Regional Intercomparison of Dobson Spectrophotometers for Asia
Aerological Observatory of the Japan Meteorological Agency in Tsukuba, Japan
6-24 March 2006
(DIC-T2006)

Final Report

Prepared by
Robert D. Evans
Koji Miyagawa
Karel Vanicek

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1. Purpose of the Intercomparison

The Japan Meteorological Agency (JMA) and the Ministry of the Land, Infrastructure, and Transport (MLIT, supervising Ministry of JMA) sponsored the WMO/GAW Regional Intercomparison of Dobson Spectrophotometer for Asia, 2006 (DIC-T2006), as the activity of WMO Regional Dobson Calibration Centre for Asia (RDCC-A) operated by the JMA. This campaign was supported by the budget of Official Development Assistance (ODA) of the Japanese Government. Additional support in the form of expert personnel was provided by the Czech Hydrometeorological Institute (CHMI, the research and development project RP/32/2004) and the U.S. National Oceanic and Atmospheric Administration (NOAA). The main purpose of the DIC-T2006 mission was to support the maintenance and to improve function of the ground-based total ozone monitoring network in the RA-II Region. The long term, quality controlled total ozone data obtained from Dobson observations within the framework of the WMO Global Atmosphere Watch (WMO/GAW) are essential to assessment of the state of the ozone layer by accurate and reliable ozone data.

The DIC-T2006 consisted of the intercomparison of Dobson Instruments with the Regional Standard Dobson Instrument D116, maintained by the JMA. Instruments and personnel from India, the I.R. of Iran, Pakistan, the Philippines, and Thailand, attended the Intercomparison. Most of these Dobson spectrophotometers were last calibrated at the previous Dobson Intercomparison in Tsukuba (DIC-T1996).

The main tasks of the mission were:

- The technical inspection, repair, and adjustment of the instruments.
- Comparison of the Dobson spectrophotometers with the Regional Standard Dobson Instrument No. 116, by simultaneous side-by-side observations on the Sun to determine the existing calibration level.
- Determination of new calibration constants for each Dobson spectrophotometer, as needed.
- To provide participants with instruction for operation of the Dobson spectrophotometers and processing the observations at home stations, and sharing of knowledge concerning the management of the ozone observing program.

2. Operation

The Intercomparison stage of the DIC-T2006 was held on the roof platform of the Aerological Observatory at Tsukuba. Technical work on instruments and processing of tests and observations were performed in the laboratory facility in the same building, which was equipped with high-tech infrastructure and the computer network. The DIC-T2006 technical operation was controlled by the Scientific Committee consisting of following experts:

R.D. Evans, Scientific Director of DIC-T2006

	Head, the World Dobson Calibration Centre, NOAA-GMD, Boulder, Colorado
Koji Miyagawa	Technical Director of DIC-T2006, Expert, Regional Dobson Calibration Centre for Asia (RDCC-A), JMA, Tsukuba, Japan
Karel Vanicek	Expert in Dobson data Quality Control and evaluation, CHMI, Czech Republic
Martin Stanek	Expert in Dobson repair and optical alignment, and data processing Regional Dobson Calibration Centre for Europe (RDCC-E), CHMI, Czech Republic

The following national Dobson spectrophotometers and their operators participated in the DIC-T2006:

Instrument.	Operator	Station/Country
D052	Mrs. Hannagrace Cristi	Manila, Philippines (Philippine Atmospheric Geophysical & Astronomical Services Administration)
D090	Mrs. Duanchai Uraiwan	Bangkok, Thailand (Thai Meteorological Department)
D100	Mr. Saifullah Shami	Quetta, Pakistan (Pakistan Meteorological Department)
D109	Dr. Majid Mazraeh Ei Farahani	Tehran, I.R. Iran (Tehran University)
D112	Dr. Sunil Kumar Peshin	New Delhi, India (India Meteorological Department)

The Intercomparison (IC) was performed and all works were done in daily schedules according to the weather conditions and with respect to the technical state of the individual instruments. The technical facilities of the Aerological Observatory of JMA, Tsukuba, were used to conduct the IC.

