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GROUND-BASED OBSERVATIONS OF SOLAR UV RADIATION IN JAPAN, BRAZIL AND CHILE

Hiromasa Nozawa[1], Hiromasa Yamamoto[2], Kazuo Makita[3], Nelson J. Schuch[4], Damaris K. Pinheiro[5],
Samara Carbone[6], Ricardo M. Mac-Mahon[7] and Alberto J. Foppiano[8]

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ABSTRACT. Ground-based observations of solar ultraviolet (UV) radiations have been carried out in Tokyo, Japan, São Martinho da Serra, Brazil, and Punta Arenas, Chile. The initial results showed that the observations were concerned with the total amount of ozone. Variations in the flux ratio between UV-B and UV-A radiation in both hemispheres show a clear anti-correlation with the amount of ozone along line-of-sight. As a result of least-square fitting, exponential functions between the UV-ratio (UV-B/UV-A) and effective ozone are obtained. Radiometer data at Punta Arenas also show sudden enhancement of UV-B radiation in the beginning of spring, indicating that the arrival of the ozone hole can be detected from the ground.

Keywords: ozone, ultraviolet radiation, radiometer, spectroradiometer.

RESUMO. Medidas de superfície de radiação solar ultravioleta (UV) têm sido feitas em Tókio, Japão, São Martinho da Serra, Brasil e Punta Arenas, Chile. São apresentados resultados iniciais de observações de ozônio total. Variações do fluxo da razão de UV-B e UV-A em ambos os hemisférios apresentaram anti-correlações claras com o ozônio. Como resultado do ajuste, funções exponenciais entre a razão e o ozônio efetivo foram obtidas. Os dados do Radiômetro de Punta Arenas também apresentaram aumento súbito do UV-B no início na primavera. Isto significa que as evidências para a chegada do buraco de ozônio podem ser detectadas a partir de equipamentos de superfície.

Palavras-chave: ozônio, radiação ultravioleta, radiômetro, espectroradiômetro.

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[1] Department of General Education, Kagoshima National College of Technology, 1460-1 Shinko, Hayato-cho, Kirishima, Kagoshima 899-5193, Japan. Phone: +81 (995) 42-9054; Fax: +81 (995) 42-9054 – E-mail: nozawa@kagohima-ct.ac.jp

[2] Department of Physics, Rikkyo University, 3-34-1 Nishi-Ikebukuro, Toshima-ku, Tokyo 171-8501, Japan. Phone: +81 (3) 3985-2671; Fax: +81 (03) 3985-2418 – E-mail: yamamoto@rikkyo.ac.jp

[3] Faculty of Engineering, Takushoku University, 815-1 Tatemachi, Hachioji, Tokyo 193-0985, Japan. Phone: +81 (426) 65-4673 – E-mail: kmakita@la.takushoku-u.ac.jp

[4] Southern Regional Space Center, CRSPE/INPE, MCT, Faixa de Camobi – 97105-900 Santa Maria, RS, Brazil. Phone: +55 (55) 3220-8827; Fax: +55 (55) 3220-8007 – E-mail: njschuch@lacesm.ufsm.br

[5] Space Science Laboratory of Santa Maria, Federal University of Santa Maria, Faixa de Camobi – 97105-900 Santa Maria, RS, Brazil. Phone: +55 (55) 3220-8827; Fax: +55 (55) 3220-8007 – E-mail: damaris@lacesm.ufsm.br

[6] Institute of Astronomy, Geophysics and Atmospheric Sciences, University of São Paulo, Rua do Matão, 1226, Butantã – 05508-090 São Paulo, SP, Brazil. Phone: +55 (11) 3091-4713; Fax: +55 (11) 3091-4714 – E-mail: samara@model.iag.usp.br

[7] CEQUA, Space Physics, University of Magallanes, Avenida Bulnes 01855, Casilla 113-D, Punta Arenas, Chile. Phone: +56 (61) 217-315; Fax: +56 (61) 219-276 – E-mail: rmonreal@ona.fi.umag.cl

[8] Department of Physics, University of Concepción, Avenida Esteban Iturra s/n, Barrio Universitario, Casilla 160-C, Concepción, Chile. Phone: +56 (41) 220-3083; Fax: +56 (41) 222-0104 – E-mail: foppiano@udec.cl

