Calibration History of the Dobson D074 and Brewer B098 Ozone Spectrophotometers

RNDr. Karel Vaníček, CSc.
Solar and Ozone Observatory
Hradec Králové

This publication was prepared under the support of the Project No. 205/01/0003 of the Grant Agency of the Czech Republic:

„Development and Implementation of Technologies for the European Cooperative Ozonometric Center", 2000-2003

Czech Hydrometeorological Institute

Prague, 2002

Acknowledgements

The author is very grateful to Mr. Martin Stanek from the Solar and Ozone Observatory Hradec Králové for his assistance in collecting and assessment of technical inputs for this report.

Many thanks are expressed to:
Mr. Archie I. Asbridge, Dobson/Brewer expert, formerly with AES Canada, Toronto, Canada
Mr. Robert D. Evans, Head, World Dobson Calibration Center, NOAA/CMDL, Boulder, Colorado, USA
Mr. Ulf Koehler, Head, Regional Dobson Calibration Center - Europe, DWD/MOHp Hohenpeissenberg, Germany
Mr. Ken Lamb, The International Ozone Service, Toronto, Canada
for their long-term assistance on maintenance of the ozone spectrophotometers at SOO-HK and for a very helpful review of this Report.

CONTENTS

INTRODUCTION

The Solar and Ozone observatory of the Czech Hydrometeorological Institute in Hradec Králové (SOO-HK) is a station in the ground-based total ozone monitoring network of the Global Atmosphere Watch (GAW) Programme of the World Meteorological Organization (WMO). The SOO-HK observatory program has a history of more than 40 years of uninterrupted total ozone measurements starting in 1961 using the Dobson ozone spectrophotometer 074 (D074). The program was expanded in January 1994 with the introduction of Brewer ozone spectrophotometer 098 (B098). Both instruments are carefully maintained by the staff of the observatory and are periodically intercompared with world reference standard spectrophotometers to maintain their accuracy within the world ozone monitoring network. Accordingly, the total ozone data from SOO-HK are considered of high quality when they are deposited at the World Ozone and UV Data Centre of WMO (WOUDC) at Toronto, Canada.".

New sets of calibration constants are determined for D074 and B098 whenever they are intercompared with world reference spectrophotometers. The new constants are then applied during the daily observing program and data processing. The Dobson reference standard is maintained by the National Oceanic and Atmospheric Administration of the USA (NOAA) while the Brewer reference standard is maintained by the Meteorological Service of Canada (MSC). The changes of the calibration constants in each particular calibration period need to be analyzed in a complex manner so that a detailed history of each spectrophotometer is known. Such analyses indicate possible long-term trends in the behaviour of the instrument. The calibration status of D074 during the sixties and seventies requires particular attention since the international system of calibration under the GAW program had not yet been established. Moreover, in recent years seasonal differences between Dobson and Brewer total ozone observations have been found at collocated Dobson/Brewer stations [Staehelin et al., 2003]. The differences need to be analyzed and explained to avoid discrepancies in trends of total ozone estimated from the Dobson and Brewer measurements and in validation of satellite observations by both types of ground-based data. As specialists from SOO-HK are going to make such study on the data sets created with D074 and B098 spectrophotometers in Hradec Králové a precise analyses of the instruments calibration and technical condition is the first step that must be done.

This report summarizes basic pieces of information on calibrations, calibration constants and other relevant technical parameters of D074 and B098 spectrophotometers including effects of their applications. For this reason a theory of the function and technologies of observations of both instruments are briefly described and explained in a simple way so that also readers not coming from the expert community can understand the physical background of calibrations and methods of measurements. The paper is to serve as a reference source of information on technical and instrumental aspects of total ozone observations at SOO-HK that will be used for a complex re-evaluation of the total ozone data base created in Hradec Králové among others. Preparation of the report was also initiated by the fact that SOO-HK has been acting as a co-operative observatory of the European Regional Dobson Calibration Center (RDCC) since 1998 and the Dobson spectrophotometer D074 is maintained as a secondary reference instrument for RDCC. Therefore, its calibration history should be analyzed in a similar way like it has been done for the operational spectrophotometer D104 maintained at RDCC Hohenpeissenberg [Koehler, 1995].

Part 1:

CALIBRATION HISTORY OF THE DOBSON SPECTROPHOTOMETER NO. 074

1.1. The Dobson Ozone Spectrophotometer – a basic description of the instrument

1.1.1. The History and the Present

'The Dobson ozone spectrophotometer (Figure 1) was developed in the early 1920's by Prof. G.M.B. Dobson (University of Oxford) for the purpose of measuring total column ozone in the atmosphere (total ozone). Six Dobson instruments were installed at selected stations around the world as early as 1926 and were providing regular observations of total ozone. Network expansion was initially slow but was given impetus by the 1957 International Geophysical Year (IGY). The present day global network (2002) comprises about 115 spectrophotometers. This network has become a key part of the ground based system for monitoring the ozone layer and is maintained mainly under the GAW programme of WMO. More detailed information about the network can be found at the Dobson web site: http://www.chmi.cz/meteo/ozon/dobsonweb/welcome.htm

Figure 1. *The Dobson ozone spectrophotometer D074 operated at the Solar and Ozone Observatory in Hradec Králové (SOO-HK) equipped with a semi-automated facility for data recording and processing of observations*

1.1.2. The Optical System

The Dobson spectrophotometer is a double monochromator device designed for comparative measurements of the intensity of solar radiation at selected wavelengths in the ultraviolet part of the spectrum. The function of the spectrophotometer is described in detail in several fundamental publications e.g. [Dobson. 1957a, 1957b, 1962], [Komhyr, 1980], [Komhyr and Evans, 1980], [Komhyr et al., 1988], [Asbridge, 2000]. A simplified design of the instrument's optical system is drawn in Figure 2 and a basic description of the optical function is given below.

The solar light emanating from either the sun's disc (Direct Solar DS) or from the overhead sky (Zenith Blue ZB or Zenith Cloud ZC) enters the instrument through the inlet window as a polychromatic (white) beam. The prism P below the inlet window directs the beam into the first half of the double monochromator system where the white light is diffracted by the prism P1, reflected by the mirror M1 and then focused by the lens L1 onto the focal plane at slits S2 and S3 where a spectrum of colors is viewed. A mask between L1 and the focal plane blocks all wavelengths except those reaching slits S2 and S3. A rotation of the quartz plate Q1 changes the angle of light incidence on P1 thus allowing various wavelengths to be selected and focused at slits S2 and S3. The selected wavelengths are then passed through S2 and S3 into the second half of the double monochromator system where L2, M2, P2 and Q2 re-assemble the light into sharply shaped monochromatic radiation fluxes which fall on the surface of the photomultiplier PM. An electrical signal is generated in the PM and registered by the external micro ammeter

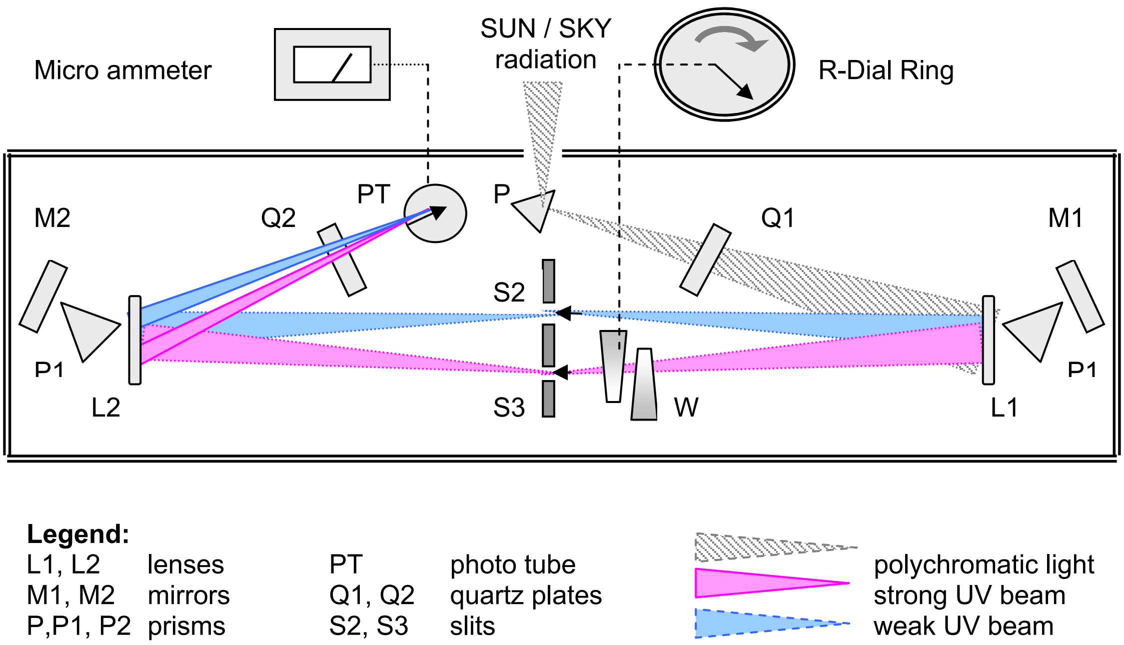

Figure 2. *Optical system of the Dobson spectrophotometer – a general design*

The optical system of the instrument is designed so that the ultraviolet part (UV) of the solar spectrum is decomposed and geometrical parameters (distance and widths) of slits S2 and S3 allow only predefined wavelengths pairs with high (SHORT wavelength λ_1) and weak

(LONG wavelength λ_2) ozone absorption to reach the photo multiplier. In the path of the LONG beam there are two optical wedges of a conic shape coated by an absorption layer which, when moving against each other in either direction, can reduce or increase the intensity of the radiation flux passing through S3. The position of the optical wedges is controlled by a manually operated external circular dial (R-dial) . The dial is equipped with a finely graduated scale for reading the so-called R-value

1.1.3. Principle of Measurement and Calculation of Total Ozone

The required SHORT (S2) and LONG (S3) pairs of wavelengths can be selected by rotating the quartz plates Q1 and Q2 to predetermined positions using external pointers. The standard wavelength pairs, identified as A, B, C, and D, were defined by Prof. Dobson based upon investigation of ozone spectral absorption. The wavelength pairs with their respective ozone absorption coefficients and molecular scattering coefficients of the atmosphere are given in Table 1. The absorption coefficients, implemented by WMO and the International Ozone Commission (IOC) in January 1992, are referred to as the Bass-Paur coefficients [Komhyr et al., 1993].

During an observation, the optical wedge is moved by the external R-dial to reduce the intensity of the LONG beam, thus simulating absorption by ozone. At a certain position of the wedges, represented by an R-value, both the LONG and Short beams reaching the PM are of the same intensity as evidenced by the zero signal (balance) of the micro ammeter. If the optical wedge density is well known (calibrated) then the real absorption of the SHORT beam by atmospheric ozone corresponds to the R-value recorded when zero balance occurs. Accordingly, total amount of column ozone in the atmosphere can be calculated from the R-values - see below.

Table 1. *Ozone absorption and atmospheric molecular scattering coefficients adopted for selected wavelength pairs in January 1992 (the Bass-Paur Scale)*

Pair	Wavelength nm		Ozone Abs. Coeff. α (atm-cm)$^{-1}$	Atm. Scatt. Coeff. β (atm)$^{-1}$
A	λ_1	305.5	1.915	0.489
	λ_2	325.4	0.109	0.375
B	λ_1	308.9	1.239	0.466
	λ_2	329.1	0.062	0.355
C	λ_1	311.5	0.873	0.450
	λ_2	332.4	0.040	0.341
D	λ_1	317.5	0.384	0.414
	λ_2	339.9	0.017	0.310

Attenuation of the λ_1 (LONG) and λ_2 (SHORT) direct sun radiation fluxes of the selected wavelength pair in the Earth's atmosphere can be described by relations:

$$\log I_1 = \log I_{01} - \alpha_1 \mu O_3 - \beta_1 m p/p_o - \delta_1 \sec ZA \qquad (1)$$

$$\log I_2 \;=\; \log I_{02} \;-\; \alpha_2 \,\mu\, O_3 \;-\; \beta_2 \, m \, p/p_o \;-\; \delta_2 \, \mathrm{secZA} \qquad (2)$$

where:

$I_{01,}$ I_{02}	...	spectral intensities of solar radiation outside the atmosphere (extraterrestrial)
I_1, I_2	...	spectral intensity at the ground (LONG and SHORT)
O_3	...	total amount of ozone in the atmosphere in Dobson Units
ZA	...	zenith angle of the Sun
m	...	relative path of the radiation through the atmosphere
p	...	observed station pressure (average value)
p_o	...	mean sea level pressure
$\alpha_{1,2}$	...	spectral absorption coefficients of ozone
$\beta_{1,2}$	...	spectral Rayleigh molecular scattering coefficients of the air
$\delta_{1,2}$	...	spectral scattering coefficients of aerosol particles
μ	...	relative path of the radiation through the ozone layer

after(1) - (2) and $N = \log(I_{01}/I_{02}) - \log(I_1/ I_2)$: (3)

$$O_3\,(\alpha_1 - \alpha_2)\,\mu \;=\; N - (\beta_1 - \beta_2)\, m\, p/p_o - (\delta_1 - \delta_2)\, \mathrm{secZA} \qquad (4)$$

The parameter N expresses a difference between logarithms of ratios of extraterrestrial and ground intensities of radiation at both wavelengths as can be measured by a Dobson instrument before and after their attenuation in the Earth atmosphere. Values of N therefore depend on actual properties of the atmosphere (mainly on total amount of ozone) represented by $\log(I_1/ I_2)$ and on technical condition of the instrument given by the ratio $\log(I_{01}/I_{02})$ that is called as an “extraterrestrial constant - ETC” of the instrument. N-values are related to position of optical wedges for equilibrium of SHORT and LONG beams (R-values on the dialing ring), as described above. The relation of N versus R is defined for individual instruments by calibration of wedges and by the final comparison of a Dobson spectrophotometer towards a reference instrument – see the par. 1.1.4.

The equation (4) can be used for calculation of total column ozone O_3 if observations are performed – N values are recorded from dialing, μ, m, ZA parameters are calculated for a date and time of observation and the coefficients $\alpha_{1,}$ α_2, , β_1, β_2, δ_1, δ_2 are constants. Then for individual wavelength pairs the relations can be written as:

$$O_3\,(\alpha_1 - \alpha_2)_A\,\mu \;=\; N_A - (\beta_1 - \beta_2)_A\, m\, p/p_o - (\delta_1 - \delta_2)_A\, \mathrm{secZA} \qquad (4a)$$
$$O_3\,(\alpha_1 - \alpha_2)_B\,\mu \;=\; N_B - (\beta_1 - \beta_2)_B\, m\, p/p_o - (\delta_1 - \delta_2)_B\, \mathrm{secZA} \qquad (4b)$$
$$O_3\,(\alpha_1 - \alpha_2)_C\,\mu \;=\; N_C - (\beta_1 - \beta_2)_C\, m\, p/p_o - (\delta_1 - \delta_2)_C\, \mathrm{secZA} \qquad (4c)$$
$$O_3\,(\alpha_1 - \alpha_2)_D\,\mu \;=\; N_D - (\beta_1 - \beta_2)_D\, m\, p/p_o - (\delta_1 - \delta_2)_D\, \mathrm{secZA} \qquad (4d)$$

To avoid influence of atmospheric aerosol particles the equations can be adjusted for double pairs AD, CD (BD is not used in routine observations) by using coefficients $\alpha_{1,}$ α_2, β_1, β_2 from Table 1 and assuming differences $\delta_1 - \delta_2$ almost the same for all pairs A,C,D. Then :

$O_3 = O_{3AD}$ for (4a) - (4d)

$O_3 = O_{3CD}$ for (4c) - (4d)

and the final relations for total ozone calculations are as follows:

$$O_{3AD} = (N_A - N_D) / 1.432\ \mu - 0.007\ m\ p / \mu\ p_o \quad (5a)$$
$$O_{3CD} = (N_C - N_D) / 0.459\ \mu - 0.011\ m\ p / \mu\ p_o \quad (5b)$$

1.1.4. Calibration Constants

The optical components of each spectrophotometer, namely, L1, L2, M1, M2, P, P1, P2, S1, S2, S3 and the PM (see Figure 2) are mounted in fixed positions defined by Dobson [Dobson, 1957a,b] and are adjusted by the manufacturer or by qualified experts. If the components are kept clean and unaffected by deterioration or physical damage, then individual instruments will mainly differ with each other due to changing characteristics of the moveable parts (i.e. the wedges W1, W2 and quartz plates Q1, Q2) and the sensitivity of the photomultiplier. In addition, each instrument possesses stray light characteristics of varying degrees which contribute to varying degrees of u-dependance. Therefore, operation of a spectrophotometer and processing of observations require definition of the following calibration constants.

Q-setting Table (Q-Table)
The Q-Table defines position of the rotated quartz plates Q1 and Q2 (in degrees) used for selection of wavelength pairs passing through the slits S2 and S3. The plates are controlled by external levers equipped with scales mounted on the front part of the body of the instrument.
A Q-Table gives the positions of the quartz plates for pairs A, B, C and D based upon a set of Discharge Lamp Tests emitting monochromatic light of different wavelengths [Komhyr, 1980]. Such tests incorporate the need to account for the temperature of the quartz optics whose diffraction and eventual wavelength selection is temperature dependant. The Q-Tables used for routine operation of D074 are given in Appendix B.

R-N Conversion Tables (N-Tables)
N-Tables (one table for each wavelength pair) define conversion of dial readings R into values of N used for total ozone calculations by the equations (5a) and (5b). The N-Tables can be developed for each wavelength pair A,C,D by laboratory measurements of the optical density of wedges represented by $\log(I_1/ I_2)$ across the wedges (for different R-values) and by estimation of ETCs. If :

$$N_0 = \log(I_{01}/I_{02}) = \log I_{01} - \log I_{02}$$

then from the relation (3):

$$N = N_0 - \log(I_1/ I_2) \quad (6)$$

When N-Table is to be developed, values of $\log(I_1/ I_2)$ are generated by artificial light from a set of external lamps heated for half power intensities (the device is called the Two-Lamp Unit) and R-values are taken from zero-dialing. In this way tables called G-Tables of R versus $\log(I_1/ I_2)$ are constructed and then corrected by extraterrestrial constants N_0 for each of the A,C,D pairs. These ETCs are specific parameters typical for each spectrophotometer and wavelength pair and in fact they express how the instrument would measure the ratio $\log(I_1/ I_2)$ outside the Earth atmosphere when extraterrestrial intensities $I_{01,}$ I_{02} enter the spectrophotometer. ETCs therefore represent actual technical condition of the optical system of the instrument which includes also selective scattering, absorption or transmission at its individual components. The values of ETCs can be estimated either by an absolute calibration of the instrument by the “Langley Plot” method (recommended only for standard spectrophotometers like WPSS - the World Primary Standard Spectrophotometer D083) or by comparison of a spectrophotometer towards standard instruments (generally performed for instruments from all GAW stations) [Komhyr et al.,1989]. Examples of the N-Tables of the spectrophotometer D074 that were determined for different time periods are given in Appendix B.

Reference Standard Lamp Readings (RR)
Each Dobson spectrophotometer is equipped with a set of two or more Standard Lamps (SLs). The lamps, when installed over the inlet window of the spectrophotometer and being heated by a stable electrical current, emit a radiation flux of the constant spectral composition. This flux generates electrical signal in the photo multiplier PM which is constant if PM (and the instrument as a system) keeps its photosensitivity stable in time. When SL is used as an artificial source of light then the R-values R_A, R_C, R_D are determined by the zero-dialing for individual pairs A,C,D. This procedure is called the Standard Lamp Test (SL-Test). When new N-Tables are developed for a Dobson spectrophotometer (see above) the SL-Tests are immediately done with a series of lamps (both with those SLs belonging to the instrument and with other lamps saved in calibration centers, e.g. in the World Dobson Calibration Center - WDCC). Values of R_A, R_C, R_D coming from these SL-Tests for each SL are called the “Reference Standard Lamp Readings”- let us sign them RR_A, RR_C, RR_D. When $RR_{A,C,D}$ readings are converted by new N-Table they give the “Reference N-Values” $RN_{A,C,D}$. Both $RR_{A,C,D}$ and $RN_{A,C,D}$ values are the calibration constants of the spectrophotometer. They are used for routine operation of the instrument in the period between its two successive calibrations/intercomparisons.

1.1.5. Operational Corrections of the Calibration Constants

The calibration constants for a new instrument are defined by the manufacturer. Subsequent adjustments to the original constants are usually determined at Dobson intercomparisons (ICs) organized by WMO. The routine operation of a spectrophotometer over an extended period of time may alter the technical state (performance) of the instrument and consequently the calibration constants may change due to shifts in optical alignment, aging and deterioration of components and possible physical damage. Therefore, from one IC to the next IC, regular performance checks and tests must be made at least monthly and always after any technical adjustment. The results of the tests are then used for correction of the calibration constants as follows.

Correction of the Q-Table (the wavelength setting table)
The Q-Table (QT) provides the settings where the external Q-levers must be positioned on the external Q-dial so that the required wavelengths pairs for A, C and D are correctly selected. In addition, the table provides the position on the Q-dial where the results of a Mercury Lamp Test (HgT) using 312.9 nm should occur. If the HgT result differs by +/- 0.3 degrees from the

QT values for Hg 312.9 nm, then the Q-settings for the A, C and D pairs Q_A, Q_C, Q_C require adjustments as defined by the equations [Komhyr, 1980]:

$$Q'_A = Q_A + 0.67 * (Q'_{Hg} - Q_{Hg}) \quad (7a)$$
$$Q'_C = Q_C + 0.99 * (Q'_{Hg} - Q_{Hg}) \quad (7b)$$
$$Q'_D = Q_D + 0.97 * (Q'_{Hg} - Q_{Hg}) \quad (7c)$$

where $Q'_{A,}$ $Q'_{C,}Q'_D$ are new corrected values in the Q-Table and Q_{Hg} , Q'_{Hg} are the values taken from the actual table and from the HgT respectively. It must be pointed out that the corrections of the Q-Table define only new parameters for operation of the instrument and they do not affect directly processing of the observations of total ozone.

Updating of the Reference Standard Lamp Readings

The Reference Standard Lamp Reference Values RRa, RRc, RRd are always redefined whenever an instrument attends a WMO IC and receives a new set of N-Tables. These values are related to the instrument's own standard lamps and to standard lamps maintained at RDCC and WDCC and may be updated by specialists at these calibration centres. Therefore, the RRa, RRc and RRd values remain unchanged from one IC until the next IC and the values are mainly used for operational corrections of the N-Tables - see below.

Correction of the N-Tables

When the values of Ra, Rc and Rd from routine monthly SL tests differ from the reference values RRa, RRc and RRd, it indicates changes in the calibration status of the instrument. Consequently, the N-Tables obtained from the most recent IC require correction before the observational R-values are converted to N-values for use in (5a) and (5b). The new N'-Tables are then defined by the relations:

$$N'_A = N_A + (RR_A - R_A) \quad (8a)$$
$$N'_C = N_C + (RR_C - R_C) \quad (8b)$$
$$N'_D = N_D + (RR_D - R_D) \quad (8c)$$

which are used for processing of total ozone observations until new set of corrections or redefinition is called for by the next monthly SL tests.:

1.2. Operation of the Dobson Spectrophotometer No. 074

1.2.1. Installation and Maintenance of the Instrument D074

Installation

The Dobson ozone spectrophotometer No. 074 (D074) was bought by CHMI in November 1959 from the R. & J. Beck, Limited, London as a calibrated instrument but without external power supply components. These parts were purchased from the Philips company in 1960. The whole system was completed and the observations started in 1961 at the Solar and Ozone Observatory of CHMI in Hradec Králové [Pícha,1967], [Vanicek,2001].

Original accessories
The instrument D074 was delivered to SOO-HK with the Standard Lamps marked A and B and with the Mercury Lamp. The documentation consisted of:

- The Calibration and Adjustment Manual developed by the producer [Beck,1956]
- The Handbook for Observation with the Dobson Spectrophotometer[Dobson,1957a]
- The nomograms for calculation of total ozone from zenith observations.

The calibration constants for D074 provided by the manufacturer were used for operation of the instrument and for processing of the observations from January 1961 until December 1969. (See Table 3 and Appendices A and B).

Maintenance, adjustments and repairs
Since the very beginning of its operation the spectrophotometer D074 was maintained according to recommendations and rules given in the Operator´s Handbook. The instrument was never out of service due to technical problems or damage. Adjustments and upgrades carried out on the spectrophotometer in the period 1961-2002 are listed in Table 2. These interventions have been documented and reflected in changes of instrument calibration constants - see Appendix B:

Table 2. *Technical adjustments and checks of the Dobson spectrophotometer D 074*

No.	Adjustment performed	Performed by	Action / Date
1	Adjustment of the photomultiplier	K.H. Grasnick, MOP J. Picha, SOO-HK	Siofok, May 1969
2	Replacing of the photomultiplier	K.H. Grasnick, MOP J. Picha, SOO-HK	SOO-HK January 1973
3	General re-adjustment of D074: - new US electronics installed - new phototube installed - re-position of wedges and lenses - adjustment of slits S2, S3, S4	R. Grass, NOAA A. Asbridge, AES	IC Potsdam June 1979
4	Complex cleaning and check of all mechanical and optical components and electronics	R. D. Evans, NOAA M. Stanek, SOO-HK	IC Arosa 1986, IC Arosa 1990 IC Hradec Kralove 1993 IC Kalavryta 1997 IC Arosa 1999 IC Hohenpeissenberg 2002

1.2.2. Calibrations and Intercomparisons of D074

The instrument D074 has been calibrated at international comparisons (ICs) organized mainly by WMO in co-operation with the Climate Monitoring and Diagnostic Laboratory (CMDL) of NOAA, Boulder, Colorado. A list of ICs is given in Table 3 together with specifications of the calibration constants. Precise details describing the work done on D074 and the intercomparison results are detailed in Appendices A and B.

Table 3. *International comparisons and calibrations of the Dobson spectrophotometer D074 and periods of calibration constants in use*

Year	Place	Acronym	Reference instrument	Calibration constants defined (see Appendices A and B) - period in use	
1959	London	IC-59	Not known, Beck-London	QT-59 NT-59 RR-59	01.01.1962 - 12.06.1979 01.01.1962 - 31.12.1969 01.01.1962 - 25.06.1979
1969	Siofok	IC-69	D084, Belsk, Poland	NT-69	01.01.1970 - 12.06.1979
1979	Potsdam	IC-79	D071, Potsdam, Germany	QT-79 NT-79 RR-79	13.06.1979 - 15.07.1990 13.06.1979 - 14.08.1986 09.06.1979 - 13.07.1986
1986	Arosa	IC-86	D083, NOAA, Boulder, USA	NT-86 RR-86	15.08.1986 - 25.07.1990 15.08.1986 - 26.07.1990
1990	Arosa	IC-90	D065, NOAA, Boulder, USA	QT-90 NT-90 RR-90	17.07.1990 - 27.07.1997 26.07.1990 - 21.07.1997 02.08.1990 - 21.07.1997
1993	Hradec Králové	IC-93	D065, NOAA, Boulder, USA	No changes of calibration constants	
1997	Kalavryta	IC-97	D065, NOAA, Boulder, USA	QT-97 NT-97 RR-97	22.08.1997 - 31.12.2002 22.07.1997 - 16.07.1999 22.07.1997 - 16.07.1999
1999	Arosa	IC-99	D065, NOAA, Boulder, USA	NT-99 RR-99	17.07.1999 - 23.07.2002 17.07.1999 - 23.07.2002
2002	Hohenpeissenberg	IC-02	D064, MOHP, Germany	NT-02 RR-02	24.07.2002 - 31.12.2002 24.07.2002 - 31.12.2002

1.2.3. Developments and Modernization

After IC-99 the instrument D074 has been established as a secondary reference Dobson spectrophotometer for the RA-VI region (Europe). Since July 1997 (after IC-97) regular SL and HG tests have been extended by regular monthly Tests of Slits (Tests of Symmetry) – see Test No.7 in [Dobson, 1957a]. In 1999 the instrument was equipped with a semi-automated facility for data recording a processing of total ozone observations by means of connected PC – see. Figure 1 and [Staněk, 2002].

