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Calibration of Indian Dobson Spectrophotometer Nos. D112 and D036 during WMO Dobson Intercomparison Campaigns

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सार – वर्तमान अध्ययन क्रमशः 7 से 18 अक्टूबर 2019 तक इरेन, दक्षिण अफ्रीका में और 15.07.2020 से 30.07.2020 तक होहेनपीसेनबर्ग, जर्मनी में आयोजित डॉबसन अंतर-तुलना अभियानों के दौरान भारतीय डॉबसन प्रकाशमापी उपकरण संख्या D112 और D036 के अंशांकन के परिणामों का सार प्रस्तुत करता है। दोनों अंतरराष्ट्रीय अंतर-तुलना अभियानों में, संदर्भ उपकरण के रूप में यूरोपीय क्षेत्रीय मानक डॉब्सन प्रकाशमापी उपकरण संख्या D064 का उपयोग किया गया था। डॉब्सन प्रकाशमापी उपकरण संख्या D112 और संख्या D036 की क्षेत्रीय मानक डॉब्सन उपकरण (D064) के साथ अंतर-तुलना के परिणामों के अनुसार, ये उपकरण विश्वसनीय हैं और उनके माप आगे के विश्लेषण के लिए सटीक और उपयुक्त हैं क्योंकि उनके विचलन स्वीकार्य सीमा के भीतर पाए गए हैं। (अर्थात् अंतिम अंशांकन के बाद क्रमशः D112 के लिए -0.3% और D036 के लिए 0.01 से कम)

ABSTRACT. The present study summarizes the results of the calibration of Indian Dobson Spectrophotometer No. D112 and D036 during Dobson inter-comparison campaigns, held at Irene, South Africa from 7-18 October, 2019 and at Hohenpeissenberg, Germany from 15.07.2020 to 30.07.2020 respectively. In both the international inter-comparison campaigns, European Regional Standard Dobson Spectrophotometer No. D064 had been used as the reference instrument. According to the results of the inter-comparison of Dobson spectrophotometer instrument No. D112 and No. D036 with Regional Standard Dobson Instrument (D064), these instruments are reliable and their measurements are accurate and appropriate for further analysis as their deviations have been found within the acceptable limits i.e. less than - 0.3% for D112 and less than 0.01 for D036 respectively after final calibration.

Key words – Total column ozone, Dobson Spectrophotometer, Inter-comparison campaign, Calibration.

1. Introduction

The ozone layer in the troposphere-stratosphere has a range of climate consequences. Although ozone absorbs ultraviolet solar radiation in the stratosphere, it also acts as a greenhouse gas in the troposphere (Kondratyev and Varotsos, 1996). The ozone layer protects the Earth's surface from harmful solar energy (Katsambas *et al*., 1997) and is important in photochemistry (Cracknell and Varotsos, 1994).

Ozone depletion and global temperature change are two key environmental challenges linked to total ozone (Cracknell and Varotsos, 1994). The detection of ozone recovery requires a continuous and long-term collection of reliable ozone observations on a worldwide scale. Ground-based observations are an important part of the worldwide ozone network, both on their own and as the ground truth for the validation of satellite-based monitoring instruments. While attempting to calculate the global distribution of ozone concentration, the unequal geographical dispersion of the present ground-based network causes a spatial sampling error. The ground-based instrument has the advantage of being easier to maintain in good condition, while satellite-based instrumentation provides better temporal-spatial coverage and resolution (Tzanis, 2009).

The measurement of total column ozone with spectrophotometers has a long historical background, the first measurements with a Dobson Ozone Spectrophotometer having been made in the mid-1920s. A global network of Dobson instruments was established following the first International Geophysical Year in 1957. The modern Ozone Spectrophotometer was developed in the 1970s and introduced into the global

TABLE 1

Total Columnar Ozone Measurement in IMD

S. No.	Name of Station	Latitude	Longitude	Instrument Type & S. No.	Frequency of Observations	Month & Year of Installation
1.	Srinagar	34° 05' N	74° 50' E	Dobson 010	6/day	Nov 1955
2.	New Delhi	28° 35' N	77° 12' E	Dobson 036	6/day	Jan 1955
3.	New Delhi	28° 35' N	77° 12' E	Brewer 089	Continuous	Aug 1994
4.	Varanasi	25° 18' N	83° 01' E	Dobson 055	6/day	Dec 1963
5.	Pune	18° 32' N	73° 51' E	Dobson 039	6/day	Mar 1973
6.	Pune	18° 32' N	73° 51' E	Brewer 170	Continuous	Oct 2005
7.	Kodaikanal	10° 14' N	77° 28' E	Dobson 045	6/day	Jul 1957
8.	Kodaikanal	10° 14' N	77° 28' E	Brewer 094	Continuous	May 1994
9.	Maitri (Antarctica)	70° 48' S	11° 42' E	Brewer 153	Continuous	Jul 1999
10.	New Delhi	National Standard		Dobson 112	Since April 1969	

network in 1982 with the delivery of instruments to Greece, Sweden and Canada. The thickness of the ozone layer is determined by comparing the intensity of two different solar radiations in the ultraviolet range which are strongly and weakly absorbed by ozone in the atmosphere.

