UV Index monitoring in Europe

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Alois W. Schmalwieser, *[a] Julian Gröbner,[b] Mario Blumthaler,[c] Barbara Klotz,[c] Hugo De Backer,[d] David Bolsée,[e] Rolf Werner,[f] Davor Tomsic,[g] Ladislav Metelka,[h] Paul Eriksen,[i] Nis Jepsen,[i] Margit Aun,[j] Anu Heikkilä,[k] Thierry Duprat,[l] Henner Sandmann,[m] Tilman Weiss,[n] Alkis Bais,[o] Zoltan Toth,[p] Anna-Maria Siani,[q] Luisa Vaccaro,[r] Henri Diémoz,[s] Daniele Grifoni,[t] Gaetano Zipoli,[u] Giuseppe Lorenzetto,[v] Boyan H. Petkov,[w] Alcide Giorgio di Sarra,[x] Francis Massen,[y] Charles Yousif,[z] Alexandr A. Aculinin,[aa] Peter den Outer,[ab] Tove Svendby,[ac] Arne Dahlback,[ad] Bjørn Johnsen, [ae] Julita Biszczuk-Jakubowska,[af] Janusz Krzyscin,[ag] Diamantino Henriques,[ah] Natalia Chubarova,[ai] Predrag Kolarž,[aj] Zoran Mijatovic,[ak] Drago Groselj,[al] Anna Pribullova,[am] Juan Ramon Moreta Gonzales,[an] Julia Bilbao,[ao] José Manuel Vilaplana Guerrero, [ap] Antonio Serrano, [aq] Sandra Andersson,[ar] Laurent Vuilleumier, [as] Ann Webb [at] and John O'Hagan[au]

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The UV Index was established more than 20 years ago as a tool for sun protection and health care. Shortly after its introduction, UV Index monitoring started in several countries either by newly acquired instruments or by converting measurements from existing instruments into the UV Index. The number of stations and networks has increased over the years. Currently, 160 stations in 25 European countries

[a]University of Veterinary Medicine, Unit of Physiology and Biophysics, Vienna, Austria. E-mail: alois.schmalwieser@vetmeduni.ac.at
[b]PMOD/WRC, Davos Dorf, Switzerland
[c]Medical Univ. Innsbruck, Innsbruck, Austria
[d]Royal Meteorological Institute of Belgium, Observations, Brussels, Belgium
[e]Royal Belgian Institute for Space Aeronomy, Brussels, Belgium
[f]Bulgarian Academy of Sciences, Stara Zagora, Bulgaria
[g]Metorological and hydrological institute of Croatia, Metorological and hydrological institute of Croati, Croatia
[h]Czech Hydrometeorological Institute, Solar and Ozone Department, Hradec Kralove, Czech Republic
[i]Danish Meteorological Institute, Copenhagen, Denmark
[j]Tartu Observatory, Tartumaa, Estonia
[k]Finnish Meteorological Institute, Helsinki, Finland
[l]Météo-France, Toulouse Cedex, France
[m]Bundesamt fur Strahlenschutz Neuherberg, Section for Optical Radiation, Neuherberg, Germany
[n]sglux GmbH, Berlin, Germany
[o]Aristotle University of Thessaloniki, Greece
[p]Hungarian Meteorological Service, Marczell György Main Observatory, Budapest, Hungary
[q]Sapienza Universita' di Roma, Physics Department, Rome, Italy
[r]ISPRA, Physical Agents Unit, Rome, Italy
[s]ARPA Valle d'Aosta loc, Saint-Christophe, Italy
[t]LaMMA Consortium, Institute of Biometeorology of the National Research Council, Sesto Fiorentino, Italy
[u]CNR-IBIMET, Florence, Italy
[v]ARPA di Vicenza, Vicenza, Italy
[w]National Research Council, Institute of Atmospheric Sciences and Climate, Bologna, Italy
[x]ENEA, Laboratory for Observations and Analyses of the Earth and Climate, Rome, Italy
[y]Lycée Classique de Diekirch, Computarium and meteoLCD, Diekirch, Luxembourg
[z]University of Malta, Institute for Sustainable Energy, Marsaxlokk, Malta
[aa]Institute of Applied Physics of the Academy of Sciences of Moldova, Kishinev, Moldova (the Republic of)
[ab]Dutch National Health Institute (RIVM), Netherlands
[ac]NILU – Norwegian Institute for Air Research, Kjeller, Norway
[ad]University of Oslo, Institute of Physics, Oslo, Norway
[ae]Statens Stralevern, Monitoring and Research, Oesteras, Norway
[af]Institute of Meteorology and Water Management, Gdynia, Poland
[ag]Institute of Geophysics, Polish Academy of Sciences, Warszw, Poland
[ah]Instituto Português do Mar e da Atmosfera, Observatório Afonso Chaves, Ponta Delgada S. Miguel, Portugal
[ai]Moscow State University, Moscow, Russian Federation
[aj]University of Belgrade, Zemun, Serbia
[ak]University of Novi Sad, Novi Sad, Serbia
[al]Slovenian Environment Agency, Ljubljana, Slovenia
[am]Slovakian Academy of Sciences, Tatranska Lomnica, Slovakia
[an]Spanish Meteorological Agency, Area of Atmospheric Observation Networks, Madrid, Spain
[ao]University of Valladolid, Valladolid, Spain
[ap]National Institute for Aerospace Technology, Mazagon, Spain
[aq]University of Extremadura, Department of Physics, Badajoz, Spain
[ar]SMHI, Norköpping, Sweden
[as]MeteoSwiss, Atmospheric data division, Payerne, Switzerland
[at]University of Manchester, Manchester, United Kingdom of Great Britain and Northern Ireland
[au]Public Health England Centre for Radiation Chemical and Environmental Hazards, Radiation Dosimetry, Didcot, United Kingdom of Great Britain and Northern Ireland

deliver online values to the public *via* the Internet. In this paper an overview of these UV Index monitoring sites in Europe is given. The overview includes instruments as well as quality assurance and quality control procedures. Furthermore, some examples are given about how UV Index values are presented to the public. Through these efforts, 57% of the European population is supplied with high quality information, enabling them to adapt behaviour. Although health care, including skin cancer prevention, is cost-effective, a proportion of the European population still doesn't have access to UV Index information.

1. Introduction

The potential of natural solar UV radiation to cause detriment has been a matter of concern for many decades. With respect to sunburn, it was the German physicist Karl Hausser, about 100 years ago, who started investigations to quantify the erythemal efficiency of UV radiation. During heliotherapy in the Alps to treat tuberculosis, he observed differences in the efficiency of UV in causing erythema, as a function of wavelength. In 1918 he started, together with his colleague Wilhelm Vahle, detailed investigations and succeeded a few years later in deriving the wavelength dependence of human erythema.[1] Henceforward it was possible to determine the erythemal efficiency of the sun and any other source of UV radiation.

For many years, measurements of solar UV radiation were done by spectroradiometers only – like the pioneering work of P. Bener at Davos[2] – and erythemally effective irradiance was calculated from these measurements. These sophisticated instruments need experienced operators and intensive care.

The need for all-day continuous measurements under all weather conditions at several, often remote, locations provoked the development of a less expensive, easy to use but accurate, instrument that can work unattended. The development of the first instrument delivering the erythemally effective irradiance was started about 1958 by Robertson.[3] Based on experience Berger[4] improved this instrument and several of these so called Robertson–Berger–Meters were installed from 1973 onward in the USA, Australia and later in Europe.[5] The spectral sensitivity was similar to that of human erythema as derived by Coblentz and Stair.[6] At this time the output was given in "sun burn units" which correspond to 250 J m^{-2} to 350 J m^{-2} of erythemally weighted dose[7] and is close to the minimal erythema dose for skin type II.[8] A later output unit was also the minimal erythema dose per hour[9] equivalent to 210 J m^{-2}.[10]

The evidence for the increasing number of skin cancer cases (*e.g.* ref. 11) made it necessary to inform the public about the risk from solar radiation. In order to provide easy understandable and useful information for sun protection and health care, a dimensionless index for the erythemally effective irradiance was devised.[12] Different UV indices were established in several countries. A joint definition for the UV Index (UVI) was internationally agreed in 1995 under the umbrella of WHO, WMO and ICNIRP[13] using the action spectrum as specified by McKinlay and Diffey[14] for weighting: the UVI is calculated by weighting the measured solar spectrum of global irradiance (in W $(m^2\ nm)^{-1}$) with the standardised erythema action spectrum, integrating from 250 to 400 nm and then dividing by 0.025 W m^{-2}. This results in a unit-less quantity. For most conditions in Europe the UVI is less than 10. By now a slightly corrected action spectrum was published in CIE S 007/E-1998 and subsequently ISO 17166:1999,[15] which may lead to slight differences (*e.g.*, less than 2%).[16] In 2002 the WHO distributed a colour scheme for visualisation of the UVI.[17] Since its definition, several promotion campaigns were undertaken (*e.g.* Intersun by WHO) to make people familiar with the UVI. Necessary parts of such a campaign are recent UVI values that are easily accessible for the public.[18] Health authorities and people that care about sun protection are often knowledgeable about the conditions at home. However many people receive a noticeable part of the annual exposure during holidays.[19] With the availability of UVI values at a holiday destination, appropriate advice can be made available. For almost 20 years such online measurements have been available on the Internet. The financial efforts for this do not only help to avoid illness and suffering but also to avoid costs for medical treatment. In the meanwhile it could be shown that skin cancer prevention initiatives are highly cost effective and cost-saving.[20] The changes in the ozone layer, climate change and those complex interaction in respect to UV radiation (*e.g.* ref. 21), have caused seasonal and local changes (*e.g.*ref. 22). Therefore up-to-date information is more important than ever.

In this paper we will provide an overview of UVI measurements in Europe, focusing on those stations and networks that do online monitoring on the Internet. As the UVI values have to be reliable, we will also consider the instruments used and the corresponding quality assurance and quality control procedures. Service radius is used to provide an estimate of the coverage provided by individual measurement sites. The area of the country or region is divided by the number of measurement sites. Assuming a circular area, the service radius is the radius of that area.

2. UV Index monitoring sites

In the following chapter a short summary of UVI monitoring in the European countries (in alphabetical order) is given. The stations which deliver online UV-Index values to the Internet are listed in Table 1, together with additional information such as location, instruments and year of start. Fig. 1 shows the locations of these stations. Table 2 summarizes the networks.

