SURFACE UV RADIATION MONITORING BASED ON GOME AND SCIAMACHY

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ABSTRACT

Solar UV radiation reaching the Earth's surface is monitored by means of two quantities: the clear-sky UV index at local solar noon and the daily UV dose. Each quantity is determined on the basis of two action spectra, describing wavelength dependent biological effects of UV radiation, namely erythema (sunburn) and DNA-damage. The quantities are derived from total ozone column measurements by the GOME and SCIAMACHY instruments, assimilated into global ozone fields. For GOME a data archive has been set up spanning the period August 1995 to May 2003. For SCIAMACHY a near-real time service is in operation, which provides a forecast of the erythemal UV index for today and a few days ahead, as well as yesterdays daily erythemal UV dose for Europe (based on METEOSAT cloud cover data). A data archive spanning the SCIAMACHY period will be set up. All data is available at the website of the TEMIS project via http://www.temis.nl/uvradiation/

1. INTRODUCTION

Atmospheric ozone shields life at the Earth's surface from the most harmful components of the solar UV radiation. Thinning of the atmospheric ozone, *e.g.* due to ozone depletion and changes in the meteorology in the stratosphere, leads to elevated levels of UV-B radiation at the Earth's surface. A decrease in ozone of 1%, for example, will lead to an estimated increase in UV-B of about 2%. Exposure to enhanced UV incidence increases the risks of biological damage to humans, animals and other organisms. It is therefore important to monitor surface UV levels on a global scale and to do this over a prolonged period of time. Information on biological effects and their dependence on ozone column values can be found in, for example, Refs. [1, 2] and references therein. Information on UV radiation for the general public can be found in Refs. [3, 4].

Within the project Tropospheric Emission Monitoring Internet Service (TEMIS) a near-real time service has been set-up for total ozone and surface UV data. The satellite measurements of the near-real time ozone column by GOME (aboard the ERS-2 satellite) and SCIAMACHY (aboard the ENVISAT satellite) are assimilated in a transport model in order to produce near-real time global maps of ozone at local solar noon. This in turn is converted to global maps of the surface UV radiation for local solar noon and clear-sky conditions (UV Index). Further, the daily UV dose is computed for the last complete day using hourly cloud information from METEOSAT for Europe. Additionally, world-wide UV doses are calculated afterwards using cloud climatology data from ISCCP as soon as these are made available. Time series of UV index and UV dose for the GOME measurement period are completed and are continued using SCIAMACHY measurements. All data files and images are delivered via the TEMIS website at http://www.temis.nl/uvradiation/.

The paper first gives a brief introduction to UV radiation and introduces the action spectra of the effects of UV radiation used for the TEMIS service. Then the method used for determining the UV index and UV dose are outlined, which is followed by some examples of a preliminary validation. Next an overview is given of the data products of TEMIS, and finally some concluding remarks and suggestions for improvements are formulated.

2. UV RADIATION AND ACTION SPECTRA

Ultraviolet light is usually divided into three components: UV-A (320-400 nm), UV-B (280-320 nm) and UV-C (200-280 nm). The UV-C component of the Solar UV light is potentially the most dangerous as it has the high-

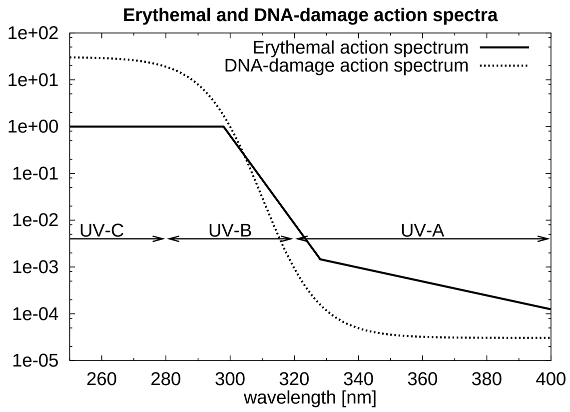

Figure 1. Action spectra of the susceptibility of the human skin to erythema (sunburn) and of generalised DNA damage due to UV radiation. The erythemal UV index is an integration between 280 and 400 nm of the UV irradiance at ground level, weighted with the erythemal action spectrum. The DNA-damage UV index is an integration between 256 and 370 nm of the UV irradiance at ground level, weighted with the DNA-damage action spectrum.

est energy levels, but this component is completely absorbed by ozone and oxygen above about 30 km. The UV-B component is strongly absorbed by ozone, but a small fraction reaches the Earth's surface. The UV-A is only weakly absorbed by ozone, with some scattering of radiation near the surface.

