparison of the measurement of the Umkehr effect was made on the evening of the 21 March 2019. These measurements were made as part of an effort to further understand this process. Instrument D093 sensitivity has a noise too much to accurately measure the curve correctly. A profile is not available. (Figure 12)

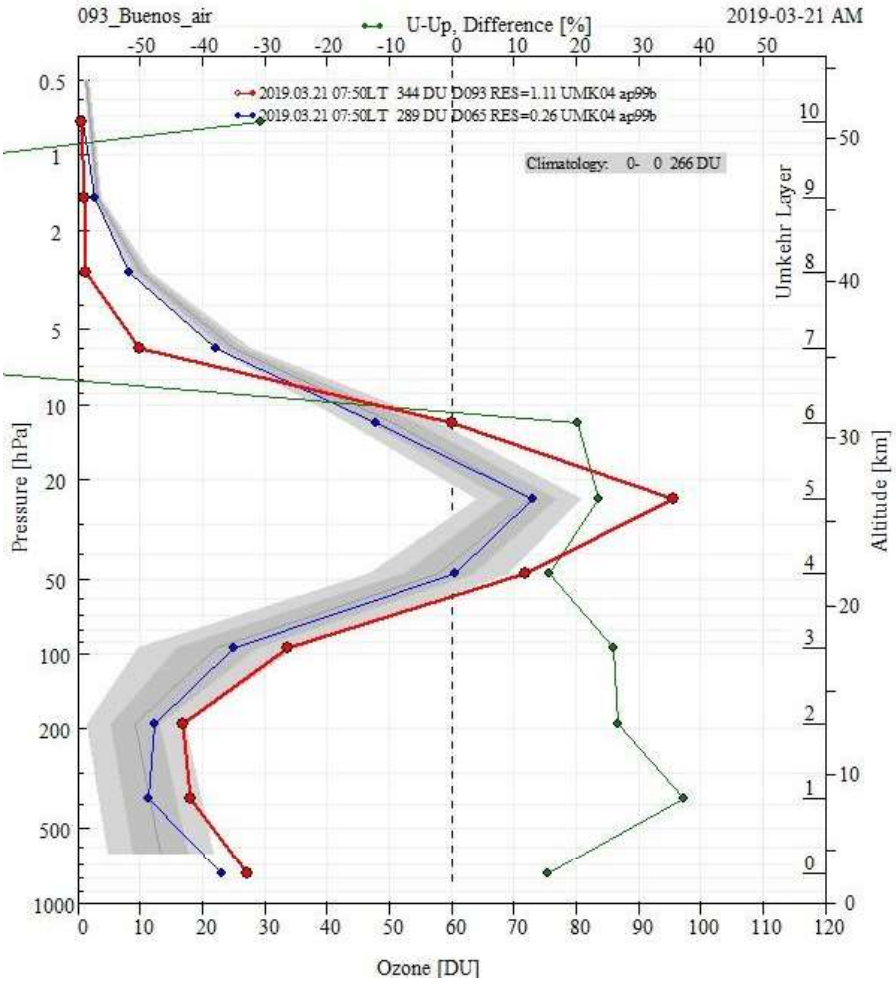


Figure 12: Comparison of Umkehr measurements of std D065 (blue line) vs cmp D093 (red line). The green line corresponds to the differences in percent, the light grey shadow represents the climatology in Buenos Aires.

5.1.5 Instrument: D097

La Quiaca, Argentina

Original calibration data:
N-tables and reference SLs values from 23 November 2010 intercomparison with D070 in Buenos Aires, Argentina. WinDobson information: PARA0612.097 and RtoN0612.097.

Initial condition:
The reference values differ from those in WinDobson PARA0612.097. (Figure 13)

Initial calibration results: 10 March 2019
Adjustments based on the results of SL tests were included.

Lamp correction values used were d_Na:-8.9 d_Nc:-4.9 d_Nd:-3.0

d_Na: -0.1 d_Nc:-1.2 d_Nd:+0.3 d_Nad:+0.2

The d_Nad value implies an average **-0.3% error** in calculated ozone value, μ = 1 to 3, Total Ozone = 300 Dobson Units.

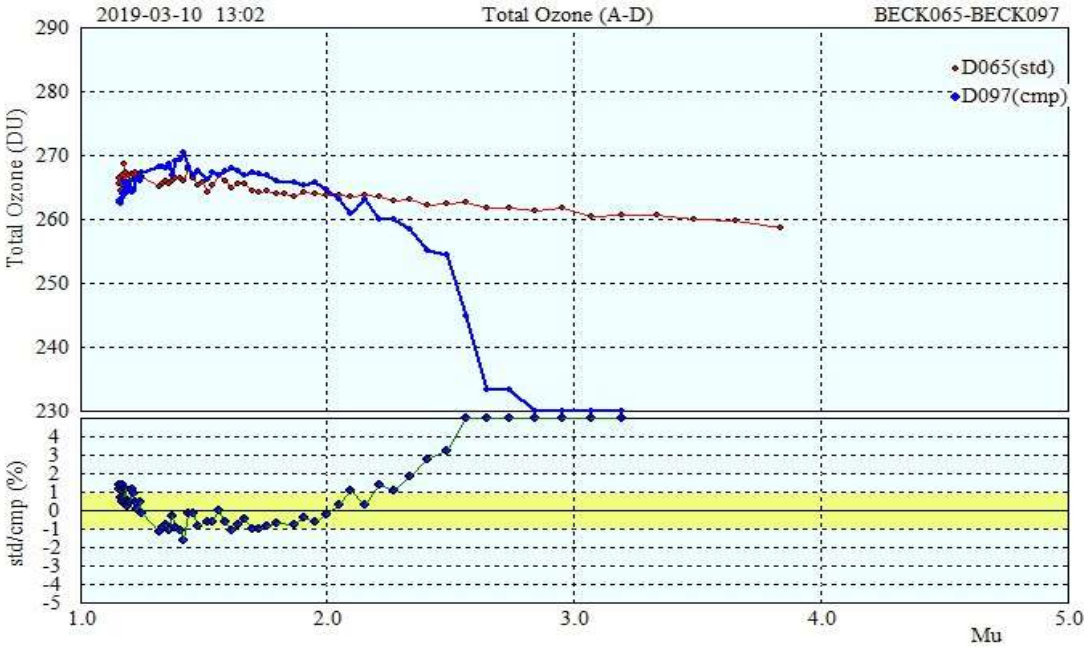


Figure 13: Initial comparison of std (D065) vs cmp (D097). Top plot represents direct comparison with red line corresponding to std, and blue line to cmp. Bottom plot represents the relationship in percent.

Work performed:

- The optics were dirty;
- The relay roller of the shutter motor was fixed;
- The cobalt filter had fallen;
- The capacitor of the noise from AC power was added.

Final intercomparison: 20 March 2019
New N-tables and reference SL values were defined from this intercomparison. (Figure 14)

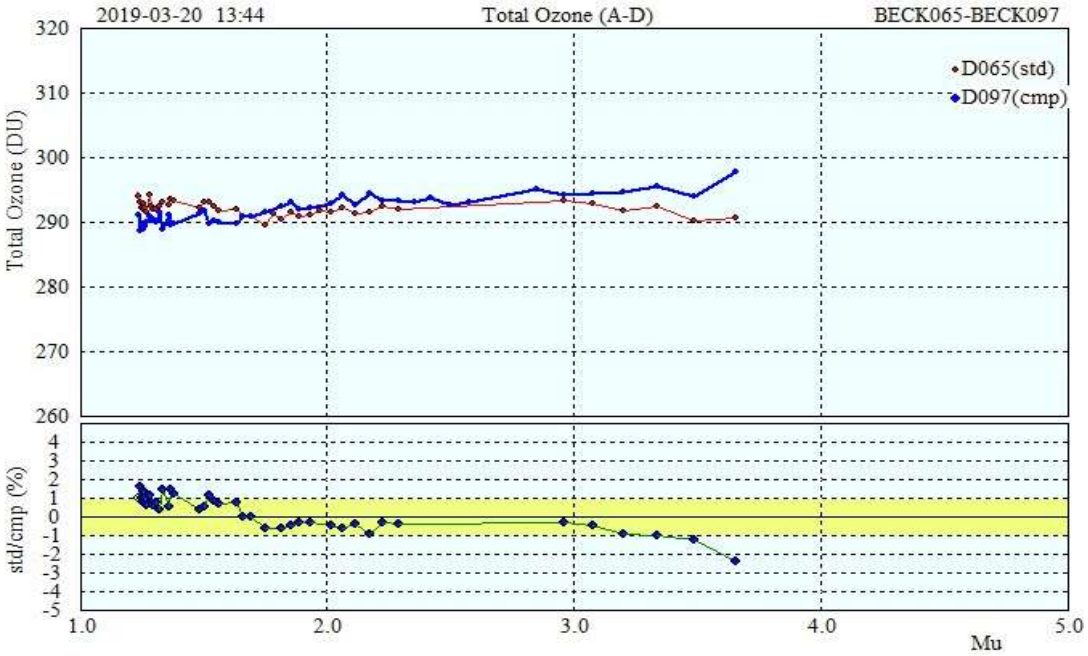


Figure 14: Final comparison of std (D065) vs cmp (D097) after adjusting D097. Top plot represents direct comparison with red line corresponding to std, and blue line to cmp. Bottom plot represents the relationship in percent.

