EVALUATION AND RE-PROCESSING OF DOBSON TOTAL OZONE OBSERVATIONS FROM BANGKOK, THAILAND, 1996-2006

Method and Results

Report for the World Ozone and UV Data Centre of WMO, Toronto

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Objectives

At the WMO intercomparison of the Dobson ozone spectrophotometers in Tsukuba 2006 (DIC-T2006) calibration stability of the Dobson ozone spectrophotometer #090 (D090) from the GAW station in Bangkok, Thailand was investigated by experts of RDCC-A and RDCC-E. The initial IC at the DIC-T2006 and the analysis of Mercury (HG) and Standard Lamp (SL) tests files of the D090 showed that the instrument had changed its calibration state since the previous IC in 1996. Therefore, a complex evaluation and re-processing of total ozone observations taken in Bangkok in the period 1996-2006 were recommended. This Report describes method used and results achieved by the above international team under the umbrella of the RDCC-A. The Report is to serve as a metadata reference related to the total ozone data files from the Bangkok station saved in the World Ozone and UV Data Centre (WOUDC), Toronto.

Operation of the D090

- The Dobson spectrophotometer D090 has been operated at the GAW station No. 216 of the Thai Meteorological Department (TMD) in Bangkok since1979.
- 3-5 DS/ZB/ZC, ADADA observations are taken every day if weather condition allows.
- In 1996-2006 total ozone observations were processed by the PC using the DOBSON 2.4 software package donated by the CHMI in 1997 and the calibration constants (N-Tables) defined at the Dobson IC, Tsukuba, 1996 (DIC-T1996).
- Total ozone data are regularly submitted into the WOUDC, Toronto.
- The operators of the D090 are experienced and supervised by a specialist trained by CHMI experts in 1997.

Calibration Constants of D090 in 1996-2006

The D090 instrument was calibrated at the DIC-T1996 in April 1996 when its N-Tables (NT), Q-Tables (QT) and Reference Readings (RR) dated March 16, 1996 were defined (the WMO/GAW Report No118) and used till February 2006. At the DIC-T2006 new constants have been fixed to be used since March 18, 2006 onwards (the DIC-T2006 Final Report).

History of HG and SL Tests

Though the HG and SL tests were not performed on the D090 every moth at the station the test records give sufficient information about calibration state of the instrument in the period 04/1996-02/2006. Test Readings (Qhg, Ra, Rc, Rd) and their differences towards the Reference Readings (QT, RRa, RRc, RRd):

$$difHG = Qhg - QT \quad (1a)$$
$$difRa = RRa - Ra \quad (1b)$$
$$difRc = RRc - Rc \quad (1c)$$
$$difRd = RRd - Rd \quad (1d)$$

are given in Appendix A and viewed in Figures 1, 2 and 3. They lead to the following conclusions:

- The difHG were permanently in the required +-0.3 deg. limits almost in the whole considered period. This confirms that alignment of the instrument´s optical system was stable in 1996-2006.
- The differences difRa, difRc, difRd calculated from the tests performed with the **SL 90Q2** show that sensitivity of the D090 varied in about 1-deg. limits in the period May 1996-August 01, 2003. These correspond to natural changes that introduce errors about 1.3% in calculated total ozone (Mu=1.1-2.5, 300 DU) being near the 1% precision of a well calibrated Dobson spectrophotometer.
- The SL test taken on August 4, 2003 indicates a sudden and significant change of sensitivity mainly on the pairs C and D that persisted with some fluctuations till the initial IC at the DIC-T2006. The shift peaked in October 2004 - February 2005 (up to 7.6 deg for difRd) when it could introduce 7-11 % errors in total ozone at the AD double pair. Such changes in calibration condition of the instrument have to be corrected by re-calculation of observations.
- SL tests were also performed with the **SL 90Q4** till September 2003 when the lamp was broken. The tests confirm the above results of the tests taken with SL 90Q2 including the change of instrument´s sensitivity in August 2003.