1.3. Calibration Constants of the Instrument D074

The calibration constants defined for instrument D074 in the period 1959-2002 are summarized in Appendix B. An analysis of the changes in the constants allows for an assessment of the consistency of the calibration state of the spectrophotometer and the possible correction and/or redefinition of the calibration constants for the various historical calibration periods outlined in Appendix B. The re-evaluated constants can then be used as input parameters for the homogenization and/or reprocessing of the entire data series of total ozone observations from Hradec Kralove.

1.3.1. Wedge Characteristics

The characteristics of the optical wedge are represented, for each wavelength pair, by the relationship Delta R versus R [Komhyr, 1980] which plays a key role in the definition of the instrument's N-Tables. The relationship is obtained by examining the density gradient of the optical wedge using a two-lamp unit (see paragraph 1.1.4.). Five wedge calibrations have been carried out on instrument D074, the first of which was done by the manufacturer in 1959 using a two-lamp unit of unknown specifications. The Delta R versus R data from 1959 are not available at SOO-HK but an estimation was made from the original N-Tables NT-59 [Asbridge, 2002]. Subsequent wedge calibrations were performed at intercomparisons IC-79,90,99,02. The outputs (delta R versus R) identified as WGD-59,79,90,99,02 are given in Appendix B (Table B-1) and are drawn in Figure 3.

The wedge density curves represent a relative transparency of the wedges in their different parts (positions/values of R on the dialing ring). Therefore, if surfaces of wedges are kept clean and not damaged, differences between curves show long-term changes of transparency - e.g. due to natural aging of coating or adhesive materials. In the case of the instrument D074 the curves in Figure 3 show that:

a) Shape of the curves is almost the same for all wavelength pairs for the period 1979-2002.
b) The WDG-59 curves, which have been estimated from NT-59 (not obtained with a known two-lamp unit), are not so sophisticated like the others and they can be taken only for a rough estimation of time changes in the next two decades..
c) Differences between the curves are most pronounced for R-values >200 degrees where the wedge density is greatest. The differences may be due to real changes in the wedge density over time but are most likely due to noisy and weak signals caused by the dense part of the optical wedge.
d) Calculations show, that if the curves WDG-90 are taken as the references, then differences towards WDG-79,99,02 can introduce errors in calculation of total ozone less than 1.2% for μ = 1.15-3.4 and R-ranges really used for total ozone observations at SOO-HK over the year (limited by the vertical red lines in graphs). Therefore, even if shifts between curves have occurred due to time changes of wedges, at least for the period 1979-2002, the WDG-90 calibration is representative for development of G-Tables and related N-Tables at ICs held in the last two decades.
e) As no significant changes of wedge characteristic have been found for the period 1979-2002 it can be expected that also during the previous 18 years from 1962 to 1979 wedges kept the general shape of their transparency (optical density). Then the wedge calibration WDG-79 can be used for a backward re-definition of N-Tables for the period 1962-1979 using results of regular Standard Lamp Tests (SLTs).

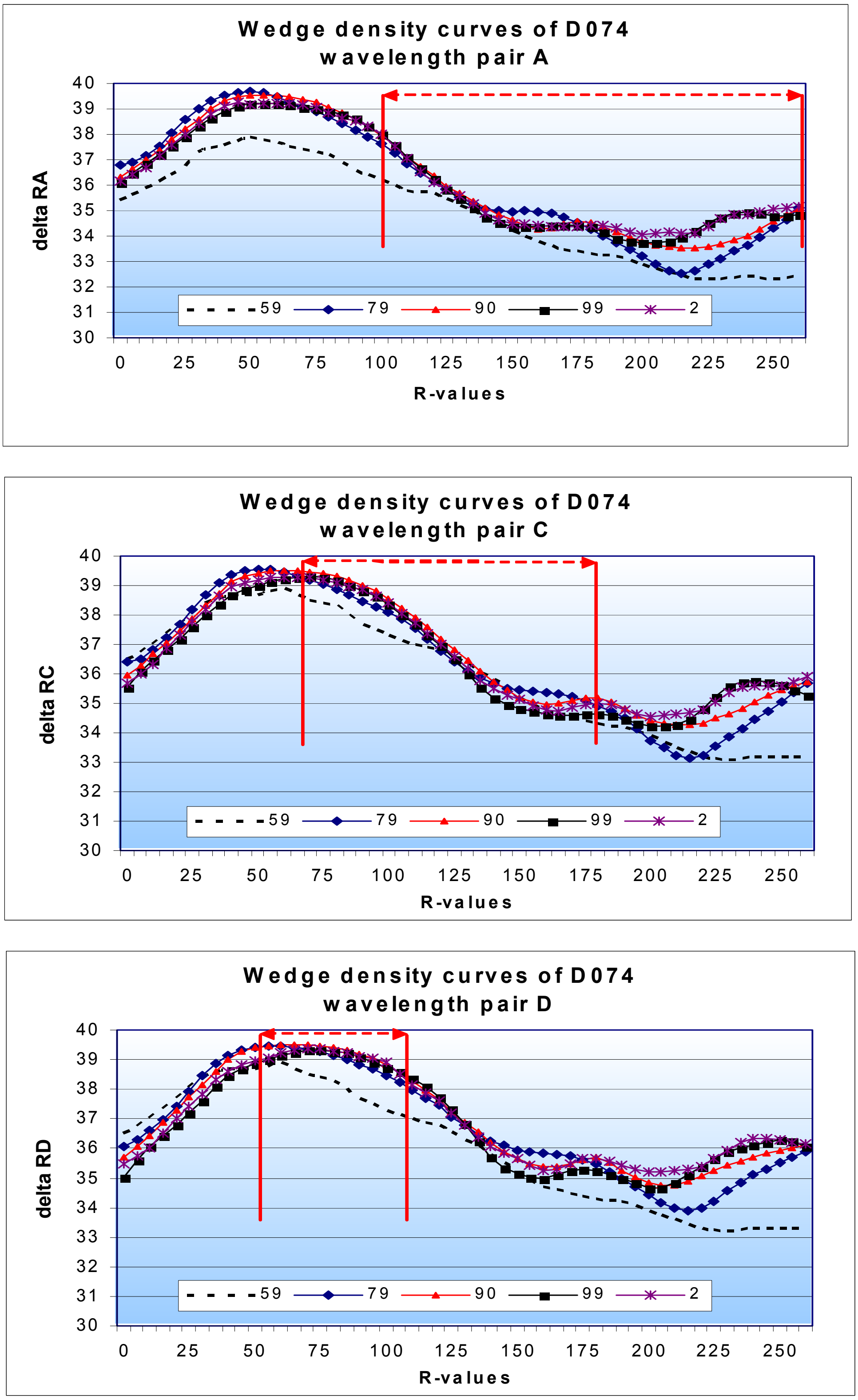

Figure 3. *Wedge density curves (ΔR versus R)of the spectrophotometer D074 for wavelength pairs A,C,D from wedge calibrations WDG-59,79,90,99,02*

1.3.2. Q-Setting Tables – Long-term record of the Mercury Lamp Tests

Table for setting positions of the Q1 and Q2 levers (Q-Table) is necessary for a correct operation of the spectrophotometer under different internal temperatures (see the paragraph 1.1.4.). Validity of a Q-Table is checked by regular Mercury Lamp Tests (HgT) which should be done at least every month. If offsets from HgT are systematically higher than +- 0.3 the Q-Table must be corrected by (7a) - (7c) relations or a new Q-Table should be defined by the Discharge Test. In Table B-2 in Appendix B there are given Q-Tables used for operation of the instrument D074 in the period 1962-2002. Figure 4 shows offsets of all HgT tests performed at D074 during its operation. It can be concluded that, except for limited cases, the majority of offsets have not exceeded the +/- 0.3 degree limits which indicates that the instrument has shown very good optical stability. This solidifies the belief that the instrument has been correctly operated with respect to selecting the desired wavelengths over the period 1962-2002.

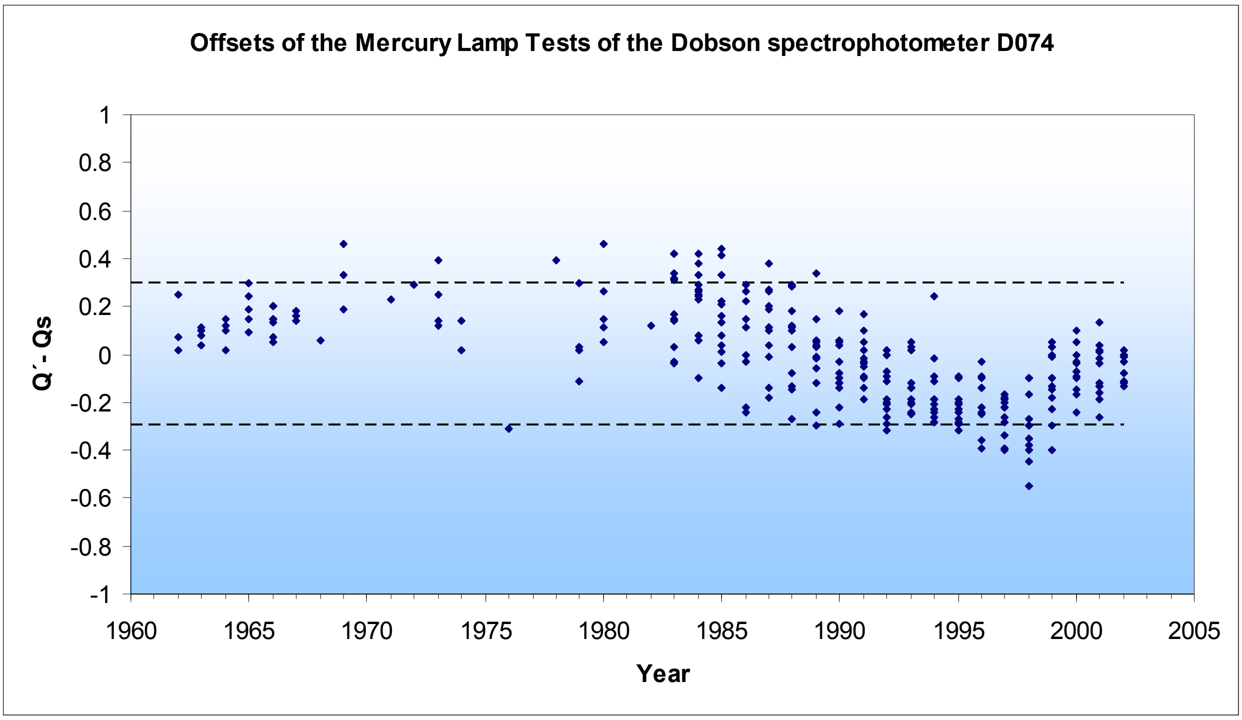

Figure 4. *Results of the Mercury Lamp Tests of the Dobson spectrophotometer D074 in the period 1962-2002*

1.3.3. N-Tables – Long-term record of Standard Lamp Tests

Standard Lamp Tests on D074 began in 1962 using SL No. 74-B, a 100 Watt tungsten filament lamp operated at 200 Volts supplied by the manufacturer and used until January 1980 but on an irregular basis. In June 1979 a new type of SL (US, tungsten-halogen, 200 W), No.: 74-QJ-I was implemented and used for SL-Tests. The tests have been performed every month since January 1983. In August 1986 a second US SL No. 74-QJ-II has been established as a reserve lamp and used every third month for tests. The results of the SL Tests during this period represent several hundreds of values and cannot be presented in this report. Therefore, only yearly averages are given in Table B-3 of Appendix B. Graphs of all R-values from SL-Tests are viewed for individual pairs A,C,D in Figure 5. Trends and break points in the curves indicate changes in technical condition (radiation sensitivity) of the instrument D074 either due to natural aging of optical elements and phototube and as a result of technical interventions. These can be specified as follows.

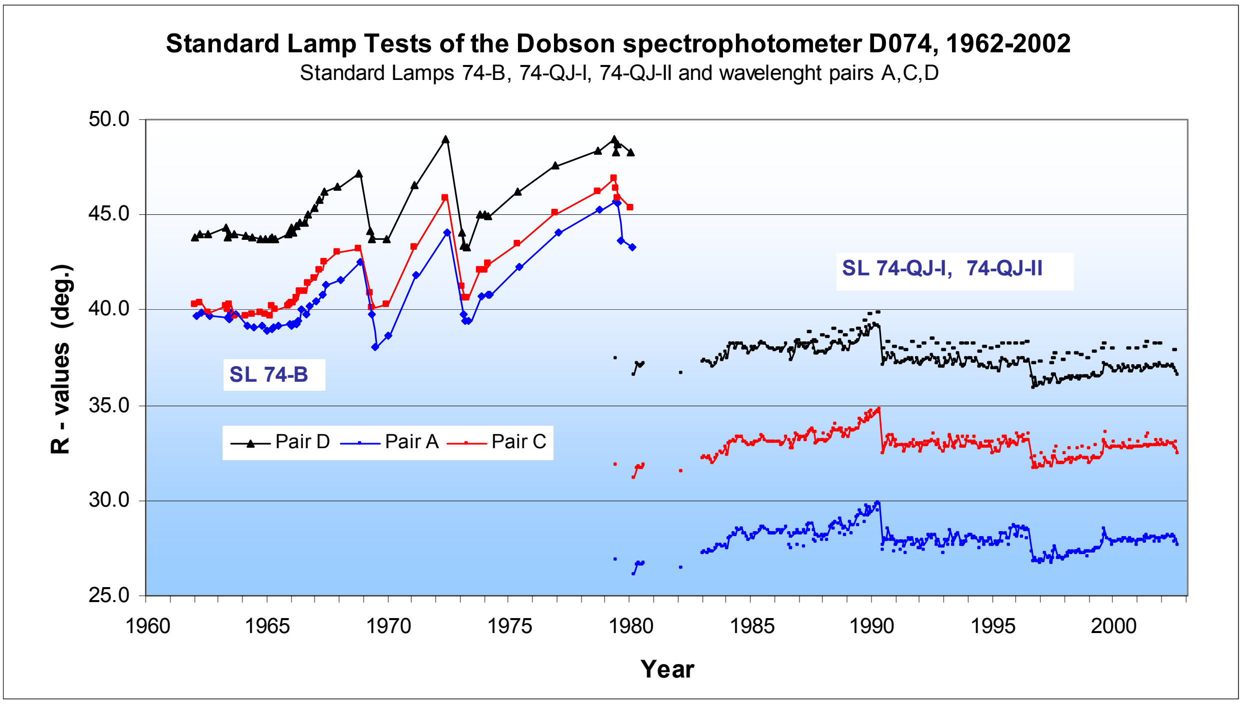

Figure 5. *Results of the Standard Lamp Tests of the Dobson spectrophotometer D074 in the period 1962-2002*

− January 1962 - June 1969.

Gradual decreasing of the sensitivity (the same magnitude for all pairs) due to aging of the phototube or by sedimentation of impurities on optical surfaces. Cleaning of the optics and re-adjustment of the photomultiplier at IC-69 in Siofok followed by a temporary increasing of sensitivity till the end of 1970.

− June 1969 – January 1973

Decreasing of sensitivity appeared again – persisting problems with the phototube

− January 1973 – June 1979

Replacing of the phototube in January 1973 followed by increasing of the sensitivity. A gradual aging of PM till June 1979 - equivalent magnitude for all wavelength pairs.

− June 1979 – December 2002

A complex re-adjustment of D079 (see Table 2) and exchange of PM were done in June 1979. New Standard Lamps have been implemented in1979 and 1986. Slow changes of sensitivity due to natural sedimentation of dust on optical elements were interrupted by cleaning of the instrument at ICs in 1990, 1997 and 1999. These breaks were registered by both SLs and they were reflected in changes of N-Tables at ICs of D074 performed in the period 1979-2002 (see Table B-3 in Appendix B).

Though the SL-Tests indicated both slow, gradual changes and sometimes sudden break changes in the sensitivity of D074, the changes were almost parallel for all wavelength pairs. Therefore, their impact on accuracy of calculation of total ozone can be assessed by investigation of changes of differences (R_D-R_A) resp. (N_D-N_A) or (R_D-R_C) resp. (N_D-N_C) - see equations (5a) and (5b). In Figure 6 there are given curves of those differences for the whole period 1962-2002 obtained with all three Standard Lamps. The curves show, that real significant breaks are evident for adjustment of PM in 1969 and 1973 and for the basic refurbishment of the instrument in1979. Generally, the curves are very smooth (even for the period 1962-1979) and they can be easily approximated. This is a positive conclusion, because a re-evaluation of the entire total ozone data series is possible using a technology of corrections of particular sets of N-Tables by monthly (actual or approximated) SL-Tests, see the relations (8a) - (8c).

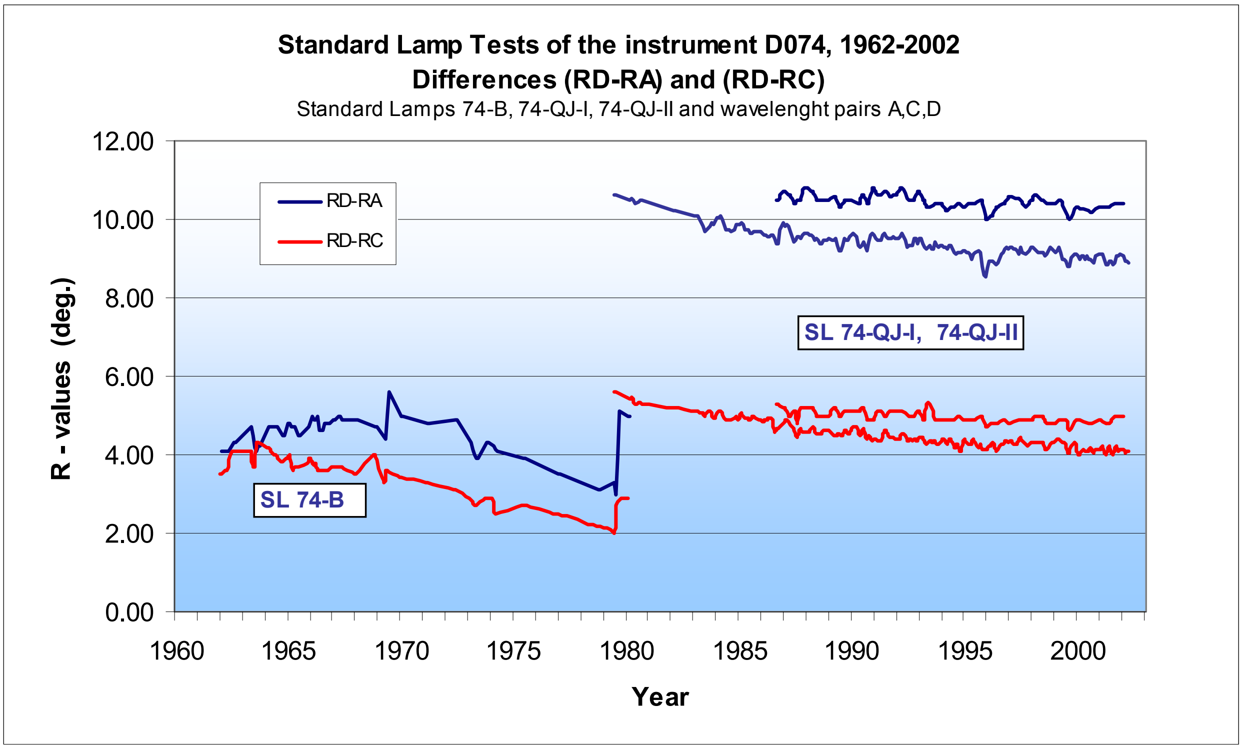

Figure 6. *Differences between Standard Lamp Test readings (R_D - R_A) and (R_D - R_C) of the Dobson spectrophotometer D074 in the period 1962-2002*

1.3.4. Relating the Calibration Level of D074 to the World Dobson Calibration Scale and the re-evaluation of its N-Tables

Tables B-4 and B-5 in Appendix B give the N-Tables and the Reference R-Readings defined for D074 in the period 1962-2002 (see Table 3). These tables and reference readings were used for processing routine total ozone observations in this period. A review of the intercomparison results listed in Table 3 and Appendix A shows that:

- After the final calibration at IC-86, the tables NT-86, NT-90, NT-93, NT-97, NT-99 and NT-02 have maintained an accuracy of ozone measurement within 1% of the world reference sprectrophotometers - see Figure 7. Therefore, for the period IX/1986 -XII2002, the calibration level of instrument D074 was maintained on the level represented by the World Primary Reference Standard D083 within the required 1% limit.

- The technical condition of D074 was stable after the refurbishment at IC-79 but the tables NT-79 need to be redefined because the final comparison at IC-79 and initial comparison at IC-86 show a significant calibration offset of about 2 percent. Based on consultations with specialists from WDCC [Evans, 2002] it was decided to develop a new set of N-Tables marked NT-79/86 defined from WDG-79 (the first reliable wedge calibrations of D074) and from the comparative observations of D074 towards D083 at IC-86. The NT-79/86 are given in Table B-4 of Appendix B. They can be used for re-calculation of total ozone observations from VIII/1986 backwards.

- The NT-79/86 tables represent the first direct calibration link of D074 to the WPDS standard instrument. The tables can be also used for a backward re-calculation of observations taken with D074 in the period I/1962-VI/1979, before IC-79. The NT-79/86 tables and SL-Test outputs available from this period allow correction and/or adjustment to the tables for particular years while covering the basic change of the technical condition of the instrument made at IC-79.

- The corrections of N-Tables have been determined from the monthly Standard Lamp tests and the Reference Readings relevant to individual periods of 1961-2002. They are given in the Table B-6. For months with missing SLTs the values were determined by linear interpolations - see the shaded areas.

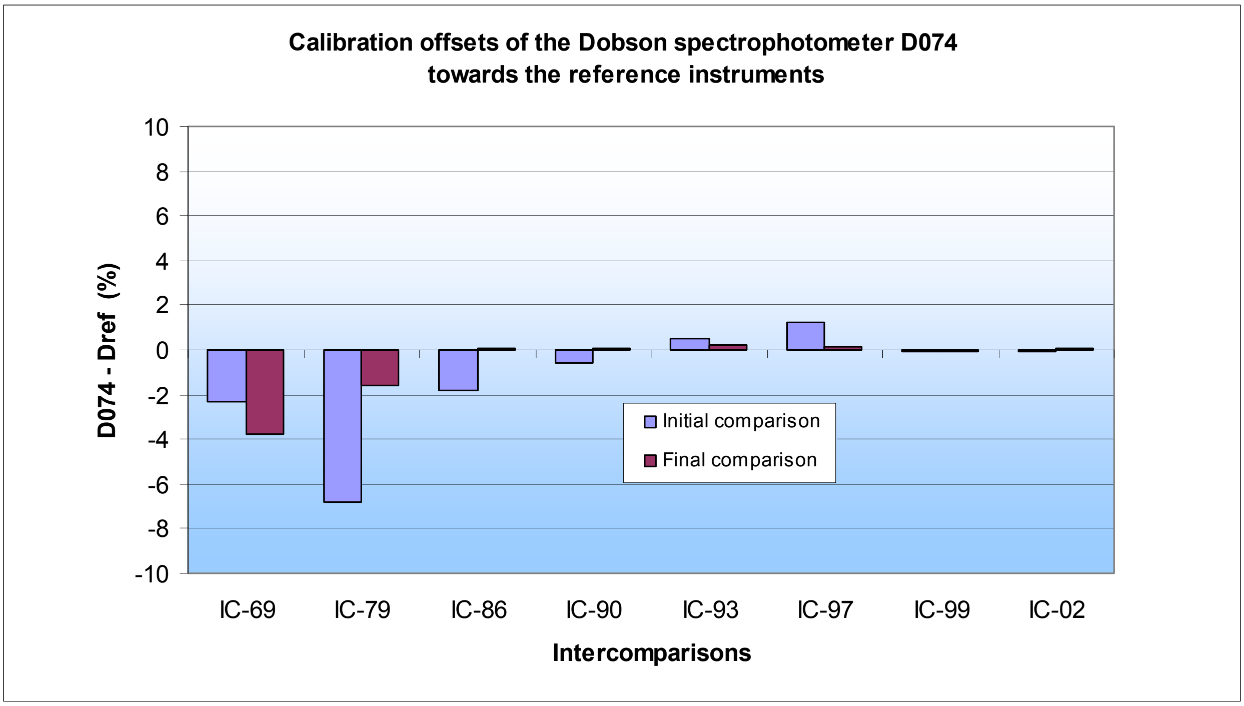

Figure 7. *Calibration offsets of the Dobson spectrophotometer D074 towards the reference instruments obtained at intercomparisons performed in the period 1962-2002*

1.3.5. Application of the re-evaluated Calibration Constants for re-processing of the Dobson D074 Total Ozone Observations from Hradec Králové

Documentation and analysis of the calibration history of the Dobson spectrophotometer D079 related to the calibration scale defined by the World Primary Dobson Spectrophotometer D083 in the whole period 1962-2002 is one of the main tasks of this report. Re-defined calibration constants allow re-processing the entire total ozone data series measured with D074 in Hradec Králové on the highest possible level of accuracy. With regards to conclusions given in the previous paragraphs and taking into account recommendations summarized in [WMO, 1993] the following methodology of re-evaluation / re-processing is suggested.

Step1
To convert all raw measured data - readings from the original written/printed historical records into magnetic files in a uniform format.

Step 2
To separate Direct Sun (DS) observations and re-process them using the calibration constants given in Appendix B in the time periods specified by Table 4. The monthly corrections of the particular N-Tables are given in the Table B-6.

Step 3
To select the quasi-simultaneous reprocessed DS and the original ZB (Zenith Blue) observations and to define new zenith polynomials for re-processing all ZB total ozone measurements as described in [Vanicek et al.,1996], [DeBacker,1998]

Step 4
To select the quasi-simultaneous reprocessed DS and the original ZC (Zenith Cloudy) observations and to define new cloud correction factors for re-processing all ZC total ozone measurements with new zenith polynomials.

Step 5
To assess quality of the re-processed total ozone measurements by a mutual comparison of the DS, ZB, ZC observations and by comparison of D074 measurements with external data sets (B098, satellite and modeled total ozone data). Reprocessing and evaluation of the measurements are recommended to be done with the software package DOBSON-3.2 and DOBSTOOL developed at SOO-HK [Stanek,1998], [Vanicek and Stanek, 2000].