Recommendations and comments:

- Existing data from this station requires no reprocessing;
- New SL reference values (097Q3, 097Q4, 097Q(T)6) were defined.

Special observations:

An intercomparison of the measurement of the Umkehr effect was made on the evening of the 21 March 2019. These measurements were made as part of an effort to further understand this process. The result is an ozone profile. Figure 15 shows the profile calculated from the measurements made with D065 and D097.

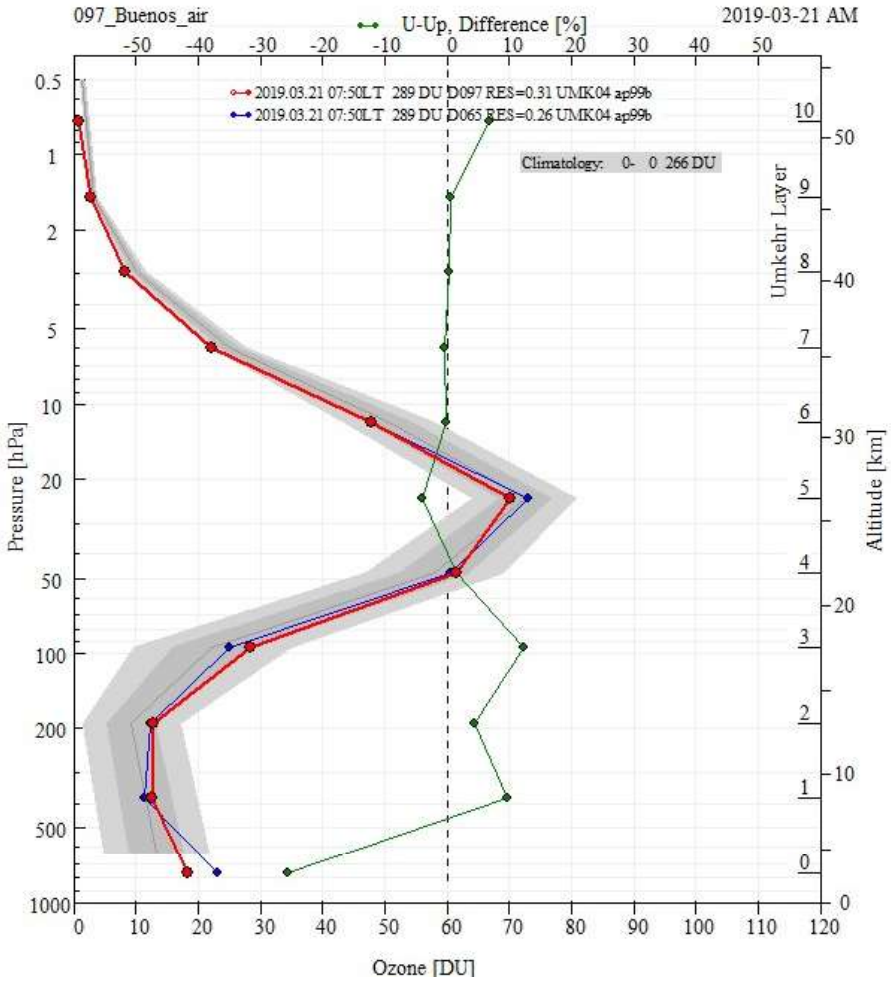


Figure 15: Comparison of Umkehr measurements of std D065 (blue line) vs cmp D097 (red line). The green line corresponds to the differences in percent, the light grey shadow represents the climatology in Buenos Aires.

5.1.6 Instrument: D098

La Universidad Nacional Autónoma de México
CD DE Mexico DF, Mexico

Original Calibration Data:
N-tables and reference SLs values from 24 November 2010 intercomparison with D070 in Buenos Aires, Argentina. WinDobson information: PARA1011.098 and RtoN1011.098. (Figure 16)

Initial calibration results: 10 March 2019
Adjustments based on the results of SL tests were included.

Lamp tests results were not included but would have small effect.

d_Na:-0.1 d_Nc:+4.1 d_Nd:-0.7 d_Nad:+0.6

The d_Nad value implies an average **-0.8% error** in calculated ozone value, μ = 1 to 3, Total Ozone = 300 Dobson Units.

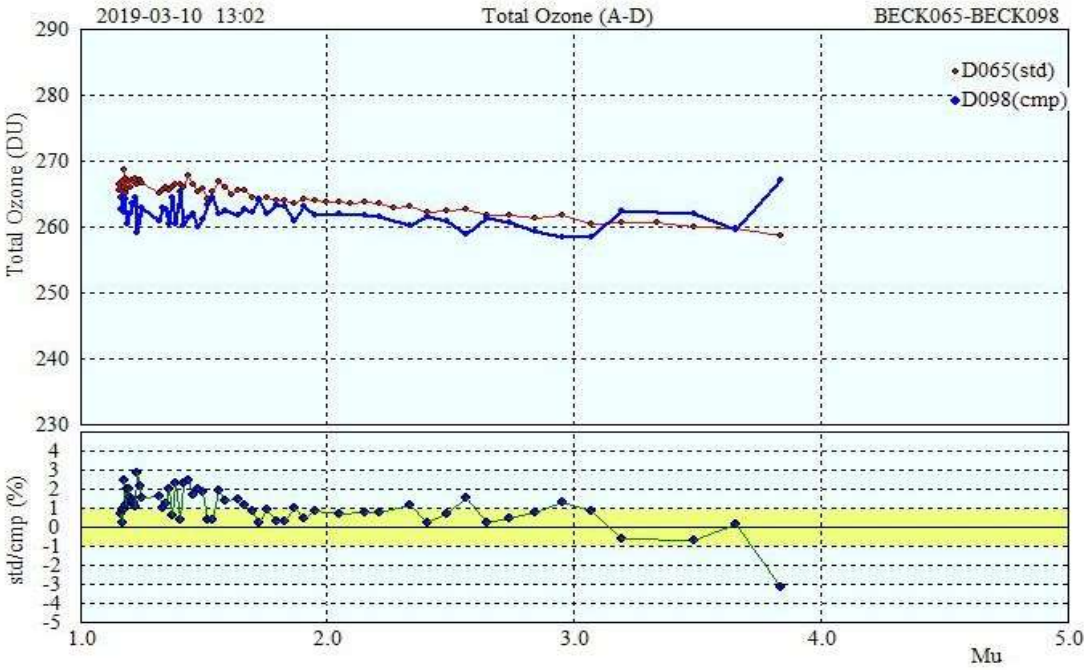


Figure 16: Initial comparison of std (D065) vs cmp (D098). Top plot represents direct comparison with red line corresponding to std, and blue line to cmp. Bottom plot represents the relationship in percent.

Work performed:

- The optics were cleaned;
- The zero of meter was biased;
- New microammeter was provided from NOAA;
- Complete Wedge Calibration.

Final intercomparison: 21 March 2019
New N-tables and reference SL values were defined from this intercomparison. (Figure 17)



Figure 17: Final comparison of std (D065) vs cmp (D098) after adjusting D098. Top plot represents direct comparison with red line corresponding to std, and blue line to cmp. Bottom plot represents the relationship in percent.

Recommendations and comments:
The new calibration – N-tables and reference SL values – dated 1 April 2019 is to be used for all data taken after that date.

There were large Standard deviations during SL tests, both in repeating measurements during a single test and day to day variation. The repeatability within a single test improved on March 20, likely because the microammeter was replaced.

New SL reference values (098Q1, 098Q2 and 098Q3) were defined.

Special observations:
An intercomparison of the measurement of the Umkehr effect was made on the evening of the 21 March 2019. These measurements were made as part of an effort to further understand this process. The result is an ozone profile. The figure 18 shows the profile calculated from the measurements made with D065 and D098.

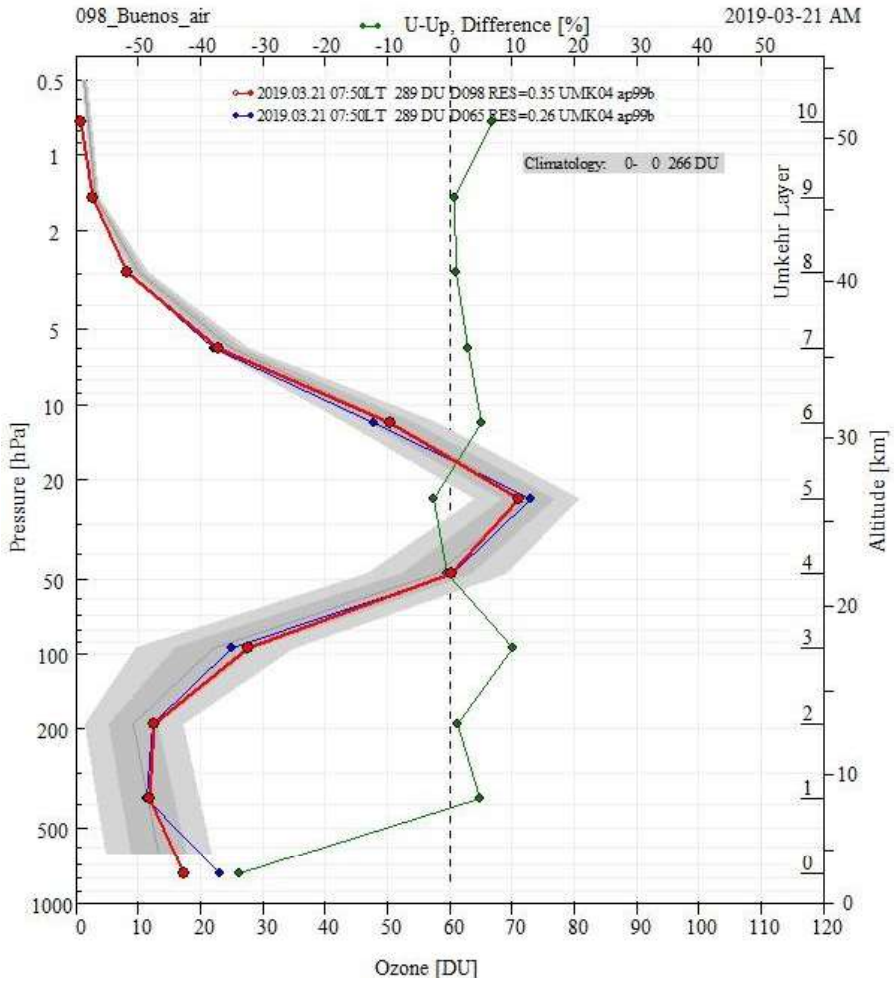


Figure 18: Comparison of Umkehr measurements of std D065 (blue line) vs cmp D098 (red line). The green line corresponds to the difference in percent, the light grey shadow is representing climatology in Buenos Aires.