Most of the UV radiation reaching the surface is therefore UV-A. Due to the higher energy levels of UV-B, however, the UV-B component has more effect on flora and fauna than UV-A. An action spectrum is a parameter function which describes the relative effect of energy at different wavelengths in producing a certain biological response. These effects may be at a molecular level, such as DNA damage, or at the level of the whole organism, such as plant growth. An action spectrum is used as a ”weighting function” for the UV spectrum in an integration of the monochromatic UV irradiance.

For the TEMIS data service the two action spectra illustrated in Fig. 1 are used:

- The CIE action spectrum for erythema (reddening of the skin due to sunburn), proposed by McKinlay & Diffey [5] and adopted as a standard by the *Commission Internationale de l'Éclairage* (*International Commission on Illumination*).
- An action spectrum for generalised DNA-damage, which has been determined by Setlow [6] and was parametrised by Bernard and Seckmeyer [7].

These action spectra stress the importance of the UV-B component. Of the global UV irradiance at the surface, 94% is UV-A and 6% is UV-B. Whereas of the erythemal UV irradiance at the surface, for example, 17% is UV-A and 83% is UV-B.

3. UV INDEX AND UV DOSE

An integration over the UV spectrum, weighted with an action spectrum, gives what is usually called the UV index: a measure for the effective UV irradiance reaching the surface at a given moment of the day. The UV index is a dimensionless quantity, where one unit equals 25 mW/m^2. Integration of the UV index over the whole day results in the daily UV dose, usually given in J/m^2.

The erythemal UV index is the quantity which is communicated to the general public in connection with warnings of high UV levels, and then it is simply referred to as the UV index. Within the TEMIS service the adjective ”erythemal” is added to distinguish it from similar quantities, such as the DNA-damage UV index. And the same is done for the UV dose.

This section describes the method used to derive the UV index and UV dose quantities for the data products of the TEMIS project.

3.1. UV index parametrisation

Groundbased measurements of UV spectra and total ozone columns in De Bilt (Netherlands) and Paramaribo (Suriname) have been used by Allaart *et al.* [8] to determine an improved parametrisation of the erythemal UV index as function of the total ozone column and the solar zenith angle. The widely used parametrisation by Burrows *et al.* [9] was found not to be globally applicable.

The parametrisation of Allaart *et al.* [8], shown in Fig. 2, provides the erythemal UV index as function of the total ozone column (TOC) in Dobson Units (DU) and the solar zenith angle (SZA) in degrees. A similar parametrisation has been made based on the DNA action spectrum and thus provides the DNA-damage UV index as function of TOC and SZA.

3.2. Clear-sky UV index derived from ozone measurements

Total ozone columns based on measurements by GOME and SCIAMACHY are assimilated in a chemistry transport model [10], driven by ECMWF forecast meteorolog-

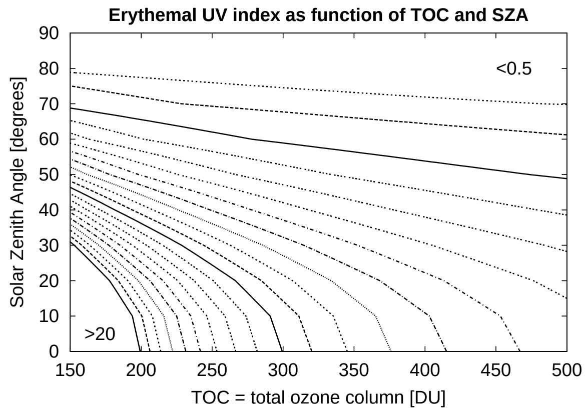

Figure 2. The erythemal UV index as function of the total ozone column and the solar zenith angle according to the parametrisation of Allaart et al. [8]. Contours are drawn at erythemal UV index values of 20, 19, . . . , 2, 1 and 0.5; the solid lines are for values 20, 11 and 2.

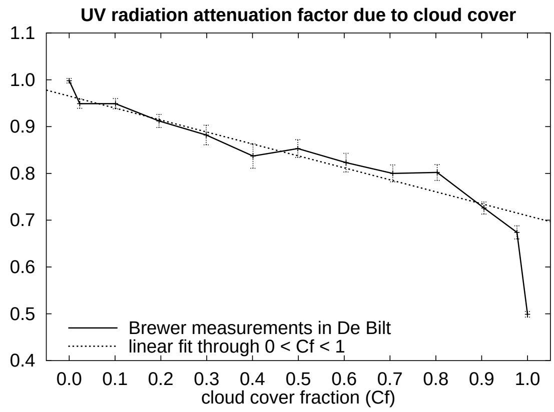

Figure 3. UV attenuation factor A_f due to cloud cover in De Bilt in 2002, as a function of the cloud cover fraction; error bars indicate the root-mean-square error divided by the number of data points. The dotted line is a fit through all data excluding the points $C_f = 0$ and $C_f = 1$.