The main steps specified below were generally accepted for each Dobson spectrophotometer:

- The instrument was unpacked, checked to determine its condition after the transportation to the DIC-T2006, and then installed at the DIC-T2006 platform.
- The technical and working condition of the spectrophotometer was monitored by means of the daily Standard and Mercury lamp tests.
- An initial comparison was made against the Regional Standard Spectrophotometer D116 to determine the existing calibration level before any technical operations are done on the instrument.
- Definition of the technical adjustments and special tests required (wedge calibrations, discharge lamp tests, cleaning, and adjustment of the optics, refurbishing of the electronics, etc.).
- Final comparison against the Regional Standard Spectrophotometer D116
- Assessment of the results, determination of the 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/her instrument intercomparison and other calibrations. At this point, copies of documentation related to the spectrophotometer calibration were given to the operator.
- Interview of the expert on Data Quality with the operator on the current state of the ozone monitoring programme in the home country. Assessment of quality of Dobson observations, recommendations for evaluation of historical data sets and future development.
- Packing of the instrument and technical accessories for transport to home station.

All repairs or adjustments which were done and the results obtained for individual instruments are described in Appendix B. These pieces of information are saved in detail in the files kept by operators, by the scientific director of the IC and at the RDCC-A.

With regards to the goal of sharing the knowledge of the operation of the instrument, 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, all wedge calibrations were performed at least partially by the instrument's own operator.

An observation of the Umkehr effect was made on the evening of 20 March 2006, by all instruments plus the Tsukuba (Tatento) station instrument and the regional standard instrument. A balloon-borne ozonesonde was also flown at the Observatory that evening. The data was processed to produce Umkehr ozone profiles to compare with the profile obtained from the ozonesonde flight.

The participants each presented an overview of their organization's activities in an afternoon workshop.

4. Conclusions

All participating instruments leave the intercomparison with proper calibration constants and in correct operating order. (See Appendix B, Individual Instrument Results.)

Discussions of station operation and instrument maintenance were held amongst the participants and experts. From these discussions, the scientific and technical directors make the following recommendations.

5. Recommendations

A recommendation is made to WMO to

- Define and sponsor a more standard and modern electronic system for the Dobson instruments.
- To sponsor a station assessment program, to evaluate operation of instruments and data processing after the previous DIC-T1996 and to ensure data quality in the coming years. Because some participants of the DIC-T1996 have retired during the last decade, four of the operators at this intercomparison were relatively inexperienced in the operation of an observing program using the Dobson instrument.

The directors of the intercomparison urge that the three to four year schedule of Dobson Ozone Spectrophotometers intercomparisons be continued. The effect of ten years between instrument calibration and repairs is quite noticeable in these instruments, and in the change of personnel at the stations.

The directors strongly recommend the parallel processing of observations from these stations at RDCC-A, after instruments are re-installed at the normal operating site, until the station is shown to be able to produce high quality observations.

The directors are impressed with the amount of resources the various agencies of the Japanese government donated to this intercomparison, and to the measurement programs in this region.

Regional Intercomparison of Dobson Spectrophotometers for Asia
Aerological Observatory in Tsukuba, Japan on 6-24 March 2006
(DIC-T2006)

Appendix A

List of Participants

Czech Republic

Dr. Karel Vanicek
Mr. Martin Stanek
Solar and Ozone Observatory of CHMI
Hvezdarna 456
500 08 Hradec Kralove 8, Czech Republic
Tel: 420-495260352
Fax: 420-495264107
Email: vanicek@chmi.cz
Email: stanek@chmi.cz

India

Dr. Sunil Kumar Peshin
India Meteorological Department
Lodi Road,
New Delhi-110003 India
Tel No: 91-11-24635797
Fax No: 91-11-24699216 OR 91-11-24623220
Email: peshinsk@yahoo.co.in

Iran

Dr. Majid Mazraeh Ei Farahani
Institute of Geophysics
Tehran University
P.O. Box 14155-6466
Tehran, Iran
Tel: 98 21 8800 11 15
Fax: 98 21 8800 95 60
Email: majid1998@yahoo.com
Mazraeh@ut.ac.ir

