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SOLAR ERYTHEMAL ULTRAVIOLET RADIATION IN ESTONIA IN 1998

Uno VEISMANN, Kalju EERME, and Rutt KOPPEL

Tartu Observatory, 61602 Tõravere, Tartumaa, Estonia; uno@aai.ee

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Abstract. Regular measurements of solar erythemal ultraviolet irradiance have been carried out at Tõravere, Estonia, since 1 January 1998, using an erythemally weighted sensor Scintec UV SET. The results obtained during 1998 are presented and preliminarily discussed. The maximum daily dose 18.27 MED (here 1 MED = 250 erythemally weighted J/m^2 for skin type II) was recorded on 10 June. The yearly mean daily dose was 4.68 MED; the maximum monthly dose was 335.27 MED (June).

Key words: erythemal ultraviolet irradiance, atmospheric column ozone, UV monitoring, UV attenuation by clouds, UV dose, albedo.

1. INTRODUCTION

The observed atmospheric total ozone has further decreased and the solar ultraviolet (UV) radiation increased during the last two decades. Measurements of UV radiation at the Earth's surface under clear sky conditions show that low overhead ozone yields high UV radiation in the amount predicted by radiative transfer theory. The increased amounts of UV radiation that reach the Earth's surface potentially add to the danger of skin cancer and cataracts in people, cause harm to some crops, and interfere with marine life.

In areas where small ozone depletion has been observed, the increase in UV radiation is more difficult to detect. Detection of UV trends associated with a decrease in ozone can also be complicated by changes in cloudiness, by local pollution, or by changes of albedo as well as by difficulties in keeping the detection instrument in precisely the same condition over many years [1].

In clear weather conditions the UV-B radiation reaching the troposphere is redistributed by the molecular and aerosol scattering and particularly absorbed by the tropospheric ozone and absorbing aerosols, such as soot and mineral dust. The attenuation by clouds depends on the cloud amount and the optical thickness of cloud cover. The attenuation by molecular (ozone) and particulate absorbers can be strongly enhanced in optically thick clouds due to the increased by multiple scattering path of photons [2]. Complicated situations arise in the cases of broken clouds when the UV-B irradiance cannot be only attenuated but also enhanced by reflection from cumulus clouds. Both the tropospheric and stratospheric weather in every geographical region are influenced by the global-scale and synoptic-scale processes in a unique way, whereas the tropospheric weather is affected by meso- and microscale processes additionally. Human beings and other biospheric species have adapted to certain UV irradiance levels and variance amplitudes. The UV climatology is expected to provide an answer to questions about the mean annual cycle of UV irradiance and its typical variance as well as to enable detecting episodes of anomalously high or low values.

2. SITE DESCRIPTION

The development of the UV monitoring network in Estonia has been a gradual process which started in 1993 with preparations for the atmospheric total ozone measurements with a laboratory spectrometer. The first results for 1994–97 were published recently in [3].

Among the advantages of the monitoring at Tõravere near Tartu (Fig. 1) the role of the meteorological station that has been operating since 1965 and belongs now to the Estonian Meteorological and Hydrological Institute should be underlined. Because of the existence of this station the UV-B measurements are automatically accompanied with meteorological and total irradiance data. The UV monitoring is conducted by the experienced scientists of Tartu

Fig. 1. Location of the study site of Tõravere.

Observatory, located in the same place. Tartu Meteorological Station is included in the Baseline Surface Radiation Network. Systematic measurements of the components of radiation budget have been provided since 1953 (until 1965 at another site near Tartu).

Below, the site description data are presented according to the World Meteorological Organization Global Atmosphere Watch (WMO GAW) guidelines [4].

Observation site description

Name of station	Tartu
Name of place	Tõravere near Tartu, Estonia
Responsible institute	Tartu Observatory/Estonian Meteorological and Hydrological Institute
Latitude	$\varphi = 58°16' N$
Longitude	$\lambda = 26°28' E$
Altitude	70 metres above sea level

The **platform** for measurements is situated on the roof of the main building of Tartu Observatory. The **horizon** is obstructed 15° in the NE direction (up to 8° in height).

