PART III

WMO/GAW International Comparison of Dobson Spectrophotometers

(Pretoria, South Africa, 18 March - 10 April 2000)

1. PURPOSE OF THE INTERCOMPARISON

The Intercomparison (SAWB2000IC) was organized by the World Meteorological Organization (WMO) Secretariat and the South Africa Weather Bureau (SAWB) in close cooperation and with the assistance of the USA National Oceanic and Atmospheric Administration's Climate Monitoring and Diagnostics Laboratory (NOAA/CMDL). In addition, the Czech Hydrometeorological Institute contributed a skilled person for training of operators in instrument and station management. It was a campaign to maintain the quality of the network of the Dobson ozone spectrophotometers operated in Africa. 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 requirements for monitoring atmospheric total ozone.

The main tasks were:

- The technical inspection and adjustment of the instruments. Three of the instruments received new amplifier electronics supplied by the WMO.
- Comparison of the Dobson spectrophotometers with the World Secondary Dobson Standard Instrument (WSSI) No. 65 from NOAA/CMDL's World Dobson Calibration Center (WDCC), Boulder, CO, USA, 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 programme.

2. ORGANIZATION

The Intercomparison was held at the South African Bureau of Standards (SABS) facility in Groenkloof, Pretoria from 18 March to 10 April 2000, and was arranged by:

Dr Gerrie Coetzee, the Convener of the intercomparison, assisted by Mr Danie Esterhuyse

Mr Robert Evans, the Scientific Director of the intercomparison, assisted by Mr Michael O'Neill.

Twenty specialists from eight countries and the WMO Secretariat participated at the Intercomparison – see Part III, Annex A. The following national Dobson spectrophotometers were inspected, adjusted and compared at the SAWB2000IC:

Dobson No.	Country	Station
D011	Algeria	Tamanrasset
D015	Botswana	Maun, Botswana (Planned GAW Station)
D018	Kenya	Nairobi
D057	Seychelles	Victoria Airport (Rawinsonde station)
D065	USA	Boulder - World Secondary Standard Instrument. (WSSI)
D089	RSA	Irene
D132	RSA	Springbok
D5703	Nigeria	Lagos

The Intercomparison was conducted and all activity arranged in daily schedules according to the weather conditions and with respect to the technical state of the individual instruments. The technical support of the SAWB, the SABS and special facilities from NOAA, Boulder, CO, USA were used during SAWB2000IC.

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

- Unpacking the instrument, and an inspection following transport to the site.
- Inspection of the technical condition of the Dobson spectrophotometer and its functioning by means of daily standard lamp (SL) and mercury (HG) lamp tests.
- Initial comparison against the WSSI to determine the existing calibration level.
- Definition of the technical adjustments and special tests required (wedge calibrations, discharge lamp tests, cleaning and adjustment of the optics etc.).
- Final comparisons against the WSSI.
- 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 with the operator in charge on the results of his instrument intercomparison and other calibrations. 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 the SAWB2000IC.

The history of repairs and adjustments and the results obtained for individual instruments are summarized in Part III, Annex B. This information has been saved in detail by operators and by the Scientific Director of the Intercomparison.

The success of the event was accomplished mainly through instructions provided by the Scientific and Technical Directors at the regular meetings of all participants.

With regard to the goal of sharing knowledge on the operation of the Dobson instrument and the management of an observing programme, the individual participants were required to perform the necessary calibration procedures under the supervision of the scientific staff. For example, the instruments own operator undertook all wedge calibrations. The operator, under the supervision of the scientific staff also made electronic and other repairs.

3. OTHER ACTIVITIES

- The participants of the SAWB2000IC took part in an Ozone Measurements Workshop and presented several contributions related to monitoring total ozone and functions of the global ozone monitoring network.

- Dr Mike Proffitt, scientific officer, WMO Secretariat, Geneva visited the SAWB2000IC and discussed important issues related to the operation of the GAW total ozone monitoring programme.

- Dr R. Stolarski and Dr Gordon Labow from the USA National Air and Space Administration visited the intercomparison in an effort to understand and reduce the differences between ground-based and satellite measurement.

- During the Intercomparison participants attended presentations by Mr Karel Vanicek from CHMI, Hradec Kralove. These were designed to increase theoretical knowledge on the Dobson instrument, improving its operation, and implementation of new tools for data processing and data management at home stations. The following topics were explained, discussed and practised at these presentations:

- Theory of measurement of total ozone by means of UV solar radiation, specifically using the Dobson spectrophotometer.