INTRODUCTION

Solar ultraviolet (UV) radiation is generally categorized into three wavelength regions: 1) UV-A: 315-400 nm, 2) UV-B: 280-315 nm, and 3) UV-C: 190-280 nm. This categorization is convenient for explaining the relation between solar UV radiation and ozone in the stratosphere. UV-C radiation causes serious problems for living things. Fortunately, UV-C radiation is completely absorbed by the atmosphere, mainly by oxygen molecules (Schuman-Runge and Herzberg continuum) in the upper atmosphere and partly by the ozone layer in the stratosphere. As a result, UV-C radiation never reaches the ground. Most UV-B radiation, which causes a large amount of damage to living things, is strongly absorbed by the stratospheric ozone (Hartley band), so only a small amount of UV-B radiation can reach the ground. Therefore, the intensity of UV-B radiation on the ground is very sensitive to the total amount of ozone. Unlike UV-B and UV-C, little UV-A radiation is absorbed by the ozone layer, so most fluxes can reach the ground. Fortunately, UV-A radiation causes a relatively smaller amount of damage to living things than other types of UV radiation. In this way, the ozone layer acts as a protector for living things from the UV radiation (see Frederick & Lubin, 1988).

Our main objectives in observing solar UV radiation were:

1. Monitoring long-term variation in solar UV radiation in both hemispheres,
2. Confirming a relationship between solar UV radiation and ozone,
3. Confirming an influence of the South Atlantic Anomaly (SAA), and
4. Determining the influence on biology caused by solar UV radiation.

To confirm the differences in UV fluxes that depend on both season and location, we installed the same instruments in both hemispheres and carried out long-term ground-based observations. In this paper, we focused on the variation in solar UV radiation and the relationship between solar UV radiation and ozone. The influence on biology is beyond the scope of this paper.

INSTRUMENTS AND DATA

UV-spectroradiometers and UV-radiometers manufactured by EKO Instrument Co., Ltd. were used for our study on solar UV radiation. The spectroradiometer (MS-701) has wavelength coverage of 300-400 nm and measures the solar UV spectrum with a wavelength resolution of $\sim$3 nm with a diffraction grating. The exposure time of the instrument can be set from 10 milliseconds to 5 seconds. In the automatic exposure mode, typical exposure times are set at 5 seconds and 2 seconds depending on the intensity of solar UV radiation. The radiometers measure integrated solar UV radiation using interference filters for UV-A (MS-212A, MS-210A) and UV-B (MS-212W, MS-210W) and output instantaneous values within 1 second. These radiometers are the same types used by Sasaki et al. (1993) and Guarnieri et al. (2004). Both spectroradiometers and radiometers have wide fields-of-view ($\sim$180°) and differences in sensitivities with respect to the solar zenith angle (Z, hereafter SZA) are negligible in the case of $Z < 70°$. Therefore, sun-trackers are not needed, and both direct (from the sun; Echer et al., 2004) and scattered (from the sky, clouds, etc.) UV components can be detected. The instruments are calibrated using a combination of an NIST traceable standard lamp and natural solar irradiance on a sunny day.

These instruments were installed in Rikkyo University (35.7°N, 139.7°E, altitude $\sim$65 m), Ikebukuro, Tokyo, Japan, and the Southern Space Observatory (SSO) of the National Institute for Space Research (INPE) in São Martinho da Serra (29.4°S, 53.8°W, altitude $\sim$490 m), Rio Grande do Sul, Brazil in 2002. São Martinho da Serra is located in the hemisphere opposite to Tokyo and in the same middle latitude region. São Martinho da Serra is also located in the SAA region, which has the weakest surface geomagnetic field because of an offset of the field. In addition, a small fraction of the stratospheric atmosphere originating from the ozone hole sometimes reaches above. Therefore, SSO in São Martinho da Serra is one of the most suitable places for our solar UV observations. In our study, solar UV spectra were obtained every 5 minutes in both SSO and Tokyo. Sampling times of UV-A and UV-B radiometers were every 5 seconds in SSO and 6 seconds in Tokyo.

Figure 1 shows the instruments at Rikkyo University, Tokyo. In addition to a spectroradiometer (MS-701) and radiometers (MS-212A and MS-212W), a total wavelength (300-3000 nm) radiometer (pyranometer, MS-802) was installed. The sheets behind the spectroradiometer were sample biological cells, although biology is beyond the scope of this paper.