Tartu Observatory is located in the southeastern part of Estonia. The **landscape pattern** is undulated moraine plain, comprising fields of some hectares and forest compartments of the same size.

The **nearest ground-based ozone station** is also at Tõravere and it belongs to Tartu Observatory and the Estonian Meteorological and Hydrological Institute.

3. THE INSTRUMENTATION

The first sensor for the UV monitoring in Estonia, UV SET, was obtained in the autumn of 1997. It has been produced by the Scintec Atmosphärenmesstechnik GmbH (Germany) and is one of the widely used UV sensors for continuous recording of the erythemally weighted UV irradiance [5]. At first the solar UV radiation is converted into visible light by a phosphor layer and then into electric current by a photodiode. Filter optics, detector, and electronic preamplifier are thermoelectrically kept at 25 °C to avoid variations of sensitivity caused by changing ambient temperatures. In order to allow monitoring, the internal temperature, an analogue voltage output $S_{t°}$ generated by an independent control circuit is available (Fig. 2). The spectral sensitivity of the sensor corresponds to the erythemal action spectrum designated by the Commission Internationale de L'Éclairage (CIE) [6] and its transformation factor has been chosen such that the value 0.4 V of the signal U_s corresponds to the effective irradiance of 250 J/m^2.

During the first observation year the manufacturer's calibration was used [5]. The cosine response of the sensor was tested and found to be in good agreement with ideal cosine function.

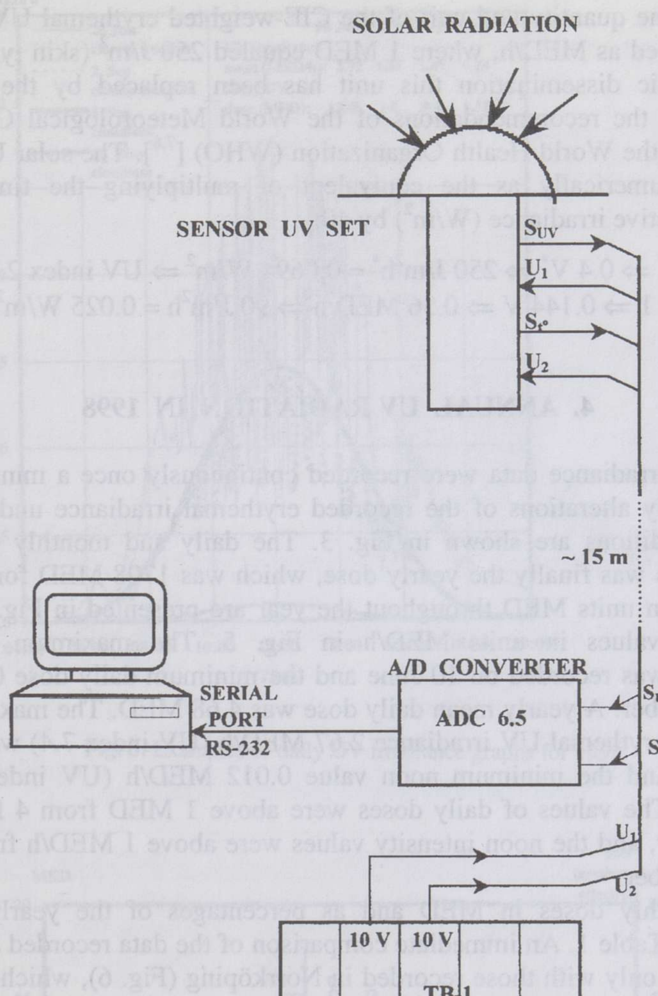

Fig. 2. Configuration of the instrumentation.