- Reason and physical background of Mercury tests and Standard lamp tests and their routine performance at stations.

- Updating of Q-tables and N-tables at stations.

- Description of the DOBSON-3.0 and DOBSTOOL software package.

- A detailed description of rules for coding total ozone data reports in extCSV format - application for the Dobson stations

- Recommended facilities at Dobson observatories for a maintenance of the instrument

- Maintenance of the Dobson network under the GAW Project:

    - All participants received an updated software DOBSON version 3.0 and received instruction in its operation. Calibration histories of individual Dobson instruments were also investigated.

4. CONCLUSIONS

All participating instruments left the intercomparison properly calibrated with a precision of the DS observations less than 1% limit with the WSSI spectrophotometer.

5. RECOMMENDATIONS

- The Scientific Director of the SAWB2000IC acknowledged the excellent support and infrastructure provided to the intercomparison by SAWB and SABS. It was recommended that the intercomparison be repeated in another four years.

- An important part of an intercomparison with a large number of participants is the sharing of instrument operations and observing programme experiences. The addition of participants who are users of the data enabled effective communication between the data producers and users. The participants recommended that WMO continue to organize regular meetings of the monitoring community and data users.

6. ACKNOWLEDGEMENT

The South African Weather Bureau, in remembrance, acknowledged the magnanimous contribution from their esteemed colleague, Cal Archer, who had devoted the last ten years to efforts ensuring the re-establishment of the Weather Bureau’s ozone research and monitoring programme. Cal Archer passed away on Friday, 17 March 2000, and unfortunately could not join the momentous occasion of participating in the First African Regional Dobson Intercomparison meeting, which undoubtedly would have been one of the most conspicuous highlights of his career.

Special appreciation was afforded to the South African Bureau of Standards, Groenkloof, Pretoria for providing the excellent facilities and infrastructure to conduct the Pretoria IC2000 Meeting and Workshop. Special thanks were given to Mr Marinus Lindhout, the facility maintenance and terrain manager for ensuring smooth logistical and technical assistance during the event.

PART III, ANNEX A

WMO/GAW International Comparison of Dobson Spectrophotometers

(Pretoria, South Africa, 18 March – 10 April 2000)

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PART III, ANNEX B

WMO/GAW International Comparison of Dobson Spectrophotometers

(Pretoria, South Africa, 18 March – 10 April 2000)

Individual Instrument Reports

Instrument: D011

Station: Tamanrasset, Algeria

Original Calibration Data:

N-tables from 22 July 1993, intercomparison in Boulder, Colorado, USA. Reference standard lamps 11Q1, 11Q2, 11Q3, UQ1 and UQ2 (Those three last lamps are held in Boulder.)

Initial Calibration Results:

24 March 2000 -- Adjustments based on the results of Standard Lamp tests included.

d_Na:-3.3 d_Nc:-1.8 d_Nd:-1.6 d_Nad:-1.7

The d_Nad value implies an average **+2.4% error** in calculated ozone value, Mu=1 to 3, Total Ozone = 300 Dobson Units.

Work Performed:

1. New Electronics for the amplifier section was installed after the initial intercomparison.
2. Instrument optics were inspected and found to be dusty, but otherwise in very good condition.
3. The Mercury tests for verification of instrument alignment were performed, and in general were in specification, except for the S2Q2 to S3Q2 relationship (0.7 difference, versus expected 0.5). This small difference is not evident in the intercomparison results.

Final intercomparison:

New N-tables and reference standard lamp values will be defined from the results of the 24 March 2000 intercomparison. (Two other intercomparisons were performed, after the electronics were installed, with very similar results)

Highest Difference against the standard for ADDSGQP observations in mu range 1.15 to 3.2 was -1% in total ozone, at high mu.

Recommendations and comments:

1. The instrument's thermometer was broken before the first intercomparison, and used in the intercomparison. Results from the other intercomparisons, using a new thermometer, implied no problem with the first intercomparison.
2. The standard lamp adjustments are quite large, (7.0, 5.7, 4.0), and do not correctly represent the instrument's calibration change. The instrument's data record should be recalculated, including both the lamp adjustments, and an additional correction of Nad Difference of –1.7 from start of observations to the present. The result ozone data set should then be compared to the satellite data set, as a verification of this reprocessing.
3. An external drier unit should be constructed for and used with this instrument.
4. A personal note: Mr. Bouziane Ouchene, the operator of this instrument was an indispensable part of this intercomparison. He took responsibility in assisting with the repair and rebuilding of other instruments participating in the intercomparison. This action is greatly appreciated by the directors of the intercomparison.

