Intercomparison of Brewer Spectrophotometers between the Meteorological Service of Canada and the Japan Meteorological Agency at Toronto, Canada in 2010

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Abstract

Experimental studies using the NIST standard lamps and the intercomparison of Brewer spectrophotometers for UV and Ozone observations between the Canadian standard (MKIII BR#145) and the Japanese standards (JMA standard MKIII BR#174 and travelling standard MKII BR#113) were conducted from March 31 to April 13, 2010, at the Meteorological Service of Canada (MSC). These studies and intercomparisons were carried out as the MSC-JMA joint project "Cooperation on the Advanced System for Hazardous Solar Ultraviolet Radiation Spectrum Monitoring with Brewer Spectrophotometer" in the framework of the Canada-Japan Cooperative Agreement on Science and Technology. The results were as follows.

1) The difference of instrument responsivity ratios determined by several NIST lamp calibration methods using three systems, MSC, IOS (International Ozone Services Inc.), and JMA, exhibited the following various ratios as "S_D" (S system and D distance between lamp filament to diffuser). (a) IOS_50/MSC_40 = 1.013. (b) IOS_50/JMA_50 = 0.979. (c) JMA_50/MSC_40 = 1.0347. The difference of 3.5 % between MSC and JMA systems confirmed an estimated difference of 3.3 % from the last comparison and test at MSC in 2006.

2) 9 days comparison between BR#145 and BR#174 (and BR#113 for 4 days) revealed the following ratios of solar UV irradiances measurement results. (a) Ir#174/Ir#145: from 0.971 to 0.977. (b) Ir#113/Ir#145: from 0.958 to 0.969. Those ratios changed after the consideration of the correction of the difference of 3.3 % between MSC and JMA NIST lamp calibration systems. These ratios changed as follows; (a) Ir#174/Ir#145: from 1.003 to 1.009. (b) Ir#113/Ir#145: from 0.990 to 1.001. After the correction, the irradiance ratios between BR#145 and BR#174 (BR#113) agreed within approx. 1 %. Based on the fact that these comparison results were almost the same as the results from the previous comparisons in 1994, 1998, 2002 and 2006, and that the JMA system has not changed since 1989, we concluded that the irradiance level (standard irradiance) of the NIST lamp calibration for the Brewer Spectrophotometers at Aerological Observatory, JMA, has been kept 3.3 % lower than MSC's lamp calibration for the past 22 years.

3) 8 days comparison between BR#145 and BR#174 revealed the following ratios of total ozone (ds O3) and total sulfur dioxide (ds SO2) measurement results. (a) O3 difference, (BR#174－BR#145)/BR#145: 0.002 (＋0.2 %). (b) SO2 difference, (BR#174－BR#145): －2.0 m atm-cm. The O3 difference between BR#145 and BR#174 agreed within about 1 %.

These experimental studies of NIST lamp calibration and intercomparisons between MSC and JMA had been carried out at MSC since 1994. This has been very useful for the highly accurate observations of UV and O3 in Japanese Brewer Networks, JMA, NIES (National Institute for Environmental Studies) and others, and also useful for the construction planning of RBCC-A (Regional Brewer Calibration Centre in Asia).

1. Introduction

JMA and MSC has been carried out the intercomparison and experimental studies of Brewer Spectrophotometer every 3 or 4 years as the MSC-JMA joint project "Cooperation on the Advanced System for Hazardous Solar Ultraviolet Radiation Spectrum Monitoring with Brewer Spectrophotometer" in the framework of the Canada-Japan Cooperative Agreement on Science and Technology, at MSC produced the instrument and maintained the world standard, in 1994, 1997, 2002, 2006 (Shitamichi and Ito : 1995, Thompson *et al.*: 1997, Ito *et al.*: 1998, Ito and Miyagawa: 2003, Ito and *et al.*: 2007). On the grounds of cooperation, the intercomparison was planed at MSC in the period from March to April in 2010.

The intercomparison was conducted as NIST lamp calibration tests, comparison for spectral UV observation and for total ozone and sulfur dioxide (ds O3/SO2) observations, the dispersion tests and other tests.

In this experiment, JMA transported standard Brewer MKIII #174 (BR#174) and a travelling standard Brewer MKII #113 (BR#113) to MSC for the intercomparison (see Photo.1). A NIST lamp calibration system of IOS (International Ozone Service new JMA type; Early *et. al*: 1998, IOS: 2000, 2006), a dispersion tests unit and an external lamp tests unit were transported as well.

As described in "Table 1, Schedule of the intercomparison at MSC", intercomparison was carried out in the following order;

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Photo. 1　Intercomparison between MSC and JMA standard Brewer Spectrophotometers on the roof top at MSC in 2010.

(1) Check the currently used constants by the comparative observation.

(2) Calibration of dispersion constants and NIST lamp.

(3) Calculation of the new instrument's constants from the comparative observation.

Please refer McElroy *et al.* (2008), Kipp&Zonen (1996, 2008a, b), and etc for all of the technical terms, used in this paper.

2. NIST lamp calibration tests

2. 1 NIST lamp calibration systems

JMA brought several pieces of highly reliable DXW type NIST 1000W lamps, calibrated in high accuracy. JMA used the same lamps for the other calibration carried out in Japan. These calibrations were carried out for the purpose of estimations of (1) differences between the MSC and JMA calibration systems, and (2) responsivity change of BR#174 and BR#113 before and after the transport to Canada. Calibration systems at MSC and JMA are following three types a) to c) and described in Table 2.

a) MSC_40: MSC portable, distance of 40 cm.

b) IOS_50: IOS portable, distance of 50 cm.

b') IOS_50 new PS: using new power supply.

c) JMA_50: JMA immovable, distance of 50 cm.

