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WMO/GAW Regional Intercomparison of Dobson Spectrophotometers for Asia (Tsukuba, Japan, 3-20 March 2003)

Final Report

Prepared by

WMO Regional Dobson Calibration Centre for Asia
Japan Meteorological Agency

And

WMO World Dobson Calibration Centre
National Oceanic and Atmospheric Administration, USA

1. PURPOSE OF THE INTERCOMPARISON

The intercomparison (DIC2003) was organized by the World Meteorological Organization (WMO) Secretariat and the Regional Dobson Calibration Center (RDCC) for Asia, the Japan Meteorological Agency (JMA) in close cooperation and with the assistance of the World Dobson Calibration Center (WDCC), the USA National Oceanic and Atmospheric Administration's Climate Monitoring and Diagnostics Laboratory (NOAA/CMDL). It was a campaign to maintain the network of the Dobson ozone spectrophotometers operated in the Asian region. The Dobson Intercomparison also served as an assurance of the quality of the total ozone data sets created at WMO Member stations. This action is a fulfillment of WMO/GAW/QC requirement for monitoring of the atmospheric total ozone.

The main tasks were:

- The technical inspection and adjustment of the instruments.
- Comparison of the Dobson spectrophotometers with the Regional Dobson Standard Instrument(RSI) No. 116 of (maintained by) Aerological Observatory, JMA, to determine the existing calibration level.
- Determination of new calibration constants for each Dobson spectrophotometer, as needed.
- To provide a forum for instruction for operating the Dobson spectrophotometers at home stations, and sharing knowledge concerning the management of an ozone-observing program.

2. ORGANIZATION

The Intercomparison was held at the Aerological Observatory (AOT, directed by Tadaaki Hamada) of JMA in Tsukuba during the period 3 to 20 March 2003. Its operation was controlled by the Scientific Director, Yukio Makino (Atmospheric Environment Division, JMA), Scientific Adviser, Robert D. Evans (NOAA/CMDL) and Technical Director, Koji Miyagawa (JMA/AOT) in cooperation with an Executive Team comprising:

Masanori Shitamichi	Head of the Ozone Layer Monitoring Office (OLMO) of the Atmospheric Environment Division
Toshifumi Fujimoto	Assistant to Head of OLMO
Kazumasa Tada	Head of the Ozone and Radiation Division (ORD) of AOT
Yasuo Hirose	Senior Researcher (ORD)

The staff of the Aerological Observatory supported the intercomparison.

Two specialists from China participated in the intercomparison – see Annex A. The following Dobson spectrophotometers were inspected, adjusted and compared:

Dobson No.	Country	Station
D003	China	Kunming
D075	China	Xianghe/Beijing – National Standard Instrument
D116	Japan	Tsukuba - Regional Standard Instrument (RSI)

The intercomparison DIC2003 was conducted and all actively arranged in daily schedules according to the weather conditions and with respect to the technical state of the individual instruments. The technical infrastructure of AOT, JMA and special facilities from NOAA, Boulder, CO, USA were utilized during DIC2003. The RSI, D116 had been compared and calibrated against the World Primary Standard Instrument, D083 in Mauna Loa, Hawaii during the period 26 Aug. to 15 Sep. 2001.

The main steps specified below were applied to each Dobson spectrophotometer:

- Unpacking the instrument and an inspection following transport to the Observatory.
- Inspection of the technical condition of the Dobson spectrophotometer and its functioning by means of daily SL(Standard lamp) and HG(Mercury) lamp tests.
- Initial comparison against the RSI to determine the existing calibration levels.
- Definition of the technical adjustments and special tests required (wedge calibrations, discharge lamp tests, cleaning and adjustment of the optics, etc).
- Final comparison against the RSI.
- Assessment of the results, determination of new calibration constants (Reference R-N tables, Q-table and Reference Standard Lamp Readings).
- Interview by the Scientific Director and the Technical Director with the operator in charge on the results of her instrument intercomparison and other calibrations (meta-data) under the assistance of the Scientific Adviser. At this point, copies of documentation related to the spectrophotometer calibration were given to the operators.
- Packing of the instrument and other technical facilities for transport to home station.
- Preparing the final report of DIC2003.

All work done and the results obtained for individual instruments are summarized in Annex B. This information has been saved in detail by operators and by the Scientific Director of the intercomparison.

The success of the intercomparison was accomplished mainly through the instructions provided by the Scientific Adviser and the Technical Director at the regular daily meetings of all participants. These instructions were determined at the daily meetings of the scientific and executive group.

With regards to the goal of sharing knowledge on the operation of the Dobson instruments and the management of an observing program, the individual participants were required to perform the necessary calibration procedures under the supervision of the scientific staff. For example, almost all wedge calibration were undertaken by the instrument's own operator.