5.1.7 Instrument: D099

Marambio (Antarctica), Argentina

Original calibration data:
N-tables and reference SLs values from 29 November 2010 intercomparison with D070 in Buenos Aires, Argentina. WinDobson information: PARA1011.099 and RtoN1011.099.

Initial condition:
Symmetry test showed a 15 degree difference between the left and right side. (Figure 19)

Initial calibration results: 10 March 2019
Adjustments based on the results of SL tests were included.

d_Na:-0.2 d_Nc:+0.2 d_Nd:-2.9 d_Nad: +2.6

Implies an average **-3.6% error** in calculated ozone value, μ = 1 to 3, Total Ozone = 300 Dobson Units and includes SL test corrections.

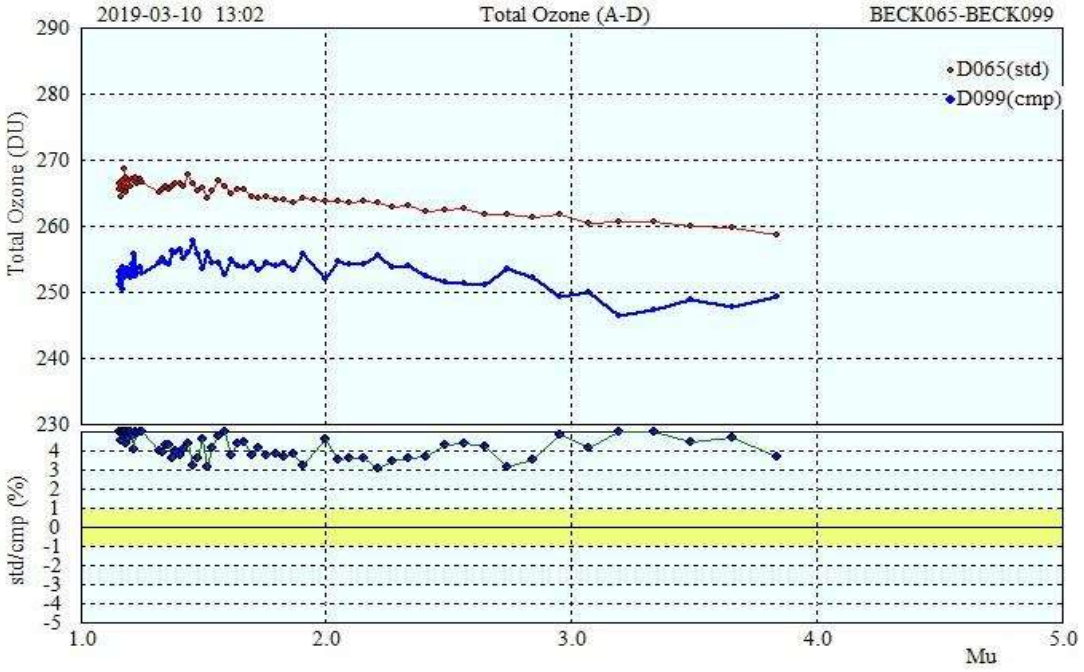


Figure 19: Initial comparison of std (D065) vs cmp (D099). Top plot represents direct comparison with red line corresponding to std, and blue line to cmp. Bottom plot represents the relationship in percent.

Work performed:

- Optics cleaned;
- Adjusted mirror M2;
- Performed wedge calibration.

Final intercomparison: 18 March 2019
New N-tables and reference SL values were defined from this intercomparison. (Figure 20)

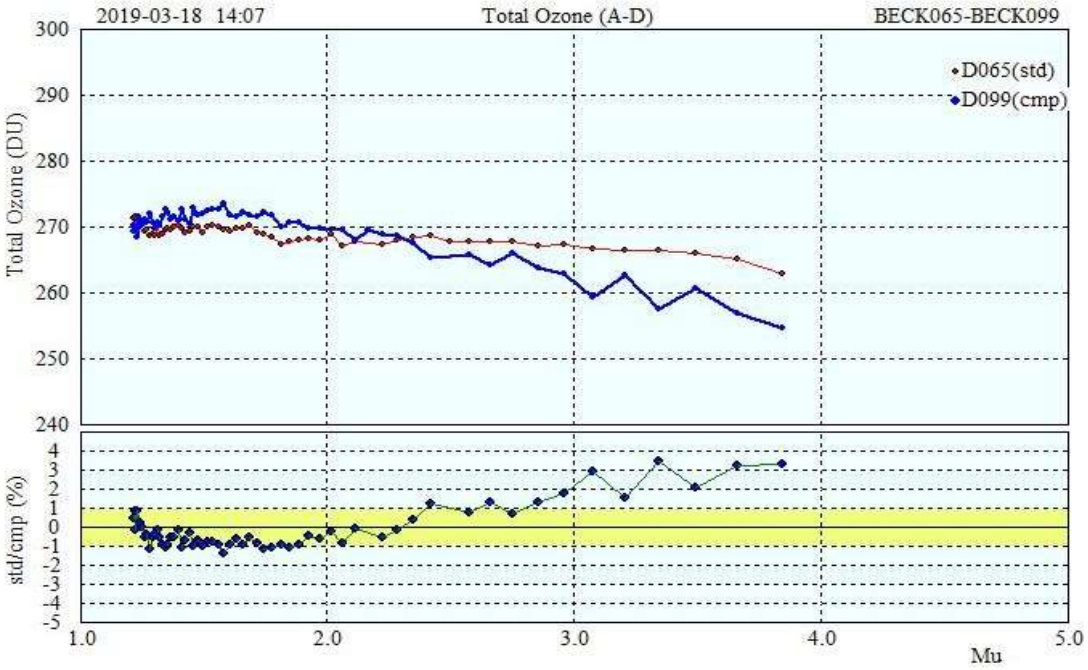


Figure 20: Final comparison of std (D065) vs cmp (D099) after adjusting D099. Top plot represents direct comparison with red line corresponding to std, and blue line to cmp. Bottom plot represents the relationship in percent.

Recommendations and comments:

- The existing data taken from this instrument since 2010 should be reprocessed;
- PARA1903.099 and RtoN1903.099 should be used for processing data beginning March 22, 2019;
- New SL reference values (099Q3, 099Q4 and 099Q5) were defined.

Special observations:
There is no Umkehr intercomparison.

5.1.8 Instrument: D114

Cachoeira Paulista, Brazil

Original calibration data:
N-tables and reference SLs values from 30 November 2010 intercomparison with D070 in Buenos Aires, Argentina. WinDobson information: PARA1011.114 and RtoN1011.114. (Figure 21)

Initial calibration results: 10 March 2019
Adjustments based on the results of SL tests were included.

d_Na:-6.1 d_Nc:-2.0 d_Nd:-2.4 d_Nad:-3.4

The d_Nad value implies an average **+4.7% error** in calculated ozone value, μ = 1 to 3, Total Ozone = 300 Dobson Units.