There was an electronic problem between the pre-amplifiers and analog-to-digital (A/D) converters of the spectroradiometers. Therefore, in the automatic exposure mode, the output voltage of the spectroradiometers at wavelength channels near 400 nm was often saturated around noon during the summer solstitial season. Although this problem was fixed in the spectroradiometer in Tokyo in 2003, it has not been fixed yet in SSO. To avoid saturation, the

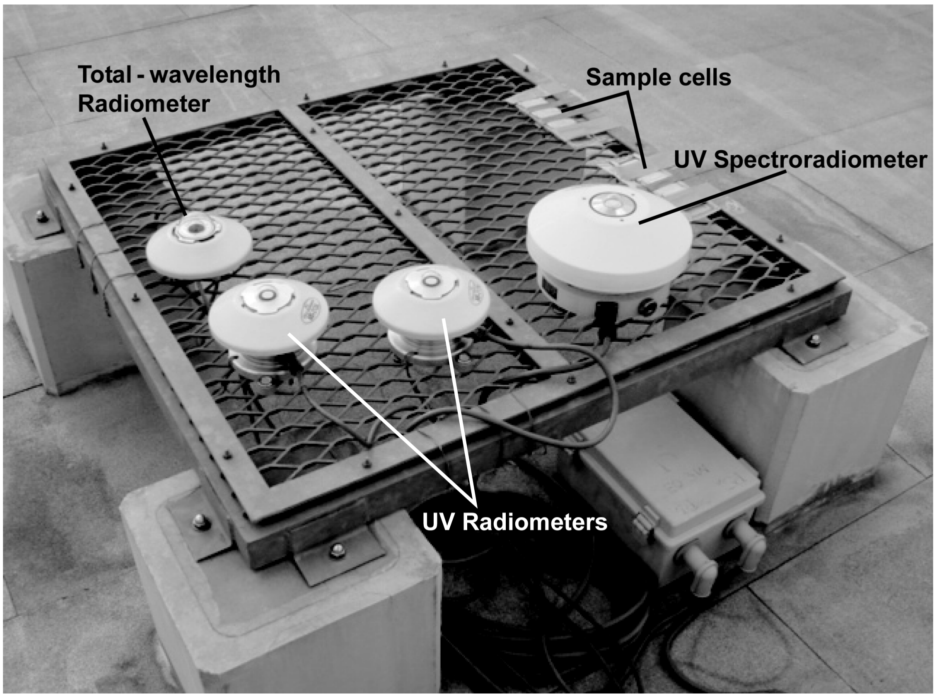

Figure 1 – UV spectroradiometer and UV radiometers for observations of solar UV radiation (EKO Co., Ltd.).

fixed exposure time mode (1 second) has been used in SSO since the beginning of the observations.

UV-A and UV-B radiometers were installed in Punta Arenas (University of Magallanes; 53.1°S, 71.0°W, altitude $\sim$10 m; Makita et al., 2004) and Concepcion (University of Concepcion; 36.8°S, 73.1°W, altitude $\sim$160 m), Chile. Punta Arenas is suitable for investigating the relationship between UV intensity and the ozone hole (Salgado et al., 1996; Kirchhoff et al., 1997a; 1997b). During the spring season, part of the ozone hole often extends above Punta Arenas and enhances UV-B radiation on the ground. UV observations have been made since 2001 with a time resolution of 1 second (Makita et al., 2004). Because of a large SZA during winter (between April and August; $Z > 70°$), the signal to noise ratio (SNR) of UV-B radiation during this period becomes quite small and cannot be used as scientific data. Since the latitude of Concepcion is similar to that of Tokyo, the data is a good counterpart to Tokyo's. A full set of UV-A and UV-B observations with a time resolution of 1 second have been carried out since March 2005. However, in this paper, the data from Concepcion were not used because the observational period for this study predated that.

For comparison, we used the spectroradiometer data in SSO and Tokyo between 2002 and 2004. In this study, data from the radiometers were not used since there were some problems with the instruments in SSO until 2003. In our analysis, precise information of solar UV spectra was not used so UV-A and UV-B wavelengths were integrated. That is, spectroradiometers were used as UV-A and UV-B radiometers. For daily UV data, only data from sunny days (days with few or no clouds) that averaged over 20 minutes around the local noon, were extracted from the dataset.

To confirm the effect of the ozone hole, data from radiometers from Punta Arenas between 2003 and 2004 were used. The same selection criteria as that used in SSO and Tokyo could not be used due to a lack of sunny days in Punta Arenas. Therefore, a threshold level with a UV-A flux is larger than 15 [W/m^2] around noon was used for the data. These selection criteria were effective for eliminating poor SNR UV-B data.