The sensor is installed on the roof platform of the main building of Tartu Observatory at Tõravere (80 m a. s. l.). The signals of the UV irradiance S_{UV} and temperature $S_{t°}$ are recorded in the laboratory where the stabilized supply voltages U_1 and U_2 for the sensor are formed (Fig. 2). The length of the power and signal cables is approximately 15 m. The analogue signals of the sensor in the region from 1 mV to 3.2 V are digitized using a 20-bit double integrating analogue-digital converter ADC 6.5 (developed by Märtens & Tramperk AS, Tallinn) and are recorded by PC 386. The UV irradiance values are recorded once in every minute.

Initially the quantity and unit of the CIE-weighted erythemal UV irradiance were expressed as MED/h, where 1 MED equaled 250 J/m^2 (skin type II). Now for the public dissemination this unit has been replaced by the UV index according to the recommendations of the World Meteorological Organization (WMO) and the World Health Organization (WHO) [7,8]. The solar UV index is expressed numerically as the equivalent of multiplying the time-weighted average effective irradiance (W/m^2) by 40:

1 MED/h* $\Rightarrow$ 0.4 V* $\Rightarrow$ 250 J/m^{2}h* = 0.0694 W/m^2 $\Rightarrow$ UV index 2.778

UV index 1 $\Rightarrow$ 0.144 V $\Rightarrow$ 0.36 MED/h $\Rightarrow$ 90 J/m^{2}h = 0.025 W/m^2

4. ANNUAL UV RADIATION IN 1998

The UV irradiance data were recorded continuously once a minute in units MED/h. Daily alterations of the recorded erythemal irradiance under different weather conditions are shown in Fig. 3. The daily and monthly doses were integrated, as was finally the yearly dose, which was 1708 MED for 1998. The daily doses in units MED throughout the year are presented in Fig. 4, and the local noon values in units MED/h in Fig. 5. The maximum daily dose 18.27 MED was recorded on 10 June and the minimum daily dose 0.053 MED on 26 December. A yearly mean daily dose was 4.68 MED. The maximum noon value of the erythemal UV irradiance 2.67 MED/h (UV index 7.4) was recorded on 26 June and the minimum noon value 0.012 MED/h (UV index 0.03) on 11 January. The values of daily doses were above 1 MED from 4 February to 15 November, and the noon intensity values were above 1 MED/h from 1 April to 23 September.

The monthly doses in MED and as percentages of the yearly dose are presented in Table 1. An immediate comparison of the data recorded at Tõravere was possible only with those recorded in Norrköping (Fig. 6), which is the only station in the Baltic–Scandinavian region at the same latitude. Regular measurements of erythemal UV doses have been performed in Norrköping (58°35′ N, 16°09′ E) since 1990. The data have been published for 1990–95 [9] and for 1996 [10]. To allow direct comparison with the Norrköping data published in the scale for skin type I (1 MED = 210 J/m^2), our data here were transformed to the same skin type. The mean (1990–96) percentages of the yearly dose are very similar to our results for April, May, and June, but in July and August the relative portions of our 1998 UV doses were significantly lower than the five-year mean in Norrköping (18.86% against 22.35% and 12.92% against 15.92%). July and August were anomalously cloudy, rainy, and windy in 1998.

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* UV SET manufacturer calibration data.

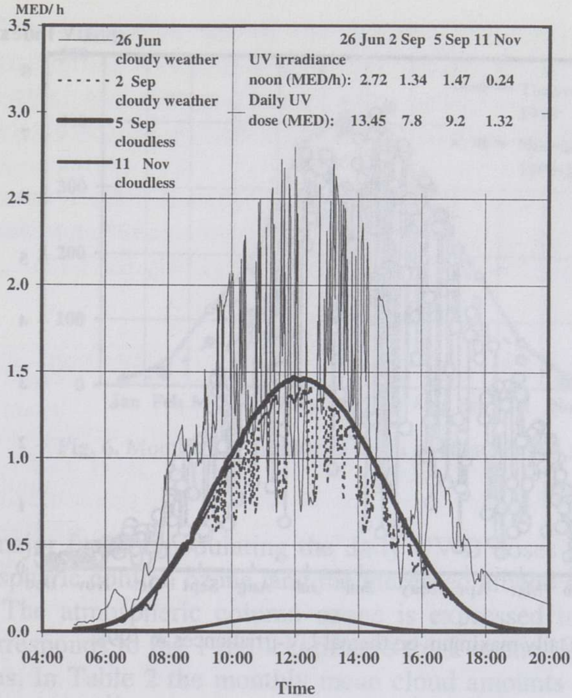

Fig. 3. Examples of daily UV irradiance graphs for 1998.

