[Technical report]

Absolute Calibration for Brewer Spectrophotometers and Total Ozone/UV Radiation at Norikura on the Northern Japanese Alps

Mahito ITO*, Itaru UESATO*, Yoshiyuki NOTO*, Osamu IJIMA*, Satoru SHIMIZU*, Masato TAKITA, Hideaki SHIMODAIRA** and Hideki ISHITSUKA****

Abstract

Aerological Observatory of JMA started "Observations of Total Ozone and UV Solar Radiation with Brewer Spectrophotometer on the Norikura Mountains" as a joint project with Institute for Cosmic Ray Research (ICRR), University of Tokyo at the Norikura Observatory of ICRR (Brewer site: 36.11 N, 137.56 E, 2,772 m a.s.l.), locating at the Northern Japanese Alps, every summer seasons since 2009 (Ito *et al.*: 2011, 2012). Purpose of this study is absolute calibration for Brewers based on the concept of developing Regional Brewer Calibration Centre for Asia, and study of total ozone and UV radiation (GL_{UV}: global UV, DF_{UV}: diffuse UV) by using Brewers (BR#174, BR#113 and BR#060) on the high mountains. In this paper, their absolute calibration results and observation results for five years from 2009 to 2013 are summarized below.

(1) By the absolute calibrations of Brewers for total O3 observations, "O3 Extra-Terrestrial Coefficients (=ETC)" of BR#174 and BR#113 could be produced as about 10 samples every year. The representative coefficients every year were stable and identical within 1% to the currently used coefficients for five years. (2) The variation of 5-years mean of total O3 at Norikura in the summer season showed the low value of about −4% compared to the value at Tsukuba (36.06 N, 140.13 E, 39 m a.s.l.) at almost same latitude. However the difference became smaller in late September. (3) The 5-years mean of daily total GL_{UV} (CIE) at Norikura for the season indicated the value of +3% compared to the value at Tsukuba, but the value in clear day did the high value of +40%. (4) The 5-years mean of daily UV (CIE) diffusibility, RDF_{UV} (=DF_{UV}/GL_{UV}), at Norikura in clear day indicated the very lower value of about 0.54 (54%) compared to the value of about 0.72 at Tsukuba, respectively. (5) The UV spectral irradiance of GL_{UV} increased in the short wavelength range at Norikura compared to the value at Tsukuba, and showed as follows; e.g. about +29% at the wavelength of 325nm and about +60% at 300nm in clear day, respectively. (6) The altitudinal increasing rate of GL_{UV} (CIE) in the clear day indicated the calculated amounts of about +14.6% per 1,000 m.

These calibrations and observations for five years elucidated the availability of absolute calibration for Brewers at Norikura, and many characteristic of O3 and UV radiation on the high mountains. The continuous observations with Brewers and other instrument are very important for the clarification of the seasonal variation and the coefficient trends.

1. Introduction

Aerological Observatory of JMA started "Observations of Total Ozone and UV Solar Radiation with Brewer Spectrophotometer on the Norikura Mountains" as a joint project with Institute for Cosmic Ray Research (ICRR), University of Tokyo at the Norikura Observatory of ICRR, locating at the Northern Japanese Alps, every summer seasons since 2009 (Ito *et al.*: 2011, 2012).

The WBCC (World Brewer Calibration Centre) of WMO/GAW (World Meteorological Organization / Global Atmospheric Watch) was established at MSC (Meteorological Service of Canada) in Toronto, Canada, and the RBCC-E (Regional Brewer Calibration Centre for Europe) was also established at Izana Observatory (Izana Atmospheric Research Centre (Redondas: 2002, 2005, 2007, WMO/RBCC-E: 2008, 2010)) in Spain. However, other regional Brewer centre has never been established. Therefore, in Asian region (RA-II), establishment of the identical regional calibration centre has been requested (WMO/GAW: 2010).

*Ozone and Radiation Division, Aerological Observatory, JMA.
** Institute for Cosmic Ray Research, the University of Tokyo.

The afore mentioned joint project has maintained the study consists of 1) the absolute calibrations for total O3 and total SO2 observations (Fioletov *et al.*: 2005), 2) the measurements of total O3 and total SO2, 3) the measurements of global and diffuse UV radiations (GL_{UV} and DF_{UV}, Ito *et al.*: 2013), 4) the measurement of

Photo.1 Brewer observation site, 36.11 N, 137.56 E, 2,772 m a.s.l., at Norikura, in the Northern Japanese Alps. Norikura observatory of ICRR (Institute for Cosmic Ray Research), University of Tokyo.

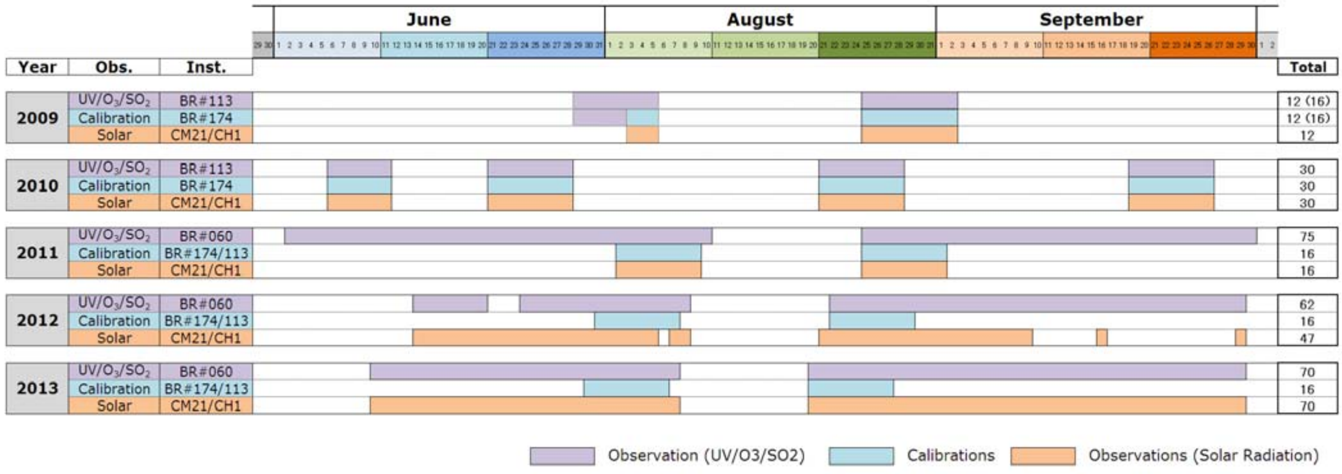

Fig. 1 Observation schedules from 2009 to 2013 at Norikura.

global and diffuse solar radiations and turbidity using pyranometer and pyrheliometer, and 5) all necessary tests for Brewer calibrations (the dispersion test, the NIST lamp calibration, the external lamp test, the spectral tests and etc.) at Norikura.

In this paper, the trends of the absolute calibration and the observation results during the measurements for five years of 2009 to 2013 are described.

The symbols used in this paper are defined in Table 1. Please refer to Ito *et al.* (2007, 2012, 2013) for detailed descriptions of the instruments, the observation site and the observational methods, and to McElroy *et al.* (2008) and Kipp & Zonen (1996, 2008a, b) for all of the technical terms used in this paper.

Table 1 Observations and instruments at Norikura.

Observation	Symbol	Contents
O_3	O_3	Total ozone m atm-cm
SO_2	SO_2	Total sulphur dioxide m atm-cm
UV Radiation	GL_{UV}	Global UV radiation J/m^2
	DF_{UV}	Diffuse UV radiation J/m^2
	RDF_{UV}	Diffusibility of UV radaition [$RDF_{UV}=DF_{UV}/GL_{UV}$]
	CIE	CIE UV irradiance by Commission Internationale de I'Eclairage J/m^2
Solar Radiation	GL_{SL}	Global solar radiation kJ/m^2 [$GL_{SL}=DF_{SL}+DH_{SL}$]
	DF_{SL}	Diffuse solar radiation kJ/m^2
	DR_{SL} (DH_{SL})	Direct (direct-horizontal) solar radiation kJ/m^2
	RDF_{SL}	Diffusibility of solar radiation [$RDF_{SL}=DF_{SL}/GL_{SL}$]

Instrument	Observations
Brewer Spectrophotometers	
BR#174	Absolute calibration, ds O_3 and ds SO_2
BR#113	Absolute calibration, ds O_3 and ds SO_2
BR#060	GL_{SL}, DF_{SL}, ds O_3 and ds SO_2
Pyranometer CM21	DF_{SL} and GF_{SL}
Pyrheliometer CH1	DR_{SL} (DH_{SL})

2. Instruments and data

2.1 Instruments

The instruments, used for the calibration and the observations were Brewer MKIII #174 (BR#174: Japanese standard), MKII #113 (BR#113: travelling standard), MKII #060 (BR#060: routine instrument), pyranometer CM21, pyrheliometer CH1 and UV radiometer UVSABT, with an equatorial mounting and an automated shadow units. The classification of the observation by using those instruments is shown in Table 1.