Generally speaking, UV-B flux on the ground has a close relationship with the total amount of ozone. Therefore, we compared UV radiation and ozone data from São Martinho da Serra, Tokyo and Punta Arenas. In SSO at São Martinho da Serra, ozone data has been measured with a Brewer spectrometer since 1992. In Tokyo, we have no available ozone data from the ground. Therefore, the ozone data at Tsukuba (36.0°N, 140.1°E) which is about 50 km to the north-east of Tokyo was used for this study. The ozone data at Tsukuba was provided by the World Ozone and Ultraviolet Radiation Data Centre (WOUDC; http://www.woudc.org/; Wardle et al., 1996) and taken by the Japan Meteorological Agency with a Brewer spectrometer. For ozone data at Punta Arenas, data from the Total Ozone Mapping Spectrometer (TOMS) onboard the Earth Probe spacecraft (EP/TOMS; http://toms.gsfc.nasa.gov), which was provided by the Ozone Processing Team of NASA/GSFC, was used.

RESULTS

Comparison of Brazil and Japan

Figure 2 shows the variation in UV-A and UV-B radiation from SSO and Tokyo on sunny days (days of low cloudiness) during the local noon period using spectroradiometers between 2002 and 2004. Since the influence of weather conditions was effectively removed, both the UV-A and UV-B radiation clearly showed seasonal variation, that is, the UV fluxes were larger in the summer solstitial season and smaller in the winter solstitial season. There were differences in the relative amplitudes of seasonal variations between the UV-A and UV-B radiation. The amplitude of the UV-A radiation showed about a difference of a factor of 2 between summer and winter. On the other hand, that of UV-B radiation reached about a factor of 3. This difference mainly results from absorption of UV-B radiation by ozone. Due to a change in the SZA, the effective ozone, which is a product of the total ozone at the zenith and secZ (airmass), varies with the season even if the amount of zenith ozone is constant. A larger SZA during the winter solstitial season makes UV-B on the ground smaller, because of an increase in airmass. This is also the case with the data for Tokyo, except for the difference in the period of the summer and winter seasons due to the northern hemisphere. A large data gap in Tokyo's data during 2003 is due to replacing the instrument as mentioned before (i.e., the problem in electronics). By comparing the data from SSO and Tokyo, we can see the following differences: Tokyo has larger UV-A variance and SSO has a larger UV-B variance. The larger variance in Tokyo's data is thought to be caused by atmospheric pollution as Ikebukuro is located in the central part of Tokyo. On the other hand, the larger variance of UV-B in SSO is caused by lack of exposure time.

Relationship between UV ratio of spectroradiometer and effective ozone

According to Takeshita et al. (2001), the relationship between solar UV radiation and ozone becomes clear when we compare the flux ratio of UV-B to UV-A with the effective ozone, which is a product of zenith ozone and airmass. Figure 3 shows the relationship between the UV-ratio (UV-B/UV-A) of the spectroradiometers and effective ozone in SSO and Tokyo. As mentioned before, the effective ozone at Tokyo consists of zenith ozone at Tsukuba and airmass in Tokyo. As can be seen in this figure, the data from Tokyo is clearly separated into two groups. This becomes clearer when the data are divided into two periods, that is, before (violet) and after (blue) replacing the instrument in 2003. From our dataset, the exponential function, as shown by the solid lines, can be derived. As a reference, the function of Takeshita et al. (2001) is also shown using a dashed line. The difference between our function and that of Takeshita et al. (2001) is not important because the characteristics of the instruments differed. The least-square fitting results showed a clear anti-correlation with coefficients of –0.94 in SSO and –0.99 in Tokyo. The strong anti-correlation in Tokyo also made it clear that that the data for ozone in Tsukuba is a good indicator of the UV data in Tokyo. That is, a position difference of 50 km did not create problems in our analysis. These fitting results also mean that the amount of effective ozone can be estimated using the derived function and the observed UV-ratio. To confirm the validity of this method, the amount of effective ozone was estimated using the UV-ratio data of an SZA of about 50° (airmass $\sim$1.55, 47.5°$<$ Z$<$ 52.5°) for SSO and 55° (airmass $\sim$1.74, 52.5°$<$ Z$<$ 57.5°) for Tokyo. Figure 4 shows a comparison of the estimated value from the UV-ratio and the calculated value from the measured ozone and average airmass. Ideally, inclinations and offsets of these plots should be 1.0 and 0.0, respectively. However, least square fitting results showed inclinations from 0.82 to 0.88 and offsets. As can be seen in Figure 3, correspondence between the data and fitting results are somewhat worse in smaller and larger effective ozone regions. In addition, Figure 4 contains data of larger effective ozone because of a larger airmass. This tendency is one of the reasons for these fitting results. A larger deviation of data in SSO can also be confirmed. The reason for this large deviation is due to a short exposure time in SSO, which is determined by the fixed exposure mode because of failure of the automatic exposure mode. Exposure times at this SZA are 5 seconds in Tokyo and 1 second in SSO. Therefore, the SNR of the data differs by 2.24 $(=\sqrt{5})$. The larger the SZA of the data becomes, the more severe the difference in SNR is. This is also confirmed by comparing the correlation coefficients for least square fitting in Figures 3 and 4. For the Tokyo data, there are differences in the offsets before and after replacing the instrument in 2003. The larger offset before replacement is simply due to an instrumental effect. After replacement, the derived function became closer to the ideal case of y = 1.0 x + 0.0. To improve the quality of data in SSO, an increase of exposure time and replacement of the spectroradiometer are needed.