Table 4. *Recommended application of the re-evaluated calibration constants of the Dobson spectrophotometer D074 for re-processing of the total ozone observations taken with the instrument D074 in the period 1962-2002 (QT, NT and RR tables see in Appendix B)*

Period of application	Q-Tables	N-Tables	Ref. R-Readings	SL-Corrections
01.01.1962 - 12.06.1979	QT-59	NT-79/86	RR-79/RR-86	Monthly approx. of SL-Tests
13.06.1979 - 14.08.1986	QT-79	NT-79/86	RR-86	Monthly approx. of SL-Tests
15.08.1986 - 18.07.1990	QT-79	NT-86	RR-86	Regular monthly SL-Tests
19.07.1990 - 21.071997	QT-90	NT-90	RR-90	Regular monthly SL-Tests
22.07.1997 - 16.07.1999	QT-97	NT-97	RR-97	Regular monthly SL-Tests
17.07.1999 - 31.12.2002	QT-97	NT-99	RR-99	Regular monthly SL-Tests

Part 2

CALIBRATION HISTORY OF THE BREWER SPECTROPHOTOMETER NO. 098

2.1. The Brewer Ozone Spectrophotometer – a basic description

2.1.1. The History and the Present

The Brewer spectrophotometer (see Figure 8) is a fully automated, PC-controlled instrument that was developed for ground-based measurements of total column of ozone in the atmosphere and spectral irradiances in the UV-B part of the solar spectrum. The spectrophotometer was designed and constructed by specialists from the Atmospheric Environment Service of Canada (AES), now the Meteorological Service of Canada (MSC), in the end of the seventies [Kerr et al., 1980], [Wardle et al., 1987]. The first commercially available instrument was produced in 1982. During the next two decades about 160 Brewer spectrophotometers have been produced with many installed in the global network. The instrument has been recognized as a reliable and important contributor to total ozone observations in the global network that represents a new generation of instrumentation. Moreover, all models Brewers allow a precise scanning of the UV-B solar radiation and also measurements of other atmospheric species like total column of sulphur dioxide, nitrogen dioxide, the aerosol optical depth in the atmosphere and the average temperature of the ozone layer [Kerr, 2003]. The Brewer spectrophotometer is a waterproof instrument (70 x 40 x 21 cm) mounted on the azimuth-following movable tracker, powered with 220 V AC and linked with a controlling PC. The spectrophotometer is produced by the SCI-TEC Instruments company, Canada - now Kipp and Zonen, Delft, the Netherlands: http://www.kippzonen.com/

Figure 8. *The Brewer MARK-IV spectrophotometer B098 operated at the Solar and Ozone Observatory in Hradec Králové*

2.1.2. The Optical System

Basic components of the optical system of the Brewer spectrophotometer (a single monochromator, MK-II model) are shown in Figure 9. The instrument is described in detail in several publications [Kerr et al., 1980], [Josefsson, 1986], [SCI-TEC, 1990, 1992, 1999]. For total ozone observations the solar radiation (direct sun beams DS or diffuse sky ZB, ZC) enters the instrument through the inlet window and through a movable prism. If UV-B spectral irradiances are measured, the solar light passes through the quartz dome, the teflon diffusor and the UVB prism. Then the radiation (still polychromatic) continues through foreoptics (iris, attenuation filters and entrance slit) to a mirror. After reflection on the mirror it falls on the movable holographic grating (1800 lines/mm) where the radiation is decomposed and a second order spectrum is created. Spectral lines are then reflected and focused by the mirror on the plane of six exit slits. The dimension of the slits combined with the position of slots on a rotated chopper mask allows penetration of only selected wavelengths to fall on the photomultiplier where the irradiances are converted into photon counts. A cutoff filter blocks rest of the scattered visible (polychromatic) light to avoid its effect on a signal from the photo tube. All movable parts of the optical system are precisely positioned with stepping motors and they are controlled by the connected PC. For example, one step of the motor moving the grating represents 0.007 nm shift in wavelength of the spectrum at the exit slits.

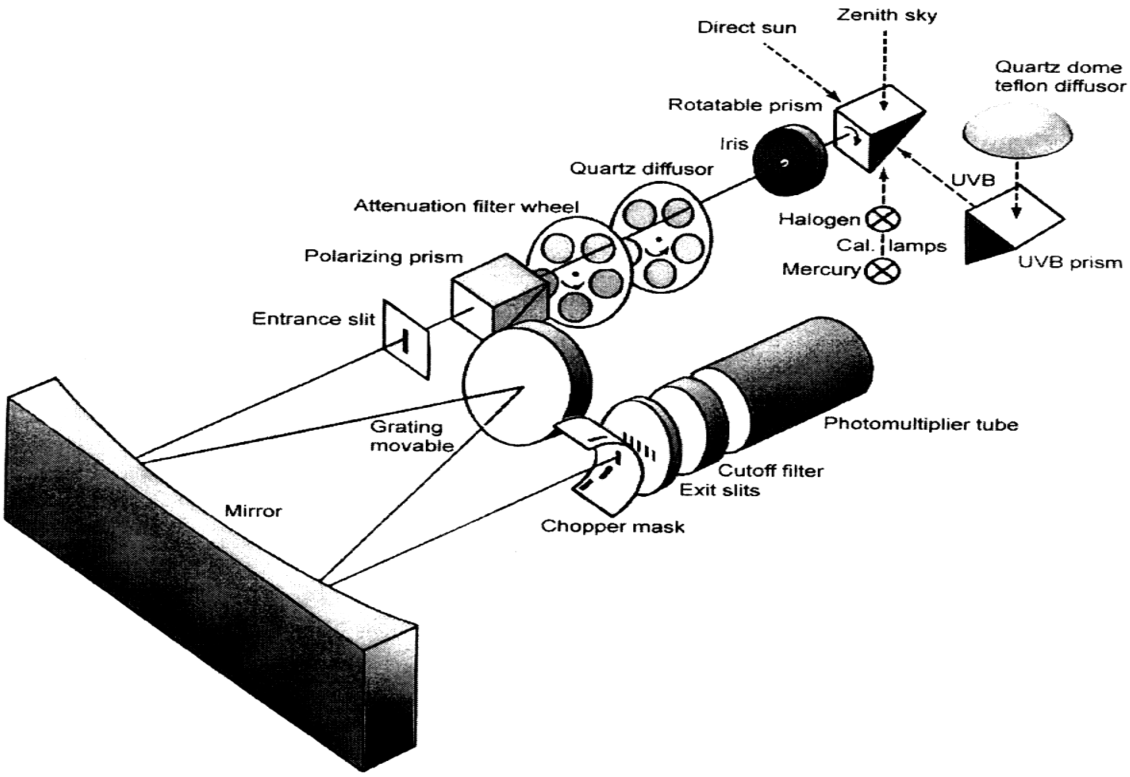

Figure 9. *The optical system of the Brewer spectrophotometer – a general design (from Josefsson, 1986)*

For total ozone observations the grating is adjusted in a fixed position and the rotating slit mask selects proper single wavelengths used for total ozone calculation and technical tests as defined in Table 5. In Table 5 there are also given wavelengths from the visible part of the solar spectrum that can be used for measurement/calculation of the total column of nitrogen dioxide [SCI-TEC, 1990]. But observations of NO_2 at SOO-HK will be not discussed in this report because they do not affect calculation of total ozone. For measurement of UV-B spectral irradiances the chopper mask is fixed so that only slit 1 is open. The grating is moved so that UV wavelengths from 285 to 325 nm can reach the photomultiplier tube (PMT) in a resolution of 0.5 nm steps.

Table 5. *Positions of the slit mask and the selected wavelengths defined for technical tests and total ozone / sulphur dioxide and total nitrogen dioxide measurements with the Brewer MARK-IV spectrophotometer*

Slitmask position	**Photon counts**	**Intensities**	**Selected wavelengths λ (nm) for O3 and SO_2**	**for NO2**
0			λ = 303.2	HG Tests
1	F1		Dark Count	
2	F2	I_1	λ_1 = 306.3	431.4
3	F3	I_2	λ_2 = 310.0	437.3
4	F4	I_3	λ_3 = 313.5	442.8
5	F5	I_4	λ_4 = 316.8	448.1
6	F6	I_5	λ_5 = 320.0	453.2
7			Dead Time λ_2 & λ_4	

2.1.3. Principle of Measurement and Calculation of Total Ozone and Sulphur Dioxide

The Brewer spectrophotometer is mounted on an azimuth tracking device which keeps the instrument's inlet window directly in alignment with the sun each day throughout the year. The tracker and all optical components are controlled and set with the connected PC according to predefined schedules of measurements [SCI-TEC, 1990]. PC also saves all outputs (mainly photon counts and test readings), calculates total ozone (SO2, NO2, UV-B), maintains all the raw and calculated data together with calibration constants in the instrument´s data base.

The principle of measurements of total ozone and SO_2 column in the atmosphere is similar to the method used for the Dobson spectrophotometer. The instrument measures spectral irradiances I_i of the solar radiation at 5 selected wavelengths $\lambda_1 \dots \lambda_5$ that are registered by PC as photon counts F2 … F6 (see Table 5) generated in the photo tube. If sulphur dioxide is taken into account as a selective absorber then the equation (4) can be re-written using linear combinations of logarithms of extraterrestrial and measured intensities I_i , I_{0i} , ozone and SO_2 absorption coefficients α_i, α_i', Rayleight molecular scattering coefficients β_i and scattering coefficients of aerosol particles δ_i [Wardle et al., 1987] as:

$$F = F_0 - \Delta\beta\, m\, p/p_o - \Delta\delta \sec Z - \Delta\alpha\, O_3\, \mu - \Delta\alpha'\, SO_2 \mu' \qquad (9)$$

where:

$$F = \log I_2 - 0.5 \log I_3 - 2.2 \log I_4 + 1.7 \log I_5 \quad (9a)$$

$$F_0 = \log I_{02} - 0.5 \log I_{03} - 2.2 \log I_{04} + 1.7 \log I_{05} \quad (9b)$$

$$\Delta\beta = \beta_2 - 0.5\,\beta_3 - 2.2\,\beta_4 + 1.7\,\beta_5 \quad (9c)$$

$$\Delta\delta = \delta_2 - 0.5\,\delta_3 - 2.2\,\delta_4 + 1.7\,\delta_5 \approx 0 \quad (9d)$$

$$\Delta\alpha = \alpha_2 - 0.5\,\alpha_3 - 2.2\,\alpha_4 + 1.7\,\alpha_5 \neq 0 \quad (9e)$$

$$\Delta\alpha' = \alpha_2' - 0.5\,\alpha_3' - 2.2\,\alpha_4' + 1.7\,\alpha_5' \approx 0 \quad (9f)$$

To make the effect of sulphur dioxide and aerosol scattering negligible, a linear combination (9a) with weighting coefficients: 0.0, 1.0, –0.5, –2.2, 1.7 has been selected - like for the Dobson observations in equation (4) where only two intensities are taken. Then, if equation (9) is rewritten ignoring the negligible terms, the following expression results:

$$F + \Delta\beta\, m\, p/p_o = F_0 - \Delta\alpha\, O_3\, \mu \quad (10)$$

Once the values F_0 and $\Delta\alpha$ are known, it is possible to calculate total ozone O_3 by substituting the results of determination of F from (9a) into the relation (10).

In a similar way like for total ozone the column of sulphur dioxide in the atmosphere SO_2 can be calculated by a linear combination of logarithms of the light intensities I_1, I_4 and I_5 by the following expressions:

$$S + \Delta^*\beta\, m = S_0 - \Delta^*\alpha\, X\, \mu - \Delta^*\alpha'\, SO_2\, \mu' \quad (11)$$

where:

$$S = \log I_1 - 4.2 \log I_4 + 3.2 \log I_5 \quad (11a)$$

$$S_0 = \log I_{01} - 4.2 \log I_{04} + 3.2 \log I_{05} \quad (11b)$$

$$\Delta^*\beta = \beta_1 - 4.2\,\beta_4 + 3.2\,\beta_5 \quad (11c)$$

$$\Delta^*\alpha = \alpha_1 - 4.2\,\alpha_4 + 3.2\,\alpha_5 \quad (11d)$$

$$\Delta^*\alpha' = \alpha'_1 - 4.2\,\alpha'_4 + 3.2\,\alpha'_5 \neq 0 \quad (11e)$$

α'_i are SO_2 absorption coefficients and μ' is the relative optical path length through the sulphur dioxide layer (5 km average height above the earth).

<u>Remark</u>
Value of μ' is different comparing the μ-value for ozone that is calculated for the fixed altitude of the ozone layer at 22 km in the Brewer algorithm. It should be noticed here, that in algorithms for calculation of μ for processing Dobson total ozone the altitude of the ozone layer is usually approximated as a parameter dependent on the latitude of a station. Therefore, μ-values calculated separately for simultaneous collocated Dobson/Brewer observations can differ with each other for the same time of measurements!

2.1.4. Calculation of Total Ozone and Sulphur Dioxide from the Photon Counts

Total ozone and sulphur dioxide are calculated by the standard data management software installed in the Brewer PC from equations (10) and (11) where logarithms of intensities log I_i are represented by logarithms of photon counts Fi. Before calculations of total ozone and SO2 are made, a conversion of the raw counts (registered from the photomultiplier) to count rates representing light intensities is necessary. This is done in the following steps described in detail in [SCI-TEC, 1988].

Correction of raw counts for dark counts
The operational counts Fi (i = 2 .. 6, see Table 5) are corrected for the dark count F1 and they are expressed as count rates F(i) in photon counts per second.

Compensating for dead time
The operational count rates F(i) are then corrected for an influence of the dead time of the photon-counting system and true count rates are calculated - see the dead time test values in the paragraph 2.1.5..

Compensating for temperature
This compensation corrects count rates F(i) for the influence of the temperature-dependent characteristics of the band pass filter inside the phototube.

Compensation for Rayleigh scattering
The last adjustments compensate for (i) the influence of Rayleigh scattering in the air mass m during the observation and (ii) a representative atmospheric pressure based upon observatory altitude and Standard Atmosphere values. In this way the part ($\Delta\beta$ m p/p_o) of the left-side equation (10) is included into adjustments of the count ratios.

Computing single and double ratios
By means of the above adjusted count ratios equation (10) can be expressed by means of the linear combination of F(i) as:

$$F(3) - 0.5\,F(4) - 2.2\,F(5) + 1.7\,F(6) = F_0 - \Delta\alpha\, O_3\, \mu \qquad (12)$$

In the Brewer data files the following single F-ratios and double M-ratios are computed and stored that should be noticed here (nomenclature is kept as given in [SCI-TEC, 1988]):

$$M(4) = F(5) - F(2) \qquad (13a)$$
$$M(5) = F(5) - F(3) \qquad (13b)$$
$$M(6) = F(5) - F(4) \qquad (13c)$$
$$M(7) = F(6) - F(5) \qquad (13d)$$

$$M(8) = M(4) - 3.2\,M(7) \qquad (13e)$$
$$M(9) = M(5) - 0.5\,M(6) - 1.7\,M(7) \qquad (13f)$$

If the M-ratios are used, equation (12) can be re-written for calculation of total ozone as:

$$O_3 = (M(9) - F_0) / \Delta\alpha\, \mu \qquad (14)$$

The linear combination F_0 is called the "extraterrestrial constant" - see N_0 in the relation (6) for the Dobson spectrophotometer. F_0 is an important instrument-dependent calibration constant.

For total sulphur dioxide the equation (11) can be also re-written by means of count ratios and relation (11a) as:

$$F(2) - 4.2\, F(5) + 3.2\, F(6) + \Delta^*\beta\, m \;=\; S_0 - \Delta^*\alpha\, O_3\, \mu \;-\; \Delta^*\alpha'\, SO_2\, \mu' \qquad (15)$$

Then, if higher-order ratios (13a)-(13f) are used, the final equation that is used in the Brewer program for calculation of total SO_2 can be written as:

$$SO_2 \;=\; (M(8) - S_0) / \Delta^*\alpha'\, \mu' \;-\; \Delta^*\alpha\, O_3\, \mu / \Delta^*\alpha'\, \mu' \qquad (16)$$

In the expression (16) the value of M(8) is measured, μ and μ' are calculated, O_3 is known from (14). The ratios of ozone and SO_2 absorption coefficients for the sulphur dioxide wavelength combinations (11d) and 11(e) are known for the exactly selected and adjusted wavelengths - see Table 5. But real selection of wavelengths can be influenced by the current technical condition of the spectrophotometer. This is checked and real wavelength combination is determined by the dispersion test. In that case the absorption coefficients and their linear combinations $\Delta\alpha$, $\Delta^*\alpha$, $\Delta^*\alpha'$ must be re-defined under re-calibration procedures. For the Brewer observations the set of the Bass-Paur ozone and SO_2 absorption coefficients is used - see par. 1.1.3.. The parameter S_0 is the "extraterrestrial constant" of the Brewer spectrophotometer for sulphur dioxide and it represents one of the most important calibration constant of the instrument - like the extraterrestrial constant F_0 for total ozone.

2.1.5. Calibration Constants and Related Technical Tests

The correct function of the Brewer spectrophotometer and consequently the accurate processing of the observations depend on precise adjustments of the optical, electronic and mechanical components. The adjustments are defined by a large set of technical parameters which are identified as the instrument calibration constants. The instrument manufacturer provides an original set of constants which can later be revised either by comparison against a reference (standard) instrument or by an absolute calibration similar to the Dobson calibration methodology. The calibration constants are saved in the Constants File and are viewed by the CF command. A set of diagnostic tests can be performed automatically using predefined commands scheduled within the operational program of the PC. These tests are usually made daily to check the current technical state of the instrument the results of which may eventually to operational adjustments of the calibration constants. In this chapter, only the key tests directly linked to the function of the Brewer optical system are mentioned. Those related to electronics and to mechanical parts are omitted because they do not directly affect the methodology of total ozone and SO_2 calculation. The following are the diagnostic tests used for a check or application of the main calibration constants [SCI-TEC, 1988].

Shutter motor (chopper) delay time SHDT

SHDT values are obtained by the Shutter Motor Timing Test (the command SH). The test determines the value for the timing constant SHDT used for the control of the shutter motor that moves the slit mask (called also slit mask motor or chopper motor). The measurements are taken with the SL light and the slit mask positions 0,1,2 (see Table 5). SHDT is an optimal value of the delay time of the motor for which the dark count is minimal. Usually the SHDT values should lie within the range 65 - 75 with a tolerance of 5 units from the reference value given by the original calibration of the instrument. If an offset is higher, then the spectrophotometer should be re-calibrated by the manufacturer.

Shutter motor Run/Stop Ratios SHRS

SHRS values are outputs from the Shutter Motor Run/Stop Test (the command RS) which verifies that the shutter motor is operating properly. It means that the movement and stopping of the slit mask slots over the exit slits are adjusted in time so that the spectral intensities can be measured with a required dynamics (131 milliseconds per slit). The test is performed with the SL light and SHRS values are calculated as ratios of photon counts obtained for each operational wavelength (slit mask positions 2-6). The shutter motor works properly if SHRS values are in the range 0.997 - 1.003. Correct SHRS depend on an accurate adjustment of SHDT.

Photomultiplier dead time PDT

PDT is a time expressed in seconds that represent dead time (a time for getting the zero signal) of the photomultiplier and photon-counting circuitry. The PDT value is calculated from the Photomultiplier Dead Time Test (the command DT) for the high and low intensities of SL. The true F_0 photon counts are calculated from the measured values F from the equation:

$$F = F_0 * \exp(- F_0 * PDT) \qquad (17)$$

The high and low intensity PDTs should agree and lie in the range of 35 - 50 nanoseconds. If this criterion is not met there could be problems either with shutter motor operation, the high-voltage circuitry or photon counting circuitry. Should the higher offset persists for a long-time, the producer should be contacted for assistance.

Mercury Lamp Test HgT

The Mercury Lamp Test (the command HG) is used to check the precise setting of all components of the Brewer optical system in a similar way like for the Dobson spectrophotometer (see par.1.3.2.). This concerns mainly a precise dispersion of the radiation wavelengths by the grating and their focusing onto appropriate exit slits. HgT is performed by the mercury discharge lamp (HgL) mounted inside the instrument and controlled by PC. A mercury line-spectrum generated by HgL passes through the optical system and it is compared with the reference spectrum stored in the instrument. The offset between both spectra is calculated and used for determination of a reference setting (position) of the micrometer that adjusts (moves) the grating. The reference position is represented by the Calibration Step Number (CSN) that is added to the result of HgT. The mercury test and the re-position of the micrometer are automated and it is PC-controlled. HgT is a very frequently used test (several times per day) being performed whenever a re-position of the micrometer (grating) is needed during operation of the Brewer spectrophotometer. The actual value of CSN is a key calibration constant stored in the Constant File of the instrument and it is printed in a daily summary of tests.

Standard Lamp Test SLT

The Standard Lamp Test (the command SL) checks a general function of the Brewer spectrophotometer in a similar way like SLT for the Dobson spectrophotometer. The test is performed with a well regulated and stable quartz-halogen lamp mounted inside the instrument and controlled by PC. The test is taken at least twice per day (before and after daily series of observations). Raw counts Fi for the dark-count channel and for five operational wavelengths are the main readings from SLT. These are corrected for dark count, dead time and temperature-dependence (see above). Then the count rates F(i) are used for calculation of single and double ratios M(4) … M(9) from (13a) … (13f) that are printed together with their standard deviations in a daily summary of SLT. If SL is stable and the spectrophotometer is maintained in a proper condition the ratios M(4) … M(7) are reasonably constant and the double ratios can vary in the limits of +- 1.5%. Therefore, the long-term changes of the ratios M(4) … M(9) characterizes calibration stability of the instrument. Values of M(8) and M(9) determined from regular daily SLTs are important outputs for operational adjustments of the extraterrestrial constants F_0 and S_0 - see the next par. 2.1.6..

Scan Test SCT

The Scan Test (the command SC) is a very important procedure for an on-going check of the current calibration status of the Brewer spectrophotometer. SCT verifies the correct value of the Calibration Step Number CSN (see the Mercury Lamp test) that is used for a proper adjustment of the position of the diffraction grating for total ozone and SO_2 measurements (for selection of defined UV wavelengths passing through the exit slits). The test is described in the instrument Acceptance Manual [SCI-TEC, 1988] and later in an updated version in [Lamb and Asbridge, 1996]. A series of SCTs allows the Brewer operator to construct a $\mu * O_3/1000$-dependence on the O_3-maximum micrometer steps (the correct positions of the grating for ozone and SO_2 measurements) and to find a cross-section of this curve with the value 0.68 that is representative for mid-latitude Brewer stations (340 DU, μ=2). If the cross-section step does not agree well with CSN, problems with aging or adjustment of HgL or SL exist.

Extraterrestrial constant for ozone F_0

F_0 is defined by equation (9b) and it is applied in the relation (14) for calculation of total ozone. Its physical meaning is the same like of N_0 for the Dobson spectrophotometer - it represents the linear combination (9b) if the UV intensities are measured with a Brewer spectrophotometer outside the Earth atmosphere. The value of F_0 can be changed either by intercomparison towards a reference instrument or by its "absolute calibration" by means of the Langley-plot technique. Operational corrections can be done by outputs of SL tests - see the next paragraph..

Extraterrestrial constant for sulphur dioxide S_0

S_0 is defined for a given SO_2 absorption scale by the equation (11b) and applied in the relation (16). Its meaning is the same like of F_0 for ozone. The value of S_0 can be determined after F_0 is known. Operational corrections of S_0 can be done by outputs of SL tests.

Linear combination of the ozone absorption coefficients $\Delta\alpha$, $\Delta^*\alpha$

$\Delta\alpha$ and $\Delta^*\alpha$ are defined for a particular ozone absorption scale by equations (9e) and (11d) and they are applied in the relations (14) and (16). The values of $\Delta\alpha$ and $\Delta^*\alpha$ can be changed after re-determination of operational wavelengths and their absorption coefficients α_i or when the absorption scale is changed.

Linear combination of the sulphur dioxide absorption coefficients $\Delta\alpha'$, $\Delta^*\alpha'$

$\Delta\alpha'$ and $\Delta^*\alpha'$ are defined for a SO_2 absorption scale by the equations (11d) and (11e) and they are applied in the relation (16). These values can be changed after re-determination of operational wavelengths or and their absorption coefficients α'_{i}.

2.1.6. Operational Corrections and Applications of Calibration Constants

Unlike the Dobson spectrophotometer the Brewer spectrophotometer is fully automated and it does not need manual adjustments of its operational parameters. The calibration constants (saved in the Constants File) initially implemented by the producer are used for routine observations before they are changed by special tests or at intercomparisons. Some tests described in the previous paragraph are performed daily or even several times per day (e.g. HgT and SLT). Their outputs are processed by the controlling PC and used for operational re-adjustment of the optical system. The calibration constants defined in the paragraphs 2.1.4. and 2.1.5. are used or re-adjusted as follows.

Shutter motor (chopper) delay time SHDT

SHDT is a diagnostic parameter determined by the SH test that is performed occasionally. If SHDT values are out of limits a professional intervention is needed and a new SHDT defined.

Shutter motor Run/Stop Ratios SHRS

SHRS is a diagnostic parameter that is measured daily to identify technical problems with the function of the shutter motor.

Photomultiplier deadtime PDT

The PDT is a diagnostic parameter measured each day to check the proper function of the photomultiplier and the photon-counting circuitry. The PDT value defined in the set of calibration constants is important for calculation of the true photon counts, see (17), the count rates and consequently the total ozone and SO2 values. It is recommended by the producer that changes of PDT value in the Constants File should not be made operationally but under professional re-calibrations of the spectrophotometer [SCI-TEC, 1988].

Calibration Step Number CSN

The CSN is a key calibration constant which defines the correct setting of the grating to be used for all types of measurements and for many tests performed with the instrument, in particular the HgT and SLT. The value of the CSN can be verified and corrected if necessary by sets of Scan Tests. If there is not an urgent technical reason such corrections are done by experts under regular intercomparisons of the instrument - usually in two-year steps.

Extraterrestrial constants F_0 and S_0

Values of ETCs F_0 and S_0 are defined as instrument calibration constants either at intercomparisons of the spectrophotometer or by the Langley-plot technique. In between these calibrations the values of F_0 and S_0 are used for processing of total ozone and SO_2 by relations (14) and (16). When new values of F_0 or S_0 are defined, corresponding SL Reference Ratios MR8 and MR9 are defined by a series of Standard Lamp tests (in the similar way like the $RR_{A,C,D}$ Reference Standard Lamp Readings for the Dobson spectrophotometer - see par.1.1.4.). If results of operational (daily) SLTs show changes of M8 or M9 towards MR8 or MR9 respectively, then the extraterrestrial constants should be corrected by the following expressions:

$$F_{0new} = F_0 + (MR9 - M9) \qquad (18)$$

$$S_{0new} = S_0 + (MR8 - M8) \qquad (19)$$

Such corrections are recommended to be done by smoothed (10-day) values of M8 or M9 of SLTs.