ical fields, to provide global maps of the ozone field at local solar noon. The parametrisations mentioned above are applied to determine both the erythemal and the DNA-damage UV index at local solar noon for clear-sky conditions. Since the total ozone column data is available in near-real time (*i.e.* within 3–6 hours after observation) and ECMWF meteorological fields are available in a forecast, it is possible to provide both clear-sky UV indices in a forecast for today and a few days ahead.

The ozone field is given at a latitude/longitude grid of $1.0^o \times 1.5^o$. The ozone data is interpolated to the desired grid of $0.5^o \times 0.5^o$ (which amounts to 50×50 km at the equator) for the UV index and UV dose data. For each of these data grid cells, the solar zenith angle is computed from the latitude of the centre of the grid cell at local solar noon.

The UV index algorithm includes corrections for the surface elevation, for the ground albedo and for the varying distance between the Sun and the Earth. The parametrisation implicitly contains the average aerosol load in De Bilt and Paramaribo, hence the current method contains a ”zero-order” aerosol correction; an improved aerosol correction (as devised by Bodesa and Van Weele [11]) will be implemented later.

3.3. Cloud cover correction for the daily UV dose

The UV index (UVI) is a quantity valid for local solar noon and for clear-sky conditions. This quantity thus does not say much about the actual dose of UV radiation one received during a day. Integration of the UV index $UVI(TOC, SZA)$ between sunrise and sunset, and including a factor for the attenuation of the UV by clouds, results in the actual daily UV dose (UVD):

$$UVD = \int_{\mathrm{sunrise}}^{\mathrm{sunset}} UVI(TOC, SZA) \cdot A_f(t_h) \cdot dt \quad (1)$$

where the solar zenith angle $SZA = SZA(t)$ now is time dependent. For Europe the daily erythemal UV dose and the daily DNA-damage UV dose can be computed by using 1-hourly cloud cover fraction data from METEOSAT: for each moment of time t in the integration the nearest METEOSAT data point t_h is used in the attenuation factor A_f. For global UV dose fields it is necessary to resort to the ISCCP (International Satellite Cloud Climatology Project) cloud database of 3-hourly monthly averaged cloud cover data, providing monthly average erythemal and DNA-damage UV dose data.

The attenuation factor A_f has been validated by comparing METEOSAT cloud cover data with measurements in De Bilt. Figure 3 shows the attenuation factor as function of the cloud cover fraction (C_f) in De Bilt as a solid line with error bars; these error bars indicate the root-mean-square error divided by the number of data points. Two special cases can be distinguished:

- $C_f = 0$: completely cloud-free (clear-sky), with no attenuation of the UV radiation
- $C_f = 1$: completely clouded (overcast), with an attenuation of 50% of the UV radiation

Except for these two special cases, the attenuation factor can be described quite well by the linear function, shown

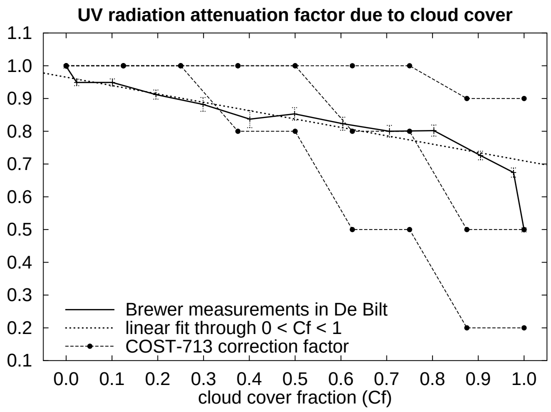

Figure 4. As Fig. 3, but with the attenuation factor as defined in the COST-713 Action programme [3] and listed in Table 1.

by the dotted line in Fig. 3. The attenuation factor is thus given by:

$$A_f = \begin{cases} 1 & C_f = 0 \\ 0.9651 - 0.2555 * C_f & 0 < C_f < 1 \\ 0.5 & C_f = 1 \end{cases} \quad (2)$$

A higher order degree fit through the data does not give a significantly better description of the cloud cover correction, hence the linear fit is sufficient for use in the TEMIS algorithm.