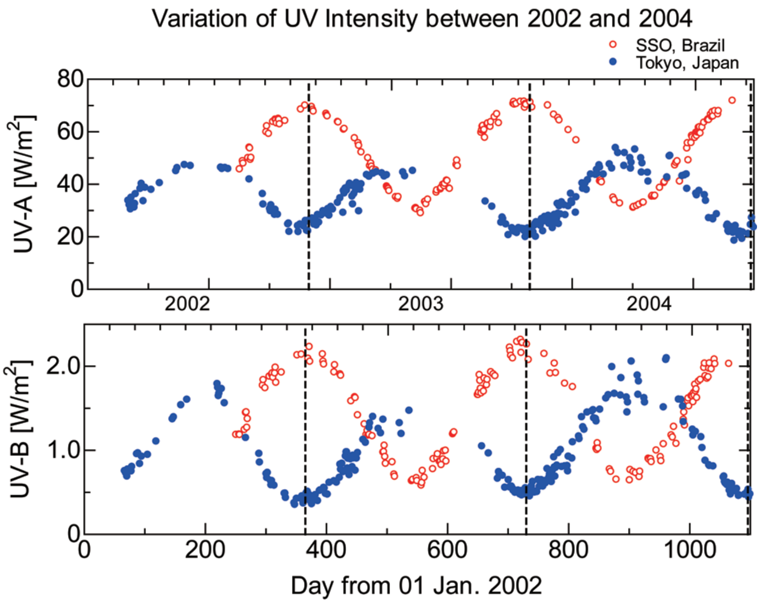

Figure 2 – Seasonal variation of UV-A (upper) and UV-B (lower) radiations in Southern Space Observatory (SSO) in São Martinho da Serra (○, red) and Tokyo (●, blue) measured with spectroradiometers under conditions of low cloudiness between 2002 and 2004. Differences in phases are due to different hemispheres. Differences in relative amplitudes of UV-A and UV-B variations are mainly due to absorption by ozone.

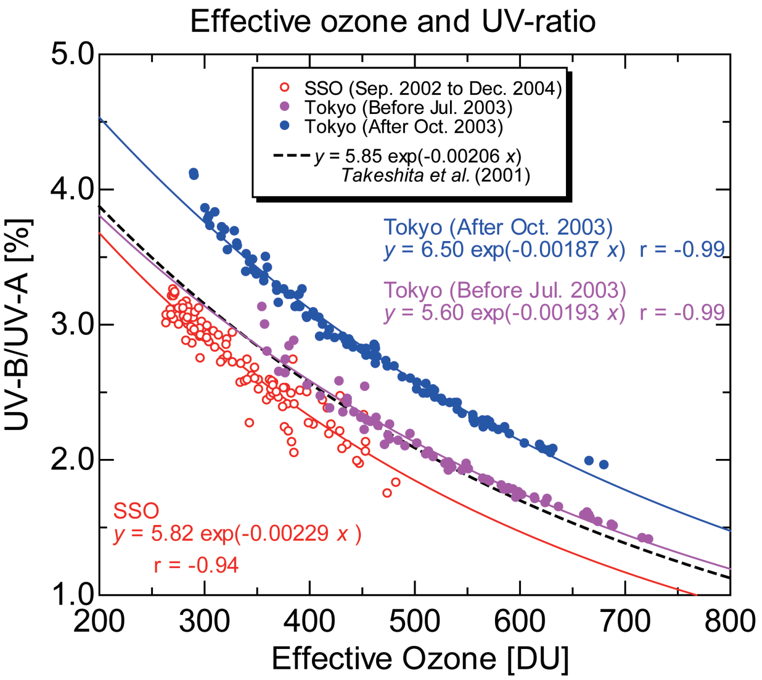

Figure 3 – UV-ratio (UV-B/UV-A) of spectroradiometer with respect to effective ozone. For SSO data (○, red), ozone data of SSO with Brewer spectrometer was used. For Tokyo (●, violet and blue), ozone data of Tsukuba was used. Data points clearly separated into two parts due to replacement of spectroradiometer. Least square fitting results are shown as solid lines. Dashed line indicates function of Takeshita et al. (2001).