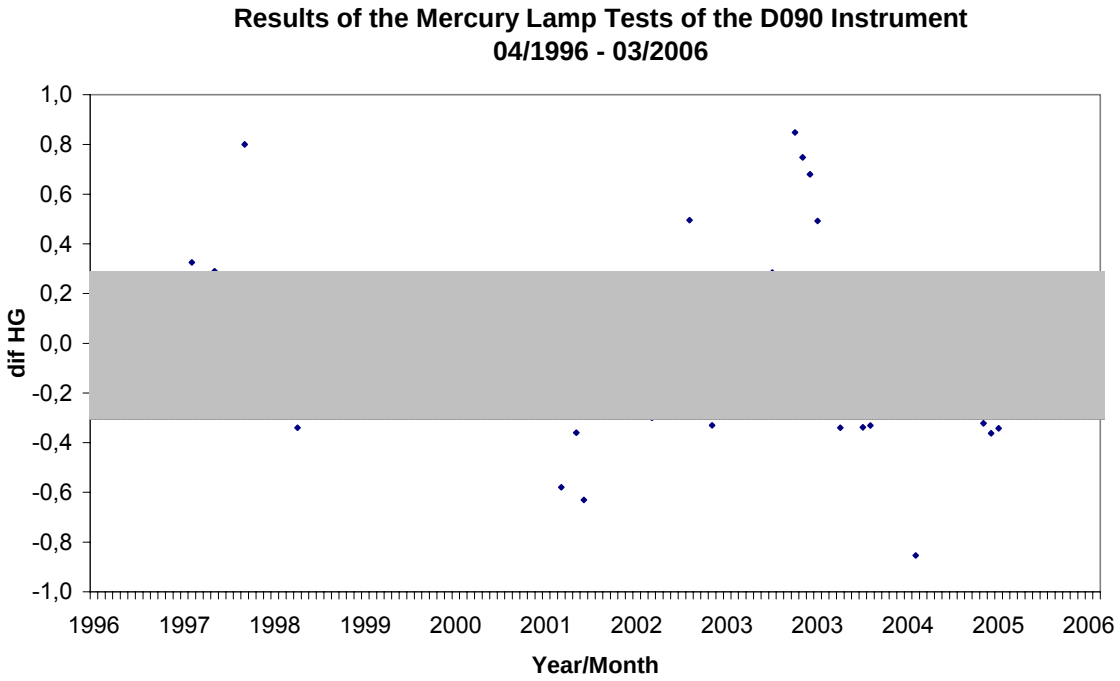

Figure 1

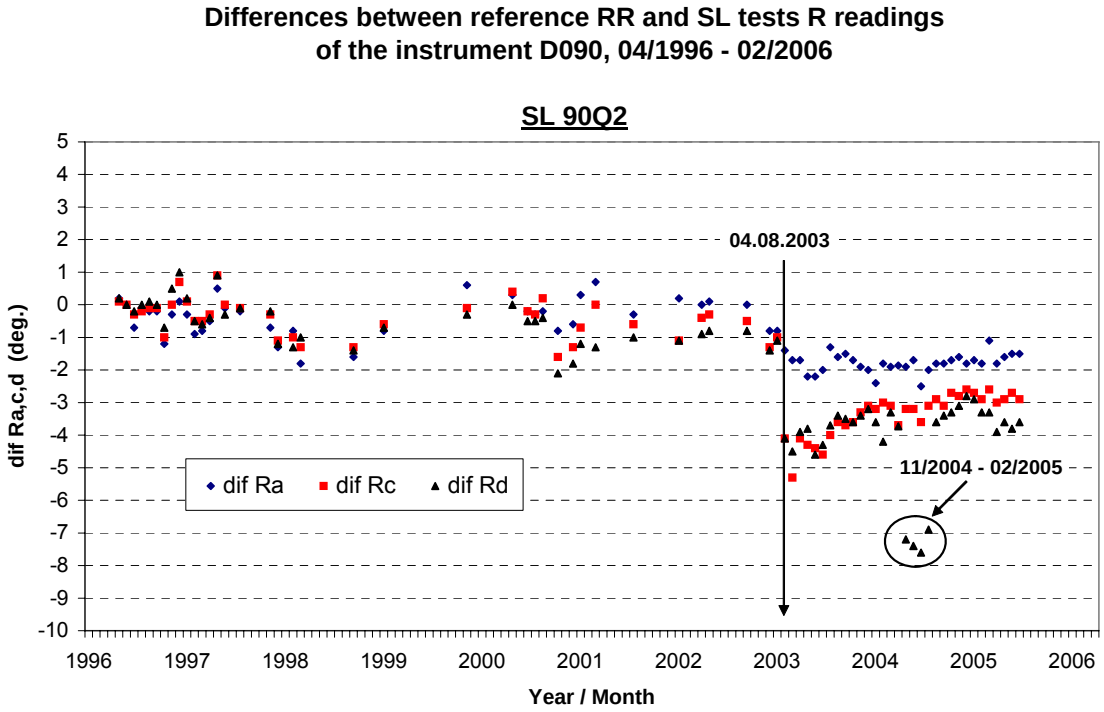

Figure 2

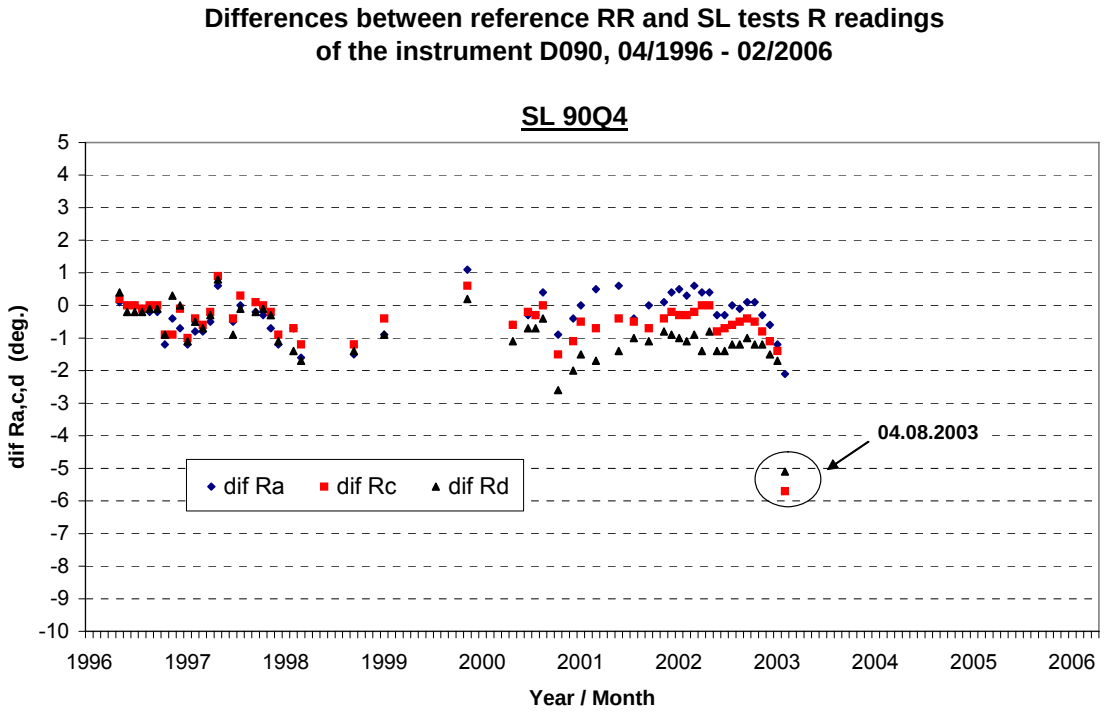

Figure 3

Corrections of N-Tables

As the Q-Table remained fixed in 1996-2006 due to stability of difHG in requested limits and the Reference Readings RRa, RRc, RRd are changed at the ICs therefore the N-Tables were the only calibration constants that could be adjusted to compensate the shift in sensitivity of the D090. The N-Tables are used to convert R-readings taken from the instrument to ***N*** values that are used for calculation of total ozone ***X*** . For Bangkok, where the ADADA sequence is measured, calculation of total ozone is performed for the standard double wavelength pair AD and the Bass-Paur ozone absorption coefficients. For Direct Sun (DS) measurements the following relation is used:

$$Xds = (Na - Nd) / 1.432*Mu - 7*m*p/Mu*p_o \qquad (2)$$

If:

Xdso is the original total ozone values in DU
Xds is corrected total ozone values in DU
Nao, Ndo are original N values converted by the N-Tables defined in 1996