The COST-713 Action programme of the European Commission [3] has established a Cloud Modification Factor. This factor is a function of the cloud cover in octas and given for clouds at low altitude, medium altitude and high altitude, as listed in Table 1. Figure 4 shows the same data as Fig. 3, together with the COST-713 attenuation factor.

From Fig. 4 it is clear that the attenuation factor as defined by COST-713 is rather coarse, even though it does make a distinction between low, middle and high clouds. Though there is some information on the altitude and the type of the clouds in the METEOSAT data, making the distinction between low, middle and high clouds is not straightforward. For the time being the METEOSAT data only provide the cloud cover fraction. This cloud cover fraction is available in multiples of 1/42 rather than octas.

Table 1. Cloud Modification Factor according to the COST-713 Action programme [3].

Octas	**0–2**	**3–4**	**5–6**	**7–8**
High clouds	1.0	1.0	1.0	1.0
Medium clouds	1.0	1.0	0.8	0.5
Low clouds	1.0	0.8	0.5	0.2

All in all it seems that the METEOSAT cloud cover data in combination with the above given linear functionality provides a better description of the attenuation of the UV radiation due to clouds than the COST-713 factor does. For that reason the TEMIS algorithm for the UV dose employs the relation given by Eq. (2).

4. VALIDATION OF THE UV DATA

Input for the UV index and the UV dose is the assimilated global ozone field, which has been validated before [10]. The parametrisation of the erythemal UV index has been validated before as well [8]. The latter validation implicitly also validates the DNA-damage UV index, as its parametrisation is based on exactly the same approach as the parametrisation of the erythemal UV index. This section presents a first validation of the daily erythemal UV dose for Europe; a more detailed validation and discussion will be performed later.

4.1. Daily erythemal UV dose validation for Europe

The daily erythemal UV dose for Europe can be validated best against the groundbased measurement data stored in the EDUCE database. This database, set up under the European Database for UV Climatology and Evaluation (EDUCE) project, contains UV spectra measured at a large number of European ground stations. Spectra can be retrieved from the database via the website http://www.muk.uni-hannover.de/EDUCE/.

At this website the BASINT tool offers the possibility to convert spectra directly into an erythemal UV dose rate, given in J/m^2s. The TEMIS algorithm performs the integration by computing the UV dose in 10-minute intervals and summing these to find the daily dose. To facilitate the comparison, the dose rate given by the BASINT tool is integrated over 10 minutes for each given measurement.

Figures 5-7 show a comparison between the 10-minute erythemal UV dose (in kJ/m^2) derived with the BASINT tool and the TEMIS results for three typical cases in 2002, on days which were completely cloud-free between at least 08h and 14h UTC according to the METEOSAT data. Also shown is the UV dose assuming full cloud cover (overcast). These three cases show the range of the expected differences between groundbased measurements and the TEMIS product.

For Lampedusa (Italy) on 14 July, the results are almost identical (Fig. 5). On 28 May (Fig. 6) there is a notable

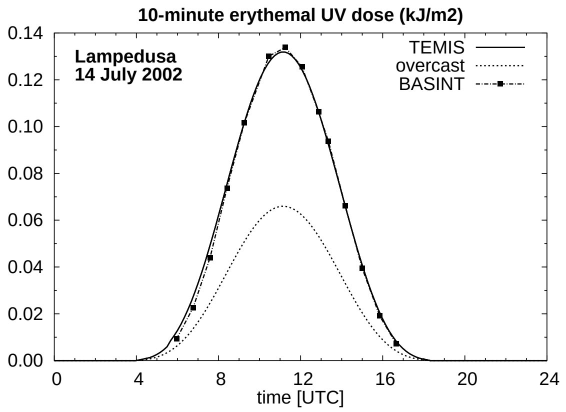

Figure 5. Erythemal UV dose integrated over 10-minute intervals as function of time for the ground station at Lampedusa on 14 July 2002. The solid line is the UV dose from the TEMIS algorithm, using METEOSAT cloud cover information, which showed that this day was (almost) entirely cloud-free. The filled squares show the results of the groundbased measurements as retrieved with the BASINT tool of the EDUCE database. The dotted line shows the UV dose as it would have been had the day been fully clouded (overcast).