Ozone and sulphur dioxide absorption coefficients

Linear combinations of ozone and sulphur dioxide absorption coefficients defined by equations (9e), (11d), (11e) are determined by absorption coefficients α_i and α'_i of the operational UV wavelengths $\lambda_1 \ldots \lambda_5$ given in Table 5. A correct selection of the wavelengths $\lambda_1 \ldots \lambda_5$ can be checked by the Dispersion Test by means of a set of discharge lamps (like for definition of the Q-Table for the Dobson spectrophotometer). If this tests show that different wavelengths are selected and passed through the exit slits, then a new set of $\lambda_1 \ldots \lambda_5$ is to be implemented (usually very close to the original ones) and therefore new α_i and α'_i absorption coefficients and their linear combinations $\Delta\alpha$, $\Delta^*\alpha$, $\Delta^*\alpha'$ must be defined from equations . (9e), (11d), (11e). Re-definition of operational wavelengths and their absorption coefficients can be done only by specialists at intercomparisons which are equipped with discharge lamps for performance of the Dispersion Test. It is not recommended to change these calibration constants by operators.

2.2. Operation of the Brewer Spectrophotometer B098

2.2.1. Installation and Maintenance of the Instrument B098

Installation and original accessories

The Brewer MK-IV ozone spectrophotometer No. 098 (B098) was bought by CHMI from the SCI-TEC Instruments Inc., Saskatoon, Canada as a calibrated instrument in 1993. The instrument was installed by A. Asbridge, an expert from the SCI-TEC company, at the Solar and Ozone Observatory of CHMI in Hradec Kralove on December 16, 1993. Regular observations of total ozone, total sulphur dioxide, total nitrogen dioxide and UV-B spectral irradiances (UV scans, 290-325 nm) with B098 started at SOO-HK on January 01, 1994. Since that date the spectrophotometer has performed without any interruptions except for participation at intercomparisons [Vanicek, 2001]. The instrument B098 was delivered to SOO-HK with the following accessories:

- sun tracker
- controlling PC
- set of UV-B external calibration lamps
- set of standard electronics spares
- cold weather kit
- Acceptance, Operating and Maintenance Manuals

Maintenance and operation

The spectrophotometer B098 is installed on the roof of the building of SOO-HK (see Figure 9). The sun tracker is fixed by a metal frame to the concrete base. The instrument is maintained according to recommendations and rules given in the Maintenance Manual [SCI-TEC, 1992] and its revisions. The controlling personal computer is located in the main office room of SOO-HK and it is connected with B098 by a 10-meter cable link. The spectrophotometer is operated in a fully automated regime that includes routine DS and ZS observations of total O3, SO2. NO2 and UV-scans for pre-defined solar zenith angles: noon, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75 degrees which cover the range of the relative air mass μ = 1.15-3.6 at the location of SOO-HK over the year. Special schedules are defined for comparative simultaneous DS observations with D074 spectrophotometer. The standard tests HG, SL, RS, DT and MI are performed daily accompanied by a printed summary sheet at the end of each 24 hour period. UV tests with the external lamps are done monthly and the Scan Test only occasionally if weather condition is very good for DS observations. The instrument has never been out of service due to technical problems or damage since the very beginning of its operation. Technical services were provided to SOO-HK on B098 by specialists from SCI-TEC and later from the International Ozone Service Inc., Toronto (IOS) during intercomparisons - see the next paragraph.

2.2.2. Calibrations and Intercomparisons of the Brewer Spectrophotometer B098

The initial calibration constants for B098 were defined by the manufacturer and contained in the Acceptance Manual of the spectrophotometer [SCI-TEC, 1993]. The constants were determined by laboratory tests and by a comparison of the spectrophotometer towards the reference instrument B011 performed in July-November 1993. The reference spectrophotometer B011 was directly tied with the World Reference Triad of Brewers maintained in AES now MSC, Toronto [Kerr et.al., 1998]. The spectrophotometer was bought with a 1-year warranty period. In the next years the spectrophotometer B098 was calibrated by a commercial firm IOS at regional intercomparisons organized by Brewer observatories from Central Europe. These ICs and the key changes of calibration constants are listed in Table 6. Protocols of all ICs are saved in the basic metadata file of B098 at SOO-HK.

Table 6 *Calibrations / intercomparisons of the Brewer spectrophotometer B098, performed in the period 1993-2002*

Date	**Place**	**Acronym**	**Company**	**Reference**	**Cal. const. changed**
July 1993	Saskatoon, Canada	IC-93	SCI-TEC	B011	The original set implemented
07.09.1995	Hradec Kralove, CR	IC-95	SCI-TEC	B017	F_0, S_0, MR8, MR9, $\Delta^*\alpha$
20.06.1997	Hradec Kralove, CR	IC-97	IOS	B017	F_0, S_0, MR8, $\Delta\alpha$, $\Delta^*\alpha$, CSN
27.05.1999	Poprad, Slovakia	IC-99	IOS	B017	none
29.05.2001	Budapest, Hungary	IC-01	IOS	B017	PDT, F_0, S_0, MR8, MR9

2.2.3. Developments and Modernization

The spectrophotometer B098 is operated in its original state without any technical reconstructions or re-adjustments. The operating software package has been updated several times by products developed and released by the producer. A significant improvement was made in data management by implementation of software developed at SOO-HK in 1997.

2.3. Calibration Constants of the Spectrophotometer B098

2.3.1. Calibration Constants used for Operation of the Instrument B098

Reference calibration constants for measurements of total ozone and SO_2

The basic calibration constants defined for the spectrophotometer (see par. 2.1.5.) that were used in particular periods from 1993 to 2002 are given in Table 7. From January 1994 until July 1997 the constants were determined at intercomparisons IC-93, IC-94, IC-95 and IC-97. But some constants (F_0, S_0, MR8, MR9) were also changed between these ICs (see Table 7) if regular SLTs showed significant changes of M8 or M9 respectively. In 1999 automated operational corrections of ETCs by smoothed SL outputs have been implemented. Therefore, since that year reference values of F_0, S_0, MR8, MR9 have been changed only at ICs. Outputs from IC-99 are not included in Table 7 because no changes of calibration constants were made at that intercomparison. The most important adjustments of constants were derived from Scan Tests and from the Dispersion Test performed at IC-97 when new ozone absorption coefficients were defined and implemented for total ozone and SO_2 calculation. The stability of the calibration level of B098 is documented by graphs of the long-term changes of some key calibration constants during the entire operation of the instrument at SOO-HK (see Figures 10,11,12. and later text)

Table 7 *Calibration constants defined for the Brewer spectrophotometer B098 and used in particular periods of its operation till 31.12.2002 (Date = date of a change of the previous constants)*

Date **Calibr. constant**	**01.01.** **1994**	**01.06.** **1994**	**01.10.** **1994**	**21.04.** **1995**	**07.09.** **1995**	**01.01.** **1997**	**20.07.** **1997**	**24.05.** **2001**
Dead Time PDT	4.4E-8	4.4E-8	4.4E-8	4.4E-8	4.4E-8	4.4E-8	4.4E-8	3.8E-8
Ozone ETC F_0	3107.0	3103.0	3101.0	3097.0	3090.5	3090.5	3125.5	3100.0
SO_2 ETC S_0	3168.0	3163.0	3156.0	3153.0	3353.0	3336.0	3331.0	3280.0
O_3 abs. coef. $\Delta\alpha$.	0.3443	0.3443	0.3443	0.3443	0.3443	0.3443	0.3347	0.3447
O_3 abs. coef. $\Delta^*\alpha$.	1.1559	1.1559	1.1559	1.1559	1.1224	1.1224	1.1214	1.1214
SO_2 abs. coef. $\Delta^*\alpha'$.	2.3500	2.3500	2.3500	2.3500	2.3500	2.3500	2.3500	2.3500
Reference Ratio MR8	3632	3600	3620	3617	3615	3593	3600	3570
Reference Ratio MR9	1932	1910	1926	1922	1916	1910	1910	1892
Calibr. Step No. CSN	290	290	290	294	294	294	294	294

Corrections of calibration constants by the Standard Lamp Tests

Graphs of the R5 (M8) and R6 (M9) ratios determined from regular daily SLTs are viewed in Figure 10. The curves have a decreasing trend that is caused by a natural aging of the instrument optical components and of the Standard Lamp. An influence of this trend on accuracy of calculation of total ozone and SO_2 was eliminated by corrections of the extraterrestrial constants F_0, S_0 and by implementation of new Reference Ratios MR8 and MR9 - as described by (18), (19) and in Table 7. Since 1999 the corrections have been made operationally by smoothed SLT readings in daily steps. No significant peaks in the curves have appeared which would indicate sudden technical problems of the instrument. It is evident from Figure 10 that changes of the R6 (M9) ratio between two successive ICs of B098 were not higher than 10-15 units. Such differences can generate offsets about 2- 4 D.U. (less than 1.2 %) in total ozone - depending on μ. This is almost the same magnitude of shifts towards the reference instruments that were found at intercomparisons of B098. Therefore, even before implementation of the operational corrections of ETCs by outputs of SLTs in 1999 the regular adjustments of ETCs and the Reference Ratios at biannual intercomparisons eliminated changes of the calibration state of the instrument B098.

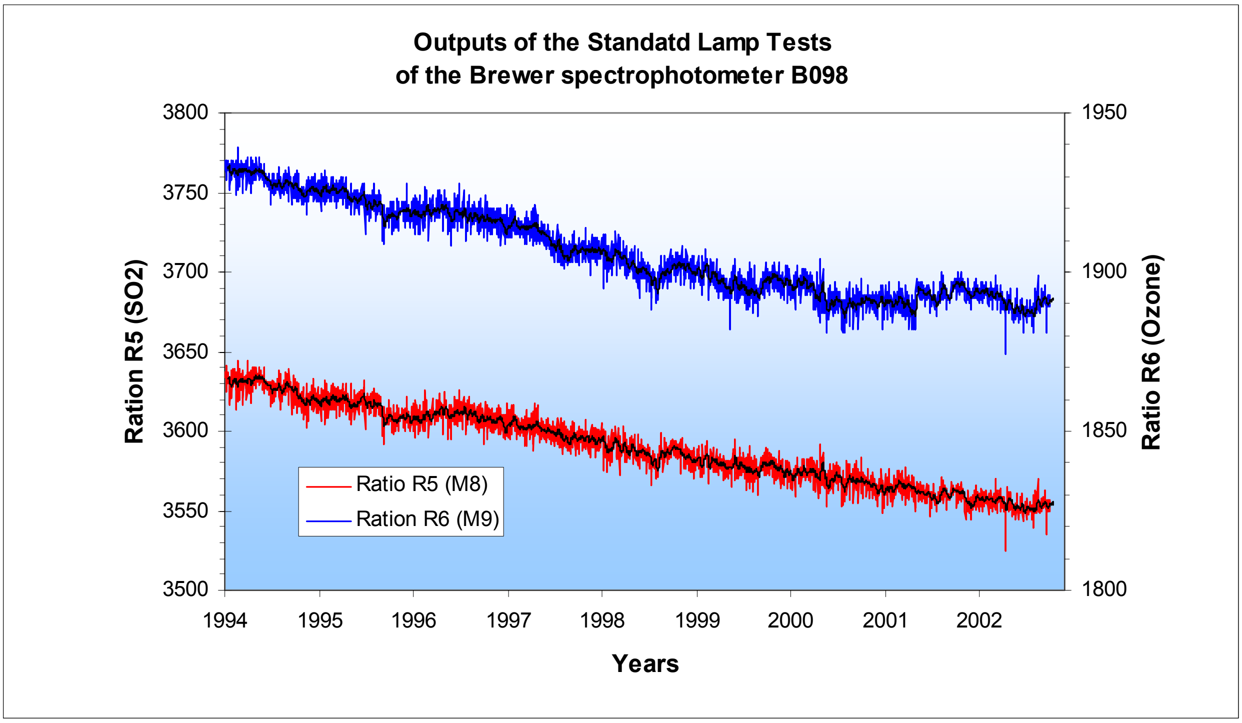

Figure 10

Figure 10. *Outputs from the Standard Lamp Tests of the Brewer spectrophotometer B098, 1994-2002*

Adjustments of the Photomultiplier Dead Time

The graph in Figure 11 expresses long-term changes of the Photomultiplier Dead Time PDT. It was stressed in par. 2.1.6. that the reference PDT value being saved in the Constants File of the instrument is a very important parameter for calculation of the true photon counts by the expression (17) and that PDT should be changed only under a complex professional re-calibration of the spectrophotometer. The curve in Figure 11 shows a decreasing trend of PDT that is probably caused by aging of the photon counts circuitry. The original reference value of PDT = 44ns defined as a calibration constant by the manufacturer was maintained from January 1994 until May 2001. But it is evident from the graph that differences between the PDT constant and the outputs of regular tests were continuously increasing. Therefore, at IC-01 the reference value was changed from 44 to 38 ns. Since that time a better agreement persists and PDT tests show remarkably lower scattering. This change of the PDT value was accompanied with a proper adjustment of the extraterrestrial constants F_0 and S_0 - see Table 7. It should be mentioned that any change of PDT creates an offset in calculation of total ozone and SO_2. This shift must be compensated by a proper change of ETCs so that the instrument is kept on the correct calibration level towards the reference spectrophotometers.

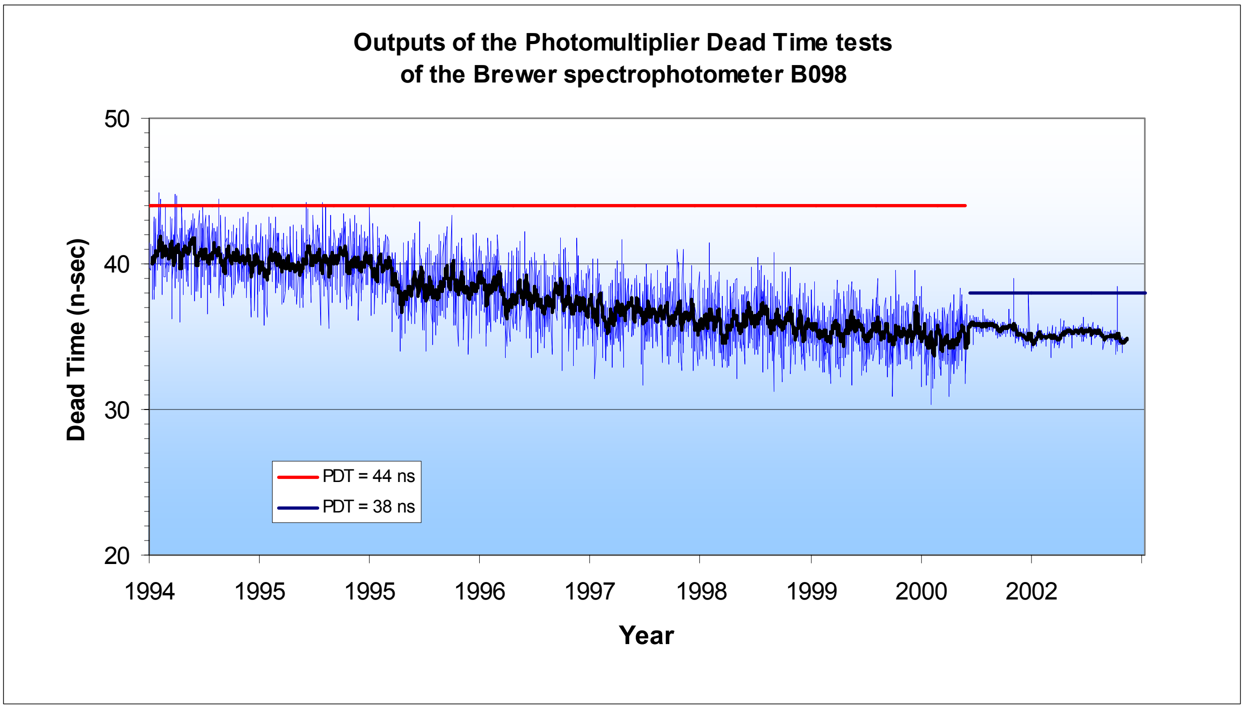

***Figure 11**.* *Outputs from the Photomultiplier Dead Time Tests of the Brewer spectrophotometer B098, 1994-2002*

Results of the Scan Tests

Figure 12 views the O_3-maximum micrometer step readings obtained from about 60 Scan Tests performed with B098 at SOO-HK since 1998 - after the paper [Lamb and Asbridge, 1996] had been released. There are two types of approximations used in the graph - linear and cubic-polynomial fits. Though the linear fit is recommended in [Lamb and Asbridge, 1996] it seems that for B098 the cubic function gives a better approximation. Nevertheless, the step numbers that correspond to cross sections of curves with the value 0.68 are representative for the location of SOO-HK are 294.4 and 294.7 respectively. These values are almost identical with the Calibration Step Number CSN = 294 that was implemented in 1995 and that was used for operation of the instrument B098 until 2002. The results of SCTs given in Figure 12 were obtained after IC-97. Therefore, the confirmation of validity of the CSN value also confirms new values of absorption coefficients defined for B098 at IC-97.

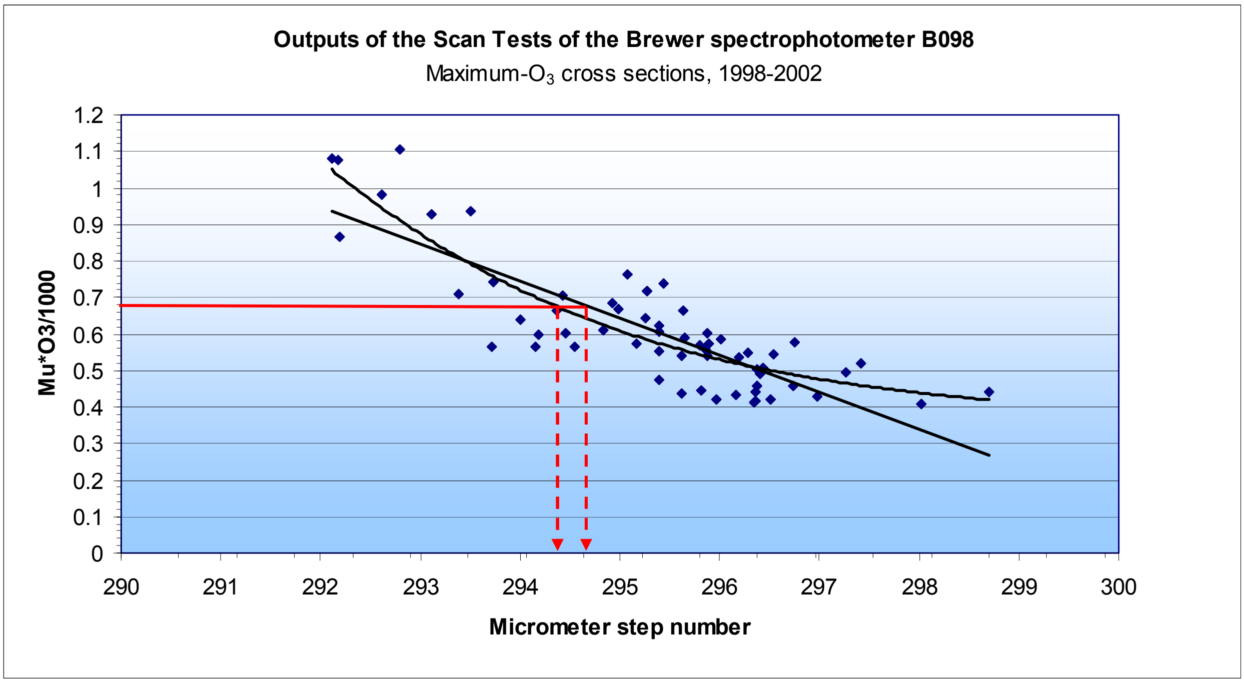

Figure 12. *Graph of the linear and cubic fits of the maximum-O_3 readings from the Scan Tests performed with the Brewer spectrophotometer B098 in the period 1998-2002.*

It can be concluded that the technical condition of the instrument B098 was fairly stable in the period 1994-2002, as it is documented by parameters in Table 7 and by Figures 10,11,12. No sudden or significant breaks of the spectrophotometer calibration state have appeared. Only slow changes of the calibration constants due to natural aging of the instrument and the Standard Lamp have been identified. These have been compensated by operational adjustments of constants or at regular intercomparisons of the spectrophotometer.

2.3.2. Relation of the Calibration Level of B098 to the World Calibration Scale

Unlike the Dobson spectrophotometer D074, the calibrations of the Brewer instrument B098 have been performed in the calibration scale represented by the World Standard Triad of Brewer spectrophotometers [Kerr et al., 1998] since the very beginning of operation of B098. This was assured by regular biannual intercomparisons and by a careful registration and documentation of the calibration constants at SOO-HK. Results of comparative observations taken with the instrument B098 at all ICs showed shifts towards the reference spectrophotometer B017 less than 1.2% in total ozone - see Figure 13. If the reference instrument B017 operated by IOS is supposed to be a stable tracer of the world calibration scale defined by the World Standard Triad, then a conclusion can be made that the spectrophotometer B098 was operated on the world calibration level with the accuracy better than 1 percent during the whole period of 1994-2002.

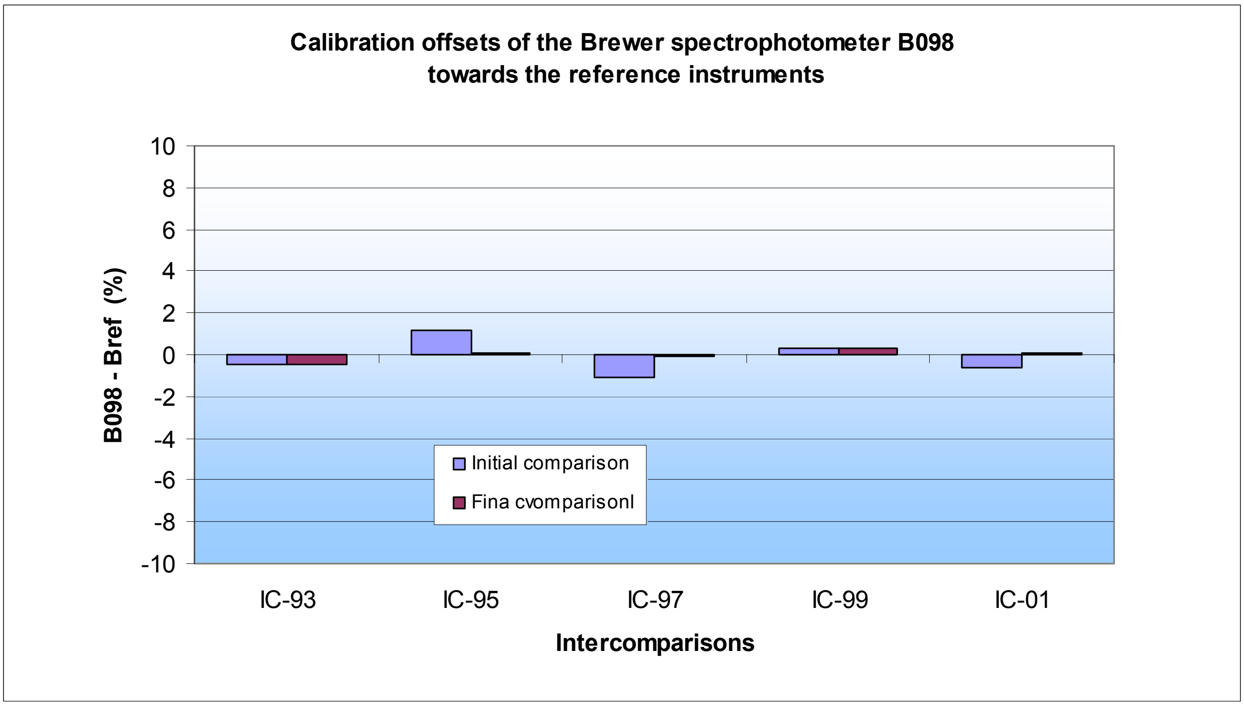

Figure 13. *Calibration offsets of the Brewer spectrophotometer B098 towards the reference instruments at intercomparisons performed in the period 1993-2002*

2.3.3. Assessment of a Need for re-processing of Total Ozone and Sulphur Dioxide Observations

The Direct Sun (DS) total ozone and sulphur dioxide measurements performed with the Brewer spectrophotometer B098 at SOO-HK in the period 1994-2002 were processed with the calibration constants defined and adjusted as described in the previous section 2.3.2. It was concluded that the calibration stability of the instrument B098 allows us to estimate accuracy of the DS observations to be in 1% limits. Therefore, if no serious reasons appear (e.g. shifts in calibration state of the reference instruments or changes of scales of the O_3 and SO_2 absorption coefficients) there is not an actual need for re-calculation of the Brewer total ozone and SO_2 data sets from SOO-HK. Nevertheless, it must be mentioned that the B098 data files deposited at WOUDC also include Zenith Sky observations that were produced with empirical zenith polynomials applicable to both instrument B098 and the location of SOO-HK. The accuracy and application of these polynomials should be assessed and updated in the same way as recommended for D074 in chapter 1.3.5. Such analyses is planned to be prepared in a study devoted to re-evaluation of the Dobson and Brewer total ozone data from Hradec Králové - separately of this technical report.

ACRONYMS

m	Relative path of the solar radiation through the atmosphere
p	Observed station air pressure (average value)
p_o	Mean sea level air pressure
A	Selected wavelength pair of UV radiation
AES	Atmospheric Environment Service of Canada
C	Selected wavelength pair of UV radiation
CF	Constants File of the Brewer spectrophotometer
CHMI	Czech Hydrometeorological Institute
CMDL	Climate Monitoring and Diagnostic Laboratory of NOAA
CSN	Calibration Step Number
D	Selected wavelength pair of UV radiation
DS	Measurements of total ozone on "Direct Sun"
DWD	German Meteorological Service
ETC	Extraterrestrial constant of the ozone spectrophotometer
F	Linear combination of $\log I_i$
Fi	Photon counts from Brewer observations
F(i)	Photon count rates
F_0	Ozone "extraterrestrial constant" of the Brewer spectrophotometer
F(i)	Count rates of the Brewer spectrophotometer
GAW	Global Atmosphere Watch program of WMO
HgL	Mercury Lamp
HgT	Mercury Lamp Test of the Dobson or Brewer spectrophotometer
IAMAP	International Association of Meteorology and Atmospheric Sciences
IC	Intercomparison of ozone spectrophotometers
IOC	International Ozone Commission of IAMAP
IOS	International Ozone Service Inc.
I_1, I_2	Spectral intensities of solar radiation at the ground
I_{01}, I_{02}	Spectral intensities of solar radiation outside the atmosphere (extraterrestrial)
LKO	Licht-Klimatische Observatory Arosa
L1,2	Lenses in the Dobson spectrophotometer
M(i)	Ratios of photon count rates F(i) from the Brewer spectrophotometer
M1,2	Mirrors in the Dobson spectrophotometer
MOHP	Meteorological Observatory Hohenpeissenberg
MSC	Meteorological Service of Canada
N_0	Ozone "extraterrestrial constant" of the Dobson spectrophotometer
NASA	National Aeronautics and Space Administration of USA
NOAA	National Oceanic and Atmospheric Administration of USA
NO_2	Total amount of nitrogen oxide in the atmosphere
O_3	Total amount of ozone in the atmosphere
PDT	Photomultiplier dead time
PM	Photomultiplier of the Dobson or Brewer spectrophotometer
P1,P2	Prisms in the Dobson spectrophotometer
QT	Q-Table of the Dobson spectrophotometer
Q1,2	Quartz plates in the Dobson spectrophotometer
R	R-readings from the dialing plate of the Dobson spectrophotometer
RDCC	Regional Dobson Calibration Center
R-N Tables	Tables for conversion of R-values to N-values

$RR_{A,C,D}$	Reference Standard Lamp Readings
$RN_{A,C,D}$	Reference Standard Lamp N-Values
SO_2	Total amount of sulphur dioxide in the atmosphere
SHDT	Shutter motor (chopper) delay time
SHRS	Shutter motor Run/Stop Ratios
SL	Standard Lamp
SLT	Standard Lamp Test of the spectrophotometer
SOO-HK	Solar and Ozone Observatory of CHMI in Hradec Králové
S2,3	Slits in the Dobson spectrophotometer
WDCC	World Dobson Calibration Center
WOUDC	World Ozone and UV Data Center of WMO, Toronto
WPDS	World Primary Dobson Spectrophotometer D083
W1,2	Optical wedges of the Dobson spectrophotometer
ZA	Zenith angle of the Sun
ZB	Measurement of total ozone on "Zenith Blue"
ZC	Measurement of total ozone on "Zenith Cloudy" condition
α_i	Spectral absorption coefficient of ozone
α'_i	SO_2 absorption coefficients
β_i	Spectral Rayleigh molecular scattering coefficient of the air
δ_i	Spectral scattering coefficients of aerosol particles
λ_i	Wavelength of the solar radiation
μ	Relative optical path length through the ozone layer (at 22 km)
μ'	Relative optical path length through the sulphur dioxide layer (at 5 km)
$\Delta\alpha$, $\Delta^*\alpha$	Linear combination of α_i
$\Delta\alpha'$, $\Delta^*\alpha'$	Linear combination of α'_i
$\Delta\beta$, $\Delta^*\beta$	Linear combination of β_i
$\Delta\delta$	Linear combination of δ_i

REFERENCES

Asbridge, I.A., (2000) Dobson Spectrophotometer Calibration Notes. GAW/MOHP, 2000

Asbridge, I.A., (2002) – a personal communication.