Na, Nd are new N values converted by corrected N-Tables
$p \approx p_o$ and $Mu \approx m$ at the Bangkok station

then:

$$Xds = ((Nao + difRa) - (Ndo + difRd)) / 1.432*Mu - 7$$

$$Xds = ((Nao - Ndo) + (difRa - difRd)) / 1.432*Mu - 7$$

$$\boldsymbol{Xds = Xo + difRad / 1.432*Mu} \qquad (3)$$

Where: $\boldsymbol{difRad = difRa - difRd}$ (4)

and difRa, difRd are defined from SL tests by equations (1b) and (1d) and Mu is the relative air mass of the ozone layer.

The Zenith Blue (ZB) or Zenith Cloud (ZC) observations are processed by means of empirical polynomials:

$$X = F(Nao,Ndo,difRad,Mu) \qquad (5)$$

that use (Na – Nd) = (Nao – Ndo + difRad) and Mu as proxies.

Re-calculation of Total Ozone Observations

Total ozone observations from Bangkok of the period 04/1996 – 02/2006 have been re-processed by relations (3) and (5) and corrections difRad defined from SL tests in Appendix A. To reflect variations of difRad (see Fig. 4) their values were further approximated for individual days of the considered period according to dates of 90Q2 and 90Q4 SL tests. Particular periods of their application are given in Table 1.