The Dobson utilizes an internal virtual ‘ozone layer’ (a variable ‘optical wedge’ attenuator) to measure the intensity ratio of two wavelengths. It is important, to characterize the individual instruments and to determine their specific calibration constants.

International Dobson instrument comparisons in the past have revealed large calibration errors for many of the instruments (Dziewulska-Losiowa and Walshaw, 1975; Gushchin, 1972). However, the accuracy of the ozone measurements within the global Dobson station network improved markedly following an international Dobson spectrophotometer inter-comparison campaign (Komhyr *et al.*, 1981) held in Boulder in 1977. At that time, eight spectrophotometers, designated by the World Meteorological Organization (WMO) as regional secondary standards, were calibrated relative to instrument No. D083 (World Primary Standard Dobson Instrument) with the intent that they may be used to calibrate the field instruments within their respective regions.

The Ozone unit at India Meteorological Department (IMD), New Delhi is a station in the ground-based total ozone monitoring network of the Global Atmosphere Watch (GAW) Programme of the World Meteorological Organization (WMO). It has a history of more than 65 years of uninterrupted total ozone measurements starting in 1955 using the Dobson ozone spectrophotometer No. D036. IMD, New Delhi is the Regional Ozone Centre for the Regional Association-II (Asia) of the World Meteorological Organization (WMO). IMD had a total column ozone monitoring program at five stations in India namely New Delhi, Kodaikanal, Pune, Srinagar and Varanasi using Dobson spectrophotometers for the last many years. At present, only two IMD Stations, *i.e.*, New Delhi and Varanasi have functional Dobson Spectrophotometers and Dobson spectrophotometers, which were installed at Pune Srinagar and Kodaikanal, are non-functional at present. IMD also installed the Brewer spectrophotometers at New Delhi, Pune and Kodaikanal and Maitri (Antarctica) Stations. Details of the Total Columnar Ozone Measurement network in IMD are given in Table 1.

Dobson Spectrophotometer No. D112 maintained by Ozone Unit, India Meteorological Department, New Delhi is designated as National Standard Instrument and it had participated in the earlier international inter-comparison campaigns of Dobson Spectrophotometer held at Boulder in 1977, Melbourne (Australia) in 1984 and Tsukuba (Japan) in 1996 (Peshin *et al*., 1998) and Tsukuba (Japan) in 2006 (Peshin and Singh, 2013). IMD failed to participate in the 2016 international inter-comparison campaign of Dobson Spectrophotometer held at Tsukuba (Japan) 2016.

The main purpose of the international inter-comparison campaign's mission is to support the maintenance and improve the function of the ground-based total ozone monitoring network. The long-term, quality-controlled total ozone data obtained from Dobson observations within the framework of the WMO Global

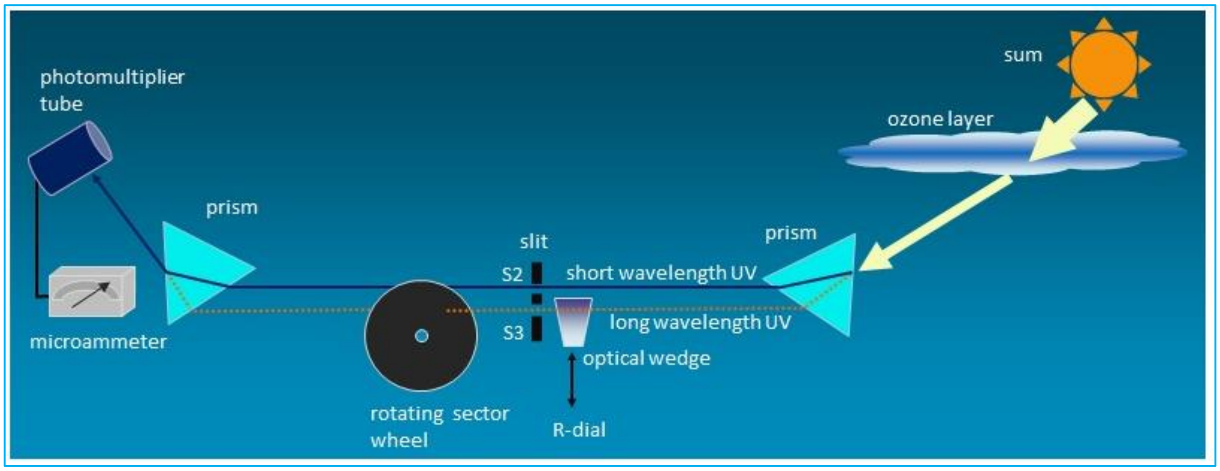

Fig. 1. Dobson Spectrophotometer observation principle. (*Source*: https://www.jma-net.go.jp/kousou/obs_third_div/ozone/ozone_dob-e.html)

Atmosphere Watch (WMO/GAW) are essential for the assessment of the state of the ozone layer by accurate and reliable ozone data.

The present study summarizes the results of the calibration of Indian Dobson Ozone Spectrophotometer No. D112 during the Dobson inter-comparison campaign which was held from 7-18 October, 2019, at the Irene Technical Centre, South Africa. Also, Indian Dobson Spectrophotometer No. D036 has been calibrated at the German Meteorological Office, Hohenpeissenberg from 15 July, 2020 to 30 July, 2020.