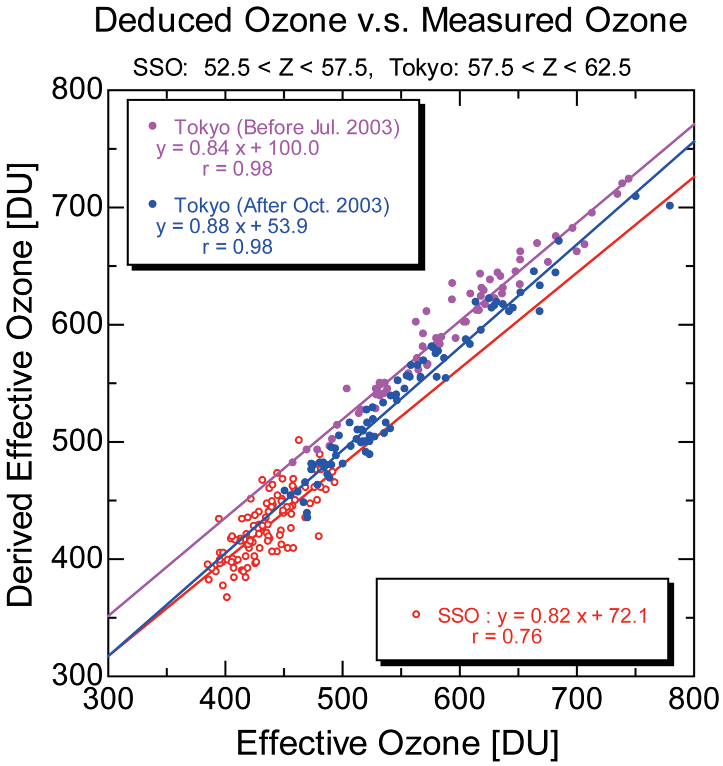

Figure 4 – Deduced effective ozone from derived function and UV-ratio with respect to measured effective ozone in SSO and Tokyo. Symbols and colors are the same as Figure 3. SZA of UV-ratio data are 47.5°< Z< 52.5° for SSO and 52.5°< Z< 57.5° for Tokyo. Least square fitting results also are shown. Larger scatter of SSO data is due to lack of exposure time.

Comparison between UV-ratio and effective ozone at Punta Arenas

Figure 5 shows seasonal variations of the UV-ratio obtained from radiometers (UV-A $>$15 [W/m^2]) and effective ozone at Punta Arenas observed by EP/TOMS between 2003 and 2004. During the winter solstitial seasons (between April and August), the SZA becomes larger than 70°, thereby making UV-B detection almost impossible. Therefore, UV data during these periods were not used. At the beginning of spring, sudden enhancements of the UV-ratio could be seen together with a sudden decrease of effective ozone, shown in the lower panel of Figure 5. The upper panels show the polar plot of the total ozone mapping data observed by EP/TOMS. The cross-marks on the world map indicate the positions of Punta Arenas. From this comparison, sudden enhancement of the UV-ratio clearly has relationship with the arrival of the ozone hole over Punta Arenas. That is, the arrival of the ozone hole can be observed with the radiometers. The relationship between the UV-ratio and effective ozone at Punta Arenas can also be confirmed, as shown in Figure 6. Although the data contains extraordinary cases as shown in Figure 5, a similar exponential function was derived with correlation coefficients of –0.92.

SUMMARY AND FUTURE WORK

We have started long-term solar UV radiation monitoring in Japan, Brazil and Chile using the same standard instruments. From the UV radiation data observed in SSO and Tokyo with spectroradiometers, similar seasonal variations were confirmed. The difference in relative amplitudes between UV-A and UV-B radiation is mainly due to UV-B absorption by ozone under a large SZA. The acquired functions from relationship between the UV-ratio and effective ozone are useful for deducing the total amount of ozone only from the UV-ratio. However, the exposure time of the instrument in SSO, must be increased to increase SNR. In Punta Arenas, the arrival of the ozone hole can be clearly seen by taking the UV-ratio from radiometers. Since solar UV radiation in Concepcion has also been observed, we will investigate differences in the northern and southern hemispheres and the effect of SAA in the near future.