Austria: The monitoring network was established in 1996 on behalf of the Federal Department of Environment. The

Table 1 Networks and stations delivering online UV-Index values to the Internet (broadband meter; solar light 501 (A)nalogue or (D)igital, Kipp&Zonen UVS-E-T. UVS-AE-T, UV-S-B-C, ECO UVb, Yankee UVB-1, Thies Clima E1c, sglux EryCa, Optix UVEM-6C, Davies Pro2+. Multichannel instruments: Biospherical instruments GUV-511, GUV-541, GUV 2511, NILU NILU-UV, UV-Rad. Spectroradiometer Type Brewer MkII, MKIII, MK IV, Spectroradiometer: Bentham DTM150, DTM 300, DILOR-XY)

Country	Station	Lat	Long	Alt	Device	Start
Austria	Bad Vöslau	47.97	16.20	286	501	1997
	Dornbirn	47.43	9.73	410	501	1997
	Gerlitzen	46.68	13.91	1526	501	2004
	Graz	47.10	15.42	348	501	1997
	Gross Enzersdorf	48.20	16.57	156	501	2004
	Hafelekar	47.32	11.39	2275	501	2005
	Innsbruck	47.26	11.38	577	501	1998
	Klagenfurt	46.65	14.32	448	501	1997
	Kirchbichl	47.49	12.09	526	501	2016
	Linz/Steyregg	48.29	14.35	335	501	1997
	Mariapfarr	47.15	13.75	1153	501	1998
	Sonnblick	47.05	12.96	3106	501	1998
	Vienna	48.26	16.43	153	501	1998
	München (D)	48.15	11.57	530	UVS-E-T	2004
	Zugspitze (D)	47.42	10.98	2660	UVS-E-T	2004
	Davos (CH)	46.80	9.83	1610	501	2006
	Weissfluhjoch (CH)	46.83	9.82	2540	501	2009
Belgium 1	Uccle	50.80	4.35	10	MkII & MKIII	1989
Belgium 2	Uccle	50.80	4.35	120	UVb	1996
	Mol	51.22	5.08	75	GUV 2511, UVb	2008
	Mont Rigi	50.52	6.08	680	GUV 2511, UVb	2011
	Oostende	51.23	2.93	0	GUV 2511, UVb	2006
	Redu (Ardennes)	50.00	5.15	450	GUV 2511, EKO	2004
	Virton	49.57	5.53	250	GUV 2511, UVb	2007
Croatia	Zagreb Maksimir	45.82	15.97	157	E1c	2004
	Parg	45.69	14.63	863	E1c	2003
	Plitvicka jezera	44.88	15.62	579	E1c	2015
	Opatija	45.34	14.31	5	E1c	1997
	Crikvenica	45.17	14.69	2	E1c	2003
	Malinska/Krk	45.13	14.53	1	E1c	1993
Cyprus	Akrotiri	34.59	32.99	32	501D + 501A	2015
Czech Republic	Hradec Kralove	50.18	15.84	278	501	1996
	Kosetice	49.57	15.08	532	501	1996
	Kucharovice	48.88	16.09	334	501	2009
Denmark	Copenhagen	55.72	12.56	35	UVB-1	1992
Estonia	Toravere	58.26	26.46	70	UVS-E-T	2000
	Haapsalu	58.96	23.53	1.2	UVS-E-T	2007
	Tallinn	59.40	24.60	33	UVS-E-T	2011
	Roomassaare	58.22	22.51	1	UVS-E-T	2009
	Pärnu	58.38	24.48	2.9	UVS-E-T	2012
Finland	Sodankylä Observatory/Arctic Res. Center	67.37	26.63	185	501	1997
	Sotkamo Kuolaniemi	64.11	28.34	171	501	1997
	Kuopio Savilahti	62.89	27.63	107	501	2014
	Jyväskylä Tikkakoski	62.40	25.67	145	501	1997
	Jokioinen Observatory	60.81	23.50	113	501	1997
	Helsinki	60.20	24.96	48	501	1997
	Parainen Utö	59.78	21.37	10	501	1997
Germany	Westerland/Sylt	54.92	8.32	20	DTM300	1995
	Zingst	54.44	12.72	5	DTM300	1993
	Norderney/Ostfries.Inseln	53.71	7.21	4	DM150	2002
	Lindenberg	52.21	14.11	127	DTM300	1995
	Lüneburg	53,25	10.46	49	DM150	2016
	Dortmund	51.53	7.45	100	DTM300	1995
	Kulmbach	50.11	11.45	310	DM150	1995
	Langen	50.01	8.65	139	DTM300	1993
	München/Neuherberg	48.21	11.58	493	DTM300	1993
	Schauinsland	47.91	7.91	1205	DTM300	1993
	Berlin	52.43	13.54	35	EryCa	2014
Gibraltar	Gibraltar	36.15	−5.35	4	501D + 501A	2015

Table 1 *(Contd.)*

Country	Station	Lat	Long	Alt	Device	Start
Greece	Athens	37.99	23.78	180	NILU-UV	2004
	Finokalia/Crete	35.34	25.67	250	NILU-UV	2011
	Ioannina	39.62	20.85	541	NILU-UV	2005
	Mytilene/Lesbos	39.11	26.55	80	NILU-UV	2005
	Patras	38.29	21.79	70	NILU-UV	2005
	Thessaloniki	40.63	22.96	60	NILU-UV	2004
	Xanthi	41.15	24.92	75	NILU-UV	2012
Hungary	Budapest	47.43	19.18	140	UVS-E-T	1994
	Kecskemét	46.97	19.55	127	501	1994
	Kékestető	47.87	20.01	1012	501	1994
	Sármellék	46.69	17.16	120	501	1994
	Siófok	46.91	18.04	108	501	1999
Iceland	Rekjavik	64.14	−21.93	10	Broadband	—
	Egilsstaði	65.27	−14.40	23	broadband	—
Italy 1	Aosta/Saint-Christophe	45.74	7.36	570	DTM300, UVS-AE-T	2006
	La Thuile	45.73	6.97	1640	UVB-1	2006
	Plateau Rosa	45.94	7.71	3500	UVS-AE-T	2007
Italy 2	Vicenza	45.53	11.59	44	501A	2011
Italy 3	Bologna, ISAC-CNR	44.52	11.34	30	UV-Rad	2005
Italy 4	Florence	43.84	11.15	45	501	2003
Italy 5	Rome, ISPRA	41.82	12.47	68	UVS-AE-T	2015
Italy 6	Rome, Sapienza Univ.	41.90	12.50	75	MK IV	1992
Italy 7	Lampedusa	35.52	12.63	45	MK III, UV-MFRSR	1997
Ireland	Malin Head	55.37	−7.34	19	501D + 501A	1995
Luxembourg	MeteoLCD	49.87	6.17	218	501	1996
Moldova	ARG IAP, Kishinev	47.00	28.82	205	UV-S-B-C	2003
Netherlands	Bilthoven	52.12	5.20	20	DILOR-XY	1994
Norway	Blindern	59.93	10.72	95	GUV-511	1994
	Oesteraas	59.95	10.60	135	GUV-541	1999
	Kise	60.77	10.80	130	GUV-541	1996
	Landvik	58.33	8.52	10	GUV-541	1996
	Bergen	60.38	5.33	40	GUV-541	1996
	Finse	60.60	7.52	1210	GUV-541	2003
	Trondheim	63.42	10.40	65	GUV-541	1996
	Andoya	69.28	16.02	380	GUV-541	2000
	Tromsoe	69.68	18.97	60	GUV-541	1995
	Ny-Aalesund	78.92	11.92	20	GUV-541	1995
Poland 1	Leba	54.75	17.53	2	501	1993
	Legionowo	52.40	20.97	96	501	1993
	Zakopane	49.30	19.97	855	501	1993
	Katovice	50.27	19.02	266	UVEM-6C	2006
Poland 2	Warsaw	52.25	20.94	113	Pro2+	2012
	Łódź	51.76	19.53	233	Pro2+	2014
	Stary Wiec	54.09	18.32	142	Pro2+	2016
	Kowala Druga	51.22	22.07	185	Pro2+	2015
	Belsk	51.84	20.79	176	UVS-E-T	2005
Portugal	Funchal	32.65	−16.89	56	501, MKII	1989/04
Serbia 1	Novi Sad	45.33	19.85	84	UVB-1	2003
Serbia 2	Belgrade	44.86	20.39	94	501	2009
Spain 1	Valladolid, University	41.66	−4.71	705	UVB-1	2014
Spain 2	Almeria Aeropuerto	36.85	−2.38	29	UVB-1	2007
	Moguer (El Arenosillo)	37.10	−6.73	45	UVB-1	2003
	Badajoz	38.88	−7.02	190	UVB-1	2001
	Barcelona	42.38	2.12	95	UVB-1	1999
	Cáceres	39.47	−6.33	405	UVB-1	2007
	Cádiz - Obs.	36.50	−6.25	2	UVB-1	2005
	Ciudad Real	38.98	−3.92	628	UVB-1	1999
	Córdoba - Aeropuerto	37.83	−4.85	91	UVB-1	2006
	A Coruña	43.37	−8.42	67	UVB-1	1999
	Granada Base Aérea	37.13	−3.28	692	UVB-1	2003
	Izaña	28.30	−16.50	2400	UVB-1	2001
	León Aeropuerto	42.58	−5.65	916	UVB-1	2007
	Madrid, Ciudad Univ.	40.45	−3.72	680	UVB-1	1995