In both the international inter-comparison campaigns,Regional Standard Dobson Spectrophotometer No. D064, stationed at DWD, Hohenpeissenberg, Germany has been used as the reference instrument. Dobson Spectrophotometer D064 was compared with the World Standard D065 (NOAA, Boulder, USA) to check and confirm its calibration level. The d_Nad value (*i.e.*, Difference in N values at A and D pair of wavelengths) for inter-comparison between D064 with D065 shows an average 0.00% error in calculated ozone value.

2. Details of Dobson Inter-comparison Campaigns (DIC)

2.1. *DIC held at Irene, South Africa*

The Dobson inter-comparison campaign (2019) was held from 7-18 October, 2019, at the Irene Technical Centre, Irene which is a part of the South African Weather Service. Six countries have participated in the inter-comparison campaign, *e.g*., Germany, the United States of America, India, South Africa, Nigeria and Kenya. World Standard Dobson Spectrophotometer No. D065 has also participated from the USA. European Regional Dobson Calibration Centre, DWD, Hohenpeissenberg, Germany has provided the technical support and spare parts during the inter-comparison campaign. Many internal optical parts of Dobson Spectrophotometer No. 112 had become very old and have been changed, *e.g*., mirrors, potentiometer, etc.

2. 2. *DIC held at Hohenpeissenberg, Germany*

Dobson Spectrophotometer No. D036 the inter-comparison campaign of the Dobson Ozone Spectrophotometer is held from 15 July, 2020 to 30 July, 2020 at the Meteorological Office, Hohenpeissenberg, Germany (MOHp). Due to the COVID-19 pandemic situation, only unaccompanied instruments from Iceland (D050), India (D036) and the Shetlands (D041) had been received by MOHp in 2020. During the inter-comparison campaign, up-gradation of electronics of the Indian Dobson Spectrophotometer No. D036 has been done and it has been compared with the European Regional Standard Dobson Spectrophotometer No. D064.

3. Working principle of Dobson Spectrophotometer

The Dobson spectrophotometer instrument and procedure are well documented (Dobson, 1968; Scarnato *et al*., 2009, 2010; Moeini *et al*., 2019). The amount of ozone in the atmosphere influences the strength of the sun's UV radiation at ground level. The Dobson spectrophotometer works by comparing the intensity ratioof selected pair of UV wavelengths, one of which is strongly affected by the ozone relative to the other. The ratio between them gives a measure of the amount of ozone in the atmosphere along

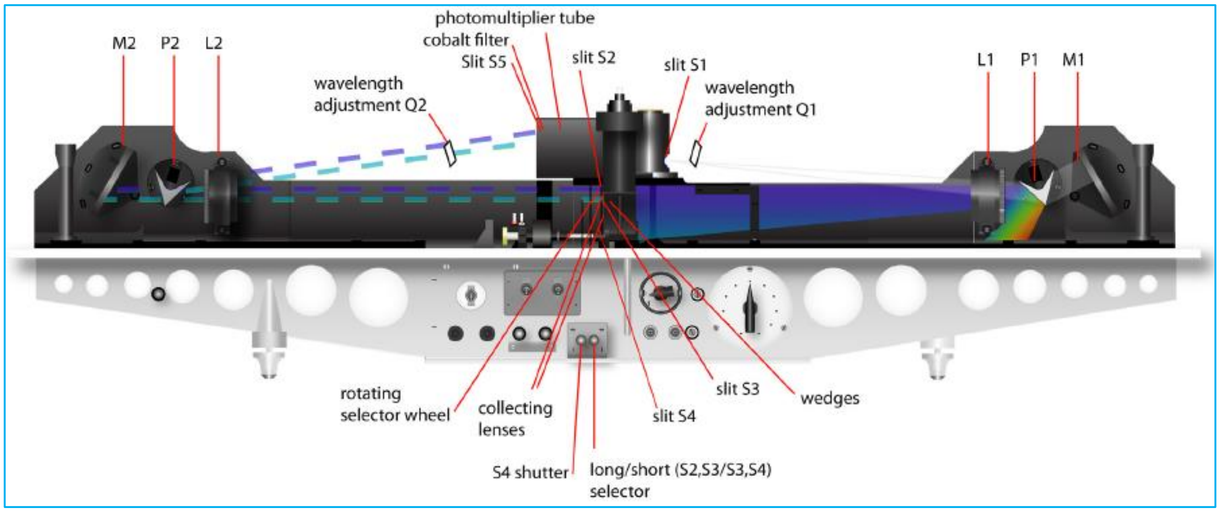

Fig. 2. Optical system of the Dobson Spectrophotometer. (*Source* : https://gml.noaa.gov/ozwv/dobson/GAW183-Dobson-WEB.pdf)

the light's path. The sun's light is diffracted by a prism in the Dobson instrument is represented in Fig. 1 and two small slits allow for the selection of several wavelength pairs typically referred to as A (305.5 nm/325.4 nm), B (308.8 nm/329.1 nm), C (311.45 nm/332.4 nm) and D (317.6 nm /339.8 nm) and C"(332.4 nm/453.6) respectively. Because they produce the most precise measurements, pairs A and D, labeled as AD, are the most commonly used (Tzanis, 2009). AD double pair wavelength observations on the direct sun with ground quartz plate in the inlet window are known as AD-DSGQP observations. It is the most reliable and most used observation. The accuracy of this mode of measurement also depends on the secant of the zenith angle, designated Mu (μ).

