[Technical report]

Altitudinal Increasing Rate of UV radiation by the Observations with Brewer Spectrophotometers at Norikura, Suzuran and Tsukuba

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Abstract

The altitudinal increasing rates of the UV radiations were elucidated by the observations with Brewer spectrophotometers at Norikura (2,772 m a.s.l) locating in the Northern Japanese Alps, and at Tsukuba (39 m a.s.l.), every summer season for six years from 2009 to 2014, and the same observation at Suzuran (1,455 m a.s.l.) in summer season, 2014. Results of those observations are summarized below.

(1) By the comparative data of "Norikura to Tsukuba", locating at almost same latitude for six years, the altitudinal increasing rate of the UV radiation (CIE) in clear day was calculated as the value of about +14.4%/1,000 m. Accuracy of the rate was verified by the observation data at Suzuran that is locating very close to the Norikura site, in particular the comparative data of "Norikura to Suzuran". (2) The altitudinal increasing rates of the UV irradiances at every wavelength could be calculated by the comparative data of "Norikura to Tsukuba". As a result, it was clarified that the altitudinal increasing rates of the UV irradiances could be classified to 3 elements of the GL_{UV} (global UV), the DF_{UV} (diffused UV) and the DH_{UV} (direct (horizontal) UV) at every wavelength, and could be calculated by the simple approximate expressions such as $Y = 0.0204\ X^2 - 13.169\ X + 2134.7$ (Y: increasing rate of GL_{UV} (%/1,000 m), X: wavelength (nm), $295 \leqq X \leqq 325$ nm). (3) The irradiance rates of the integrated UV radiations of TUV, UVB, DUV and CIE, and of the UV irradiances at every wavelength by the comparative data of "Norikura to Suzuran" in clear day did not show the daily variation. Therefore, the altitudinal increasing rates are estimated to indicate constant rates in all the day.

In this paper, the altitudinal increasing rates of the integrated UV radiations and the UV irradiances at every wavelength could be elucidated. And the increasing rates at every wavelength could be calculated briefly by using the approximate expressions. However, observations by using high accurate instruments of Brewer MKIII type at those sites are necessary in the future. Moreover the study of seasonal variation of the increasing rate is also very important.

1. Introduction

Some reports clarified the altitudinal increasing rate of UV as 10 to 20% per 1,000 m (WHO: 2002, MOE: 2004). However, precise measurements reports of the UV spectral irradiance on the high mountains were very rare (e.g. McKenzie *et al.*: 2001) and such precise steady observation of each individual wavelength has never been carried out in Japan

On the other hand, 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), the University of Tokyo at the Norikura Observatory of ICRR (36.11 N, 137.56 E, 2,772 m a.s.l), in the Northern Japanese Alps, for (1) the concept of planning of the regional Brewer calibration centre for Asia and (2) the study of total ozone and UV solar radiation on the high mountains (Ito *et al.*: 2011, 2012, 2014). The joint project was clarified the results, (1) the 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.), (2) the daily total GL_{UV} (CIE) at Norikura for the season indicated the high value of +40% in clear day compared to the value at Tsukuba, (3) the daily UV (CIE) diffusibility, RDF_{UV} ($=DF_{UV}/GL_{UV}$), at Norikura in clear day indicated the very lower value compared to the value at Tsukuba, etc.

However, the study for calculate of the altitudinal increasing rate of UV radiation in high accuracy at every wavelength is important for the high accuracy products of the information of UV forecast and the climatic modeling. Since the distance between highland of Norikura and lowland of Tsukuba is about 150 km, although both sites locating at almost same latitude, confirmation of the observation at lowland, near the Norikura site is necessary in order to validate the comparative data of "Norikura to Tsukuba". Therefore, new observation was started at Suzuran (Suzuran branch office of Norikura Observatory, ICRR, 36.12 N, 137.63 E, 1,455 m a.s.l.), since the summer season in 2014.

In this paper, the altitudinal increasing rates of the integrated UV radiations and the UV irradiance at every wavelength are elucidated by using the comparative data of "Norikura to Tsukuba" in summer season for six years from 2009 to 2014, and the results are confirmed by using the data at Suzuran.

The symbols used in this paper are defined in Table 1. Please refer to Ito *et al.* (2014) 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.

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Photo 1 Brewer observation sites.

(a) Norikura: Norikura Observatory of ICRR (Institute for Cosmic Ray Research), the University of Tokyo, 36.11 N, 137.56 E, 2,772 m a.s.l., on the Norikura mountains, (b) Suzuran: Suzuran branch office of Norikura Observatory, ICRR, 36.12 N, 137.63 E, 1,455 m a.s.l., at Norikurakogen and (c) Tsukuba: Aerological Observatory, JMA, 36.06 N, 140.13 E, 39 m a.s.l, at Tsukuba.

2. Observation sites, and instruments

2.1 Observation sites

Brewer spectrophotometers are located at three sites, Norikura, Suzuran and Tsukuba shown in Photo 1. These three sites are located at almost same latitudes in direction of east-west. However the Tsukuba site is located at the long distance of 150 km from the Norikura site. The Suzuran site is locating very close from Norikura site. It is locating east direction from Norikura and the distance is about 7 km.

2.2 Observations and instruments

The classification of observations and instruments are shown in Table 1. Brewer MKII #060 was mainly used for the observations of GL_{UV} (global UV) and DF_{UV} (diffused UV) at Norikura. Brewer MKII #052 was used for the observation of GL_{UV} at Suzuran. Brewer MKIII #200 and MKII #058 were used for the observations of GL_{UV} and DF_{UV} at Tsukuba.

The observations of GL_{SL} (global solar radiation) and DF_{SL} (diffused solar radiation) at Norikura and Tsukuba used pyranometers CM21/22 and pyrheliometers CH1/CHP1, respectively.

The observations of DF_{UV} and DF_{SL} at Norikura and Tsukuba did with the automate shadow units and the equatorial mounting.

