

Surface solar and UV products for Europe by combination of MSG and SCIAMACHY (SUPREMACY)

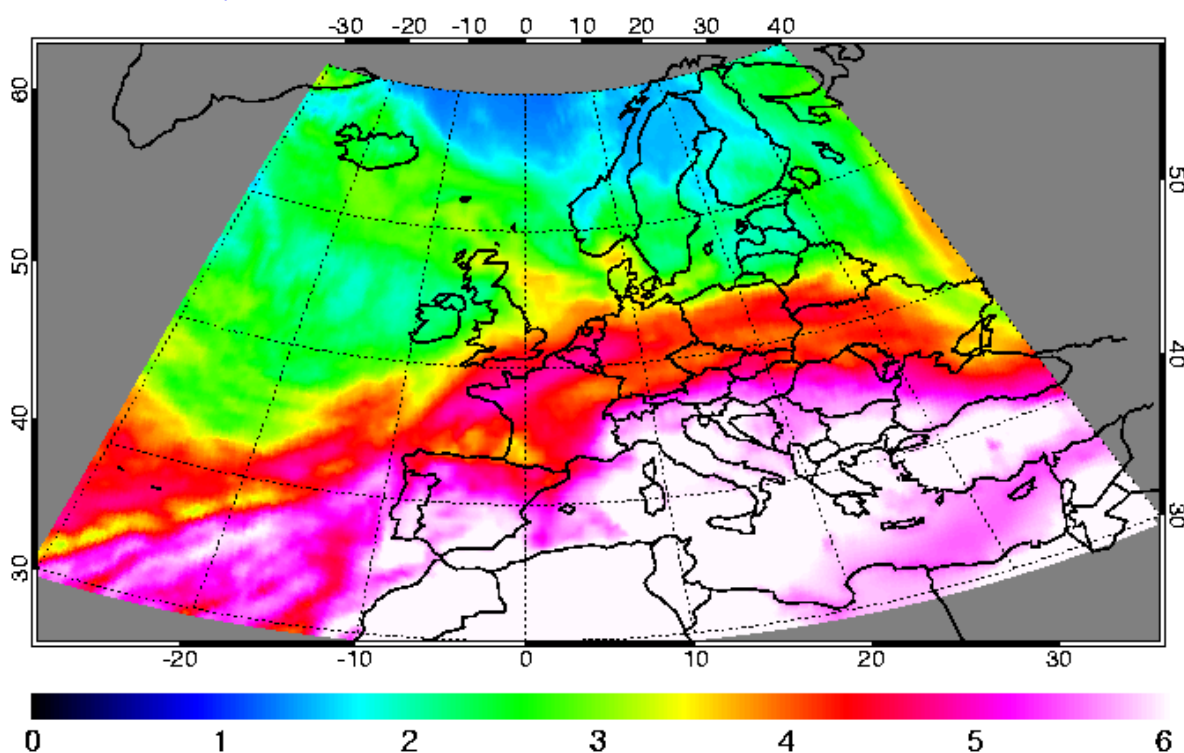
Final report

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Erythemal UV dose (kJ/m²)

SCIAMACHY, METEOSAT - KNMI/ESA

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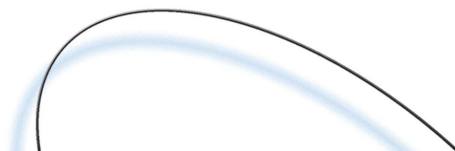
NATIONAL USER SUPPORT PROGRAMME (NUSP) 2001-2005

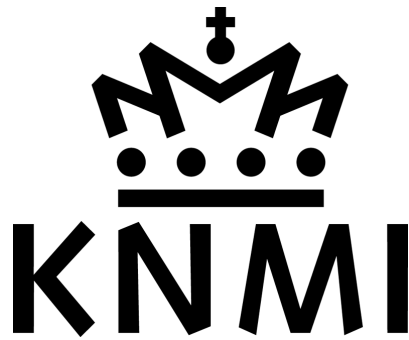
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The National User Support Programme 2001-2005 (NUSP) is executed by the Netherlands Agency for Aerospace Programmes (NIVR) and the SRON Netherlands Institute for Space Research. The NUSP is financed from the national space budget. The NUSP subsidy arrangement contributes to the development of new applications and policy-supporting research, institutional use and use by private companies.

The objectives of the NUSP are:

- To support those in the Netherlands, who are users of information from existing and future European and non-European earth observation systems in the development of new applications for scientific research, industrial and policy research and operational use;
- To stimulate the (inter)national service market based on space-based derived operational geo-information products by means of strengthening the position of the Dutch private service sector;
- To assist in the development of a national Geo-spatial data and information infrastructure, in association with European and non-European infrastructures, based on Dutch user needs;
- To supply information to the general public on national and international space-based geo-information applications, new developments and scientific research results.





Het Koninklijk Nederlands Meteorologisch Instituut (KNMI) is hét nationale data- en kenniscentrum voor weer, klimaat en seismologie.

Het KNMI verstrekt weerinformatie ten behoeve van veiligheid, economie en duurzaam milieu aan het algemeen publiek, de overheid, de luchtvaart en de scheepvaart. Voor langetermijn-ontwikkelingen verricht het KNMI onderzoek naar de veranderingen in het klimaat. Het beschikbaar stellen van bij het KNMI aanwezige kennis, data en informatie is een kernactiviteit. Het instituut is een agentschap van het Ministerie van Verkeer & Waterstaat. De taken van het KNMI zijn vastgelegd in de Wet op het KNMI.