3. OTHER ACTIVITIES

Special morning Umkehr observations on the zenith sky were made by all participating instruments on 13 March 2003 – the profiles calculated from the measurements are shown in Figure 1.. A dual ozonesonde flight was made from this site in the afternoon of the 12 March 2003.

4. CONCLUSIONS

All participating instruments left the intercomparison properly calibrated within the instrumental precision limit with the Regional Dobson Standard Instrument using the DS(Direct Sun) observations. Thanks to the fine weather, and the hard work of the participants, the intercomparison was completed by 17 March 2003

5. RECOMMENDATIONS

The Scientific Director of the DIC2003 acknowledged the excellent support and infrastructure provided to the intercomparison by JMA/AOT. He also acknowledged Mr. Robert D. Evans for his excellent scientific advice and instruction to the intercomparison. It was recommended that the intercomparison be repeated in the future for these instruments, and that the means be found to expand the number of participant observing programs included in the intercomparison meetings.

ANNEX A

WMO/GAW Regional Intercomparison of Dobson Spectrophotometers for Asia
(Tsukuba, Japan, 3-20 March 2003)

List of Participants

China:

Ms. Zhang Wenxing
Institute of Atmospheric Physics
Chinese Academy of Sciences
Beijing 100029 China
Tel: (086) 010 62 04 89 22
Fax: (086) 010 62 02 86 04
E-mail: zwx@mail.iap.ac.cn

Ms. Zhao Yanliang
Institute of Atmospheric Physics
Chinese Academy of Sciences
Beijing 100029 China
Tel: +86 010 62 04 07 34
Fax: +86 010 62 02 86 04
E-mail: zyl49@mail.iap.ac.cn

Japan:

Regional Dobson Calibration Center for Asia

Mr. Toshifumi Fujimoto
Ozone Layer Monitoring Office
Atmospheric Environment Division
Japan Meteorological Agency
1-3-4, Otemachi, Chiyoda-ku
Tokyo 100-8122, Japan
Tel: +81-3-3287-3439
Fax: +81-3-3211-4640
E-mail: fujimoto@met.kishou.go.jp

Mr. Yasuo Hirose
Ozone and Radiation Division
Aerological Observatory
Japan Meteorological Agency
1-2, Nagamine,
Tsukuba 305-0052, Japan
Tel: +81 29 851 2572
Fax: +81 29 851 5765
E-mail: y-hirose@met.kishou.go.jp

Mr. Yukio Makino
Atmospheric Environment Division
Japan Meteorological Agency
1-3-4, Otemachi, Chiyoda-ku
Tokyo 100-8122, Japan
Tel: +81-3-3287-3439
Fax: +81-3-3211-4640
E-mail: y-makino@met.kishou.go.jp

Mr. Koji Miyagawa
Ozone and Radiation Division
Aerological Observatory
Japan Meteorological Agency
1-2, Nagamine,
Tsukuba 305-0052, Japan
Tel: +81 29 851 2572
Fax: +81 29 851 5765
E-mail: miyagawa@met.kishou.go.jp

Mr. Masanori Shitamichi
Ozone Layer Monitoring Office
Atmospheric Environment Division
Japan Meteorological Agency
1-3-4, Otemachi, Chiyoda-ku
Tokyo 100-8122, Japan
Tel: +81-3-3287-3439
Fax: +81-3-3211-4640
E-mail: shitamichi@met.kishou.go.jp

Mr. Kazumasa Tada
Ozone and Radiation Division
Aerological Observatory
Japan Meteorological Agency
1-2, Nagamine,
Tsukuba 305-0052, Japan
Tel: +81 29 851 2572
Fax: +81 29 851 5765
E-mail: kazu.tada@met.kishou.go.jp

USA:

World Dobson Calibration Center

Mr. Robert D. Evans
DOC/NOAA/OARCMDL R/CMDL1
Climate Monitoring and Diagnostic Laboratory
Dobson Ozone Project,
World Dobson Calibration Center,
325 Broadway
Boulder, CO 80303
Tel: +1 303-497-6679
Fax: +1 303-497-5590
Email: Robert.D.Evans@noaa.gov

ANNEX B

WMO/GAW Regional Intercomparison of Dobson Spectrophotometers for Asia
(Tsukuba, Japan, 3-20 March 2003)

Individual Instrument Reports

Instrument: D075
Station: Beijing, China

Original Calibration Data:

N-tables and Reference Standard Lamp values from August-September 1996, Tsukuba Japan intercomparison.
Reference Standard Lamps 75Q1 and 75Q2.

Initial Calibration results (Adjustments based on the results of Standard Lamp tests included.)
05 March 2003

d_Na: -0.55 d_Nc: -0.12 d_Nd: -1.83 d_Nad: +1.26

The d_Nad value implies an average **+1.8%** error in calculated ozone value, Mu=1 to 3, Total Ozone = 300 Dobson Units (Figure 1). This adjustment makes the results track the standard instrument results quite well.