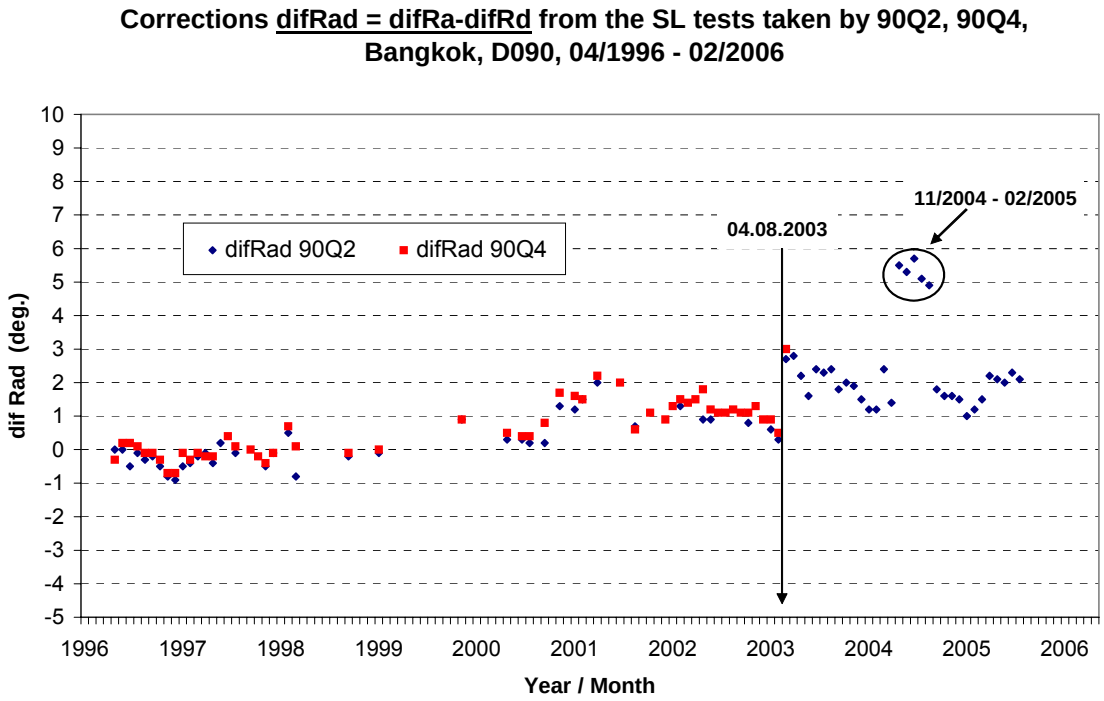

Figure 4

Table1

Periods and values of difRad to be used for correction of total ozone observations taken with the Dobson spectrophotometer D090 in Bangkok. 1996-2006

From (yyyy/mm/dd)	**To** (yyyy/mm/dd)	**difRad**	**From** (yyyy/mm/dd)	**To** (yyyy/mm/dd)	**difRad**
1996/10/01	1996/10/31.	-0.3	2003/12/01	2004/01/31	2.2
1996/11/01	1997/01/15	-0.5	2004/02/01	2004/05/31	2.0
1997/01/16	1997/03/31	-0.3	2004/06/01	2004/07/31	1.5
1997/04/01	1999/12/31	0.0	2004/08/01	2004/10/09	2.0
2000/01/01	2001/02/28	0.5	2004/10/10	2005/02/22	5.2
2001/03/01	2001/03/31	1.0	2005/02/23	2005/06/15	1.7
2001/04/01	2001/12/31	1.7	2005/06/16	2005/08/15	1.2
2002/01/01	2003/08/03	1.2	2005/08/16	2005/09/15	1.7
2003/08/04	2003/09/30	2.5	2005/09/16	2006/02/28	2.3
2003/10/01	2003/11/30	2.0	2006/03/01	2006/03/18	3.8

The re-processing was performed at RDCC-A using the JMA´s software. In the first step the DS observations were corrected and then ZB and ZC measurements were re-calculated using updated zenith polynomials. Accuracy of the polynomials can be assessed from differences between 7.940 simultaneous DS and zenith observations that are viewed in Fig. 5. The graph shows that only a small number of zenith observations differ more that 5% from the DS values (mostly because of heavy clouds during measurements). The statistics gives standard error of calculation of ZB and ZC values about 1.5 % (about 4 DU) that confirms a very good accuracy of the polynomials. Altogether 24.051 observations of the period 1996/04/26 –2006/02/15 have been re-processed and daily averages of total ozone were calculated for 3.383 days.