2.2 Progresses of Calibration and observation

The calibration and observation progresses from 2009 to 2013 are shown in Fig.1, and they are maintained for the working period of the observatory in summer season from July to September.

The calibration and the routine observation were implemented two times (about two weeks) in 2009 and four times (about four weeks) in 2010. Since 2011, the calibration of two times and the routine observation for about 70 days was implemented in parallel.

3. Absolute calibration results

The absolute calibrations of O3 ETC, "Extra-terrestrial coefficient for the O3 wavelength combination", and SO2 ETC, "Extra-terrestrial coefficient for the SO2 wavelength combination", with BR#174 and BR#113 had been carried out at Norikura for five years as shown in Fig.1.

The calibration data of O3 and SO2 could be obtained within the wide range of air-mass (μ) from 7.93 (maximum) to 1.03 (minimum) for the period at Norikura. The value of ETCs could be calculated by using regression method of the OLS, Ordinary Least Square, by RBCC-E (Redondas: 2002, 2007). The calculated data were picked out by the definition of the deviation of R-square above 0.9997 ($R^2 \geqq 0.9997$) for more precise analysis and the using the data of μ under 5.0 ($\mu \leqq 5.0$), for half a day. The examples of the regression line were shown in Fig.2. Upper figures indicate the results using all data in a half day, and lower figures indicate the results using selected data under the air-mass of 5.0.

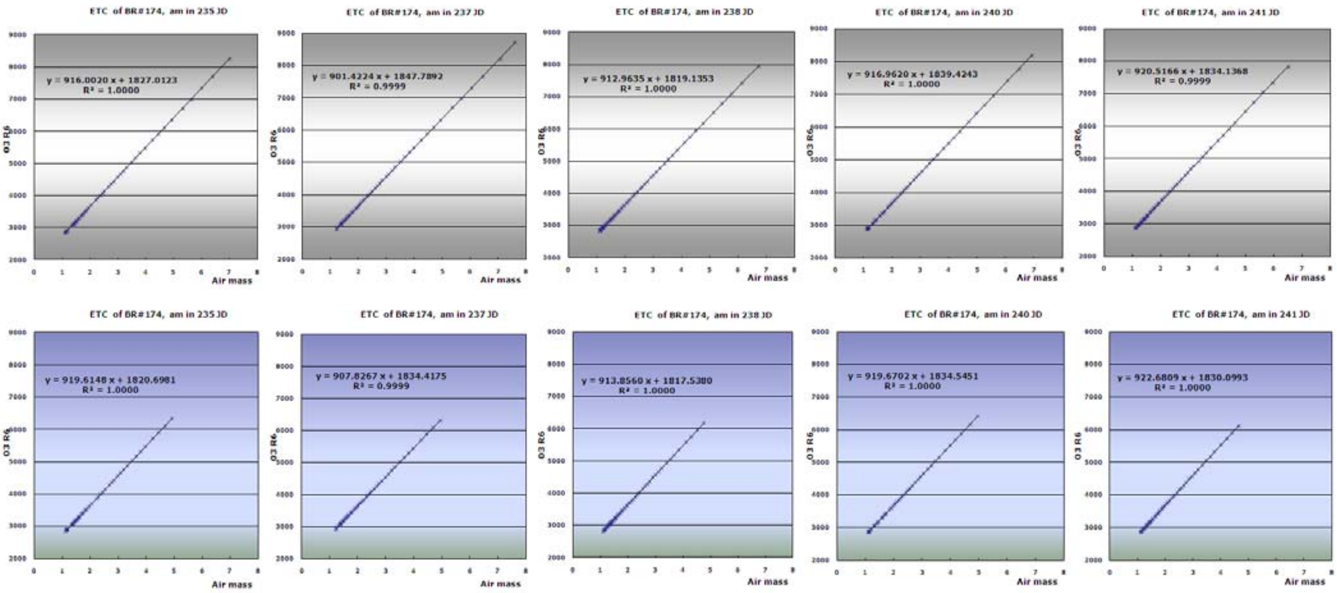

Fig. 2 The examples of the regression line, air-mass versus ozone double ratio by the absolute calibration for BR#174, am in 235 to 241 JDs, 2012. Upper figures indicate the result using all data. Lower figures indicate the results using data selected by the definition of " air-mass $\mu \leqq 5.0$".

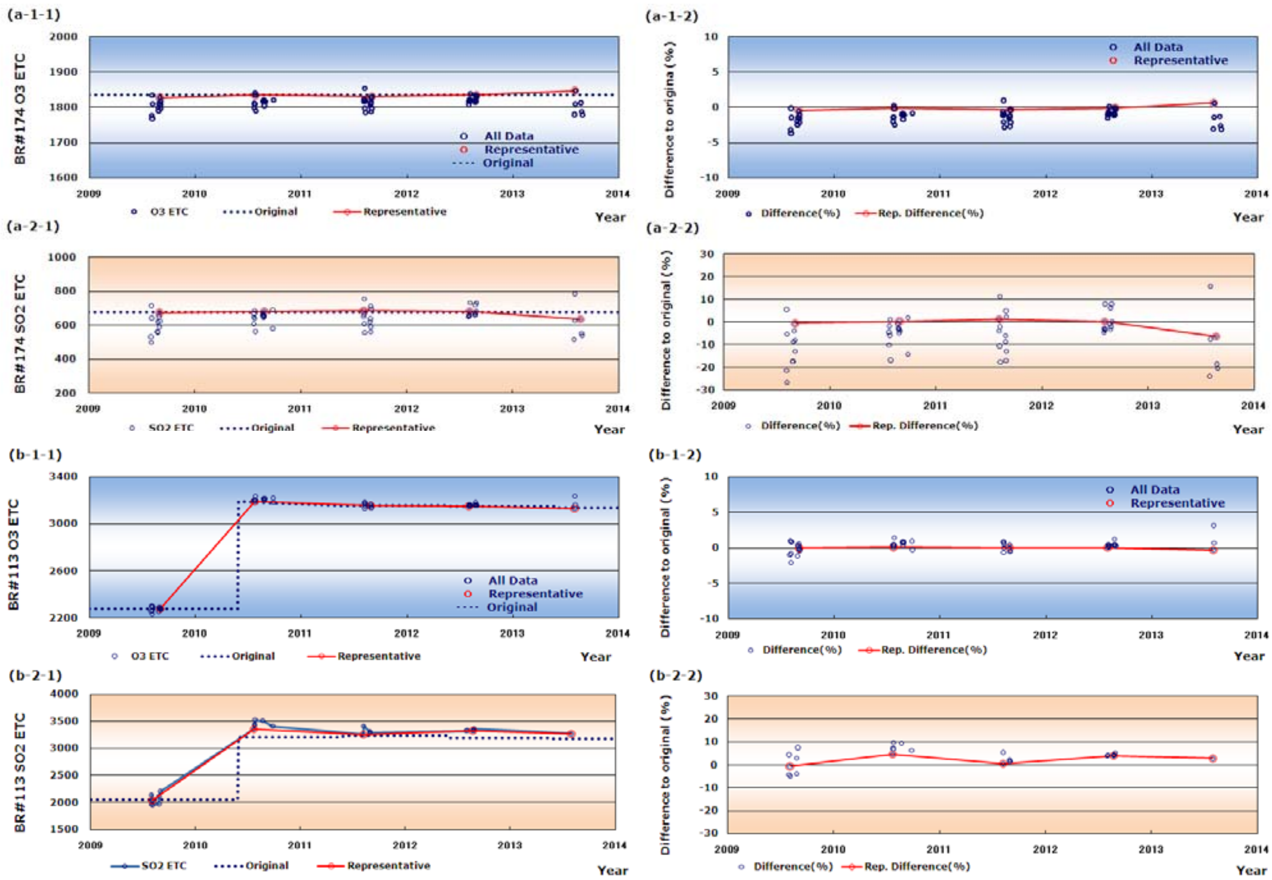

Fig. 3 O3 and SO2 extra-terrestrial coefficients with BR#174 and BR#113 by the absolute calibrations at Norikura from 2009 to 2013. Left figures, (a-1-1) to (b-2-1) from upper to lower indicate "O3 ETC" with BR#174, "SO2 ETC" with BR#174, "O3 ETC with BR#113 and "SO2 ETC" with BR#113, respectively. Right figures, (a-1-2) to (b-2-2), from upper to lower indicate the difference (percentage) of their calibrated ETCs against the original ones in use. Their figures show all data calibrated by the definition of " R2 $\geqq 0.9997$" and " air-mass $\leqq 5.0$".