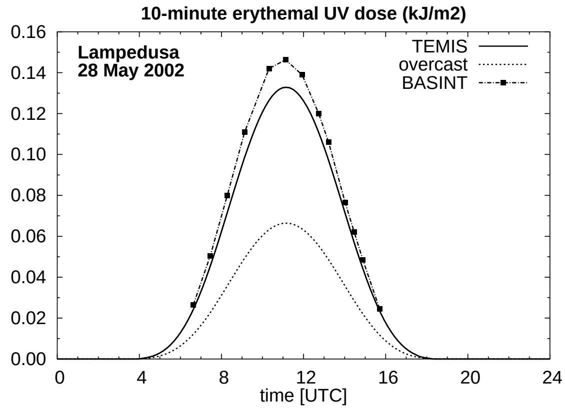

Figure 6. Same as Fig. 5, but for Lampedusa on 28 May 2002, an (almost) entirely cloud-free day.

difference: the Lampedusa station gives distinctly higher UV doses than the estimate by the TEMIS method. Apparently, 28 May was a very clear day, with less aerosols than the average aerosol load at De Bilt and Paramaribo which is currently accounted for in the parametrisation of the UV index. This is confirmed by measurements of the aerosol optical depth (AOD) at 500 nm: on 28 May the AOD was 0.091, whereas on 14 July it was 0.284. [12]

For Thessaloniki on 28 June (Fig. 7) the situation is reversed: the ground station gives distinctly lower UV dose values than the TEMIS method. This difference could be due to the enhanced presence of aerosols at Thessaloniki. Also the presence of small clouds at the moments of the measurement, which do not show up in the METEOSAT data, may cause a smaller UV dose derived from the groundbased measurements.

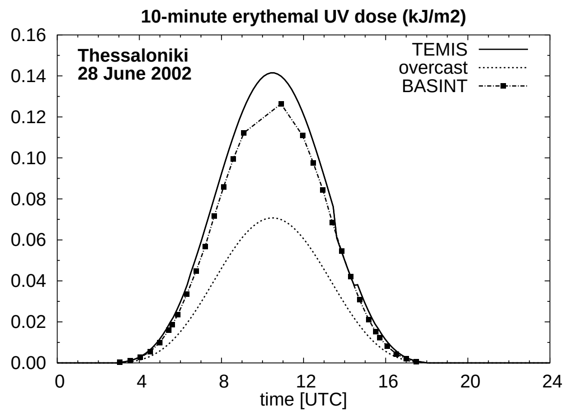

Figure 7. Same as Fig. 5, but for Thessaloniki on 28 June 2002, an (almost) entirely cloud-free day.

Figure 8 shows an example of an almost fully clouded day in Thessaloniki, namely 6 June 2002. The curve of the result of the TEMIS algorithm using METEOSAT cloud cover data (solid line) shows that during most of this day it was fully clouded. During the first half of the day, the results of the groundbased measurement are well above the TEMIS results.

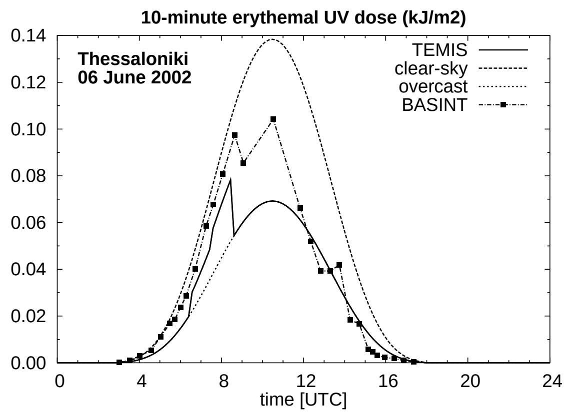

Figure 8. Similar as Fig. 5, but for Thessaloniki on 6 June 2002, which was an almost fully clouded day. The dashed line shows the clear-sky UV dose, i.e. the maximum possible values for this day.

The pixel size of the TEMIS results measures $0.5^o{\times}0.5^o$: it covers a rather large area. The groundbased measurement, however, is a point measurement and so it is well possible that the instrument was looking through small

Table 2. Daily erythemal UV dose for the examples given in the text, as follows from the TEMIS algorithm (which uses METEOSAT cloud cover data), from the BASINT tool of the EDUCE database, from assuming that the day was completely cloud-free, and from assuming that the day was fully clouded.

groundstation	**date**	**TEMIS**	**BASINT**	**Clear-sky**	**Overcast**	**Figure**
Lampedusa	14 July 2002	4.86 kJ/m^2	4.83 kJ/m^2	4.86 kJ/m^2	2.43 kJ/m^2	5
Lampedusa	28 May 2002	4.84	5.31	4.85	2.42	6
Thessaloniki	28 June 2002	5.32	4.82	5.38	2.69	7
Thessaloniki	06 June 2002	2.81	3.55	5.21	2.61	8

openings in the clouds, which have little effect on the cloud cover reported by the METEOSAT data. Before 06h and between 09h and 12h UTC this effect seems to be rather strong. During the afternoon, on the other hand, the match between the TEMIS results and the ground-based measurements is reasonably good.