Calibration system c): JMA_50 is a large size system, so that JMA could not transport it to MSC. Thus, the system b) was brought to MSC, in order to verify the difference between systems a) and b). Difference between the system a) and c) can be verified by the comparing systems b) and c) in Japan. Details of those calibration systems were described in Ito *et al.* (2007).

2. 2 NIST lamp calibration test results

Differences between those three types of calibration systems were calculated by the same test method used in during the previous visit. Test classification is indicated in Table 2, and test results are described in Table 3 (Hereinafter, test classification will be indicated by the symbols, defined in Table 2).

Table 1　Schedule of the intercomparison at MSC.

Date in 2010 JD	MSC Standard MKIII BR#145	JMA Standard MKIII BR#174	JMA Traveling Standard MKII BR#113	Remarks
March				
31 Wed 90 AM	Routine	Setup inside	Setup inside	Consultation
PM	Routine	Ex inside	Ex inside	new large QW
		Constants	U11 exchange	PMT repair methods
April				
1 Thu 91 AM		Setup outside	PMT test	
	Comparison (clear/fine)		SH test	PMT test
PM	Comparison (fine)		Dispersion	Dispersion
2 Fri 92 AM	Comparison (clear)		Constants	
PM	Comparison (fine)		Constants	
3 Sat 93 AM	Comparison (fine)			
PM	Comparison (fine)			
4 Sun 94 AM	Comparison (cloudy/fine)			
PM	Comparison (fine)			
5 Mon 95 AM	Comparison (rainy/fine)		Constants	
PM	Comparison (fine)		Constants	
6 Tue 96 AM	Routine	Setup inside	Dispersion	new AZ connector
			Ex inside	
PM	Routine	Dispersion	SH tests	SH/GS tests
7 Wed 97 AM	Routine	NIST (IOS_50)	SH tests	SH/GR repair method
PM	Routine	Ex inside	NIST (IOS_50)	Dispersion
8 Thu 98 AM	Routine	GS test	NIST (MSC_40)	GS test
PM	Routine	NIST (MSC_40)	Ex inside	
		Setup outside	Setup outside	
9 Fri 99 AM	Comparison (cloudy)			absolute calibration
PM	Comparison (cloudy)			UM algorithm
10 Sat 100 AM	Comparison (fine)			
PM	Comparison (fine)			
		EX outside	EX outside	
11 Sun 101 AM	Comparison (fine)			
PM	Comparison (fine)			
12 Mon 102 AM	Comparison (clear)			TE and HU sensors
PM	Comparison (clear)			absolute calibration
		EX outside	EX outside	TE calibration
13 Tue 103 AM	Routine	Packing	Packing	Network calibration
PM	Routine	Carry out	Carry out	

Notes　Comp: Comparison for UV and O3/SO2 observations under solar radiation.
NIST: NIST lamp test using IOS_50 and MSC_40 calibration units.
Ex: External lamp test using 50W lamps.
Dispersion: Dispersion test using spectral lamps.
Constants: Confirmation tests for instrumet's constants.

Table 2　NIST lamp calibration systems of MSC_40, IOS_50, IOS_50 new PS, and JMA_50.

System	MSC_40	IOS_50	IOS_50 newPS	JMA_50
Producer	MSC	IOS		JMA
Distance	40 cm	50 cm		50 cm
Control of beam	Cylinder	Baffle		Lamp house
Type of lamp	NIST 1000W DXW or FEL	NIST 1000W DXW or FEL		NIST 1000W DXW or FEL
Power supply	XANTREX XHR 150-7	XANTREX XHR 150-7	AMETEK XFR 150-8	TAKASAGO IPSO130-10
Control of DC Multimeter	Shunt resistance KEITHLEY 2000	Shunt resistance KEITHLEY 2000		(Direct)

(1) The test results at MSC.

The difference between MSC_40 and IOS_50 was tested at MSC in April, 2010. In the case of MKIII BR#174, average ratio was calculated overall from 286.5 to 363.0 nm per 0.5 nm and in the case of MKIII BR#113 it was calculated overall from 290.0 to 325.0 nm. The responsivity ratio using BR#174 is indicated in Table 3 as following ratio.

$$IOS\_50 / MSC\_40 = 1.013 \quad \cdots\cdots\cdots\cdots(1)$$

(2) The test results at JMA.

The difference between IOS_50 and JMA_50 was tested at JMA in May, 2010, and calculated as same average ratio mentioned

Table 3 Difference of responsivity ratios by the NIST lamp tests using MSC_40, IOS_50, IOS_50 new PS and JMA_50 systems. Their ratios were calculated as average ratio overall from 286.5 to 363.0 nm per 0.5 nm in the case of MKIII BR#174 and from 290.0 to 325.0 nm in the case of MKII BR#113. (1) indicates ratios of IOS_50 to MSC_40 by the tests at MSC. (2) and (4) indicates ratios of IOS_50 and IOS_50 new PS to JMA_50 by the tests at Aerological Observatory, JMA.