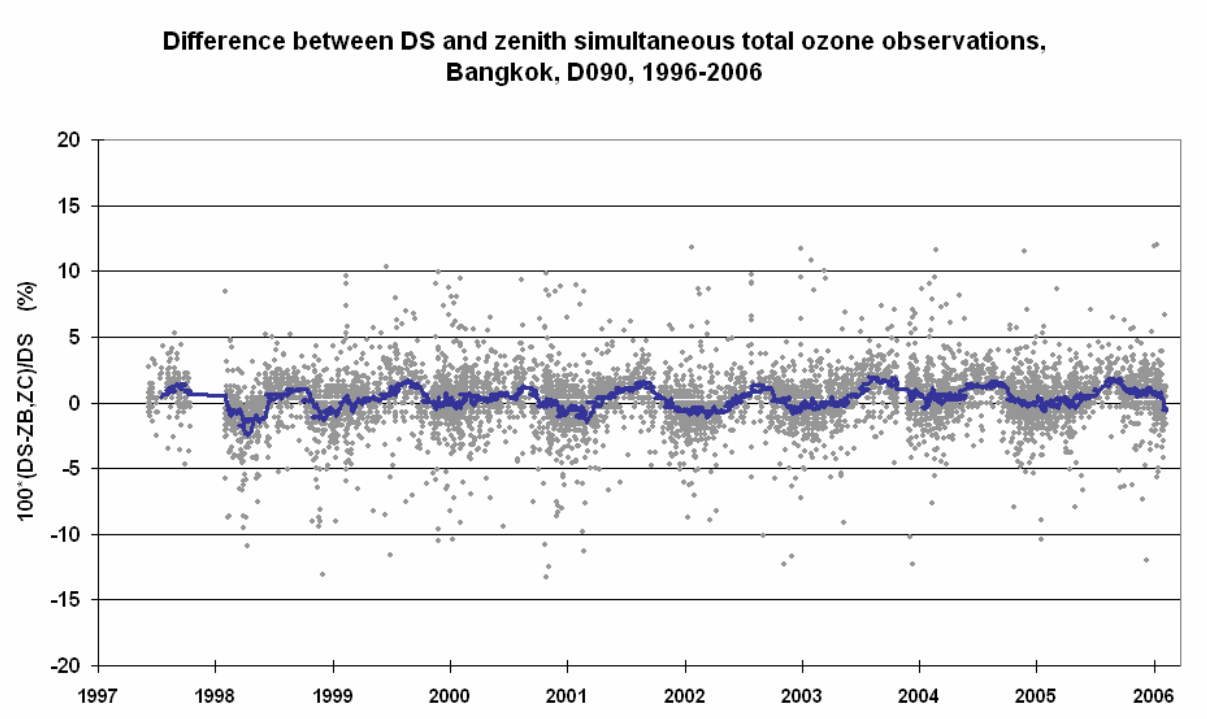

Figure 5

Comparison of Dobson and Satellite Observations

Daily averages of uncorrected and corrected Dobson total ozone from Bangkok were compared with the overpass TOMS-V8 data of the period 1996/04/26 – 2004/12/31 and towards the OMI (Ozone Monitoring Instrument onboard of the AURA satellite) total ozone observations of the period 2005/01/01 – 2006/02/15 that were downloaded from the OMI at the RDCC-A in March 2006. The comparison that is demonstrated by graphs in Fig. 6 allows the following conclusions.

- Till March 2001 the corrected and uncorrected Dobson observations show almost the same relation to the TOMS data due to stability of calibration condition of the D090 and the TOMS instruments (see Tab. 1).
- In 2003-2006 the uncorrected Dobson observations gradually increased their positive offsets towards the satellite measurements. The differences peaked in winter 2004/2005 both for TOMS and OMI – evidently due to change of calibration state of the D090
- Since April 2001 when corrections difRad exceeded 1.0 deg. limit the corrected measurements were permanently lower than the TOMS satellite data. This is an important change comparing to uncorrected data set that agrees with relation between TOMS and ground observations at the majority of GAW stations after 2002 when a change of technical condition of the EP-TOMS facility has appeared.
- The corrected data show evidently better fit with satellite observations after January 2005 when the OMI measurements were used for comparison.
- A general conclusion can be made that the corrected Dobson data set gives much better and consistent relation to the independent satellite observations. This confirms its better quality.