Work Performed:

1. A wedge calibration was performed, and the resultant G-table applied to the data of the 05 March 2003 – no real change in the results.
2. Optics cleaned of dust
3. Optical symmetry checked, and found to be within limits.
4. The S2/S3 response curves in the Photomultiplier Tube (PMT) were measured, and found to be correct – indicating that the position of the tube is correct. The original PMT had replaced during March 1999. This test verified that the PMT was replaced correctly.
5. Several two-lamp calibrations are done on the instrument, but none of the resultant G-functions produce better matching with the standard instrument than the original N-table.
6. The shutter motor was replaced – the original motor was a 110 Volt motor – rest of the instrument electrics is 220V. New motor is a 220V, 50HZ Bodaine motor. Shutter drive is US style pulley drive.
7. The lens in the sun director was removed to increase the size of the sunspot on the Ground Quartz Plate, which will aid in making repeatable observations.
8. The operators of the instrument were supplied from the intercomparison sponsors with a new Standard Lamp 75Q3.
9. The rotation speed of the shutter was measured at 840 RPM, with the Motor Speed at 1485. The specification of the shutter speed is 825, but the calibration of the measuring device is questionable.
10. The output signal waveform from the electronics was measured as an attempt to understand the non-standard placement of the shutter position detector. The signal does appear to respond properly to the changes in wedge position as the R-dial is moved through the zero reading on the microammeter (light source: standard lamp).

Final intercomparison: 12 March 2003

New N-tables and Reference Standard Lamp values for lamps 75Q1, 75Q2 and 75Q3 as well as 116Q7 were defined.

Highest Difference against the standard for ADDSGQP observations in mu range 1.3 to 2.5 was less than 1.0% in total ozone. (Figure 3)
Use new N-tables and reference standard lamp values for data taken after 12 March 2003.

Recommendations and Comments

- The sky conditions on the 05 March 2003 intercomparison were marginal for an intercomparison. The total ozone amount was high (~370) for an intercomparison.
- The sky condition for the final intercomparison was very good, but the ozone amount was higher than normal (~360). Such high ozone amounts lower the solar intensity at the A-pair wavelengths, affecting the measurements at high mu. Both instruments exhibited some of this affect. The calibration analysis is based on measurements at mu=<2.5.
- The LED/Phototransistor shutter position detector for this instrument is at about 45 degrees clockwise from the center of the slits S2/S3/S4 – normal position for this device is fixed at 90

degrees (the top edge of the base case). For this instrument, this means the switching of the amplifier is synchronized at the center of S2/S3 full open – normally the synchronization is at the center-point of the shutter transition from S2 to S3 (or reverse).

- Concerning the data set from the observations made at the instrument's home station since the last intercomparison with the standard: the N-table appears to not changed it's "shape" (G-function) but the standard lamp tests have not accounted completely for the calibration shift. The lamp test record and instrument history should be investigated for some sudden shift in the lamp test results, or in the total ozone results (Consider comparing against another instrument record, for example the satellite overpass ozone record for the station). The period when the PMT was replaced should especially be investigated. If such a shift is found, then the extra correction defined from the initial intercomparison should be applied to the data from that shift to 05 March 2003. Otherwise, a linear interpolation of the correction can be applied to the existing data set (zero at last intercomparison, to 1.28 for March 2003, for example). A more complete reference for this process is: Hudson, R.D., and W.G. Planet (eds.), *Handbook for Dobson Ozone Data Re-evaluation*, WMO Global Ozone Research and Monitoring Project, Report No. 29, WMO/TD-No. 597, 1993. **A report of the reprocessing of the data must be made and the reprocessed data submitted to the World Ozone and UV Data Center in Toronto, Canada.**

Instrument: D003
Station: Kunming, China

Original Calibration Data:
N-tables and Reference Standard Lamp values from 1979 Canadian intercomparison with D077; Reference Standard Lamps 3A and 3B.

Initial Calibration results (Adjustments based on the results of Standard Lamp tests included.)
05 March 2003

d_Na: -5.86 **d_Nc: -5.56** **d_Nd: -2.74** **d_Nad:-2.94**

The d_Nad value implies an average **-4.2%** error in calculated ozone value, Mu=1 to 3, Total Ozone = 300 Dobson Units. (Figure 2.) **The matching on the A and the D wavelengths show a odd response with Mu, with the A results increasing, D results decreasing with respect to the standard instrument with increasing Mu. The C results were "flat", a desired result.**

Work Performed:

1. The instrument arrived with several problems – **problems that make evaluation of the intercomparison results difficult with respect the existing data from the station**.
   I. The results of the normal Mercury were different from the table value by about 5 units, indicating some shift in the optical components.
   II. The Q2 lever was loose, so that the Q2 plate was not following the movement correctly so that the Q2 mercury test could not performed. The Q2 plate was set to the correct position (Q2 pointer reads 84.0+/-0.5 degree when the plate is perpendicular to the lid's base). The Q2 test then was possible to perform, and gave results close to the table value. This implied that the mirror M1 was in the wrong position. The mirror was moved to give the correct results to the mercury test.
   III. "Lock-Tite Red" was applied to adjusters for the mirrors as an attempt to keep the mirrors from shifting during transport.