The μ is defined as theratio of the actual path length of a ray of light through the ozone layer as compared to the vertical path length. It is computed using Eqn. 1.

$$\mu = \frac{(R+h)}{\sqrt{(R+h)^2 - (R+r)^2 \sin^2(SZA)}} \qquad (1)$$

where, R implies mean earth radius (6371.229 km), r implies height of the station above mean sea level, h implies height of the ozone layer above mean sea level at the location of the station and SZA represent solar zenith angle. The fundamental AD-DSGQP observations can only be made when the sun is unobscured by clouds and when it is fairly high in the sky [Mu (μ)] is less than 3.0 or Solar Zenith Angle (SZA) is less than about 70 degrees). When the elevation of the sun is greater than 80° (SZA < 1.015), the instrument's sun director becomes unusable and AD-DSGQP observations cannot be made.

The N values are calculated as:

$$N = \log\frac{(I_0)}{(I_0^{'})} - \log\frac{(I)}{(I')} \qquad (2)$$

where, I_0 and I'_0 are the intensities outside the atmosphere of solar radiation at the short and long wavelengths, respectively, of the A-C-D wavelength pairs and I and I' are the measured intensities at the ground of solar radiation at the short and long wavelengths respectively.

The parameter N expresses a difference between logarithms of ratios of extraterrestrial and ground intensities of radiation at both wavelengths for A pair of as can be measured by a Dobson instrument before and after their attenuation in the Earth's atmosphere.

4. Methodology of calibration during Inter-comparison

The calibration of the instrument consists of the following steps:

(*i*) *Adjustment of the Optics* : All-optical components, *i.e*., lenses, prisms, slits, etc., must be in proper adjustment.

(*ii*) *Q Calibration (or wavelength)* : The Q settings vary with temperature owing to the change of refractive indexof quartz with temperature and the expansion or contraction of the metal of the instrument. It is necessarythen, to establish a correct table of Q settings *vs*. temperature for the spectrophotometer.

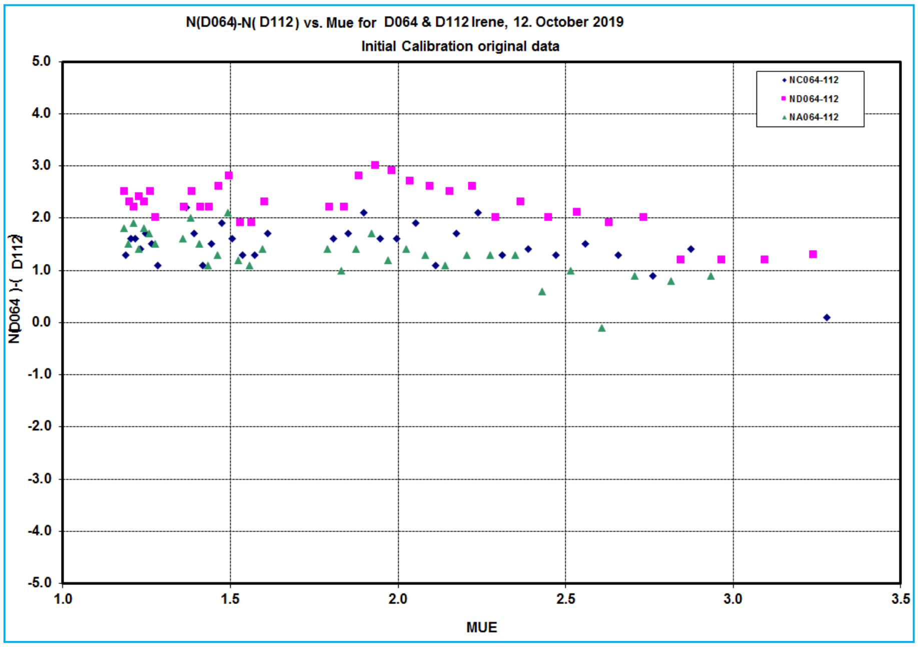

Fig. 3. Initial Calibration of original data of Indian Dobson Spectrophotometer No. D112 with Regional Standard Dobson Spectrophotometer No. D064 showing the average difference for "A" wavelength, "D" wavelength and "C" wavelength