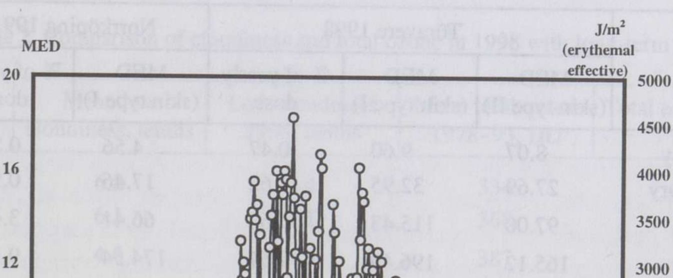

Fig. 4. Daily erythemal UV doses in 1998.

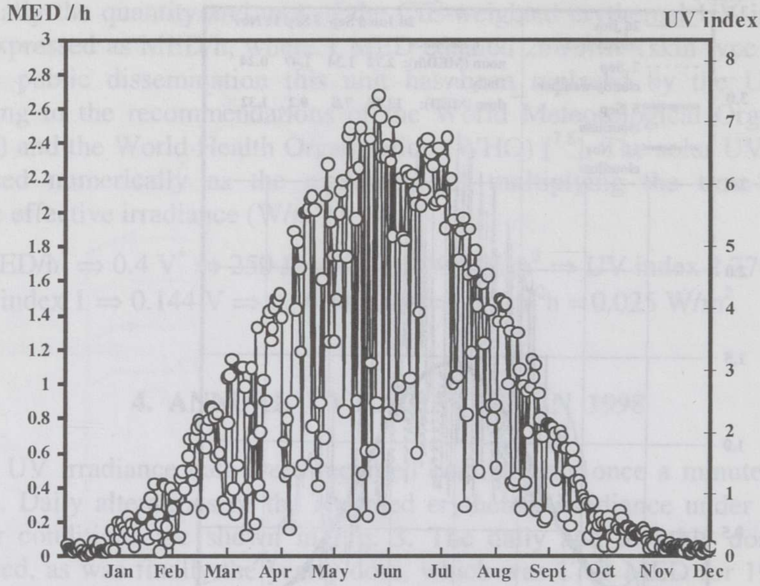

Fig. 5. Daily maximum erythemal UV irradiances in 1998.

Table 1. Monthly doses of erythemal UV radiation

	Tõravere 1998			Norrköping 1991–96	
	MED (skin type II)	MED (skin type I)	% of yearly dose	MED (skin type I)	% of yearly dose
January	8.07	9.60	0.47	4.56	0.24
February	27.69	32.95	1.62	17.46	0.92
March	97.00	115.43	5.68	66.41	3.49
April	165.12	196.49	9.67	174.54	9.18
May	307.42	365.83	18.00	335.62	17.65
June	335.27	398.97	19.63	389.61	20.49
July	322.08	383.28	18.86	424.99	22.35
August	220.69	262.62	12.92	302.62	15.92
September	143.87	171.20	8.42	130.85	6.88
October	58.07	69.10	3.40	44.43	2.34
November	16.79	19.98	0.98	7.24	0.38
December	6.02	7.17	0.35	2.88	0.15
Yearly dose	1708.09	2032.63		1901.21	

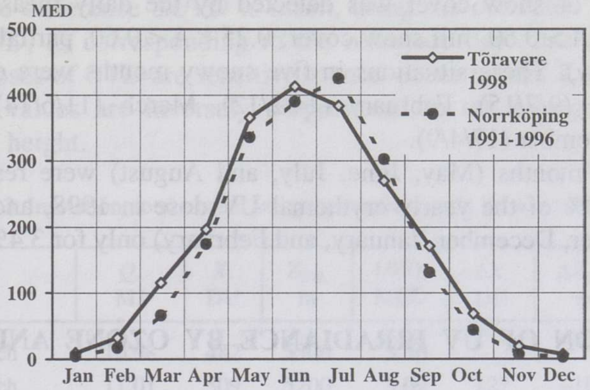

Fig. 6. Monthly UV irradiance doses at Tõravere and Norrköping.