			(1)		(2)	(4)	
		MSC_40	IOS_50	JMA_50	IOS_50	IOS_50 newPS	
		at MSC April 08		at Tsukuba May 03-04			Scan
BR#174	Lamp S-1038	1.000	1.024	1.000		0.985	ux scans
	Lamp S-1094	1.000	1.009	1.000	0.976	0.985	ux scans
	Lamp S-1117	1.000	1.005	1.000	0.982	0.988	ux scans
	AVG	**1.000**	**1.013**	**1.000**	**0.979**	**0.986**	
BR#113	Lamp S-1038	1.000	1.016	1.000		0.981	uv scans
	Lamp S-1094	1.000	1.025	1.000	0.982	0.984	uv scans
	Lamp S-1117	1.000	1.021	1.000	0.972	0.975	uv scans
	AVG	**1.000**	**1.020**	**1.000**	**0.977**	**0.980**	

BR#174
(1) IOS_50 / MSC_40 = 1.013
(2) IOS_50 / JMA_50 = 0.979
(3) : (1)/(2) JMA_50 / MSC_40 = 1.013 / 0.979 = 1.0347
(4) IOS_50 new PS / JMA_50 = 0.986

BR#113
(1) IOS_50 / MSC_40 = 1.020
(2) IOS_50 / JMA_50 = 0.977
(3) : (1)/(2) JMA_50 / MSC_40 = 1.020 / 0.977 = 1.0440
(4) IOS_50 new PS / JMA_50 = 0.980

Notes: The former comparison result of (3) in 2006 was shown as 'JMA_50 / MSC_40 = 1.033'.

Table 4 Difference of responsivity ratios by two methods, reverse/normal tests of the baffles in the IOS_50 system.

		Normal	Reverse	
		at Tsukuba May 04		Scan
BR#174	Lamp S-1170R	1.000	0.997	ux scans
BR#113	Lamp S-1170R	1.000	0.993	uv scans
	AVG	**1.000**	**0.995**	

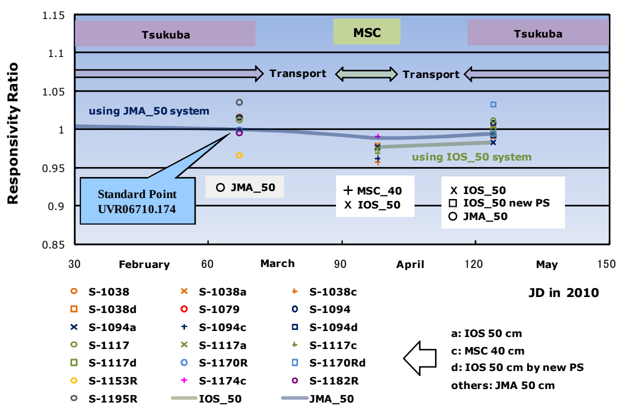

Fig. 1 Trend of responsivity ratio of BR#174 by 1000W NIST lamp tests using MSC system at MSC and using JMA system at Tsukuba, from February to May in 2010.
The trend was to the fundamental result of UVR06710.174.

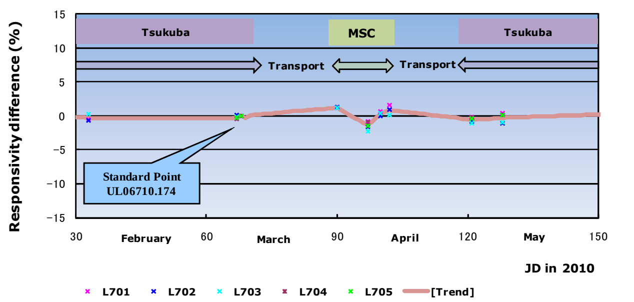

Fig. 2 Trend of responsivity difference (%) of BR#174 by 50W external lamp tests using external lamp test unit at MSC and JMA, from February to May in 2010.
The trend was to the fundamental result of UL06710.174.

above (1). The responsivity ratio using BR#174 is indicated in Table 3 as following ratio.

IOS_50 / JMA_50 = 0.979 ･･････････････(2)

(3) The relation of JMA_50 to MSC_40.

The responsivity ratio of JMA_50 to MSC_40 can be calculated as the following ratio by the relation of (1) and (2) in Table 3.

JMA_50 / MSC_40 = 1.0347 ････････････(3)

This ratio of about 3.5 % is almost the same as the previous ratio of about 3.3 %, measured at the last intercomparison in 2006.

(4) Other tests results.

IOS_newPS was deployed as a new power supply, due to the occasional defects of power supply of IOS_50, that contains a shunt resistance. The responsivity ratio of IOS_50 new PS to JMA_50 can be calculated as following ratio.

IOS_50 new PS / JMA_50 = 0.986 ････････(4)

Four baffles are used for the IOS_50 system. When fitting the bigger baffle to the upper side, and small baffle to the lower side, light was scattering inside of the protection. By this reverse test, the responsivity ratio could be calculated as the following ratio, indicated in Table 4.

Reverse / Normal = 0.995 ･･･････････････(5)

2. 3 Responsivity trend of BR#174 by transport

The trend of responsivity ratio of BR#174 by NIST lamp calibration tests from March to May in 2010 was described in Fig.1. Fundamental result of the trend was UVR06710.174 as described in Table 6. As mentioned in Fig.1, a maximum of 5 % difference could be recognized between the several type of lamps, but compared to the variation of the responsivity of the instrument due to the transportation to MSC, responsivity variation at MSC was small (approx. 1 %).