Het klimaatonderzoek bij het KNMI richt zich op het waarnemen, begrijpen en voorspellen van veranderingen in het klimaatsysteem. De keuze van onderzoeksthema's is gebaseerd op de stand van zaken in het (inter)nationale klimaatonderzoek en op de vragen die vanuit overheid en samenleving gesteld worden, nl: Hoe verandert ons klimaat? Waardoor verandert het klimaat? en Hoe ziet ons toekomstig klimaat eruit?

De afdelingen Aardobservatie Klimaat en Chemie en Klimaat houden zich bezig met het waarnemen, begrijpen en verwachten van veranderingen in de atmosferische samenstelling in relatie tot het klimaat, waaronder veranderingen in de ozonlaag en de inkomende UV straling.

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Executive summary

The SUPREMACY project has provided the continuation and extension of the near-real time UV services that have been developed within the ESA data delivery service TEMIS (Tropospheric Emission Monitoring Internet Service; <http://www.temis.nl>). TEMIS is part of the Data User Programme (DUP) of ESA. It is an operational processing and archiving center for monitoring the ozone hole, local UV forecasts, monitoring air pollution and support to aviation control. Products are often made available within a few hours after observation. This also holds for the new UV services that are developed and extended within SUPREMACY.

A semi-operational monitoring service for surface UV radiation reaching the Earth's surface has been established by combining ozone information of the SCIAMACHY instrument on ENVISAT with cloud information of the SEVIRI instrument on Meteosat Second Generation (MSG). The SCIAMACHY total ozone column data is global in extent and forms the base of the cloud-free surface UV products including the UV clear-sky index used for UV forecasting. Continued validation of the TOSOMI total ozone observations is needed because the offset could change over time, e.g. caused by long-term drift in the instrument calibration. The SEVIRI cloud data is regional in extent and forms the base of the UV dose products used for long-term UV monitoring over Europe.

Based on feedback from users the extensions to TEMIS provided by SUPREMACY include primarily the extended and improved European near-real time UV products and their archives. Secondly, European as well as global Vitamin-D UV products have been added to the TEMIS service. A third important extension to TEMIS that has been provided by SUPREMACY is that archives have been created and made available for all global cloud-free UV products, most importantly for the clear-sky UV index.

The new UV services have been integrated in the TEMIS services hosted by KNMI. The SUPREMACY UV products extend and improve for the project period 2004/2005 – 2008 on the TEMIS UV data sets and time series based on GOME and Meteosat that were available for the time period 1995-2003.

Correction algorithms for clouds as well as for aerosol optical thickness have been evaluated and the SUPREMACY UV products have been compared with surface measurements.

1. Introduction, objectives, and methods

The SUPREMACY project provides the continuation and extension of the UV services that have been developed within the ESA data delivery service TEMIS (Tropospheric Emission Monitoring Internet Service; <http://www.temis.nl>).

TEMIS is part of the Data User Programme (DUP) of ESA. It is an operational processing and archiving center for tropospheric data sets for targeted user groups. These data sets consists of global concentrations of tropospheric gases, aerosols, clouds and surface UV products derived from observations of nadir-viewing UV-VIS satellite instruments such as GOME, SCIAMACHY and OMI. The TEMIS data products are often made available within a few hours after observation. The data is widely used for monitoring the ozone hole, local UV forecasts, monitoring air pollution and support to aviation control.

Figure 1.1. TEMIS web portal providing access to the TEMIS UV products that are extended and improved within the SUPREMACY project under the links related to UV radiation monitoring, including the clear-sky UV index forecast and archive, as well as yesterday's fields and archives of the UV daily dose.

1.1 Project objectives

The goal of the SUPREMACY project is to establish a semi-operational monitoring service for surface UV radiation by combining ozone information of the SCIAMACHY instrument on

ENVISAT with cloud information of the SEVIRI instrument on Meteosat Second Generation. Compared to the existing UV products based on Meteosat and GOME products, the products from this service are improved with respect to cloud corrections and spatial and temporal resolution. Based on the requirements as indicated by TEMIS users (listed in Chapter 2), some new products are added to the UV service. These new products include archives for global cloud-free products and UV dose products related to Vitamin-D production. Feedback of the end users is used to optimise the UV products and the presentation formats.

The correction algorithms for clouds as well as for aerosol optical thickness are evaluated and verification of the SUPREMACY products is performed with surface measurements.

The SUPREMACY products are incorporated in the TEMIS infrastructure. At the end of the project the improved TEMIS UV service is established and the SUPREMACY products over the project period will be available as TEMIS products.

1.2 Project deliverables

The SUPREMACY project deliverables are:

- An extension of the existing TEMIS near-real time UV service based on GOME and Meteosat by implementing the use of SCIAMACHY for near-real time ozone and MSG for near-real time cloud information
- The addition of new products including the daily dose for DNA-damage and Vitamin-D production over Europe, cloud-free daily dose products worldwide and time series of all UV products at selected locations
- The provision and automatic update of archives of the UV products over the project period
- An operational website for automated near-real time dissemination of the UV products including display of UV data and images in near-real time
- Documentation and information on the quality of the data

1.3 Heritage and relation to other projects

The project builds on existing expertise and software developed. The near-real time UV index service relies on the near-real time assimilation of total ozone columns which has been installed and maintained at KNMI via various projects since the late nineties, first based on ERS-2/GOME and later on Envisat/SCIAMACHY. Especially notably with regard to the near-real processing and archiving of SCIAMACHY data are the national GO-projects that established the SCIAMACHY data centre (NEONET).