Beck, R,J, LTD, (1956) Adjustment and Calibration of Ozone Spectrophotometer - Manual for the Instrument No.074. Publication No.142 London, January 1956.

DeBacker, H., (1998), Zenith observations of total ozone in Uccle, Scientific Publication No.006 of The Royal Meteorological Institute of Belgium, Brussels, 1998.

Dobson, G. M. B., (1957a) Observers' handbook for the ozone spectrophotometer, in Annals of the International Geophysical Year, V, Part 1, 46-89, Pergamon Press

Dobson, G. M. B., (1957b). Adjustment and calibration of the ozone spectrophotometer, ibid. V, Part I, 90-113, Pergamon Press

Dobson, G. M. B., and C. W. B. Normand, (1962). Determination of the constants etc. used in the calculation of the amount of ozone from spectrophotometer measurements and of the accuracy of the results, ibid., XVI, Part II, 161-191, Pergamon Press

Dziewulska-Losiowa, A. and M. Gorski, (1971a), Analysis of the comparison of Dobson spectrophotometers at Siofok. Publications of the Institute of Geophysics Polish Academy of Sciences, Vol.42, 95-116, Warsaw, 1971

Dziewulska-Losiowa, A., (1971b), An attempt to determine corrections to extra-terrestrial constants by means of the least squares method. Publications of the Institute of Geophysics Polish Academy of Sciences, Vol.42, 89-94, Warsaw, 1971

Evans R.D., (2002) - a personal communication.

Grasnick, K.H., (1983). Intercomparison of Dobson spectrophotometers within the RA-VI (1978) in Arosa, Switzerland and 1979 Potsdam, G.D.R.). Official letter to participants dated Potsdam, July 11,1983)

Grasnick, K.H., P. Plessing and U. Feister, (1991). Intercomparison of Dobson spectrophotometers within the Regional Association VI in 1978 and 1979. Zeitschrift fuer Meteorologie, 41 (4), 283-285, 1991.

Guschin,G.P., (1972), Comparison of ozonometric instruments. In Actinometry, Atmospheric Optics, Ozonometry. Trudy GGO No.279, 118-126, Gidrometizdat, Leningrad, 1972

Kerr, J.B., McElroy, C.T. and Olafson, R.A. (1980). Measurements of ozone with the Brewer ozone spectrophotometer. Proc. Quadrennial Ozone Symposium, Boulder, Colorado, August 1980. Edited by J. London, p. 79

Kerr, J.B., C.T. McElroy and D.I. Wardle, (1998). The Brewer instrument calibration center 1984-1996, in Atmospheric Ozone, Proc. Quad. Ozone Symp., R.D. Bojkov and G. Visconti eds., 915-918, 1998.

Kerr, J.B., (2003). New methodology for deriving total ozone and other atmospheric variables from Brewer spectrophotometer direct sun spectra. J.G.R 2003 - in print.

Koehler, U., (1995). Homogenization and re-evaluation of the long-term ozone series at the Meteorological Observatory Hohenpeissenberg. The Final Report of the DWD-Project K/U 31, DWD, Hohenpeissenberg, July 1995.

Komhyr, W.D., (1980). Operations Handbook - Ozone Observations with a Dobson Spectrophotometer. WMO Global Ozone Research and Monit. Project, Report No.6.

Komhyr, W.D., and R.D. Evans (1980). Dobson spectrophotometer total ozone measurement error caused by interfering absorbing species such as SO2, NO2 and photochemically produced O3 in polluted air, Geophys. Res. Letters, 7, No. 2, 157-160

Komhyr, W.D., R.D. Grass and R.K. Leonard, (1989). Dobson Spectrophotometer 83: A Standard for Total Ozone Measurements, 1962-1987, Journal for theGeophysical Research, D7, 94:9847-9861

Komhyr, W.D., Mateer, C.L. and R.D. Hudson, (1993). Effective Bass-Paur 1985 Ozone Absorption Coefficients for Use With Dobson Ozone Spectrophotometers, J. Geophys. Res., D11, 98, 20451-20465

Lamb, K. and A.I. Asbridge (1996). Sun scans and relationship to the wavelength calibration step number. International Ozone Services, Brewer Technical Note No.96.01.

Pícha, J., (1967). Measurement of atmospheric ozone. Meteorological Bulletin, 3, 97-98

Plessing P. (1979). Specification of corrections of N-Tables for the instrument D074, Potsdam, 23.07.1979 – unofficial paper.

SCI-TEC, (1988). Brewer ozone spectrophotometer - Acceptance Manual. Serial No.92-098. SCI-TEC Instruments Inc., publication MM-BA-C05 Rev. C, Saskatoon, 1988.

SCI-TEC, (1990). Brewer MARK-IV ozone spectrophotometer - Operator´s Manual. SCI-TEC Instruments Inc., publication OM-BA-C01/B Rev, Saskatoon, 1990

SCI-TEC, (1992). Brewer ozone spectrophotometer - Maintenance Manual. SCI-TEC Instruments Inc., publication MM-BA-C05 Rev. J, Saskatoon, 1993

SCI-TEC, (1993). The Acceptance Manual of the Brewer Ozone Spectrophotometer No.098, SCI-TEC Instruments Inc., Saskatoon, November, 1993

SCI-TEC, (1999). Brewer MARK-IV ozone spectrophotometer - Operator´s Manual. SCI-TEC Instruments Inc., publication OM-BA-C231 Rev B, Saskatoon, 1999

Staehelin,J., Evans R.D., Kerr, J.B. and K. Vanicek, Comparison of total ozone measurements of Dobson and Brewer spectrophotometers and recommended transfer functions" a GAW/WMO report No: 149, TD: 1147, Geneva, 2003.

Stanek, M., (1998). PC software for Dobson total ozone data reduction DOBSON and DOBSTOOL. . Proc. of the Quadr. Ozone Symp., L´Aquila. 12-21 September 1996. Edited by R.D. Bojkov and G. Visconti, 1998, p. 975

Vaníček, K., (1991). Recalculated Total Ozone Data, Hradec Králové, 1962-1990. Publ. of The Czech Hydrometeorological Institute, Prague

Vaníček,K., Asbridge A.I. and Stanek M., (1998). Application of Dobson zenith polynomials for different instruments, locations and seasons. Proc. of the Quadr. Ozone Symp., L´Aquila. 12-21 September 1996. Edited by R.D. Bojkov and G. Visconti, 1998, p. 979.

Vaníček, K. and M., Stanek (2000). New data management and communication tools for the total ozone network. Proceedings of the Quadrennial Ozone Symposium, Sapporo, NASDA Publ,.July 2000, p.37

Vaníček, K., (2001). Solar and Ozone Observatory Hradec Kralove 1951-2001. Publ. of the Czech Hydrometeorolgical Institute, Prague

Wardle, D.I., Evans,W.P.J., Fast, H., Forester, A.J., Henderson, G.S., Kerr, J.B. and R.K.R. Vupputuri (1987). Stratospheric Ozone Science in Canada - Internal Report of the Atmospheric Environment Service No.ARD-87-3, Toronto, 1987.

WMO (1993), Handbook for Dobson Ozone Data Re-evaluation, WMO/GAW Global Ozone Research and Monitoring Project, Report No.29, Geneva, 1993

WMO (1994), Survey of WMO-Sponsored Dobson spectrophotometer intercomparisons, WMO/GAW Global Ozone Research and Monit. Project, Rep. No.19, Geneva, 1994

APPENDIX A

Records of calibrations / intercomparisons of the Dobson ozone spectrophotometer D074

This Appendix gives summaries of output parameters and calibration constants developed at individual calibrations (intercomparisons) of the Dobson spectrophotometer D074. The numerical values of the calibration constants used for routine operation of D074 and for the calculation of total ozone are given in Appendix B.

Initial Calibration, 1959 (IC-59)

The Beck Laboratories, London 1959

The initial calibration of D074 was performed by the manufacturer, R&J Beck Ltd., London. The instrument was delivered to SOO-HK in November 1959, accompanied by the calibration documentation which comprised:

- Q-Setting Table for D074 marked as QT-59 (see Appendix B) - not dated
- Standard Lamp readings for the lamps No. A and B - not dated
- R-NC Table for D074 plus formulae for calculation of R-NA and R-ND Tables
- Charts No. IAD , IC ,II and III for reduction of ZB and ZC observations - dated July 1953 and updated for D074

The above calibration parameters were used at the start of the SOO-HK total ozone observing program which began in January 1962. The original N-Tables, marked as NT-59 in Appendix B, were used for processing total ozone observations at SOO-HK from January 1962 until December 1969. The original documentation does not specify the method of establishing the original N-Tables (NT-59) provided with the instrument in 1959. It is possible that D074 was referenced against another Dobson instrument under the supervision of Prof. Dobson but it is also possible that the calibration fixation of the NT-59 Tables was provided by a transfer of 'N' using Standard Lamps. It can only be expected that instrument D074 was delivered with a calibration state that was consistent with other Dobson spectrophotometers produced and installed in the world network in the end of the fifties and in the beginning of the sixties.

International Comparison at Siofok, 1969 (IC-69)

Meteorological Observatory Siofok, Hungary, 04.-26.05.1969

The first international comparison of D074 was performed during the 1969 International Ozone Symposium at Siofosk, Hungary which was organized by the Working Group 7.4 of KAPG (Commission for Planetary and Geophysical Research of Eastern European Countries) and by the Hungarian Meteorological Service. The intercomparison was held at the observatory Siofok and the Dobson spectrophotometer D084 (from Belsk, Poland) was used as a reference instrument. IC-69 and its results are described in several papers [Dziewulska-Losiowa, 1971b], [Guschin,1972] and summarized by Basher [WMO,1994].

Initial calibration:
Observations dated May 12/13 1969 were evaluated using the original R-N Tables of D074 dated 1959. The average differences with D084 were +1.3% total ozone when compared on the XAD level over the range of μ = 1 to 2.3.

Technical works done on D074:
Adjustment of the photomultiplier

Application of results
Though calibration level of the reference instrument D084, re-defined in [Dziewulska-Losiowa, 1971b], was not officially acknowledged as internationally representative in 1969, corrections of R-N Tables for D074 were introduced after IC-69 as defined in [Dziewulska-Losiowa,1971a]:

dNA = 0.98*NA + 1.1
dNC = 0.98*NC + 0.6
dND = 0.97*ND + 4.9

Final calibration
Observations dated 12. and 13.05.1969 and R-N Tables of D074 corrected towards D084 (see above) were applied. Total ozone average differences towards D084 were -0.3% in calculated total ozone X_{AD} for μ = 1-2.3.

Definition of new calibration constants

- Corrected tables marked as NT-69 in Appendix B were used for routine total ozone observations performed with D074 from 01. January 1970 to 16. June 1979. According to Basher [WMO, 1994] the next ICs after Siofok showed that D084 was lower by 3.5% at Siofok comparing the calibration level of the World Primary Standard Spectrophotometer (WPSS) D083. Therefore the initial shift of D074 towards WPSS can be estimated by -2.3% in Siofok.

- A new Q-Setting table and RR values were not established - routine total ozone observations continued with the original QT-59 and RR-59 at SOO-HK.

International Comparison at Potsdam, 1979 (IC-79)

Meteorological Observatory Potsdam, Germany, 05.-22.06.1979

The 1979 WMO intercomparison was hosted by the Potsdam Meteorological Observatory, assisted by specialists from AES Canada and NOAA USA. Dobson spectrophotometer D071 from Potsdam was designated by WMO as a Regional Standard Spectrophotometer and used in that capacity at IC-79.

<u>Initial comparison of D074</u>

Observations dated 13.06.1979 were performed with new QT-79 defined at Potsdam. The N-Tables NT-69 gave a an average error -6.8% in calculated total ozone X_{AD} for μ = 1-3 and total ozone 300 DU towards the reference instrument D071.

<u>Technical works done on D074:</u>

- Re-adjustment of the slits and the mirror M2
- Installation of the US electronics
- Installation of a new photo tube
- Development of a new Q-setting table QT-79
- Calibration of the wedges by the two-lamp unit

<u>Final comparison of D074</u>

Observations dated 13.06.1979 gave the following corrections of the initial N-Tables NT-69:

[Plessing, 1979]:		[Grasnick,1983], [Grasnick et.al, 1991]:	
dNA	= + 0.3	dNA	= + 0.4
dNC	= - 5.9	dNC	= - 6.1
dND	= - 4.3	dND	= - 5.3

A difference towards D071 in percents has never been published – a comparison with TOMS overpassing measurements estimated a shift about –1.6% [Grasssnick, 1983].

<u>Definition of new calibration constants</u>

- The corrections given by [Grasnick, 1983,1991] were somewhat different and delayed very much. Therefore, new N-Tables marked as NT-79 were defined by means of the previous corrections [Plessing, 1979] that were applied to the NT-69 tables. The NT-79 tables were in use for routine processing of total ozone observations in Hradec Králové till IC-86. The Grasnick´s corrections have never been applied.
- In Potsdam the first calibration of wedges of D074 was performed with the two-lamp unit on 13.07.79 and N-Tables marked as NT-79wdg were developed. But as final official results of IC-79 were not available for several years, the NT-79wdg tables were never used for processing of total ozone observations at SOO-HK.
- New Q-setting table marked QT-79 was established and used since 13.06.79 at SOO-HK. This table replaced the original QT-59 prepared by Beck.
- At IC-79 the instrument D074 was equipped by two new quartz iodine lamps marked QJ-74- I and QJ-74- II but without a power supply. During IC-79 several SL Tests were performed with these lamps and SL UQ-2 (USA). The readings (see Appendix B, part RR values) were used later at SOO-HK as RR constants [Vanicek, 1990] before new RR values were defined at IC-86.

International Comparison at Arosa, 1986 (IC-86)

Light and Climatological Observatory Arosa, Switzerland, 11.-29.08.1986

This WMO intercomparison was hosted by the Light and Climatological Observatory (LKO) of the Electrotechnical University (ETH) Zurich in Arosa and assisted by specialists from NOAA/CMDL, Boulder, USA. The World Primary Standard Dobson Spectrophotometer D083 from Boulder was used as the reference instrument at IC-86.

Initial comparison

Observations dated 15.08.1986 were performed with QT-79 adjusted for the altitude of Arosa. The N-Tables NT-79 gave an error from -2.2 to -1.4 % in calculated total ozone X_{AD} for μ = 1-3 and total ozone 300 DU. Corrections of initial N-Tables NT-79 have been established as follows:

In Arosa on 15. August 1986:		After the final adjustment (Komhyr, 1988):	
dNA	= + 0.3	dNA	= + 0.3
dNC	= + 2.1	dNC	= + 2.1
dND	= + 0.7	dND	= + 0.3

Technical works done on D074:

- Inspection of the instrument
- Cleaning of the optical elements

Final comparison

Observations dated 15.08.1986 and corrected NT-79 [Komhyr, 1988] were used for the final comparison and for definition of new calibration constants. The total ozone differences towards D083 varied from +0.3 to –0,2 %. for the range of μ = 1-3 and total ozone 300 DU (see Appendix B).

Definition of new calibration constants

- The table QT-79 has not been changed and was in use till IC-90
- The tables NT-79 were corrected first by corrections defined at IC-86 and later by the Komhyr´s values. These new tables NT-86 were used for routine processing of total ozone observations till IC-1990
- New RR values dated 15. August 1986 (see Appendix B) were defined and used for regular monthly adjustments of NT-86 at SOO-HK.

International Comparison at Arosa, 1990 (IC-90)

Light and Climatological Observatory Arosa, Switzerland, 22.07.-10.08.1990

This WMO Intercomparison was hosted by the Light and Climatological Observatory (LKO) of the Electrotechnical University (ETH) Zurich in Arosa and assisted by specialists from NOAA/CMDL, Boulder, USA. The World Secondary Standard Dobson Spectrophotometer D065 from Boulder was used as the reference instrument at IC-90.

Initial comparison

Observations dated 19.07.1990 were performed with new Q-setting table QT-90 defined for the altitude of Arosa. The N-Tables NT-86 gave an error from –1.1 to –0.1 % in calculated total ozone X_{AD} for μ = 1-3 and total ozone 300 DU. Corrections of N- values were calculated as:

dNA = +0.3
dNC = - 0.6
dND = - 0.2

Technical works done on D074:

- Inspection of the instrument
- Cleaning of the optical elements
- Calibration of the wedges dated 26.07.1990

Final comparison

New N-Tables NT-90 were developed from the wedge calibrations and used for the final intercomparison coming from observations dated 19.07.1990. An error from –0.3 to +0.3 % in calculated total ozone X_{AD} for μ = 1-3 and total ozone 300 DU was found.

Definition of new calibration constants

- A new table QT-90 was developed and used till IC-97
- New N-Tables NT-90 were defined from wedge calibration and from the final intercomparison dated 19.07.1990. These tables were used for routine processing of total ozone observations till IC-97
- New RR-90 values dated 02.08.1990 were defined and used for regular monthly adjustments of NT-90 at SOO-HK.

International Comparison at Hradec Králové, 1993 (IC-93)

Solar and Ozone Observatory Hradec Králové, Czech Republic, 20..-30.05.1993

This WMO Intercomparison was hosted by the Solar and Ozone Observatory of the Czech Hydrometeorological Institute in Hradec Králové (SOO-HK) and assisted by specialists from NOAA/CMDL, Boulder, USA, AES Canada and the Meteorological Bureau, Australia. The World Secondary Standard Dobson Spectrophotometer D065 from Boulder was used as the reference instrument at IC-93.

Initial comparison

Observations dated 25.05.1993 were performed with new QT-90 checked by the Discharge Lamp Test.. The N-Tables NT-86 gave an error from 0.0 to +1.0 % in calculated total ozone X_{AD} for μ = 1-3 and total ozone 300 DU. Corrections of N-values were calculated as:

dNA = + 0.1
dNC = + 0.1
dND = + 0.4

Technical works done on D074:

- Inspection of the instrument
- Cleaning of the optical elements

Final comparison

The results of the initial comparison gave an average difference of +0.4% when
compared with the reference instrument. This confirmed a stable calibration level of D074 after IC-90. Therefore, it was decided to keep the previous calibration constants of D074 and to continue using constants from IC-90 for routine total ozone observations at SOO-HK.

Definition of new calibration constants

New calibration constants were not defined for D074 at IC-93 (see above).

International Comparison at Kalavryta, 1997 (IC-97)

Stiga Ski Field Facility (SSF), Kalavryta, Greece, 20..07.-07.08.1997

This WMO intercomparison was hosted by the Ozone and Solar Radiation Research Team (OSORT), Department of Physics, University of Athens and assisted by specialists from NOAA/CMDL, Boulder, USA, MOHP/DWD Germany and SOO-HK/CHMI Czech Republic. The World Secondary Standard Dobson Spectrophotometer D065 from Boulder was used as the reference instrument at IC-97.

Initial comparison

Observations dated 22.07.1997 were performed with a new Q-Table developed for the altitude 1850m a.s.l. of SSF from a Discharge Lamp Test. The N-Tables NT-90 gave an error from -1.7 to +0.7 % in calculated total ozone X_{AD} for μ = 1-3 and total ozone 300 DU.

Corrections of N-values were calculated as:

dNA = - 0.7
dNC = + 0.5
dND = + 0.2

Technical works done on D074:

- Inspection of the instrument
- Cleaning of the optical elements

Final comparison

The observations dated 01.08.1997 and new N-Tables NT-97 developed on 22.07.1997 were used for the final comparison. The results gave difference towards the reference instrument D065 from +0.4 to –0.1% in calculated total ozone X_{AD} for μ = 1-3 and total ozone 300 DU.

Definition of new calibration constants

- A new table QT-97 dated 22.08.1997 was developed after D074 returned to SOO-HK and used till IC-99
- New N-Tables NT-97 were defined on 22.07.1997 by correction of NT-90. These tables were used for routine processing of total ozone observations till IC-99
- New RR-97 values dated 22. 07.1997 were defined and used in the next years for regular monthly adjustments of NT-97 at SOO-HK.

International Comparison at Hohenpeissenberg /Arosa, 1999 (IC-99)

Meteorological Observatory Hohenpeissenberg, 04.-11.07.1999
Light and Climatological Observatory Arosa, Switzerland, 12.-31.07.1999

This WMO intercomparison was hosted by the Light and Climatological Observatory (LKO) of the Electrotechnical University (ETH) Zurich in Arosa and it was assisted by specialists from NOAA/CMDL, Boulder, USA, MOHP/DWD Germany and SOO-HK/CHMI Czech Republic. The World Secondary Standard Dobson Spectrophotometer D065 from Boulder was used as the reference instrument at IC-99. Before Arosa IC-99 an intercomparison of Dobson spectrophotometers D065, D064 and D074 was performed at the Meteorological Observatory Hohenpeissenberg that had been established as a Regional Dobson Calibration Center (RDCC) for Europe (RA-VI Region) in 1999. The main reason of Hohenpeissenberg IC-99 was to compare calibration levels of the spectrophotometers mentioned above as reference instruments in geographical and climate condition of MOHP before Arosa IC-99 was held.

Initial comparison

Observations at MOHP dated 05.07.1999 were performed with Q-Table QT-97 adjusted for the altitude of MOHP and the N-Tables NT-97. The results gave an error from –0.4 to +0.2 % towards D065 in calculated total ozone X_{AD} for μ = 1-3 and total ozone 300 DU.

Observations at LKO Arosa dated 17.07.1999 were performed with QT-97 adjusted for the altitude of Arosa and NT-97. The results gave an error from –0.6 to -0.2 % towards D065.The initial calibrations confirmed a good calibration stability of D074 in the geographical and climate condition both of MOHP and of LKO Arosa. Corrections of N-values were calculated for the Arosa IC-99 as:

dNA = + 0.3
dNC = + 0.4
dND = 0.0

Technical works done on D074:

- Inspection of the instrument
- Cleaning of the optical elements
- Calibration of the wedges dated 14.07.1999

Final comparison

Observations at LKO Arosa dated 17.07.1999 and corrected NT-97 were taken for the final comparison. The results gave a an error from –0.2 to 0.0 % towards D065 in calculated total ozone X_{AD} for μ = 1-3 and total ozone 300 DU.

Definition of new calibration constants

- The previous Q-Table QT-97 was kept in use after IC-99
- New N-Tables NT-99 were defined by correction of NT-97 and used for routine processing of total ozone observations after IC-99. As results of MOHP and Arosa IC-99 confirmed validity of NT-97 the wedge calibration dated 14.07.199 was not used for definition of new G-Tables.
- New RR-99 values dated 17. 07.1999 were defined and used for regular monthly adjustments of NT-99 at SOO-HK.

International Comparison at Hohenpeissenberg, 2002 (IC-02)

Meteorological Observatory Hohenpeissenberg, 14.-27.07.2002

This WMO intercomparison was hosted by the Regional Dobson Calibration Center (RDCC) for Europe (RA-VI Region) - Meteorological Observatory Hohenpeissenberg (MOHP), Germany and assisted by a specialist from SOO-HK/CHMI Czech Republic. The Regional Standard Dobson Spectrophotometer D064 from MOHP was used as the reference instrument at IC-02. The calibration constants of D064 defined by comparison of D064 towards the World Primary Standard Dobson Spectrophotometer D083 in Boulder, 12 June 2002 were used for IC-02.

Initial comparison

Observations taken with D074 at MOHP on 20.07.2002 were performed with Q-Table QT-02 developed on 15.07.02 and processed with the N-Tables NT-99. The results gave an error from - 0.6 to +0.4 % towards D064 in calculated total ozone X_{AD} for μ = 1-3 and total ozone 300 DU.

Corrections of N-values were calculated as:

dNA = - 0.4
dNC = - 0.4
dND = - 0.4

Technical works done on D074:

- Inspection of the instrument
- Cleaning of optical elements
- Calibration of the wedges dated 15.07.2002

Final comparison

Observations taken at MOHP dated 23.07.2002. were used for the final comparison and for correction of NT-99. The results gave an error from 0.0 to 0.1 % towards D064 in calculated total ozone X_{AD} for μ = 1-3 and total ozone 300 DU.

Definition of new calibration constants

- The previous Q-Table QT-97 remained to be used after IC-02
- New N-Tables NT-02 were defined by correction of NT-99 based on the observations dated 23.07.2002 and used for routine processing of total ozone observations after IC-02. As results of MOHP IC-02 confirmed validity of NT-99, the wedge calibration performed on 15.07.2002 was not used for definition of new G-Tables.
- New RR-02 values dated 23.07.2002 were defined and used for regular monthly adjustments of NT-02 at SOO-HK after IC-02

Appendix B

The calibration constants of the Dobson ozone spectrophotometer D074

This Appendix includes the basic calibration constants of the Dobson spectrophotometer D074 that were determined at the calibration campaigns in the period 1962-2002 or which have been re-defined / re-evaluated afterwards. These constants represent a reference calibration data set that can be used for re-calculation of the entire series of total ozone observations performed with the instrument D074 in Hradec Králové.