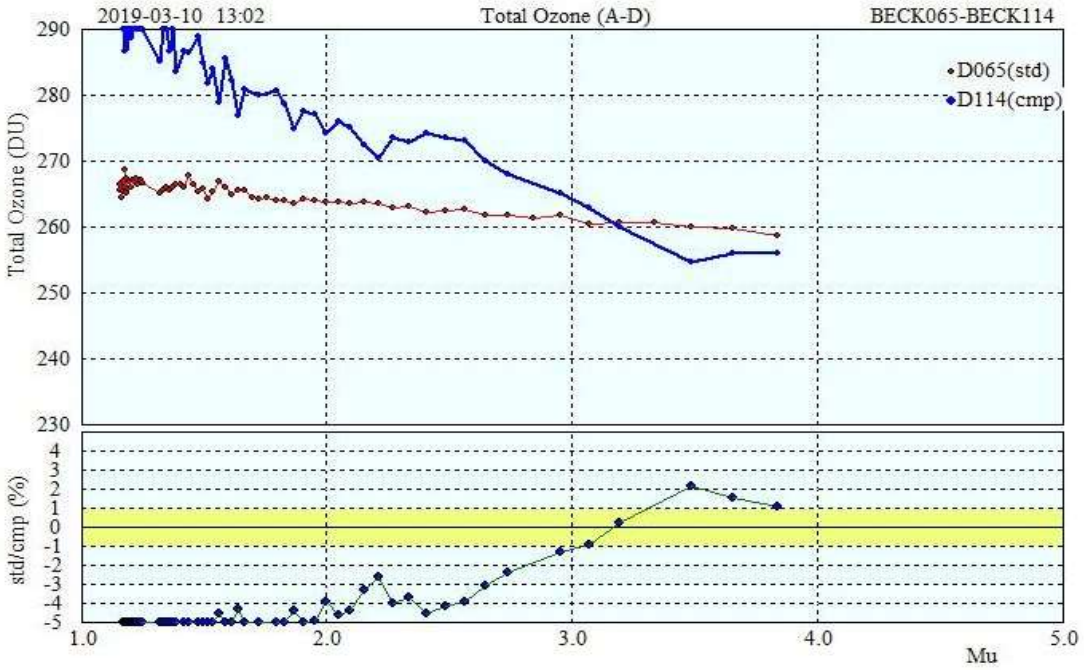


Figure 21: Initial comparison of std (D065) vs cmp (D114). Top represents direct comparison with red line corresponding to std, and blue line to cmp. Bottom plot represents the relationship in percent.

Work performed:

- Cleaned Optics;
- Replaced mirror M1;
- Performed wedge calibration.

Final intercomparison: 18 March 2019

New N-tables and reference SL values were defined from this intercomparison. (Figure 22)

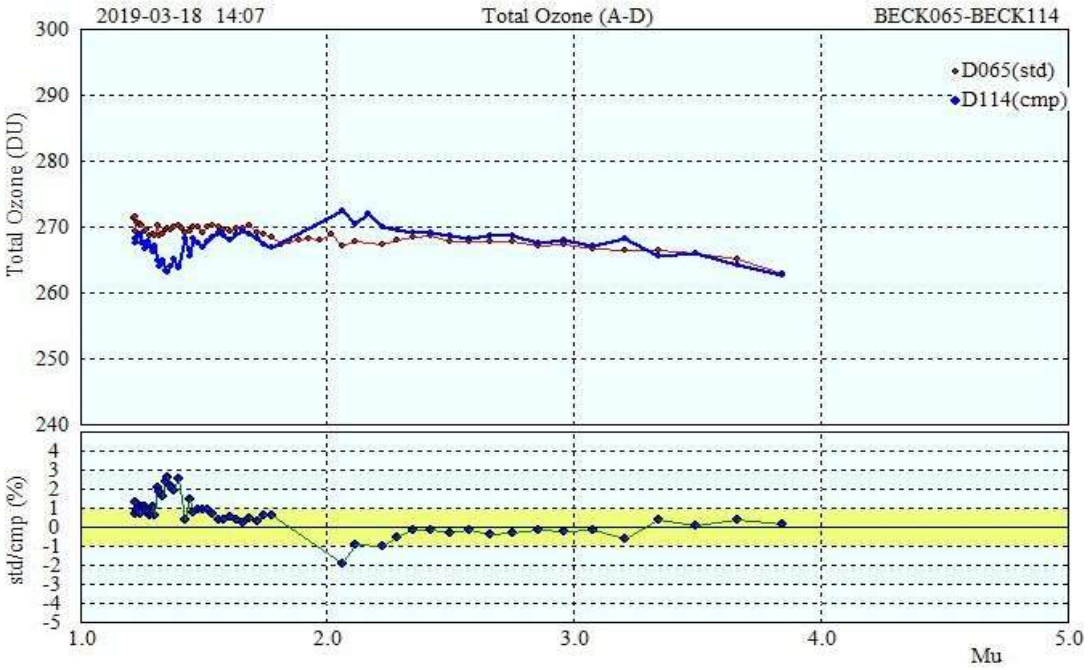


Figure 22: Final comparison of std (D065) vs cmp (D114) after adjusting D114. Top plot represents direct comparison with red line corresponding to std, and blue line to cmp. Bottom plot represents the relationship in percent.

Recommendations and comments:

- PARA1904.114 and RtoN1903.114 should be used for all future processing;
- New SL reference values (114Q5, 114Q6 and 114Q3) were defined;
- The existing data set from this instrument must be reprocessed.

Special observations:
An intercomparison of the measurement of the Umkehr effect was made on the evening of the 21 March 2019. These measurements were made as part of an effort to further understand this process. A profile is not of good quality. (Figure 23)

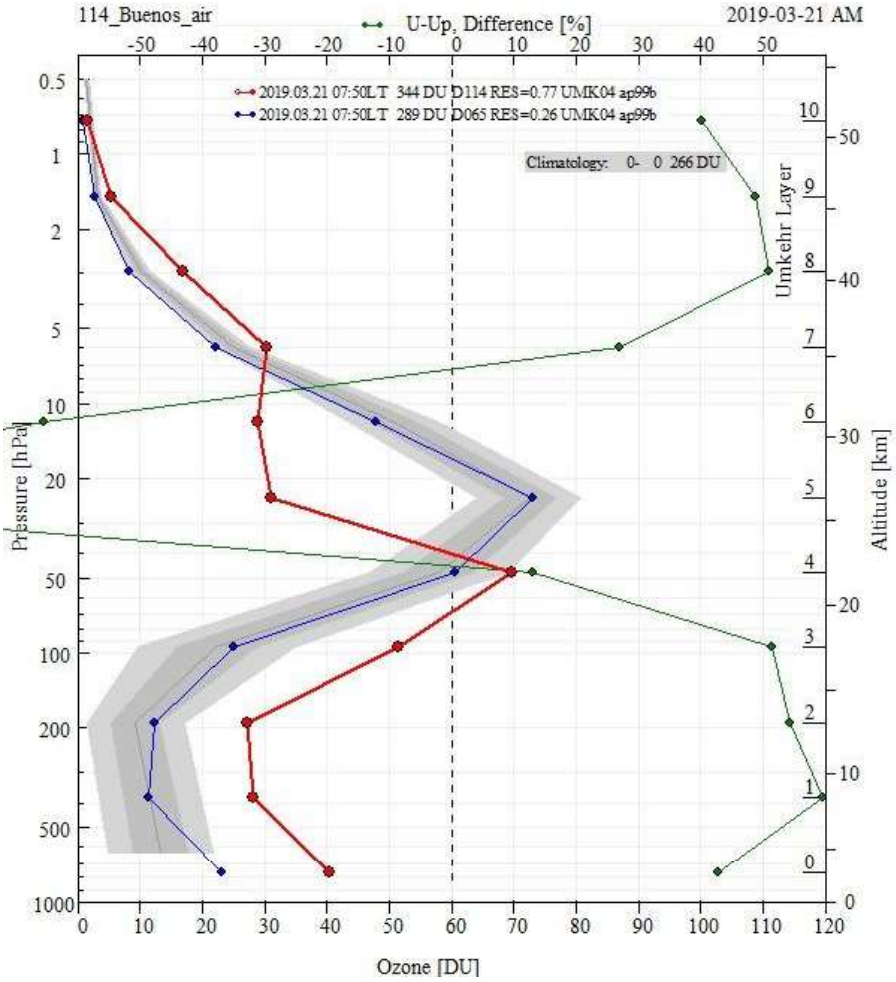


Figure 23: Comparison of Umkehr measurement of std D065 (blue line) vs cmp D114 (red line). The green line corresponds to the differences in percent, the light grey shadow is the climatology in Buenos Aires.

5.1.9 Instrument: D131

Ushuaia, Argentina

Original calibration data:
N-tables and reference SLs values from 17 November 2010 intercomparison with D070 in Buenos Aires, Argentina. WinDobson information: PARA1011.131 and RtoN1011.131. (Figure 24)

Initial calibration results: 10 March 2019
Adjustments based on the results of Standard Lamp tests were included.

d_Na:-1.8 d_Nc:-1.7 d_Nd:-2.3 d_Nad:+.5

The d_Nad value implies an average **-0.7% error** in calculated ozone value, μ = 1 to 3, Total Ozone = 300 Dobson Units.

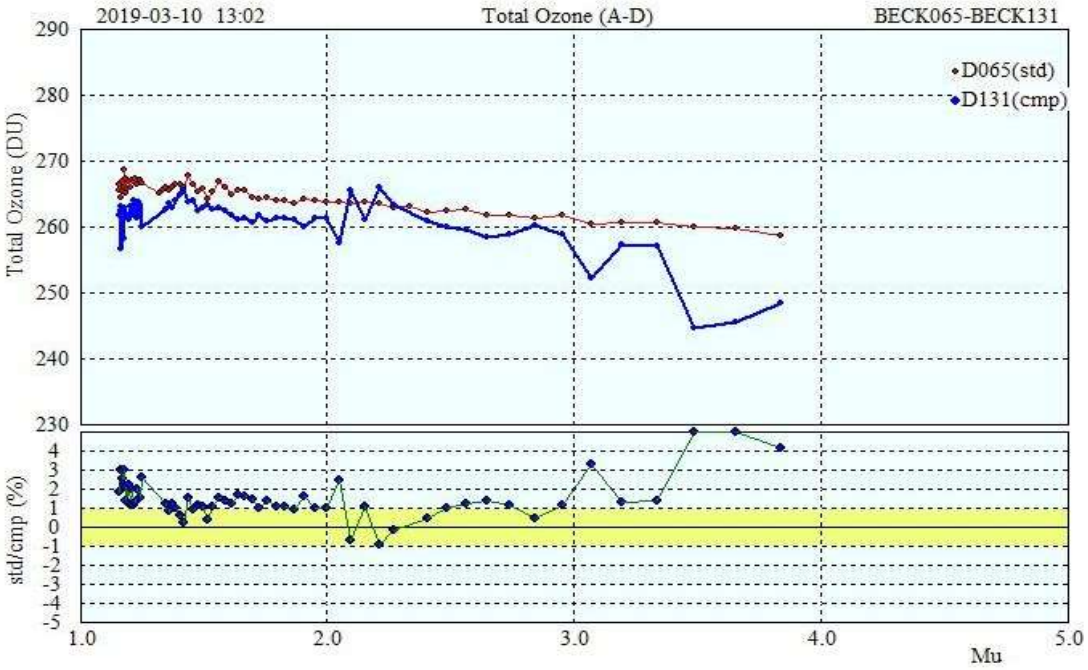


Figure 24: Initial comparison of std (D065) vs cmp (D131). Top plot represents direct comparison with red lines corresponding to std, and blue line to cmp. Bottom plot represents the relationship in percent.