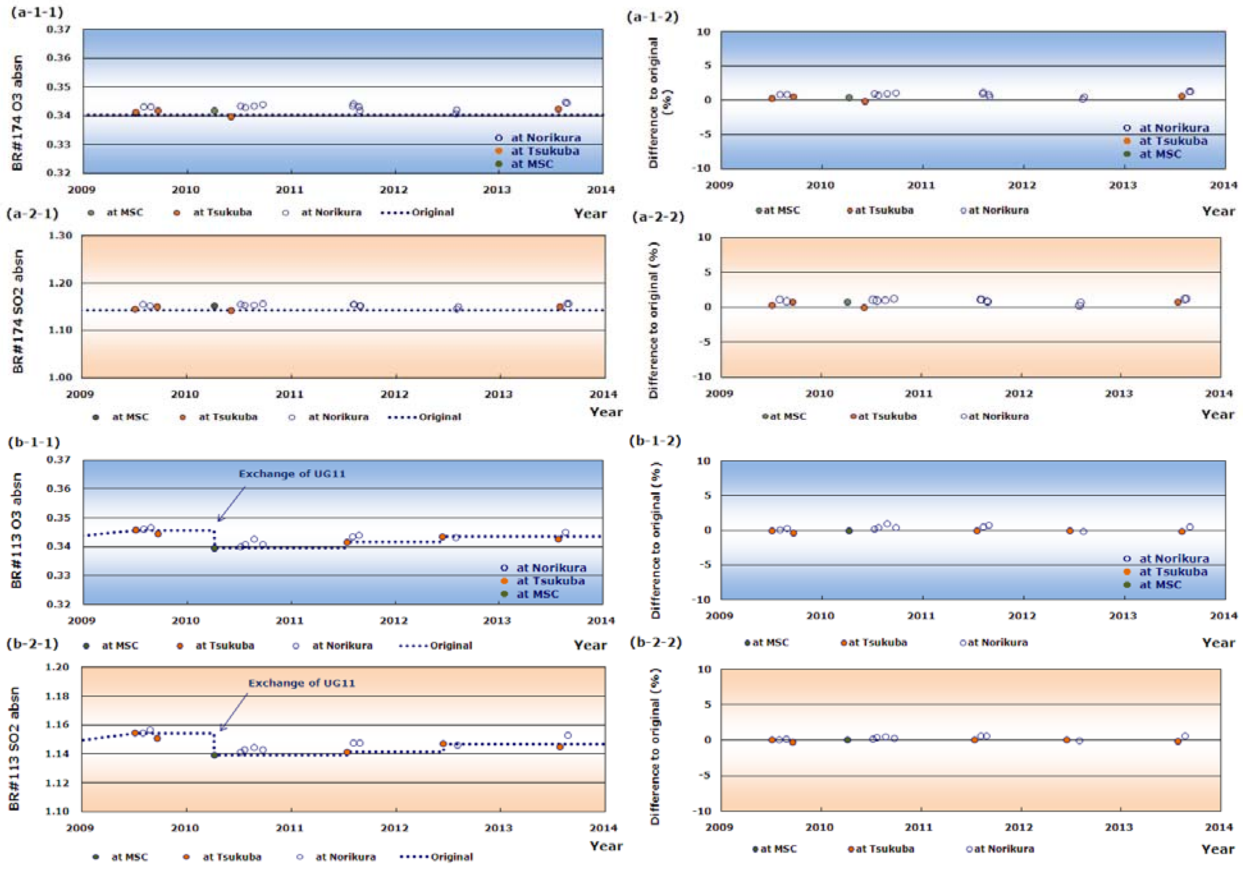

Fig. 4　O3 and SO2 absorption coefficients with BR#174 and BR#113 by dispersion tests using spectral lamps at Norikura and Tsukuba from 2009 to 2013. Left figures, (a-1-1) to (b-2-1) from upper to lower indicate "O3 absn" with BR#174, "SO2 absn" with BR#174, "O3 absn" with BR#113, and "SO2 absn" with BR#113, respectively. Right figures, (a-1-2) to (b-2-2), from upper to lower indicate the difference (percentage) of their calibrated absns against the original ones in use.

The absolute calibration results for five years were shown in Fig.3. About ten data could be picked out every year. In the figure, the red color line shows the trend of representative data in the most clear day every year, and the horizontal dot line of dark blue color shows the currently used ETCs by the intercomparison against a world standard Brewer at MSC (Ito et *al.*, 2007, 2011), respectively.

O3 ETCs of red color line in Fig.3 are agreed within 1% against to the currently used ETCs for five years. SO2 ETCs are also agreed within several percentages. As mentioned, the absolute calibration at Norikura can produce highly accurate data. However, participation of standard BR#174 in the intercomparison, including the absolute calibration with the world standard Brewer at Mauna Loa (or the European standard and the world standard Brewers at Isana) for the confirmation of their calibration results at Norikura, must be carried out immediately in the future.

On the contrary, Brewers need other absorption coefficients, O3 absn of "the differential O3 absorption coefficient for O3 wavelength combination", and SO2 absn of "the differential O3 absorption coefficient for the SO2 wavelength combination", for O3 and SO2 observations (Kipp & Zonen: 1996). Their coefficients are calibrated by the dispersion test using spectral lamps. The tests had been obtained at Norikura every year. Their test results including the test results at Tsukuba are shown in Fig.4. As shown in this figure, the coefficients of BR#174 and BR#113 had been indicated stable values at Norikura for five years.

4. Total O3 and total SO2 at Norikura

The trends of daily means of total O3 and total SO2 at Norikura in the observation periods of summer season for five years were shown in Fig.5 (a) and (b), respectively. The thin line in these figures shows the 5-years mean of daily total and the heavy line shows the seven day-running means of the 5-years mean. In these figures, the trends of same values at Tsukuba (36.06 N, 140.13 E, 39 m a.s.l.) were added for the comparison. The averages and the differences between Norikura and Tsukuba were indicated in Table 2.

Compare to the data acquired at Tsukuba, the seven day-running means of total O3 at Norikura indicated lower values in the observation periods. The value of total O3 at Norikura indicated lower intensity of about 15m atm-cm in July and about 10m atm-cm from August to early September, however those differences became insignificant in late September.

Table 2 The average of annual mean of daily mean of total O3 and total SO2 with Brewer Spectrophotometers at Norikura and Tsukuba from 2009 to 2013.

		Norikura (m atm-cm)	Tsukuba (m atm-cm)	Difference to Tsukuba	
O3	AVG of annual means	283.2	294.6	-3.9	%
SO2	AVG of annual means	0.2	1.0	-0.7	m atm-cm

Observation
2009: 16 days, 2010: 30 days, 2011: 75 days, 2012: 62 days, 2013: 70 days.

Table 3 The difference of total ozone between Norikura (2,772m) and Tsukuba (39m) using by Brewers, and the total ozone from ground to the altitude of 2,772m at Tsukuba using by ozone sonde.