	Orig. tables 1959			IC Potsdam 1979			IC Arosa 1990			IC Arosa 1999			IC MOHP 2002		
R	**dRA**	**dRC**	**dRD**	**dRA**	**dRC**	**dRD**	**dRA**	**dRC**	**dRD**	**dRA**	**dRC**	**dRD**	**dRA**	**dRC**	**dRD**
0	35.40	36.50	36.50	36.80	36.40	36.07	36.33	35.95	35.68	36.08	35.54	35.03	36.16	35.69	35.49
5	35.65	36.75	36.75	36.90	36.50	36.30	36.65	36.28	36.07	36.45	36.07	35.59	36.43	36.00	35.76
10	35.90	37.00	37.00	37.14	36.80	36.60	36.98	36.67	36.44	36.84	36.47	36.07	36.70	36.31	36.02
15	36.15	37.35	37.35	37.55	37.22	36.99	37.37	37.03	36.87	37.20	36.80	36.42	37.16	36.86	36.50
20	36.40	37.70	37.70	38.03	37.70	37.40	37.77	37.45	37.30	37.53	37.16	36.77	37.59	37.33	37.00
25	36.75	38.05	38.05	38.57	38.20	37.90	38.20	37.87	37.73	37.90	37.57	37.19	38.02	37.76	37.43
30	37.30	38.40	38.40	39.00	38.70	38.44	38.58	38.31	38.15	38.30	38.00	37.61	38.43	38.19	37.81
35	37.45	38.55	38.55	39.32	39.08	38.85	38.98	38.72	38.58	38.62	38.35	38.11	38.81	38.63	38.34
40	37.60	38.70	38.70	39.51	39.36	39.15	39.30	39.12	39.02	38.92	38.66	38.46	39.09	38.93	38.58
45	37.75	38.70	38.70	39.65	39.50	39.32	39.47	39.34	39.27	39.11	38.88	38.70	39.26	39.08	38.84
50	37.90	38.70	38.70	39.69	39.55	39.42	39.53	39.43	39.39	39.19	39.01	38.86	39.17	39.18	38.98
55	37.80	38.80	38.80	39.63	39.54	39.45	39.55	39.48	39.46	39.21	39.12	38.99	39.22	39.26	39.05
60	37.70	38.90	38.90	39.48	39.44	39.45	39.52	39.51	39.50	39.19	39.22	39.12	39.24	39.26	39.23
65	37.55	38.70	38.70	39.25	39.33	39.42	39.47	39.50	39.52	39.14	39.29	39.24	39.22	39.29	39.32
70	37.40	38.50	38.50	39.07	39.20	39.35	39.39	39.47	39.50	39.07	39.32	39.32	39.15	39.28	39.36
75	37.30	38.40	38.40	38.87	39.03	39.26	39.24	39.39	39.47	38.99	39.27	39.32	39.07	39.20	39.36
80	37.20	38.30	38.30	38.66	38.86	39.13	39.03	39.30	39.39	38.91	39.17	39.28	38.82	39.08	39.26
85	36.90	38.00	38.00	38.42	38.66	39.00	38.82	39.17	39.30	38.81	39.02	39.21	38.66	38.95	39.22
90	36.60	37.70	37.70	38.15	38.45	38.84	38.58	39.02	39.18	38.63	38.84	39.11	38.50	38.84	39.10
95	36.40	37.50	37.50	37.90	38.27	38.67	38.29	38.80	39.03	38.34	38.63	38.93	38.32	38.64	39.05
100	36.20	37.30	37.30	37.62	38.10	38.47	37.97	38.54	38.81	37.98	38.37	38.75	37.99	38.41	38.89
105	36.00	37.15	37.15	37.28	37.85	38.25	37.58	38.24	38.54	37.56	38.02	38.60	37.54	38.07	38.52
110	35.80	37.00	37.00	36.85	37.55	37.96	37.13	37.92	38.27	37.12	37.66	38.39	37.03	37.71	38.15
115	35.75	36.90	36.90	36.45	37.18	37.70	36.74	37.57	37.97	36.67	37.31	38.11	36.51	37.37	37.86
120	35.70	36.80	36.80	36.15	36.77	37.48	36.35	37.20	37.64	36.24	36.95	37.73	36.08	37.01	37.59
125	35.45	36.55	36.55	35.85	36.41	37.06	35.97	36.83	37.25	35.85	36.48	37.31	35.82	36.60	37.22
130	35.20	36.30	36.30	35.55	36.10	36.77	35.67	36.46	36.90	35.49	35.98	36.85	35.59	36.18	36.79
135	35.00	36.05	36.05	35.25	35.87	36.48	35.36	36.10	36.55	35.12	35.54	36.24	35.26	35.78	36.39
140	34.80	35.80	35.80	35.07	35.67	36.25	35.10	35.75	36.20	34.76	35.18	35.71	34.91	35.48	36.06
145	34.50	35.50	35.50	34.98	35.50	36.10	34.85	35.44	35.89	34.51	34.97	35.36	34.64	35.29	35.83
150	34.20	35.20	35.20	34.96	35.45	35.95	34.63	35.19	35.67	34.38	34.81	35.14	34.50	35.13	35.65
155	34.00	34.95	34.95	34.98	35.42	35.88	34.42	35.05	35.48	34.37	34.71	35.01	34.45	34.93	35.43
160	33.80	34.70	34.70	34.95	35.36	35.84	34.28	34.94	35.37	34.39	34.64	35.00	34.43	34.76	35.26
165	33.65	34.60	34.60	34.87	35.30	35.80	34.32	34.98	35.40	34.40	34.58	35.11	34.38	34.74	35.31
170	33.50	34.50	34.50	34.75	35.22	35.75	34.46	35.08	35.49	34.41	34.59	35.26	34.35	34.84	35.49
175	33.40	34.40	34.40	34.53	35.09	35.62	34.56	35.17	35.63	34.43	34.62	35.30	34.39	34.96	35.64
180	33.30	34.30	34.30	34.26	34.90	35.46	34.55	35.19	35.70	34.37	34.63	35.24	34.44	35.01	35.68
185	33.25	34.25	34.25	34.00	34.73	35.22	34.38	35.04	35.53	34.15	34.57	35.13	34.41	34.94	35.58
190	33.20	34.20	34.20	33.75	34.48	34.98	34.17	34.82	35.27	33.91	34.45	34.99	34.30	34.79	35.42
195	33.05	34.05	34.05	33.47	34.15	34.70	33.97	34.60	35.01	33.80	34.34	34.82	34.14	34.65	35.29
200	32.90	33.90	33.90	33.19	33.75	34.43	33.79	34.42	34.82	33.75	34.25	34.67	34.05	34.56	35.22
205	32.75	33.70	33.75	32.87	33.48	34.17	33.65	34.31	34.73	33.75	34.21	34.68	34.09	34.57	35.21
210	32.60	33.50	33.60	32.62	33.23	34.00	33.57	34.26	34.74	33.80	34.26	34.85	34.16	34.62	35.24
215	32.45	33.35	33.45	32.52	33.15	33.90	33.53	34.26	34.90	33.96	34.44	35.11	34.12	34.67	35.28
220	32.30	33.20	33.30	32.65	33.25	33.97	33.53	34.34	35.08	34.22	34.83	35.40	34.13	34.79	35.39
225	32.30	33.15	33.25	32.90	33.55	34.20	33.58	34.48	35.27	34.51	35.22	35.67	34.39	35.07	35.63
230	32.30	33.10	33.20	33.13	33.85	34.55	33.67	34.64	35.42	34.74	35.57	35.90	34.70	35.36	35.95
235	32.35	33.15	33.25	33.40	34.12	34.84	33.82	34.83	35.58	34.89	35.74	36.04	34.83	35.53	36.21
240	32.40	33.20	33.30	33.65	34.44	35.10	34.00	35.05	35.72	34.96	35.76	36.13	34.86	35.58	36.34
245	32.35	33.20	33.30	33.93	34.72	35.30	34.25	35.26	35.82	34.88	35.72	36.22	34.95	35.57	36.35
250	32.30	33.20	33.30	34.29	35.04	35.50	34.56	35.45	35.92	34.79	35.63	36.28	35.06	35.59	36.27
255	32.35	33.20	33.30	34.65	35.35	35.68	34.85	35.59	36.02	34.81	35.47	36.23	35.12	35.71	36.20
260	32.40	33.20	33.30	35.11	35.70	35.86	35.07	35.72	36.12	34.86	35.28	36.08	35.14	35.89	36.14

Table B-1. *Outputs of the wedge calibrations of the Dobson spectrophotometer D074 performed in the period 1959-2002*

Temp. deg.	QT-59 01.01.62 - 12.06.79				QT-79 13.06.79 - 15.07.90				QT-90 17.07.90 - 27.07.97				QT-97 22.08.97 - 31.12.02			
	A	**C**	**D**	**HG**	**A**	**C**	**D**	**HG**	**A**	**C**	**D**	**HG**	**A**	**C**	**D**	**HG**
-5.0	47.8	73.7	105.4	81.3	47.1	73.2	104.4	80.9	46.9	73.1	104.3	80.7	46.9	73.0	104.2	80.6
0.0	48.2	74.4	106.0	82.0	47.5	73.9	105.1	81.6	47.4	73.7	104.9	81.3	47.3	73.6	104.8	81.2
5.0	48.7	75.1	106.6	82.7	48.0	74.5	105.8	82.3	47.8	74.3	105.5	82.0	47.8	74.3	105.5	81.8
10.0	49.1	76.0	107.2	83.4	48.5	75.2	106.4	82.9	48.2	75.0	106.2	82.6	48.2	74.9	106.1	82.5
15.0	49.6	76.4	107.8	84.1	48.9	75.9	107.1	83.6	48.7	75.6	106.8	83.2	48.6	75.5	106.7	83.1
20.0	50.0	77.1	108.4	84.7	49.4	76.6	107.8	84.3	49.1	76.3	107.4	83.9	49.1	76.2	107.3	83.8
25.0	50.5	77.8	109.0	85.4	49.8	77.3	108.4	85.0	49.5	76.9	108.0	84.5	49.5	76.8	108.0	84.4
30.0	51.0	78.4	109.6	86.1	50.3	77.9	109.1	85.7	50.0	77.5	108.7	85.2	49.9	77.5	108.6	85.1
35.0	51.4	79.1	110.2	86.8	50.8	78.6	109.8	86.4	50.4	78.2	109.3	85.8	50.4	78.1	109.2	85.7
40.0	51.9	79.7	110.8	87.5	51.2	79.3	110.4	87.1	50.8	78.8	109.9	86.5	50.8	78.8	109.8	86.4

Table B-2. *Q-Tables of the instrument D074 defined at calibration campaigns and used in different periods of 1959-2002 for total ozone observations - see Table 3.*

Year	SL 74-B				SL 74-QJ-I				SL 74-QJ-II			
	RA	RC	RD	dRAD	RA	RC	RD	dRAD	RA	RC	RD	dRAD
1962	39.8	40.3	43.9	4.1								
1963	39.7	40.2	44.1	4.4								
1964	39.9	39.8	43.5	3.6								
1965	39.2	40.2	43.9	4.7								
1966	39.8	40.9	44.6	4.8								
1967	41.2	42.5	46.2	5.0								
1968	42.5	43.2	47.2	4.7								
1969	41.9	43.4	46.8	4.9								
1970	42.0	43.4	46.8	4.8								
1971	41.8	43.3	46.6	4.8								
1972	44.1	45.9	49.0	4.9								
1973	39.9	41.8	43.8	3.9								
1974	40.8	42.3	45.0	4.2								
1975	42.2	43.5	46.2	4.0								
1976	44.1	45.1	47.6	3.5								
1977	44.8	45.7	48.0	3.2								
1978	45.3	46.2	48.4	3.1								
1979	45.6	46.6	48.6	3.0	26.7	31.8	37.1	10.4				
1980	43.5	45.6	48.5	5.0	26.6	31.7	37.0	10.4				
1981					27.0	32.0	37.3	10.3				
1982					27.3	32.3	37.4	10.1				
1983					27.6	32.5	37.5	9.9				
1984					28.2	33.1	38.0	9.8				
1985					28.3	33.1	38.1	9.8				
1986					28.3	33.1	38.0	9.7	27.6	33.0	38.1	10.5
1987					28.4	33.3	38.0	9.6	27.9	33.4	38.5	10.6
1988					28.6	33.5	38.1	9.5	28.2	33.7	38.8	10.6
1989					29.1	34.0	38.5	9.4	28.8	34.2	39.3	10.5
1990					28.7	33.7	38.2	9.5	28.0	33.6	38.6	10.6
1991					27.8	32.9	37.3	9.5	27.5	33.0	38.1	10.6
1992					27.9	32.9	37.3	9.4	27.6	33.2	38.2	10.6
1993					28.0	33.0	37.3	9.3	27.8	33.2	38.2	10.4
1994					28.0	32.9	37.2	9.2	27.7	33.1	38.0	10.3
1995					28.1	32.9	37.1	9.0	27.9	33.3	38.2	10.3
1996					27.8	32.6	36.9	9.1	27.4	32.9	37.8	10.4
1997					27.1	32.0	36.3	9.2	27.0	32.6	37.5	10.5
1998					27.3	32.2	36.4	9.1	27.2	32.7	37.6	10.5
1999					27.7	32.5	36.8	9.1	27.8	33.2	38.0	10.3
2000					27.9	32.8	36.9	9.0	27.8	27.8	38.0	10.3
2001					28.0	32.9	37.0	9.0	27.9	33.3	38.2	10.4
2002					28.0	32.8	36.9	8.9	27.8	33.2	38.0	10.2

Table B-3. *Yearly averages of Standard Lamp Test readings for the Dobson spectrophotometer D074, 1962-2002*

R	NT-59			NT-69			NT-79			NT-86			NT-90			NT-97			NT-99			NT-02			NT-79/86		
deg.	**NA**	**NC**	**ND**	**NA**	**NC**	**ND**	**NA**	**NC**	**ND**	**NA**	**NC**	**ND**	**NA**	**NC**	**ND**	**NA**	**NC**	**ND**	**NA**	**NC**	**ND**	**NA**	**NC**	**ND**	**NA**	**NC**	**ND**
0.0	-14.3	-9.6	-8.5	-12.9	-4.4	-7.7	-12.6	-10.3	-12.0	-12.3	-8.2	-11.3	-10.0	-10.4	-13.2	-9.4	-9.8	-11.9	-10.1	-10.2	-12.3	-10.5	-10.9	-12.7	-10.1	-10.0	-12.5
10.0	-5.7	-1.3	-0.2	-4.5	3.6	0.4	-4.2	-2.3	-3.9	-3.8	-2.0	3.2	-1.6	-2.0	-4.7	-1.0	-1.4	-3.4	-1.8	-1.8	-3.8	-2.2	-2.5	-4.2	-1.8	-1.7	-4.3
20.0	2.8	7.0	8.1	3.8	11.7	8.5	4.1	5.8	4.2	4.4	7.9	4.9	6.8	6.4	3.8	7.4	7.0	5.1	6.6	6.6	4.7	6.2	5.9	4.3	6.4	6.6	4.1
30.0	11.3	15.2	16.3	12.1	19.6	16.6	12.4	13.7	12.3	12.7	15.8	13.0	15.1	14.7	12.1	15.6	15.3	13.4	14.9	14.9	13.0	14.5	14.2	12.6	14.6	14.9	12.4
40.0	19.6	23.3	24.4	20.3	27.5	24.5	20.6	21.6	20.2	20.9	23.7	20.9	23.0	22.8	20.3	23.6	23.4	21.6	22.8	23.1	21.2	22.4	22.4	20.8	22.6	23.0	20.5
50.0	27.7	31.2	32.3	28.2	35.2	32.3	28.5	29.3	28.0	28.8	31.4	28.9	30.8	30.7	28.2	31.4	31.3	29.5	30.7	30.9	29.1	30.3	30.2	28.7	30.5	30.8	28.3
60.0	35.7	38.9	40.0	36.1	42.6	39.8	36.4	36.7	35.5	36.7	38.8	36.2	38.6	38.4	36.0	39.2	39.1	37.3	38.4	38.7	36.9	38.0	38.0	36.5	38.0	38.5	35.9
70.0	43.5	46.5	47.6	43.7	50.0	47.2	44.0	44.1	42.9	44.3	46.2	43.6	46.2	46.1	43.6	46.8	46.7	44.9	46.0	46.3	44.5	45.6	45.6	44.1	45.5	46.1	43.5
80.0	51.6	54.4	55.5	51.7	57.7	55.0	52.0	51.8	50.7	52.3	53.9	51.4	53.7	53.6	51.2	54.3	54.2	52.5	53.5	53.9	52.1	53.1	53.2	51.7	53.1	53.7	51.1
90.0	59.5	62.0	63.1	59.4	65.0	62.4	59.7	59.1	58.1	60.0	61.2	58.8	61.3	61.2	58.8	61.9	61.9	60.1	61.1	61.5	59.7	60.7	60.8	59.3	60.8	61.3	58.7
100.0	67.6	69.9	71.0	67.3	72.7	70.2	67.6	66.8	65.9	67.9	68.9	66.6	69.1	68.9	66.5	69.7	69.6	67.8	68.9	69.2	67.4	68.5	68.5	67.0	68.5	69.0	66.5
110.0	75.7	77.8	78.9	75.3	80.4	77.9	75.6	74.5	73.6	75.9	76.6	74.3	76.8	76.6	74.1	77.4	77.2	75.4	76.6	76.8	75.0	76.2	76.1	74.6	76.3	76.8	74.3
120.0	84.1	85.9	87.0	83.5	88.2	85.9	83.8	82.3	81.6	84.1	84.4	82.3	84.6	84.3	81.8	85.1	84.9	83.1	84.4	84.5	82.7	84.0	83.8	82.3	84.3	84.7	82.1
130.0	92.4	94.0	95.1	91.7	96.1	93.8	92.0	90.2	89.5	92.3	92.3	90.2	92.6	92.2	89.5	93.2	92.8	90.9	92.4	92.4	90.4	92.0	91.7	90.0	92.4	92.6	90.1
140.0	100.9	102.2	103.3	100.0	104.0	101.8	100.3	98.1	97.5	100.6	100.2	98.2	100.9	100.2	97.5	101.5	100.9	98.9	100.7	100.5	98.5	100.3	99.8	98.1	100.6	100.7	98.1
150.0	109.3	110.4	111.5	108.2	112.0	109.9	108.5	106.1	105.6	108.8	108.2	106.3	109.3	108.4	105.6	109.9	109.0	106.9	109.1	108.6	106.5	108.7	107.9	106.1	109.1	109.0	106.4
160.0	117.9	118.7	119.8	116.6	120.0	118.0	116.9	114.1	113.7	117.2	116.2	114.4	117.8	116.7	113.8	118.4	117.4	115.1	117.6	117.0	114.7	117.2	116.3	114.3	117.7	117.5	115.0
170.0	126.7	127.3	128.4	125.3	128.4	126.4	125.6	122.5	122.1	125.9	124.6	122.8	126.5	125.3	122.3	127.1	126.0	123.6	126.3	125.6	123.2	125.9	124.9	122.8	126.3	126.0	123.4
180.0	135.6	135.9	137.0	134.0	136.7	134.9	134.3	130.8	130.6	134.6	132.9	131.3	135.3	134.0	130.9	135.9	134.6	132.2	135.1	134.2	131.8	134.7	133.5	131.4	134.9	134.4	131.9
190.0	144.6	144.7	145.8	142.8	145.3	143.5	143.1	139.4	139.2	143.4	141.5	139.9	144.1	142.6	139.4	144.7	143.2	140.7	143.9	142.8	140.3	143.5	142.1	139.9	143.5	143.0	140.5
200.0	153.6	153.4	154.5	151.6	153.7	152.0	151.9	147.8	147.7	152.2	149.9	148.4	152.8	151.1	147.8	153.4	151.7	149.1	152.6	151.3	148.7	152.2	150.6	148.3	152.3	151.6	149.1
210.0	162.7	162.2	163.3	160.5	162.2	160.6	160.8	156.3	156.3	161.1	158.4	157.0	161.4	159.6	156.2	162.0	160.3	157.5	161.2	159.9	157.1	160.8	159.2	156.7	161.2	160.3	157.7
220.0	171.7	171.0	172.1	169.4	170.8	169.3	169.7	164.9	165.0	170.1	167.0	165.7	170.4	168.4	164.8	171.0	169.0	166.1	170.2	168.6	165.7	169.8	167.9	165.3	170.2	169.1	166.5
230.0	181.0	180.0	181.1	178.5	179.5	178.1	178.8	173.6	173.8	179.1	175.7	174.5	179.5	177.3	173.7	180.1	177.9	175.0	179.3	177.5	174.6	178.9	176.8	174.2	179.4	178.2	175.7
240.0	190.4	189.1	190.2	187.7	188.3	187.0	188.0	182.4	182.7	188.3	184.5	183.4	188.4	186.0	182.3	188.9	186.7	183.6	188.2	186.3	183.2	187.8	185.6	182.8	188.8	187.4	184.8
250.0	199.6	198.1	199.2	196.7	197.1	195.8	197.0	191.2	191.5	197.3	193.3	192.2	197.3	194.7	190.6	197.9	195.3	191.9	197.1	195.0	191.5	196.7	194.3	191.1	198.0	196.3	193.8
260.0	209.0	207.2	208.3	205.9	205.9	204.7	206.2	200.0	200.4	206.5	202.1	201.1	206.3	203.4	199.1	206.9	204.0	200.4	206.1	203.6	200.0	205.7	202.9	199.6	206.7	204.9	202.4
270.0	218.3	216.2	217.3	215.0	214.6	213.6	215.3	208.7	209.3	215.6	210.8	210.0	215.1	212.0	207.6	215.6	212.6	209.0	214.9	212.2	208.6	214.5	211.5	208.2	215.6	213.7	211.1
280.0	227.6	225.2	226.3	224.1	223.3	222.4	224.4	217.4	218.1	224.7	219.5	218.8	223.5	220.3	215.9	224.1	220.9	217.2	223.3	220.5	216.8	222.9	219.8	216.4	224.4	222.2	219.7
290.0	236.9	234.3	235.4	233.3	232.2	231.3	233.6	226.3	227.0	233.9	228.4	227.7	232.1	228.7	224.1	232.7	229.3	225.4	231.9	228.9	225.0	231.5	228.2	224.6	232.7	230.5	227.9
300.0	246.2	243.3	244.4	242.4	240.9	240.1	242.7	235.0	235.8	243.1	237.3	236.6	240.7	237.1	232.3	241.3	237.7	233.6	240.5	237.3	233.2	240.1	236.6	232.8	241.0	238.8	236.1

Table B-4. *N-Tables of the Dobson spectrophotometer D074 defined at calibration campaigns and used for processing of total ozone in different periods of 1962-2002*

Double pairs	RR-59	RR-69	RR-79	RR-86	RR-90	RR-97	RR-99	RR-02
SL: 74-B								
A	43.8	38.1	45.7					
C	43.2	40.1	46.6					
D	41.7	43.7	48.6					
SL: QJ-74-I								
A			26.7	28.3	28.6	26.8	28.0	27.8
C			31.8	33.2	33.4	31.8	32.7	32.6
D			37.1	37.8	37.9	36.3	36.8	36.8
SL: QJ-74-II								
A			25.9	27.7	28.0	26.7	27.9	27.7
C			31.6	33.0	33.4	32.3	33.2	33.2
D			37.6	37.9	38.4	37.2	37.9	38.0
SL: UQ-1								
A					29.2	28.4		
C					34.9	34.1		
D					40.0	39.1		
SL: UQ-5								
A					27.3			
C					33.0			
D					38.0			
SL: UQ-7								
A						26.5	27.3	
C						31.9	32.5	
D						36.9	37.5	

Table B-5. *Reference R-Readings (RR-values) for the Standard Lamps of the Dobson spectrophotometerD074 defined at intercomparisons in the period 1962-2002*

Year	Month	SL 74B			SL QJ-74-I			RR			RNcor			Cor
		RA	RC	RD	RA	RC	RD	RRA	RRC	RRD	RAcor	RCcor	RDcor	RD-RA
1961	1	39.7	40.3	43.8				44.9	46.9	48.8	5.2	6.6	5.0	-0.2
1961	2	39.7	40.3	43.8				44.9	46.9	48.8	5.2	6.6	5.0	-0.2
1961	3	39.7	40.3	43.8				44.9	46.9	48.8	5.2	6.6	5.0	-0.2
1961	4	39.7	40.3	43.8				44.9	46.9	48.8	5.2	6.6	5.0	-0.2
1961	5	39.7	40.3	43.8				44.9	46.9	48.8	5.2	6.6	5.0	-0.2
1961	6	39.7	40.3	43.8				44.9	46.9	48.8	5.2	6.6	5.0	-0.2
1961	7	39.7	40.3	43.8				44.9	46.9	48.8	5.2	6.6	5.0	-0.2
1961	8	39.7	40.3	43.8				44.9	46.9	48.8	5.2	6.6	5.0	-0.2
1961	9	39.7	40.3	43.8				44.9	46.9	48.8	5.2	6.6	5.0	-0.2
1961	10	39.7	40.3	43.8				44.9	46.9	48.8	5.2	6.6	5.0	-0.2
1961	11	39.7	40.3	43.8				44.9	46.9	48.8	5.2	6.6	5.0	-0.2
1961	12	39.7	40.3	43.8				44.9	46.9	48.8	5.2	6.6	5.0	-0.2
1962	1	39.7	40.3	43.8				44.9	46.9	48.8	5.2	6.6	5.0	-0.2
1962	2	39.7	40.3	43.8				44.9	46.9	48.8	5.2	6.6	5.0	-0.2
1962	3	39.9	40.4	44.0				44.9	46.9	48.8	5.0	6.5	4.8	-0.2
1962	4	39.9	40.3	44.0				44.9	46.9	48.8	5.1	6.6	4.8	-0.3
1962	5	39.8	40.2	44.0				44.9	46.9	48.8	5.1	6.8	4.8	-0.3
1962	6	39.8	40.0	44.0				44.9	46.9	48.8	5.2	6.9	4.8	-0.4
1962	7	39.7	39.9	44.0				44.9	46.9	48.8	5.2	7.0	4.8	-0.4
1962	8	39.7	39.9	44.0				44.9	46.9	48.8	5.2	7.0	4.8	-0.4
1962	9	39.7	40.0	44.1				44.9	46.9	48.8	5.2	6.9	4.7	-0.5
1962	10	39.7	40.0	44.1				44.9	46.9	48.8	5.2	6.9	4.7	-0.5
1962	11	39.7	40.0	44.1				44.9	46.9	48.8	5.2	6.9	4.7	-0.6
1962	12	39.6	40.1	44.2				44.9	46.9	48.8	5.3	6.8	4.6	-0.6
1963	1	39.6	40.1	44.2				44.9	46.9	48.8	5.3	6.8	4.6	-0.7
1963	2	39.6	40.1	44.2				44.9	46.9	48.8	5.3	6.8	4.6	-0.7
1963	3	39.6	40.2	44.3				44.9	46.9	48.8	5.3	6.7	4.5	-0.8
1963	4	39.6	40.2	44.3				44.9	46.9	48.8	5.3	6.7	4.5	-0.8
1963	5	39.5	40.0	43.8				44.9	46.9	48.8	5.4	6.9	5.0	-0.4
1963	6	39.9	40.3	44.0				44.9	46.9	48.8	5.0	6.6	4.8	-0.2
1963	7	39.8	39.7	44.0				44.9	46.9	48.8	5.1	7.2	4.8	-0.3
1963	8	39.8	39.7	44.0				44.9	46.9	48.8	5.1	7.2	4.8	-0.3
1963	9	39.7	39.7	44.0				44.9	46.9	48.8	5.2	7.2	4.8	-0.4
1963	10	39.6	39.7	44.0				44.9	46.9	48.8	5.3	7.2	4.8	-0.5
1963	11	39.5	39.7	44.0				44.9	46.9	48.8	5.4	7.2	4.8	-0.6
1963	12	39.4	39.7	43.9				44.9	46.9	48.8	5.5	7.2	4.9	-0.6
1964	1	39.3	39.7	43.9				44.9	46.9	48.8	5.6	7.2	4.9	-0.7
1964	2	39.2	39.7	43.9				44.9	46.9	48.8	5.7	7.2	4.9	-0.8
1964	3	39.2	39.7	43.9				44.9	46.9	48.8	5.7	7.2	4.9	-0.8
1964	4	39.2	39.7	43.9				44.9	46.9	48.8	5.7	7.2	4.9	-0.8
1964	5	39.1	39.8	43.8				44.9	46.9	48.8	5.8	7.1	5.0	-0.8
1964	6	39.1	39.8	43.8				44.9	46.9	48.8	5.8	7.1	5.0	-0.8
1964	7	39.1	39.8	43.8				44.9	46.9	48.8	5.8	7.1	5.0	-0.8
1964	8	39.1	39.8	43.8				44.9	46.9	48.8	5.8	7.1	5.0	-0.8
1964	9	39.2	39.9	43.7				44.9	46.9	48.8	5.7	7.0	5.1	-0.6
1964	10	39.2	39.9	43.7				44.9	46.9	48.8	5.7	7.0	5.1	-0.6
1964	11	39.2	39.9	43.7				44.9	46.9	48.8	5.7	7.0	5.1	-0.6
1964	12	38.9	39.8	43.7				44.9	46.9	48.8	6.0	7.1	5.1	-0.9
1965	1	38.9	39.8	43.7				44.9	46.9	48.8	6.0	7.1	5.1	-0.9
1965	2	39.0	39.7	43.7				44.9	46.9	48.8	5.9	7.2	5.1	-0.8
1965	3	39.1	40.2	43.8				44.9	46.9	48.8	5.8	6.7	5.0	-0.8
1965	4	39.1	40.2	43.8				44.9	46.9	48.8	5.8	6.7	5.0	-0.8
1965	5	39.2	40.0	43.7				44.9	46.9	48.8	5.7	6.9	5.1	-0.6
1965	6	39.2	40.0	43.7				44.9	46.9	48.8	5.7	6.9	5.1	-0.6
1965	7	39.2	40.0	43.7				44.9	46.9	48.8	5.7	6.9	5.1	-0.6
1965	8	39.2	40.0	43.7				44.9	46.9	48.8	5.7	6.9	5.1	-0.6
1965	9	39.2	40.0	43.7				44.9	46.9	48.8	5.7	6.9	5.1	-0.6
1965	10	39.2	40.0	43.7				44.9	46.9	48.8	5.7	6.9	5.1	-0.6
1965	11	39.3	40.2	44.0				44.9	46.9	48.8	5.6	6.7	4.8	-0.8
1965	12	39.2	40.3	44.2				44.9	46.9	48.8	5.7	6.6	4.6	-1.1