Work performed:

- Optics Cleaned;
- The shutter rod was bent in transportation. It was repaired.

Final intercomparison: 18 March 2019
New N-tables and reference standard lamp values were defined from this intercomparison. (Figure 25)

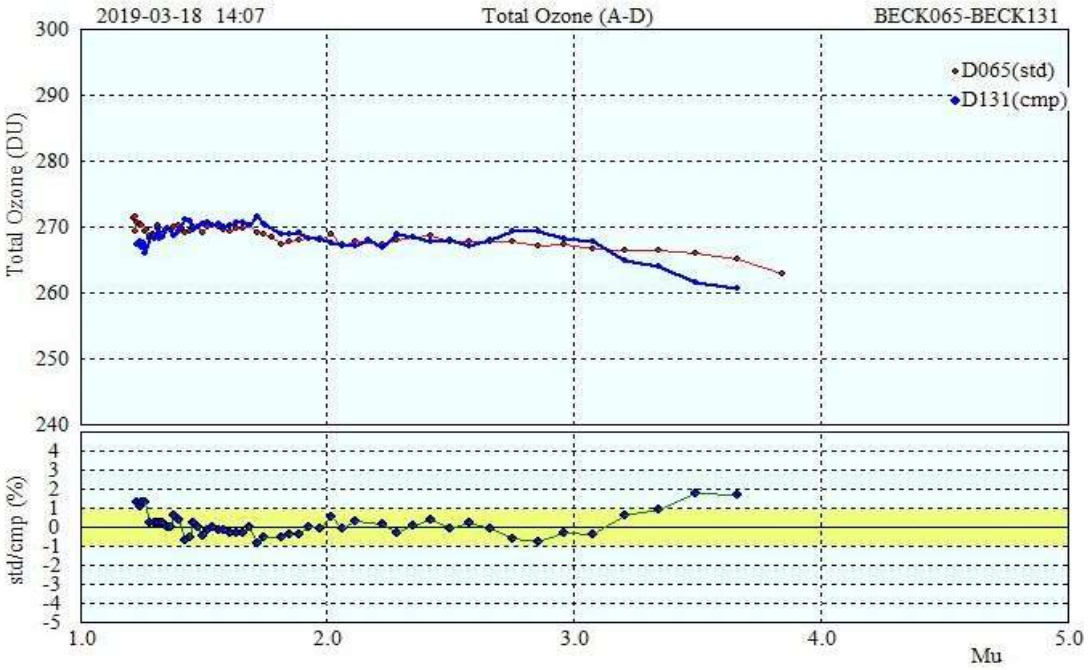


Figure 25: Final comparison of std (D065) vs cmp (D131) after adjusting D131. Top plot represents direct comparison with red line corresponding to std, and blue line to cmp. Bottom plot represents the relationship in percent.

Recommendations and comments:

- RtoN1903.131 dated 18 March 2019 should be used for processing future observations;
- New Standard Lamp reference values (131Q3, 131Q6 and 131T5) were defined;
- The Data should be recalculated using only the 131Q6 correction values.

Special observations:
An intercomparison of the measurement of the Umkehr effect was made on the evening of the 21 March 2019. These measurements were made as part of an effort to further understand this process.

The result is an ozone profile. Figure 26 shows the profile calculated from the measurements made with D065 and D131.

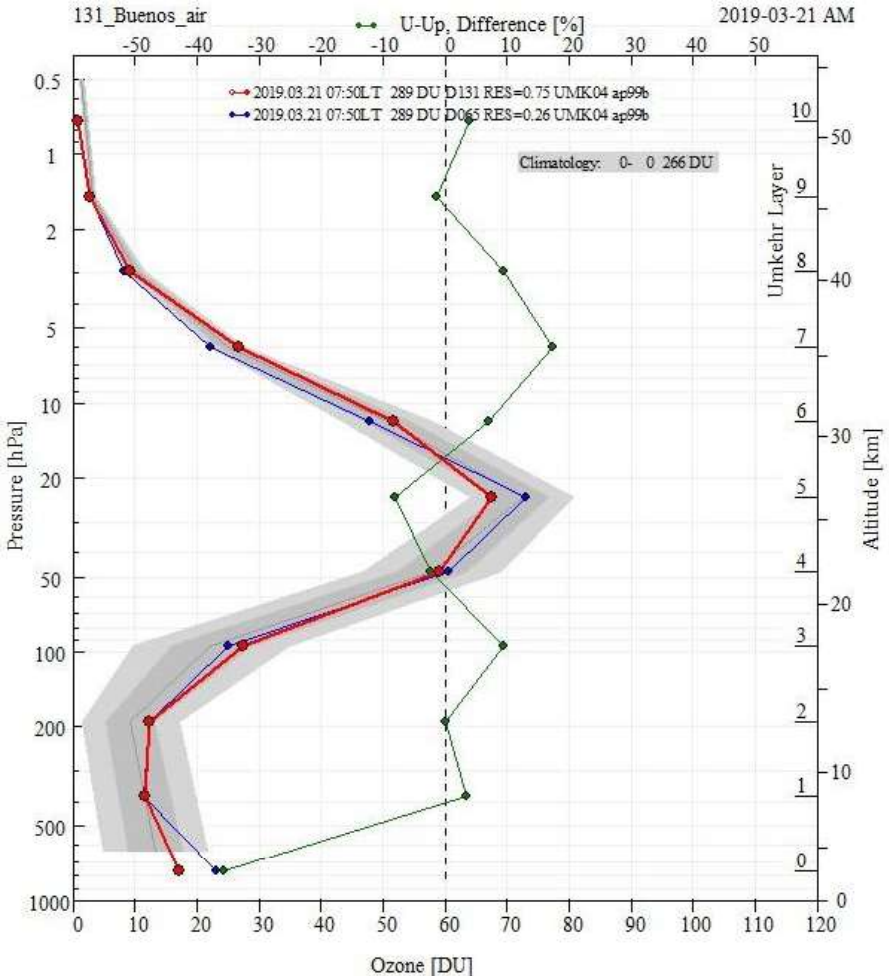


Figure 26: Comparison of Umkehr measurement of std D065 (blue line) vs cmp D131 (red line). The green line corresponds to the differences in percent, the light grey shadow is the climatology in Buenos Aires.

5.1.10 Instrument: D133

Comodoro Rividavia, Argentina

Original calibration data:
N-tables and reference standard lamp values from 26 November 2010 intercomparison with D070 in Buenos Aires, Argentina. WinDobson information: PARA1011.133 and RtoN1011.133. (Figure 27)

Initial calibration results: 10 March 2019
(Adjustments based on the results of Standard Lamp tests included.)

d_Na:-1.7 d_Nc:-1.1 d_Nd:-1.2 d_Nad:-0.5

The d_Nad value implies an average **+0.7% error** in calculated ozone value, μ = 1 to 3, Total Ozone = 300 Dobson Units.

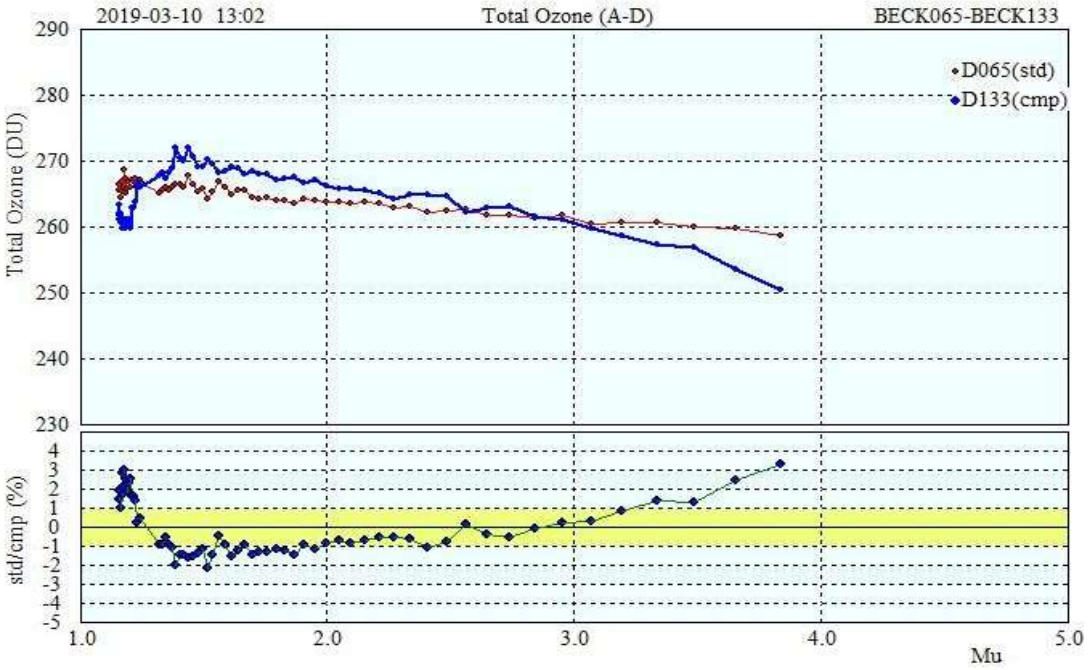


Figure 27: Initial comparison of std (D065) vs cmp (D133). Top plot represents direct comparison with red line corresponding to std, and blue line to cmp. Bottom plot represents the relationship in percent.