2.3 Progress of Observation

The progresses of observation from 2009 to 2013 are shown in the former report (Ito *et al.*: 2014). The observation in 2014 was almost same as the observation in 2013. 63 days of observation data of GL_{UV} and DF_{UV} at Norikura, and 79 days of the data of GL_{SL} and DF_{SL} at Norikura, and 45 days of observation data of GL_{UV} at Suzuran were obtained in the summer season of this year respectively. Routine observation values were used for the observation data of GL_{UV}, DF_{UV}, GL_{SL} and DF_{SL} at Tsukuba.

Table 1 Observations and instruments.

Observation	Symbol	Contents
UV Radiation	GL_{UV}	Global UV radiation J/m^2
	DF_{UV}	Diffuse UV radiation J/m^2
	TUV	Total UV (290 to 325 nm) radiation J/m^2
	UVB	Total UV (290 to 315 nm) radiation J/m^2
	DUV	Damaged UV radiation J/m^2
	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
	DH_{SL}	Direct-horizontal solar radiation kJ/m^2

Instrument		Observations
Brewer Spectrophotometers		
BR#060	Norikura	GL_{UV} and DF_{UV} (ds O_3 and ds SO_2)
BR#052	Suzuran	GL_{UV} (ds O_3 and ds SO_2)
BR#200	Tsukuba	GL_{UV} (ds O_3 and ds SO_2)
BR#058	Tsukuba	DF_{UV} (ds O_3 and ds SO_2)
Pyranometer		
CM21	Norikura	DF_{SL} [$GL_{SL}=DF_{SL}+DH_{SL}$]
CM22	Tsukuba	DF_{SL} [$GL_{SL}=DF_{SL}+DH_{SL}$]
Pyrheliometer		
CH1	Norikura	DH_{SL}
CHP1	Tsukuba	DH_{SL}

3. The trend of UV radiation (e.g. CIE) for six years

The trends of daily means (the seven day-running means) and maximums of daily total UV radiation (e.g. CIE) for six years from 2009 to 2014 are shown in Fig.1 (a), and the same trends of daily total solar radiation were shown in Fig.1 (b).

In Fig.1 (a), the daily means of the daily totals of GL_{UV} (global UV) at Norikura, DF_{UV} (diffused UV) at Norikura, GL_{UV} at Tsukuba, and DF_{UV} at Tsukuba are indicated as the heavy lines of violet, orange green and pink colors, and the these maximums are indicated as the dot lines with the same colors, respectively.

In Fig.1 (b), the daily means and the maximums of solar radiations, GL_{SL} (global solar radiation) and DF_{SL} (diffused solar radiation), at Norikura and Tsukuba, are indicated as same of Fig.1 (a). The trend of daily total GL_{UV} at Suzuran in 2014 is added as the thin line of blue color in Fig.1 (a). The observation of solar radiation is not implemented at Suzuran.

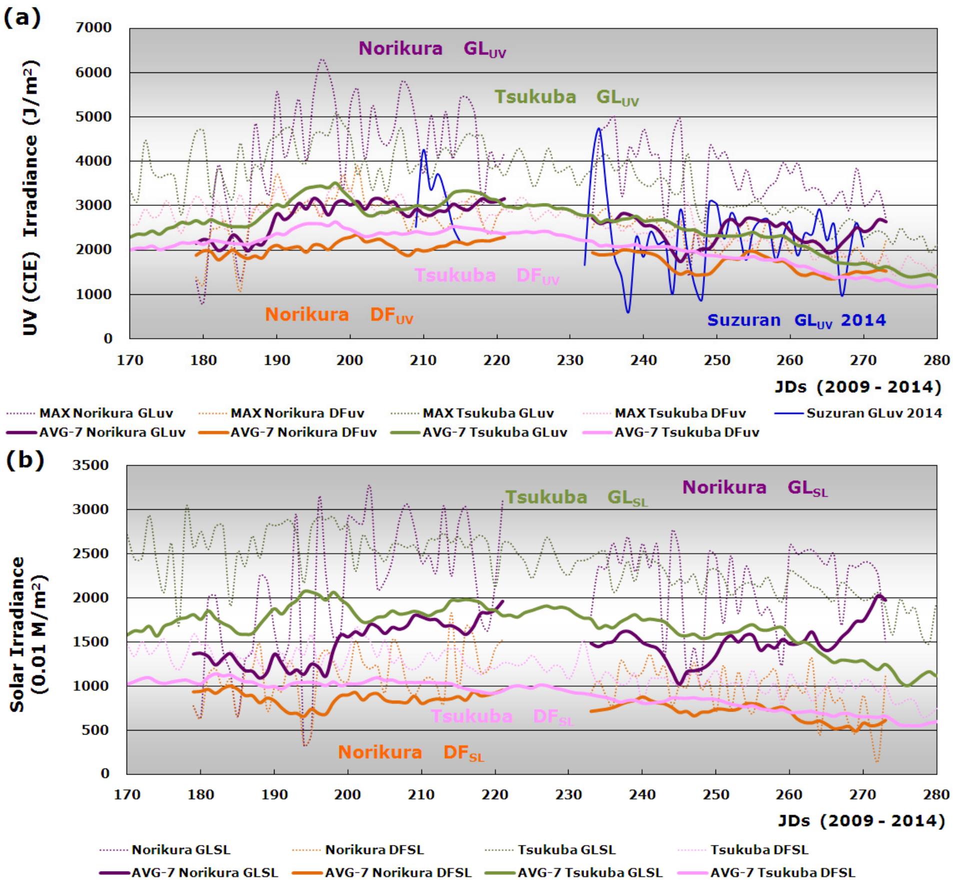

Fig. 1 The trends of UV (CIE) radiations and solar radiations from 2009 to 2014, at Norikura, Suzuran and Tsukuba.
Figures of (a) and (b) show the UV (CIE) radiation with Brewer spectrophotometers (#052, #058, #060 and #200) and the solar radiation with pyranometer CM21 (CM22) and pyrheliometer CH1 (CHP1) respectively. The heavy lines show the seven day-running means of the average of daily total irradiance for six years, from 2009 to 2014. The dot lines show the maximum of daily total irradiance for six years from 2009 to 2014. GL_{UV}, DF_{UV}, GL_{SL} and DF_{SL} indicate the global UV (CIE), the diffused UV (CIE), the global solar radiation and the diffused solar radiation respectively.