Year	Month	SL 74B			SL QJ-74-I			RR			RNcor			Cor
		RA	RC	RD	RA	RC	RD	RRA	RRC	RRD	RAcor	RCcor	RDcor	RD-RA
1966	2	39.3	40.4	44.1				44.9	46.9	48.8	5.6	6.5	4.7	-0.9
1966	3	39.4	40.6	44.4				44.9	46.9	48.8	5.5	6.3	4.4	-1.1
1966	4	39.7	40.8	44.5				44.9	46.9	48.8	5.2	6.1	4.3	-0.9
1966	5	40.0	41.0	44.6				44.9	46.9	48.8	4.9	5.9	4.2	-0.7
1966	6	39.9	41.0	44.6				44.9	46.9	48.8	5.0	5.9	4.2	-0.8
1966	7	39.8	41.0	44.6				44.9	46.9	48.8	5.1	5.9	4.2	-0.9
1966	8	40.0	41.2	44.6				44.9	46.9	48.8	4.9	5.7	4.2	-0.7
1966	9	40.2	41.4	45.0				44.9	46.9	48.8	4.7	5.5	3.8	-0.9
1966	10	40.3	41.5	45.1				44.9	46.9	48.8	4.6	5.4	3.7	-0.9
1966	11	40.4	41.6	45.3				44.9	46.9	48.8	4.5	5.3	3.5	-1.0
1966	12	40.5	41.7	45.4				44.9	46.9	48.8	4.4	5.2	3.4	-1.0
1967	1	40.6	42.5	45.6				44.9	46.9	48.8	4.3	4.4	3.2	-1.1
1967	2	40.7	42.3	45.7				44.9	46.9	48.8	4.2	4.6	3.1	-1.1
1967	3	40.8	42.1	45.8				44.9	46.9	48.8	4.1	4.8	3.0	-1.1
1967	4	41.0	42.3	46.0				44.9	46.9	48.8	3.9	4.6	2.8	-1.1
1967	5	41.3	42.5	46.2				44.9	46.9	48.8	3.6	4.4	2.6	-1.0
1967	6	41.3	42.6	46.2				44.9	46.9	48.8	3.6	4.3	2.6	-1.0
1967	7	41.4	42.6	46.3				44.9	46.9	48.8	3.5	4.3	2.5	-1.0
1967	8	41.4	42.7	46.3				44.9	46.9	48.8	3.5	4.2	2.5	-1.0
1967	9	41.5	42.8	46.4				44.9	46.9	48.8	3.4	4.1	2.4	-1.0
1967	10	41.5	42.9	46.4				44.9	46.9	48.8	3.4	4.0	2.4	-1.0
1967	11	41.6	42.9	46.5				44.9	46.9	48.8	3.3	4.0	2.3	-1.0
1967	12	41.6	43.0	46.5				44.9	46.9	48.8	3.3	3.9	2.3	-1.0
1968	1	41.7	43.0	46.6				44.9	46.9	48.8	3.2	3.9	2.2	-1.0
1968	2	41.8	43.0	46.6				44.9	46.9	48.8	3.1	3.9	2.2	-1.0
1968	3	41.9	43.1	46.7				44.9	46.9	48.8	3.0	3.8	2.1	-0.9
1968	4	42.0	43.1	46.8				44.9	46.9	48.8	2.9	3.8	2.0	-0.9
1968	5	42.1	43.1	46.9				44.9	46.9	48.8	2.9	3.8	2.0	-0.9
1968	6	42.1	43.1	46.9				44.9	46.9	48.8	2.8	3.8	1.9	-0.9
1968	7	42.2	43.1	47.0				44.9	46.9	48.8	2.7	3.8	1.8	-0.9
1968	8	42.3	43.2	47.1				44.9	46.9	48.8	2.6	3.7	1.7	-0.8
1968	9	42.4	43.2	47.1				44.9	46.9	48.8	2.5	3.7	1.7	-0.8
1968	10	42.5	43.2	47.2				44.9	46.9	48.8	2.4	3.7	1.6	-0.8
1968	11	42.1	42.8	46.7				44.9	46.9	48.8	2.9	4.1	2.1	-0.8
1969	12	41.6	42.4	46.2				44.9	46.9	48.8	3.3	4.5	2.6	-0.7
1969	1	41.2	42.1	45.7				44.9	46.9	48.8	3.8	4.9	3.1	-0.7
1969	2	40.7	41.7	45.2				44.9	46.9	48.8	4.2	5.2	3.6	-0.6
1969	3	40.3	41.3	44.7				44.9	46.9	48.8	4.7	5.6	4.1	-0.6
1969	4	39.8	40.9	44.2				44.9	46.9	48.8	5.1	6.0	4.6	-0.5
1969	5	38.1	40.1	43.7				44.9	46.9	48.8	6.8	6.8	5.1	-1.7
1969	6	38.2	40.1	43.7				44.9	46.9	48.8	6.7	6.8	5.1	-1.6
1969	7	38.3	40.2	43.7				44.9	46.9	48.8	6.6	6.7	5.1	-1.5
1969	8	38.4	40.2	43.7				44.9	46.9	48.8	6.5	6.7	5.1	-1.4
1969	9	38.4	40.2	43.7				44.9	46.9	48.8	6.5	6.7	5.1	-1.4
1969	10	38.5	40.2	43.7				44.9	46.9	48.8	6.4	6.7	5.1	-1.3
1969	11	38.6	40.3	43.7				44.9	46.9	48.8	6.3	6.6	5.1	-1.2
1969	12	38.7	40.3	43.7				44.9	46.9	48.8	6.2	6.6	5.1	-1.1
1970	1	38.9	40.5	43.9				44.9	46.9	48.8	6.0	6.4	4.9	-1.1
1970	2	39.1	40.7	44.1				44.9	46.9	48.8	5.8	6.2	4.7	-1.1
1970	3	39.4	40.9	44.3				44.9	46.9	48.8	5.5	6.0	4.5	-1.1
1970	4	39.6	41.2	44.5				44.9	46.9	48.8	5.3	5.7	4.3	-1.0
1970	5	39.8	41.4	44.7				44.9	46.9	48.8	5.1	5.5	4.1	-1.0
1970	6	40.0	41.6	44.9				44.9	46.9	48.8	4.9	5.3	3.9	-1.0
1970	7	40.3	41.8	45.2				44.9	46.9	48.8	4.7	5.1	3.7	-1.0
1970	8	40.5	42.0	45.4				44.9	46.9	48.8	4.4	4.9	3.4	-1.0
1970	9	40.7	42.2	45.6				44.9	46.9	48.8	4.2	4.7	3.2	-1.0
1970	10	40.9	42.4	45.8				44.9	46.9	48.8	4.0	4.5	3.0	-1.0
1970	11	41.1	42.7	46.0				44.9	46.9	48.8	3.8	4.2	2.8	-0.9
1970	12	41.4	42.9	46.2				44.9	46.9	48.8	3.5	4.0	2.6	-0.9

Year	Month	SL 74B			SL QJ-74-I			RR			RNcor			Cor
		RA	RC	RD	RA	RC	RD	RRA	RRC	RRD	RAcor	RCcor	RDcor	RD-RA
1971	1	41.6	43.1	46.4				44.9	46.9	48.8	3.3	3.8	2.4	-0.9
1971	2	41.8	43.3	46.6				44.9	46.9	48.8	3.1	3.6	2.2	-0.9
1971	3	42.0	43.5	46.8				44.9	46.9	48.8	2.9	3.4	2.0	-0.9
1971	4	42.1	43.6	46.9				44.9	46.9	48.8	2.8	3.3	1.9	-0.9
1971	5	42.3	43.8	47.1				44.9	46.9	48.8	2.6	3.1	1.7	-0.9
1971	6	42.4	44.0	47.2				44.9	46.9	48.8	2.5	2.9	1.6	-0.9
1971	7	42.6	44.2	47.4				44.9	46.9	48.8	2.3	2.7	1.4	-0.9
1971	8	42.7	44.3	47.6				44.9	46.9	48.8	2.2	2.6	1.2	-0.9
1971	9	42.9	44.5	47.7				44.9	46.9	48.8	2.0	2.4	1.1	-0.9
1971	10	43.0	44.7	47.9				44.9	46.9	48.8	1.9	2.2	0.9	-1.0
1971	11	43.2	44.9	48.0				44.9	46.9	48.8	1.7	2.0	0.8	-1.0
1971	12	43.3	45.0	48.2				44.9	46.9	48.8	1.6	1.9	0.6	-1.0
1972	1	43.5	45.2	48.4				44.9	46.9	48.8	1.4	1.7	0.4	-1.0
1972	2	43.6	45.4	48.5				44.9	46.9	48.8	1.3	1.5	0.3	-1.0
1972	3	43.8	45.6	48.7				44.9	46.9	48.8	1.1	1.3	0.1	-1.0
1972	4	43.9	45.7	48.8				44.9	46.9	48.8	1.0	1.2	0.0	-1.0
1972	5	44.1	45.9	49.0				44.9	46.9	48.8	0.8	1.0	-0.2	-1.0
1972	6	44.1	45.9	49.0				44.9	46.9	48.8	0.8	1.0	-0.2	-1.0
1972	7	44.1	45.9	49.0				44.9	46.9	48.8	0.8	1.0	-0.2	-1.0
1972	8	44.1	45.9	49.0				44.9	46.9	48.8	0.8	1.0	-0.2	-1.0
1972	9	44.1	45.9	49.0				44.9	46.9	48.8	0.8	1.0	-0.2	-1.0
1972	10	44.1	45.9	49.0				44.9	46.9	48.8	0.8	1.0	-0.2	-1.0
1972	11	44.1	45.9	49.0				44.9	46.9	48.8	0.8	1.0	-0.2	-1.0
1972	12	44.1	45.9	49.0				44.9	46.9	48.8	0.8	1.0	-0.2	-1.0
1973	1	39.8	41.2	44.1				44.9	46.9	48.8	5.1	5.7	4.7	-0.4
1973	2	39.4	40.6	43.4				44.9	46.9	48.8	5.5	6.3	5.4	-0.1
1973	3	39.4	40.6	43.4				44.9	46.9	48.8	5.5	6.3	5.4	-0.1
1973	4	39.4	40.6	43.3				44.9	46.9	48.8	5.5	6.3	5.5	0.0
1973	5	39.6	40.9	43.6				44.9	46.9	48.8	5.3	6.1	5.2	-0.1
1973	6	39.8	41.1	43.9				44.9	46.9	48.8	5.1	5.8	4.9	-0.1
1973	7	40.1	41.4	44.2				44.9	46.9	48.8	4.9	5.6	4.7	-0.2
1973	8	40.3	41.6	44.4				44.9	46.9	48.8	4.6	5.3	4.4	-0.3
1973	9	40.5	41.9	44.7				44.9	46.9	48.8	4.4	5.1	4.1	-0.3
1973	10	40.7	42.1	45.0				44.9	46.9	48.8	4.2	4.8	3.8	-0.4
1973	11	40.7	42.1	45.0				44.9	46.9	48.8	4.2	4.8	3.8	-0.4
1973	12	40.7	42.1	45.0				44.9	46.9	48.8	4.2	4.8	3.8	-0.4
1974	1	40.8	42.1	45.0				44.9	46.9	48.8	4.1	4.8	3.8	-0.3
1974	2	40.8	42.4	44.9				44.9	46.9	48.8	4.1	4.5	3.9	-0.2
1974	3	40.9	42.5	45.0				44.9	46.9	48.8	4.0	4.4	3.8	-0.2
1974	4	41.0	42.5	45.1				44.9	46.9	48.8	3.9	4.4	3.7	-0.2
1974	5	41.1	42.6	45.2				44.9	46.9	48.8	3.8	4.3	3.6	-0.2
1974	6	41.2	42.7	45.2				44.9	46.9	48.8	3.7	4.2	3.6	-0.1
1974	7	41.3	42.8	45.3				44.9	46.9	48.8	3.6	4.1	3.5	-0.1
1974	8	41.4	42.8	45.4				44.9	46.9	48.8	3.5	4.1	3.4	-0.1
1974	9	41.5	42.9	45.5				44.9	46.9	48.8	3.4	4.0	3.3	-0.1
1974	10	41.6	43.0	45.6				44.9	46.9	48.8	3.3	3.9	3.2	-0.1
1974	11	41.7	43.1	45.7				44.9	46.9	48.8	3.2	3.8	3.1	-0.1
1974	12	41.8	43.1	45.8				44.9	46.9	48.8	3.1	3.8	3.0	-0.1
1975	1	41.9	43.2	45.9				44.9	46.9	48.8	3.0	3.7	2.9	-0.1
1975	2	42.0	43.3	45.9				44.9	46.9	48.8	2.9	3.6	2.9	0.0
1975	3	42.1	43.4	46.0				44.9	46.9	48.8	2.8	3.5	2.8	0.0
1975	4	42.2	43.4	46.1				44.9	46.9	48.8	2.7	3.5	2.7	0.0
1975	5	42.3	43.5	46.2				44.9	46.9	48.8	2.6	3.4	2.6	0.0
1975	6	42.4	43.6	46.3				44.9	46.9	48.8	2.5	3.3	2.5	0.0
1975	7	42.5	43.7	46.3				44.9	46.9	48.8	2.4	3.2	2.5	0.0
1975	8	42.6	43.8	46.4				44.9	46.9	48.8	2.3	3.1	2.4	0.1
1975	9	42.7	43.8	46.5				44.9	46.9	48.8	2.2	3.1	2.3	0.1
1975	10	42.8	43.9	46.6				44.9	46.9	48.8	2.1	3.0	2.2	0.1
1975	11	42.9	44.0	46.6				44.9	46.9	48.8	2.0	2.9	2.2	0.1
1975	12	43.0	44.1	46.7				44.9	46.9	48.8	1.9	2.8	2.1	0.1

Year	Month	SL 74B			SL QJ-74-I			RR			RNcor			Cor
		RA	RC	RD	RA	RC	RD	RRA	RRC	RRD	RAcor	RCcor	RDcor	RD-RA
1976	1	43.1	44.2	46.8				44.9	46.9	48.8	1.8	2.7	2.0	0.2
1976	2	43.2	44.3	46.9				44.9	46.9	48.8	1.7	2.6	1.9	0.2
1976	3	43.2	44.3	46.9				44.9	46.9	48.8	1.7	2.6	1.9	0.2
1976	4	43.3	44.4	47.0				44.9	46.9	48.8	1.6	2.5	1.8	0.2
1976	5	43.4	44.5	47.1				44.9	46.9	48.8	1.5	2.4	1.7	0.3
1976	6	43.5	44.6	47.2				44.9	46.9	48.8	1.4	2.3	1.6	0.3
1976	7	43.6	44.7	47.2				44.9	46.9	48.8	1.3	2.2	1.6	0.3
1976	8	43.7	44.8	47.3				44.9	46.9	48.8	1.2	2.1	1.5	0.3
1976	9	43.8	44.8	47.4				44.9	46.9	48.8	1.1	2.1	1.4	0.3
1976	10	43.9	44.9	47.5				44.9	46.9	48.8	1.0	2.0	1.3	0.4
1976	11	44.0	45.0	47.5				44.9	46.9	48.8	0.9	1.9	1.3	0.4
1976	12	44.1	45.1	47.6				44.9	46.9	48.8	0.8	1.8	1.2	0.4
1977	1	44.2	45.2	47.6				44.9	46.9	48.8	0.7	1.7	1.2	0.4
1977	2	44.2	45.2	47.7				44.9	46.9	48.8	0.7	1.7	1.1	0.4
1977	3	44.3	45.3	47.7				44.9	46.9	48.8	0.6	1.6	1.1	0.5
1977	4	44.3	45.3	47.8				44.9	46.9	48.8	0.6	1.6	1.0	0.5
1977	5	44.4	45.4	47.8				44.9	46.9	48.8	0.5	1.5	1.0	0.5
1977	6	44.4	45.4	47.8				44.9	46.9	48.8	0.5	1.5	1.0	0.5
1977	7	44.5	45.5	47.9				44.9	46.9	48.8	0.4	1.4	0.9	0.5
1977	8	44.6	45.5	47.9				44.9	46.9	48.8	0.3	1.4	0.9	0.6
1977	9	44.6	45.6	47.9				44.9	46.9	48.8	0.3	1.3	0.9	0.6
1977	10	44.7	45.6	48.0				44.9	46.9	48.8	0.2	1.3	0.8	0.6
1977	11	44.7	45.7	48.0				44.9	46.9	48.8	0.2	1.2	0.8	0.6
1977	12	44.8	45.7	48.1				44.9	46.9	48.8	0.1	1.2	0.7	0.6
1978	1	44.8	45.8	48.1				44.9	46.9	48.8	0.1	1.1	0.7	0.6
1978	2	44.9	45.8	48.1				44.9	46.9	48.8	0.0	1.1	0.7	0.7
1978	3	45.0	45.9	48.2				44.9	46.9	48.8	-0.1	1.0	0.6	0.7
1978	4	45.0	45.9	48.2				44.9	46.9	48.8	-0.1	1.0	0.6	0.7
1978	5	45.1	46.0	48.2				44.9	46.9	48.8	-0.2	0.9	0.6	0.7
1978	6	45.1	46.0	48.3				44.9	46.9	48.8	-0.2	0.9	0.5	0.7
1978	7	45.2	46.1	48.3				44.9	46.9	48.8	-0.3	0.8	0.5	0.8
1978	8	45.2	46.1	48.4				44.9	46.9	48.8	-0.3	0.8	0.4	0.8
1978	9	45.3	46.2	48.4				44.9	46.9	48.8	-0.4	0.7	0.4	0.8
1978	10	45.4	46.3	48.5				44.9	46.9	48.8	-0.5	0.6	0.3	0.8
1978	11	45.4	46.4	48.6				44.9	46.9	48.8	-0.5	0.5	0.3	0.8
1978	12	45.5	46.5	48.6				44.9	46.9	48.8	-0.6	0.4	0.2	0.7
1979	1	45.5	46.6	48.7				44.9	46.9	48.8	-0.6	0.4	0.1	0.7
1979	2	45.6	46.6	48.8				44.9	46.9	48.8	-0.6	0.3	0.0	0.7
1979	3	45.6	46.7	48.9				44.9	46.9	48.8	-0.7	0.2	-0.1	0.6
1979	4	45.7	46.8	48.9				44.9	46.9	48.8	-0.8	0.1	-0.1	0.6
1979	5	45.7	46.9	49.0				44.9	46.9	48.8	-0.8	0.0	-0.2	0.6
1979	6	45.6	46.4	48.8				44.9	46.9	48.8	-0.7	0.5	0.0	0.7
1979	7	43.6	45.9	48.7	26.9	31.9	37.5	28.3	33.2	37.8	1.4	1.3	0.3	-1.1
1979	8				26.9	31.9	37.5	28.3	33.2	37.8	1.4	1.3	0.3	-1.1
1979	9				26.8	31.9	37.4	28.3	33.2	37.8	1.5	1.3	0.4	-1.1
1979	10				26.8	31.8	37.4	28.3	33.2	37.8	1.5	1.4	0.4	-1.1
1979	11				26.8	31.8	37.4	28.3	33.2	37.8	1.5	1.4	0.4	-1.1
1979	12				26.7	31.8	37.3	28.3	33.2	37.8	1.6	1.4	0.5	-1.1
1980	1	43.3	45.4	48.3	26.7	31.8	37.3	28.3	33.2	37.8	1.6	1.4	0.5	-1.1
1980	2				26.7	31.7	37.3	28.3	33.2	37.8	1.6	1.5	0.5	-1.1
1980	3				26.6	31.7	37.2	28.3	33.2	37.8	1.7	1.5	0.6	-1.1
1980	4				26.6	31.7	37.2	28.3	33.2	37.8	1.7	1.5	0.6	-1.1
1980	5				26.7	31.8	37.1	28.3	33.2	37.8	1.6	1.4	0.7	-0.9
1980	6				26.6	31.7	37.0	28.3	33.2	37.8	1.7	1.5	0.8	-0.9
1980	7				26.6	31.7	37.1	28.3	33.2	37.8	1.7	1.5	0.7	-1.0
1980	8				26.7	31.9	37.2	28.3	33.2	37.8	1.6	1.3	0.6	-1.0
1980	9				26.7	31.9	37.2	28.3	33.2	37.8	1.6	1.3	0.6	-1.0
1980	10				26.7	31.9	37.2	28.3	33.2	37.8	1.6	1.3	0.6	-1.0
1980	11				26.8	31.9	37.2	28.3	33.2	37.8	1.6	1.3	0.6	-1.0
1980	12				26.8	31.9	37.2	28.3	33.2	37.8	1.5	1.3	0.6	-0.9

Year	Month	SL 74B			SL QJ-74-I			RR			RNcor			Cor
		RA	RC	RD	RA	RC	RD	RRA	RRC	RRD	RAcor	RCcor	RDcor	RD-RA
1981	1				26.8	32.0	37.2	28.3	33.2	37.8	1.5	1.3	0.6	-0.9
1981	2				26.8	32.0	37.2	28.3	33.2	37.8	1.5	1.2	0.6	-0.9
1981	3				26.8	32.0	37.2	28.3	33.2	37.8	1.5	1.2	0.6	-0.9
1981	4				26.8	32.0	37.2	28.3	33.2	37.8	1.5	1.2	0.6	-0.9
1981	5				26.9	32.0	37.2	28.3	33.2	37.8	1.5	1.2	0.6	-0.9
1981	6				26.9	32.0	37.2	28.3	33.2	37.8	1.4	1.2	0.6	-0.9
1981	7				26.9	32.0	37.2	28.3	33.2	37.8	1.4	1.2	0.6	-0.9
1981	8				26.9	32.0	37.2	28.3	33.2	37.8	1.4	1.2	0.6	-0.8
1981	9				26.9	32.0	37.2	28.3	33.2	37.8	1.4	1.2	0.6	-0.8
1981	10				26.9	32.0	37.2	28.3	33.2	37.8	1.4	1.2	0.6	-0.8
1981	11				27.0	32.1	37.3	28.3	33.2	37.8	1.4	1.2	0.5	-0.8
1981	12				27.0	32.1	37.3	28.3	33.2	37.8	1.3	1.1	0.5	-0.8
1982	1				27.0	32.1	37.3	28.3	33.2	37.8	1.3	1.1	0.5	-0.8
1982	2				27.0	32.1	37.3	28.3	33.2	37.8	1.3	1.1	0.5	-0.8
1982	3				27.0	32.1	37.3	28.3	33.2	37.8	1.3	1.1	0.5	-0.7
1982	4				27.0	32.1	37.3	28.3	33.2	37.8	1.3	1.1	0.5	-0.7
1982	5				27.1	32.1	37.3	28.3	33.2	37.8	1.3	1.1	0.5	-0.7
1982	6				27.1	32.1	37.3	28.3	33.2	37.8	1.2	1.1	0.5	-0.7
1982	7				27.1	32.1	37.3	28.3	33.2	37.8	1.2	1.1	0.5	-0.7
1982	8				27.1	32.1	37.3	28.3	33.2	37.8	1.2	1.1	0.5	-0.7
1982	9				27.1	32.2	37.3	28.3	33.2	37.8	1.2	1.1	0.5	-0.7
1982	10				27.1	32.2	37.3	28.3	33.2	37.8	1.2	1.0	0.5	-0.7
1982	11				27.2	32.2	37.3	28.3	33.2	37.8	1.2	1.0	0.5	-0.6
1982	12				27.2	32.2	37.3	28.3	33.2	37.8	1.1	1.0	0.5	-0.6
1983	1				27.2	32.2	37.3	28.3	33.2	37.8	1.1	1.0	0.5	-0.6
1983	2				27.2	32.2	37.3	28.3	33.2	37.8	1.1	1.0	0.5	-0.6
1983	3				27.2	32.3	37.4	28.3	33.2	37.8	1.1	0.9	0.4	-0.7
1983	4				27.2	32.2	37.3	28.3	33.2	37.8	1.1	1.0	0.5	-0.6
1983	5				27.4	32.3	37.3	28.3	33.2	37.8	0.9	0.9	0.5	-0.4
1983	6				27.3	32.1	37.2	28.3	33.2	37.8	1.0	1.1	0.6	-0.4
1983	7				27.3	32.0	37.0	28.3	33.2	37.8	1.0	1.2	0.8	-0.2
1983	8				27.5	32.2	37.2	28.3	33.2	37.8	0.8	1.0	0.6	-0.2
1983	9				27.7	32.4	37.5	28.3	33.2	37.8	0.6	0.8	0.3	-0.3
1983	10				27.7	32.4	37.5	28.3	33.2	37.8	0.6	0.8	0.3	-0.3
1983	11				27.7	32.6	37.6	28.3	33.2	37.8	0.6	0.6	0.2	-0.4
1983	12				27.6	32.5	37.4	28.3	33.2	37.8	0.7	0.7	0.4	-0.3
1984	1				27.7	32.8	37.8	28.3	33.2	37.8	0.6	0.4	0.0	-0.6
1984	2				27.5	32.4	37.5	28.3	33.2	37.8	0.8	0.8	0.3	-0.5
1984	3				28.0	33.0	38.1	28.3	33.2	37.8	0.3	0.2	-0.3	-0.6
1984	4				28.1	33.1	38.2	28.3	33.2	37.8	0.2	0.1	-0.4	-0.6
1984	5				28.3	33.2	38.2	28.3	33.2	37.8	0.0	0.0	-0.4	-0.4
1984	6				28.2	33.1	38.0	28.3	33.2	37.8	0.1	0.1	-0.2	-0.3
1984	7				28.5	33.3	38.2	28.3	33.2	37.8	-0.2	-0.1	-0.4	-0.2
1984	8				28.4	33.3	38.2	28.3	33.2	37.8	-0.1	-0.1	-0.4	-0.3
1984	9				28.5	33.3	38.2	28.3	33.2	37.8	-0.2	-0.1	-0.4	-0.2
1984	10				28.3	33.1	38.0	28.3	33.2	37.8	0.0	0.1	-0.2	-0.2
1984	11				28.3	33.1	38.1	28.3	33.2	37.8	0.0	0.1	-0.3	-0.3
1984	12				28.1	33.0	38.0	28.3	33.2	37.8	0.2	0.2	-0.2	-0.4
1985	1				27.9	32.9	37.7	28.3	33.2	37.8	0.4	0.3	0.1	-0.3
1985	2				28.2	33.0	38.1	28.3	33.2	37.8	0.1	0.2	-0.3	-0.4
1985	3				28.0	32.9	37.9	28.3	33.2	37.8	0.3	0.3	-0.1	-0.4
1985	4				28.3	33.1	38.1	28.3	33.2	37.8	0.0	0.1	-0.3	-0.3
1985	5				28.3	33.1	38.0	28.3	33.2	37.8	0.0	0.1	-0.2	-0.2
1985	6				28.4	33.2	38.2	28.3	33.2	37.8	-0.1	0.0	-0.4	-0.3
1985	7				28.6	33.4	38.3	28.3	33.2	37.8	-0.3	-0.2	-0.5	-0.2
1985	8				28.6	33.3	38.2	28.3	33.2	37.8	-0.3	-0.1	-0.4	-0.1
1985	9				28.5	33.2	38.2	28.3	33.2	37.8	-0.2	0.0	-0.4	-0.2
1985	10				28.4	33.1	38.1	28.3	33.2	37.8	-0.1	0.1	-0.3	-0.2
1985	11				28.3	33.1	38.0	28.3	33.2	37.8	0.0	0.1	-0.2	-0.2
1985	12				28.3	33.1	38.0	28.3	33.2	37.8	0.0	0.1	-0.2	-0.2