Meanwhile, the trend of responsivity ratio of BR#174 by external lamp tests using 50W external lamps was shown in Fig.2. This trend was the fundamental result of UL06710.174 on the same day as UVR06710.174. The decrease in the responsivity was small at approx. 1 % at MSC. That is identical to the above described method, although the responsivity variation had the amplitude of approx. ±1 %.

3. Intercomparison of UV (uz/ux) and Ozone (ds O3/SO2)

3. 1 Instruments and situation

The instruments, MSC standard MKIII BR#145, JMA standard MKIII BR#174 and travelling standard MKII BR#113, used in the comparison were shown in Photo.1 and Table 1. BR#145 was located on the central-south-western position at Brewer site of MSC, BR#174 and BR#113 were located on the south-eastern corner. The open sky areas at each location were almost the same. Data from BR#113 were used as reference since the instrument needed time to stabilize the responsivity after the exchange of UG11 filter.

3. 2 Routine and schedule for the comparison

Uz.rtn (wave length: 290.0 – 325.0 nm per 0.25 nm / timing of scanning start: every 00 and 30 minutes / required time: 8 minutes) and ux.rtn (wavelength: 286.5 – 363.0 nm per 0.5 nm / timing of scanning start: every 10 and 40 minutes / required time: 8 minutes) were used for the comparison of spectral UV observations. Scan of uz.rtn can be started accurately at the time mentioned above. Ds.rtn was used for the comparison for ds O3/SO2 observations in continuity interim periods of above spectral UV scans.

Although the Japanese skc.rtn uses time as the trigger for schedule advancement, the comparison schedule was set up as “compjma.skd” in the skc.rtn using the zenith angle controlled method, commonly used worldwide. By the comparison schedule described in Table 5, more than 20 samples of UV (uz and ux) data and more than 50 samples of ds O3/SO2 could be obtained in a day.

3. 3 UV (uz/ux) comparison results

(1) UV (uz/ux) comparison data and results

The comparison data of **3.2** and the responsivity files, uvr files in Table 6 were used for the analysis process. The data collected by BR#174 and BR#113 were corrected by the daily responsivity trend which was calculated by the external lamp test results in the Fig.2 (Ito *et al.*: 2000), e.g. the correction of BR#174 was calculated as ＋0.29 % in 094 JD.

The UV irradiances of BR#145, BR#174 and BR#113 were expressed as Ir#145, Ir#174 and IR#113 respectively. The UV irradiance ratios were expressed as Ir#174/Ir#145 and Ir#113/Ir#145 to Ir#145 expressed as a standard and produced as seven kinds of irradiance ratios in Table 7. These results were described in Fig.3, Table 8 (a) and (b).

The six UV daily variations using uz.rtn in the case of clear-fine days were indicated as examples in Fig.3. (a) in the figure is the total UV (TUV and UVB) daily change, (b) is the total UV (TUV and UVB) irradiance ratio and the average ratio over all wavelength from 300.0 to 325.0 nm to Ir#145, and (c) is the irradiance ratios per wavelength to Ir#145, every half an hour, respectively.

(a) in Table 8 indicates daily averages of irradiance ratios every half an hour using uz.rtn to Ir#145, (b) dose the same averages using ux.rtn. (c) indicates average ratios of (a) and (b) after correction of the difference, 3.3%, between MSC and JMA systems for NIST lamp calibration.

Table 5　Schedule of the comparison at MSC.

ZA	Commands
-180	pd po hp hg sl pf
-110	pd hp hg sl pf 2
-95	pd b1 uz hg b1 ux hg ds ds b1 ux hg b1 ux hg ds ds pf 30
110	pd ap hp hg sl pf 2
180	compjma

Table 6　Responsivity files of Brewer Spectrophotometers.

Brewer	Responsivity file for comparison	
BR#145	UVR33307.145	November 29 2007
BR#174*	UVR06710.174	March 03 2010
BR#113*	UVR12710.113	May 07 2010

Table 7　Classification of solar UV irradiance ratios in comparison.

	Contents
UVAB	Total irradiance ratio from 290.0 to 360.0 nm
TUV	Total irradiance ratio from 290.0 to 325.0 nm
UVB	Total irradiance ratio from 290.0 to 315.0 nm
W (300-)	Average ratio over all wavelength from 300.0 to 325.0 nm
Daily total UVAB	Daily total irradiance ratio of UVAB
Daily total TUV	Daily total irradiance ratio of TUV
Daily total UVB	Daily total irradiance ratio of UVB

(2) UV Irradiance ratio of Ir#174/Ir#145

The UV irradiance ratio of Ir#174/Ir#145 as the average of 9 days using uz.rtn is indicated as following ratio in Table 8 (a).

Ir#174 / Ir#145 = 0.971 ～ 0.977

This ratio means Ir#145 is larger by 2.3 to 2.9 % than Ir#174. After the correction of the difference, 3.3 %, between MSC and JMA systems for NIST lamp calibration, the ratio was corrected as the following ratio in Table 8 (c).

Ir#174 / Ir#145 = 1.003 ～ 1.009 (after correction)

This ratio shows the difference near 1 %. The same irradiance ratio using the ux.rtn is similar in Table 8 (b).

The daily variation of irradiance ratios, Ir#174/Ir#145, in Fig.3 (b) seems to be increased in the afternoon. It was caused by the very small difference of the open sky area and the cosine response between BR#145 and BR#174. Contrary, the irradiance ratios in every half an hour in Fig.3 (c) did not indicate the dependency on different wavelengths.