As shown in Fig.1 (a), the trend of daily means of daily total GL_{UV} at Norikura indicated almost same value as the trend at Tsukuba. The trend of daily means of daily total DF_{UV} at Norikura indicated the lower value compared to the trend at Tsukuba.

On the contrary, the trend of maximums of daily total GL_{UV} at Norikura indicated the higher value compared to the trend at Tsukuba. However, the trend at Norikura in late June to early June (180 to 190 JDs) showed the lower value compared to the trend at Tsukuba, due to the effect of bad weather in rainy season. The trend of maximums of daily total DF_{UV} at Norikura indicated the almost same as the value at Tsukuba.

As shown in Fig.1 (b), the trends of GL_{SL} and DF_{SL} showed the different variations compared to the trends of GL_{UV} and DF_{UV}.

The means of daily total UV radiation and solar radiation for six years are summarized in Table 2. The means in clear day are added in the tables as well. As shown in Table 2, the mean of GL_{UV} at Norikura for six years indicates the almost same values compared to the mean at Tsukuba. However, the mean at Norikura in clear day shows the high value of about +39% compared to the mean at Tsukuba.

Table 2 Means of the daily total UV (CIE) with Brewer spectrophotometers and the daily total solar radiation with pyranometers and pyrheliometers at Norikura and Tsukuba, summer season for six years from 2009 to 2014.

(a)

		Norikura	Tsukuba	Difference to Tsukuba (%)
GL_{UV} (J/m²)	AVG of annual means	2728	2706	1
	clear day	*5573*	*4000*	39
DF_{UV} (J/m²)	AVG of annual means	1936	2138	-9
	clear day	*2933*	*2894*	1

(b)

		Norikura	Tsukuba	Difference to Tsukuba (%)
GL_{SL} (0.01 MJ/m²)	AVG of annual means	1613	1782	-10
	clear day	*2854*	*2471*	16
DF_{SL} (0.01MJ/m²)	AVG of annual means	859	915	-6
	clear day	*674*	*824*	-18

The mean of DF_{UV} at Norikura for six years indicates the low value of about -9% compared to the mean at Tsukuba. The mean at Norikura in clear day shows the almost same value compared to the mean at Tsukuba. On the contrary, the difference of the means of solar radiations, GL_{SL} and DF_{SL}, between Norikura and Tsukuba shows the different values compared to the means of UV radiations.

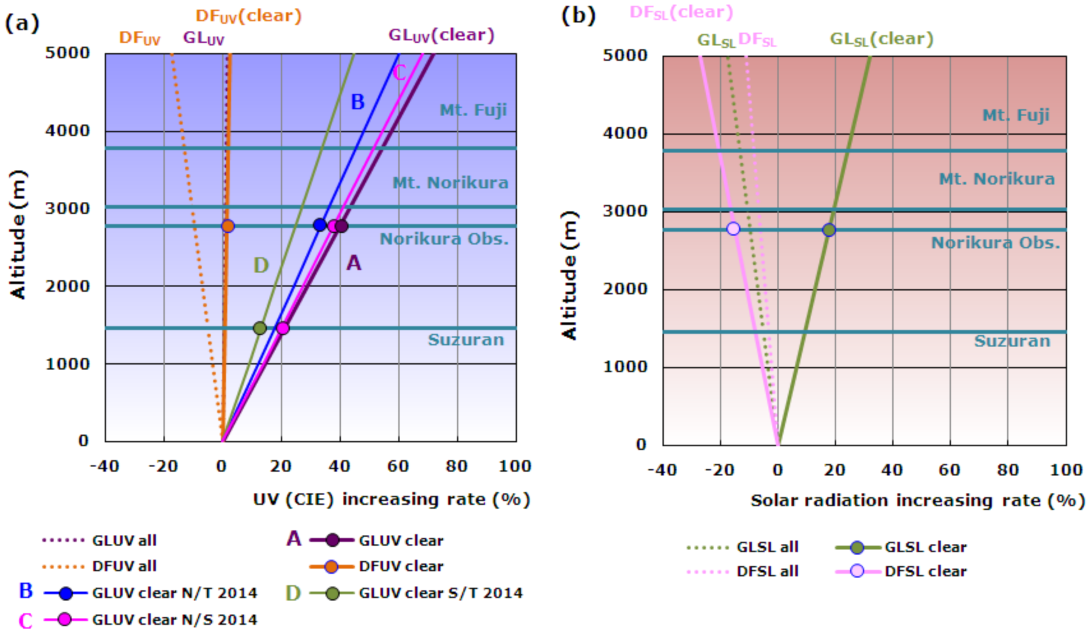

Fig. 2 The altitudinal increasing rates of the UV (CIE) radiation and the solar radiation by using the data, summer season for six years from 2009 to 2014. Figure (a) shows the rate of the UV (CIE) radiation, and figure (b) shows the rates of the solar radiation increasing rate. The heavy lines indicate the rates by using the data in clear day, and the heavy dot lines indicate the rates by using the all data. "A" heavy line shows the rate of UV (CIE) by using the comparative data of "Norikura to Tsukuba" in clear day for six years from 2009 to 2014. "B", "C" and "D" heavy lines show the rates of UV (CIE) by using the comparative data of "Norikura to Tsukuba", "Norikura to Suzuran" and "Suzuran to Tsukuba" for five fine days in 2014, respectively.

4. The altitudinal increasing rate of the integrated UV radiation

The former report (Ito *et al.*: 2014) clarified the altitudinal increasing rate of GL_{UV} (global UV: e.g. CIE) as the value of about +14.6% /1,000 m in clear day by using the comparative data of "Norikura to Tsukuba". However, the distance between Norikura site and Tsukuba site is about 150 km. Therefore, afore mentioned increasing rate needed to be confirmed by using the data at Suzuran site (locating 7 km from Norikura site).