Japan
Regional Dobson Calibration Centre for Asia

Mr. Toru Sasaki
Mr. Kazuaki Akagi
Ozone Layer Monitoring Office
Atmospheric Environment Division
Global Environment and Marine Department
Postal address:
Japan Meteorological Agency
1-3-4 Otemachi, Chiyoda-ku
Tokyo 1008122
Japan
E-mail: tsasaki@met.kishou.go.jp
Email: akagi@met.kishou.go.jp

Mr. Yasuo Hirose
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: y-hirose@met.kishou.go.jp
E-mail: miyagawa@met.kishou.go.jp

Pakistan:

Mr. Saifullah Shami
Geophysical Center,
Pak. Met. Dept.
Brewery Road
P.O. Box 2
Quetta, Pakistan
Tel: 92 81 853034
Fax: 92 81 854218
Email: dydirsushami@yahoo.com
metq@qta.paknet.com.pk

Philippines

Mrs. Hannagrace Cristi,
Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA)
Science Garden Complex,
Agham Road, Diliman, Quezon City
Philippines, 1101
Tel: 63 2 434 0955
Fax: 63 2 434 0955
Email: hannacristi@yahoo.com

Thailand

Mrs. Duanchai Uraiwan
4353 Sukhumvit Road,
Bangna, Bangkok 10260
Tel: 66 (2) 361 3640
Fax: 66 (2) 361 3640; +66 (2) 399 4563
Email: duanchai@metnet.tmd.go.th cc: ozone@metnet.tmd.go.th

United States

Mr. Robert Evans
NOAA/ESRL Global Monitoring Division
R/GMD-1
325 Broadway
Boulder, Colorado, 80303 USA
Tel: 1-303 497 6679
Fax: 1-303 497 5590
Email: Robert.d.evans@noaa.gov

Regional Intercomparison of Dobson Spectrophotometers for Asia Aerological Observatory in Tsukuba, Japan on 6-24 March 2006 (DIC-T2006)

Appendix B

Individual Instrument Reports

Instrument D052
Manila, Philippines

Original Calibration Data:

N-tables from the 1996 intercomparison against D116 in Tsukuba, Japan. Standard lamp 52Q1 without reference values.

History:

- The D052 was operated after DIC-T1996 routinely at the Manila station with a short interruption in December 2003 - March 2004 due to movement of the instrument to a new platform at the station.
- Total ozone data of the period 1996 - May 2002 have been submitted to the World Ozone and UV Data Centre (WOUDC). Total ozone observations of the period June 2002 onwards exist but they need to be evaluated using DIC-T2006 results for their quality before they are submitted to WOUDC.
- Until the present time, the observations have been processed manually. This method could cause subjective errors because current Dobson observers have not passed through an extensive training program.
- Some technical problems appeared on the D052 during its operation, mostly due to impacts of high humidity penetrating inside the instrument. These were investigated and partially fixed by the expert of JMA (K. Miyagawa) during his mission at the station in March 2004 – see his report available at the RDCC-A, Tsukuba.
- HG and SL tests were performed sporadically at the station. Results are very different in time and noisy – most probably due to different sensitivity of the instrument adjusted from test to test. Therefore a conclusion on long-term stability of the calibration state of D052 can not be made from the tests.
- The whole series of Dobson observations at Manila needs to be re-processed and re-evaluated using software tools developed by the RDCC-A. For this all the raw data have to be converted into electronic files.
- Relation of the existing ground and satellite observations confirm the above conclusions.

Initial Calibration Results:

Initial ICs was taken on 8 and 11 March, 2006. The results were not consistent. High differences have been found between morning and afternoon observations. Daily HG tests taken at DIC were in limits but SL tests showed changes that were equivalent to about 2% in total ozone – see below. The decision was made to open and clean the instrument and to fix it before the next IC.