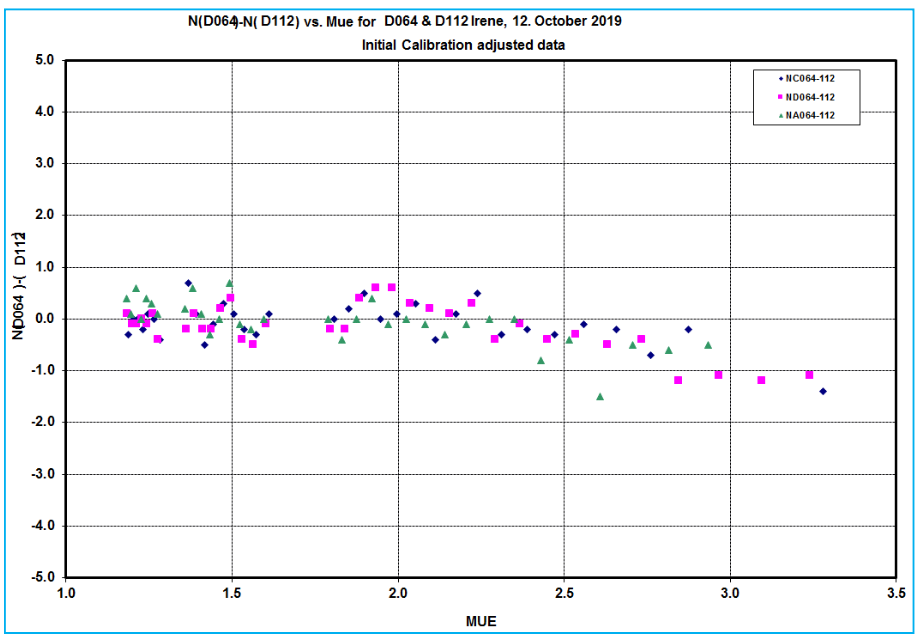

Fig. 4. Initial Calibration of adjusted data of Indian Dobson Spectrophotometer No. D112 with Regional Standard Dobson Spectrophotometer No. D064 showing the average difference for "A" wavelength, "D" wavelength and "C" wavelength

(*iii*) *Optical Wedge Calibration* : The relative transmission along the spectrophotometer optical wedge must be known accurately to estimate, to a high degree of precision, the relative intensity of the two-wavelength beams on which observations are made.

(*iv*) *Mercury Test* : The Mercury Lamp Test (the command HG) is used to check the precise setting of all components of the Dobson optical system at wavelength 3129 A.U.The wavelengths falling on slits S2, S3 and S4 may change because of slow deformation of the

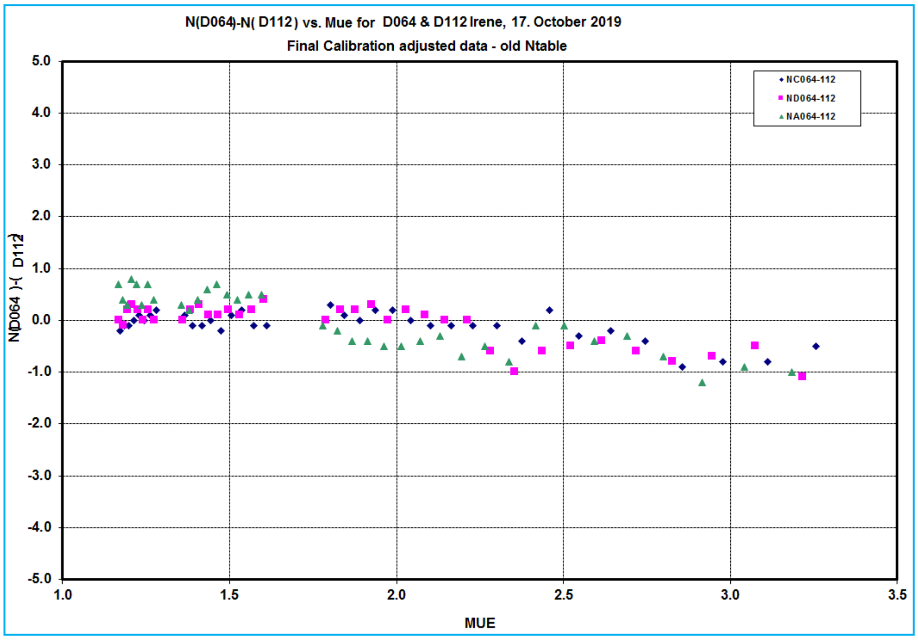

Fig. 5. Final Calibration of adjusted data of Indian Dobson Spectrophotometer No. D112 with Regional Standard Dobson Spectrophotometer No. D064 showing the average difference for "A" wavelength, "D" wavelength and "C" wavelength

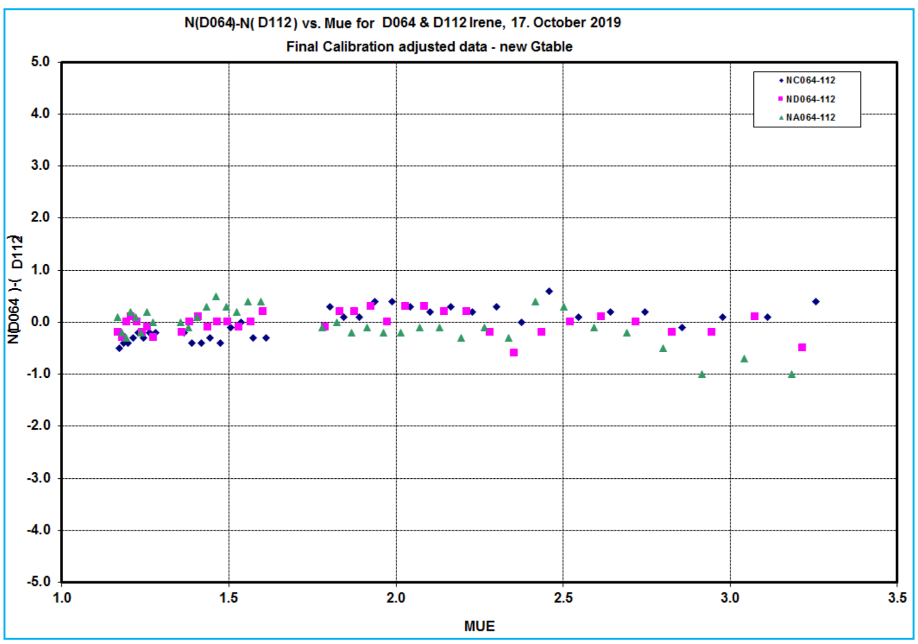

Fig. 6. Final Calibration of adjusted data of Indian Dobson Spectrophotometer No. D112 with Regional Standard Dobson Spectrophotometer No. D064 showing the average difference for "A" wavelength, "D" wavelength and "C" wavelength