Work performed:

- Optics were cleaned, including wedge;
- The wedge attachment screw under R-dial axis was loose;
- Performed wedge calibration.

Final intercomparison: 18 March 2019
New N-tables and reference standard lamp values were defined from this intercomparison. (Figure 28)

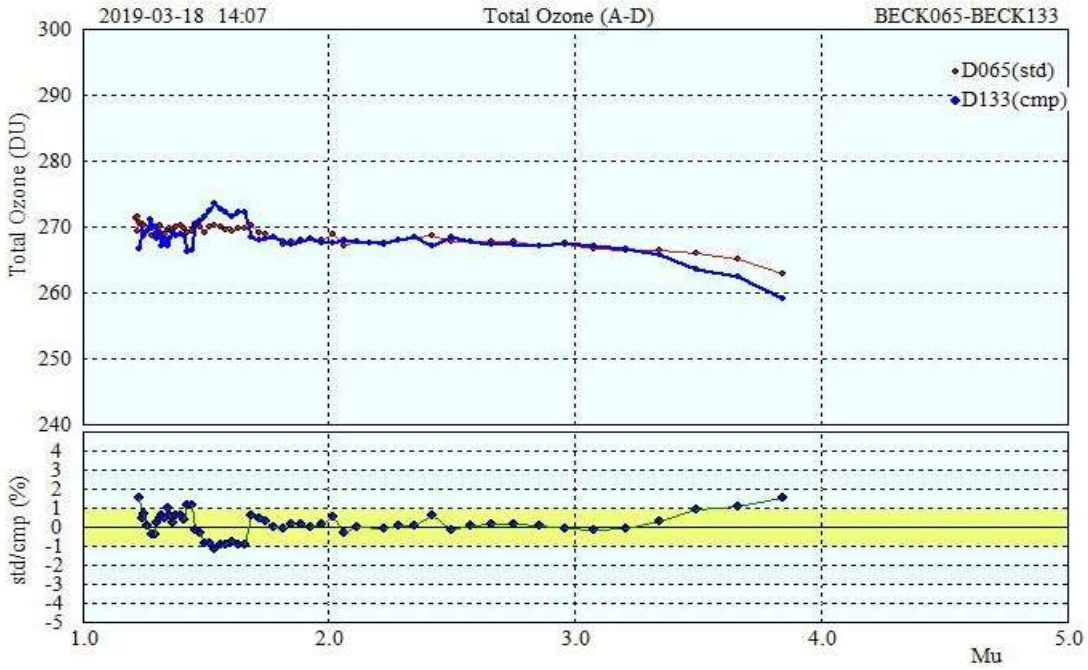


Figure 28: Final comparison of std (D065) vs cmp (D133) after adjusting D133. Top plot represents direct comparison with red lines corresponding to std, and blue line to cmp. Bottom represents the relationship in percent.

Recommendations and comments:

- The existing data should be investigated;
- Para1903.133 and RtoN1903.133 should be used for future processing;
- New Standard Lamp reference values (133A, 133B and 133Q3) were defined.

Special observations:
An intercomparison of the measurement of the Umkehr effect was made on the evening of the 21 March 2019. These measurements were made as part of an effort to further understand this process.

The result is an ozone profile. Figure 29 shows the profile calculated from the measurements from D065 and D133.

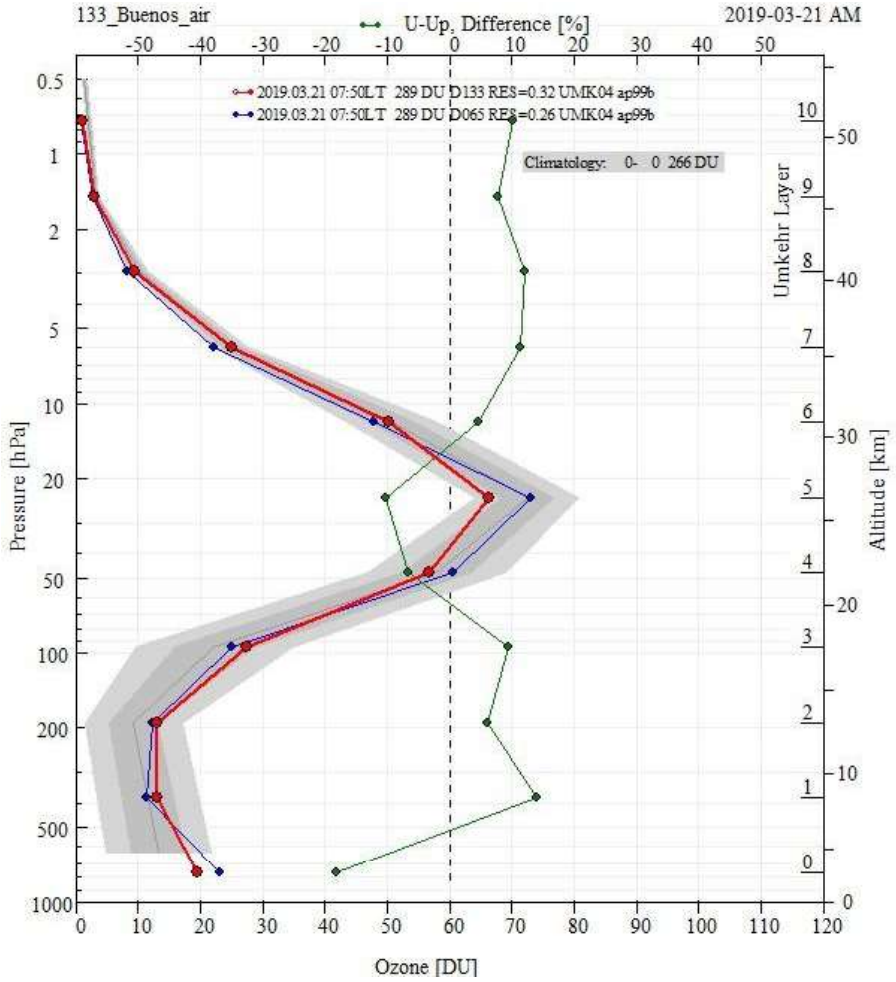


Figure 29: Comparison of Umkehr measurement of std D065 (blue line) vs cmp D133 (red line). The green line corresponds to the differences in percent, the light grey shadow is the climatology in Buenos Aires.

5.1.11 Instrument: D134

Salto, Uruguay

Original calibration data:
N-tables and reference standard lamp values from 23 November 2010 intercomparison with D070 in Buenos Aires, Argentina. WinDobson information: PARA1011.134 and RtoN1011.134. (Figure 30)

Initial calibration results: 10 March 2019
Adjustments based on the results of Standard Lamp tests were included.

d_Na:-1.2 d_Nc:-1.4 d_Nd: -1.4 d_Nad: +0.2

The d_Nad value implies an average **-0.3%** error in calculated ozone value, μ = 1 to 3, Total Ozone = 300 Dobson Units.

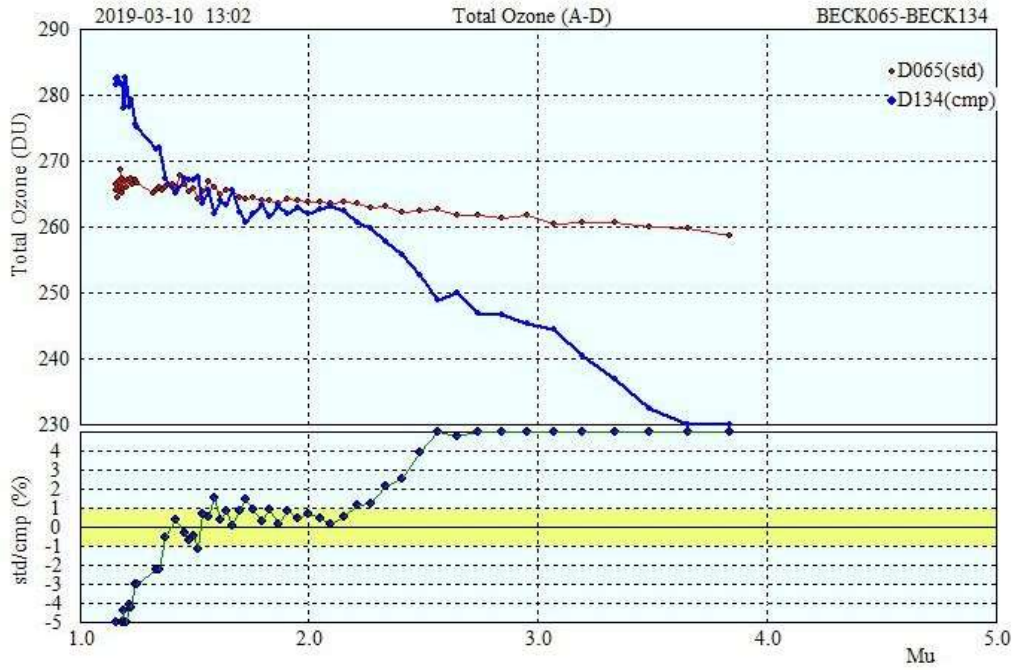


Figure 30: Initial comparison of std (D065) vs cmp (D134). Top plot represents direct comparison with red line corresponding to std, and blue line to cmp. Bottom plot represents the relationship in percent.