The major factors modulating the daily UV-B doses are the low cloudiness, the atmospheric column ozone, and the increased albedo of snow cover in winter months. The atmospheric column ozone is expressed in Dobson Units (DU); 1 DU corresponds to the 1-millicentimetre-thick ozone layer in normal sea level conditions. In Table 2 the monthly mean cloud amounts are compared with the long-term mean [11], and the monthly mean column ozone values of 1998 are compared with the 1978–93 mean for Tõravere, calculated using the data obtained by Nimbus-7 TOMS (Total Ozone Mapping Spectrometer).

Table 2. Comparison of cloudiness and total ozone in 1998 with long-term mean

	Mean low cloudiness, tenths	Low cloudiness 1998, tenths	Mean total ozone 1978–93, DU	Total ozone 1998, DU
January	6.8	8.4	334	339
February	6.1	7.1	368	355
March	4.6	3.9	387	408
April	4.5	4.7	390	406
May	4.0	4.0	375	395
June	3.7	6.0	353	362
July	4.1	5.4	341	369
August	4.2	6.6	321	355
September	5.1	4.6	300	307
October	6.3	5.6	290	312
November	7.5	4.8	289	308
December	7.5	8.8	316	349

The presence of snow cover was detected by the daily measured integral albedo A values ($A > 0.60$, full snow cover; $0.25 < A < 0.60$, partial snow cover; $A < 0.25$, no snow). These situations in five snowy months were distributed as follows: January (9/7/15), February (14/2/12), March (11/6/14), November (21/3/6), and December (17/4/9).

Four summer months (May, June, July, and August) were responsible for approximately 70% of the yearly erythemal UV dose in 1998, and four winter months (November, December, January, and February) only for 3.4%.

5. MODULATION OF UV IRRADIANCE BY OZONE AND CLOUDS

The main difference between the UV-B (280–320 nm) irradiance, and the UV-A (320–400 nm) and the visible at the ground level (400–700 nm) irradiances is that UV-B depends highly on the atmospheric column ozone.

The attenuation by other atmospheric factors is not radically different. This is illustrated by the regression between the measured daily UV-B doses and the daily insolation sums recorded by the actinometric station at Tõravere. The erythemal UV doses *UVD* were recorded in units MED and the daily sums of the insolation Q in MJ/m^2. The correlation coefficient between them was 0.946 and the regression in linear approximation was

$$UVD = 0.57Q - 0.32.$$

The correlation less than 1 is due to the fact that *UVD* is partly controlled by factors not controlling Q immediately; the major such factor is the value of atmospheric total ozone. Despite the overall high correlation, quite big differences were registered between the observed changes in the insolation and UV-B irradiance in individual cases. Quite often day-to-day changes occurred in which the decrease in the daily sum of insolation corresponded to the increase in the UV-B daily dose and vice versa. These cases were studied separately, taking into account the total ozone and cloudiness data as well as the 500 mb geopotential height data. The geopotential height levels in the upper troposphere are usually inversely correlated to atmospheric total ozone.

To determine how the UV-B irradiance really depends on different cloudiness conditions, the days with the close values of total ozone were selected; the episodes with significantly different total ozone values and as similar cloudiness as possible were selected to study the total ozone contribution. The crudest characteristic for comparison is the daily UV-B dose. One cannot expect to find two or more days with the highly coinciding daily attenuation by clouds. Direct comparison is possible for instantaneous clear episodes and in a less justified version for the same cloud amounts of the same type at the same values of the solar zenith angle.