Table 1 *(Contd.)*

Country	Station	Lat	Long	Alt	Device	Start
	Málaga	36.72	−4.48	61	UVB-1	1999
	Mas Palomas	27.83	−15.95	25	UVB-1	2001
	Murcia	38.00	−1.17	69	UVB-1	1997
	Puerto de Navacerrada	40.78	−4.02	1894	UVB-1	2012
	Palma de Mallorca	39.55	2.63	6	UVB-1	1999
	Tortosa	40.82	0.48	44	UVB-1	1999
	Salamanca, Matacan	40.95	−5.50	803	UVB-1	2003
	Santander	43.48	−3.80	79	UVB-1	1999
	San Sebastián, Igueldo	43.30	−2.03	259	UVB-1	2005
	Sta Cruz de Tenerife	28.47	−16.25	31	UVB-1	2006
	Valencia Aeropuerto	39.48	−0.47	57	UVB-1	1999
	Valladolid	41.65	−4.77	740	UVB-1	1999
	Zaragoza Base Aérea	41.67	−1.07	298	UVB-1	1999
Spain 3	Arenosillo	37.10	−6.73	52	UVB-1	1996
	Alacalá de Guadaira	37.34	−5.83	72	UVS-E-T	2013
	Algeciras	36.14	−6.73	30	UVS-E-T	2013
	Córdoba	37.90	−4.78	144	UVS-E-T	2013
	Marbella	36.51	−4.87	10	UVS-E-T	2013
	Badajoz	38.88	−7.01	199	UVS-E-T	2001
	Cáceres	39.48	−6.34	397	UVS-E-T	2001
	Covatilla	40.36	−5.69	1965	UVS-E-T	2008
	Fuente de Cantos	38.24	−6.30	582	UVS-E-T	2007
	Orellana	39.00	−5.53	323	UVS-E-T	2007
	Plasencia	40.06	−6.04	372	UVS-E-T	2004
Switzerland	Payerne	46.81	6.94	491	501	1998
	Jungfraujoch	46.55	7.99	3582	501	1996
	Davos	46.81	9.84	1610	501	2003
	Locarno	46.18	8.78	366	501	2000
UK	Chilton	51.58	−1.32	135	501	1990
	Camborne	50.22	−5.33	81	501	1993
	London	51.50	0.12	40	501	2013
	Swansea	51.61	−3.98	24	501	2013
	Leeds	53.85	−1.61	157	501	1992
	Belfast	54.60	−5.83	31	501	2013
	Inverness	57.47	−4.19	34	501	2013
	Lerwick	60.14	−1.18	80	501	1993
	Reading	51.44	−0.94	66	DM150	1993
	Manchester	53.47	−2.23	76	DM150	1997

locations have been selected by an objective method[23] and quality assurance was well defined from the beginning.[24] Austria possesses a high alternating topography and is within 4 climatic zones (Oceanic European, Alpine, Pannonian continental, Mediterranean). At the present time the network consists of 13 stations. At 3 stations a second device is equipped with a shadow band to measure diffuse irradiance. By taking into account the area of the country (83.879 km^2) each station covers approximately 6450 km^2 on average, denoting a service radius of 45 km for each station. The altitude of stations ranges from 150 m to 3105 m above sea level (asl). Online-publication of measurements includes two stations from Germany (Munich and Zugspitze) and two stations from Switzerland (Davos and Weissfluhjoch). A special feature of the website is a map which shows the spatial distribution of the UVI over Austria. This map is produced by combining measurements from all stations, clear sky model calculations, digital elevation information, and cloud attenuation factors derived from high resolution Meteosat pictures every 15 minutes.[25] Highest UVI values at the stations span a relatively wide range although the difference in latitude is only 1.6°. At Vienna (156 m asl) the UVI may reach values between 7 and 8 while at Sonnblick (3105 m asl) it may go up to 11.

Belgium: In contrast to Austria, altitude does not significantly influence the UVI over Belgium. Two institutions monitor the UVI there. The Royal Meteorological Institute of Belgium (RMI) has been measuring the UV radiation since 1989 at Uccle in the south of Brussels with a Brewer spectroradiometer.[26] Presently, several instruments run there in parallel. The second institution is the Royal Belgian Institute for Space Aeronomy (BIRA-IASB) at Brussels which operates another five stations and is responsible for publication. The website also includes the UVI from Luxemburg (see below). Each of the Belgian stations is equipped with a multichannel instrument and a broadband meter which provide one measurement per minute. The stations are relatively homogeneously distributed over the country. The highest station is Mont Rigi (680 m asl), a skiing and hiking resort in the vicinity of Mt. Botrange (694 m asl), and the highest Mountain of Belgium. The six Belgian stations are responsible for an area

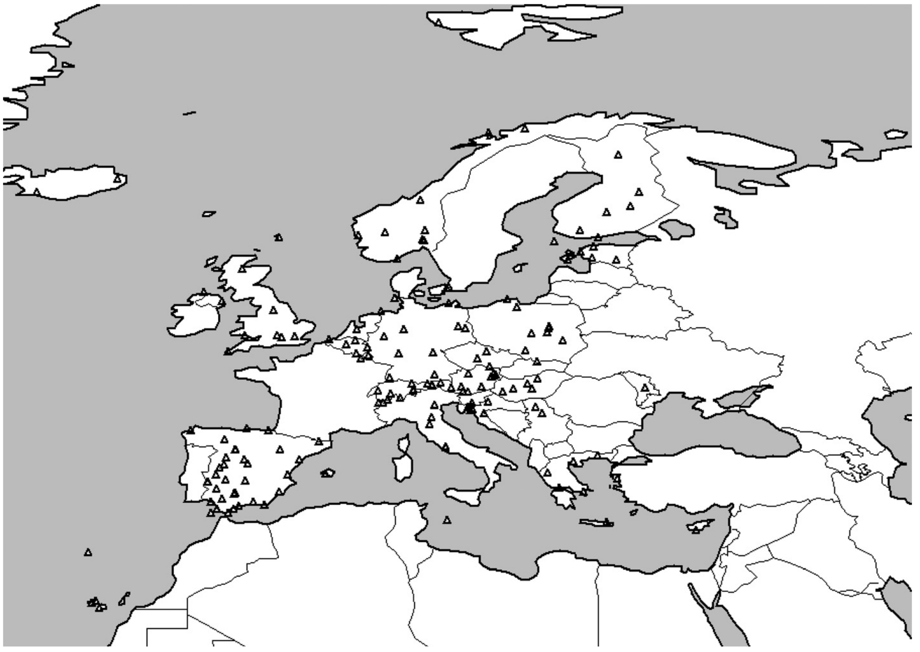

Fig. 1 UV Index monitoring sites in Europe which deliver online values.

of 30 528 km^2, denoting a service radius of 40 km each. There are no large differences in the UVI on a clear-sky day in summer. For low altitude stations, the highest UVI values observed during recent years were between 8 and 9. For Mont Rigi, the highest UVI was up to 9.8.[27] Both institutes measure the UVI also in Antarctica at the Princess Elisabeth Station with a broadband meter (BIRA-IASB) and a Brewer (RMI) where the UVI may reach a value between 10 and 11 in December. The maximum UVI was 12.3, measured in 2015.

Bulgaria: In February 2015 a multichannel instrument was installed at Stara Zagora,[28] in the centre of the country, just south of the Balkan Mountains and near to the famous tourist attraction, Rose Valley. Since this time regular measurements of the UV irradiance have been carried out and the total ozone column is retrieved. The Space Research and Technology Institute plans to start the determination of the UVI during 2017.

Croatia: Croatia is a very popular holiday destination, especially famous for its beaches and the hundreds of islands. About 10 million tourists are welcomed each year. The UVI network consists of 11 stations, equipped with broadband meters, with 6 of them providing UVI values online. The stations are spread over the whole country including locations close to the beaches and on some islands (Krk and Solta). Another station, important for tourists, is located in the national park Plitvicka Jezera, which is well known for its lakes and waterfalls. The highest station (Parg, 863 m asl) is located in the woodlands north of Rijeka, and the largest city and capital Zagreb has an instrument. Bringing all 11 stations online would reduce the service radius from 111 km to 81 km.

Cyprus: The island of Cyprus itself belongs geographically to Asia, but culture and economy are strongly connected to Europe and the Republic of Cyprus is a member of the European Union. An important branch of economy in Cyprus is tourism. The island is well known for summer vacation but also for its pleasant climate during winter. Beside the beaches, attractions for visitors are the historical places but also the high mountain areas up to Mt. Olympus (1952 m asl). These result in about 14 million guest-nights per year. Apart from short term stays, many Europeans, especially from the UK, have chosen Cyprus as their secondary residence. One UVI station is located in Akrotiri (a British air base) and participates in the UVI network of Public Health England (see below). During summer UVI up to 10 can be measured. This value differs significantly from the highest values experienced on the British Isles and justifies the efforts of online monitoring.

Czech Republic: Measurements at the solar and ozone observatory in Hradec Kralove by the Czech Hydrometeorological Institute (CHMI) have a long tradition dating back to the 1960s. UVI monitoring using a broadband meter started there, and at another station, in 1996. In 2009 a third station was added. At all locations global and diffuse irradiance is measured. Main attractions for visitors from all over the world are the capital Prague, cities possessing a core from the middle age as well as the long traditional spa resorts like Carlsbad. Skiing resorts can be found in the north, west and south-west and are visited mainly by natives. The stations span a triangle centred to the middle of the country and provide new data every 10 minutes. Another broadband meter is operated by the Masaryk University in Brno in the south of the country but it is not yet included in the network. In the near future the network will be expanded by a station at Krkonose Mountain (Giant Mountains – about 1400 m asl) in North Bohemia. The establishment of this station will reduce the

Table 2 Descriptions of networks and stations delivering online UV-Index values to the websites (presentation: M: spatial distribution, G: graph, S: single value, T: table, P: purchaser/financer, R: responsibility, O: operator)

Country	Update	Presentation	Colour system	Archive	Language
Austria	10–30 min	M/G/S	WHO	Y	D/E
P:	Federal Department for Environment				
R:	M. Blumthaler				
O:	Land Niederösterreich; ZAMG, Vienna; Observatorium Kanzelhöhe, University Graz; Amt der Steiermärkischen Landesregierung; Universität für Bodenkultur, Vienna; Sektion für Biomedizinische Physik, Medical University Innsbruck; CMS Schreder, Kirchbichl; Amt für Natur- und Umweltschutz, Land Oberösterreich; WG Environmental Health, VUW Vienna; Meteorologisches Institut, University Munich; Forschungsstation Schneefernerhaus; WRC-PMO Davos				
Web:	http://www.uv-index.at				
Belgium 1	30 min	G	Other	N	NL/F/E/D
P:	Federal service for scientific affairs				
R:	H. De Backer				
O:	Koninklijk meteorologisch Instituut				
Web:	http://www.meteo.be/meteo/view/en/522044-UV.html				
Belgium 2	1 min	T	WHO	Y	E
P:	Federal service for scientific affairs				
R:	D. Bolsee				
O:	BIRA-IASB, Brussels				
Web:	http://uvindex.aeronomie.be				
Croatia	10 min	T	WHO	N	E
P:	Meteorological and hydrological institute of Croatia; City of Crikvenica; City of Malinska; National park Plitvicka jezera; City of Opatija				
R:	D. Tomsic				
O:	Meteorological and hydrological institute of Croatia				
Web:	http://vrijeme.hr/aktpod.php?id=uvi				
Cyprus	5 min	G	WHO	Y	E
P/O:	Public Health England				
R:	J. B. O'Hagan				
Web:	https://uk-air.defra.gov.uk/data/uv-index-graphs				
Czech Republic	10 min	G/S	WHO	Y	CZ
P/O:	Czech Hydrometeorological Institute				
R:	L. Metelka				
Web:	http://portal.chmi.cz/aktualni-situace/aktualni-stav-pocasi/ceska-republika/ozonove-a-uv-zpravodajstvi				
Denmark	30 min	G/S	WHO	N	DK
P/O:	Danish Meteorological Institute				
R:	P. Eriksen, N. Jepsen				
Web:	http://www.dmi.dk/vejr/sundhedsvejr/uv-indeks				
Estonia	1 min	G/S	WHO	Y	EE/E/RU
P:	Republic of Estonia, Ministry of the Environment				
R:	K. Nurmela				
O:	Estonian Environment Agency, KAUR				
Web:	http://www.ilmateenistus.ee/ilm/ilmavaatlused/uv-indeks/				
Finland	10 min	G	WHO	N	FI/SV/E
P/O:	Finnish Meteorological Institute				
R:	A. Aarva				
Web:	http://en.ilmatieteenlaitos.fi/uv-index (EN)				
Germany 1	1 day	G/S	Other/ WHO	n	D
P:	Federal Office for Radiation Protection				
R:	H. Sandmann				
O:	Institute for Med. Climatology of Kiel University; German Environment Agency; Trade Supervisory Office Hildesheim; German Weather Service; Federal Institute for Occupational Safety and Health; Bavarian Environment Agency; Federal Office for Radiation Protection;				