The SUPREMACY activities are directly relevant to the ESA Data User Programme (DUP) project TEMIS, “Tropospheric Emission Monitoring Internet Service” because SUPREMACY provides an extension on the TEMIS UV services with improved products for Europe and extended global UV records. TEMIS is a project of ESA ESRIN and is being coordinated by KNMI (Project leader: Ronald van der A). TEMIS aims to develop and maintain a service to deliver global concentrations of tropospheric trace gases, and aerosol and UV products derived from observations of satellite instruments. Current partners in this project are BIRA-IASB (Belgian Institute for Space Aeronomy), VITO (“Vlaamse Instelling voor Technologisch Onderzoek”), FMI (Finnish Meteorological Institute), EMPA (Swiss

Federal Laboratories for Materials Testing and Research) and NUIG (National University of Ireland, Galway).

Within TEMIS a UV index forecast system was developed based on GOME ozone data. UV dose monitoring was developed by combining the analysed UV index with cloud mask data based on Meteosat-7 and by using cloud information as derived from ISCCP (the International Satellite Cloud Climatology project – <http://isccp.giss.nasa.gov>). TEMIS UV index forecasts for De Bilt are operationally used at KNMI to inform the general public in the Netherlands. Forecasts are published by KNMI on the internet and on national television via NOS teletekst page 708.

The users of the SUPREMACY project are the users of the TEMIS UV service. Therefore, SUPREMACY profits directly from the user requirements defined within the TEMIS UV service. The ESA GMES Service Element, GSE, is targeting the actual provision of operational and sustainable information services which respond to the needs of users in support of environment and security policies. KNMI has been coordinating PROMOTE-I and provided to PROMOTE the near-real time UV products from TEMIS / SUPREMACY.

The screenshot shows the SCIAMACHY web portal. At the top, there is a navigation menu with links: Home, Products, Validation, Science, Operations, Calibration, and Monitoring. Below the menu, there is a section titled "Click on an institute to get product details" which contains a table of "all UV products".

product	made by	order	period	maturity				val
				AD	PSD	Av	C	
UV index	KNMI	go	Jul 2002 to now	✓	✓	✓ (*)		
UV dose	KNMI	go	Jul 2002 to now	✓	✓			

Below the table, there is a note: "(*): some restrictions on data use, see product details (click on institute)".

The main content area shows details for the "UV index by KNMI (last update: 28-02-2008)".

available data	July 2002 to now. Data can be accessed via the TEMIS website and via the PROMOTE website .
point of contact	Michiel van Weele
algorithm description	The algorithm is described on the PROMOTE website .
product details	Current software version will be called version 1. Further details can be found on the PROMOTE website .
validation results	<ol style="list-style-type: none"> 1. PROMOTE website 2. J. van Geffen, R. van der A, M. van Weele, M. Allaart and H. Eskes, in: Proceedings of the ENVISAT & ERS Symposium, 6-10 September 2004, Salzburg, Austria, ESA publication SP-572, 2004 (CD-ROM)

On the right side of the page, there are sections for "Register", "Quality criteria", "Literature overview", and "Add literature".

Figure 1.2. Web portal to SCIAMACHY scientific products with information and access to the UV products of SUPREMACY

The SUPREMACY project uses cloud information derived from MSG which is made available via the Nowcasting Satellite Application Facility (NWC-SAF) and the Climate Monitoring Satellite Application Facility (CM-SAF). The CM-SAF software to derive cloud parameters is also available at KNMI and is being used in the NIVR GO project “Surface Insolation under Cloudy Conditions derived from SEVIRI imagery” (SICCS, AO-GO Project 3.4 DE-05) to derive solar irradiance at the surface for the Netherlands and close

surroundings. Product validations as performed in SICCS have provided supplementary information on the use of the CM-SAF cloud optical thickness for the derivation of surface UV radiation.

The TEMIS / SUPREMACY UV products are made available as SCIAMACHY scientific products via a link on <http://www.sciamachy.org>

1.4 General background information

Ultraviolet (UV) radiation from the Sun is both harmful and beneficial to humans and the environment. Sunburn and the resultant skin cancer are the best known health problems with a latest estimate of 60,000 deaths a year worldwide caused by too much exposure to UV (WHO, 2006). At the same time a minimal casual exposure to UV radiation is needed, e.g., to maintain healthy Vitamin-D levels. Large groups in the population of western countries are known to have a deficit in Vitamin-D (Hickey and Gordon, 2004; Holick, 2007). The associated health problems might even outweigh the health problems associated with skin cancer. The duality in the relation between UV radiation and health is an important UV research topic in recent years.