spectrophotometer main frame casting, compression of the gasket between the base and lid, or a shift of some of the optical components (Fig. 2). To determine whether the Q-setting table in use is applicable (*i.e.*, that ozone observations are being made on correct wavelengths), mercury lamp tests are performed. A mercury lamp supplied with the instrument can be fixed above the inlet window to illuminate slit S1. For routine checks, it is sufficient to measure the value of Q1 when the effective mercury wavelength 3129 A.U. falls centrally on slit S2.

TABLE 2

Data summary using corrected Dobson Spectrophotometer No. D112 using mean

Measurements	Mu (μ) Range						
	1.15 - 1.5	1.5 - 2.0	2.0 - 2.5	2.5 - 3.2	3.2 - 4.0	4.0 - 5.0	1.15 - 3.2
XAD064	279 (.001)	279 (.001)	279 (.001)	278 (.001)	278 (.000)	-	279(.000)
XAD112	279 (.001)	279 (.001)	279 (.001)	279 (.001)	279 (.000)		279 (.001)
DXAD112	-0.31	+0.09	+0.21	+0.24	+0.36	-	0.06 %
XCD064	282 (.002)	283 (.002)	283 (.001)	282 (.001)	283 (.000)	-	283(.001)
XCD112	287 (.002)	284 (.004)	281 (.003)	280 (.002)	276 (.000)		283 (.001)
DXCD112	+1.50	+0.16	-0.81	-0.41	-2.47	-	0.11 %
XA 064	285 (.001)	285 (.000)	285 (.000)	284 (.000)		-	285 (.000)
XA 112	284 (.001)	285 (.001)	285 (.001)	285 (.001)			285 (.000)
DXA 112	-0.10	-0.09	+0.10	+0.30		-	0.05 %
XC 064	292 (.001)	294 (.001)	294 (.000)	293 (.001)	293 (.000)	-	293 (.000)
XC 112	295 (.001)	293 (.002)	293 (.001)	293 (.001)	292 (.000)		294 (.001)
DXC 112	+1.08	-0.11	-0.44	-0.06	-0.34	-	0.12 %
XD 064	304 (.001)	307 (.002)	308 (.001)	307 (.001)	307 (.000)	-	307 (.001)
XD 112	306 (.003)	306 (.003)	308 (.003)	308 (.001)	311 (.000)		307 (.001)
DXD 112	+0.54	-0.45	-0.05	+0.27	+1.30	-	0.08 %

*Values in brackets are Standard Deviations

Tests should be conducted at different temperatures to check on the temperature dependence of the Q-lever settings.

(*v*) *Standard lamp Test* : The standard lamp test checks the general function of the Dobson spectrophotometer. Standard lamp tests are performed to confirm that the level of calibration of the spectrophotometer has remained constant. Also, when a permanent change occurs in the spectral characteristics of the instrument, the lamp test data may be used to determine corrections to be applied to ozone data. Instruments that have just been refurbished or that are in the process of being rebuilt should have their calibration reviewed more frequently. Regularly, usually every four years, the instrument should be compared to a standard instrument. The comparison is also a good opportunity to go through observation techniques and data management procedures.

(*vi*) *Symmetry Test* : It checks the optical alignment of the Dobson Spectrophotometer. One test per year is sufficient. Doing the test, the temperature of the instrument should be stable.

The final calibration of the Dobson Ozone Spectrophotometer is conducted by direct comparison with a regional standard instrument. This calibration is thus traceable to a primary standard, which improves the station-to-station consistency. The instrument performance concerning the sun's zenith angle is then also evaluated to the standards.

The Inter-comparisons were performed and all works were done on a daily schedule according to the weather conditions and concerning the technical state of the individual instruments. The main purpose of both the inter-comparison campaign was to evaluate each instrument calibration and the existing total ozone datasets, repair, clean and improve the instrument as needed and redefine a new calibration level (where applicable) for the future measurements at the home station before returning the instruments in good operating order. Also, initial comparison against Regional standard Dobson Spectrophotometer No. D064 has been done to determine the existing calibration level and final comparison against the Regional standard Dobson Spectrophotometer No. D064 was performed by simultaneous observations of total ozone by both instruments.