The altitudinal increasing rates was recalculated from the comparative data of "Norikura to Tsukuba" in summer season for six years from 2009 to 2014 and the results were shown in Fig.2. In Fig.2 (a), the increasing rates of GL_{UV} (global UV of CIE) and the DF_{UV} (diffused UV of CIE) in clear day are indicated as the heavy line of violet and orange colors respectively. These rates of means for six years are done as the dot line of same colors. In the Fig.2 (b), the increasing rates of GL_{SL} (global solar radiation) and the DF_{SL} (diffused solar radiation) are indicated as the heavy line of green and pink colors respectively. Means of those rates for six years are indicated as the dot line of the same colors as well. Those rates of increase are almost same as the values of Ito *et al.* (2014).

On the other hand, the altitudinal increasing rates were calculated by using the mean of daily total UV at Norikura, Suzuran and Tsukuba for five fine (not clear) days in 2014. These rates are indicated as the lines of "B", "C" and "D" in Fig.2 (a). The heavy line "A" of violet color indicates the increasing rate calculated by afore comparative data of "Norikura to Tsukuba" in clear day for six years.

The heavy lines "B" of blue color, "C" of pink color and "D" of green color indicate the increasing rates calculated by using the comparative data of "Norikura to Tsukuba", "Norikura to Suzuran" and "Suzuran to Tsukuba", respectively. These increasing rates are shown as follows.

"A" = +14.4% "Norikura to Tsukuba" (in "clear" days from 2009 to 2014)
"B" = +12.0% "Norikura to Tsukuba" (five "fine" days in 2014)
"C" = +13.6% "Norikura to Suzuran" (five "fine" days in 2014)
"D" = + 8.9% "Suzuran to Tsukuba" (five "fine" days in 2014)

As mentioned above, increasing rates of "B" was slightly lower value, "C" was almost the same value, and "D" was lower value, compared to the rate of "A", respectively.

The rate of "C" verified the availability of the rate of "A" by using the comparative data of "Norikura to Tsukuba" in "clear" day, because the rate of "C" calculated by using the comparative data of "Norikura to Suzuran" that is locating close each other, under the consideration which (1) "C" was calculated by the data in five "fine" days and (2) the open sky area at Suzuran site is slightly lower than the same area at Norikura site.

The reason that the rate of "B" by using the comparative data of "Norikura to Tsukuba" shows a slightly lower value compared to the rate of "A" is estimated due to above (1).

5. The altitudinal increasing rates of the UV irradiances at every wavelength

As the effectiveness of altitudinal increasing rate of UV (integrated UV) by the comparative data of "Norikura to Tsukuba" was verified in Section 4, the rates at every wavelength are produced by the same data as follows. The rates calculated by using the all data for six years are shown in Fig.3, and the rates by using the data in clear day for six years are shown in Fig.4. These rates are summarized in Table 3.

The case by using all data (Fig.3 and Table 3)

The altitudinal increasing rates of GL_{UV} (global UV) of TUV, UVB, DUV and CIE, included solar radiation calculated by using the all data are shown in Fig.3 (a-1). As shown in this figure, most of the rates of increase became negative values. In addition, increasing rate of afore mentioned 5 integrated values became higher with the order of DUV > CIE > UVB > TUV > solar radiation. This order elucidates that the integrated UV of the higher content of UV irradiance at shorter wavelength indicates the higher increasing rate.

The altitudinal increasing rates at every wavelength are shown in Fig.3 (a-2). The rates at shorter wavelength indicate higher values. However, it was recognized that that order was partially reversed, e.g. the rate of increase at the wavelength of 305.0 nm indicated slightly lower value than at the wavelength of 305.5 nm. Therefore, by a definition of "the rates uniformly increase at shorter wavelength as shown as a smooth curve", the rates at wavelength of 290 to 325 nm were recalculated by using an approximate expression made by the accurate data at wavelength of 300 to 325 nm. The approximate expression is shown in Fig.3 (a-3), and the recalculated rates at every wavelength are done in Fig.3 (a-4), respectively.

The recalculated rates indicate the higher value at shorter wavelength with uniformly is shown in Fig.3 (a-4). The rate changes from positive to negative values at the wavelength of about 310 nm. However, as the UV irradiance under wavelength of 300 nm is estimated to not almost observe on the ground surface, the rates under the wavelength of 300 nm need to be confirmed by the observation by using high accurate instrument of Brewer MKIII type instruments.

The rates of DF_{UV} (diffused UV) are shown in Fig.3 (b-1) to (b-4), as the same of GL_{UV}. The rate changes from positive to negative values at the wavelength of about 302 nm.

The rates of DH_{UV} (direct (horizontal) UV) calculated by using the data of GL_{UV} and DF_{UV} are shown in Fig.3 (c-1) to (c-4) too. All rates of DH_{UV} indicate positive values. However, the rates of DH_{UV} at the shorter wavelength do not indicate the uniformly higher values.

The case by using the data in clear day (Fig.4 and Table 3)

The altitudinal increasing rates of GL_{UV} of TUV, UVB, DUV and CIE, included solar radiation calculated by using the data in clear day are shown in Fig.4 (a-1). As shown in this figure, all rates of increase became positive values. Increasing rate of afore mentioned 5 integrated values became higher with the order of DUV > CIE > UVB > TUV > solar radiation as shown in Fig.3 (a-1).

The rates at every wavelength in clear day are shown in Fig.4 (a-2). All of those rates at wavelength of 290 to 325 nm indicate positive values, and the rates at shorter wavelength indicate the higher values as the same of Fig.3 (a-2).

The approximate expression in clear day is shown in Fig.4 (a-3), and the recalculated rates at every wavelength are shown in Fig.4 (a-4), respectively. In Fig.4 (a-4), the rates at shorter wavelength indicates higher values, e.g. about 10%, about 13% and about 20% per 1,000 m at the wavelength of 325, 310 and 300 nm, respectively.