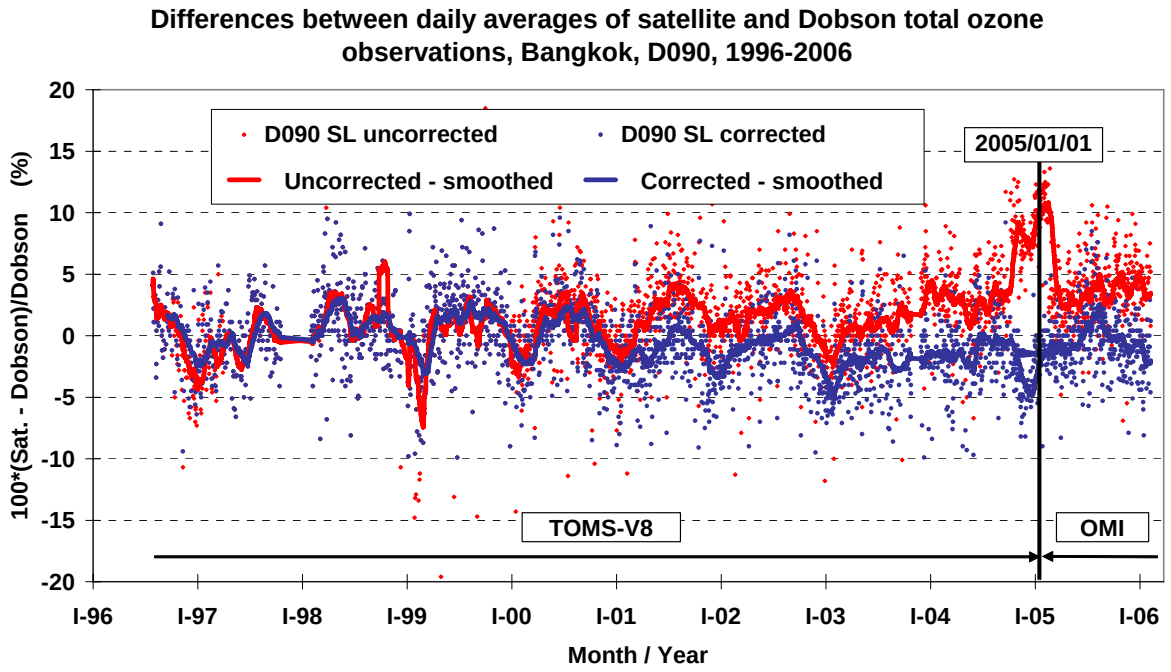

Figure 6

Data quality check

Figure 6 shows that the D090 data set evidently included a certain amount of unreliable or bad observations. Therefore a final check of quality of the corrected observations was made in cooperation of the TMD team and the experts from RDCCs. In the first step the days were identified when Dobson daily averages differ from the satellite values more than by +-7 % (the triple of the standard error). Then quality of single observations taken on those days was investigated from the observation protocols. If the measurements were found unreliable or wrong (e.g. bad weather condition, errors in readings) then these observations were canceled and not included into the final corrected data set that has included into the re-evaluated data set and re-deposited into the WOUDC data base in June 2006.

Recommendations

- The GAW station in Bangkok has generated one of the longest and most continuous Dobson total ozone data series in the tropical and subtropical regions. The re-evaluation and correction of observations of the period 1996-2006 should be therefore extended also for the period 1979-1996.
- To keep the high quality of total ozone observations performed at Bangkok in the future a close cooperation between the station and the RDCC-A at Tsukuba should continue both on maintenance of the instrument and in the area of processing the observations and their Quality Assurance.

Appendix A

Dobson spectrophotometer No.090
Results of Mercury and Standard Lamp Tests, 1996-2006

90Q2 Ra = 32.0
90Q3 Rc = 33.5
90Q4 Rd = 34.4

90Q4 tRa = 31,6
90Q5 tRc = 33,1
90Q6 tRd = 33,8

Date			HG	SL 90Q2							SL 90Q4						
YYYY	MM	DD	**difHg**	**Ra**	**Rc**	**Rd**	**difRa** RRa-Ra	**difRc** RRc-Rc	**difRd** RRd-Rd	**difRad** difRa-difRd	**Ra**	**Rc**	**Rd**	**difRa** RRa-Ra	**difRc** RRc-Rc	**difRd** RRd-Rd	**difRad** difRa-difRd
1996	1																
1996	2																
1996	3																
1996	4	30	-0,2	31,8	33,4	34,2	0,2	0,1	0,2	0,0	31,5	32,9	33,4	0,1	0,2	0,4	-0,3
1996	5	31	0,0	32,0	33,5	34,4	0,0	0,0	0,0	0,0	31,6	33,1	34,0	0,0	0,0	-0,2	0,2
1996	6																
1996	7	1	0,1	32,7	33,8	34,6	-0,7	-0,3	-0,2	-0,5	31,6	33,1	34,0	0,0	0,0	-0,2	0,2
1996	8	1	0,2	32,1	33,7	34,4	-0,1	-0,2	0,0	-0,1	31,7	33,2	34,0	-0,1	-0,1	-0,2	0,1
1996	9	1	0,0	32,2	33,6	34,3	-0,2	-0,1	0,1	-0,3	31,8	33,1	33,9	-0,2	0,0	-0,1	-0,1
1996	10	1	0,1	32,2	33,6	34,4	-0,2	-0,1	0,0	-0,2	31,8	33,1	33,9	-0,2	0,0	-0,1	-0,1
1996	10	31	0,1	33,2	34,5	35,1	-1,2	-1,0	-0,7	-0,5	32,8	34,0	34,7	-1,2	-0,9	-0,9	-0,3
1996	12	2	0,2	32,3	33,5	33,9	-0,3	0,0	0,5	-0,8	32,0	34,0	33,5	-0,4	-0,9	0,3	-0,7
1997	1	4	0,2	31,9	32,8	33,4	0,1	0,7	1,0	-0,9	32,3	33,2	33,8	-0,7	-0,1	0,0	-0,7
1997	1	31	0,3	32,3	33,4	34,2	-0,3	0,1	0,2	-0,5	32,8	34,1	34,9	-1,2	-1,0	-1,1	-0,1
1997	3	1	0,2	32,9	34	34,9	-0,9	-0,5	-0,5	-0,4	32,4	33,5	34,3	-0,8	-0,4	-0,5	-0,3
1997	4	1	0,2	32,8	34	35	-0,8	-0,5	-0,6	-0,2	32,4	33,7	34,5	-0,8	-0,6	-0,7	-0,1
1997	4	30	0,3	32,5	33,8	34,8	-0,5	-0,3	-0,4	-0,1	32,1	33,3	34,1	-0,5	-0,2	-0,3	-0,2
1997	6	3	-0,1	31,5	32,6	33,5	0,5	0,9	0,9	-0,4	31,0	32,2	33,0	0,6	0,9	0,8	-0,2
1997	7	1	-0,2	32,1	33,5	34,7	-0,1	0,0	-0,3	0,2							
1997	8	6	-0,1								32,1	33,5	34,7	-0,5	-0,4	-0,9	0,4
1997	9	3	0,8	32,2	33,6	34,5	-0,2	-0,1	-0,1	-0,1	31,6	32,8	33,9	0,0	0,3	-0,1	0,1
1997	10																
1997	11	8	0,1								31,8	33,0	34,0	-0,2	0,1	-0,2	0,0
1997	12	2	-0,1								31,9	33,1	33,9	-0,3	0,0	-0,1	-0,2
1998	1	8	0,0	32,7	33,8	34,6	-0,7	-0,3	-0,2	-0,5	32,3	33,3	34,1	-0,7	-0,2	-0,3	-0,4
1998	2	5	-0,3	33,3	34,6	35,6	-1,3	-1,1	-1,2	-0,1	32,8	34,0	34,9	-1,2	-0,9	-1,1	-0,1
1998	3	31	-0,3	32,8	34,5	35,7	-0,8	-1,0	-1,3	0,5	32,3	33,8	35,2	-0,7	-0,7	-1,4	0,7
1998	4																
1998	5	6	-0,2	33,8	34,8	35,4	-1,8	-1,3	-1,0	-0,8	33,2	34,3	35,5	-1,6	-1,2	-1,7	0,1
1998	6																
1998	7																
1998	8																
1998	9																
1998	10																
1998	11																
1998	12	1	-0,3	33,6	34,8	35,8	-1,6	-1,3	-1,4	-0,2	33,1	34,3	35,2	-1,5	-1,2	-1,4	-0,1
1999	1																
1999	2																
1999	3	31	-0,2	32,8	34,1	35,1	-0,8	-0,6	-0,7	-0,1	32,5	33,5	34,7	-0,9	-0,4	-0,9	0,0
1999	4																
1999	5																
1999	6																
1999	7																
1999	8																
1999	9																
1999	10																
1999	11																
1999	12																