Apart from clouds, the presence of aerosols may also play a role, in combination with the prevailing wind direction, but before 12h UTC the presence or absence of clouds must be the main cause of the difference between the two methods used in this example.

Table 2 presents the UV dose integrated over the whole day for the four examples given above.

5. OVERVIEW OF THE TEMIS DATA SERVICE

UV radiation data products of TEMIS are delivered via http://www.temis.nl/uvradiation/ in the form of HDF-4 data files and images on a $0.5^o \times 0.5^o$ latitude/longitude grid. Grid cells that lack sufficient data are marked as "no data": these have '-1' in the data file and are grey in the plot. Images shown on the webpages are given for two geographical scales: Europe and the whole world, if available; the HDF-4 data file always covers the whole world. The header of each data file specifies the product name, product version number, details on the data structure, etc.

UV radiation data is based on global ozone fields from either the GOME or the SCIAMACHY instrument. These data sets are kept separate so as not to cause confusion to the user. This section described briefly what data sets are available for what periods.

5.1. GOME: data archive

GOME-based assimilated ozone fields, the basis of the UV index and UV dose, are avaliable for the period August 1995 up to May 2003. The clear-sky UV index and the daily UV dose are based on the two action spectra mentioned above: for erythema and for DNA-damage. The UV dose is computed using cloud cover information on two geographic scales: Europe, based on METEOSAT observation, and the whole world, based on the ISCCP cloud data base. The UV index is always computed for the whole world.

Table 3. Overview of the GOME-based UV index and UV dose data archive at the TEMIS website, valid for both the erythemal and DNA-damage UV data.

product	**data period**
clear-sky UV index	
daily data	Aug. 1995 – May 2003
monthly averages	Aug. 1995 – May 2003
climatologies	Aug. 1995 – May 2003
yearly averages & extrema	1996 – 2002
daily UV dose	
Europe	
daily data	Aug. 1998 – May 2003
monthly averages	Aug. 1998 – May 2003
climatologies	Aug. 1998 – May 2003
yearly averages & extrema	1999 – 2002
whole world	
monthly averages	Aug. 1995 – Sep. 2001
climatologies	Aug. 1995 – Sep. 2001
yearly averages & extrema	1996 – 2000

The data products and their respective coverage in time are listed in Table 3; this overview is valid for both the erythemal and the DNA-damage UV index and UV dose. The GOME data archive can be accessed via http://www.temis.nl/uvradiation/GOME/ . There are four main data set subjects:

- *daily data*
  For individual days the UV index is available world-wide, but the UV dose is available only for Europe, as world-wide daily cloud data is not available.
- *monthly data*
  Monthly averages are averages over all days of a given month. Also supplied under this header are 10-day averages, since the difference between two successive monthly averages may be too large for comparison studies.
- *climatological data*
  Montly climatologies are averages of a given month over all available years. Seasonal climatologies are averages of the three months of a given season (*e.g.* winter: December, January and February) over all available years. The yearly climatology is an average over all monthly climatologies.
- *yearly data*
  Yearly averages are averages over all months of the year, available only for those years for which all 12 months are available. The same is valid for the given yearly extrema: minimum and maximum of the daily data for each grid cell (these extrema are not available for the ISCCP-based UV dose).

Note that the ISCCP cloud data base covers at the moment only the months up to September 2001; if more ISCCP data becomes available, the UV dose quantities will be computed and added to the archive.

The time evolution of the erythemal UV index at local solar noon and the daily erythemal UV dose has been gathered together in a single data file for each of the ground stations of the EDUCE database (mentioned in Section 4) and some other selected places in and outside Europe. Figure 9 shows an example of such a time series, in this case for a selected year.

The GOME data spans a period of nearly 8 years for the UV index, and less for the UV dose. These periods are unfortunately too short to do any trend analysis. It has been estimated that trend analysis in the UV require at least 11 to 15 years of data, depending on the wavelength being considered. Hence a combination of GOME data with other satellite-based data sets will be necessary.