Instrument: D015

Station: Maun, Botswana (proposed)

Original Calibration Data:

G-tables from August 1994

Initial Calibration Results:

Not Applicable, as the instrument has no history of measurements

Work Performed:

1. Electronics were replaced with latest USA type, and shutter drive was replaced with induction motor with toothed belt and pulley drive.
2. The LHS mirror was found to be out of symmetry with the RHS by about 10 degrees of Q-setting. The mirror was adjusted to within a degree.

Final intercomparison:

09 April 2000

Highest Difference against the standard for ADDSGQP observations in mu range 1.15 to 3.2 was +1.7% in total ozone, at low mu.

Recommendations and comments:

3. This instrument was originally used at Arosa, Switzerland since the 1930's, was rebuilt at least twice, the latest was in 1994. The instrument was compared against D065 in 1995, and this intercomparison repeats the Nad difference and Ncd differences to a tenth.
4. The higher ozone values at low mu (high sun) were not evident at the intercomparison in 1995, which was done at a higher total ozone value.
5. The N-values associated with the standard lamp values are unusually large.

Instrument D018

Station: University of Nairobi, Kenya

Original Calibration Data:

Ntables dates date 07 March 1995. Archie Asbridge in Nairobi produced the tables, and the ETC was determined by standard lamps. Reference standard lamps: 18V, 18W, 18Y, and 18Z, dated the same.

Initial Calibration Results:

24 March 2000

Adjustments based on the results of Standard Lamp tests included

d_Na:-2.6 d_Nc:-1.5 d_Nd:-2.5 d_Nad:-0.1

The d_Nad value implies an average **+0.2% error** in calculated ozone value, Mu=1 to 3, Total Ozone = 300 Dobson Units.

Work Performed:

1. A wedge calibration was performed on 28 March 2000. This wedge calibration was applied to the 24 April 2000 intercomparison without making a useful difference.
2. The wedge and optics were cleaned, and another wedge calibration performed.

Final intercomparison:

03 April 2000 – Use this intercomparison, and the 1995 Ntable to define new tables, and new reference standard lamp values.

Highest Difference against the standard for ADDSGQP observations in mu range 1.15 to 3.2 was –1.8% in total ozone, at low mu.

Recommendations and comments:

1. Existing data set from 1995 appears to be correct as existing.
2. The wedge calibration after the cleaning is not significantly difference from 1995-wedge calibration, and the 1995-wedge calibration will continue.
3. When the instrument arrived there was an unexpected shift of approximated -0.6 in the Mercury test results. (Home station is about the altitude.) Investigation showed that the right hand mirror had likely moved slightly. Only the Q-setting table was changed.
4. The instrument seems to have some instability in mercury lamp unit. The operators are advised to repair or replace the lamp.
5. An insulating cover should be used on the instrument.
6. An external drier unit should be constructed and used.
7. The rhodium plate for slit S2 should removed, so that it will not be accidentally moved into the light path.

8. The Q2 lever becomes loose in temperatures below 18DegreesC. The mechanism is of an ancient design, and it unclear how to correct this problem with out making the lever inoperative at high temperature. If repair at the station is needed, other experts should be consulted. (Note the reading, if the Q-plate is made to 90 degrees to the bottom of the lid.)
9. The instrument does produce lower ozone values on the AD pair on high sun. The observing schedule at the station is for observation at Mu=1.7, and higher, so this is not a problem in the data set.

Instrument: D057

Station: Seychelles Rawinsonde

Original Calibration Data:

Ntables from 1988. One standard lamp 57Q7, with no references. Note that the instrument is used only on the AD pair. Observations are made on a limited basis – daily early morning or late afternoon. This is approximately mu range 2.0 to 1.5.

Initial Calibration Results:

31 March 2000

d_Na:+0.8 d_Nc:na d_Nd:+2.1 d_Na:-1.3

The d_Nad value implies an average **+2.0% error** in calculated ozone value, Mu=1 to 3, Total Ozone = 300 Dobson Units.

Work Performed:

1. The instrument's electronics were the of the UK "spinning lights" type. After the initial intercomparison, and a light cleaning of the optics (wedge was not cleaned, as it was not dirty.), The electronics were replaced with a combination of the Bertan high voltage supply, and the amplifier of the 1972 "Bob Grass" type. This combination can be supported by regional and international calibration centers.