Work performed:

- Optics were cleaned;
- M1 and M2 mirrors replaced;
- The right shutter rod was fixed.

Final intercomparison: 18 March 2019
New N-tables and reference standard lamp values were defined from this intercomparison. (Figure 31)

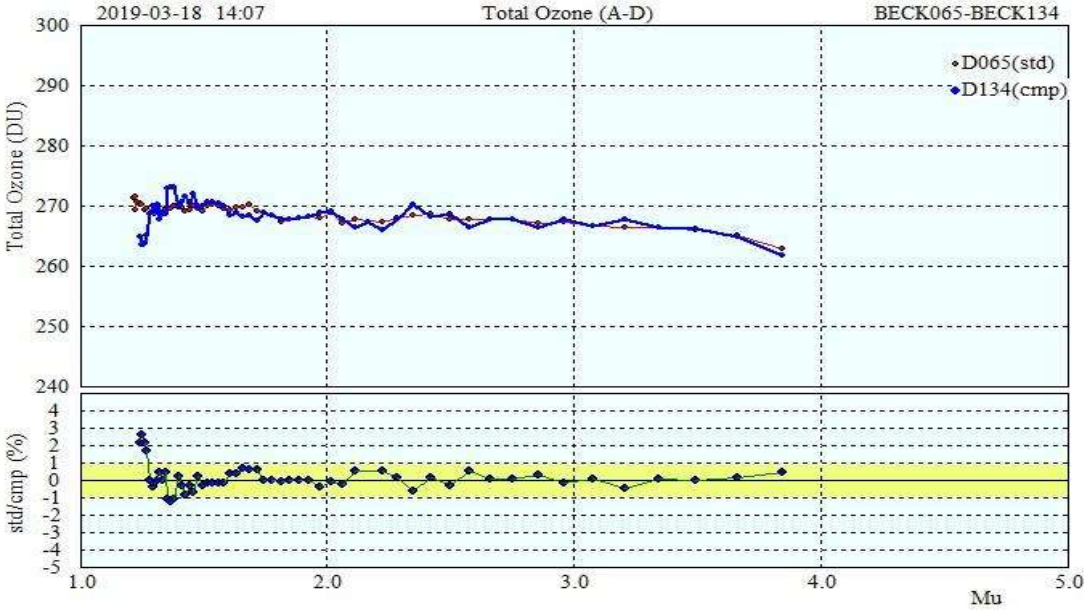


Figure 31: Final comparison of std (D065) vs cmp (D134) after adjusting D134. Top plot represents direct comparison with red line corresponding to std, and blue line to cmp. Bottom plot represents the relationship in percent.

Recommendations and comments:

- Existing data set required no reprocessing within the range of μ 1.3 to μ 2.2;
- Use RtoN1903.134 for processing of all new measurements;
- New Standard Lamp reference values (134B4, 134T3 and 134Q3) were defined.

Special observations:
An intercomparison of the measurement of the Umkehr effect was made on the evening of the 21 March 2019. These measurements were made as part of an effort to further understand this process.

The result is an ozone profile. Figure 32 shows the profile calculated from the measurements from D065 and D134 (New 2019 Nc-Table).

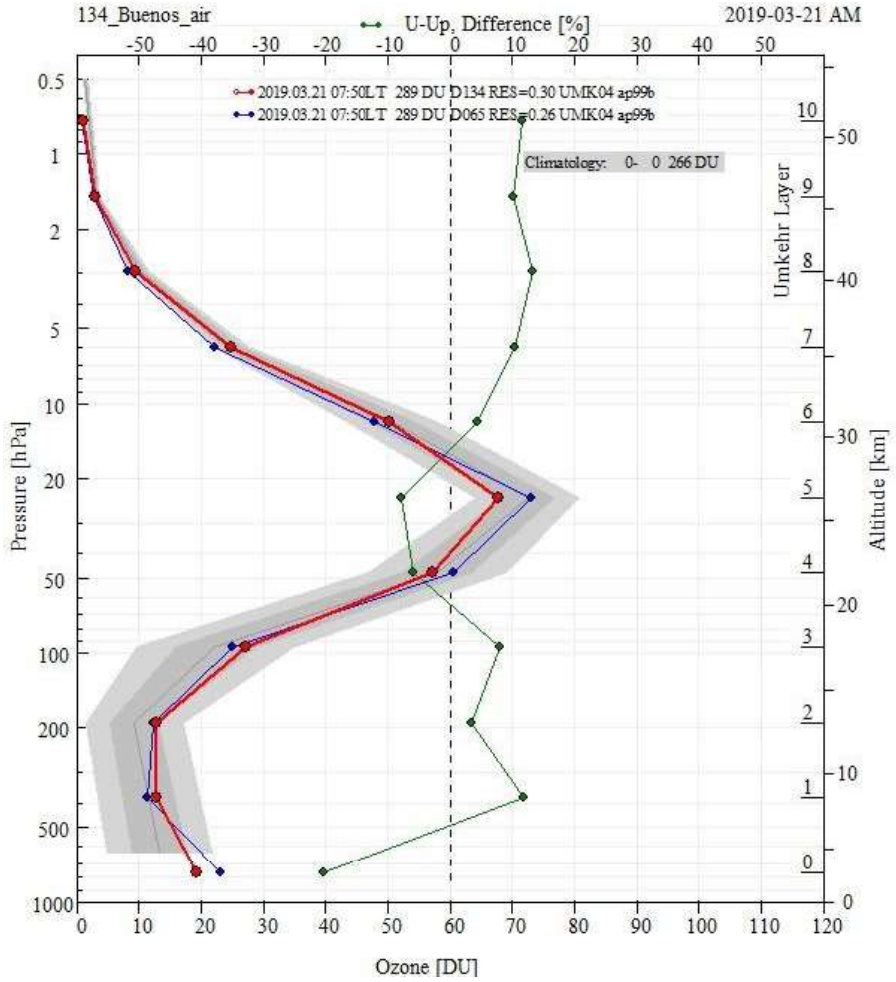


Figure 32: Comparison of Umkehr measurement of std D065 (blue line) vs cmp D134 (red line). The green line corresponds to the differences in percent, the light grey shadow is the climatology in Buenos Aires.

5.2 Analysis of Uncertainties

5.2.1 Initial and Final IC/BUA-19

Initial IC

Figures 33, 34 and table 1 show the ozone error of the individual instrument from the initial and final intercomparison.

It is evident that Dobson D067, D093, D099, and D114 have differences higher than 1%.

Table 1: Values, and error for d_NAD for each Dobson.

	D067	D070 ST	D087	D093	D097	D098	D099	D114	D131	D133	D134
d_NAD	1,8	-0,7	+0,6	+2,3	+0,2	+0,6	+2,6	-3,4	+0,5	-0,5	+0,2
% Err	-2,5	1,0	-0,8	-3,2	-0,3	-0,8	-3,6	4,7	-0,7	0,7	0,3

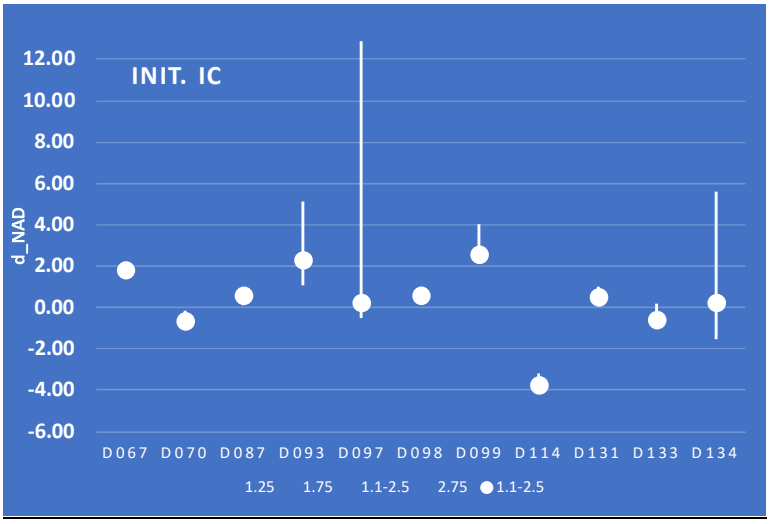


Figure 33: NAD differences for each instrument normalized to μ– ranges during intercomparisons.