(3) UV Irradiance ratio of Ir#113/Ir#145

The UV irradiance ratio of Ir#113/Ir#145 as the average of 4 days

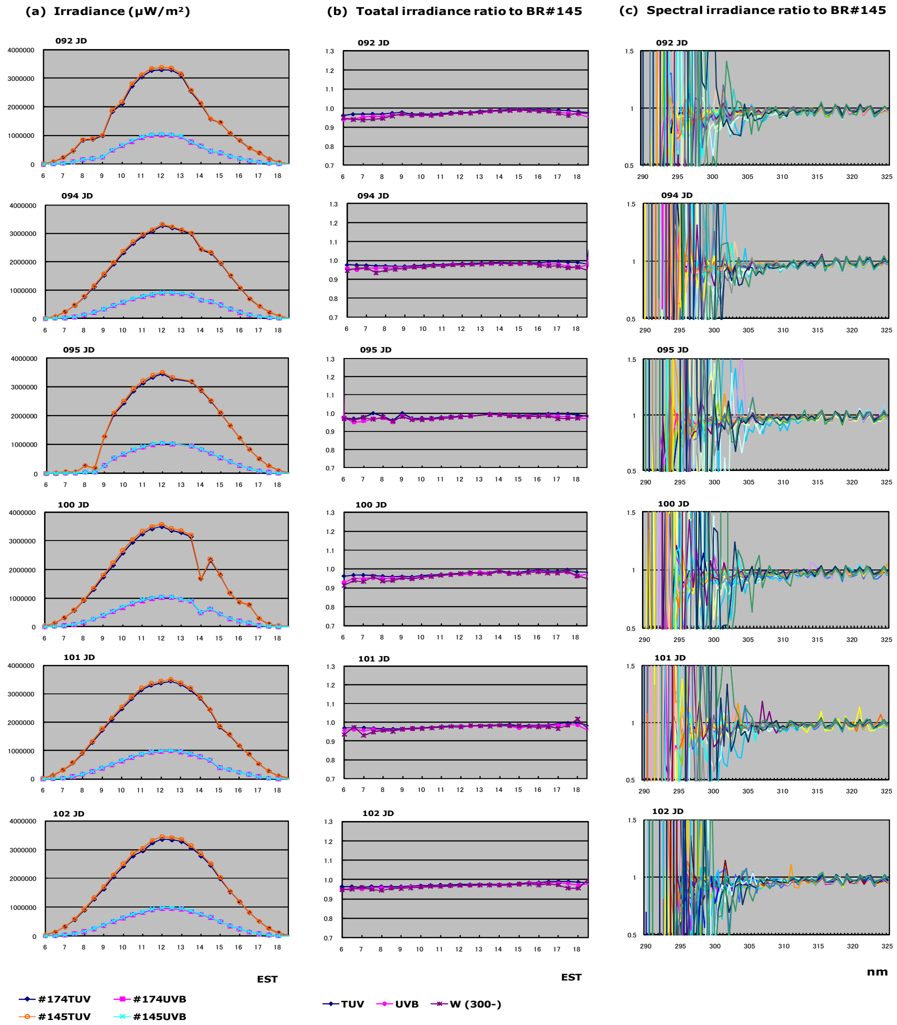

Fig. 3 Example of comparison results under solar radiation by BR#145 and BR#174 at MSC.
(a) Total irradiances of TUV and UVB with BR#174 and BR#145. **(b)** Total irradiance ratios of TUV and UVB, and average of irradiance ratio of W(300-) per wavelength from 300.0 to 325.0 nm by BR#174 to BR#145. **(c)** Irradiance ratios per wavelength by BR#174 to BR#145.

Table 8 Irradiance ratios of BR#174 and BR#113 to BR#145 under solar radiation at MSC.
(a) indicates irradiance ratios using uz.rtn, **(b)** indicates using ux.rtn, and **(c)** indicates average ratios of **(a)** and **(b)** after the correction of the difference (3.3 %) between MSC and JMA systems for NIST lamp calibration. 'UVAB', 'TUV', 'UVB' and 'W(300-)' were shown in Table 7. 'Hourly data' show the average of every half an hour ratios from 10 to 15 h and 'Daily total' show the ratio of daily total irradiance.

(a) using uz.rtn

		IR#174(JMA) / IR#145(MSC)							IR#113(JMA) / IR#145(MSC)								
		Hourly data				Daily total			Hourly data			Daily total		Sample #174		Sample #113	
	JD	UVAB	TUV	UVB	W(300-)	UVAB	TUV	UVB	TUV	UVB	W(300-)	TUV	UVB	Hourly	Daily	Hourly	Daily
1st	091 JD		0.963	0.956	0.957		0.964	0.956						11	23		
	092 JD		0.979	0.975	0.976		0.978	0.973						11	27		
	093 JD		0.983	0.979	0.982		0.982	0.977						11	27		
	094 JD		0.983	0.978	0.977		0.982	0.976						11	27		
	095 JD		0.984	0.979	0.979		0.984	0.979						10	27		
AVG	1st		0.978	0.973	0.974		0.978	0.972									
2nd	099 JD		0.971	0.959	0.957		0.970	0.958	0.954	0.962	0.967	0.952	0.959	11	28	11	28
	100 JD		0.977	0.973	0.972		0.975	0.970	0.955	0.961	0.960	0.951	0.957	11	28	11	28
	101 JD		0.980	0.977	0.977		0.979	0.975	0.972	0.971	0.975	0.967	0.969	11	28	11	28
	102 JD		0.974	0.969	0.969		0.973	0.969	0.967	0.972	0.973	0.962	0.970	11	28	11	20
AVG	2nd		0.976	0.970	0.969		0.974	0.968	0.962	0.966	0.969	0.958	0.964				
AVG	**all**		**0.977**	**0.972**	**0.972**		**0.977**	**0.971**	**0.962**	**0.966**	**0.969**	**0.958**	**0.964**				