5.2. SCIAMACHY: near-real-time service

The SCIAMACHY instrument, aboard the ENVISAT satellite, is currently operational. Based on the assimilated global ozone fields, derived from SCIAMACHY

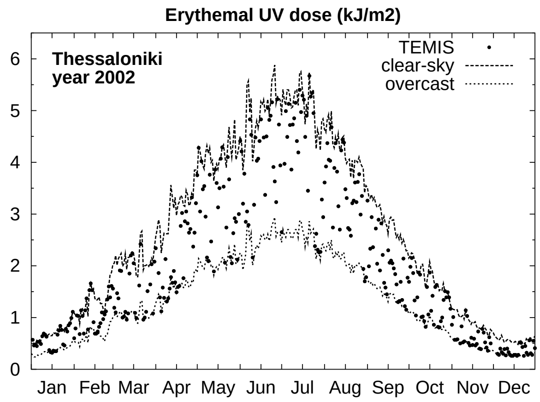

Figure 9. Daily erythemal UV dose for the ground station at Thessaloniki in 2002 extracted from the GOME-based dataset (dots). The dashed line shows the clear-sky UV dose, i.e. the maximum possible values for each day. The dotted line shows the UV dose as it would have been had the day been fully clouded (overcast), i.e. the minimum values for each day.

measurements, the UV index and UV dose are derived, as outlined above.

Most of the SCIAMACHY data arrives at the Royal Netherlands Meteorological Institute (KNMI) in near-real time, within 3–6 hours after observation. On the basis of this data stream a near-real time service of ozone columns and assimilated global ozone fields has been set up. The data assimilation is performed in a chemistry transport model [10], driven by ECMWF forecast meteorological fields, to provide global maps of the ozone field at local solar noon.

Since the total ozone column data are available in near-real time and ECMWF meteorological fields are available in a forecast, it is possible to provide a forecast of the global ozone field, and based on that a forecast of the clear-sky erythemal UV index for today and for a few days ahead. METEOSAT cloud cover data for Europe is available at an 1-hourly interval, making it possible to compute the daily erythemal UV dose for Europe with a delay of one day. This data is available via http://www.temis.nl/uvradiation/ (To avoid confusion, the DNA-damage UV index and UV dose are not provided via this near-real time service, though it would be possible in the same way.)

A forecast for a few days ahead of the erythemal UV index, valid for local solar noon and for clear-sky conditions, makes it possible to issue warnings to the general public when unusually high UV index levels are expected: the people then have time to take precautions and/or change their plans.

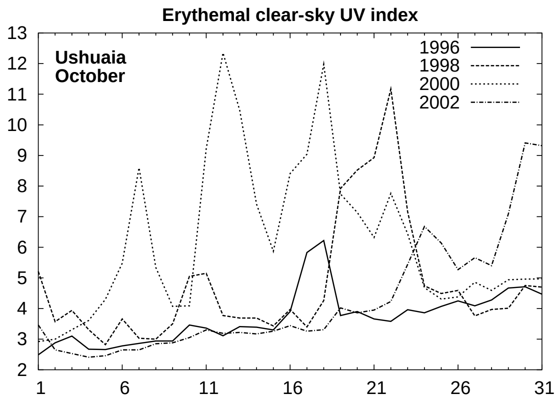

Figure 10. Erythemal clear-sky UV index at Ushuaia (longitude -68.30, latitude -54.80) in Argentina for the month of October in four selected years, based on GOME observations. The monthly average values are 3.7 for 1996, 4.7 for 1998, 6.2 for 2000 and 4.2 for 2002. The climatological average over the GOME data period for October is 4.6.

As an illustration may serve the very high UV index levels the southern tip of South America was exposed to in October 2000, when a part of the Antarctic ozone hole skirted the area. The town of Ushuaia (population 69,500), for example, had an erythemal UV index of 12.4 on 12 October. The next day the UV index was 10.5 and five days later it exceeded 10 again, reaching 12.0. This was not the first time that the erythemal UV index at Ushuaia exceeded 10, but it is very unusual in October. As an example, Fig. 10 shows the clear-sky erythemal UV index in Ushuaia for October in four selected years. The peak value for 1998 reached 11.2 on 22 October.

5.3. SCIAMACHY: data archive

The UV data archive based on SCIAMACHY observations consists at the moment only of the daily erythemal UV dose since 1 January 2004, up to the most recent available data. The plan is to provide a SCIAMACHY-based UV data archive in the same manner as done for the GOME-based UV data, described in Section 5.1, starting with January 2003, so that yearly averages over 2003 can be included as well.

To be able to start with UV data for January 2003, spectral data must be available starting in December 2002, to initialise the data assimilation in the chemistry transport model. Unfortunately, the spectral data for the months December 2002 and January 2003 is at the moment of writing not yet completely available: this awaits (re)processing of the SCIAMACHY data by ESA.

6. CONCLUDING REMARKS

As a support to UV radiation monitoring, the TEMIS project provides as data products the UV index and UV dose based on ozone observations by the GOME and SCIAMACHY instruments. The paper outlined the method used to derive these quantities and gave an overview of the available and planned data products.