5. Results and discussion

The results of Dobson Spectrophotometer No. D112 is given below:

(*i*) Initial comparison of D112 was done on 12.10.2019 with Regional Standard Dobson Spectrophotometer No. D064 and the error was +1.4% error in calculated ozone

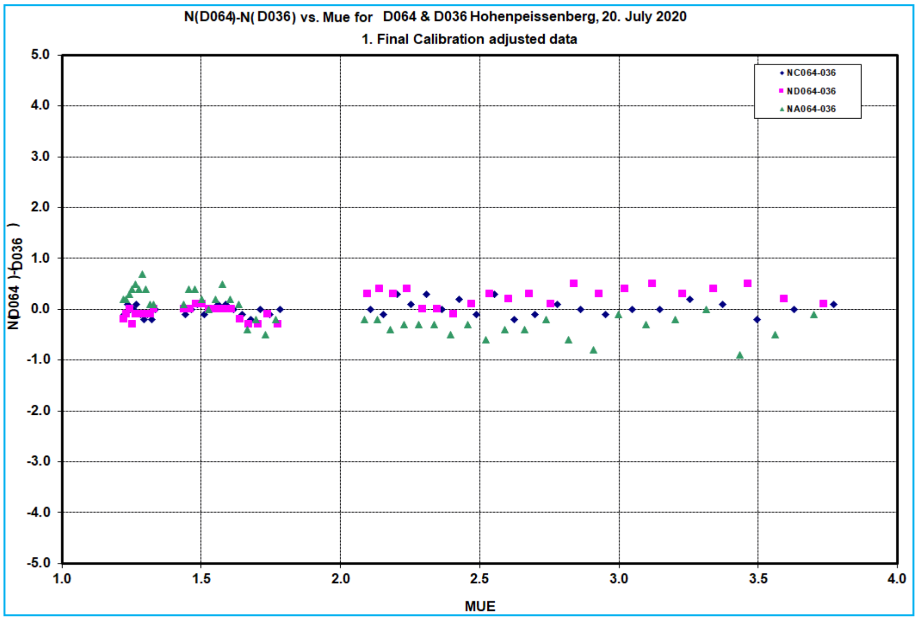

Fig. 7. Final Calibration of adjusted data of Indian Dobson Spectrophotometer No. D036 with Regional Standard Dobson Spectrophotometer No. D064 showing the average difference for "A" wavelength, "D" wavelength and "C" wavelength

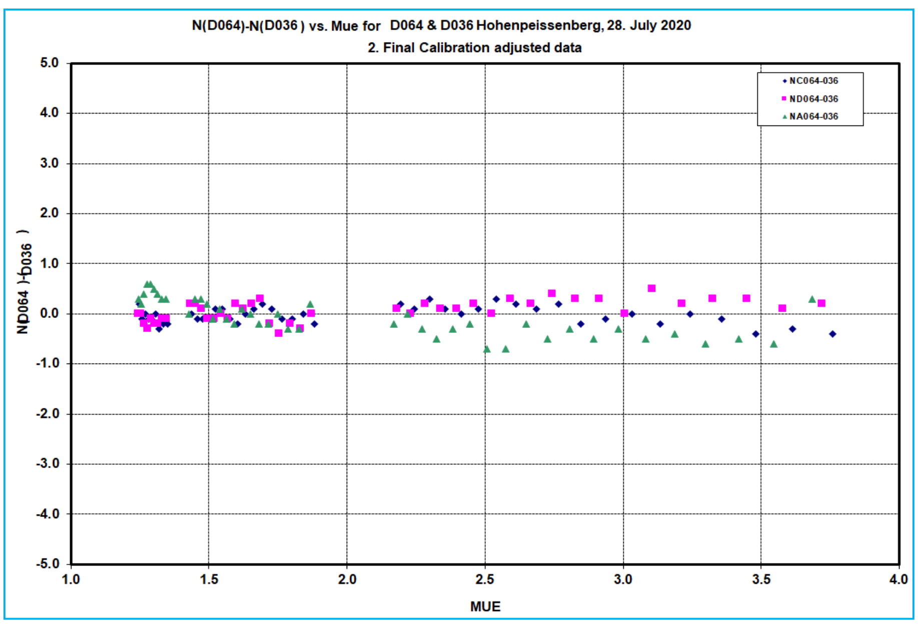

Fig. 8. Final Calibration of adjusted data of Indian Dobson Spectrophotometer No. D036 with Regional Standard Dobson Spectrophotometer No. D064 showing the average difference for "A" wavelength, "D" wavelength and "C" wavelength

value in the mu range 1.15 to 2.5 for Total ozone equal to 300 D.U.

(*ii*) The final inter-comparison shows an average difference against the standard for ADDSGQP observations of Regional Standard Dobson Spectrophotometer No. D064 in Mu (μ) range 1.15 to 3.2 was -0.3% in total ozone.

(*iii*) Figs. 3, 4, 5 and 6 show the comparison of the average difference of the measurements of D112 and D064 for "A", "C", "D" and "A-D" wavelengths.