The rates of DF_{UV} in clear day are shown in Fig.4 (b-1) to (b-4) as the same of GL_{UV}. The rate changes from positive to negative values at the wavelength of about 309 nm.

The rates of DH_{UV} (direct (horizontal) UV) calculated by using the data of GL_{UV} and DF_{UV} in clear day are shown in Fig.4 (c-1) to (c-4). The rates of DH_{UV} indicate very the higher values compared to the rates of GL_{UV} and DF_{UV}.

The approximate expressions of the altitudinal increasing rates in clear day are summarized as follows.

GL_{UV} increasing rate per 1,000 m

$$Y = 0.0204\,X^2 - 13.169\,X + 2134.7 \quad \cdots\cdots \quad (1)$$

DF_{UV} increasing rate per 1,000 m

$$Y = 0.0136\,X^2 - 8.9033\,X + 1452.0 \quad \cdots\cdots \quad (2)$$

DH_{UV} increasing rate per 1,000 m

$$Y = 0.0569\,X^2 - 35.388\,X + 5552.0 \quad \cdots\cdots \quad (3)$$

X: wavelength (nm) $295 \leqq X \leqq 325$ nm

By using these expressions, the altitudinal increasing rates at any wavelengths can be produced as follows, e.g. on the mountain top of Mt. Fuji (3,776 m a.s.l.), the rates at the wavelength of 325, 315, 305 and 295 nm show the values of 35, 41, 60 and 94%, respectively. However, as mentioned above, the rates under the wavelength of 300 nm need to be confirmed by the accurate observation by using Brewer MKIII type instruments.

6. The daily change of the altitudinal increasing rate of the UV radiation

The altitudinal increasing rates of UV irradiances at every wavelength could be estimated by Section 5. In this Section, the daily change of the rates included the rates of integrated UV radiation are elucidated.

The daily changes of GL_{UV} (CIE) at Norikura, Suzuran and Tsukuba in 264 JD, 2014, are shown in Fig.5. The irradiance ratios are shown in Fig.6, as the ratios of (a) "Norikura / Tsukuba", (b) "Suzuran / Tsukuba" and (c) "Norikura / Suzuran", respectively. The weathers at these three sites in 264 JD AM were in fine, but the weathers in PM were in cloudy depend on the locations.