Table 2 *(Contd.)*

Country	Update	Presentation	Colour system	Archive	Language
Web:	http://www.bfs.de/DE/themen/opt/uv/uv-index/aktuell/aktuell_node.html				
Germany 2	5 min	G	other	N	D/E
P/O:	sglux GmbH				
R:	T. Weiss				
Web:	http://www.sglux.de				
Gibraltar	5 min	G	WHO	Y	E
P/O:	Public Health England				
R:	J. B. O'Hagan				
Web:	https://uk-air.defra.gov.uk/data/uv-index-graphs				
Greece	20 min	G	WHO	Y	GR/E
P:	General Secretariat for Research and Technology, Greece				
R:	A. F. Bais				
O:	Laboratory of Atmospheric Physics, AUTH (M. Zempila and K. Garane)				
Web:	http://www.uvnet.gr/content/stationDetails.php?id=9&time=0&p=UV_INDEX				
Hungary	1 -10 min	G	other	Y	H/E
P:	Ministry Of Agriculture				
R:	Z. Tóth				
O:	Hungarian Meteorological Service				
Web:	http://met.hu/en/idojaras/humanmeteorologia/uv-b/				
Iceland	1 day	S	other	n	Ice
P/R:	—				
O:	Icelandic Radiation Protection Authority				
Web:	uv.gr.is				
Italy 1	5—15 min	G	WHO	Y	I
P:	Regional government of Aosta Valley				
R:	H. Diémoz				
O:	ARPA Valle d'Aosta				
Web:	http://www.uv-index.vda.it				
Italy 2:	5 min	G/S	WHO	N	I
P/O:	ARPAV (Veneto Regional Agency for environmental protection and prevention)				
R:	G.Lorenzetto, L.M. Belleri				
Web:	http://www.arpa.veneto.it/temi-ambientali/agenti-fisici/radiazioni-ionizzanti/ radiazioni-uv/dati-in-diretta				
Italy 3:	30 min	G	WHO	N	I/E
P/O:	ISAC-CNR				
R:	Petkov				
Web:	http://www.bo.cnr.it/meteo.html				
Italy 4:	15 min	G	WHO	Y	I/E
P:	National Research Council				
R:	G. Zipoli & D. Grifoni				
O:	Institute of Biometeorology				
Web:	http://www.lamma.rete.toscana.it/en/weather-stations-data				
Italy 5:	10 min	G	WHO	N	I
P/O:	ISPRA, Acoustics Group, Physical Agents Unit				
R:	S. Curcuruto				
Web:	http://www.agentifisici.isprambiente.it/radiazioni-ottiche/radiazioni-uv-60/ monitoraggio-giornaliero-della-radiazione-ultravioletta/l-indice-uv-orario.html				
Italy 6:	30 min	G	WHO	Y	I
P/O:	Physics Dept., Sapienza University of Rome				
R:	A. M. Siani				
Web:	http://www.gmet.eu/				
Italy 7:	20 min	G	WHO	N	I/E
P:	ENEA (Lampedusa)				
R:	A. G. di Sarra				
O:	Laboratory for Observations and Analyses of Earth and Climate, ENEA (A. Iaccarino, D. Sferlazzo)				

Table 2 *(Contd.)*

Country	Update	Presentation	Colour system	Archive	Language
Web:	http://www.lampedusa.enea.it/dati/uvindex/				
Ireland	5 min	G	WHO	Y	E
P/O:	Public Health England				
R:	J. B. O'Hagan				
Web:	https://uk-air.defra.gov.uk/data/uv-index-graphs				
Luxembourg	30 min	G/T	other	Y	E
P/O:	Lycée classique Diekirch				
R:	F. Massen				
Web:	http://meteo.lcd.lu/today_01.html				
Moldova	1 min	G/T		D	E
P:	Institute of Applied Physics(IAP)				
R:	A. A. Aculinin				
O:	Atmospheric Research Group(ARG), IAP				
Web:	http://arg.phys.asm.md/				
Norway	60 min	G/T	WHO	Y	NO/E
P:	Ministry of Climate and Environment Ministry of Health and Care Services				
R:	B. Johnsen, T. Svendby, A. Dahlback				
O:	NILU; Phys. Depth, University of Oslo; Norwegian Radiation Protection Authority (NRPA); Bioforsk Øst, Kise; Geophys Inst, University of Bergen; Finse Res. Center/Univ. Of Oslo; Inst of Phys, Norwegian University of Science and Technology; ALOMAR Observatory; Norwegian Polar Institute				
Web:	www.nrpa.no/uvnett				
Netherlands	12 min	G	Other	Y	NL
P:	National Fund for Environmental Protection and Water Management				
R:	P.N. den Outer, E. van Putten, H. Slaper				
O:	National Institute for Public Health and the Environment				
Web:	http://www.rivm.nl/en/Topics/U/UV_ozone_layer_and_climate/current_UV_level				
Poland 1	5 min	G	WHO	N	PL
P:	National Fund for Environmental Protection and Water Management				
R:	J. Biszczuk-Jakubowska, A. Curyło				
O:	Institute of Meteorology and Water Management - National Research Institute http://www.pogodynka.pl/indeksuv				
Poland 2	1 min	S	Other	N	E/PL
P/O:	Institute of Geophysics PAS				
R:	J. Krzyścin, P.Sobolewski, J.Jarosławsk				
Web:	http://www.weatherlink.com/user/igfpan/index.php?view=summary&headers=1 http://www.weatherlink.com/user/davis3/index.php?view=summary&headers=1 http://www.weatherlink.com/user/cog2/index.php?view=summary&headers=1 http://www.weatherlink.com/user/davis4/index.php?view=summary&headers=1 http://uvb.igf.edu.pl				
Portugal	10 min	S	WHO	N	PT/E
P/O:	Instituto Português do Mar e da Atmosfera				
R:	V. Prior				
Web:	ftp://uvb:20bvu14@ftpserver.meteo.pt/UVBFUNC/CurrUVB.html				
Serbia 1	10–30 min	G/S	WHO	Y	Serb
P/O:	Department of Physics, Faculty of Sciences, University of Novi Sad				
R:	Z. Mijatovic				
Web:	http://cmep-serbia.df.pmf.uns.ac.rs/index.php?option=com_wrapper&Itemid=54 http://uv-srbija.rs/UVIndeks/IzmereneVrednosti/NoviSad				
Serbia 2	30 min	G/S		N	Serb
P/O:	Institute of Physics Belgrade, Serbia				
R:	P. Kolarž				
Web:	http://www.weather2umbrella.com/sr/uv-indeks-beograd-danas/eta/9/319 http://uv-srbija.rs/UVIndeks/IzmereneVrednosti/Beograd http://uranus.ipb.ac.rs/~uvif/				

Table 2 *(Contd.)*

Country	Update	Presentation	Colour system	Archive	Language
Spain 1	5 min	G	OTHER	Y	Sp/E
P:	Univ. of Valladolid/Spanish Ministry (MINECO), Spanish Research and Economy Ministry				
R:	J. Bilbao, A. De Miguel				
O:	Atmosphere and Energy Laboratory UVA				
Web:	http://www5.uva.es/laten				
Spain 2	1 day	G/T/S	WHO	Y	Sp
P:	AEMET				
R/O:	Area of Atmospheric Observation Networks				
Web:	http://www.aemet.es/es/eltiempo/observacion/radiacion/ultravioleta?datos=mapa				
Spain 3	20 min	M/G	WHO	N	Sp
P/O:	Instituto Nacional de Técnica Aeroespacial (INTA) Departamento de Física, Universidad de Extremadura				
R:	J. M. Vilaplana Guerrero, M. Cancillo Fernández				
Web:	http://aire.unex.es/uvi				
Switzerland	15 min	G	WHO	N	D/F/I
P:	Federal Department of Home Affairs				
R:	L. Vuilleumier, J. Gröbner				
O:	Federal Office of Meteorology and Climatology MeteoSwiss, PMOD/WRC Davos				
Web:	http://www.bag.admin.ch/uv_strahlung/10652/10683/index.html				
UK	5–30 min	G	WHO	Y	E
P:	Public Health England; Department of Environment Food and Rural Affairs				
R:	J. B. O'Hagan; A. R. Webb				
O:	Public Health England; University of Manchester				
Web:	https://uk-air.defra.gov.uk/data/uv-index-graphs				

service radius from 183 km to 159 km. The highest UVI is usually 8, and on rare days 9.