(b) using ux.rtn

		IR#174(JMA) / IR#145(MSC)							IR#113(JMA) / IR#145(MSC)								
		Hourly data				Daily total			Hourly data			Daily total		Sample #174		Sample #113	
	JD	UVAB	TUV	UVB	W(300-)	UVAB	TUV	UVB	TUV	UVB	W(300-)	TUV	UVB	Hourly	Daily	Hourly	Daily
1st	091 JD	0.979	0.978	0.980	0.978	0.984	0.982	0.980						11	20		
	092 JD	0.995	1.006	1.009	0.999	0.980	0.984	0.982						11	27		
	093 JD	0.996	0.989	0.985	0.992	0.987	0.975	0.969						11	27		
	094 JD	0.989	1.000	0.994	0.987	0.989	0.992	0.986						11	27		
	095 JD	1.012	0.978	0.975	1.008	0.994	0.975	0.976						11	27		
AVG	1st	0.994	0.990	0.989	0.993	0.987	0.982	0.979									
2nd	099 JD	0.948	0.939	0.937	0.945	0.976	0.962	0.953						11	27		
	100 JD	0.922	0.936	0.952	0.933	0.933	0.946	0.956						11	24		
	101 JD	0.979	0.992	0.992	0.982	0.968	0.974	0.973						11	27		
	102 JD	0.990	0.991	0.987	0.989	0.984	0.984	0.979						11	24		
AVG	2nd	0.960	0.964	0.967	0.962	0.965	0.966	0.965									
AVG	**all**	**0.979**	**0.979**	**0.979**	**0.979**	**0.977**	**0.975**	**0.973**									

(c) after correction

	IR#174(JMA) / IR#145(MSC)							IR#113(JMA) / IR#145(MSC)				
	Hourly data				Daily total			Hourly data			Daily total	
	UVAB	TUV	UVB	W(300-)	UVAB	TUV	UVB	TUV	UVB	W(300-)	TUV	UVB
(a) AVG by uz.rtn		**1.009**	**1.004**	**1.004**		**1.009**	**1.003**	**0.994**	**0.998**	**1.001**	**0.990**	**0.995**
(b) AVG by ux.rtn	**1.011**	**1.011**	**1.011**	**1.011**	**1.009**	**1.007**	**1.005**					

using uz.rtn is indicated as following ratio in Table 8 (a).

Ir#113 / Ir#145 = 0.958 ～ 0.969

This ratio means Ir#145 is larger by 3.1 to 4.2 % than Ir#113. After the correction of the difference, 3.3 %, as (2) mentioned above, the ratio was corrected as the following ratio in Table 8 (c).

Ir#113 / Ir#145 = 0.990 ～ 1.001 (after correction)

This ratio shows the difference of near 1 %, as well.

The daily variation of irradiance ratios, Ir#113/Ir#145, also seems to be increased in the afternoon. In the case of BR#113, the irradiance ratios per wavelength indicates the increment at short wavelengths by the stray light of BR#113 and the very small decrement at long wavelengths (Figures and Tables omitted).

3. 4 Ozone (ds O3/SO2) comparison results

(1) Ozone (ds O3/SO2) comparison data

The process of ozone (ds O3/SO2), analysis used in the comparison data of b files and instrument constants files were described in Table 9. The constants from BR#174 established in 2001 from the first comparison to BR#158, the Kipp & Zonen standard, were used. However the ds O3 measurements from BR#174 needed a correction of approx. −1 %, because the values were approx. 1 % higher than the other standard instruments from the past comparisons, e.g. to BR#113 at JMA in 2001 and BR#145 at MSC in 2006. On the other hand, the ds SO2 measurements from BR#174 did not require any correction.

Now that the correction value, −1 %, of ds O3 from BR#174 could be reconfirmed by the comparison as well, and the absorption coefficients were almost same as the previous values by the dispersion tests at MSC on April and at JMA (Tsukuba) on June, BR# 174's ETC constants were changed from the old values to new ones in Table 9. These comparison results were described in Fig.4 and Table 10.

Due to stability issues with R5 and R6 values caused by the UG11 filter replacement at MSC, the calibration of BR#113 was done at JMA (Tsukuba) following this comparison using BR#174 with its new constants.

(2) ds O3 comparison results

The ds O3 comparison results after the BR#174's correction of −1 %, the ds O3 values of BR#174 versus to BR#145, ds O3 differences of "(BR#174 − BR#145)/BR#145", and ETCs of BR#174, were shown in Fig.4 (a-1) to (a-3) and Table 10. The difference as an average of 205 samples under air mass 5.0 for 8 clear-fine days from 01 (091 JD) to 12 (102 JD) in April, is indicated as following ratio in Table 10 and Fig.4 (a-2).

(BR#174−BR#145) / BR#145 = 0.002 ・・・・ +0.2 %

This ratio shows an acceptable difference of approx. +0.2 % and an update from the previous constants of BR#174 is not required. However, the correction is much more complicated, and the constants were updated to a new value in Table 9.