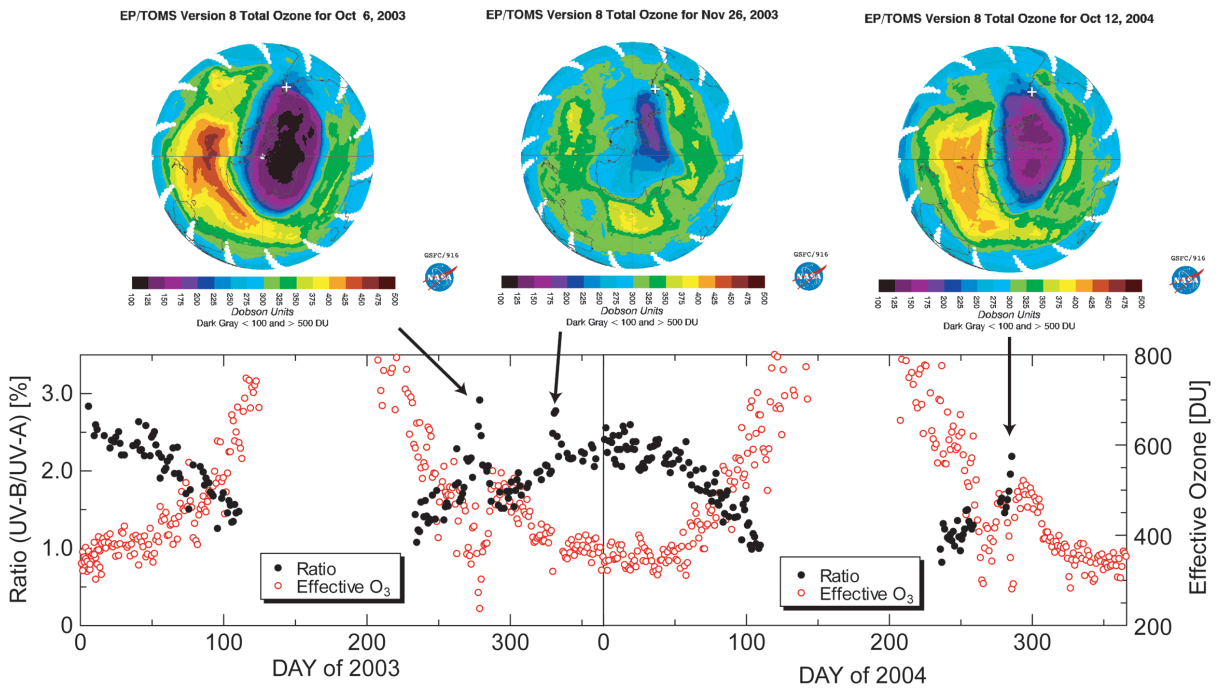

Figure 5 – Variation of UV-ratio (UV-B/UV-A, •) and effective ozone (○) at Punta Arenas between 2003 and 2004. Sudden enhancement of ratio can be seen in spring. Ozone mapping data observed by TOMS onboard the Earth Probe spacecraft (EP/TOMS) are shown on top. Cross-marks on upper panels indicate positions of Punta Arenas. All sudden enhancements of UV-ratio concern expansion of the ozone hole.

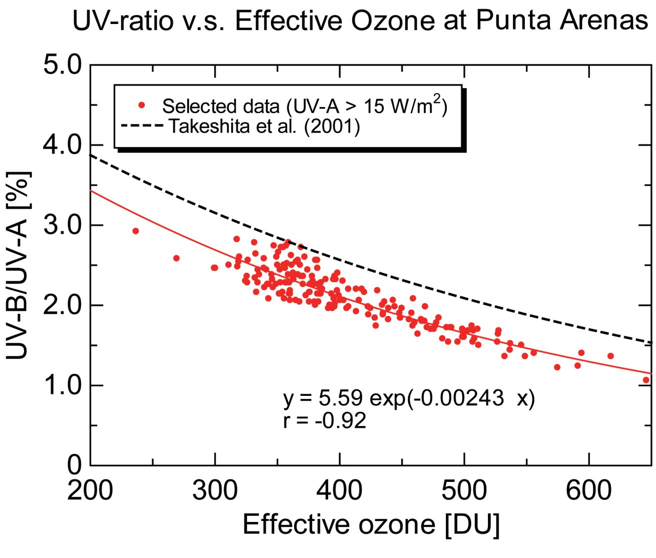

Figure 6 – Relationship between UV ratio and effective ozone at Punta Arenas. Solid line indicates result of least-square fitting. Dashed line indicates result of Takeshita et al. (2001).

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NOTES ABOUT THE AUTHORS

Hiromasa Nozawa. B. Science, Tohoku University (1996); Master of Science, Tohoku University (1998); Ph.D. in Geophysics, Tohoku University (2002); Research Fellow, Tohoku University (2002-2003); Research Fellow, Institute of Space and Astronautical Science (2003-2004); Research Fellow, Rikkyo University (2004-2006). Presently, associate professor of Kagoshima National College of Technology. Current research interests are solar UV radiation and stratospheric ozone on earth, plasma environment in the magnetosphere of Jupiter, and exosphere of Mercury.