2. Inspection of the interior revealed that the cobalt filter is cracked in to two pieces – the crack is not in the field of view of the slit S5. The filter is 2mm larger in the diameter than any possible spares, so the existing filter was put back in the instrument.
3. The results of the mercury test after the cover was put back on the instrument indicated that the mirror M2 was out of position. This was surprising, but the mirror was adjusted for proper results.
4. A wedge calibration was performed, and the resultant G-table applied to the data of the 05 March 2003. This did not make any real improvement to the mu response of the A and D.
5. Replacement of the shutter drive motor (pulley drive) was investigated, but not attempted as the existing motor is operating well, and the replacement would be difficult, and the motor mount is quite different from other instruments.
6. A discharge lamp series was performed. Again, little difference from the table in use.
7. The Q-levers were repaired for correct, smooth operation.
8. Optics cleaned of dust.
9. Optical symmetry checked – and found to well out of specification, especially the prism P2, which defines the primary dispersion of the instrument. During the investigations as to why this problem, the prisms were found to be loose. The screws attaching the mounts to the instrument case were not tight on either prism. The prisms were tightened in their holders, and the mounts tightened. The prism P2 was rotated so that the results of the S2Q1 and S2Q2 mercury tests were within 0.5 degree, and the M1 moved so that the S2Q1 and S2Q2 results were also correct. S3Q2 results are out of specification (0.65 difference from S2Q2), but this particular adjustment is very difficult, and also the least important of the results. **This looseness of the prisms also makes evaluation of the intercomparison results difficult with respect to the station's data.**
10. The focus of the instrument was checked using the mercury lamp traverse lamp method developed by the Canadian Dobson specialists during the 1970's and described in Dobson Spectrophotometer Calibration Notes, archived at the following website: (http://www.chmi.cz/meteo/ozon/dobsonweb/messages/archie00.pdf). The result of the series

of tests indicated that the lenses are in the correct positions.
11. The plotting the S2/S3 mercury line response curves checked the position of the Photomultiplier tube. The plot shows the desired flat and equal response in the 75-95 Q2 reading range.
12. Two-Lamp (wedge) calibration repeated.
13. Lock-Tite Red was again applied to the mirror adjusters as an attempt to make the adjusters more resistant to vibration.
14. A small amount of epoxy was applied to the prisms in a manner designed to glue the back edges of the prism to the mount, as an attempt made a more robust attachment to the mount.
15. The instrument was fitted with a connector for the external drier.
16. The operators of the instrument were supplied from the intercomparison sponsors with a new Standard Lamp 003C, a new microammeter and a new quilted cover for the instrument.
17. The lens in the sun director was removed to increase the size of the sunspot on the Ground Quartz Plate, which will aid in making repeatable observations.
18. A spare 220VAC, 50 HZ motor and accessories was given from WMO supplies to the operators.
19. The rotation speed of the shutter was measured at 1640 RPM, with the motor speed at 1640. The specification of the shutter speed is 825, but the calibration of the measuring device is questionable. Note that this is approximately double the specified speed. The shutter drive is a pulley system with a rubber o-ring belt with a ratio of one to one.
20. The output signal waveform from the electronics was measured as an attempt to understand the non-standard placement of the shutter position detector. The signal does appear to respond properly to the changes in wedge position as the R-dial is moved through the zero reading on the microammeter (light source: standard lamp).

Final intercomparison: 12 March 2003

New N-tables and Reference Standard Lamp values for lamps 003A, 003B and 003C as well as 116Q7 were defined.

Highest Difference against the standard for ADDSGQP observations in mu range 1.3 to 2.5 was less than 1% in total ozone. (Figure 4) Observation results matched the standard quite well

Use new N-tables and reference standard lamp values for data taken after 12 March 2003.