2000	1																
2000	2	3	-0,1	31,4	33,6	34,7	0,6	-0,1	-0,3	0,9	30,5	32,5	33,6	1,1	0,6	0,2	0,9
2000	3																
2000	4																
2000	5																
2000	6																
2000	7																
2000	8																
2000	9	13	-0,3	31,7	33,1	34,4	0,3	0,4	0,0	0,3	32,2	33,7	34,9	-0,6	-0,6	-1,1	0,5
2000	10																
2000	11	4	-0,1	32,2	33,7	34,9	-0,2	-0,2	-0,5	0,3	31,9	33,3	34,5	-0,3	-0,2	-0,7	0,4
2000	12	9	-0,2	32,3	33,8	34,9	-0,3	-0,3	-0,5	0,2	31,9	33,4	34,5	-0,3	-0,3	-0,7	0,4
2001	1																
2001	2	2	-0,2	32,2	33,3	34,8	-0,2	0,2	-0,4	0,2	31,2	33,1	34,2	0,4	0,0	-0,4	0,8
2001	3																
2001	4	5	-0,6	32,8	35,1	36,5	-0,8	-1,6	-2,1	1,3	32,5	34,6	36,4	-0,9	-1,5	-2,6	1,7
2001	5																
2001	6	5	-0,4	32,6	34,8	36,2	-0,6	-1,3	-1,8	1,2	32,0	34,2	35,8	-0,4	-1,1	-2,0	1,6
2001	7	11	-0,6	31,7	34,2	35,6	0,3	-0,7	-1,2	1,5	31,6	33,6	35,3	0,0	-0,5	-1,5	1,5
2001	8																
2001	9	16	-0,1	31,3	33,5	35,7	0,7	0,0	-1,3	2,0	31,1	33,8	35,5	0,5	-0,7	-1,7	2,2
2001	10																
2001	11	13	-0,2								31,0	33,5	35,2	0,6	-0,4	-1,4	2,0
2001	12																
2002	1	5	-0,2	32,2	34,1	35,6	-0,2	-0,6	-1,2	1,0							
2002	1	31	-0,3	32,3	34,1	35,4	-0,3	-0,6	-1,0	0,7	32,0	33,6	34,8	-0,4	-0,5	-1,0	0,6
2002	2	28	-0,3								31,6	33,8	34,9	0,0	-0,7	-1,1	1,1
2002	3	31	0,1	32,3	34	35,8	-0,3	-0,5	-1,4	1,1							
2002	4	30	-0,1								31,5	33,5	34,6	0,1	-0,4	-0,8	0,9
2002	5	31	-0,3								31,2	33,3	34,7	0,4	-0,2	-0,9	1,3
2002	6	30	0,2	31,8	34,6	35,5	0,2	-1,1	-1,1	1,3	31,1	33,4	34,8	0,5	-0,3	-1,0	1,5
2002	7	31	0,5								31,3	33,4	34,9	0,3	-0,3	-1,1	1,4
2002	8																
2002	9	1	-0,2								31,0	33,3	34,7	0,6	-0,2	-0,9	1,5
2002	9	30	-0,1	32,0	33,9	35,3	0,0	-0,4	-0,9	0,9	31,2	33,1	35,2	0,4	0,0	-1,4	1,8
2002	11	5	-0,3	31,9	33,8	35,2	0,1	-0,3	-0,8	0,9	31,2	33,1	34,6	0,4	0,0	-0,8	1,2
2002	11	30	0,0								31,9	33,9	35,2	-0,3	-0,8	-1,4	1,1
2003	1	1	-0,1								31,9	33,8	35,2	-0,3	-0,7	-1,4	1,1
2003	1	31	0,2								31,6	33,7	35,0	0,0	-0,6	-1,2	1,2
2003	2	28	0,1								31,7	33,6	35,0	-0,1	-0,5	-1,2	1,1
2003	4	1	0,2	32,0	34,0	35,2	0,0	-0,5	-0,8	0,8	31,5	33,5	34,8	0,1	-0,4	-1,0	1,1
2003	4	30	0,1								31,5	33,6	35,0	0,1	-0,5	-1,2	1,3
2003	6	2	0,0								31,9	33,9	35,0	-0,3	-0,8	-1,2	0,9
2003	7	1	0,3	32,8	34,8	35,8	-0,8	-1,3	-1,4	0,6	32,2	34,2	35,3	-0,6	-1,1	-1,5	0,9
2003	8	1	0,1								32,8	34,5	35,5	-1,2	-1,4	-1,7	0,5
2003	8	31	0,8								33,7	38,8	38,9	-2,1	-5,7	-5,1	3,0
2003	9	4	0,2	33,4	37,6	38,5	-1,4	-4,1	-4,1	2,7	34,1	38	39	-2,5	-4,9	-5,2	2,7
2003	10	2	0,7	33,7	37,6	38,3	-1,7	-4,1	-3,9	2,2							
2003	11	2	0,7	34,2	37,8	38,2	-2,2	-4,3	-3,8	1,6							
2003	11	30	0,5	34,2	37,9	39,0	-2,2	-4,4	-4,6	2,4							
2004	1	1	-0,3	34,0	38,1	38,7	-2,0	-4,6	-4,3	2,3							
2004	2	1	-0,2	33,3	37,5	38,1	-1,3	-4,0	-3,7	2,4							
2004	2	29	-0,3	33,6	37,1	37,8	-1,6	-3,6	-3,4	1,8							
2004	3	31	-0,2	33,5	37,2	37,9	-1,5	-3,7	-3,5	2,0							
2004	4	30	-0,2	33,7	37,1	38,0	-1,7	-3,6	-3,6	1,9							
2004	5	31	-0,3	33,9	36,8	37,8	-1,9	-3,3	-3,4	1,5							
2004	7	1	-0,3	34,0	36,6	37,6	-2,0	-3,1	-3,2	1,2							
2004	7	31	0,1	34,4	36,7	38,0	-2,4	-3,2	-3,6	1,2							
2004	8	31	-0,1	33,8	36,5	38,6	-1,8	-3,0	-4,2	2,4							
2004	9	30	-0,1	33,9	36,6	37,7	-1,9	-3,1	-3,3	1,4							
2004	10	31	-0,1	33,9	36,7	41,6	-1,9	-3,2	-7,2	5,3							
2004	11	30	-0,9	33,7	36,7	41,8	-1,7	-3,2	-7,4	5,7							
2004	12																