Denmark: In Denmark the UVI is made available online for Copenhagen by the Danish Meteorological Institute (DMI). Copenhagen is located on the eastern shore of the island of Zealand and partly on the island of Amager. Measurements at Copenhagen have been made with a broadband meter since 1992. Values are updated every 30 minutes. Beside this instrument there is a Brewer MK IV (since 1992), MK III (since 2014) and another broadband meter (UVS-B-T, since 2016) in operation which ensures high quality data. While the UVI from Copenhagen may be representative for a large part of the Danish archipelago, which consists of more than 440 islands, the peninsula of Jutland may remain uncovered depending on meteorological conditions. To overcome this, the online values are connected to model calculations that use cloud cover information. With that, the UVI distribution over Denmark is estimated. Altitude is not an issue as the highest hills are around 170 m asl. There are also other instruments running, *e.g.* in Greenland, but not online. The highest UVI value in Copenhagen is of the order of 7.[29]

Estonia: In Estonia there are five stations operated by the Estonian Environmental Agency, which deliver online values. Broadband meter measurements started in 2000 at the Tartu-Toravere meteorological station and the network has been expanded over the years. Together with two other stations it builds a measuring chain in the southern part of the country, whereas one of these (Pärnu), lies on the west coast and the other one on the Island of Saaremaa, around 50 km off shore. The fourth station is located in the middle of the country. The most northern station is Tallinn which is also the main region for tourism. The service radius is approximately 107 km. Summer UVI values can exceed 7.

Finland: Measurements of erythemally effective irradiance using broadband meters started in 1991.[30] The online network of the Finish Meteorological Institute started with 6 stations in 1997. A seventh station was added in 2014. Data is measured with a resolution of 1 minute, the update frequency being 10 min. The most southerly station on the mainland is located in the metropolitan region of Helsinki and supports approximately 1.5 million people with real-time values. A second urban station was established in central Finland (Jyväskylä Tikkakoski). Another three stations are located in the southern and central part of the country where most of the population lives. The most northerly station is Sodankylä, located just above the northern polar circle where the sun does not rise around the winter solstice. Measurements have been carried out there since 1989 using a Brewer MkII. Another special station is Parainen Utö, located on the island of Utö, which lies half way between Helsinki and Stockholm, and borders an archipelagoes national park. On average the service radius is 248 km on the mainland. UVI values as high as 6 and even 7 are reached in the summertime.

France: Meteo-France started UVI monitoring a couple of years ago with broadband meters at three locations. The devices are located in the southern part of the country. Considering the size of France, 3 stations cannot give an adequate estimate of UVI across the country. Therefore a UVI forecast is provided to the public instead of measurements. UVI data are collected every hour for climatological purposes and for validation of the forecast. The highest UVI values during the past years were around 9 to 10. France also has two NDACC stations which record the UVI, but do not provide data online.

Germany: Since 1993, the Federal Office for Radiation Protection (BfS) together with the German Environment Agency (UBA), the German Weather Service (DWD), and associated institutions operates the German UV monitoring network.[31] Today, the network consists of ten stations which are located at relevant sites for UV radiation and climate. Significantly, all instruments in the network are spectroradiometers. Two of the stations are located on islands in the North Sea: Sylt[32] and Norderney. Both are important holiday destinations with about 10 million guest-nights per year. The most northern station on the mainland is located on the peninsula of Zingst in the Baltic Sea, which is a popular recreational site too. The highest station is Schauinsland (1205 m asl) in the south-west of the country where UVI may be of the order of 9 in summer. The lowest summer maximum values are measured in the densely populated Ruhr-region (Dortmund) with values around 7. The service radius of one station is around 213 km. BfS informs the public by publishing the maximum UVI of the day. In case of extraordinary high UVI values, *e.g.* at low ozone events,[33] BfS issues a press release. In the near future, the varying UVI values throughout a day will be presented. Furthermore it is planned to extend the network with three array radiometers (*e.g.* one of them at the Zugspitze at about 2660 m asl) and with about 20 broadband meters.

In the capital **Berlin**, a manufacturer of a miniature erythema meter (sg-lux, Berlin, Germany) publishes recent values together with those from a station in Brazil.

Gibraltar: The most southern station on the European continent is located in Gibraltar, on the southern end of the Iberian Peninsula. Public Health England operates the device there, because it is a British Overseas Territory, and more than a quarter of the inhabitants are of British ancestry and therefore light skinned. The south of the Iberian Peninsula is not only popular for summer vacation but also a favoured golf destination in winter. The UVI may reach a value of 9 in summer.

Greece: Greece is one of the most popular holiday destinations for Europeans in summer, where visitors spent a lot of time outdoors either on beaches or on the usually treeless ancient sites. The National Network for monitoring solar UV radiation was established by the Aristotle University of Thessaloniki, Laboratory of Atmospheric Physics in 2004 aimed at providing long-term monitoring over Greece and related services such as the UVI to the local population and visitors.[34] Since 2004 a few stations ceased operation due to technical reasons. Presently, 7 stations are in operation distributed at locations with different environmental conditions ranging from rural and coastal to urban. Five stations are located on the mainland and 2 at the islands of Crete and Lesbos. Stations cover a range in altitudes from 60 to 540 m asl. Measurements are conducted with NILU-UV multi-filter radiometers. Online publication takes advantage of the multi-channel data and provides also other biologically weighted irradiances. The maximum monthly averaged UVI of about 10 has been measured at Finokalia while in Thessaloniki and Ioannina maximum monthly values are about 8.

Hungary: Solar radiation measurements have a long tradition at the Hungarian Meteorological Service, starting in the 1930s in Budapest and resulting in the longest (homogenized) global radiation data series in Europe. The Hungarian UV network consists of 5 stations and was established under a collaboration between the cooperation of the Ministry of Agriculture and the Hungarian Meteorological Service in 1994.[35] Agriculture is an important branch of the economy in Hungary, so that UV-B-radiation is also an important factor for food production.[36] The network covers the recreational region of Lake Balaton by a station on the western end and one on the eastern end. The station at Budapest (where a Brewer has run in parallel since 1998) delivers the UVI for the urban region with about 1.7 million inhabitants. One station is also located at a rural site on top of the highest Hungarian mountain (Mt. Kékes, 1012 m asl). The fifth station (Kecskemet) is located in the north of one of the Puszta regions. It is representative of this unique habitat as well as for tourists' activities there. On average each station represents an area of 18 600 km^2 denoting a service radius of 154 km. In summer UVI may reach 7 in most of the cases when sky is clear or partly covered and the ozone content is not extremely high and may exceed 8 in cases of clear sky and very low ozone. It can reach or exceed 9 in very few cases almost every summer.

Iceland: Currently, two stations are operated by the Icelandic Radiation Safety Authority. One station is located in the capital Reykjavik on the west-coast of the island. The second one is located in Egilsstaðir close to Lake Lagarfljot near the east-coast. The highest UVI values of the day are published on a web-page.

Ireland: UVI monitoring is done in Malin Head, on the Inishowen Peninsula, which is the most northerly point of the island of Ireland. This meteorological station provides essential data for shipping traffic. Apart from this site in the Republic of Ireland, another station operates in Belfast in Northern Ireland. Both stations are equipped with broadband meters and are operated by Public Health England (see below). In summer, the maximum UVI is usually 7.

Italy: In Italy UVI monitoring and publishing is done separately by different institutions. In the **Aosta Valley** (3262 km^2), an attractive tourism region in the north-west of Italy, a network consisting of three stations was established in 2006 by ARPA (Agenzia Regionale per la Protezione Ambientale) Valle d'Aosta supported by the regional government. The northern border of Valle d'Aosta is formed by the highest mountains in Europe like the Matterhorn and Mont Blanc. A special characteristic of this network is that the stations are geographically close to each other but span a large range in altitude from 570 m to 3500 m asl. This network is able to communicate the UVI to the public, especially to the tourists, for the varying environmental conditions from the bottom of the valley[37] up to the glacier ski field of Plateau Rosa where skiing is done also during summer.[38] Online values are updated every 5 minutes. The network allows the altitude effect to be studied,[39] including the annual variation of the snow line. At the bottom of the valley the UVI can be 9 for clear sky (10 for broken-clouds conditions) but it can reach a value of 14 at the Plateau Rosa.

In between Verona and Venetia, the ARPA Veneto has been measuring the UVI in **Vicenza** with a broadband meter since 2011. Values are updated every 5 minutes and may reach 9 in summer. In the near future the ARPA Veneto will install another broadband meter in a mountain place within the Belluno dolomites.

Another station in Italy is operated by the Institute of Atmospheric Sciences and Climate (ISAC) from the National Research Council (CNR) in **Bologna**. An in-house developed narrow-band filter radiometer,[40] which determines the UVI with a temporal resolution of 5 min was installed in 2005. Data are delivered every 30 min. During summer a UVI of 10 was measured.[41] This station may cover the eastern part of the Emilia-Romagna. The UVI for the famous tourist region of Tuscany is provided by the Institute of Biometeorology (CNR-IBIMET) in **Florence**. A broadband meter has been operating since 2003. The station delivers an update every 15 minutes and could cover the region from Siena to the Apennines, and from Pisa to San Marino, at least for lowland locations during days with homogeneous atmospheric conditions. The highest UVI values can be between 8 and 9 during the summer.[42]

Information about the UVI for the metropolitan region of **Rome**, with around 4 million inhabitants, as well as the nearby popular seaside locations at the Tyrrhenian Sea is provided by the Physics Department of the Sapienza University of Rome. Spectral measurements started in 1992 using a Brewer MkIV spectrophotometer[43–45] and are displayed and updated on the Internet every 30 minutes. A broadband UV radiometer has also been in operation since 2000 located in the same place close to the Brewer. Another broadband device, installed in Rome by the Italian National Institute for Environmental Protection and Research (ISPRA) in 2015, delivers a graphical bulletin of hourly UVI based on erythemally weighted irradiance values measured every 10 minutes. In summer the UVI in Rome (at both locations) at local noon may reach values in the very high category (between 8 and 9) under clear sky conditions due to the combined effect of lower total ozone content and solar zenith angle.[46]

The most southerly station is located on the island of **Lampedusa**, in between Malta and Tunisia. A Brewer has been operated there by ENEA since 1997,[47] together with an UV multi-filter rotating shadowband radiometer (UV-MFRSR[48]). The UVI at Lampedusa may exceed 10 during the summer. A large modulation effect is produced at Lampedusa, in addition to clouds[49] and ozone, by Saharan dust events,[50] which may produce significant enhancements of the aerosol optical depth. UVI values are derived from these measurements and are available online.

Luxemburg: In 1996, the Lycée Classique de Diekirch (LCD) (a secondary school) built up the meteorological station MeteoLCD. Apart from the usual meteorological parameters, atmospheric gases (*e.g.* CO_2, NO_x), total ozone column, total solar irradiance and UV-A are measured. UVI measurements are available as an average over the past 30 minutes. Recent and past data are freely available on the web site. In contrast to many other stations, MeteoLCD is not an official government financed station, but an ongoing project of the LCD that provides financing for the day to day operation and equipment, and the Ministry of Education helps in an unofficial manner to pay for maintenance of the sensors. All work is done graciously by volunteers. The UVI values from Diekirch are also displayed on the web-page of the Belgium UVI network. By being responsible for Luxemburg the station has a service radius of 57 km. During summer the UVI may reach a value of 8.