Recommendations and Comments

- The sky conditions on the 05 March 2003 intercomparison were marginal for an intercomparison. The total ozone amount was high (~370) for an intercomparison.
- The sky condition for the final intercomparison was very good, but the ozone amount was higher than normal (~360). Such high ozone amounts lower the solar intensity at the A-pair wavelengths, affecting the measurements at high mu. Both instruments exhibited some of this affect. The calibration analysis is based on measurements at mu=<2.5.
- The stop for the Q1 lever's D wavelength pair position was difficult to set during the early part of the first intercomparison, and was repaired during the first break. (Mu was greater than 2.5.)
- The LED/Phototransistor shutter position detector for this instrument is at about 135 degrees clockwise from the center of the slits S2/S3/S4 – normal position for this device is fixed at 90 degrees (the top edge of the base case). For this instrument, this means the switching of the amplifier is synchronized at the center of S2/S3 full open – normally the synchronization is at the center-point of the shutter transition from S2 to S3 (or reverse).
- Concerning the data set from the observations made at the instruments home station since 1979: The problem of the loose Q2-lever, and the loose prisms make it difficult to evaluate the results of the intercomparison with respect to the station's data. Normally the instrument is operated in the first intercomparison in the condition and manner as used at the station, so the results are representative of the station operation. As the looseness of the optical parts make the condition of the instrument unstable, it is unclear if the initial intercomparison is representative of station operation. The history of the standard lamp test and mercury lamp tests indicate that the results of standard test become "noisy" after 1995. A suggestion is to compare the results of the station measurements to the TOMS overpass data for the station in a time series, before deciding on a method of re-processing the existing data. **A report of the reprocessing of the data must be made and the reprocessed data submitted to the World**

Ozone and UV Data Center in Toronto, Canada.

- No operator from the instrument's home station was present at the intercomparison. It is highly recommended that special training be given to the operators at the home station when the instrument is returned to operation.

General Comments about D003 condition.

- This instrument arrived in China in 1937, and is the oldest Dobson instrument still in operation. The original instrument was likely designed to operate on the C wavelengths only. The instrument was modified to be able to select wavelengths in Canada in 1979, with the addition of the Q-plates and pointers. The electronics were replaced with more modern (for 1979) electronics.
- The mounts for the optical components are different than in newer instruments. In particular, the mirror mounts are designed for more easily and precisely moving the mirror than the mounts in newer instruments. The Prism mounts seem more fragile than those in more modern instruments. Other components have more adjustments available than in other instruments, showing that this instrument is more of a prototype.
- The Wedges are installed the reverse of other instruments – and the R-dial is scribed backwards of other instruments.
- The arrangement of the rods that operated the shutter masks for the slits is different from other instruments, and is on the right side of the right-left centerline (reverse of other instruments).

ANNEX C

WMO/GAW Regional Intercomparison of Dobson Spectrophotometers for Asia (Tsukuba, Japan, 3-20 March 2003)