2005	1	2	0,0	34,5	37,1	42,0	-2,5	-3,6	-7,6	5,1		
2005	2	3	-0,1	34,0	36,6	41,3	-2,0	-3,1	-6,9	4,9		
2005	3	2	-0,1	33,8	36,4	38,0	-1,8	-2,9	-3,6	1,8		
2005	3	31	-0,2	33,8	36,6	37,8	-1,8	-3,1	-3,4	1,6		
2005	4	30	-0,1	33,7	36,2	37,7	-1,7	-2,7	-3,3	1,6		
2005	5	31	0,2	33,6	36,3	37,5	-1,6	-2,8	-3,1	1,5		
2005	6	30	-0,2	33,8	36,1	37,2	-1,8	-2,6	-2,8	1,0		
2005	7	31	-0,2	33,7	36,2	37,3	-1,7	-2,7	-2,9	1,2		
2005	8	31	-0,3	33,8	36,4	37,7	-1,8	-2,9	-3,3	1,5		
2005	10	1	-0,4	33,1	36,1	37,7	-1,1	-2,6	-3,3	2,2		
2005	10	31	-0,3	33,8	36,5	38,3	-1,8	-3,0	-3,9	2,1		
2005	11	30	-0,2	33,6	36,4	38,0	-1,6	-2,9	-3,6	2,0		
2005	12	29	0,0	33,5	36,2	38,2	-1,5	-2,7	-3,8	2,3		
2006	1	31	0,0	33,5	36,4	38,0	-1,5	-2,9	-3,6	2,1		
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