TABLE 3

Data summary using corrected Inst. D036 using mean

Measurements	Mu (μ) Range						
	1.15 - 1.5	**1.5 - 2.0**	**2.0 - 2.5**	**2.5 - 3.2**	**3.2 - 4.0**	**4.0 - 5.0**	**1.15 - 3.2**
XAD064	298 (.001)	300 (.001)	301 (.000)	302 (.001)	301 (.001)		300 (.000)
XAD036	296 (.002)	300 (.001)	302 (.001)	303 (.001)	302 (.001)		300 (.001)
DXAD036	**-0.75**	**+0.00**	**+0.39**	**+0.58**	**+0.33**		0.06%
XCD064	299 (.002)	302 (.001)	306 (.001)	306 (.001)	302 (.002)		303 (.001)
XCD036	299 (.003)	302 (.002)	306 (.001)	307 (.002)	305 (.001)		304 (.001)
DXCD036	**+0.08**	**-0.06**	**-0.05**	**+0.37**	**+1.06**		0.08 %
XA064	304 (.001)	306 (.000)	306 (.000)	306 (.000)	305 (.001)		306 (.000)
XA 036	303 (.001)	306 (.001)	307 (.001)	307 (.000)	306 (.000)		306 (.000)
DXA 036	**-0.45**	**+0.05**	**+0.27**	**+0.33**	**+0.16**		0.05 %
XC064	312 (.001)	314 (.001)	314 (.001)	314 (.001)	312 (.001)		314 (.000)
XC 036	313 (.001)	314 (.001)	313 (.000)	314 (.001)	312 (.001)		314 (.000)
DXC 036	**+0.27**	**+0.10**	**-0.27**	**-0.12**	**+0.26**		-0.01%
XD 064	329 (.001)	329 (.001)	324 (.001)	324 (.001)	323 (.001)		326 (.000)
XD 036	330 (.003)	330 (.002)	322 (.001)	321 (.001)	322 (.000)		326 (.000)
DXD 036	**+0.40**	**+0.20**	**-0.46**	**-0.70**	**-0.49**		-0.14 %

*Values in brackets are Standard Deviations

(*iv*) Data Summary using corrected Dobson Spectrophotometer No. D112 using the mean is given in Table 2.

The results of Dobson Spectrophotometer No. D036 calibrations are given below:

(*i*) The complete electronics of Dobson Spectrophotometer No. D036 has been changed during MoHP, 2020 in DWD, Germany. The first comparison with Standard Dobson 064 has been done on 20 July, 2020.

(*ii*) Difference between Dobson Spectrophotometer No. D036 Values and Regional Standard Dobson Spectrophotometer No. D064 Values are less than 0.01 after final calibration.

(*iii*) Figs. 7&8 show the comparison of the average difference for "A", "C", "D" and "A-D" wavelengths.

(*iv*) Data Summary using corrected Dobson Spectrophotometer No. D036 using mean is given in Table 3.

Dobson spectrophotometer is a key component of the Global Ozone Observing System and the International Ozone Trends Panel has chosen Dobson stations for trend analysis. Thus, the accuracy and precision of the Dobson instruments, used in the Dobson WMO Network, must be known to perform trend analysis. A good knowledge of total column ozone variability over the northern hemisphere is very crucial for the validation of satellite observations. Thus, periodic calibration of India's Dobson Spectrophotometers against world standard instruments is very necessary. The inter-comparison data confirms that the existing ozone data, derived from Dobson spectrophotometer nos. D112 and No. D036 is accurate. Dobson spectrophotometer No. D112 is used to calibrate other Dobson instruments in the Indian network to ensure that the existing data recorded at IMD stations meet the international standard of reliability. Total Ozone Observations made by Dobson Spectrophotometer No. D112 during WMO Inter-comparison campaign in 2019, held at Irene, South Africa, in the Mu(μ) range 1.15 - 3.2 shown a deviation less than -0.3 % from the TCO observations made by European Regional Standard Dobson Spectrophotometer No. D064. The difference between Dobson D036 values and regional standard Dobson D064 values is less than 0.01 after final calibration in the 2020 at the Meteorological Office, Hohenpeissenberg, Germany (MOHp). Previously, Dobson Spectrophotometer No. D112 was compared with Asia's Regional Standard Dobson Spectrophotometer No. D116 and the accuracy of 0.1% has been recorded in the Mu(μ) range 1.15 - 3.2 during inter-comparison campaign held from 6 to 24 March 2006 at the Aerological Observatory, Tsukuba, Japan (Peshin and Singh, 2013). Similarly, Dobson Spectrophotometer No. D112 was compared with Regional Standard Dobson Spectrophotometer No. D116 during the year 1996 and the accuracy, within a range of 0.1%, was recorded in the Mu(μ) range 1.15 - 3.2 during inter-comparison campaign held at the Aerological Observatory of the Japan Meterological Agency (Peshin and Singh, 1998). The world-wide ban of Ozone-Depleting Substances (ODS) under the Montreal Protocol and its amendments has been successful as recovery of the ozone layer have been observed in recent years. The ozone has increased during the past 10 to 15 years in the upper stratosphere and a reduction in the severity of the Antarctic ozone hole in September are the most obvious indications so far (Steinbrecht *et al*., 2018).

6. Conclusions

The inter-comparison data demonstrates the accuracy of the existing ozone data obtained from instrument No. D112 and D036. The final inter-comparison between Dobson spectrophotometer nos. D112 and D064 shows an average difference of -0.3% in total ozone for ADDSGQP observations in Mu (μ) range 1.15 to 3.2 in the year 2019. Also, difference values were found less than 0.01 after final inter-comaprison between Dobson Spectrophotometer No. D036 and Europian Regional Standard Dobson Spectrophotometer No. D064 in the year 2020. Dobson spectrophotometer nos. D112 is used to calibrate other Dobson instruments in the Indian network. Results of WMO's Dobson Inter Comparison Campaigns confirms that the existing data at various IMD stations meet the international standard of reliability.

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