Figures

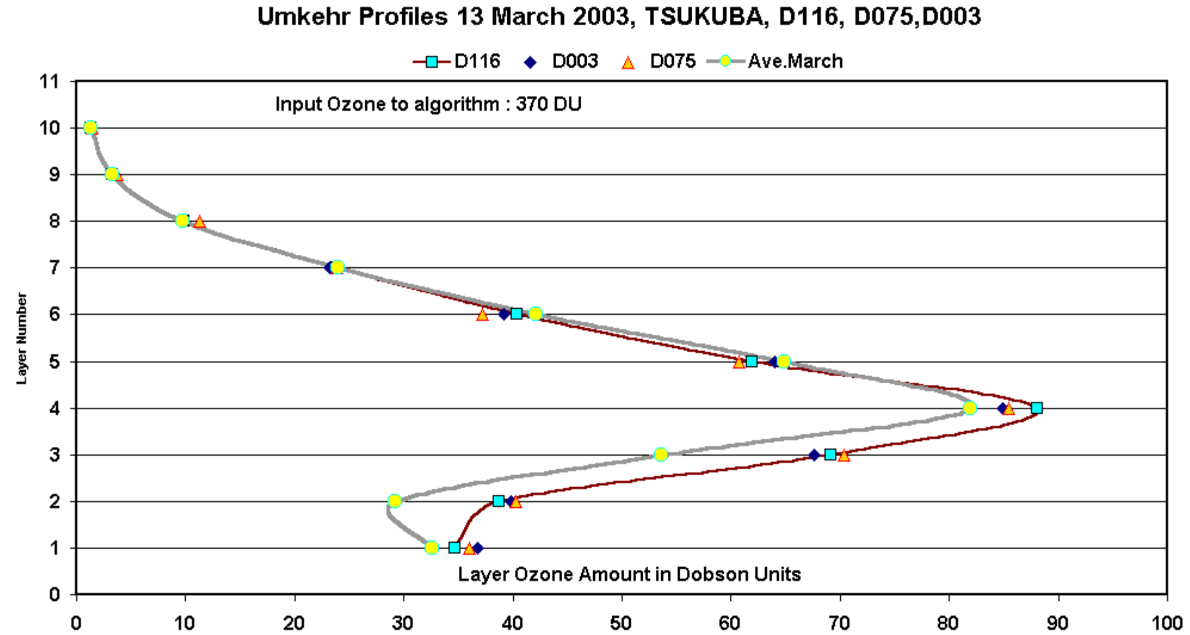

Figure 1. Results of Umkehr Observation

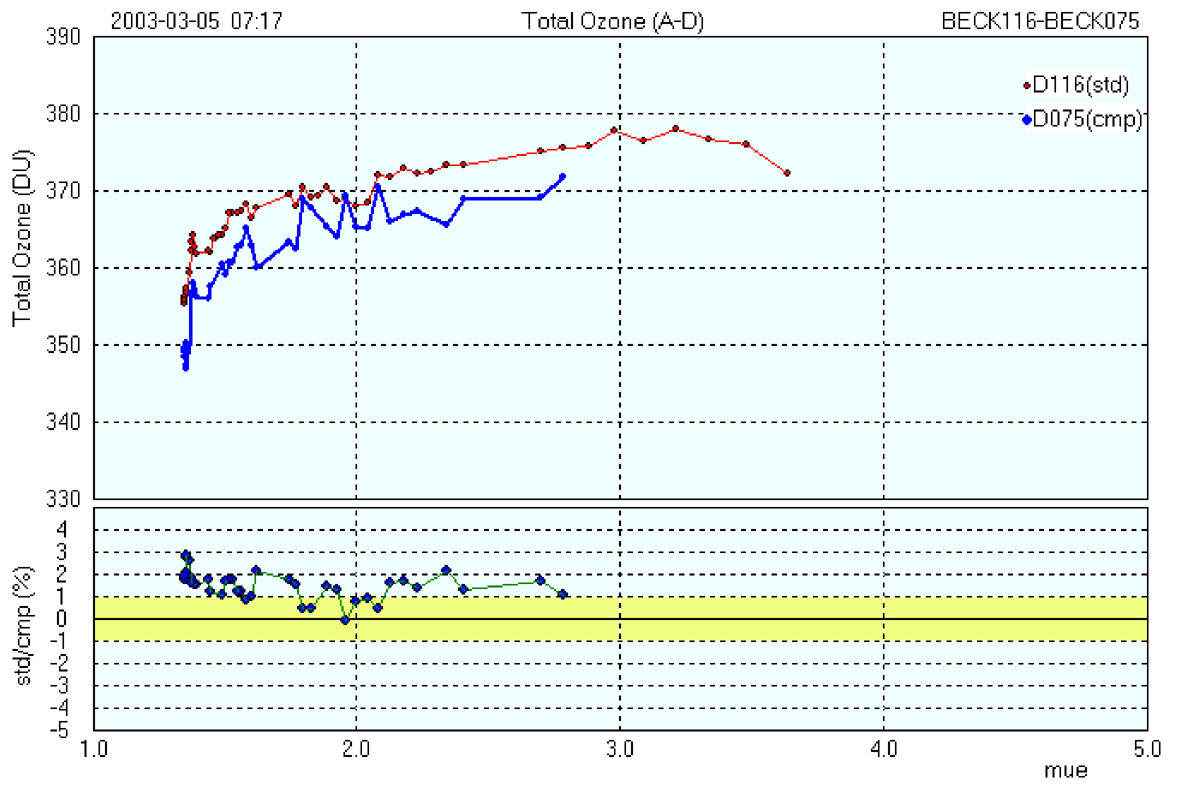

Figure 2. Results of initial intercomparison D116 Vs D075

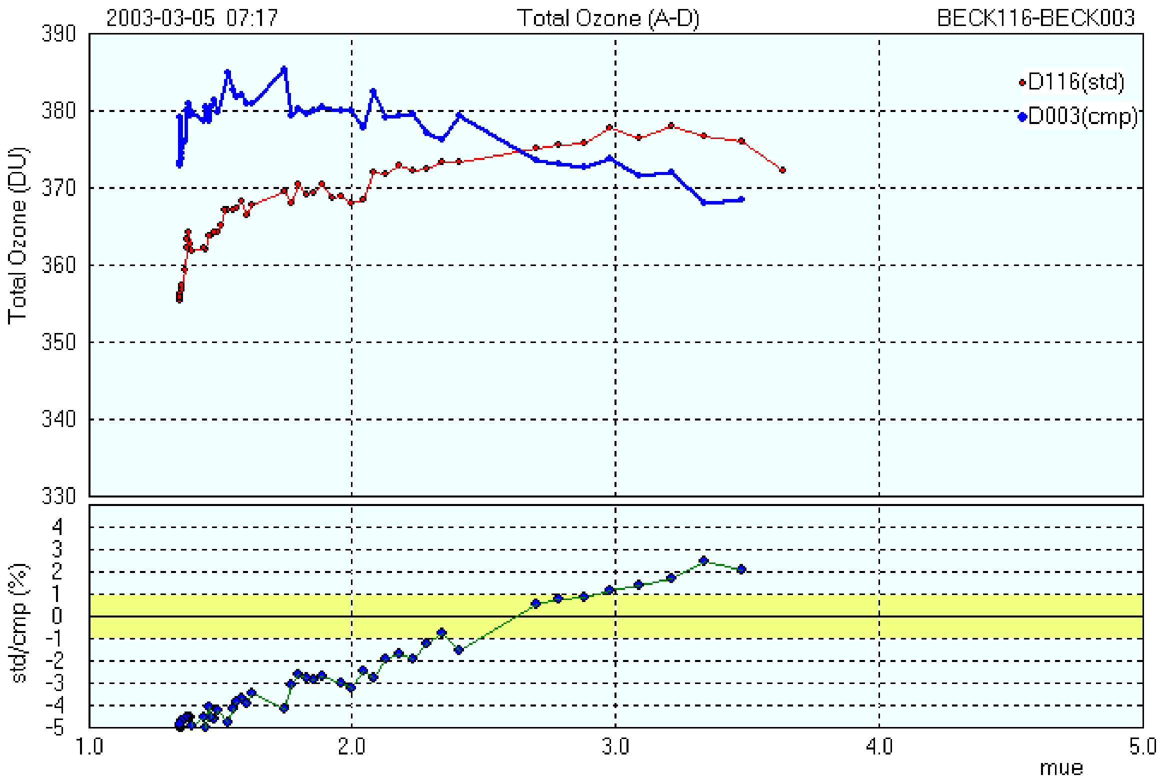

Figure 3. Results of initial intercomparison D116 Vs D003

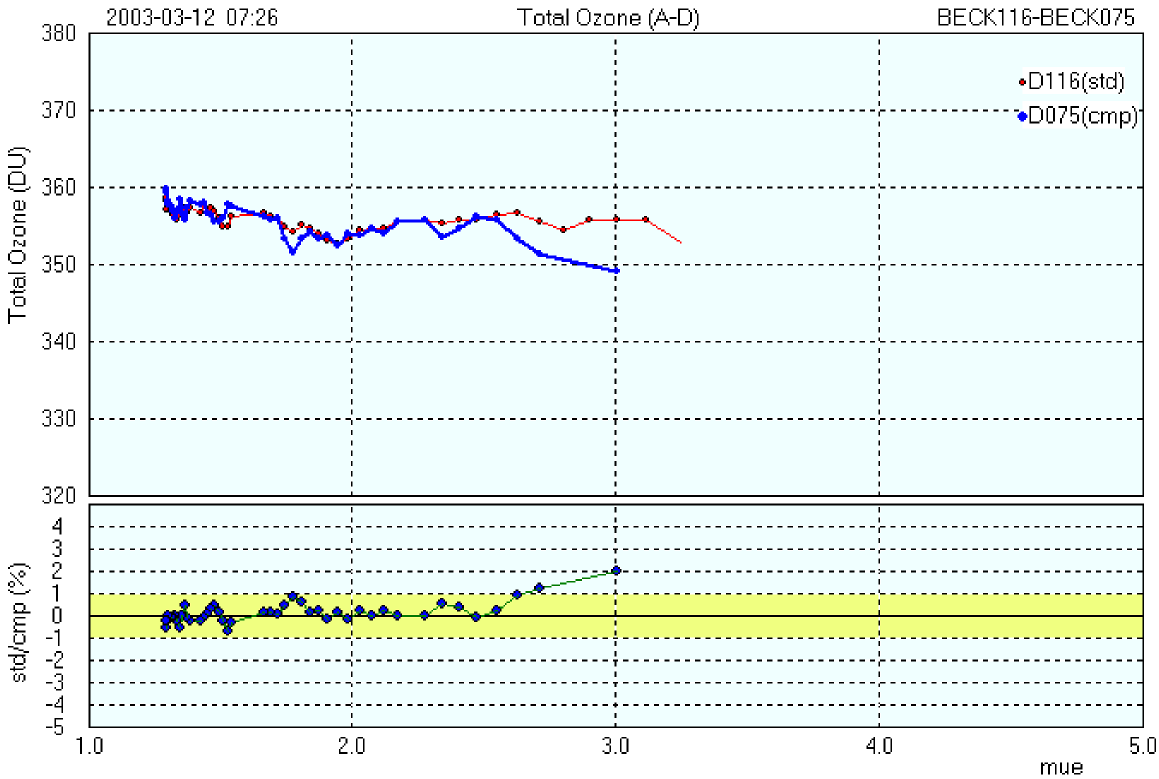

Figure 4. Results of final intercomparison D116 Vs D075

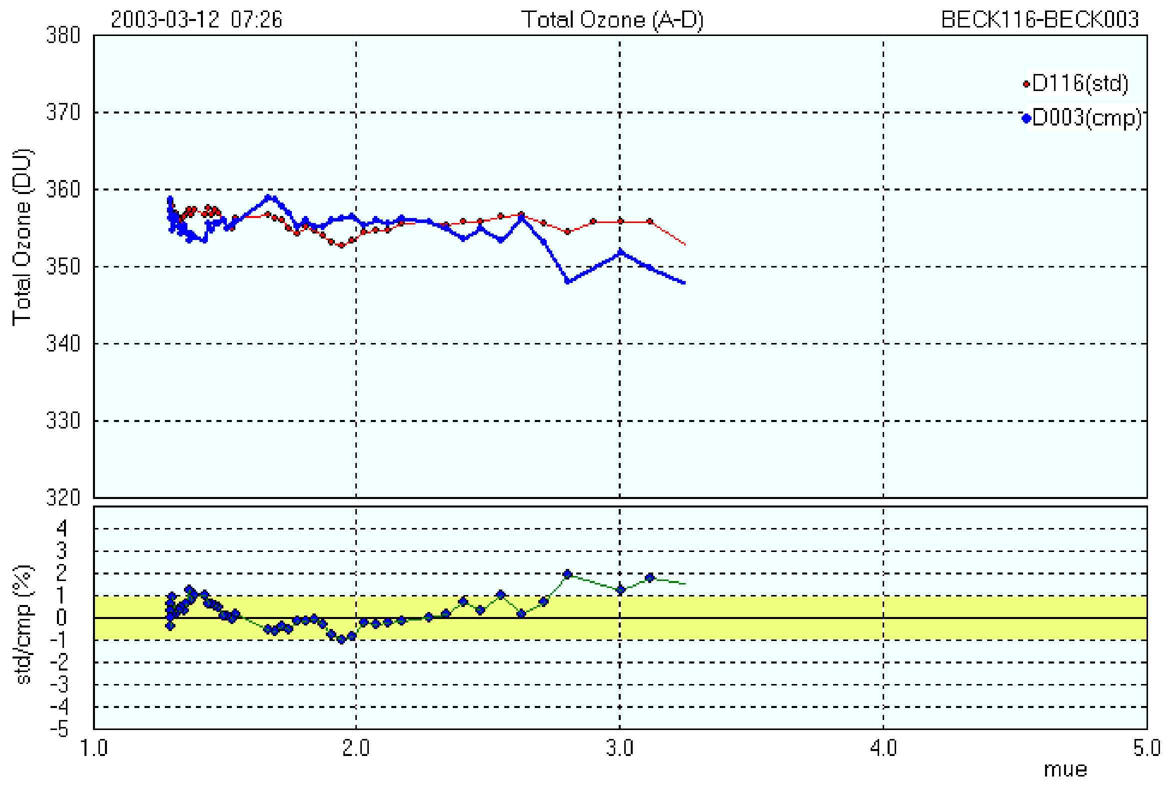

Figure 5. Results of final intercomparison D116 Vs D003

ANNEX D

DEFINITIONS

A, C and D Wavelength Pairs: The Dobson instrument measures the difference between the intensity of selected wavelengths in the range of 3000 to 3400 Angstrom. Certain pairs were chosen to measure ozone. These are called the A, C and D pairs. There was a B, but it is rarely used due to interference by other atmospheric absorbers.

Intercomparison: Series of simultaneous measurements made by several Dobson instruments, one of which is a standard. Usually, the time period is chosen so the measurements are made over a wide range of Mu.