1.4.1 Clear-sky UV index

Diseases caused by UV overexposure are almost entirely preventable by simple sun safety practices. These should be taken for UV index predictions of 3 or higher (WHO, 2006). The WHO also recommends countries to inform the general public on a daily basis and to maintain a certain level of awareness. Nowadays UV index predictions are made available in many countries. The UV index is defined as the daily maximum CIE-weighted (McKinlay and Diffey, 1987) UV surface irradiance, where 1 unit of the UV index unit equals 25 mWm^{-2} . In the Netherlands KNMI has the obligation by law to provide UV forecasts (“zonkrachtverwachtingen”) for the Netherlands. Specific warnings on UV are published as part of the weather bulletins for a UV index of 7 or more. These high levels are typically reached each year during a couple days in the weeks around the summer solstice (21 June). SUPREMACY aims to provide daily worldwide UV index forecasts and to build-up archives of past clear-sky UV index values. The TEMIS worldwide UV index forecasts already have proven their value by provision of UV forecasts for end users in countries that do not have the capacity to set-up their own UV forecasts. For example, Malta International Airport uses already for a couple of years the TEMIS UV service for their UV predictions for Malta.

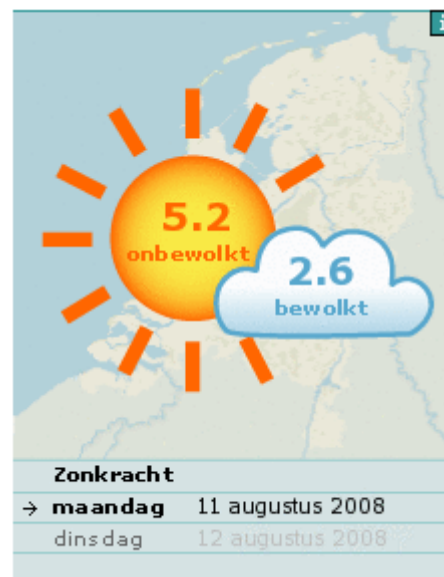


Figure 1.3. UV forecast on the KNMI web-site

1.4.2 Daily UV dose

Dose-effect relationships are important to epidemiological and environmental studies. The response of the human body to (changes in) the long-term integrated UV dose is still badly understood. Epidemiological studies require long-term homogeneous data sets with extensive geographical coverage such that the data can be related to, e.g., population densities and health statistics. For example, high incidence rates of non-melanoma skin cancer have been reported in white skin people in Australia and New Zealand (AIHW, 2008; Swerdlow et al., 1995). Environmental consequences of changing UV levels on aquatic and terrestrial ecosystems have been shown in many studies but effects remain uncertain and many studies so far have been hampered by technical difficulties in predicting, measuring and applying realistic UV levels. The UV dose is the time-integrated UV irradiance, typically in units of kJm^{-2} . Daily UV doses are considered to form an adequate basis of a UV climatology that consists of monthly and yearly averages as well as information on extreme day values. Long-term satellite-based operational monitoring of the daily UV dose will offer the required temporal and geographical coverage for epidemiological and environmental studies.

For a given location and season cloudiness and overhead ozone amounts are the main causes for day-to-day variability in UV doses. For some locations differences in aerosol load and snow cover are important as well. SUPREMACY aims to provide the daily UV dose over Europe for yesterday and to build-up archives of the UV dose for the derivation of climatologies.

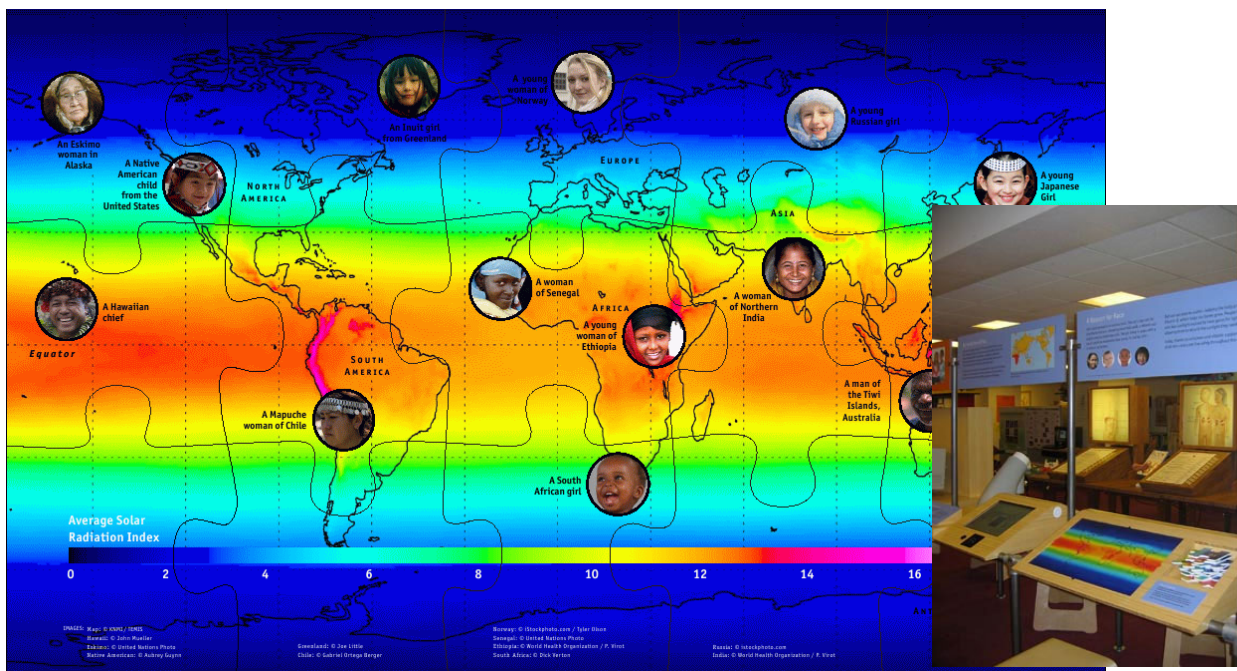


Figure 1.4. UV map from SUPREMACY used for educational purposes in the American museum “Hall of Health” in Berkeley. The puzzle shows the relation between UV dose and racial skin color.