The changes in daily UV doses *UVD* in some exceptional cases of comparable sums of insolation Q recorded at different total ozone values X are presented in

Table 3. The difference ΔUVD is taken, using the corrected to the change ΔQ value of *UVD*, as corresponding to the reference day. One can see that daily erythemal doses of *UVD* are sensitive to total ozone values *X*, and the changes in total ozone values are inversely proportional to the changes in the 500 mb geopotential height.

Table 3. Insolation, total ozone, and geopotential height for selected days in 1998

	Q, MJ	X, DU	Z_{500}, m	UVD, MED	ΔX, DU	ΔZ_{500}, m	ΔUVD, %
19 March	10.98	482	5300	3.30			
20 March	11.01	509	5200	3.09	+27	–100	–6.4
9 April	20.17	461	5300	6.91			
10 April	20.24	453	5320	6.92	–8	+20	+0.3
20 July	22.06	453	5520	11.78			
22 July	20.29	352	5750	15.34	–101	+230	+41.6
11 August	19.67	408	5610	10.10			
13 August	19.62	359	5640	11.39	–49	+30	+13.1
20 September	10.72	324	5740	5.05			
21 September	10.82	270	5820	6.34	–54	+80	+24.4

Q, daily sum of insolation; X, total ozone; Z_{500}, 500 mb geopotential height; UVD, daily UV dose; ΔX, ΔZ_{500}, and ΔUVD are differences for pairs of days with similar values of Q.

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REFERENCES

1. World Meteorological Organization. Scientific assessment of ozone depletion. *WMO Report*, 1994, **37**.
2. Mayer, B., Kylling, A., Madronich, S. and Seckmeyer, G. Enhanced absorption of UV radiation due to multiple scattering in clouds: experimental evidence and theoretical explanation. *J. Geophys. Res.*, 1998, **103**, 31 241–31 254.
3. Eerme, K., Veismann, U., Koppel, R. and Pehk, M. First four years of atmospheric total ozone measurements in Estonia. *Proc. Estonian Acad. Sci. Biol. Ecol.*, 1998, **47**, 188–203.
4. Webb, A. R. (lead author). Guidelines for site quality control of UV Monitoring. *WMO GAW Report*, 1997, **126**.

5. UV Standard Series (II). User's manual. *Scintec Atmosphärenmesstechnik GmbH*, 1997.
6. McKinlay, A. F. and Diffey, B. L. A reference action spectrum for ultraviolet induced erythema in human skin. *CIE J.*, 1987, **6**, 17–22.
7. The International Commission on Non-Ionizing Radiation Protection. *Global Solar UV Index*. 1995.
8. World Meteorological Organization. Report of the WMO–WHO Meeting of Experts on Standardization of UV Indices and their Dissemination to the Public. *WMO GAW Report*, 1998, **127**.
9. Josefsson, W. Five years of solar UV-radiation monitoring in Sweden. *SMHI Reports, Meteorol. Climatol.*, 1996, **71**.
10. Josefsson, W. Solar UV-radiation monitoring 1996. *SMHI Reports, Meteorol. Climatol.*, 1997, **74**.
11. Russak, V. Pilvisus. In *Tartu kliima ja selle muutumine viimastel kümnenditel*. Tartu, 1990, 100–108.

PÄIKESE ERÜTEEMNE ULTRAVIOLETTKIIRGUS EESTIS AASTAL 1998

Uno VEISMANN, Kalju EERME ja Rutt KOPPEL

Regulaarseid Päikese ultraviolettkiirguse mõõtmisi alustati Eestis 1. jaanuaril 1998 naha erüteemsele spektraalsele tundlikkusele vastava kiirgustajuriga Scintec UV SET. On tehtud kokkuvõte aasta mõõtmistulemustest Tõraveres ja võrreldud andmeid lähimas samal laiuskraadil asuvas mõõtmispunktis Norrköpingis eelmistel aastatel saadutega. Aasta keskmine erüteemne päevadoos oli Eestis 4,68 MED-ühikut (1 MED = 250 J/m^2 II tüüpi nahale), maksimaalne päevadoos mõõdeti 10. juunil ja see oli 18,27 MED-ühikut.