2013 Month day	JD	BR#060 Norikura 2,772m	BR#200 Tsukuba 39m	Difference Tsukuba−Norikura	O3 Sonde Tsukuba Groud to 2,772m
Jul. 31	214	284.1	304.3	**20.2**	**14.1**
Aug. 22	234	286.5	301.3	**14.8**	**11.3**
Aug. 26	235	292.9	307.7	**14.8**	**13.8**
Sep. 06	244	286.9	298.4	**11.5**	**12.5**
Sep. 09	249	293.0	302.4	**9.4**	**10.8**
Sep. 18	255	287.4	300.6	**13.2**	**12.1**
Sep. 27	264	279.9	287.3	**7.4**	**10.7**
AVG (7days)		287.2	300.3	13.0	12.2

(m atm-cm)

As shown in Table 2, the average of total O3 in the observation period for five years showed the value of 283m atm-cm at Norikura, and the value of 295m atm-cm at Tsukuba. The total O3 at Norikura was indicated as the lower value of −3.9% compared to Tsukuba. As reviewed in former report, those differences could be considered due to the difference of altitude between Norikura and Tsukuba.

In the same day the ECC ozone was obtained, the differences between daily O3 from ground level to the altitude of 2,772m a.s.l. (same altitude at Norikura station) by the sonde at Tsukuba, and daily O3 by Brewer at Norikura differed from the value by Brewer at Tsukuba, were shown in Table 3. As shown in Table 3, these differences for eight days was estimated to about 13.0m atm-cm by Brewer data, compared to the value of 12.2m atm-cm by the ozone sonde. Therefore, those O3 values from ground level to altitude of 2,772 m by using ozone sonde data were almost identical to the difference between Norikura and Tsukuba by using Brewer data.

Fig.6 shows the trends of daily means of total O3 with Brewers for five years at Norikura, Sapporo (43.06 N, 141.33 E), Tsukuba, Naha (26.21 N, 127.69 E), and Minamitorishima (24.29 N, 153.98 E) stations, respectively. Those trends were calculated by the seven day-running means of the daily averages for five years. The trend at Norikura indicated the lower values compared to the trend at Tsukuba, and the similar to little larger values compared to the trends at Naha and Minamitorishima.

On the contrary, total SO2 were not recognized at Norikura, as Fig.5

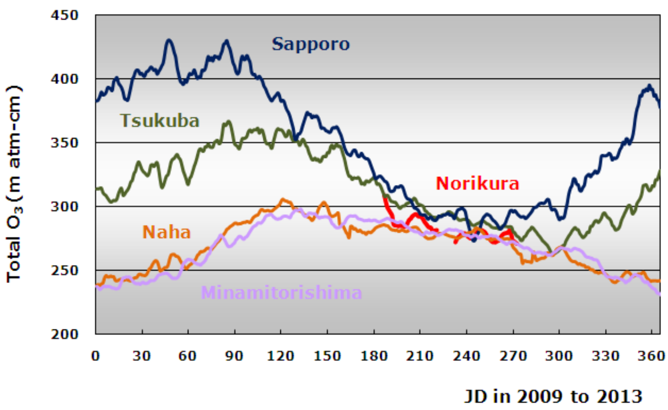

Fig. 6 The annual change of daily mean of total O3 with Brewer spectrophotometers, BR#169 at Sapporo, BR#200 (BR173) at Tsukuba, BR#175 at Naha, BR#173 (BR#096) at Minamitorishima, and BR#060 (BR#113, BR#174) at Norikura, for five years from 2009 to 2013.

Their lines show the seven day-running means of the daily mean for five years.

(b) shows the values of almost 0m atm-cm for five years. The SO2 is not influenced to the calibration with Brewers at the site, though some active volcano and hot springs are located around Mt. Norikura.

5. UV radiation (e.g. CIE) at Norikura

5.1 Global UV (GL_{UV}), diffuse UV (DF_{UV}), global solar radiation (GL_{SL}) and diffuse solar radiation (DF_{SL})

The trends of maximum of daily total UV radiation, e.g. as the CIE (Erythema UV) value, and the trends of maximum of daily total solar radiation at Norikura every day for five years are shown in Fig.7 (a) and (b), respectively.

In Fig.6 (a), GL_{UV} at Norikura, DF_{UV} at Norikura, GL_{UV} at Tsukuba and DF_{UV} at Tsukuba are shown as the thin dot lines of violet, orange, green and pink colors, respectively. The upper limit lines of each of 4 factors are shown as the heavy lines with the same colors of each factor. In Fig.6 (b), GL_{SL} and DF_{SL} at Norikura and Tsukuba are shown as the same style as Fig.6 (a).

As shown in Fig.6 (a), the trend of upper limit line of GL_{UV} at Norikura indicated the high value of about +20% compared to the same line at Tsukuba. On the contrary, the trend of upper limit line of DF_{UV} at Norikura indicated the almost same value of DF_{UV} at Tsukuba. The trend of upper limit line of GL_{UV} at Norikura in early July indicated the lower value compared to the value at Tsukuba. The lower value was due to bad weather of rainy season, and the small number of data at Norikura.

Compare to the UV radiation mentioned above, as shown in Fig.6 (b), the trend of upper limit line of GL_{SL} at Norikura indicated slightly higher value of about +10% compared to the same line at Tsukuba. The trend of upper limit line of DF_{SL} at Norikura indicated the almost same value of DF_{SL} at Tsukuba, as almost same as DF_{UV}.

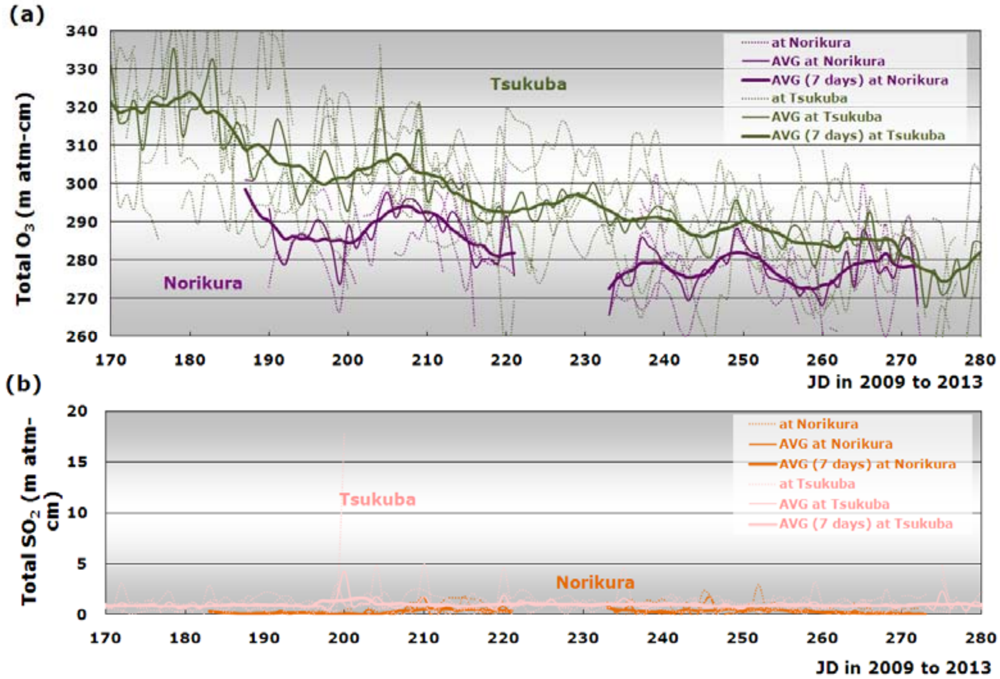

Fig. 5 Trends of daily mean of total O3 and total SO2 with Brewer Spectrophotometers at Norikura and Tsukuba from 2009 to 2013. Upper figure (a) show the daily mean of ds O3, and lower figure (b) shows the daily mean of ds SO2, respectively. Heavy lines indicate the seven day -running means of the daily mean for five years.