1.4.3 Need for surface UV measurements from space

Only long-term satellite-based operational monitoring of the daily UV dose can offer the required temporal and geographical coverage for epidemiological and environmental studies. At the same time long-term stable surface UV records from a ground network are needed for continuous validation of the satellite-based monitoring system. The determination of surface

UV radiation from satellite observations is possible because of present-day's accurate knowledge of UV radiative transfer modelling in the atmosphere. Satellite observations are needed to provide the two most important and variable input parameters for the UV radiative transfer modelling or derived parameterizations: the total ozone column and cloud parameters.

The only alternative to the use of satellite observations for UV dose monitoring would be modelling and/or interpolation between surface stations. However, ground networks for measurement of solar incoming radiation are sparse; even more limited are the ground networks for UV radiation. In addition, comparison of measurements performed by different regional ground networks may suffer from changes from instrument-to-instrument and calibration issues. Modelling is hampered by the large sensitivity of the UV dose to the spatial and temporal variability in cloudiness. For example, a cloud that is shielding the sun around noon has much more impact than the same cloud in the early morning or late afternoon. The present-day generation of cloud imagers on board of geostationary satellite platforms such as MSG can provide quantitative cloud information every 15 minutes, 24 hours a day.

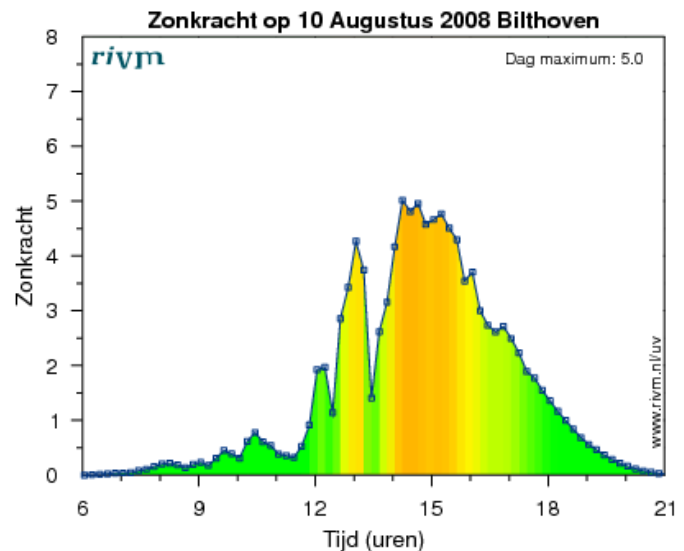


Figure 1.5. Example of the variability of the UV index over a day

1.4.4 Near-real time UV services

An essential element of the UV service is the near-real time aspect. Prevention is considered crucial to reduce health problems caused by excessive UV radiation. Forecasting of the UV index for today and the next few days is the best way to inform the general public on a daily basis on the UV radiation levels that can be expected.

Near-real time delivery of the UV dose is probably less critical. The advantage of daily processing of the UV dose is in the small effort and disk space that it takes on each day. A large amount of cloud input data is needed for the calculation of the daily UV dose, which hampers processing over long time periods, but can be handled efficiently on a day-by-day basis.

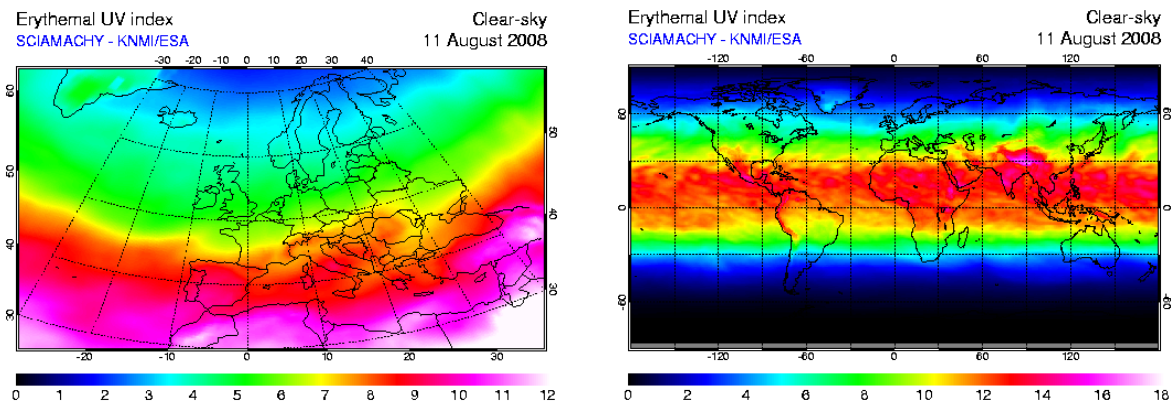


Figure 1.6. The resulting Erythemal UV maps provided in near-real time.