The condition of the instrument is such that an initial intercomparison to determine the level of calibration was not possible. Due to the loose optical wedge, we can only estimate that the measurements are 3-8% to high, with very high variability. Using the results of Standard Lamp tests would perhaps bring the level down, but will not help the variability.

Work Performed:

- The cleaning was performed on 13 March 2006. All elements of the optical system were found dirty and the cobalt filter was cracked at many places and thus completely destroyed - evidently due to frequent penetration of the moisture inside the instrument at the station. This was the main reason of low accuracy of total ozone observations in recent years and it also caused inconsistent results of the initial ICs.
- Optical wedges were cleaned, and then glued into place.
- Since 14 March 2006 the SL tests were performed with a new SL power supply unit provided by JMA. Two new Standard lamps were also supplied by JMA.
- New mirrors have been installed at the D052 on 15 March 2006.

- Wedge calibration was performed on 16 March 2006.
- The lamp tests taken after the replacement of the mirrors have results that are shifted by +30 Units. Inspection of the boxes from which the mirrors came, indicated that these mirrors were likely from a batch on mirror made by Coherent Industries in the mid-1990's. Other mirrors from this batch appeared to have been made with the incorrect surface material. On 18 March 2006, prior to the final intercomparison the mirrors were replaced again with mirrors re-surfaced in Germany, and protected with a quartz layer.
- Shutter motor replaced.
- Many small improvements were made, including:
  - New Galvanometer, digital thermometer, and new insulating cover were supplied by JMA.
  - External drier system installed with assistance of JMA.
  - Other electronic spares were supplied by NOAA.

Final Intercomparison: **18 March 2006**

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

Recommendations/Comments.

- The instrument D052 should be operated and total observations processed with calibrations constants (N-Tables, Standard Lamp Reference Readings) defined at the DIC-T2006 from March 2006 onwards.
- The Q-Table must be verified by HG tests after the D052 returns from DIC-T2006 back to Manila.
- SL and HG tests should be done monthly and their results used for correction of N-Tables (Q-Table) before observations are processed.
- Total ozone observations of the period June 2002 - February 2006 should be evaluated using DIC-T2006 results for their quality before they are processed and submitted to WOUDC.
- Processing of Dobson observation by a PC must be implemented at the station. For this software tools either from JMA or CHMI are available. Before the software is installed and used at the station the measurements can be processed at RDCC-A, Tsukuba if raw data are submitted to Tsukuba together with HG and SL tests every month.
- Regular submission of total ozone observations to WOUDC, Toronto should be revived after DIC-T2006.
- The operating agency must provide a digital voltmeter for the new Standard lamp power Supply.
- The instrument must be protected from high humidity and high temperatures. The external drier must be operational continuously, and checked often.
- The operator is reminded that assistance is available with repairs and spare parts when needed through RDCC-A in Tsukuba, Japan. The support of the WMO/GAW programme is for stations that report the data to WOUDC in Toronto, Canada.

Instrument D090
Bangkok, Thailand

Original Calibration Data:

N-tables from the 1996 intercomparison against D116 in Tsukuba, Japan. Standard lamp 90Q2 and reference values.

History:

- The D090 is routinely operated at the Bangkok station with calibration constants defined at the DIC-T1996.
- The total ozone data are regularly reported to WOUDC.
- HG and SL tests are well performed almost every month and properly filed in forms.
- HG tests were in limits in 1996-2006.
- SL tests show a change of sensitivity of the instrument in October 2003 that affected accuracy of calculation of total ozone both at AD and CD double pairs. Magnitude of this change for AD total ozone was about 3.5 percent (for total ozone 270 DU and Mu=2).
- As it is not clear that proper corrections of the N-Tables were performed regularly every month at the station a re-evaluation of the data series of May 1996-February 2006 should be done – see instructions for observers given in the Recommendation section of this report below.

Initial Calibration Results

08 March 2006

d_Na: -3.1 d_Nc:-1.8 d_Nd:-2.9 d_Nad:-0.2
(Adjustments based on the results of Standard Lamp tests included.)