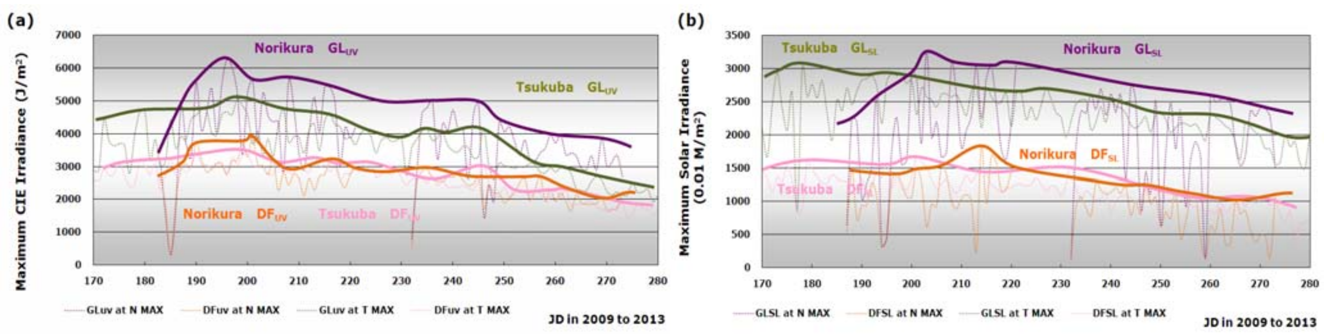

Fig. 7 Trends of maximum of daily total of GL_{UV}, DF_{UV}, GL_{SL}, and DF_{SL} at Norikura and Tsukuba, for five years, from 2009 to 2013. GL_{UV}, DF_{UV} GL_{SL} and DF_{SL} indicate global UV (CIE), diffuse UV (CIE), global solar radiation and diffuse solar radiation, respectively.

Left figure (a) shows the daily total GL_{UV} and DF_{UV} with Brewers for five years, respectively. Right figure (b) shows the daily total GL_{SL}, and DF_{SL} with pyranometer CM21 (CM22) and pyrheliometer CH1 for five years, too. Heavy lines indicate the upper limit lines in clear day.

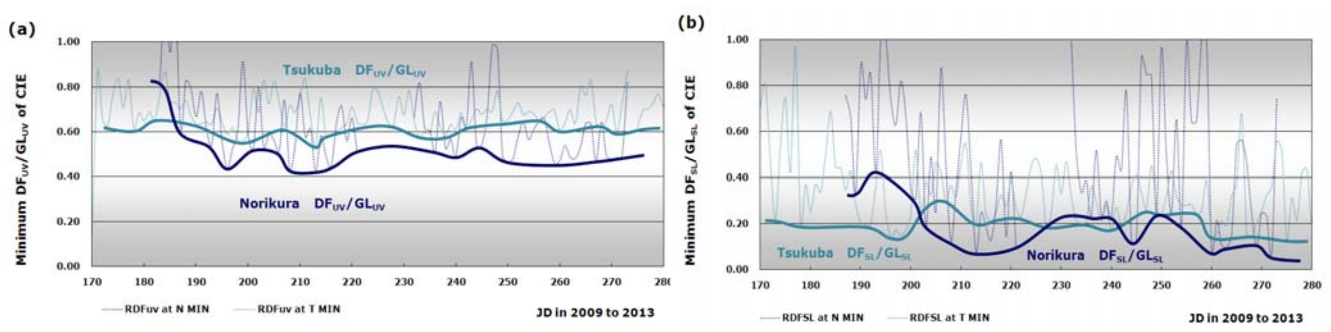

Fig. 8 Trends of minimum of the daily diffusibility of UV (CIE), DF_{UV}/GL_{UV}, and solar radiation, DF_{SL} $/GL_{SL}$, at Norikura and Tsukuba, for five years, from 2009 to 2013.

Left figure (a) show the daily diffusibility of UV (CIE) with Brewers for five years. Right figure (b) shows the daily diffusibility of solar radiation with pyranometer CM21 (CM22) and pyrheliometer CH1 for five years, too. Heavy lines indicate the lower limit lines in clear day.

Table 4 Average of the daily total UV (CIE) with Brewers and the daily total solar radiation with pyranometer and pyrheliometer at Norikura and Tsukuba for five years, from 2009 to 2013.

(a)

		Norikura	Tsukuba	Difference to Tsukuba (%)
GL_{UV} (J/m^2)	AVG of annual means	2799	2705	3
	clear day	*5531*	*3949*	40
DF_{UV} (J/m^2)	AVG of annual means	1970	2131	-8
	clear day	*2967*	*2825*	5
RDF_{UV} [DF_{UV}/GL_{UV}]	AVG of annual means	0.70	0.79	
	clear day	*0.54*	*0.72*	
RDF_{UV}	AVG of anuual means of daily RDF_{UV}	0.78	0.82	

Observation -- 2009: 12 days, 2010: 30 days, 2011: 75 days, 2012: 62 days, 2013: 70 days.
Clear day -- Representative clear day in every year.

(b)

		Norikura	Tsukuba	Difference to Tsukuba (%)
GL_{SL} (0.01 MJ/m^2)	AVG of annual means	1650	1808	-9
	clear day	*2846*	*2493*	14
DF_{SL} (0.01MJ/m^2)	AVG of annual means	876	916	-4
	clear day	*684*	*777*	-12
RDF_{UV} [DF_{SL}/GL_{SL}]	AVG of annual means	0.53	0.51	
	clear day	*0.24*	*0.31*	
RDF_{SL}	AVG of anuual means of daily RDF_{SL}	0.65	0.58	

Observation -- 2009: 12 days, 2010: 30 days, 2011: 15 days, 2012: 47 days, 2013: 69 days.
Clear day -- Representative clear day in every year.

The 5-years means of daily total UV (CIE) and daily total solar radiation in the observation period were calculated as Table 4 (a) and (b). The averages in clear days for those 5-years were added in the tables as well.

As shown in Table 4 (a), the 5-years mean of GL_{UV} at Norikura indicated the value of about +3% compared to the value at Tsukuba, however the mean at Norikura in clear day did the very higher value of about +40%. On the contrary, the 5-years mean of DF_{UV} at Norikura indicated the lower value of −8% compared to the value at Tsukuba, and the mean at Norikura in clear day was slightly higher value of +5%.

On the contrary, as shown in Table 4 (b), the 5-years mean of GL_{SL} at Norikura indicated slightly lower value of about −9% compared to the value at Tsukuba, however the mean at Norikura in clear day did the higher value of about +14%. The 5-years mean of DF_{SL} at Norikura indicated slightly lower value of −4% compared to the value at Tsukuba, and the mean at Norikura in clear day was lower value of −14%.

As mentioned above, in the case of comparison by the average of 5-years mean between the values at Norikura and Tsukuba, the above results point out that the UV radiation at Norikura on the high mountain do not always indicate the high irradiance. The reason was estimated by the weather condition that UV radiation and solar radiation were very much decreased by deep fog and many rain drops under the bad weather.

5.2 Diffusibility of UV (RDF_{UV}) and solar radiation (RDF_{SL})

The trends of minimum of daily diffusibility (RDF=DF/GL) of daily total UV radiation, e.g. as the CIE value, and the trends of minimum of daily diffusibility of daily total solar radiation at Norikura every day for five years are shown in Fig.8 (a) and (b), respectively.

In Fig.8 (a), RDF_{UV} at Norikura and Tsukuba are shown as the thin dot lines of violet and blue colors, respectively. The lower limit lines of each of those 2 factors are shown as the heavy lines of same colors. In Fig.8 (b), RDF_{SL} at Norikura and Tsukuba are shown as the same style as Fig.8 (a).

As shown in Fig.8 (a), the trend of lower limit line of RDF_{UV} at Norikura was kept the lower value from −10 to −20% compared to the trend of same line at Tsukuba. The minimum of RDF_{UV} at Norikura in the observation period indicated very low ratio of about 0.45, compared to the ratio of about 0.55 at Tsukuba. The trend of lower limit line of RDF_{UV} at Norikura in early July indicated the higher value compared to the trend at Tsukuba. As mentioned above **5.1**, the lower ratio was also due to the bad weather in rainy season, and the data of small number at Norikura.

Compare to the diffusibility of UV radiation mentioned above, as shown in Fig.8 (b), the trends of the diffusibility of solar radiation indicated very different patterns. The trend of lower limit line of RDF_{SL} at Norikura indicated slightly lower ratio from −5 to −10% compared to the trend of same line at Tsukuba. However, the ratios at Norikura sometimes indicated the higher ratio than the ratio at Tsukuba. The minimum of RDF_{SL} at Norikura in the observation period indicated slightly lower ratio of about 0.10, compared to the ratio of about 0.15 at Tsukuba.