1.5 Instrument and algorithm description

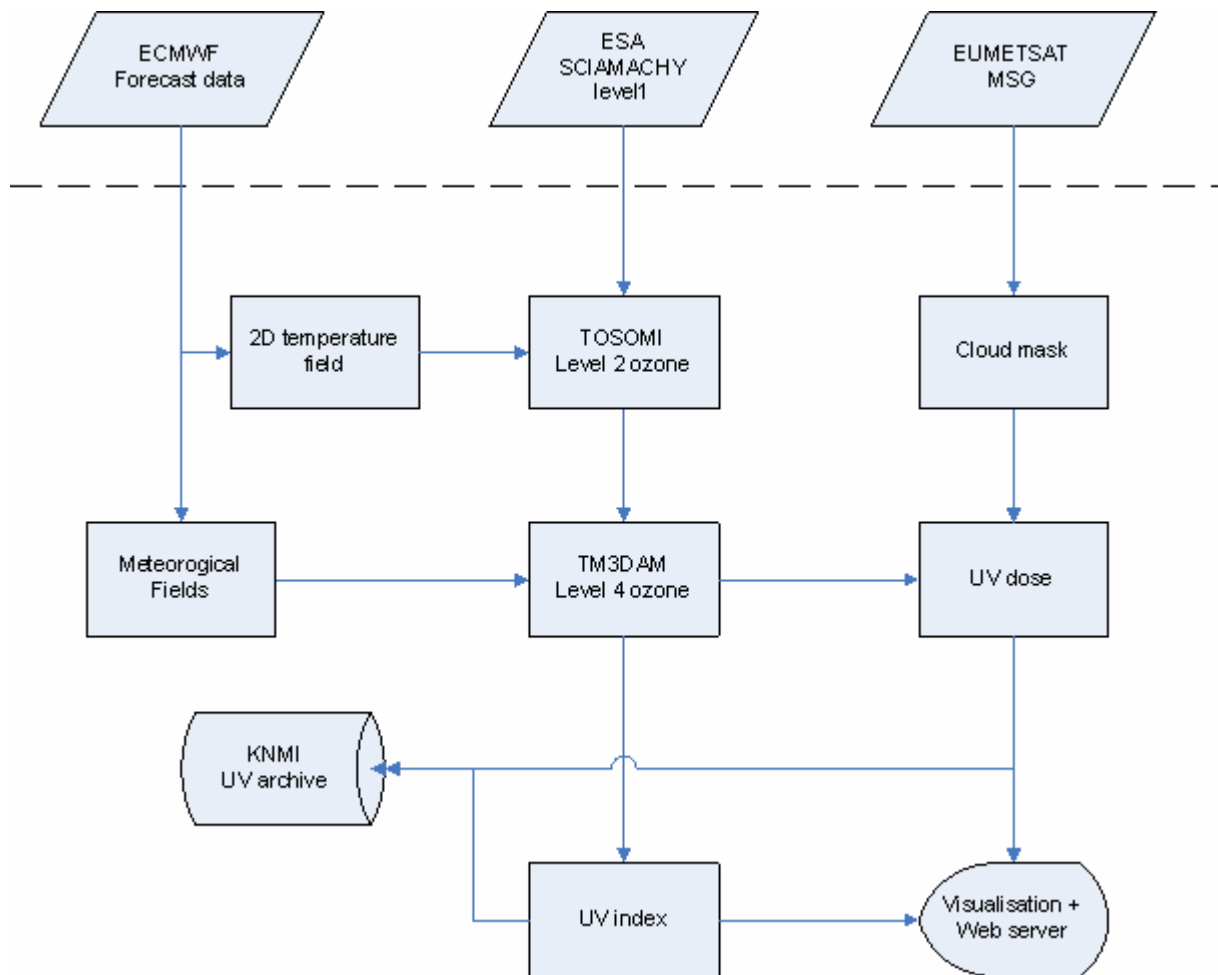


Figure 1.7. Flow diagram of the processes involved in the calculation of the UV index and UV dose products.

1.5.1 SCIAMACHY data acquisition and ozone retrieval

SCIAMACHY is an UV-VIS-NIR instrument on board of Envisat that was launched 2002. SCIAMACHY level-0 and level-1 data are obtained daily in near-real time at KNMI via the Netherlands SCIAMACHY data center ('NEONET'). The level-1 data are input to the SCIAMACHY total ozone retrieval algorithm TOSOMI (Eskes et al., 2005). TOSOMI is an application of the TOGOMI algorithm to SCIAMACHY. TOGOMI (Valks and Van Oss, 2003) is based on the total ozone DOAS (Differential Optical Absorption Spectroscopy) algorithm developed for the OMI instrument (Veefkind and De Haan, 2001). With respect to total ozone column retrieval using the DOAS method, the OMI, SCIAMACHY and GOME instruments are very similar. TOSOMI combines a SCIAMACHY Level-1 product reading module with the TOGOMI DOAS modules. The SCIAMACHY total ozone data retrieved using TOSOMI are used in the ozone assimilation.

1.5.2 The ozone assimilation

Since the end of the 1990s an ozone data assimilation and forecast system is available at KNMI and used for the TEMIS internet services. It has been developed at KNMI over the last decade and is based on a transport-chemistry model driven by ECMWF meteorological forecasts, and assimilates the TOSOMI near-real time total column ozone measurements of SCIAMACHY (i.e. within 3–6 hours after observation). It has been shown (Eskes et al., 2002, 2003) that the produced ozone analyses are realistic, and the detailed ozone distribution compares favourably with independent ozone observations. Short-range forecasts show a small bias (generally < 1%) and are able to predict the new ozone observations with a globally averaged precision of about 3%. Meaningful medium-range ozone forecast can run up to more than a week and these are performed routinely. With these total ozone forecasts, it is possible to provide the clear-sky UV index in a meaningful forecast for today and more than a week ahead.