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

Comment on Initial intercomparison: This intercomparison consisted on measurements over the full day, but the readings for the afternoon from this instrument were used for the analysis. There was a discernable difference between results from the individual wavelength pairs in the morning to afternoon readings. The afternoon was taken better, as the instrument temperature was more stable, and the operator was more confident. The C-readings from the instrument were more noisy that normal in an intercomparison.

Work Performed:

- The instrument had many small faults that made the operation difficult. Numerous repairs were made to attempt to reduce electrical noise, and sudden changes in sensitivity. The electronics are of the 1976 USA type, and both the ten and twelve position selector switches were worn. A replacement twelve position switch was supplied by the JMA, but the ten position switch is not available. A circuit was devised to make the instrument usable.
- The power switches were replaced.
- The left side mirror was replaced.
- Q2 lever was repaired.
- Many small improvements were made, including:
  - New Galvanometer, digital thermometer, and new insulating cover were supplied by JMA.
  - External drier system repaired with assistance of JMA.
  - Other electronic spares were supplied by NOAA.

Final intercomparison: **18 March 2006**

Average Difference against the standard for ADDSGQP observations in mu range 1.15 to 3.2 was +0.1% in total ozone.

Recommendations/Comments:

- The instrument D090 should be operated and total observations processed with calibration constants (N-Tables, Standard Lamp Reference Readings) defined at the DIC-T2006 from March 2006 onwards.
- The Q-Table must be verified by HG tests after the D090 returns from DIC-T2006 back to Bangkok.
- SL and HG tests should be done monthly and their results used for correction of N-Tables (Q-Table) before observations are processed.
- NOAA/GMD will supply the station with new Mercury lamps and power supply, to be sent directly from the USA. The station personnel will make a new housing for the lamps.
- Regular submission of total ozone observations to WOUDC, Toronto should continue as in the past.
- An analysis of SL tests of 1996-2006 was made at the DIC-T2006. It shows that the calibration state of the instrument D090 was almost stable from May 1996 to September 2003 and thus total ozone observations of this period do not need to be corrected. A shift in the calibration condition of D090 appeared in August-October 2003. Then it was also almost stable onwards till February 2006. Because of this change the N-Tables of DIC-T1996 had to be corrected for processing of total ozone observations in the period October 2003-February 2006.
- The above correction can be made either month-by-month using monthly corrections for the whole period 1996-2006 (do not use shifted standard lamp readings in November 2004-February 2005) or to assume calibration condition of D090 stable in the period 1996-September 2003 and to apply only average corrections for the period October 2003-February 2006 as follows:

  to the 1996 Na-Table add: **- 1.8** units
  to the 1996 Nc-Table add: **- 3.3** units
  to the 1996 Nd-Table add: **- 3.6** units
- The above correction of the total ozone observations can be done either using the Czech software package currently available at the Bangkok station or in cooperation with the RDCC-A, Tsukuba.
- The instrument's drier must be used to avoid the damage to the optics by high humidity.
- The operator is reminded that assistance is available with repairs and spare parts when needed through RDCC-A in Tsukuba, Japan. The support of the WMO/GAW programme is for stations that report the data to WOUDC in Toronto, Canada.

Remark:
The re-evaluation of the Dobson data series from Bangkok was performed by experts of CHMI, JMA, and TMD and reported to the WOUDC in 2006 in the paper:
"Miyagawa, K, Sudhibrabha, S., Uraiwan, D. and Vanicek, K.: Evaluation and Re-processing of Dobson Total ozone Observations from Bangkok, Thailand, 1996-2006".

Instrument D100
Quetta, Pakistan

Original Calibration Data:

N-tables from the 1996 intercomparison against D116 in Tsukuba, Japan. Standard lamp 100Q1, 100Q2, 100Q3 and reference values.