The 5-years means of daily diffusibility (RDF_{UV}) of daily total UV radiation and daily diffusibility (RDF_{SL}) of daily total solar radiation in the observation period are calculated in Table 4 (a) and (b). The averages in clear days for those 5-years were added in the tables as well.

As shown in Table 4 (a), the 5-years mean of RDF_{UV} at Norikura indicated slightly lower value of about a few percentages compared to the value at Tsukuba. However the mean at Norikura in clear day indicated very low ratio of about 0.54 compared to the ratio of about 0.72 at Tsukuba.

On the contrary, as shown in Table 4 (b), the 5-years mean of RDF_{SL} at Norikura indicated slightly higher value of about a few percentages compared to the value at Tsukuba. However the mean at Norikura in clear day indicated slightly lower ratio of about 0.24 compared to the ratio of about 0.31 at Tsukuba.

As mentioned above, in the case of comparison by the average of 5-years mean between their diffusibility at Norikura and Tsukuba, the difference was not recognized, however it was markedly recognized in clear day.

6. UV spectra

The daily total GL_{UV} and DF_{UV} spectra at Norikura and Tsukuba are shown as overlaid spectra of annual means in the observation periods for five years in Fig.9.

In the figure, (a-1) and (a-2) are shown the daily total GL_{UV} spectra

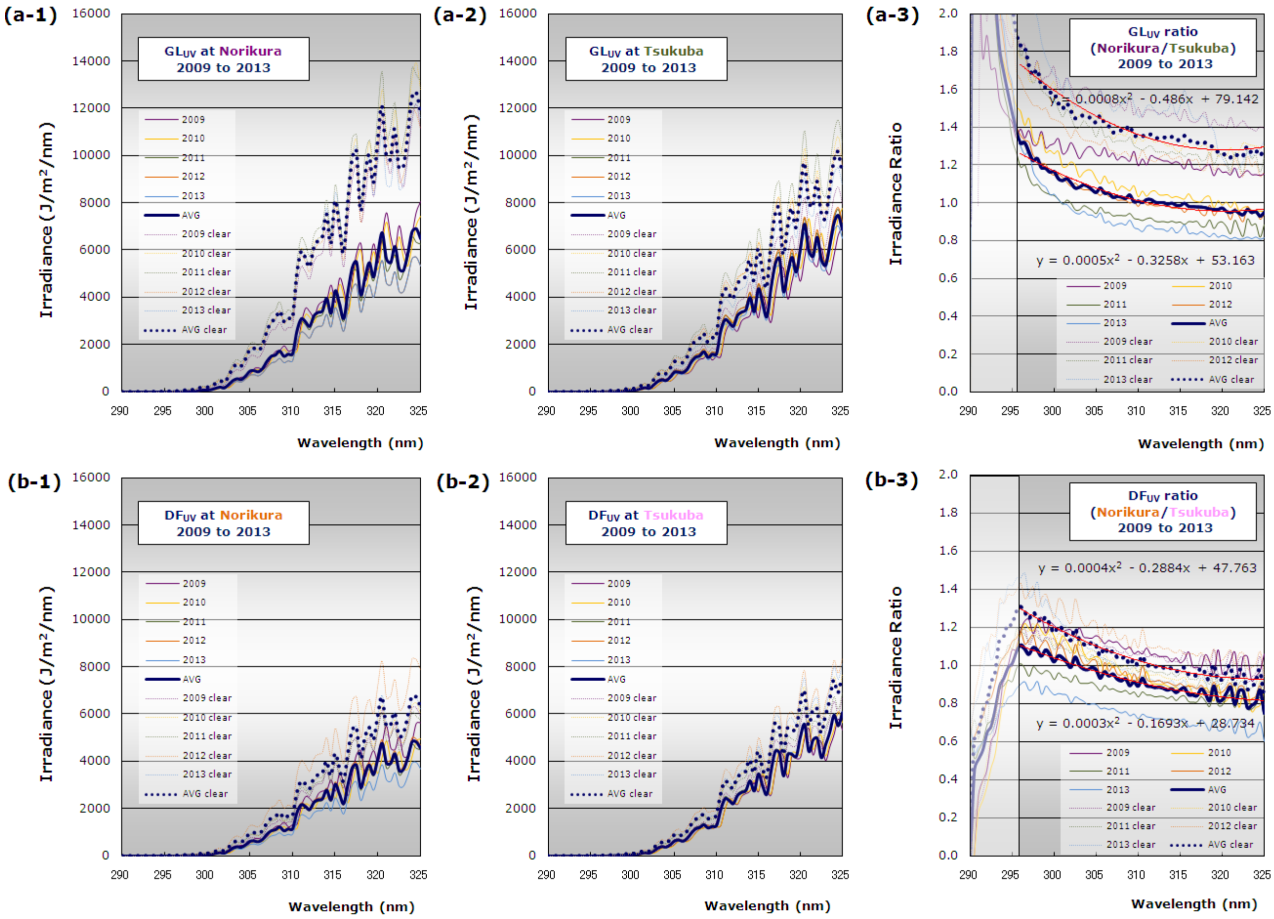

Fig. 9 Daily GL_{UV} spectra and GL_{UV} spectral ratios in the observation period, for five years, 2009 to 2013.
(a-1): GL_{UV} spectra at Norikura, (a-2): GL_{UV} spectra at Tsukuba and (a-3): GL_{UV} spectral ratios at Norikura versus the average of GL_{UV} spectra at Tsukuba. (b-1): DF_{UV} spectra at Norikura, (b-2): DF_{UV} spectra at Tsukuba and (b-3): DF_{UV} spectral ratios at Norikura versus the average of DF_{UV} spectra at Tsukuba. The heavy line of dark blue color shows an average spectrum for five years. The heavy dot line of dark blue color shows an average spectrum in clear day for five years.

Table 5 The daily total UV (CIE) spectral ratio at Norikura against Tsukuba for five years, from 2009 to 2013.

	Norikura / Tsukuba					
	300 nm	305 nm	310 nm	315 nm	320 nm	325 nm
GL_{UV} AVG	1.17	1.05	1.01	0.99	0.97	0.95
GL_{UV} AVG (clear day)	1.60	1.44	1.37	1.35	1.27	1.29
DF_{UV} AVG	1.02	0.98	0.89	0.87	0.82	0.75
DF_{UV} AVG (clear day)	1.17	1.10	1.00	0.98	0.93	0.84

at Norikura and Tsukuba, and (b-1) and (b-2) are shown the DF_{UV} spectra at Norikura and Tsukuba, respectively. The spectral irradiance ratios of the daily total GL_{UV} and DF_{UV} spectra at Norikura against to Tsukuba are shown in (a-3) and (b-3), respectively. The heavy lines of dark blue color in their figures show the 5-years mean of the spectra and the 5-years mean of the spectral irradiance ratios. The heavy dot lines of same color show the same spectra and the ratios in clear days. In addition, the results at the wavelength area under 297.0nm have low accuracy, due to the limitation of the measurement.

As shown in Fig.9 (a-1) and (a-2), the GL_{UV} spectra (heavy line) at Norikura indicated almost same intensities as Tsukuba, however the spectra (dot line) at Norikura indicated high intensities against to Tsukuba in clear days.

On the contrary, as shown in Fig.9 (a-3) and (b-3), the spectral irradiance ratios of the daily total GL_{UV} spectra and DF_{UV} spectra at Norikura increased in the short wavelength range. The difference between the spectral irradiance ratios (heavy line) in clear days and the spectral irradiance ratios (dot line) by all data, indicated the very high intensities from 30 to 40% in the case of GL_{UV}, and the high intensities from 10 to 20% in the case of DF_{UV}, at all wavelength range, respectively.