The assimilated ozone fields for either analysis or forecast are given at a latitude/longitude grid of $1.0^{\circ} \times 1.5^{\circ}$. The ozone data is interpolated to a grid of $0.5^{\circ} \times 0.5^{\circ}$ (which amounts to about 50×50 km at the Equator, and about 50×25 km at 60 degrees North) for calculations of the UV index and UV dose data.

1.5.3 MSG data acquisition, cloud mask and cloud optical thickness

Meteosat Second Generation (MSG) is a new series of European geostationary satellites operated by EUMETSAT. Meteosat-8 is the first MSG satellite and has been launched in August 2002 and provides operational data since early 2004. Meteosat-9 has been launched in 21 December 2005 and provides operational data since Summer 2006. The SEVIRI instrument allows the retrieval of quantitative cloud information over Europe 4 times per hour with high spatial resolution.

The cloud correction algorithm that is used for the daily UV dose is based on the MSG near-real time cloud mask (CMa, version 1.2), developed within the Nowcasting Satellite Application Facility (NWC-SAF; <http://nwcsaf.inm.es/>). The NWC-SAF cloud mask product aims to support nowcasting applications. The central aim of the CMa is to delineate all cloud-free pixels in a satellite scene with a high confidence. In addition, the product provides information on the presence of snow/sea ice, dust clouds and volcanic plumes. Every 15

minutes a cloud mask field is available for the MSG-N region (Europe, North Africa and adjacent seas). The algorithm is based on a multi-spectral threshold technique applied to each pixel of the image. The channels from SEVIRI that are applied to derive the CMA product include R0.6 μm , R0.8 μm , R1.6 μm , T3.9 μm , T8.7 μm , T10.8 μm , and T12.0 μm . The CMA product distinguishes 6 categories: 0=non-processed; 1=cloud-free; 2=cloud-contaminated; 3=cloud-filled; 4=snow/ice-contaminated; 5 =Undefined. Details on the CMA algorithm are given on the webpages of the NWC-SAF (<http://nwcsaf.inm.es/>). KNMI receives, processes and archives the nowcasting cloud mask data based on MSG since July 2005.

Within SUPREMACY it is explored to combine the NWC-SAF cloud-mask data with information on the daily mean cloud optical thickness (COT) from SEVIRI that is made available via the Climate Monitoring Satellite Application Facility CM-SAF (<http://www.dwd.de/en/FundE/Klima/KLIS/int/CM-SAF/index.htm>). In the framework of the CM-SAF KNMI is responsible for the extraction of cloud physical products. The cloud products of the CM-SAF comprise cloud mask, cloud thermodynamic phase, cloud liquid water path, cloud optical thickness and cloud droplet effective radius. The retrieval method is based on meteorological satellite radiances at a non-absorbing visible and a moderately absorbing solar infrared wavelength (Roebeling et al., 2006). In 2004 the first release of the cloud physical products software for MSG became available for the CM-SAF. This software is used to provide daily cloud products for the SUPREMACY project.

1.5.4 The UV processor

The incoming solar UV radiation depends on location and season via the Earth-Sun distance, the solar zenith angle and the elevation of the location. The radiation intensity is modified on its path through the atmosphere by absorption and scattering processes. In the higher atmosphere the most important reduction for the erythemal weighted UV radiation reaching the surface is by ozone absorption. The most important modification in the lower atmosphere is by cloud scattering. Enhanced surface reflection is important for the incoming radiation intensity via multiple reflections. This effect is most important for cloudy skies. Aerosol scattering and absorption further contribute to the modification of the incoming UV intensities.

For a given location and time the clear-sky UV index can be estimated rather accurately by taking into account only the total ozone column (Burrows et al., 1994). Ground-based measurements of UV spectra and total ozone columns in De Bilt (Netherlands) and Paramaribo (Suriname) have been used to determine an improved parameterisation of the erythemal UV index as function of the total ozone column and the solar zenith angle (Allaart et al., 2003). The widely used parameterisation by Burrows et al. (1994) was found not to be globally applicable. A similar parameterisation has been made for the DNA-damage and Vitamin-D.

The parameterization 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 (Badosa and Van Weele, 2002) can be implemented as soon as aerosol forecasts would become feasible. For analysis backward in time aerosol modification factors can be applied using aerosol optical parameters (mainly optical thickness and single scattering albedo are required) as input.

The daily erythemal UV dose algorithm is mostly identical to the algorithm for the clear-sky UV index, but essential for the daily UV dose is the time-dependent shielding effects of clouds. A UV index calculation is based on the noontime ozone and to integrate over the day it is applied for the full range of local solar zenith angles during the day. In addition a cloud correction algorithm is being applied using MSG cloud information. The cloud correction algorithm is detailed in Chapter 3. The daily erythemal UV dose is derived by integration over the day of the cloud corrected UV indices with a time step of 10 minutes. Results are produced on a grid of 0.5×0.5 degrees covering Europe from -30W to 40E and from 30N to 70N. Maps of the daily erythemal UV dose map for Europe are presented in Chapter 3.