Table 9　Constants of BR#174 for ds O3/SO2 observations.

BR#174		OLD*	NEW
ETC Values	O3 =	1811	1836
	SO2 =	676	678
O3 Absn Coeffs	O3 =	0.3403	0.3403
	SO2 =	1.1419	1.1419
SO2 Absn Coeffs	O3 =	0	0
	SO2 =	2.3500	2.3500

* Correction; O3 value: x 0.99, SO2 value: none

Table 10 ds O3/SO2 comparison results of BR#174 to BR#145.

		OLD*	NEW
dsO3 (BR#174-BR#145)/BR#145	Maximum	0.013	0.010
	Minimum	-0.009	-0.010
	Average	**0.002**	**-0.001**
dsSO2 BR#174-BR#145	Maximum	1.1	1.8
	Minimum	-4.4	-1.9
	Average	**-2.0**	**-0.2**

* Correction; O3 value: x 0.99, SO2 value: none

(3) ds SO2 comparison results

The ds SO2 comparison results, the ds SO2 values of BR#174 versus to BR#145, ds SO2 differences of "BR#174−BR#145", and ETCs of BR#174, were shown in Fig.4 (b-1) to (b-3) and Table 10. The difference as an average of the same samples as ds O3 comparison of (1) is indicated as the following ratio in Table 10 and Fig.4 (b-2).

BR#174−BR#145 = −2.0 m atm-cm

The ds SO2 measurements from BR#174 indicated a few m atm-cm lower than BR#145. This difference seemed to account for accidental errors under low SO2 levels, however, the constant was updated to a new value as seen in Table 9.

4. Conclusion

The intercomparison of Brewer spectrophotometers between the Canadian standard and Japanese standards were carried out as a MSC-JMA joint project, at MSC, March 31 to April 13, 2010. In this paper, some results of NIST lamp calibration tests, spectral UV comparison, and ozone comparison were described as followings (1) to (3).

(1) NIST lamp calibration tests

The difference of instrument responsivity ratios determined by NIST lamp calibration methods using three systems, MSC_40, IOS_50 and JMA_50 as "S_D" (S system and D distance between lamp filament to diffuser), exhibited the following various ratios.

IOS_50 / MSC_40 = 1.013

IOS_50 / JMA_50 = 0.979

JMA_50 / MSC_40 = 1.0347

The difference of 3.5% between MSC and JMA systems proved an estimated difference of 3.3 % from the last comparison and test at MSC in 2006.

(2) UV (uz/ux) comparison

Comparison between MSC standard BR#145 and JMA standard BR#174 for 9 days (JMA travelling standard BR#113 for 4 days) revealed the following ratios of measured solar UV irradiances.

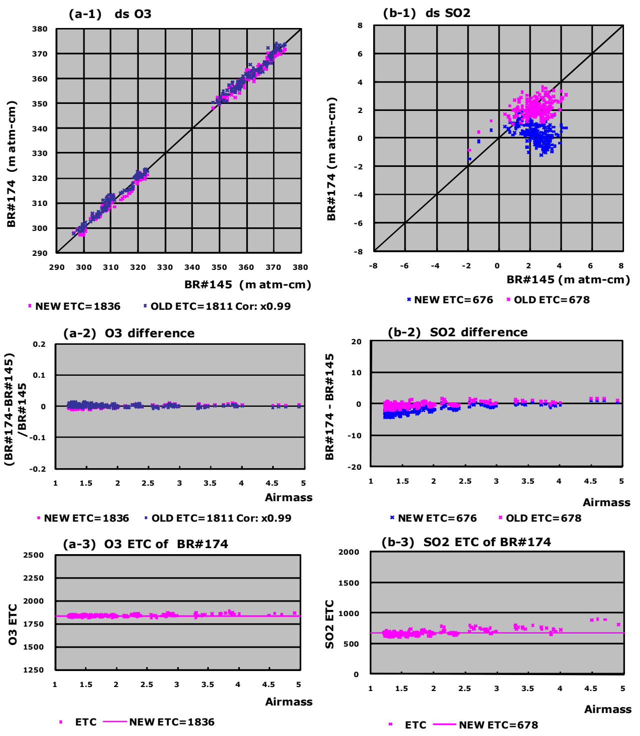

Fig. 4 ds O3/SO2 comparison results of BR#174 to BR#145 using 205 samples, at MSC for 8 clear-fine days from 01 (091 JD) to 12 (102 JD) in April, 2010.
(a-1) Observation results of ds O3 of BR#174 versus to BR#145. **(a-2)** Difference of ds O3, (BR#174 - BR#145) / BR#145. **(a-3)** New ds O3 ETCs of BR#174. **(b-1)** Observation results of ds SO2 of BR#174 versus to BR#145. **(b-2)** Difference of ds SO2, BR#174 - BR#145. **(b-3)** New ds SO2 ETCs of BR#174.

Ir#174 / Ir#145 = 0.971 ～ 0.977

Ir#113 / Ir#145 = 0.958 ～ 0.969

After the correction considering the difference of 3.3 % between MSC and JMA NIST lamp calibration systems, their ratios changed as follows.

Ir#174 / Ir#145 = 1.003 ～ 1.009 (after correction)

Ir#113 / Ir#145 = 0.990 ～ 1.001 (after correction)

The irradiance ratios after the correction, agreed within 1 %.