Hiromasa Yamamoto. B. Science, Kobe University (1968); Master of Science, Kobe University (1971); Ph.D. in Physics, Rikkyo University (1976); Research fellow of Japan Society for the Promotion of Science (1976-1977); Instructor, Department of Physics, Rikkyo University (1979-1984); Associate Professor, Department of Physics, Rikkyo University (1984-2001); Professor, Department of Physics, Rikkyo University since 2001. Current research interests are upper atmospheric physics with ground-based observations of OH and O2 airglows, and differences in stratospheric ozone and solar UV variation between both hemispheres with ground-based observations.

Kazuo Makita. B. Science, Shizuoka University (1971); Master of Science, University of Tokyo (1973); Ph.D. in Geophysics, University of Tokyo (1979); Technical Associate – Member of Japanese Antarctic Research Expedition (1974-1976); Instructor, Faculty of Economics, Takushoku University (1979-1981); Associate Professor, Faculty of Economics, Takushoku University (1981-1989); Professor, Faculty of Engineering, Takushoku University since 1989. Current research interests are auroral physics, airglows in the upper atmosphere, and South Atlantic Anomaly of geomagnetic field. Member of the 17th Japanese Antarctic Research Expedition.

Nelson Jorge Schuch. B. Science, Federal University of Santa Maria – UFSM (1972); Master of Science, Presbyterian Mackenzie University (1975); Ph.D. in Physics, Cambridge University (1979); Pos-Doctorate, Cambridge University (1980); Senior Researcher/Vice-Director of National Observatory (1980-1995); Coordinator of the Radioastronomy Project – RA, in the partnership between INPE – UFSM (1996). Head of the Southern Regional Space Research Unit and Coordinator of the actions 1275 and 6237 from PPA2004-2007 of Implantation and Operation of the Southern Regional Space Research Center PNAE, of the National Institute for Space Research.

Damaris Kirsch Pinheiro. B.Sc., Federal University of Santa Maria (1990); Master of Science, Campinas State University (1992); Ph.D. in Geophysics, National Institute for Space Research – INPE (2003). Professor of the Chemical Engineering Department of the Federal University of Santa Maria and Director of the Space Science Laboratory of Santa Maria – LACESM/CT/UFSM. Coordinator of the Atmospheric Ozone Monitor Program of the Federal University of Santa Maria, which works partnership with Southern Regional Space Center of the National Institute for Space Research – CRSPE/INPE – MCT, at Southern Space Observatory, in São Martinho da Serra.

Samara Carbone. B.Sc., Federal University of Santa Maria (2006); Graduate Student, University of São Paulo (2006). Graduated in Chemical Engineering at Santa Maria Federal University – UFSM, Brazil, on February 2006. Participated on the Program of Monitoring the Atmospheric Ozone from 2001 to 2006 at UFSM, researching about UV radiation, aerosols and atmospheric ozone. On March 2006 began Meteorology Master Program at University of São Paulo – USP, Brazil, developing a Master Project related to air quality photochemical modeling at São Paulo's atmosphere.

Ricardo Monreal Mac-Mahon. B.Sc, P. Univ. Católica de Chile (1982); M.Sc., P. Univ. Católica de Chile (1988); Ph.D, National Institute for Space Research – INPE, Brazil (1994); Research Fellow, National Geophysical Data Center – NOAA (1993); Research Visitor, British Antarctic Survey (1995); Research Visitor, National Institute for Space Research (2004); Associate Professor, Dept. Math. and Physics, University of Magallanes (1996); Research Staff, Center for Quaternary Studies – CEQUA (2002). Associate professor of University of Magallanes and research staff of the Center for Quaternary Studies. Current research interests are particle motion in the magnetosphere, solar wind - magnetosphere coupling during the storm.

Alberto José Foppiano Bachmann. Teacher of Mathematics and Physics, University of Chile (1970); Ph.D. in Electrical Engineering, University of London (1977); T.A., University of Concepción (1964-1966); Instructor, Institute of Physics, University of Concepción (1967-1974); Assistant Professor, Institute of Physics, University of Concepción (1974-1977); Professor, Institute of Physics, University of Concepción (1977-1981); Associate Professor, Department of Physics, University of Concepción (1981-1989); Professor, Department of Physics, University of Concepción since 1989. Professor of University of Concepción. Current research interests are auroral absorption of HF and VHF radio waves, morphology of the ionosphere in the southern hemisphere, and climatology of Chile.