Malta: The Institute for Sustainable Energy of the University of Malta measures solar radiation at its premises in the village of Marsaxlokk situated on the south-east coast of the Island of Malta. In 2014, broadband instruments were added to measure the UVI and other parameters others. One-minute average data are being collected. Although the solar radiation data is online, the UV data is still not displayed on the Internet. The maximum UVI measured was 11 at around solar noon in summer.[51,52] The service radius of this station is 11 km.

Moldova: Since 2003 the erythemally effective UV radiation has been measured at a station in the urban environment of the capital, Kishinev city. The Atmospheric Research Group of the Institute of Applied Physics operates two broadband meters (global and diffuse). The daily radiant exposure is provided on web-page (but not the UVI). The highest measured value was 12 UVI.

The Netherlands: In the Netherlands, one station delivers online UVI values. The station was established in 1994 and is equipped with two double monochromator spectroradiometers that run in parallel. The station is located at the premises of the National Institute for Public Health and the Environment (RIVM) in Bilthoven, in the centre of The Netherlands, close to Utrecht. The measured UVI, with a frequency of one per 12 minutes, is show in a graph together with the cloudless sky forecast. During summer the UVI may lie between 6 and 7: values above 8 have been measured over the last 23 years.[53] Within a radius of approximately 50 km there is an agglomeration of large cities (Randstad) like Amsterdam and Rotterdam where about 7 million people live.

Norway: Monitoring started in 1994[54] and was expanded over the years.[55] Today, the UVI is measured at nine different stations. Data are updated every hour. The measurements are performed by the Norwegian Radiation Protection Authority, the University of Oslo, the Norwegian Institute for Air Research on behalf of the Ministry of Climate and Environment, and the Ministry of Health and Care Services. The distinctiveness of the Norwegian network is the type of devices used: multichannel, moderate bandwidth filter instruments, model GUV (Biospherical Instruments, San Diego, USA). A description of this instrument can be found in section 3.3. The network covers the southern part of the country (where most of the people live) up to Trondheim, with 7 stations. On a few days the UVI reaches a value of 7. The highest location of the whole network, is Finse (1210 m asl), a small village reachable only by a railway, which is a tourist attraction as well as a starting point for hiking, cross country skiing and glacier hiking. The highest ever measured UVI was 10. In addition, there are two stations north of the Arctic Circle (Andøya and Spitzbergen). The most spectacular station is located at Ny-Ålesund (78.9°N) on the island of Spitsbergen, which is the northernmost UVI monitoring site in Europe and the third northernmost in the world. The highest UVI measured at Ny-Ålesund was 3. Besides UVI, there are currently nine other irradiance detectors for the UV and visible radiation for each location (*e.g.* Vitamin-D irradiance) with complementary data sets since 1995.

Poland: In Poland two networks exist. One is operated by the Institute of Meteorology and Water Management – National Research Institute and was established under a project of the State Environmental Monitoring at the request of the Chief Inspector of Environmental Protection, funded by the National Fund for Environmental Protection and Water Management in July 1993. Three broadband meters were placed at selected sites. One station (Leba) is located on the Baltic coast which is an important site for recreational exposure. UVI may reach values between 6 and 7. The device in Legionowo provides UVI values for the urban region of Warsaw (summer: 7). Another monitoring site, representative for outdoor activities like skiing in winter and hiking in summer, is Zakopane (855 m asl) in the Tatra Mountains where UVI values can reach around 7 to 8. In 2006 these three sites were equipped additionally with a new broadband meter and a fourth station was established in the south of Poland (Katovice). However production of this broadband meter and of spare parts has been stopped so it is uncertain how long the fourth station will continue. The loss of this station would enlarge the service radius for each station from 315 km to 364 km.

The second network, started in 2012, was expanded over the years and today consists of four stations (Warsaw, Lodz, and stations near Lublin and Gdansk). It is carried out by the Institute of Geophysics of the Polish Academy of Sciences. The network uses miniature devices which are part of low cost weather stations. UVI values are available *via* the web page of the manufacturer. The core of the network is the Central Geophysical Observatory Belsk where various broadband meters (since 1975) and the Brewer No. 64 Mark II (since 1991)[56] measured in parallel. UVI is published on a web-page every 24 hours. In Warsaw, Brewer No. 207 Mark III started to operate in 2013. UVI can reach a value of 8 for a few days each year in Warsaw and Belsk. One purpose of this network is to support people in antipsoriatic heliotherapy.[57]

Portugal: UVI values are collected on two islands (Funchal, Madeira and Angra do Heroísmo, Terceira, Azores) by the Instituto Português do Mar e da Atmosfera.[58] Online values are available for the island of Madeira, a year-round holiday destination for around 1 million tourists (mainly from Germany, UK and Scandinavia) per year. The main attraction for tourists is not the coastal region but the flora-rich landscape so tourists spend a lot of time walking and hiking up to the highest Mountain Pico Ruivo (1862 m asl). Because of the location and the resulting climate, UVI and air temperature are not that closely related to other locations. At moderate temperatures UVI may reach values around 11 which are comparable to those in the Saharan desert. UV measurements started in 1989 with a Brewer and have been accompanied by a broadband instrument since 2004.

Russia: Potentially, there are around 20 stations in Russia with Brewer instruments operated by the Russian Hydrometeorological Service. However no online data are available. Long UVI data series exists from the Meteorological Observatory of the Moscow State University. The devices have been running since 1999[59] in accordance with WMO standards. The maximum UVI in Moscow during this period reached 7.7 in June.[60]

Serbia: UVI measurements have been made in the two largest cities of the country: Belgrade and Novi Sad[61] since 2009 and 2003, respectively. The station in Belgrade is operated by the Institute of Physics and provides values for around 1.7 million people. The station in Novi Sad is operated by the Department of Physics, University of Novi Sad and provides information for around 350 000 people. Both cities are also the most popular tourism destinations in Serbia. Each station is equipped with a broadband meter. The values on the joint web-page are updated every 30 minutes, but are also available from other web-pages. The UVI may exceed 9 at both locations.

Slovakia: Measurements of solar UV radiation started in the 1970s with broadband UV-A meters at stations of the Geophysical Institute of the Slovakian Academy of Sciences.[62] In 1993, Brewer spectrophotometer measurements were established and daily information about UV radiation has been provided for mass-media since that time by the Slovak Hydrometeorological Institute (SHMI). UVI monitoring started in 1997 in Bratislava in a cooperation of the Ministry of Environment and the SHMI. Over the years the network was expanded and now consists of 5 stations[63] located in the capital (Bratislava), nearby regional centres Košice and Banská Bystrica, at Poprad-Gánovce (close to a mountain tourist resort) and Hurbanovo at the Danubian lowland region, rich with sunshine in the summer. The Institute of the Earth's sciences provides UV radiation measurements at the Tatra mountain station Skalnaté Pleso (1778 m asl). Due to past problems with internal network capacity, measurements are not currently available online. The UVI values exceed 7 from May till August at all stations under clear-sky condition. The mean hourly UVI values exceeded 8 during low total column ozone and under cumuliform clouds.

Slovenia: At the present time the Slovenian Environment Agency operates 4 stations equipped with UV-B broadband meters. The network started in 2014 with its first station in the west of the country close to the Mediterranean Sea. In the following year a second device was installed at 2512 m asl, close to the top of Mt. Triglav (2864 m asl) which is the highest mountain in the country. In 2016 another two instruments started operation. One was mounted in the east of the country (Murska Sobota-Rakičan) and one at the ski resort in Rogla (1496 m asl). Measured UVI values are not yet provided to the public but are available on request.

Spain: The UVI network operated by Agencia Estatal de Meteorología (AEMet) has the largest number of stations. It started in 1995 and currently devices are mounted at 26 locations. 22 stations are spread over the mainland. The highest location is Puerto de Navacerrada (1858 m asl), a mountain pass and skiing resort, in the Sierra de Guadarrama close to the capital Madrid where another instrument operates. Most stations are in the vicinity of the larger cities so that many of them are on or close to the coast. The Spanish beaches are attractive holiday destinations for tourists from all over Europe. After France and the USA, Spain is the most visited country in the world. UVI values may come close to a value of 11. Apart from the mainland, stations are also located on the important tourism archipelagos of the Baleares in the Mediterranean Sea (Palma de Mallorca) and Canary islands. Each of these archipelagos is visited by more than 12 million tourists per year. At the Canaries there is a station at Maspalomas (Gran Canaria) and two on the island of Tenerife whereas one station is located at sea level (Santa Cruz), while the other is located at the mountain plateau of Mt. Izana (2400 m asl). At Palma de Mallorca the UVI may reach a value of 10. At Maspalomas and Izana, the UVI reaches a value of 11 on 12% and 51% of the days, respectively. The update frequency of the AEMet network is once per day, displaying the highest values as well as the daily graph of the past day.

Additionally, southwestern Spain is covered by the regional **Extremadura-Andalusia** UV network, which started in 2002[64–66] and is currently operated in cooperation with the Universidad de Extremadura (UEX) and the Instituto Nacional de Técnica Aeroespacial (INTA). The monitored region covers Extremadura and Western Andalusia with 11 stations equipped with UV broadband radiometers measuring erythemally-weighted irradiance. A large range of altitudes is sampled, varying from sea level (*e.g.* El Arenosillo station) to almost 2000 m asl at a ski resort (La Covatilla station). The network reports measured UVI values every 20 minutes *via* its website, as well as foreseeable cloud-free-sky maximum UVI values for each day. The highest UVI in summer in the area is around 9 to 10, with occasional values of 11.

Beside these networks, the Laboratory for Atmosphere and Energy at University of **Valladolid** has been measuring erythemally effective UV radiation for more than a decade[67] and has been providing online measurements from a broadband meter since 2014. The highest UVI values in summer are 9 to 10.[68]

Sweden: Several years ago, four stations delivered current UVI values to the public. Today there is only one station running (Norrköping) but data are not available on the web. The Swedish Meteorological and Hydrological Institute (SMHI) provides a forecast instead. In summer, the UVI may be as high as 7.