History:

- The D100 has been maintained as the reference instrument at the Quetta station since the DIC-T1996 and it is used for calibration of the D043 routine operation instrument.
- Total ozone observations are taken with D043 and submitted to WOUDC regularly.
- HG tests were not taken in the period 1996-2006 both at D100 and D043 as the HG lamp was broken and thus not available at the station.
- When the D100 arrived to DIC-T2006 the HG test was performed with the HG lamp of JMA. The test showed that the Q1 lever was not properly adjusted. This could influence total ozone observation taken with D100 and consequently calibration of the D043 instrument at the Quetta station.
- SL tests are performed at D043 and D100 almost every month. The SL results were not available at DIC-T2006 but the original files are saved at the station. Analysis of the history of SL tests is therefore needed to identify a possible impact (date and magnitude) of bad setting of Q1 at D100.
- In the period 1996-2005 semi-regular comparisons of D100 and D043 were taken at the station that allowed the observers to keep D043 in good fit with D100. Comparative observations of January 2006 show that D100 total ozone values are higher approximately by 1.5 percent than values of D043. A more comprehensive analysis of the comparisons need to be made and reported to RDCC-A.
- SL tests performed after re-setting of Q1 on 8 March 2006 show a shift of about 1.2 units of Nad difference during the period 1996-2006. This would imply about 2 % offset in total ozone. Influence of the offset on routine total ozone observations can be eliminated by correction of 1996 N-Tables using historical record of SL tests results.
- The new Dobson PI (Mr. Shami) appointed at the Quetta station in 2005 has been instructed how to do the above analysis including recommendations on data re-evaluation prior 1996.

Initial Calibration Results:

08 March 2006

d_Na: -0.2 **d_Nc:-0.9** **d_Nd:-1.4** **d_Nad:+1.3** (From analysis)
(Adjustments based on the results of Standard Lamp tests included.)

The d_Nad value implies an average **-1.8% error** in calculated ozone value, Mu=1 to 3, Total Ozone = 300 Dobson Units.

Note for initial intercomparison: The instrument was repaired before the intercomparison, as the Q1-lever could not be set for the D reading, if the results of the mercury lamp test are used to adjust the Q-setting table. This repair changes the original condition of the instrument, and makes the results less likely to be representative of the station observations.

Work Performed:

- Q1 lever was adjusted on 8 March 2006 before the initial IC.
- Cleaning of D100 on 10 March 2006.
- New Q-Table defined on 11 March 2006.

- Many small improvements were made, including:
  - New Galvanometer, digital thermometer, and new insulating cover were supplied by JMA.
  - External drier system installed with assistance of JMA and CHMI.
  - New short wave calibration lamp and power supply system supplied by JMA, NOAA and WMO.

Final intercomparison: 11 March 2006

Average Difference against the standard for ADDSGQP observations in mu range 1.15 to 3.2 was ~0.1% in total ozone.

Recommendations/Comments:

- The instrument D100 should be operated and total observations processed with calibrations constants (N-Tables, Standard Lamp Reference Readings) defined at the DIC-T2006 from March 2006 onwards.
- The Q-Table must be adjusted by HG tests after the D100 returns from DIC-T2006 back to Quetta using the new HG lamp received at this intercomparison.
- Intercomparison of the operational D043 instrument has to be done as soon as the calibration condition of D100 is checked by HG and SL tests after its arrival from DIC-T2006 back to Quetta. Results of intercomparisons should be reported to RDCC-A, Tsukuba.
- The above comparisons of D043 and D100 should be performed regularly (several times per year at different Mu and total ozone values) so that calibration condition of D043 is well fixed towards D100 for the range of Mu=1.15-3.2 and for the major part of N-Tables of D043.
- SL and HG tests should be done on D043 monthly and their results used for correction of N-Tables (Q-Table).
- Regular submission of total ozone observations to WOUDC, Toronto should continue as in the past.
- Investigation of historical records of SL tests of D100 and D043 should be performed to identify and to correct changes of calibration condition of both instruments in the period 1996-2006. Results of such evaluation and definition of corrections can be consulted with specialists from JMA or CHMI.
- Special attention has to be paid to identification of the date of the bad setting of the Q1 lever at D100.
- The instruments D043 and D100 must be covered with a sheet when not in use to protect the instruments from dust.
- The operator is reminded that assistance is available with repairs and spare parts when needed through RDCC-A in Tsukuba, Japan. The support of the WMO/GAW programme is for stations that report the data to WOUDC in Toronto, Canada.