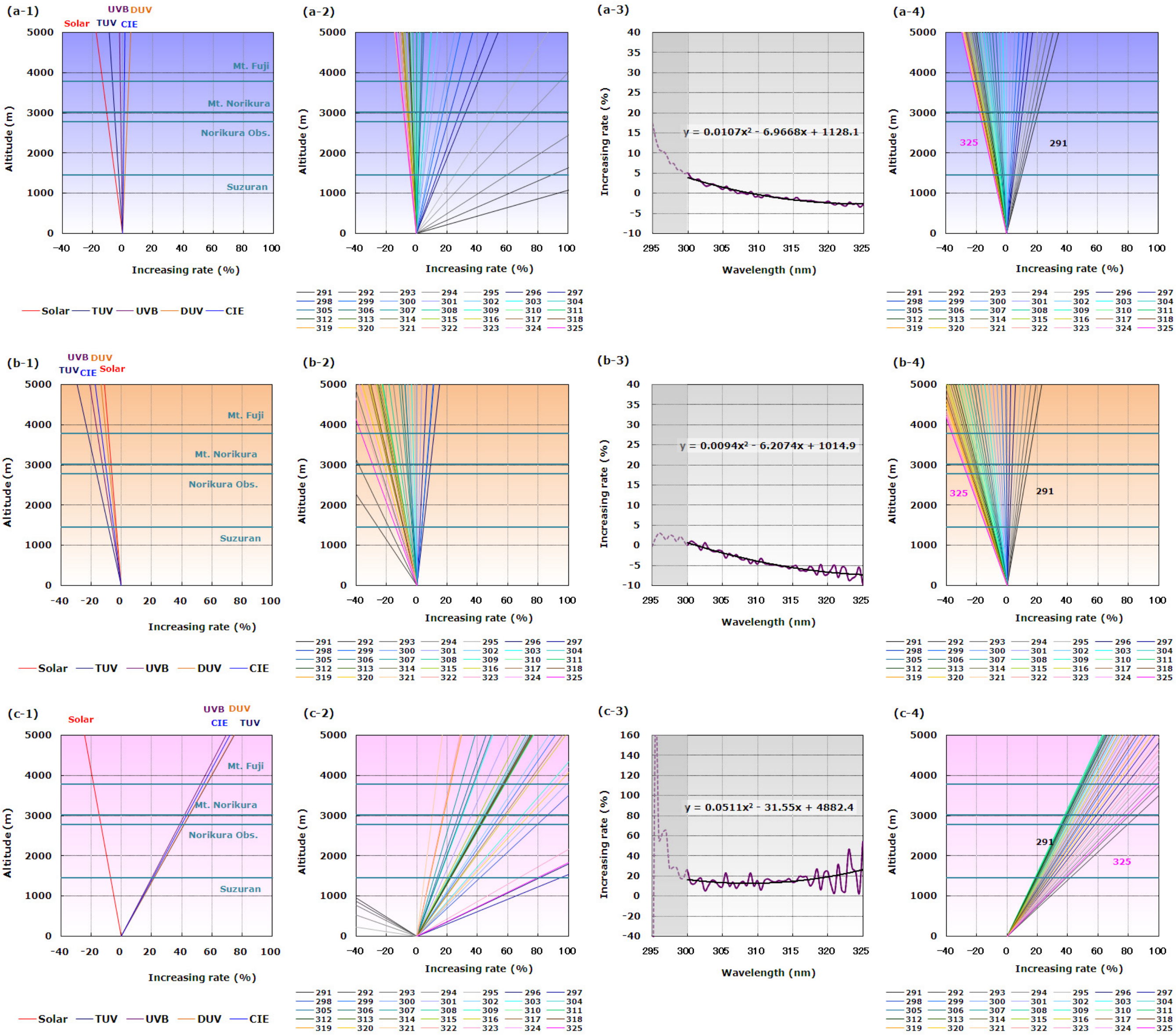

Fig. 3 The altitudinal increasing rates of UV radiation by using all data in summer season for six years from 2009 to 2014. Figure (a-1) shows the altitudinal increasing rates of GL_{UV} (global UV radiation) of TUV, UVB, DUV and CIE, including the GL_{SL} (global solar radiation). Figure (a-2) shows the rates at every wavelength from 290 to 325 nm, by using all observed data. Figure (a-3) indicates an approximate expression of the rate, calculated by using all observed data in figure (a-1). Figure (a-4) shows the ideal UV increasing rate at every wavelength from 291 to 325 nm, calculated by using the approximate expression in figure (a-3). Figures (b-1), (b-2), (b-3) and (b-4) show the altitudinal increasing rates of DF_{UV} (diffused UV radiation) as same of figures (a-1) to (a-4), respectively. Figures (c-1), (c-2) (c-3) and (c-4) shows also the altitudinal increasing rates of DH_{UV} (direct (horizontal) UV radiation).

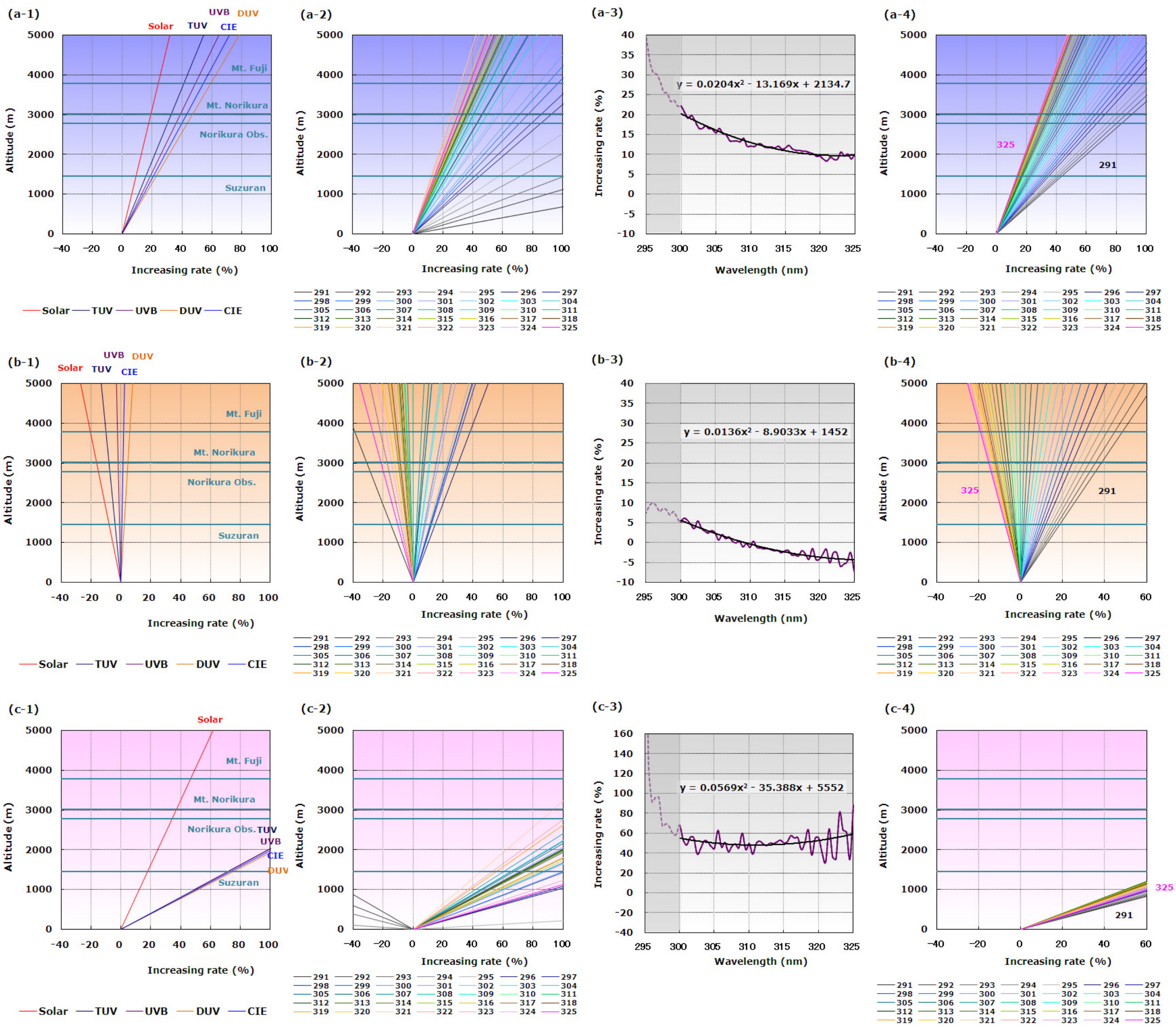

Fig. 4 The altitudinal increasing rates of UV radiation by using data in clear day in summer season for six years from 2009 to 2014.
Caption shared with Fig.3.

Table 3 The altitudinal increasing rates of UV radiation included solar radiation using by "all observed data" and "the data in clear day" in summer season for six years from 2009 to 2014.
GL, DF and DH indicate the global, the diffused and the direct (horizontal) radiations, respectively. The rates at the wavelength from 290 to 325 nm were calculated by the approximate expressions. The values at the wavelengths of 290 and 295 nm are shown only as a guide.