(3) Ozone (ds O3/SO2) comparison

Comparison between BR#145 and BR#174 for 8 days revealed the following ratios of measured total ozone (ds O3) and total sulfur dioxide (ds SO2).

ds O3 : (BR#174－BR#145) / BR#145 = 0.002

ds SO2 : BR#174－BR#145 = －2.0 m atm-cm

The O3 value showed a difference of about ＋0.2 %.

Based on the fact that these UV comparison results were almost the same as the results by previous comparisons in 1994, 1998, 2002 and 2006, and that the JMA NIST lamp system was not changed from 1989, we concluded that the irradiance level (standard irradiance) of the NIST lamp calibration for all Brewers at JMA has been kept about 3.3% lower than MSC's NIST lamp calibration system over the past 21 years.

In the immediate future, all past data in JMA UV network from 1990 need a constant correction of about 3.3% or 2.7% to agree with MSC_40 or IOS_50 levels at all wavelengths from 286.5 to 363.0 nm (Ito *et al.*: 2007). This correction is available at any time, because all Brewer responsivity trends for every instrument for every day has been recorded using NIST lamp calibrations every 3 years and external lamp tests every week, in JMA UV network from 1990 (Ito *et al.*: 2000).

During the last several years, the RBCC-E (Regional Brewer Calibration Centre in Europe) in WMO/Region-IV was constructed in Spain, and the intercomparison and calibration for European Brewers were convened almost every two years (Redondas: 2002, 2005, 2007, MeteoSwiss and AEMet: 2008, WMO/RBCC-E: 2008, 2010), in WMO/GAW Brewer network (WMO: 1998, 2002). Those technologies provided by MSC and developed in JMA were useful for the high accurate UV and O3 observations in Japanese Brewer Networks, JMA, NIES (National Institute for Environmental Studies) and others, and also useful for the construction planning of RBCC-A (Regional Brewer Calibration Centre in Asia).

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カナダ MSC におけるブリューワー分光光度計 2010 年における国際測器相互比較

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要旨

2010 年 4 月に，カナダ国との二国間技術協力に基づく MSC(Meteorological Service of Canada, Environment Canada : カナダ環境省気象局)との国際測器相互比較を実施した．当比較では，従来と同様 JMA 国内準器 Brewer MKIII #174(BR#174)と国内移動準器 Brewer MKII #113(BR#113)を MSC に持ち込み, MSC 準器 Brewer MKIII #145(BR#145)との波長別紫外域日射量と直射光オゾン・二酸化硫黄全量(ds O3/SO2)の比較観測, NIST ランプ検定，分光常数試験等々を実施した．これらは以下のとおりである．

(1) NIST ランプ検定装置による照射誤差 : MSC 型(MSC_40 : MSC 製の装置，照射距離 40cm)，IOS 改良型(IOS_50 : IOS(カナダ国 International Ozone Services Inc.)製の装置，JMA 用として照射距離 40cm を 50cm に改良)，および JMA 型(JMA_50 : JMA 製の装置，照射距離 50cm)の 3 種類の NIST ランプ検定装置による相互の照度差について試験した．その結果，IOS_50 / MSC_40 = 1.013，IOS_50 / JMA_50 = 0.979，JMA_50 / MSC_40 = 1.0347 となり，両国の検定差は約 3.5%で 2006 年の結果約 3.3%とほぼ一致した．

(2) 波長別紫外域日射の測器相互比較 : MSC 準器 BR#145 に対する JMA 準器 BR#174 と移動準器 BR#113 の紫外域日射測器相互比較観測を 9 日間(BR#113 は 4 日間)実施した．その結果，照度(Ir)比は，両国間の検定差を考慮すると，Ir#174 / Ir#145 = 1.003～1.009，Ir#113 / Ir#145 = 0.990～1.001 となり，両国の照度差は 1%以内で一致した．

(3) 直射光オゾン・二酸化硫黄全量の測器相互比較 : MSC 準器 BR#145 に対する JMA 準器 BR#174 の直射光オゾン・二酸化硫黄全量(dsO3/SO2)の測器相互比較観測を 9 日間実施した．その結果，ds O3 は (BR#174－BR#145) / BR#145 = 0.002，ds SO2 は BR#174－BR#145 = －2.0 m atm-cm となり，dsO3 は＋0.2%と非常に良い結果が得られた．

以上の比較結果は，従来の結果(1994 年，1997 年，2002 年，2006 年)とほぼ同様で，また JMA の検定は 1989 年から同じ方法をとっていたことから，JMA の全ブリューワー分光光度計のための NIST ランプ検定の標準照度は，過去 21 年間，MSC の照度に比べて約 3.3%低い照度を常に維持してきたと言える．近い将来，JMA の紫外域日射観測網における 1990 年からの全データについて，MSC_40 を基準とするならば約 3.3%, IOS_50 を基準とするならば約 2.7%, 波長に関係なく(全波長 286.5～363.0nm)補正する必要がある．この補正について，1990 年以降，JMA の紫外域日射観測網では NIST ランプ検定を 3 年毎に，外部標準ランプ点検を毎週実施しており，全ブリューワー分光光度計の観測期間全てにわたる感度トレンドを作成しているので，過去に遡った補正がいつでも可能である．今後，MSC から提供された技術や JMA で開発した技術が，国内だけではなく，アジア地区(WMO Region II)校正センターの構築のために役立つことを期待したい．

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