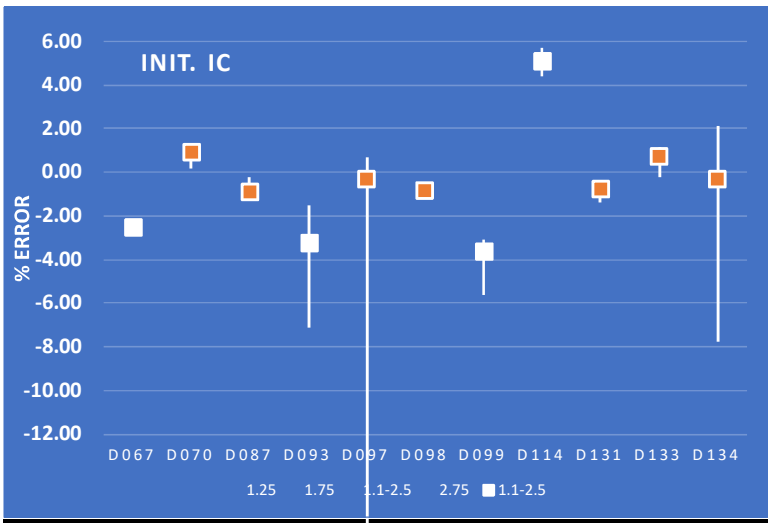


Figure 34: The ozone error within 1% is indicated by orange boxes. The values above 1% are shown with white boxes.

Final IC

After making the adjustments, and checking the operation of the Dobson spectrophotometers, the error was reduced, as shown in Figures 35 and 36. The ozone errors were within 0.5%.

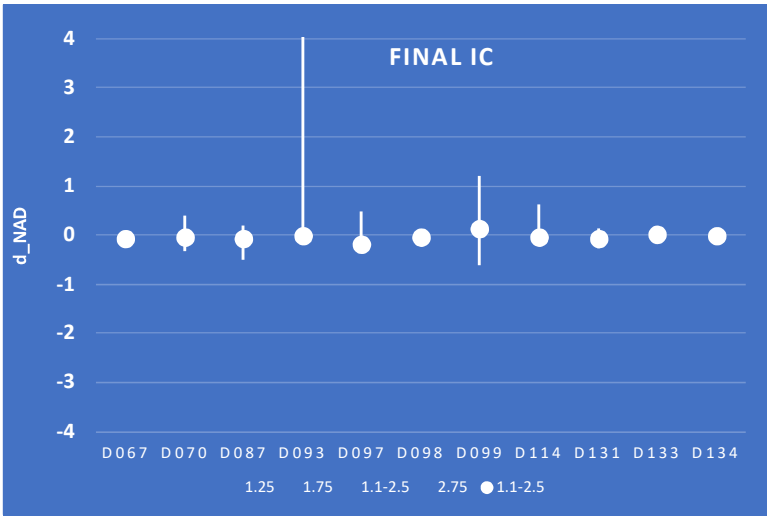


Figure 35: NAD differences for all instruments after making repairs to all Dobsons.

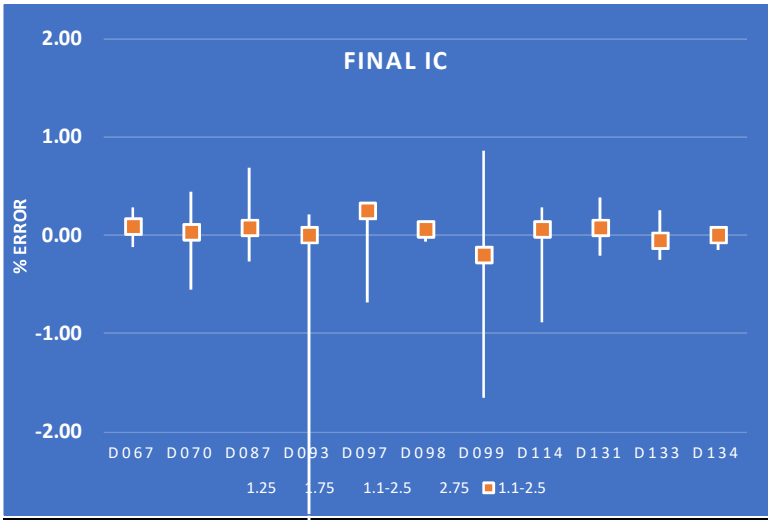


Figure 36: The ozone errors are within 0.5% as shown by the orange boxes.

5.2.2 Special Umkehr IC/BUA-19

The Umkeher measurements were compared with the OMPS_NP satellite ozone profile data available from NASA archive (https://earthdata.nasa.gov/earth-observation-data/near-real-time/download-nrt-data/omps-nrt) and the results are shown in Figures 37 and 38.

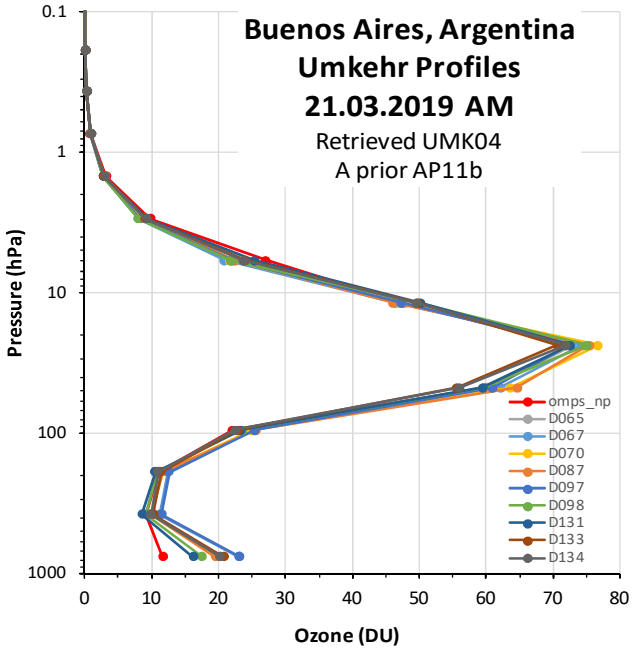


Figure 37: Comparison of all Dobson spectrophotometers vs NASA Ozone Mapping and Profiler Suite (omps_np) profiles.

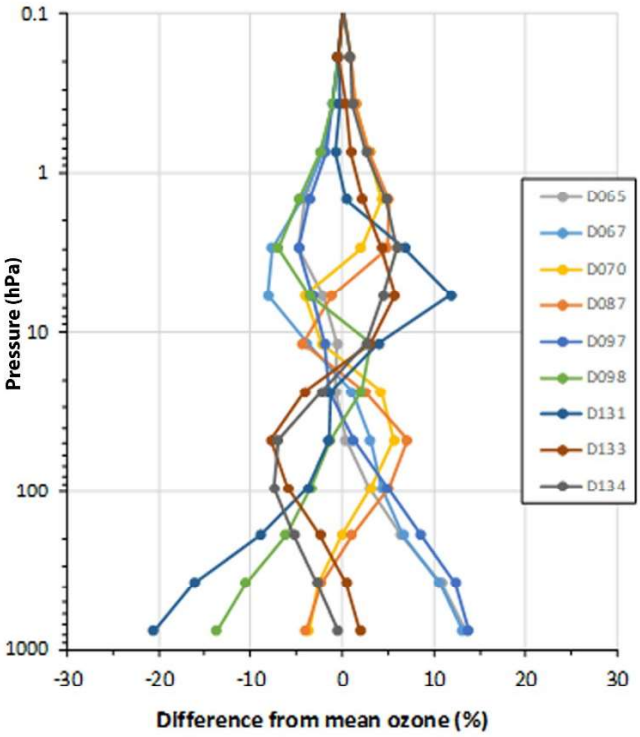


Figure 38: Percentage differences between the Ozone Mapping and Profiler Suite (OMPS) and all Dobson Umkehr profiles.



Figure 39: A special Training session on Dobson operation and data quality assurance was provided to all participants along with practical help and guidance on instrument maintenance. A special part of the training was dedicated to the processing of Dobson observations for Total Column Ozone (TCO) data and their submission to the World Ozone and UV Data Center (WOUDC).



Figure 40: Participating Dobson spectrophotometers were subjected to lab inspection, service and to outdoor intercomparison.

6 CONCLUSIONS

Eleven Dobson spectrophotometers were intercompared, using the Dobson D065 as World Secondary Standard. It was necessary to review, correct and adjust all participating Dobson instruments, but some of them required additional work (D067, D093, D099, and D114).

A seminar was held to train the observers in Dobson operations and data quality assurance (QA). It also provided observers' training on the processing of TCO data and its submission to the WOUDC.

Dr Koji Miyagawa, delivered the software "WinDobson" to all participants of IC/BUA-19.

All participating instruments left the intercomparison properly calibrated with an ADDSGQP (AD Direct Sun measurement using a ground quartz plate) precision of better than 1%.

7 RECOMMENDATIONS

We recognize the excellent infrastructure and support provided by the Argentine SMN, Region III calibration centre and extremely responsive personnel of Villa Ortúzar Observatory. It was evident that Region III relies heavily on Dobson spectrophotometers for TCO measurements, and thus the Region III calibration center is critical for maintaining the ozone monitoring network.

We recommend that IC/BUA be done every 4 or 5 years, in order to ensure data quality (QA), and homogenization of the measurement network in Latin America.

We recommend more training for Dobson operations and TOC data QA, using various platforms such as WMO.

8 REFERENCES

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- WMO/UNEP, Dobson Data Quality Workshop, GAW Report No. 225, 2011.

APPENDIX

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