Instrument D109
Station: Tehran, I. R. Iran

Original Calibration Data:

N-tables from intercomparison with D083, 15 February 1994. Standard lamps 109Q1, 109Q2 and 109Q3 and reference values.

History:

- The instrument is owned by the Tehran University and was last calibrated in 1994 in Boulder, CO, USA.
- Since 1994 the D109 was operated at the Isfahan station of the Meteorological Organization of the Islamic Republic of Iran.
- SL and HG tests were performed every month till 05 November 1999 - then they were stopped because of retirement of the operator.
- In May 2000 the instrument was re-located to Tehran but without SL and HG test files. Since 2002, the instrument has been operated at this new station (GAW No. 464) using the calibration constants of 1994.
- SL and HG tests have not been performed after re-location of the D109 to Tehran.
- The observations are processed by the DOS version of the Czech Dobson software package and results are submitted to WOUDC.

Initial Calibration Results: **08 March 2006**

d_Na: -0.7 d_Nc:-1.0 d_Nd:-3.0 d_Nad:+2.3
(Adjustments based on the results of Standard Lamp tests included, though these adjustments make little difference in the results.)

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

Comment on initial intercomparison: The instrument had some small repairs made that will not compromise the initial intercomparison as representative of operation at the station. Note that the operator was not yet experienced in the observations, and the Q-lever hairlines are difficult to use to set the wavelength pairs.

Work Performed

- The long short rod was repaired.
- The loose Q1 mechanism was repaired.
- Instrument interior was cleaned, and the gaskets replaced.
- Symmetry test was performed – there is a small deviation in the right to left matching, this is considered to be of the order that would not affect the results of the measurements.
- Wedge calibration was performed on 10-11 March 2006.
- Many small improvements were made, including:
  - New Galvanometer, digital thermometer, and new insulating cover were supplied by JMA.
  - New Standard Lamp Power supply was supplied by JMA.
  - External drier system installed with assistance of JMA and CHMI.
  - New short wave calibration lamp and power supply supplied by NOAA and WMO.
  - Other electronic spares were supplied by NOAA.
  - New Q-lever hairline plates supplied by JMA.

Final intercomparison: **14 March 2006**

Average Difference against the standard for ADDSGQP observations in mu range 1.37 to 2.5 was -0.1% in total ozone.

Recommendations/Comments:

- The instrument D109 should be operated and total observations processed with calibrations constants (N-Tables, Standard Lamp Reference Readings) defined at the DIC-T2006 from March 2006 onwards.
- The Q-Table must be adjusted by HG tests after D109 returns from DIC-T2006 to Tehran using the new HG lamp received at this intercomparison.
- SL and HG tests should be done monthly and their results used for correction of N-Tables (Q-Table) when observations are processed.
- Historical files of HG and SL tests of the instrument D109 should be collected at the Tehran University and analyzed to determine whether re-calculation of the data series from Isfahan (1994-2000) and Tehran (2000-2006) is needed. For this relation between Isfahan/Tehran ground measurements should be also compared towards satellite overpass observations.
- The operating agency must provide a digital voltmeter for the new standard lamp power supply.
- The operator is reminded that assistance is available with repairs and spare parts when needed through RDCC-A in Tsukuba, Japan. The support of the WMO/GAW programme is for stations that report the data to WOUDC in Toronto, Canada.

Instrument D112
New Delhi, India

Original Calibration Data: N-tables and standard lamp reference values from March, 1996 intercomparison in Tsukuba, Japan.