Year	Month	SL 74B			SL QJ-74-I			RR			RNcor			Cor
		RA	RC	RD	RA	RC	RD	RRA	RRC	RRD	RAcor	RCcor	RDcor	RD-RA
1986	1				28.3	33.1	38.0	28.3	33.2	37.8	0.0	0.1	-0.2	-0.2
1986	2				28.3	33.1	37.9	28.3	33.2	37.8	0.0	0.1	-0.1	-0.1
1986	3				28.4	33.1	38.0	28.3	33.2	37.8	-0.1	0.1	-0.2	-0.1
1986	4				28.4	33.1	38.0	28.3	33.2	37.8	-0.1	0.1	-0.2	-0.1
1986	5				28.3	32.9	37.8	28.3	33.2	37.8	0.0	0.3	0.0	0.0
1986	6				28.4	33.0	38.0	28.3	33.2	37.8	-0.1	0.2	-0.2	-0.1
1986	7				28.6	33.3	38.2	28.3	33.2	37.8	-0.3	-0.1	-0.4	-0.1
1986	8				28.3	33.2	37.8	28.3	33.2	37.8	0.0	0.0	0.0	0.0
1986	9				28.1	32.7	37.4	28.3	33.2	37.8	0.2	0.5	0.4	0.2
1986	10				28.1	32.7	37.4	28.3	33.2	37.8	0.2	0.5	0.4	0.2
1986	11				28.3	33.2	37.8	28.3	33.2	37.8	0.0	0.0	0.0	0.0
1986	12				28.3	33.5	38.3	28.3	33.2	37.8	0.0	-0.3	-0.5	-0.5
1987	1				28.4	33.4	38.2	28.3	33.2	37.8	-0.1	-0.2	-0.4	-0.3
1987	2				28.3	33.2	38.1	28.3	33.2	37.8	0.0	0.0	-0.3	-0.3
1987	3				28.3	33.3	38.2	28.3	33.2	37.8	0.0	-0.1	-0.4	-0.4
1987	4				28.4	33.3	38.1	28.3	33.2	37.8	-0.1	-0.1	-0.3	-0.2
1987	5				28.3	33.3	38.0	28.3	33.2	37.8	0.0	-0.1	-0.2	-0.2
1987	6				28.7	33.4	38.1	28.3	33.2	37.8	-0.4	-0.2	-0.3	0.1
1987	7				28.8	33.6	38.2	28.3	33.2	37.8	-0.5	-0.4	-0.4	0.1
1987	8				28.8	33.8	38.3	28.3	33.2	37.8	-0.5	-0.6	-0.5	0.0
1987	9				28.4	33.6	38.0	28.3	33.2	37.8	-0.1	-0.4	-0.2	-0.1
1987	10				28.2	33.0	37.7	28.3	33.2	37.8	0.1	0.2	0.1	0.0
1987	11				28.2	33.1	37.7	28.3	33.2	37.8	0.1	0.1	0.1	0.0
1987	12				28.1	33.2	37.8	28.3	33.2	37.8	0.2	0.0	0.0	-0.2
1988	1				28.2	33.2	37.8	28.3	33.2	37.8	0.1	0.0	0.0	-0.1
1988	2				28.1	33.2	37.8	28.3	33.2	37.8	0.2	0.0	0.0	-0.2
1988	3				28.2	33.1	37.7	28.3	33.2	37.8	0.1	0.1	0.1	0.0
1988	4				28.2	33.2	37.9	28.3	33.2	37.8	0.1	0.0	-0.1	-0.2
1988	5				28.6	33.3	38.0	28.3	33.2	37.8	-0.3	-0.1	-0.2	0.1
1988	6				28.7	33.6	38.2	28.3	33.2	37.8	-0.4	-0.4	-0.4	0.0
1988	7				28.8	33.8	38.3	28.3	33.2	37.8	-0.5	-0.6	-0.5	0.0
1988	8				28.9	33.7	38.3	28.3	33.2	37.8	-0.6	-0.5	-0.5	0.1
1988	9				28.8	33.7	38.2	28.3	33.2	37.8	-0.5	-0.5	-0.4	0.1
1988	10				29.0	33.8	38.4	28.3	33.2	37.8	-0.7	-0.6	-0.6	0.1
1988	11				28.7	33.6	38.2	28.3	33.2	37.8	-0.4	-0.4	-0.4	0.0
1988	12				28.5	33.3	37.9	28.3	33.2	37.8	-0.2	-0.1	-0.1	0.1
1989	1				28.6	33.5	38.1	28.3	33.2	37.8	-0.3	-0.3	-0.3	0.0
1989	2				28.4	33.3	37.9	28.3	33.2	37.8	-0.1	-0.1	-0.1	0.0
1989	3				28.9	33.8	38.3	28.3	33.2	37.8	-0.6	-0.6	-0.5	0.1
1989	4				28.7	33.7	38.2	28.3	33.2	37.8	-0.4	-0.5	-0.4	0.0
1989	5				28.7	33.7	38.2	28.3	33.2	37.8	-0.4	-0.5	-0.4	0.0
1989	6				29.1	33.8	38.3	28.3	33.2	37.8	-0.8	-0.6	-0.5	0.3
1989	7				29.2	33.8	38.4	28.3	33.2	37.8	-0.9	-0.6	-0.6	0.3
1989	8				29.5	34.3	38.7	28.3	33.2	37.8	-1.2	-1.1	-0.9	0.3
1989	9				29.3	34.2	38.8	28.3	33.2	37.8	-1.0	-1.0	-1.0	0.0
1989	10				29.2	34.1	38.7	28.3	33.2	37.8	-0.9	-0.9	-0.9	0.0
1989	11				29.7	34.5	39.1	28.3	33.2	37.8	-1.4	-1.3	-1.3	0.1
1989	12				29.2	34.2	38.7	28.3	33.2	37.8	-0.9	-1.0	-0.9	0.0
1990	1				29.6	34.6	39.2	28.3	33.2	37.8	-1.3	-1.4	-1.4	-0.1
1990	2				29.4	34.4	39.0	28.3	33.2	37.8	-1.1	-1.2	-1.2	-0.1
1990	3				29.6	34.5	39.3	28.3	33.2	37.8	-1.3	-1.3	-1.5	-0.2
1990	4				29.8	34.6	39.2	28.3	33.2	37.8	-1.5	-1.4	-1.4	0.1
1990	5				29.9	34.7	39.2	28.3	33.2	37.8	-1.6	-1.5	-1.4	0.2
1990	6				29.8	34.6	39.1	28.3	33.2	37.8	-1.5	-1.4	-1.3	0.2
1990	7				27.7	32.5	37.1	28.6	33.4	37.9	0.9	0.9	0.8	-0.1
1990	8				28.0	32.8	37.5	28.6	33.4	37.9	0.6	0.6	0.4	-0.2
1990	9				28.5	33.3	37.7	28.6	33.4	37.9	0.1	0.1	0.2	0.1
1990	10				28.2	33.3	37.6	28.6	33.4	37.9	0.4	0.1	0.3	-0.1
1990	11				27.9	32.9	37.5	28.6	33.4	37.9	0.7	0.5	0.4	-0.3
1990	12				28.1	33.4	37.7	28.6	33.4	37.9	0.5	0.0	0.2	-0.3

Year	Month	SL 74B			SL QJ-74-I			RR			RNcor			Cor
		RA	RC	RD	RA	RC	RD	RRA	RRC	RRD	RAcor	RCcor	RDcor	RD-RA
1991	1				27.9	33.2	37.6	28.6	33.4	37.9	0.7	0.2	0.3	-0.4
1991	2				27.8	32.9	37.2	28.6	33.4	37.9	0.8	0.5	0.7	-0.1
1991	3				27.8	32.9	37.3	28.6	33.4	37.9	0.8	0.5	0.6	-0.2
1991	4				27.8	32.9	37.2	28.6	33.4	37.9	0.8	0.5	0.7	-0.1
1991	5				27.8	32.9	37.3	28.6	33.4	37.9	0.8	0.5	0.6	-0.2
1991	6				27.6	32.6	37.3	28.6	33.4	37.9	1.0	0.8	0.6	-0.4
1991	7				27.8	32.9	37.4	28.6	33.4	37.9	0.8	0.5	0.5	-0.3
1991	8				28.0	32.8	37.5	28.6	33.4	37.9	0.6	0.6	0.4	-0.2
1991	9				27.9	33.0	37.4	28.6	33.4	37.9	0.7	0.4	0.5	-0.2
1991	10				28.0	33.0	37.5	28.6	33.4	37.9	0.6	0.4	0.4	-0.2
1991	11				27.8	32.8	37.2	28.6	33.4	37.9	0.8	0.6	0.7	-0.1
1991	12				27.9	33.0	37.5	28.6	33.4	37.9	0.7	0.4	0.4	-0.3
1992	1				27.8	32.9	37.2	28.6	33.4	37.9	0.8	0.5	0.7	-0.1
1992	2				27.5	32.6	37.1	28.6	33.4	37.9	1.1	0.8	0.8	-0.3
1992	3				27.9	33.0	37.3	28.6	33.4	37.9	0.7	0.4	0.6	-0.1
1992	4				27.7	32.9	37.4	28.6	33.4	37.9	0.9	0.5	0.5	-0.4
1992	5				27.9	32.9	37.5	28.6	33.4	37.9	0.7	0.5	0.4	-0.3
1992	6				28.2	33.1	37.5	28.6	33.4	37.9	0.4	0.3	0.4	0.0
1992	7				28.1	33.1	37.4	28.6	33.4	37.9	0.5	0.3	0.5	0.0
1992	8				28.2	33.2	37.6	28.6	33.4	37.9	0.4	0.2	0.3	-0.1
1992	9				28.2	33.1	37.5	28.6	33.4	37.9	0.4	0.3	0.4	0.0
1992	10				27.9	33.0	37.5	28.6	33.4	37.9	0.7	0.4	0.4	-0.3
1992	11				27.9	33.0	37.5	28.6	33.4	37.9	0.7	0.4	0.4	-0.3
1992	12				27.6	32.7	37.0	28.6	33.4	37.9	1.0	0.7	0.9	-0.1
1993	1				27.6	32.6	37.0	28.6	33.4	37.9	1.0	0.8	0.9	-0.1
1993	2				27.9	33.0	37.5	28.6	33.4	37.9	0.7	0.4	0.4	-0.3
1993	3				27.8	32.8	37.2	28.6	33.4	37.9	0.8	0.6	0.7	-0.1
1993	4				27.9	32.8	37.3	28.6	33.4	37.9	0.7	0.6	0.6	-0.1
1993	5				28.4	33.4	37.6	28.6	33.4	37.9	0.2	0.0	0.3	0.1
1993	6				27.8	32.8	37.1	28.6	33.4	37.9	0.8	0.6	0.8	0.0
1993	7				28.0	33.0	37.4	28.6	33.4	37.9	0.6	0.4	0.5	-0.1
1993	8				28.2	33.1	37.3	28.6	33.4	37.9	0.4	0.3	0.6	0.2
1993	9				28.3	33.1	37.7	28.6	33.4	37.9	0.3	0.3	0.2	-0.1
1993	10				27.7	32.8	37.1	28.6	33.4	37.9	0.9	0.6	0.8	-0.1
1993	11				27.7	32.8	37.0	28.6	33.4	37.9	0.9	0.6	0.9	0.0
1993	12				27.8	32.8	37.1	28.6	33.4	37.9	0.8	0.6	0.8	0.0
1994	1				28.1	33.2	37.5	28.6	33.4	37.9	0.5	0.2	0.4	-0.1
1994	2				28.2	33.1	37.5	28.6	33.4	37.9	0.4	0.3	0.4	0.0
1994	3				28.2	33.1	37.5	28.6	33.4	37.9	0.4	0.3	0.4	0.0
1994	4				28.0	33.1	37.3	28.6	33.4	37.9	0.6	0.3	0.6	0.0
1994	5				28.0	33.1	37.3	28.6	33.4	37.9	0.6	0.3	0.6	0.0
1994	6				28.0	33.0	37.5	28.6	33.4	37.9	0.6	0.4	0.4	-0.2
1994	7				27.8	32.7	37.0	28.6	33.4	37.9	0.8	0.7	0.9	0.1
1994	8				28.0	32.9	37.1	28.6	33.4	37.9	0.6	0.5	0.8	0.2
1994	9				28.0	32.8	37.1	28.6	33.4	37.9	0.6	0.6	0.8	0.2
1994	10				27.8	32.8	37.1	28.6	33.4	37.9	0.8	0.6	0.8	0.0
1994	11				27.8	32.8	36.9	28.6	33.4	37.9	0.8	0.6	1.0	0.2
1994	12				28.0	33.1	37.2	28.6	33.4	37.9	0.6	0.3	0.7	0.1
1995	1				28.0	32.8	37.2	28.6	33.4	37.9	0.6	0.6	0.7	0.1
1995	2				27.7	32.5	36.9	28.6	33.4	37.9	0.9	0.9	1.0	0.1
1995	3				27.8	32.7	36.9	28.6	33.4	37.9	0.8	0.7	1.0	0.2
1995	4				27.8	32.6	36.9	28.6	33.4	37.9	0.8	0.8	1.0	0.2
1995	5				27.8	32.6	36.8	28.6	33.4	37.9	0.8	0.8	1.1	0.3
1995	6				28.3	33.0	37.4	28.6	33.4	37.9	0.3	0.4	0.5	0.2
1995	7				28.3	33.3	37.5	28.6	33.4	37.9	0.3	0.1	0.4	0.1
1995	8				28.1	33.0	37.2	28.6	33.4	37.9	0.5	0.4	0.7	0.2
1995	9				28.0	33.0	37.3	28.6	33.4	37.9	0.6	0.4	0.6	0.0
1995	10				27.9	32.8	37.0	28.6	33.4	37.9	0.7	0.6	0.9	0.2
1995	11				28.5	33.0	37.1	28.6	33.4	37.9	0.1	0.4	0.8	0.7
1995	12				28.7	33.1	37.3	28.6	33.4	37.9	-0.1	0.3	0.6	0.7

Year	Month	SL 74B			SL QJ-74-I			RR			RNcor			Cor
		RA	RC	RD	RA	RC	RD	RRA	RRC	RRD	RAcor	RCcor	RDcor	RD-RA
1996	1				28.2	33.0	37.2	28.6	33.4	37.9	0.4	0.4	0.7	0.3
1996	2				28.1	32.9	37.1	28.6	33.4	37.9	0.5	0.5	0.8	0.3
1996	3				28.6	32.3	37.5	28.6	33.4	37.9	0.0	1.1	0.4	0.4
1996	4				28.5	33.3	37.5	28.6	33.4	37.9	0.1	0.1	0.4	0.3
1996	5				28.6	33.1	37.5	28.6	33.4	37.9	0.0	0.3	0.4	0.4
1996	6				28.4	33.2	37.3	28.6	33.4	37.9	0.2	0.2	0.6	0.4
1996	7				28.5	33.2	37.3	28.6	33.4	37.9	0.1	0.2	0.6	0.5
1996	8				28.4	33.2	37.4	28.6	33.4	37.9	0.2	0.2	0.5	0.3
1996	9				27.3	32.2	36.5	28.6	33.4	37.9	1.3	1.2	1.4	0.1
1996	10				26.8	31.7	35.9	28.6	33.4	37.9	1.8	1.7	2.0	0.2
1996	11				27.0	32.0	36.4	28.6	33.4	37.9	1.6	1.4	1.5	-0.1
1996	12				26.8	31.7	36.0	28.6	33.4	37.9	1.8	1.7	1.9	0.1
1997	1				26.9	31.9	36.2	28.6	33.4	37.9	1.7	1.5	1.7	0.0
1997	2				26.9	31.8	36.2	28.6	33.4	37.9	1.7	1.6	1.7	0.0
1997	3				26.8	31.8	36.1	28.6	33.4	37.9	1.8	1.6	1.8	0.0
1997	4				27.2	32.2	36.4	28.6	33.4	37.9	1.4	1.2	1.5	0.1
1997	5				27.0	32.0	36.3	28.6	33.4	37.9	1.6	1.4	1.6	0.0
1997	6				27.1	32.0	36.2	28.6	33.4	37.9	1.5	1.4	1.7	0.2
1997	7				26.8	31.8	36.0	26.8	31.8	36.3	0.0	0.0	0.3	0.3
1997	8				27.3	32.2	36.6	26.8	31.8	36.3	-0.5	-0.4	-0.3	0.2
1997	9				27.6	32.3	36.6	26.8	31.8	36.3	-0.8	-0.5	-0.3	0.5
1997	10				27.0	32.0	36.2	26.8	31.8	36.3	-0.2	-0.2	0.1	0.3
1997	11				27.1	32.0	36.2	26.8	31.8	36.3	-0.3	-0.2	0.1	0.4
1997	12				27.0	32.0	36.3	26.8	31.8	36.3	-0.2	-0.2	0.0	0.2
1998	1				27.1	32.0	36.3	26.8	31.8	36.3	-0.3	-0.2	0.0	0.3
1998	2				27.1	32.1	36.4	26.8	31.8	36.3	-0.3	-0.3	-0.1	0.2
1998	3				27.2	32.1	36.4	26.8	31.8	36.3	-0.4	-0.3	-0.1	0.3
1998	4				27.3	32.2	36.5	26.8	31.8	36.3	-0.5	-0.4	-0.2	0.3
1998	5				27.2	32.0	36.3	26.8	31.8	36.3	-0.4	-0.2	0.0	0.4
1998	6				27.3	32.2	36.5	26.8	31.8	36.3	-0.5	-0.4	-0.2	0.3
1998	7				27.3	32.1	36.4	26.8	31.8	36.3	-0.5	-0.3	-0.1	0.4
1998	8				27.3	32.2	36.5	26.8	31.8	36.3	-0.5	-0.4	-0.2	0.3
1998	9				27.4	32.2	36.3	26.8	31.8	36.3	-0.6	-0.4	0.0	0.6
1998	10				27.2	32.3	36.5	26.8	31.8	36.3	-0.4	-0.5	-0.2	0.2
1998	11				27.2	32.2	36.5	26.8	31.8	36.3	-0.4	-0.4	-0.2	0.2
1998	12				27.3	32.2	36.5	26.8	31.8	36.3	-0.5	-0.4	-0.2	0.3
1999	1				27.3	32.2	36.5	26.8	31.8	36.3	-0.5	-0.4	-0.2	0.3
1999	2				27.3	32.0	36.4	26.8	31.8	36.3	-0.5	-0.2	-0.1	0.4
1999	3				27.3	32.2	36.6	26.8	31.8	36.3	-0.5	-0.4	-0.3	0.2
1999	4				27.4	32.3	36.7	26.8	31.8	36.3	-0.6	-0.5	-0.4	0.2
1999	5				27.5	32.2	36.5	26.8	31.8	36.3	-0.7	-0.4	-0.2	0.5
1999	6				27.5	32.2	36.5	26.8	31.8	36.3	-0.7	-0.4	-0.2	0.5
1999	7				27.8	32.5	36.7	28.0	32.7	36.8	0.2	0.2	0.1	-0.1
1999	8				28.5	33.2	37.2	28.0	32.7	36.8	-0.5	-0.5	-0.4	0.1
1999	9				28.2	33.0	37.1	28.0	32.7	36.8	-0.2	-0.3	-0.3	-0.1
1999	10				28.0	32.8	37.1	28.0	32.7	36.8	0.0	-0.1	-0.3	-0.3
1999	11				27.9	32.7	37.0	28.0	32.7	36.8	0.1	0.0	-0.2	-0.3
1999	12				27.8	32.8	36.9	28.0	32.7	36.8	0.2	-0.1	-0.1	-0.3
2000	1				27.8	32.8	36.8	28.0	32.7	36.8	0.2	-0.1	0.0	-0.2
2000	2				27.8	32.8	36.8	28.0	32.7	36.8	0.2	-0.1	0.0	-0.2
2000	3				27.9	32.8	37.0	28.0	32.7	36.8	0.1	-0.1	-0.2	-0.3
2000	4				27.9	32.8	36.9	28.0	32.7	36.8	0.1	-0.1	-0.1	-0.2
2000	5				27.8	32.7	36.8	28.0	32.7	36.8	0.2	0.0	0.0	-0.2
2000	6				28.0	33.0	37.1	28.0	32.7	36.8	0.0	-0.3	-0.3	-0.3
2000	7				28.0	32.8	36.9	28.0	32.7	36.8	0.0	-0.1	-0.1	-0.1
2000	8				27.9	32.7	37.0	28.0	32.7	36.8	0.1	0.0	-0.2	-0.3
2000	9				28.0	32.8	36.8	28.0	32.7	36.8	0.0	-0.1	0.0	0.0
2000	10				27.8	32.7	36.8	28.0	32.7	36.8	0.2	0.0	0.0	-0.2
2000	11				27.9	32.8	37.0	28.0	32.7	36.8	0.1	-0.1	-0.2	-0.3
2000	12				27.8	32.8	36.9	28.0	32.7	36.8	0.2	-0.1	-0.1	-0.3

Year	Month	SL 74B			SL QJ-74-I			RR			RNcor			Cor
		RA	RC	RD	RA	RC	RD	RRA	RRC	RRD	RAcor	RCcor	RDcor	RD-RA
2001	1				27.9	32.8	37.0	28.0	32.7	36.8	0.1	-0.1	-0.2	-0.3
2001	2				27.9	32.8	37.0	28.0	32.7	36.8	0.1	-0.1	-0.2	-0.3
2001	3				27.9	32.8	36.8	28.0	32.7	36.8	0.1	-0.1	0.0	-0.1
2001	4				28.1	32.9	36.9	28.0	32.7	36.8	-0.1	-0.2	-0.1	0.0
2001	5				28.2	32.9	37.1	28.0	32.7	36.8	-0.2	-0.2	-0.3	-0.1
2001	6				28.0	32.8	37.0	28.0	32.7	36.8	0.0	-0.1	-0.2	-0.2
2001	7				28.0	32.9	36.9	28.0	32.7	36.8	0.0	-0.2	-0.1	-0.1
2001	8				28.1	32.9	36.9	28.0	32.7	36.8	-0.1	-0.2	-0.1	0.0
2001	9				28.1	32.9	37.1	28.0	32.7	36.8	-0.1	-0.2	-0.3	-0.2
2001	10				28.0	32.9	37.1	28.0	32.7	36.8	0.0	-0.2	-0.3	-0.3
2001	11				28.0	33.0	37.0	28.0	32.7	36.8	0.0	-0.3	-0.2	-0.2
2001	12				28.0	32.9	37.2	28.0	32.7	36.8	0.0	-0.2	-0.4	-0.4
2002	1				28.1	33.0	37.0	28.0	32.7	36.8	-0.1	-0.3	-0.2	-0.1
2002	2				28.0	32.9	37.0	28.0	32.7	36.8	0.0	-0.2	-0.2	-0.2
2002	3				28.1	32.9	37.0	28.0	32.7	36.8	-0.1	-0.2	-0.2	-0.1
2002	4				28.2	33.1	37.1	28.0	32.7	36.8	-0.2	-0.4	-0.3	-0.1
2002	5				28.1	33.0	37.0	28.0	32.7	36.8	-0.1	-0.3	-0.2	-0.1
2002	6				28.2	33.0	37.1	28.0	32.7	36.8	-0.2	-0.3	-0.3	-0.1
2002	7				28.2	33.0	37.1	27.8	32.6	36.8	-0.4	-0.4	-0.3	0.1
2002	8				28.1	32.8	36.9	27.8	32.6	36.8	-0.3	-0.2	-0.1	0.2
2002	9				27.9	32.7	36.8	27.8	32.6	36.8	-0.1	-0.1	0.0	0.1
2002	10				27.7	32.5	36.6	27.8	32.6	36.8	0.1	0.1	0.2	0.1
2002	11				27.8	32.6	36.7	27.8	32.6	36.8	0.0	0.0	0.1	0.1
2002	12				27.8	32.6	36.7	27.8	32.6	36.8	0.0	0.0	0.1	0.1

Table B-6. *Monthly Standard Lamp Tests readings RA,RC,RD, Reference R-readings RR and corrections of N-Tables RNcor of the instrument D074 obtained with the lamps SL-74B and SL-QJ-74- in the period 1961-2002. The shaded areas contain values determined by linear interpolations.*