Final intercomparison:

08 April 2000 – On a limited mu range

Highest Difference against the standard for ADDSGQP observations in mu range 1.5 to 2.5 was 0.2% in total ozone.

Recommendations and comments:

2. The Power supply for the standard lamps is damaged, and an external meter at the main terminals inside the power supply must be used to read the voltage. The power supply should be repaired in a manner that the voltage can be read more easily.
3. The mercury lamp power supply is highly corroded. A newer, safer mercury lamp and power supply should be obtained. (Bob Evans will supply from WMO stock.)
4. The Standard lamp holder is highly corroded. Again a new holder should be obtained. (Bob Evans will supply from WMO Stock.)
5. The initial intercomparison and the existing standard lamp should be used to process the existing data set. The 57Q7 bulb is given the reference values of **RA=20.1, RC=24.7, and RD=29.7,** based on lamp test on 31 March 2000.
6. The station is supplied with two new bulbs: 57Q8 and 57Q9. The 57Q8 should be used for monthly tests, the 57Q9 should be used every 6 months with the 57Q8, and the 57Q7 should run yearly with the other two bulbs.
7. The observation schedule used in the past at the station should be maintained.
8. The final intercomparison was made with the operator learning how to use a different set of electronics, and just before the operator was to leave for the airport. There is more uncertainty in the results.
9. A wedge calibration was performed, due to lack of time. This instrument should attend the next possible regional intercomparison to have the wedge calibrated.

Instrument: D089

Station: Irene, RSA

Original Calibration Data:

Ntables from 12 February 1997 intercomparison with D083 in Perth, Australia. Many Standard Lamps.

Initial Calibration Results:

24 March 2000

Adjustments based on the results of Standard Lamp tests included

d_Na:+0.7 d_Nc:-0.3 d_Nd:0.2 d_Nad:+0.5

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

Work Performed:

1. Electronics were replaced with the newest NOAA type. The instrument had been modified with a Bertan type high voltage power supply with twin fine control potentiometers.
2. Reference values of 89Q6, 89Q7, UQ1 and UQ2 were defined on the same level as the existing lamps.

Final intercomparison: None, as the instrument is within calibration of the standard.

Highest Difference against the standard for ADDSGQP observations in mu range 1.15 to 3.2 was –1.1% in total ozone.

Recommendations and comments:

3. No change in the calibration, but the calibration date will be changed to 24 March 2000 so as to reflect the work done here.
4. The instrument participated in two other intercomparisons (31 March and 08 April 2000, including one after the electronics were replaced. The results matched the initial intercomparison results within tenths of an N-value. All of the intercomparisons showed a match of less than one percent.
5. This instrument can be considered a regional standard, and can be used to calibrate other instrument. As the instrument has shown a high mu dependence at high ozone, and high mu, the intercomparison period should be restricted to mu less than 2.5.

Instrument: D132

Station: Springbok, South Africa

Original Calibration Data:

11 February 1995 Ntable by comparison with D089, and G-table performed during the same period. Many reference lamps. Note: Reference lamp values have been adjusted based on a 1997 intercomparison with D089 after the calibration was verified in Perth, Australia, against D083.

Initial Calibration Results:

An initial intercomparison was performed on 24 March 2000. The results were that the instrument was approximated 2 per cent too high on calculated ozone. A wedge calibration was performed, but during the set up for the wedge calibration, a loose ”connection” between the R-dial and the wedge was discovered. An extremely small setscrew on the pulley at the bottom of the R-dial was loose. As this pulley was loose, the wedges could be moved independent of the R-dial. As one wedge would touch the end of the wedge

bridge before the R-dial stop would stop the movement, it was apparent that the wedges had shifted. The setscrew was tightened, and wedge calibration performed. This calibration was applied to the intercomparison of the 24 March 2000, without improving the results. Another intercomparison was performed on 03 April 2000, with good results against the standard.

Because of this mechanical failure, the intercomparison of 24 March 2000 cannot be used to evaluate the calibration level of the instrument and level of the existing data set.

Work Performed:

1. Tightened setscrew.
2. The electronics were replaced with the latest USA type. During the replacement a cable carrying the digital signal from the photon-coupled interrupter to the electronics was routed close to the anode circuit of the photo-multiplier tube (PMT). When the instrument was turned on, an offset was evident in the output. An electronic filter was added to the amplifier circuit to eliminate the offset. After this, the instrument sensitivity was incorrect – the instrument output would ”blank out”, and take time to recover, if the signal was slightly too strong. An intercomparison was performed in this condition, but will not be used due to this problem, which was corrected after the intercomparison.
3. No intercomparison was performed after the replacement of the electronics – four other instruments had a replacement of the electronics, without a change in calibration.