Those lines (heavy line and dot line) of spectral ratios in shown Fig.9 (a-3) and (b-3) could be approximated by following quadratic

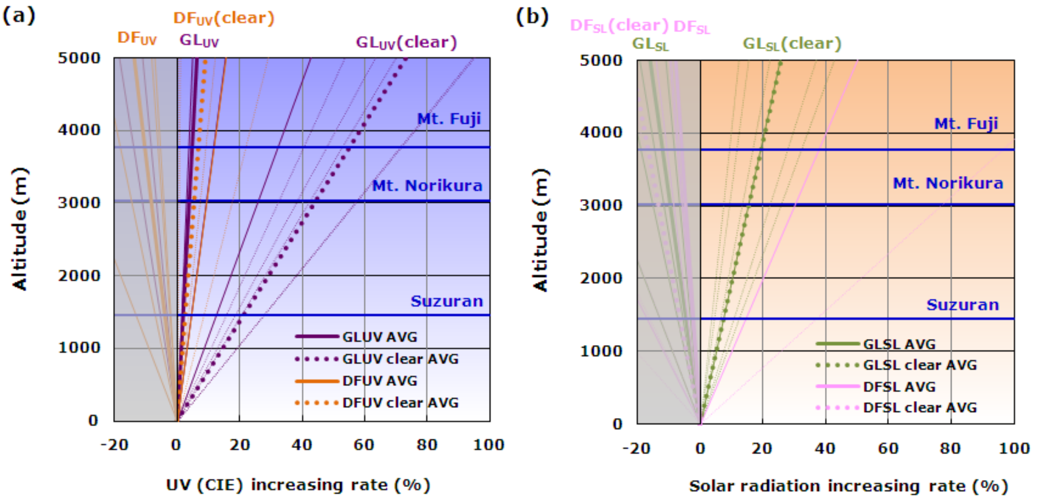

Fig. 10 UV (CIE) increasing rate and solar radiation increasing rate versus to the altitude, for five years, 2009 to 2013.
(a) and (b) show the UV (CIE) increasing rate and the solar radiation increasing rate. The heavy line indicates the average rate for five years, and the heavy dot line indicates the average rate in clear day.

Table 6 The average of UV (CIE) increasing rate and solar radiation increasing rate per 1,000m, for five years, 2009 to 2013.

	UV (CIE) % / 1,000m	Solar Radiation % / 1,000m
GL_{UV} AVG	1.3	-3.2
GL_{UV} AVG (clear day)	14.6	5.2
DF_{UV} AVG	-2.8	-1.6
DF_{UV} AVG (clear day)	1.8	-4.4

expressions of (1) to (4). The spectral irradiances at Norikura will be able to be estimated by these expressions.

$$R\ GL_{UV(AVG)} = 0.0008W^2 - 0.486W + 79.1 \quad \cdots\cdots(1)$$
$$R\ GL_{UV(clear)} = 0.0005W^2 - 0.326W + 53.1 \quad \cdots\cdots(2)$$
$$R\ DF_{UV(AVG)} = 0.0004W^2 - 0.288W + 47.8 \quad \cdots\cdots(3)$$
$$R\ DF_{UV(clear)} = 0.0003W^2 - 0.169W + 28.7 \quad \cdots\cdots(4)$$

AVG: average for five years

clear: average in clear days for five years

W: wavelength (nm) $297 \leqq W \leqq 325$nm

e.g.;

$$IR_{Norikura} = IR_{Tsukuba} * R\ GL_{UV\ (AVG)} \quad \cdots\cdots\cdots\cdots(5)$$

$IR_{Norikura}$ and $IR_{Tsukuba}$: Irradiance at Norikura and Tsukuba

Their main spectral ratios were shown in Table 5. The table clarified that the irradiance ratios, the value at Norikura against to Tsukuba, increased in the short wavelength range as follows; e.g. 1.29 at 325nm of GL_{UV}, 1.60 at 300nm of GL_{UV}, 0.84 at 325nm of DF_{UV}, 1.17 at 300nm of DF_{UV}, respectively.

7. Altitudinal increasing rate of GL_{UV} and GL_{SL}

The altitudinal increasing rates of GL_{UV} (e.g. as the CIE value) and GL_{SL} were calculated by the different data between Norikura and Tsukuba. Those results are shown in Fig.10 and Table 6.

The altitudinal increasing rate of GL_{UV} was estimated as the rate of +1.3% / 1,000m by using the 5-years means of all data, and the rate of +14.6% / 1,000m by using the 5-years means in clear days. On the contrary, The rate of GL_{SL} was estimated as the rate of −3.2% / 1,000m by using the 5-years means of all data, and the rate of +5.2% / 1,000m by using the 5-years means in clear days. In clear day, the increasing rate of GL_{UV} indicates about triple-values against to the rate of GL_{SL}.

On the other hand, the rate of DF_{UV} was estimated as the rate of −12.8% / 1,000m by using the 5-years means of all data, and the rate of +1.5% / 1,000m by using the 5-years means in clear days. On the contrary, The rate of DF_{SL} was estimated as the rate of −1.6% / 1,000m by using the 5-years means of all data, and the rate of −4.4% / 1,000m by using the 5-years means in clear days.

If the increasing rate were constant at every altitudes, the GL_{UV} could be estimated as the increase rate of about 60% on Mt. Fuji (3,776m) and about 20% on Norikura-highland (Suzuran hill town: 1,450m), against to ground level, respectively, by using above UV increasing rate. However, clarification of more accurate increasing rate is necessary for the future.

8. Conclusion

Purpose of the absolute calibration for Brewer spectrophotometers based on the concept of developing Regional Brewer Calibration Centre for Asia, and the study of total ozone and UV radiation by using Brewers on the high mountains, the observations of total ozone, the UV radiation and etc had been obtained at Norikura Observatory of the Institute for Cosmic Ray Research (ICRR), University of Tokyo.

In this paper, results of absolute calibration and observation with in last 5 years of summer seasons, from 2009 to 2013 are summarized as follows;

(1) Absolute calibrations for total O3 and total SO2 observations

By the absolute calibrations of Brewers for total O3 and total SO2 observations, O3 and SO2 Extra-Terrestrial Coefficients (=ETC) of BR#174 and BR#113 could be produced as about 10 samples every year. The representative coefficients of O3 ETC had been stable and identical within 1% to the currently used coefficients for five years. Therefore, the absolute calibration of Brewers can be useful at Norikura.

(2) Total O3 and total SO2

The variation of 5-years mean of daily O3 at Norikura for the season from July to September showed the low value of about −4% compared to the value at Tsukuba in ground level. However the difference had been smaller in late September. On the other hand, the same daily SO2 was not recognized, because the logged data had been indicated the very low values due to the limitation of the measurement.

(3) Global UV (GL_{UV}), diffuse UV (DF_{UV}), global solar radiation (GL_{SL}) and diffuse solar radiation (DF_{SL})

The 5-years mean of daily total GL_{UV} (e.g. CIE) at Norikura for the season indicated the value of about +3%, but the value in clear day was high value of about +40%, compared to the value at Tsukuba. On the contrary, the daily total DF_{UV} at Norikura indicated the value of about −8%, however the value in clear day indicated the value of about +5%, compared to the value at Tsukuba.

On the other hand, the 5-years mean of daily total GL_{SL} at Norikura for the season indicated the value of about −9%, but the value in clear day was high value of about +14%, compared to the value at Tsukuba. On the contrary, the daily total DF_{SL} at Norikura indicated the value of about −4%, however the value in clear day indicated the low value of about −14%, compared to the value at Tsukuba.

(4) Diffusibility of UV (RDF_{UV}) and solar radiation (RDF_{SL})

The 5-years mean of daily UV (e.g. CIE) diffusibility, RDF_{UV} (DF_{UV}/GL_{UV}), at Norikura indicated the very low value of about 0.54 (54%) compared to the value of about 0.72 (74%) at Tsukuba, in clear day, respectively. On the other hand, the 5-years mean of daily diffusibility of solar radiation, RDF_{SL} (DF_{SL}/GL_{SL}), at Norikura indicated slightly lower value of about 0.24 (24%) compared to the value of about 0.31 (31%) at Tsukuba, in clear day, respectively.

(5) UV spectra

The UV spectral irradiance of GL_{UV} increased in the short wavelength range at Norikura compared to the value at Tsukuba, and showed the ratio to the value at Tsukuba as follows; e.g. as the GL_{UV}: about 1.29 at the wavelength of 325nm, about 1.60 at 300nm, e.g. as the DF_{UV}: 0.84 at 325nm, 1.17 at 300nm, in clear day, respectively. The spectral irradiance at Norikura could be estimated by the approximate expression using the spectral data at Tsukuba.