Switzerland: For Switzerland, UVI values for 5 locations are available. 4 of them are connected to a network operated by MeteoSwiss. One of these and a fifth station participate in the Austrian UVI network. Switzerland is an important holiday destination in winter as well as in summer for visitors from all over the world. Tourism focuses mainly on the alpine region which covers the southern part of the country. Most inhabitants live in the northern plateau and hill lands. There are several large lakes within the foothills of the Alps that are important for recreational activities. The network covers a range of altitude from 366 m (Lago Maggiore) to 3582 m asl (Jungfraujoch) and includes an inner-alpine valley (Davos) and the region around Lake Neuchatel in the north-west. The service radius is 115 km. A special feature of the network is that direct radiation is measured with a separate broadband meter at each station. The broadband meters are equipped with a collimating system and mounted on a sun tracker. Such measurements can be used in conjunction with a 3D-human model to estimate the personal UV exposure.[69] UVI during summer can reach values up to about 8 in the lowland regions (near Lake Neuchatel or Lago Maggiore), slightly higher than 9 at Davos and up to 12 at Jungfraujoch.

United Kingdom: Broadband monitoring started in Chilton, near Oxford, in 1990. In 1995 six stations were in operation, one of which was in the Republic of Ireland (see above). During the past 4 years another 6 stations were added, giving Public Health England 12 stations today. One of these stations is in London (since 2013). In this metropolitan region more than 13.5 million people live within a radius of 50 km, meaning this station now represents the sun exposure of more people than any other station in Europe. Further instruments operate in Wales, Scotland and Northern Ireland, plus the Republic of Ireland (see above). The most northern station is located in Lerwick on Mainland, the largest of the Shetland Islands. In 2015 the UVI monitoring was expanded to British Overseas Territories to enable proper sun care for tourists from UK but also for the military staff. One station is at Cyprus and one is on Gibraltar, both are described above.

A further two stations provide UVI data to the public through the same Internet interface. The fourteen stations that participate in this network include Reading and Manchester. These are operated on behalf of the Department of Environment Food and Rural Affairs by the University of Manchester and the sites provide a much broader suite of data including ozone and a wide range of meteorological parameters.[70] While at all other locations broadband meters are in use, the UVI at Reading (most representative of London from 1993–2013) results from a spectroradiometer, while that at Manchester (since 1997) comes from a multifilter radiometer, supported by spectral UV irradiance from a Brewer spectrophotometer. The maximum UVI value for the south of the UK is 8.

3. Instruments and quality assurance

The number of stations where erythemally effective UV radiation is measured has increased over time. Fig. 2 shows the number of stations as a function of time. By the end of 1995, 32 stations were in operation. With the standardization of the UVI the number increased significantly and is further increasing. Today, online UVI values are available from 160 locations. At several stations different instruments run in parallel so that the number of instruments involved in UVI measurements is higher. The following chapter delivers an overview on the instruments used for UVI monitoring and the quality assurance and control procedures.

3.1 Broadband meters

Most of the stations are equipped with broadband meters. At present, 125 of these deliver online UVI values. The most common detector is the Model 501 (Solar Light Inc., Philadelphia, USA) followed by the UVB-1 (Yankee Env. Sys. Inc., Turnters Falls, USA) and by UV-S-A-E-T, UV-S-E-T and UV-S-E-C (all Kipp&Zonen, Delft, The Netherlands). Beside these, there are a few OPTIX UVEM-6C instruments in use (which are no longer manufactured), a few Thies Clima E1c (Adolf Thies GmbH, Göttingen, Germany), a few MS-212 W UVB Meters (EKO Instruments Co. Ltd, Tokyo, Japan) which are restricted to the UV-B range, a miniature meter Model EryCa (sglux GmbH, Berlin, Germany) as standalone instruments and a few miniature erythema meters as part of a weather station (Davis Instruments, Hayward, USA). The UVS-AE-T (Kipp&Zonen, Delft, The Netherlands) is used at 4 stations and measures both UV-A irradiance and erythemally weighted irradiance. It is a dual-band radiometer which has two separate detection systems.

Broadband meters are generally easy to operate. However, there are certain requirements on calibration and maintenance to ensure reliable measurements. Both have been topics of a variety of national and international co-operations (*e.g.* ref. 71) but also as European wide initiatives (*e.g.* COST Action 713,[72] COST Action 726[73,74]).

3.1.1 Properties and calibration. A broadband meter measures the total irradiance over a certain wavelength range (broad band) and delivers a single electrical output value S (either voltage or current) which has to be converted into the UVI by a certain factor c_0. An appropriate broadband meter for measuring the UVI must have the same spectral response as the human skin for erythema.[15] This is realized by the combination of the spectral response of the photodetector and the transmission curve of an optical filter. However it is technically not possible to gain a perfect fit. So, differences remain which vary with wavelength (see Fig. 3). With that, the difference between the erythemally effective irradiance and the output value of the device depends on the spectrum of the source, in our case the sun. Further, this means that the magnitude of the difference changes whenever the spectrum changes. The solar spectrum at the earth's surface is mainly influenced by the solar zenith angle (SZA) and the total ozone content of the atmosphere (O_3). Therefore it changes during the day and during the year. To overcome this, a correction factor $c_1(O_3, SZA)$ is necessary that takes both into account.

Another source of error is the angular response of the instrument which must follow a cosine-function. Deviations need a correction factor $c_2(SZA)$ dependent on solar elevation. Temperature sensitivity $c_3(T)$ could be also matter of concern,[75] but is generally solved by an internal heater that stabilizes the temperature of the device. Humidity (c_4(rH)) can

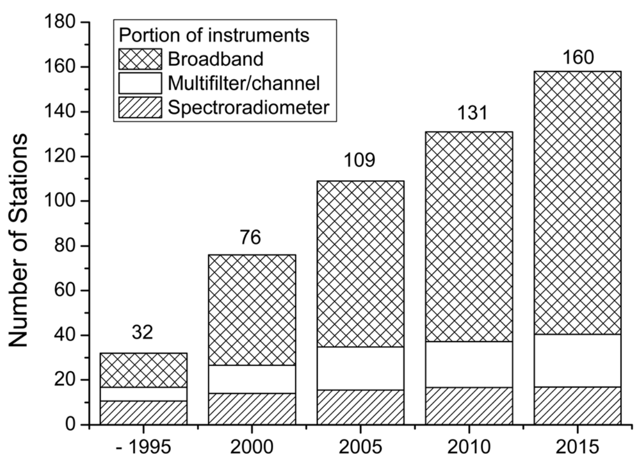

Fig. 2 Number of stations publishing the UVI on the internet. The different patterns indicate the portion of different instruments.

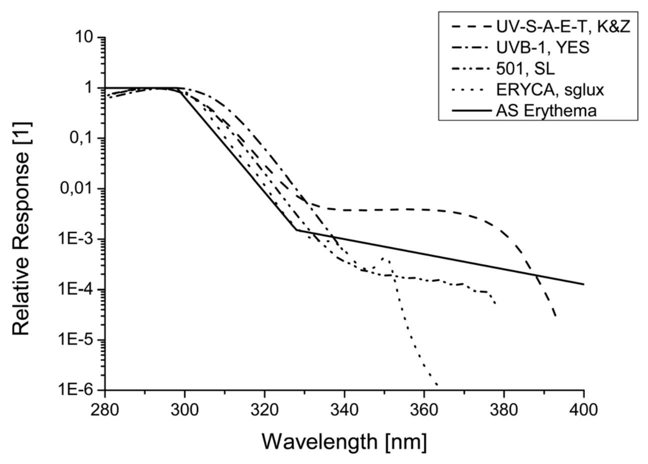

Fig. 3 Relative spectral response of broadband instruments and of the human skin for erythema according CIE.[11]

also influence measurements.[76] A silica gel reservoir within the device can absorb ingressing water vapour. This reservoir has to be changed periodically. Deviation from linearity $c_5(S)$ is rarely seen because the dynamic range necessary for the UVI is not that large. Any dark signal S_0 also has to be subtracted first. The following correction formula takes all these factors into account:

$$E_{\mathrm{UVI}} = (S - S_0) \times c_0 \times c_1(\mathrm{O3}, \mathrm{SZA}) \times c_2(\mathrm{SZA}) \times c_3(T) \times c_4(\mathrm{rH}) \times c_5(S)$$

For some types of instrument in use (SL501, UV-S-A-E-T, UV-S-E-T and UVB-1) the correction factors $c_3(T)$, $c_4(\mathrm{rH})$, $c_5(S)$ can be neglected,[77] and therefore are respectively equal to one.

The methods to derive all of these calibration factors are described in detail *e.g.* by WMO/GAW.[78] As shown by several international intercomparisons, all these parameters must be proven for each single instrument separately,[72,79,80] as there are obvious differences. Each single low cost miniature erythema meter needs the same care (characterisation, calibration factors, mounting, and maintenance) as a research grade broadband meter. Otherwise measurements are not trustworthy, can be incorrect by up to 50%[81] and publication would be even counterproductive to health care.

Other biologically effective irradiances can be measured with these broadband meters only if the corresponding action spectrum is close to the spectral response curve. Otherwise, the calibration matrix c_1 cannot be determined with the necessary accuracy. An appropriate action spectrum for the instruments used is that for vitamin D photosynthesis.[82] The same raw data can be used as for UVI monitoring but a calibration function is needed which differs in c_0 and c_1.[83]

3.1.2 Quality assurance and control. The performance of a broadband meter alters with time due to aging of the filter or of the photodetector. Therefore a detailed schedule for maintenance has to be implemented. A practical guide for operating was released within the COST Action 726.[77] This guide also includes mounting and data acquisition. To assure high quality UVI measurements, the most important points are:

(1) Calibrations should be repeated periodically, typically on a yearly basis.

(2) Redundant instrumentation should help with detecting drifts in individual instruments.

(3) Silica gel to keep instrument dry, because filters maybe hydrophilic.

3.2 Spectroradiometers and spectrophotometers

There are two types of spectral instrument in use for UVI measurements. Common spectroradiometers (*e.g.* DTM series from Bentham, Reading, UK) adapted for outdoor measurements and spectrophotometers type Brewer Mark II and III (Kipp&Zonen, Delft, The Netherlands). These are the most sophisticated instruments, deliver spectral information and correct operation requires the considerable effort.

The Brewers spectrophotometers[84] are especially designed for high quality outdoor measurements of total ozone,[85] NO_2 [86] and UV radiation in a harsh environment. The operators are well organized *e.g.* by the WMO-Global Atmospheric Watch Brewer Users Group with periodic meetings, or the recent COST Action ES1207, and possess detailed QA/QC and calibration procedures.