Standard Lamp Test: A measurement of the N-values of a specific Quartz-Halogen(normally) bulb for the standard wavelength pairs. These bulbs are usually specific to an instrument. The result is used as a measure of the drift of the instrument's specific ETC.

Q-setting Table: The table used to set the instrument's wavelength controls to a wavelength pair. The setting is dependent on instrument temperature. The controls are rotatable quartz plates, hence the name Q-setting.

Discharge lamp test series: A series of measurements on various spectral lines from discharge lamps to calibrate the instrument's wavelength controls.

Mercury Test: A test to determine the correctness of the Q-setting table with respect to a single spectral line of mercury. Normally performed routinely to verify the optical alignment of the primary (right hand side) optics to the slit S2.

Symmetry Test: A series of tests on two spectral lines of mercury to verify the spectral dispersion, and the right to left side alignment of the optics.

Wedge Calibration: The procedure used to determine the density of the optical wedge used in the instrument.

Mu: Normalized optical path length through the atmosphere of radiation at the wavelength used by the Dobson instrument. Calculated from the solar zenith angle, Mu ranges from 1.0 (sun overhead) to greater that 12.0 (sun on the horizon).

G-table: Table relating the position of the optical wedge, defined by degrees of arc on the R-dial, to relative attenuation. The Wedge Calibration defines G-tables for each A, C and D wavelength pair.

N-table: A G-table converted by the addition of the instrument's extra-terrestrial constant (ETC) to all the entries. The ETC can be determined by lamps with a known N-value, direct intercomparison with a standard Dobson instrument, or by a Langley plot method.

Umkehr Measurement: A series of measurements made on the clear zenith sky as the sun rises or sets. The shape of the measurements when plotted against zenith angle is controlled by the ozone distribution with height. The series of measurements can be used to determine the ozone vertical profile.