History:

- The D112 is maintained as the reference instrument of the Dobson network of the Indian Meteorological Department (IMD) that now consists of three stations – New Delhi, Poona and Varanasi. The station Ahmadabad has been maintained by the Physical Research Laboratory (PRL).
- Routine total ozone observations are performed at New Delhi with the instrument D036.
- HG and SL tests are performed regularly on D112 at least every three – four months.
- Results of HG tests varied somewhat out from the limits (0.3-0.7) but without a systematic tendency.
- Results of SL tests were stable in the whole period 1996-2005 with a shift less than 0.2 in the difference between Na and Nd.
- The operational Dobson instruments at the stations of IMD are calibrated towards D112 every four years. All stations perform HG and SL tests monthly and submit the test data together with raw observation data to the National Ozone Centre (NOC) in New Delhi where they are processed, analyzed and filed. After check for their quality the total ozone data are submitted to WOUDC.
- The instrument D054 from Ahmedabad is calibrated against D112 occasionally (last in 2003) but D054 is not under the control of NOC.
- This instrument D112 has not been operational since October 2005 till DIC-T2006 because of failure of the electronics.

Initial Calibration Results: **18 March 2006**

Comment on Initial intercomparison: Several intercomparisons were performed against D116, with results noisier than expected. During the repairs and refurbishment, the prism in the sun director was discovered to have been installed incorrectly. There was a gap of approximately three millimeter behind the prism, allowing skylight to be seen by the instrument. Skylight has a different N-value compared to direct sunlight, thus giving an incorrect reading. As the ratio of skylight to direct sun light would change as the solar zenith angle changes, this error is difficult to evaluate. The operator of this instrument states that the sun director was disassembled in September 2005 to assist in the repair of another unit. Therefore this problem should not affect measurements taken with D112 prior September 2005. The intercomparison of 18 March 2006 was performed with very good results, and will be used for both the initial and final intercomparison.

d_Na: -1.8 d_Nc:-1.4 d_Nd:-1.7 d_Nad:-0.1
(Adjustments based on the results of Standard Lamp tests included.)

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:

- The amplifier, chopper circuit and detector, and high voltage sections were replaced before the initial intercomparison. The original shutter position detector system had failed, and no repair was possible. The new electronics installed are the current Japanese system.
- The Instrument optics were cleaned, including mirrors.
- Many small improvements were also made, including new galvanometer, digital thermometer, and new insulating cover supplied by JMA.

- Several intercomparisons were made with this instrument (11 and 15 March 2006), with noisy and unrepeatable results.
- A wedge calibration was performed, but the results were little different from the 1996 G-table.
- While inspecting the sun director, it was noticed that the prism was not installed correctly, and that there was a gap of approximately 3 millimeter behind the prism and holder. (See notes on Initial intercomparison). The sun director was repaired.

Final intercomparison: **18 March 2006**

Average difference against the standard for ADDSGQP observations in mu range 1.15 to 3.2 was 0.1% in total ozone.

Recommendations/Comments:

- The instrument D112 should be maintained as the reference Dobson. spectrophotometer of NOC and operated with calibrations constants (N-Tables, Standard Lamp Reference Readings) defined at the DIC-T2006 from March 2006 onwards.
- The Q-Table must be checked by HG tests after the D112 returns from DIC-T2006 back to New Delhi.
- SL and HG tests should be done regularly like as in the previous years.
- Intercomparisons of the operational Dobson instruments from IMD and Ahmadabad stations towards D112 have to be done as soon as its calibration condition is checked after arrival from DIC-T2006. Such comparisons should be performed regularly to keep calibration condition of station instruments fixed with the reference D112.
- Regular submission of total ozone observations from the Dobson network of IMD to WOUDC, Toronto should continue as in the past.
- No reprocessing of the existing data record from this instrument appears to be needed. The past calibration of other instruments by this instrument appears to be correct.
- The history of intercomparisons within the Indian Network of Dobson Instruments and their results should be published in the open literature to confirm the above statements.
- The operator is reminded that assistance is available with repairs and spare parts when needed through RDCC-A in Tsukuba, Japan. The support of the WMO/GAW programme is for stations that report the data to WOUDC in Toronto, Canada.

Appendix C
Definitions

A, C, and D Wavelength Pairs: The Dobson instrument measures the difference between the intensity of selected wavelengths in the range of 300 to 340 nm. 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 (see N-table below).

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. Normally done if there is a change made in the optical alignment of the instrument.

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 than 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. G-tables are defined for each A, C, and D wavelength pair by the Wedge Calibration.

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.