(6) Altitudinal increasing rate of GL_{UV} and GL_{SL}

The altitudinal increasing rate of GL_{UV} (e.g. CIE) in the clear day indicated the calculated amounts of about +14.6% per 1,000m. On the contrary, the rate of GL_{SL} in the clear day indicated the value of about +5.2% per 1,000m.

These calibrations and observations for five years had clarified the availability of absolute calibration for Brewers at Norikura, and many characteristics of O3 and UV radiation on the high mountains. The continuous observations with Brewers and other instrument at Norikura are very important for the clarification of the seasonal variation of O3 and UV, the coefficient trends of Brewers, the procedure of highly accurate altitudinal increasing rate of UV, and etc. in the future.

The summaries in this paper were presented at "the Meetings for Presenting the Results of Inter-University Research" of ICRR in 2013, and "the 13th WMO Biennial Brewer Workshop, Beijing, China" in 2011.

Acknowledgment

We would like to thank Dr. V. Savastiouk, Mr. T. Grajnar and Mr. M. Brohart of ARQX of Environment Canada and Dr. A. Redondas of the RBCC-E (Meteorological State Agency, Spain), for the advices with the absolute calibrations. Also, we thank Mr. K. Yamamoto, Mr. Y. Agematsu, Mr. T. Ushimaru, Dr. C. Tokoku, Dr. N. Okazaki and Ms. Y. Kokubun of the Norikura Observatory, ICRR, Mr. M. Shitamichi of the previous Director , Mr. T. Jomura of the Director and the staffs of Aerological Observatory, and the staff of Ozone Layer Monitoring Office, JMA.

References

Fioletov, V.E., J.B.Ker, C.T. McElroy, D.I.Wardle, V. Savastiouk and T.S. Grajnar (2005) : The Brewer reference triad. *Geophysical Research Letters*, **Vol. 32**, L20805, 1 - 4.

Ito, M., T. Grajnar, M. Brohart, V. Savastiouk and K. Lamb (2007) : Intercomparison of Brewer Spectrophotometers between MSC and JMA at Toronto, Canada in 2006 and accuracy of MSC, IOS and JMA systems for NIST lamp calibration. *Jour. of Aerological Observatory*, **67**, 39 - 52.

Ito, M., T. Grajnar, M. Brohart and V. Savastiouk (2011) : Intercomparison of Brewer spectrophotometers between the Meteorological Service of Canada and the Japan Meteorological Agency at Toronto, Canada in 2010. *Jour. of the Aerological Observatory*, **69**, 33 - 40.

Ito, M., M. Takano, H. Oguri, M. Takita, H. Shimodaira, H. Ishitsuka (2011) : Observations of total ozone and UV solar radiation with Brewer spectrophotometers on the Norikura mountains in 2009. *Jour. of the Aerological Observatory*, **69**, 41 - 54.

Ito, M., S. Shimizu, Y. Noto, T. Shimamura, M. Takita, H. Shimodaira and H. Ishitsuka (2012) : Total ozone and UV solar radiation with Brewer spectrophotometers at Norikura station on the Japanese high mountain in recent three years. *Jour. of the Aerological Observatory*, **70**, 51 - 60.

Ito, M., O. Ijima, T. Shimamura, I. Uesato, Y. Noto, Y. Esaki and N. Oshiki (2013) : Seasonal variations of global, reflected, and diffuse spectral UV observations based on Brewer Spectrophotometers at Tsukuba, 2004 to 2012. *Jour. of the Aerological Observatory*, **71**, 51 - 62.

Kipp & Zonen (1996) : Brewer MKIII Spectrophotometer Final Test Record, BR#174. *Kipp & Zonen Inc.*, 75pp.

Kipp & Zonen (2008a) : Brewer MKIII Spectrophotometer Operators Manual. *Kipp & Zonen Inc.*, 132pp.

Kipp & Zonen (2008b) : Brewer MKIII Spectrophotometer Service Manual. *Kipp & Zonen Inc.*, 125pp.

McElroy, C.T., V. Savastiouk and T. Grajnar (2008) : Standard operating procedures manual for the Brewer Spectrophotometer, Ver. D.01. *Environment Canada*, 138pp.

Redondas, A. (2002) : Izana atmospheric observatory, ozone absolute calibration, langley regression method. *Ozone Absolute Calibration _update.pdf.*, 32pp.

Redondas, A. (2005) : Regional Brewer Calibration Centre – Europe (RBCC-E): results and first test-campaign. *Edited by C. T. McElroy and E. W. Hare. The Ninth Biennial WMO Consultation on Brewer Ozone and UV Spectrophotometer Operation, Calibration and Data Reporting., Gaw Report*. No.**175** (WMO TD No.1419), 12 - 13.

Redondas, A. (2007) : Ozone absolute Langley calibration. *Edited by C. T. McElroy and E. W. Hare. The Tenth Biennial WMO Consultation on Brewer Ozone and UV Spectrophotometer Operation, Calibration and Data Reporting., Gaw Report*. No.**176** (WMO TD No.1420), 12 - 14.

WMO/GAW (2010) : Recommendations of the SAG-Ozone meeting 2010. *Minutes of the WMO-GAW SAG-Ozone meeting 2010*, 5pp.

WMO/RBCC-E (2008) : RBCC-E Arosa 2008 Calibration Report, (Calibration Summary, 11pp. Redondas A.: Brewer #017 25pp., #040,#064, #072, #156 and #163 Calibration Report).

WMO/RBCC-E (2010) : RBCC-E Arosa 20108 Calibration Report, (Redondas A.: Brewer #040, 27pp., #064, #072, #156 and #163 Calibration Report).

北アルプス乗鞍におけるブリューワー分光光度計の絶対検定とオゾン・紫外線の観測

伊藤 真人*・上里　至*・能登 美之*・居島　修*・清水 悟*・瀧田 正人**・下平 英明**・石塚 秀喜**

要旨

高層気象台では，ブリューワー分光光度計アジア地区校正センター構築構想と，高山におけるオゾン全量(Total O3)と紫外線(UV)の研究を目的とし，東京大学宇宙線研究所との共同研究「ブリューワー分光光度計を使用したオゾン・紫外線の観測」を2009年より同研究所付属乗鞍観測所(観測地点：36.11 N, 137.56 E, 2,772 m a.s.l)において開始した(伊藤ほか：2011，2012)．本稿では，過去5年間の観測データを解析し，下記の結果を得た。

(1) オゾン全量(Total O3)と二酸化硫黄全量(Total SO2)観測用常数の絶対検定については，過去5年間とも，毎年10サンプル程度の常数を取得することができ，5年間のBR#174とBR#113のこれらの常数は，現在使用中の常数に対しほぼ1%以内で安定に推移した．(2) 乗鞍のオゾン全量(Total O3)は，過去5年間，平地のつくばのオゾン全量(Total O3)に対し，約4%低く推移するが，9月下旬には両者の差が小さくなる．(3) 乗鞍の全天紫外線量(GL_{UV})の5年平均値は，つくばに対し約+3%程度であるが，晴天日では約+40%となる．(4) 晴天日の紫外線散乱率(RDF_{UV})の5年平均値は，乗鞍が約0.54，つくばが約0.72となり，乗鞍では非常に低い値となる．(5) 乗鞍のつくばに対する5年平均紫外線スペクトル照度は短波長域で増大し，晴天の場合，325nmで29%増，300nmで60%増となる．(6) 高度による紫外線(GL_{UV})増加率は，晴天の場合，14.6%/1,000mとなった．

過去5年間の観測により，乗鞍においてBrewerの観測用常数の絶対検定が可能であること，また乗鞍のような高地における波長別紫外線量や日射量の推移が詳細に把握されるようになってきた．特に，乗鞍では平地よりもオゾン全量が少な目に推移し，晴天日には短波長域の紫外線量が非常に強く，その散乱成分については少ないということ等が明らかとなった．今後，乗鞍においてより長期間のデータを取得し，オゾンや紫外線量の季節変化や経年変化を把握するとともに，ブリューワー分光光度計の観測用常数の経年変化を監視する必要がある．

* 気象庁 高層気象台 観測第三課．**東京大学 宇宙線研究所．