	All Days			Clear Days		
	GL	DF	DH	GL	DF	DH
Solar	-3.5	-2.2	-4.9	**6.4**	**-5.4**	**12.3**
TUV	-1.8	-5.8	15.0	**10.9**	**-2.6**	**49.4**
UVB	-0.4	-4.2	13.9	**13.0**	**-0.6**	**49.3**
DUV	1.1	-2.7	14.9	**15.7**	**1.6**	**51.9**
CIE	0.3	-3.5	14.4	**14.4**	**0.5**	**50.6**
Re-calc.						
290	7.6	5.3	30.4	**31.3**	**13.8**	**74.8**
295	4.1	1.8	22.1	**25.2**	**9.1**	**64.3**
300	1.1	-1.3	16.4	**20.0**	**5.0**	**56.6**
305	-1.4	-3.9	13.2	**15.9**	**1.6**	**51.8**
310	-3.3	-6.1	12.6	**12.8**	**-1.1**	**49.8**
315	-4.7	-7.7	14.5	**10.7**	**-3.1**	**50.7**
320	-5.6	-8.9	19.0	**9.6**	**-4.4**	**54.4**
325	-5.9	-9.6	26.1	**9.5**	**-5.1**	**61.0**

(%/1,000m)

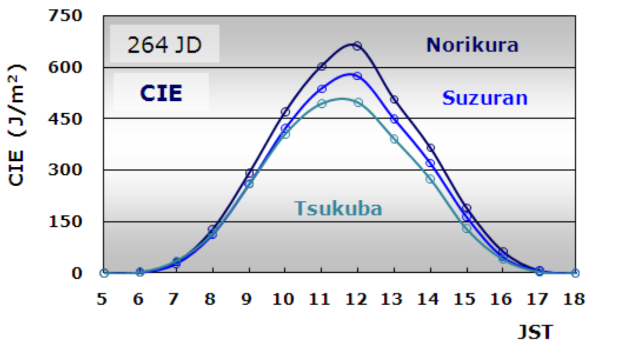

Fig. 5 Daily changes of UV radiation of GL_{UV} (CIE) at Norikura, Suzuran and Tsukuba in 264 JD, 2014.

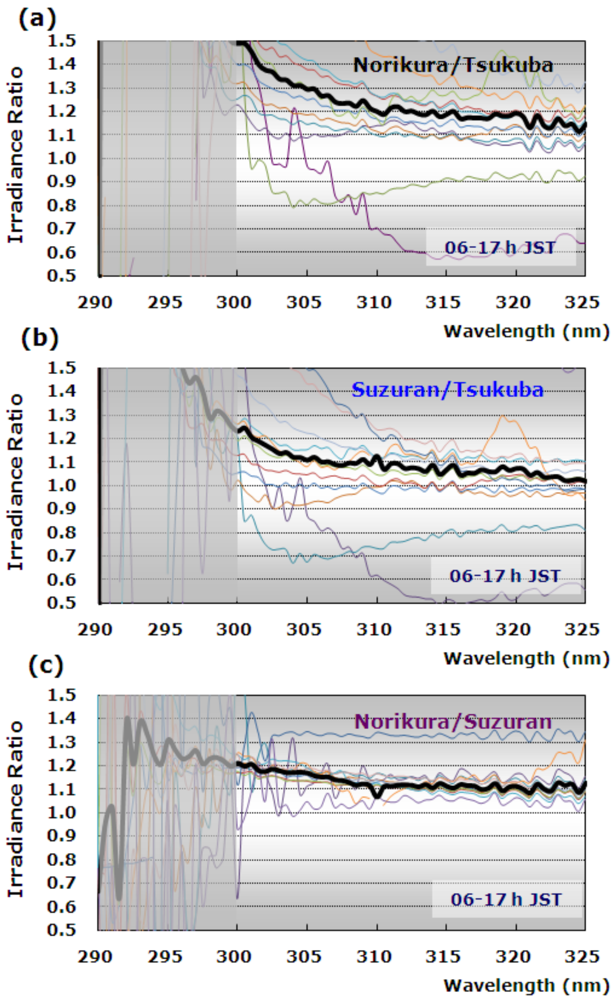

Fig. 6 Irradiance ratios at the wavelengths from 290 to 325 nm. The figures (a) to (c) show the irradiance ratios as the ratios of "Norikura / Tsukuba", "Suzuran / Tsukuba", and "Norikura / Suzuran", every hour from 06 to 17 h in 264 JD, 2014, respectively.

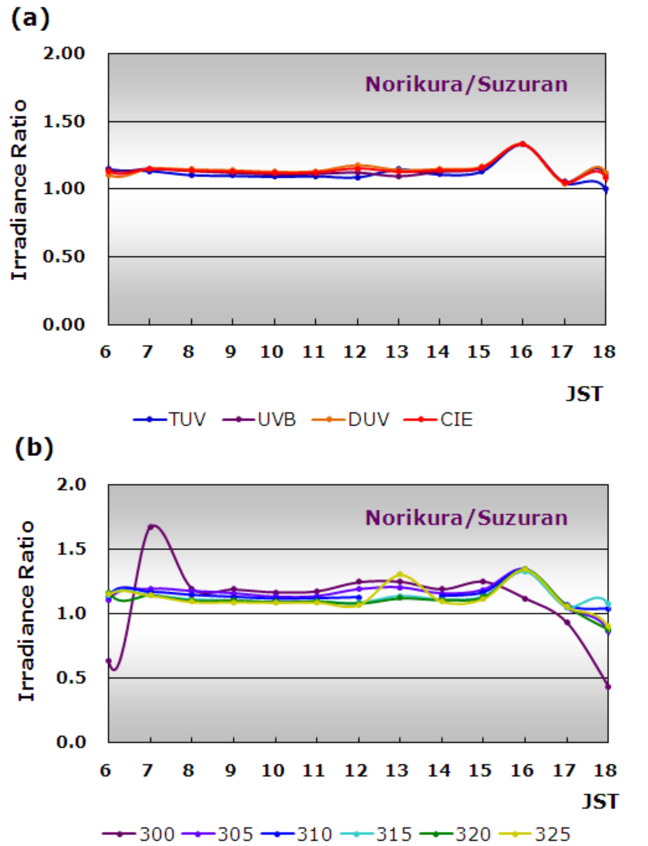

Fig. 7 Daily changes of the irradiance ratios in 264 JD, 2014. The figure (a) shows the irradiance ratios of GL_{UV} of TUV, UVB, DUV and CIE, and the figure (b) shows the ratios at the wavelength of 300, 305, 310, 315, 320 and 325 nm, as the ratios of "Norikura / Suzuran" in 264 JD, 2014, respectively.