Final intercomparison:

03 April 2000. A new calibration will be created from the existing N-table and new Reference standard lamp values will be defined.

Highest Difference against the standard for ADDSGQP observations in mu range 1.15 to 3.2 was –0.8% in total ozone.

Recommendations and comments:

1. This instrument is one of four built in 1994. Other instruments in this series have had the problem with the setscrew also. This problem should be solved in a more permanent manner. (Suggest contacting Ing. Maximo Ginzburg, who has the other three instruments for a consistent repair for the series of instruments.)
2. The other instruments have had problems with the shutter speed varying due to wearing of the pulleys in the friction drive system. Again, a solution should be found for all the series.

Instrument 5703

(Dobson Style Shimatzu Ozone Spectrophotometer)

Station: Lagos, Nigeria

Original Calibration Data:

Ntables from 22 July 1993 intercomparison with D065 in Boulder, Colorado. Reference Standard Lamps.

Initial Calibration Results:
(See Recommendations and Comments section.)

31 March 2000

Adjustments based on the results of Standard Lamp tests included

d_Na:+2.3 d_Nc:-0.2 d_Nd:-0.7 d_Nad:+3.0

The d_Nad value implies an average **-4.4% error** in calculated ozone value, Mu=1 to 3, Total Ozone = 300 Dobson Units.

Work Performed:

- The instrument arrived with a problem that made it almost impossible to get reliable results from the mercury lamp test. Investigation showed that the shutter motor speed had dropped to a value that made it very sensitive to AC line noise interference. As the motor drive system is a pulley drive with an induction motor, the output shaft speed is defined by the AC line frequency, and the shutter speed is then defined by the pulley drive ratio. Some time was spent in repairing this problem, including replacing the motor starting capacitor. The problem may be more in the bearings on the shutter drive shaft.
- The instrument was cleaned, and the mirror reset to match the LHS side. The Q-plates were checked with a 90-degree angle, and found to be correct. There was an obvious film on the wedges – almost like a spider web. (Note: The wedges are tilted in this instrument.)
- The instrument is different enough from a standard instrument, that a wedge calibration cannot be easily performed, unless a special mounting plate for the S4 bulb is made, and a connector from the R-dial to the encoder fabricated.
- The instrument has three rod for wavelength selection. Normal operation is with the center rod out, and the right and left rods at the ”B” position. To perform the S3Q-test, the right rod is pulled out.
- Q-levers were tightened – note that this instrument has an adjustment for this purpose.
- High voltage power supply was replaced after the intercomparison.

Final intercomparison:

03 April 2000 (See Comments and Recommendation section.)

Highest Difference against the standard for ADDSGQP observations in mu range 1.15 to 3.2 was –0.3% in total ozone.

Recommendations and comments:

- The Intercomparison on 31 March 2000 was performed on a limited range of mu. A second set of measurements was made in the afternoon of 01 April, 2000, on a lower sun through breaks in the cloud cover. The D_Nad was the same; implying that the difference was not due to wavelength errors. This large D_Nad at a low latitude station making observations on lower amounts of ozone, would create larger errors, and a marked mu dependence in the calculated ozone.
- The Intercomparison on 31 March 2000 was also performed with the RHS mirror out of place by about 3 degrees. The Q-table had been adjusted to account for this shift.
- After cleaning the wedge and resetting of the RHS mirror, an intercomparison was performed on 03 April 2000. If the results of standard lamp corrections from tests made after the cleaning are included, the result is that the instrument matches the standard within one percent – in all mu ranges and wavelengths. This implies that the wedge calibration is correct. Performance is very similar to the intercomparison with D065 in 1992.
- New Ntables and reference standard lamp values were defined from the 03 April 2000 intercomparison -- these are to be used for all future data reduction.
- External drier unit should be made and used.
- Body of instrument can be cleaned with cleaner wax for automobiles.
- The quilted cover should be used at all times, but a sheet over the instrument will help to keep dust out of the instrument.
- Reference values for Q5 and Q6(Q4new) for the period before the intercomparison are taken as the values from the tests of 31 March 2000.
- The Q4new was renamed Q6 after the intercomparison to avoid confusion.

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 Ångstroms. 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-value 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(μ): Normalized optical path length through the atmosphere of radiation at the wavelengths 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.