A common spectroradiometer needs special adaption to be resistant for all day outdoor measurements *e.g.* weatherproof input optics[87] and arrangements to avoid any influences that may affect the stability of the instruments (*e.g.* temperature). For spectroradiometers, calibration, and QA and QC procedures are well defined (*e.g.* ref. 88). The portable UV European reference spectroradiometer QASUME[89] has been on duty for more than a decade, improved recently to the QASUME II[90] and is available from the World Radiation Center (PMOD/WRC), Davos, Switzerland.

These spectroradiometers and the Brewers are often in use as a reference instrument for a broadband meter network. Both instruments can measure any biologically effective irradiance by simple weighting of the measured spectrum with the corresponding action spectrum.

3.3 Multichannel filter radiometers

In between the broadband meters and the spectroradiometers are the multichannel, moderate or narrow bandwidth filter instruments.[91] Those used for UVI monitoring are the GUV541, GUV511 and GUV2511 (all Biospherical Instruments, San Diego, USA), NILU-UV (Norwegian Institute for Air Research, Norway)[92] and narrowband filter radiometers UV-Rad (ISAC-CNR, Bologna, Italy)[93] and UV-MFRSR[94] (Yankee Env. Sys. Inc., Turnters Falls, USA).

This type of instrument consists of a cosine-adapted diffuser element as the front optic and one or multiple sensor elements fitted with stacks of interference- and blocking filters. Instruments are hermetically sealed and temperature stabilized, which helps to keep the front optic free from snow and ice. A special case is the UV-Rad instrument, which instead of individual, stationary filter and sensor elements applies a rotating wheel, which sequentially positions filter stacks above a single sensor element to make a wavelength scan. By definition, a multichannel filter radiometer has several channels, in the UV, and sometimes also in the visual and near-infrared part of the spectrum (*e.g.* photosynthetically active radiation). Originally, the instrument type was designed to measure not only UV irradiance but also total ozone (utilizing a pair of channels in the UV-B and UV-A) and cloud optical depth (UV-A). The retrieval of these atmospheric parameters, in addition to surface albedo, relies on a characterization of spectral and angular response functions, combined with radiative transfer modelling to generate look-up tables as a function of SZA.[92,93,95,96] Different irradiance data products, based on *e.g.* health- or plant-response functions, are based on linear combinations of detector signals and corrections for SZA.[92,96–99]

International intercomparisons and harmonisations were carried out (*e.g.* ref. 100) which resulted in documents describing calibration and quality assurance procedures (*e.g.* ref. 91), that are similar to those dealing with broad band instruments and spectroradiometers. This instrument type is robust and very flexible in offering a large set of data products.

4. Presentation of measurement

The simplest way to publish the UVI is to give a single integer number (or with one decimal). The number can be coloured as proposed by WHO[17] (*e.g.* Madeira, Estonia). Some networks use this way of visualisation in conjunction with a symbolised map of the country to indicate locations (Germany, Norway, Extramendura-Spain). The presentation can be accompanied by symbols for sun protection recommendations (*e.g.* Switzerland).

Another way for visualisation is a plot which shows the daily progress either by providing numbers (*e.g.* Croatia) or by a line graph together with a legend that rates the values (*e.g.* Czech Rep). Another possibility is to colour the line according to the WHO scale (*e.g.* Denmark, Hungary, and Luxembourg). The background of the graph can be WHO-coloured instead (*e.g.* Tartu-Observatory, UK, Lampedusa) or the area under the line can be filled by the colour which corresponds to the plotted UVI values (*e.g.* Finland, Poland, and Greece). The Belgian network gives such line graphs for all stations on an underlying map of the country. Bar charts (*e.g.* Serbia) and WHO coloured bar charts (*e.g.* ISPRA,) are also in use to indicate the daily progress.

Plots which show the daily course are often accompanied by a second line that provides a forecast for the whole day (*e.g.* Netherlands, Denmark). Such forecasts can be shown for different cloud coverages (*e.g.* Hungary). With that it is possible to estimate the further progress of the UVI. Especially before midday such forecasts provide helpful information for sun protection applications.

The most sophisticated way of presentation is to show the spatial distribution over a region or over the whole country. This needs a mathematical model and additional information, at least a near real-time cloud cover distribution and topography.[25] An example can be found on the web page of the Austrian monitoring network (see Fig. 4). An additional animation visualises the progress from sunrise onwards until the recent status.

There are two different strategies for the update frequency. One is to publish the noon value. The German and the Spanish AEMET-network do it this way for each station. This strategy is based on the original recommendation that the UVI is the average within a 30 minutes period about solar noon.[13]

Information technology now enables the provision of real-time values. Therefore the other strategy is to update values a few times per hour whereas most common are mean values over the past 15 minutes. More frequent updates, like every minute, could be critical as values would vary very strongly under broken clouds conditions. Such short term updates may not be presented as a single number but as a line graph or bar chart. Much less frequent updates, like once per hour, lead to underestimations before noon and to overestimations after noon because changes up to 1.5 UVI per hour can be observed in Europe under clear sky.

Most of the networks provide measurements through all the year but several networks restrict the service to the main period of interest (March to September).

5. Summary

Twenty years after the establishment of the UVI, a proportion of the European population still lacks adequate information about the acute risk of health damage from solar UV radiation in their countries. UV overexposure is a creeping epidemic and is manifested by severe diseases with long latency periods. For

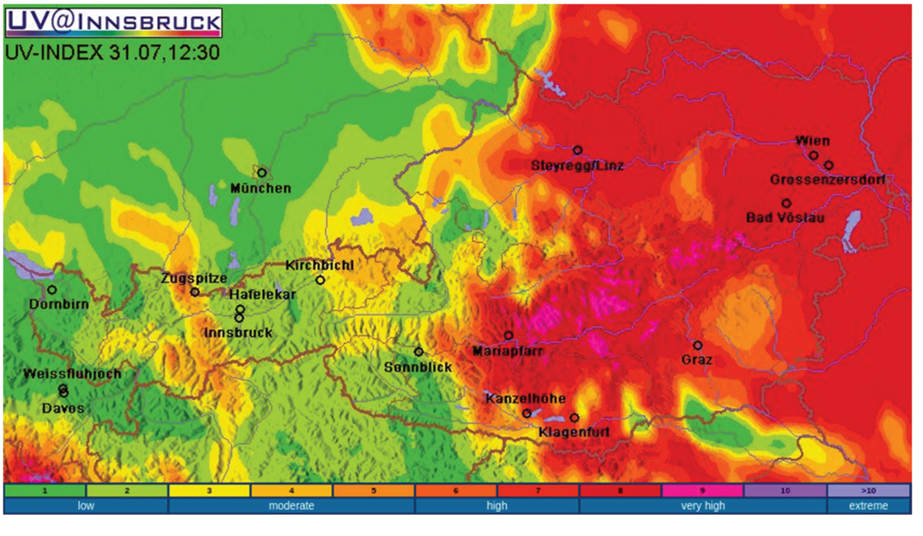

Fig. 4 Example for the near real-time distribution of the UV Index gained from measurements at marked locations (black symbols).

skin cancer, Gordon and Rowell[20] provided an overview of the estimates of the direct health system costs for skin cancer in Europe and the cost-effectiveness of interventions for skin cancer prevention or early detection. It was shown that skin cancer prevention initiatives are highly cost-effective and are cost-saving. Online UVI values and connected sun protection recommendations are an appropriate tool not only for skin cancer prevention but also for avoiding other diseases, such as cataracts, the economic dimensions of which are less well studied. A main problem in finding financial support for UVI monitoring is that the general health improvement and cost-savings are not countable from the first day onwards. However, in many countries the importance was recognized and online information is supported. Currently, in 25 of the 46 European countries online UVI values are available on the Internet. With that, approximately 32% of the area of Europe is covered and 57% of the European population can have access to information. As seen in Fig. 1 there are large differences in the spatial coverage. Especially in the east and the south-east, coverage is lacking.

The number of instruments delivering online UVI has increased over time (see Fig. 2). Measurements are obtained mainly from broadband meters (75%), partly from multi-channel filter instruments (15%) and less from spectroradiometers (10%). The quality of these instruments and of the measurements was well studied in the past (see chapter 3). Appropriate quality assurance and quality control procedures are available and in use to guarantee accurate values.

An important parameter of a network is the distance between the stations. The appropriate service radius depends on climate and topography. Locations can be selected by objective methods and spatial representativeness can be calculated.[23] In countries with a highly alternating topography the distance between stations should be shorter than in flat lands. The shortest service radius found was on the order of 40 km while on average it is around 180 km.

The colour scheme suggested by WHO for the UVI is adopted by most of the institutes as well as the rating and also the WHO recommendations for sun protection are provided by many web pages.

The radiant exposure is the relevant parameter (rarely the irradiance) for quantifying photobiological effects. In the case of the UVI, Saxebøl[101] has suggested the usage of "UV Index hours" as the corresponding unit for the erythemally effective exposure. The minimal erythema dose (exposure necessary to cause a noticeable erythema) is usually given in J m^{-2} or in the arbitrary defined SED[15] but can be expressed easily in UV Index hours as 1 UVIh is 90 J m^{-2}.[102] In conjunction with the UVI it would provide an easy way to estimate the maximum time that could be spent in the sun or to select the minimum sun protection factor.

All of the instruments used possess the potential to deliver the vitamin D effective irradiance too. The broadband meters and the multifilter radiometers would need a different calibration factor while the spectroradiometers need the action spectrum only.[83,92] Today vitamin D effective irradiance is given in effective W_{VitD}/m^2 (*e.g.* as provided by the Norwegian Network). However it is questionable if this unit is appropriate for public information because the levels of vitamin D circulating in the body cannot be predicted reliably from the effective irradiance. Units similar to those for the erythema are under discussion.[103] Another perspective for the use of the instruments is supporting people in antipsoriatric heliotherapy as done in Poland.[57]

At present, it is not so easy to find online UV-Index measurements for a certain region or country (*e.g.* for a holiday destination) by Internet search engines because of several reasons (language, names of stations, *etc.*). In some countries UVI publishing is done by different institutions on different web-pages. For the future and the further promotion of the UVI and related health care we propose a European Internet portal that guides users to the different networks. A first approach was undertaken on the web-page of the COST Action 726 which ended in 2009 (which is now out of date). For the future consideration should be given to the possibility of increasing the coverage of Europe.

Finally, it should be noted that all web pages provide the UVI values for free.

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