As shown in Fig.6, the daily changes of the irradiance ratios are not clearly indicated. With regard of the irradiance ratios of (a) "Norikura / Tsukuba" and (b) "Suzuran / Tsukuba", variation due to the difference of the solar zenith angle was remarkable. Compare to Norikura and Suzuran, local time at Tsukuba is about eleven minutes earlier. The correction of UV data at Tsukuba by using the solar zenith angle has limitations in maintaining high accuracy, because of the less number of data (observations at every hour).

In consequently, the daily changes of the irradiance ratios of "Norikura / Suzuran" at the same local time are shown in Fig.7. The figure (a) indicates the daily changes of irradiance ratios of TUV, UVB, DUV and CIE, and the figure (b) indicates the daily changes of irradiance ratios at the wavelengths of 300, 310, 315, 320 and 325 nm, respectively. These ratios in the figures (a) and (b) indicate in almost constant in all the day, except for the time that the weather turned to be cloudy. Therefore, the altitudinal increasing rates of the UV radiations were estimated to indicate the constant rates in all the day.

7. Conclusion

In this paper, the altitudinal increasing rates of the UV radiations were elucidated by the observation with Brewer spectrophotometers at Norikura and Tsukuba in summer season for six years from 2009 to 2014, and the observation at Suzuran in summer season, 2014. Results of those observations are summarized below.

(1) The altitudinal increasing rate of the integrated UV radiation.

By the comparative data of "Norikura to Tsukuba" at almost same latitude for six years, the altitudinal increasing rate of the UV (CIE) radiation in clear day was calculated as the value of about +14.4% per 1,000 m. The accuracy of the value could be verified by the data at Suzuran (Norikurakogen) that is locating very close to the Norikura site, with particular of the comparative data of "Norikura to Suzuran".

(2) The increasing rates of the UV irradiances at every wavelength.

The altitudinal increasing rates of the UV irradiances at every wavelength could be calculated by the comparative data of "Norikura to Tsukuba". The results produced the three approximate expressions for calculation of the altitudinal increasing rates of the GL_{UV} (global UV), the DF_{UV} (diffused UV) and the DH_{UV} (direct (horizontal) UV) at every wavelength, e.g. $Y = 0.0204 X^2 - 13.169 X + 2134.7$ (Y: increasing rate of GL_{UV} (%/1,000 m), X: wavelength (nm), $295 \leqq X \leqq 325$ nm).

By using one of these expressions, e.g. the irradiance of GL_{UV} at the wavelength of 305 nm on the mountain top of Mt. Fuji (3,776 m a.s.l.) in clear day can be estimated as the increase rate of about +60% versus to the lowland.

(3) The daily change of the altitudinal increasing rate of the UV radiation.

The irradiance rates of the integrated UV radiations of TUV, UVB, DUV and CIE, and of the UV irradiances at every wavelength by the comparative data of "Norikura to Suzuran" in fine day did not show the daily variation. Therefore, the altitudinal increasing rates of the UV radiations were estimated to indicate the constant rates in all the day.

The altitudinal increasing rates of the integrated UV radiations and the UV irradiances at every wavelength could be elucidated. And the increasing rates at every wavelength could be calculated briefly by using the approximate expressions.

On the other hand, the expressions were produced on the basis of a definition of "the rates at shorter wavelength uniformly increase". The observation error of stray light under the wavelength of about 300 nm by using MKII instruments cannot corrected in high accuracy. The absorptions at some specific wavelengths cannot be characterized.

Therefore, the observations using high accurate instruments of Brewer MKIII type at the sites are needed in the future. And the study of seasonal variation of the increasing rate is also very important.

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乗鞍，鈴蘭，及びつくばのブリューワー分光光度計観測値から得られた高度による紫外線増加率

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要旨

ブリューワー分光光度計を使用した乗鞍(2,772 m a.s.l)とつくば(39 m a.s.l.)における過去 6 年間(2009～2014)の紫外線の観測，及び乗鞍高原の鈴蘭(1,455 m a.s.l.)における 2014 年の同観測により，高度による紫外線増加率の算出を試みた．これらは以下の通りである．

(1) ほぼ同緯度に位置する「つくばに対する乗鞍」の過去6年間の観測値から，快晴日の場合，高度による紫外線量(CIE)の増加率を約＋14.4%/1,000 mと算出した．また，鈴蘭における観測値(特に「鈴蘭に対する乗鞍」の比較観測値)により，上記の「つくばに対する乗鞍」の比較観測値から得られた増加率の有効性を確認した．(2) 高度による波長別紫外線量の増加率を，「つくばに対する乗鞍」の比較観測値から算出した．その結果，波長別紫外線量の増加率を全天GL_{UV}，散乱DF_{UV}，直射(水平面)DH_{UV} の3成分に区分し，$Y = 0.0204 X^2 - 13.169 X + 2134.7$ (Y: GL_{UV} Increasing Rate (%/1,000 m), X: wavelength (nm)　295≦W≦325 nm) 等の簡単な近似式で算出できることを明らかにした．(3)「鈴蘭に対する乗鞍」の比較観測値から快晴日の各種積算紫外線量(TUV，UVB，DUV，CIE)の照度比，及び波長別紫外線量の照度比を算出したところ，これらの照度比に日変化が認められなかった．そのため，高度に対する紫外線量の増加率には，日変化がないものと判断した．

以上のように，紫外線量の高度に対する増加率を明らかにし，簡単な近似式で波長別紫外線量の増加率を算出することができた．しかし，今後，各地点とも高精度で測定波長範囲が広い MKIII 型測器による観測を行う必要がある．また，増加率の季節変化についても把握する必要がある．

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