Section 4.1 presented a preliminary validation of the erythemal UV dose. A more detailed validation is necessary, initially based on cloud-free dates. The EDUCE database is of great importance for this validation, as it provides UV spectra measured on a variety of European locations. For this validation, individual measurements at specific times of the day will be compared, as well as daily total and monthly average values.

A more detailed validation will have to take into account characteristics of the groundbased instruments, such as a dependency of the measurements on the solar zenith angle (which may cause a difference of a few percent), the aerosol amount and the ozone column. Furthermore, the groundbased instruments usually do not measure at wavelengths all the way up to the 400 nm relevant for the erythemal UV index and UV dose. Instruments such as the double monochromator Brewer spectrometers at *e.g.* De Bilt, Lampedusa and Thessaloniki measure up to 365 nm, and a correction must be made for the range between 365 and 400 nm. This causes only a small difference, since the impact of the missing UV-A wavelengths on the erythemal UV index and UV dose is small (*cf.* the action spectrum in Fig. 1). [12, 13]

A validation of the world-wide UV dose data can only be performed on the basis of monthly averages, as the ISCCP cloud data base used for determining the world-wide UV dose has only monthly-averaged cloud cover fields. Such a validation will therefore be of limited value only.

As mentioned in Section 3.2, the parametrisation used for the UV index implicitly contains the average aerosol load in De Bilt and Paramaribo, hence the TEMIS algorithm currently only contains a ”zero-order” aerosol correction. For situations in which there are clearly more aerosols or less aerosols than the average in De Bilt and Paramaribo, a proper aerosol correction is needed, as the preliminary validation of the erythemal UV dose clearly showed. Some work on this has been done by Bodesa and Van Weele [11] and their method will be implemented in the TEMIS algorithm at a later stage.

The TEMIS algorithm for the daily UV dose for Europe currently uses the cloud cover fraction derived from the 1-hourly METEOSAT observations. An improvement would be to use data from the Meteosat Next Generation (MSG) satellites, which is available every 15 minutes. It may then also be possible to further improve the cloud cover correction by using information on the cloud height, available in the MSG data. Furthermore, it would be useful if all data of MSG and other geostationary satellites can be used to determine a UV dose which covers the whole world on a daily base, rather than having to resort to the monthly-averaged data of the ISCCP database.

The TEMIS data service will be continued in the future, extending beyond the end of the project (December 2004), providing an archive of UV data based on GOME and SCIAMACHY measurements, as well as a forecast of the erythemal UV index for today and a few days ahead for the whole world. A reprocessing of these data will take place when either the input global ozone data fields are updated or when the TEMIS algorithm is improved.

Data from GOME spans a period of nearly 8 years, which is insufficiently long to do trend studies. A combination of GOME and SCIAMACHY based UV data is therefore necessary. As both the ozone and the UV data are computed with the same algorithm for both instruments, a combination of data records may provide enough data for trend analysis. But since the two instruments are intrinsically different, such a combination must be done with care, so as not to introduces artificial features.

The UV index and UV dose presented here cover the UV-A and UV-B wavelength ranges. For some biological research fields it may be useful to split this and have index and dose values for UV-A and UV-B separately. Though such a devision is certainly possible when deriving the parametrisation of the UV index as function of total ozone column and solar zenith angle, the resulting parametrisations will have larger uncertainties, as the parametrisation is based on fewer data points (wavelengths) than when using the full wavelength range.

The UV data currently provided is based on two action spectra, namely those for erythema (reddening of the skin due to sunburn) and generalised DNA-damage, as discussed in Section 2. Other action spectra can be used as well for a parametrisation of the UV index. This could be useful, as each action spectrum has a different wavelength dependency, thus giving more information as to how changes in the ozone concentration in the stratosphere affect the UV irradiance at the Earth's surface, and the possible biological effects of these changes.

For example the mammalian non-melanoma skin cancer action spectrum [14], which lies between the erythemal and DNA-damage action spectrum (see Fig. 1), but shows a sine-like wavelength dependency between 340 and 400 nm. Another example is the action spectrum for melanoma induction in platyfish-swordtail hybrids [15], which has a much more significant UV-A component, indicating that ozone depletion would not have as great an influence on melanoma in these species of fish as would the responses described by other action spectra. For references to more action spectra, see Refs. [1, 2].

Note that the action spectra in themselves only give an indication of the relative wavelength dependency of biological effects: the actual biological response is determined by the actual dose amount, *i.e.* the UV irradiance weighted with the action spectrum and integrated over the wavelength range and the exposure time, keeping in mind that the dose-response relation may not be linear.

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