The processing for other action spectra is similar to the processing for the erythemal UV dose. The main difference is the equations similar to those presented in (Allaart et al., 2004) relating variations in total ozone column and solar zenith angle to a UV radiation level that is spectrally weighted differently than the UV index.

2. Users

2.1 User requirements

Three end-users of the TEMIS UV service have been asked to provide their requirements and suggestions with regard to the UV products delivered by TEMIS. These end-users are:

- L'Oréal Recherche, France
- Agenzia Regionale Prevenzione E Ambiente (ARPA) - Emilia Romagna, Italy
- KNMI, The Netherlands

The users indicated most interest in the following (types of) UV products:

- UV index forecasts
- UV daily dose monitoring for different purposes, including UV-A and UV-B
- Climatologies / long-time series

An issue that has been put forward over the last couple of years in the international arena of UV research is on the duality of UV with regard to health. In communications to users it is advised to prevent information that is limited to warnings against the Sun, and to mention that there are also health benefits of moderate exposure to solar UV radiation, e.g. in relation to the production of Vitamin-D in the human skin.

In response to these user requirements the following UV products were identified as the UV products on which the SUPREMACY project should focus:

- Clear-sky UV index (forecast and archive)
- Erythemat UV daily dose (near-real time for yesterday and archive)
- DNA damage UV daily dose (near-real time for yesterday and archive)
- Vitamin D UV daily dose (near-real time for yesterday and archive)

Other important aspects as required by users include:

- To provide continuation of the TEMIS UV service (after December 2004)
- To apply algorithm improvements with respect to cloud modification and to verify the products

2.2 Users and statistics

The TEMIS UV index forecast is among the most popular products of TEMIS. The TEMIS UV service currently (July 2008) gets more than 10000 unique visitors per month. Via the TEMIS feedback forms about each month one or two specific requests are being made by new users from around the world for UV products at specific locations or for certain regions/countries. The total amount of data available via the TEMIS UV service currently exceeds 25 Gb (per July 2008).

On a national level the TEMIS UV processing chain as maintained during the SUPREMACY

project is used to produce daily predictions of the UV index ('zonkracht'). These predictions are made available on the internet and via national television on NOS teletekst page 708. In case of UV index predictions larger than 7 a warning is added to the weather bulletins and a free SMS service becomes active (<https://www.alarmbericht.nl/sms-diensten.html>). The number of visitors of the KNMI website on days with high UV index and to the NOS teletekst page 708 are unknown, but will exceed by far the 10000 visitors to the TEMIS UV service. These users are typically only from the Netherlands only, while TEMIS serves people around the world.

Other countries that uses the UV index from TEMIS for their national UV forecast bulletins are Malta and Bermuda. Several citizens around the world are using the TEMIS UV forecasts on their personal web-pages. The French TV5–science website has made a permanent link to the UV images on the ozone hole bulletins (<http://www.tv5.org/sciences>). The global UV information is also used by the WMO in their ozone bulletin, and several scientific institutes and meteorological services.

Table 2.1 includes a list of users which are known within TEMIS because of direct communications that took place, e.g. via the TEMIS feedback forms. The overview shows that the UV data are used by researchers and for applications all over the world. Of special interest is the use of the data in many countries with less well-developed infrastructures. Clearly, the processing as set up by SUPREMACY has helped them to get direct access to near-real time UV data.

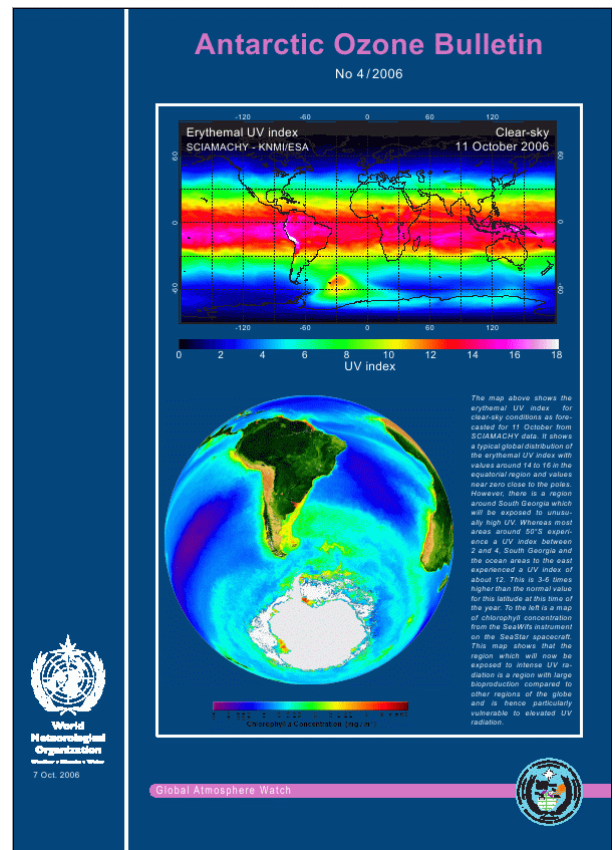


Figure 2.1. Example of the WMO ozone bulletin with information on the effect of the ozone hole on the UV radiation in the Antarctic region.

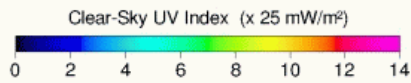
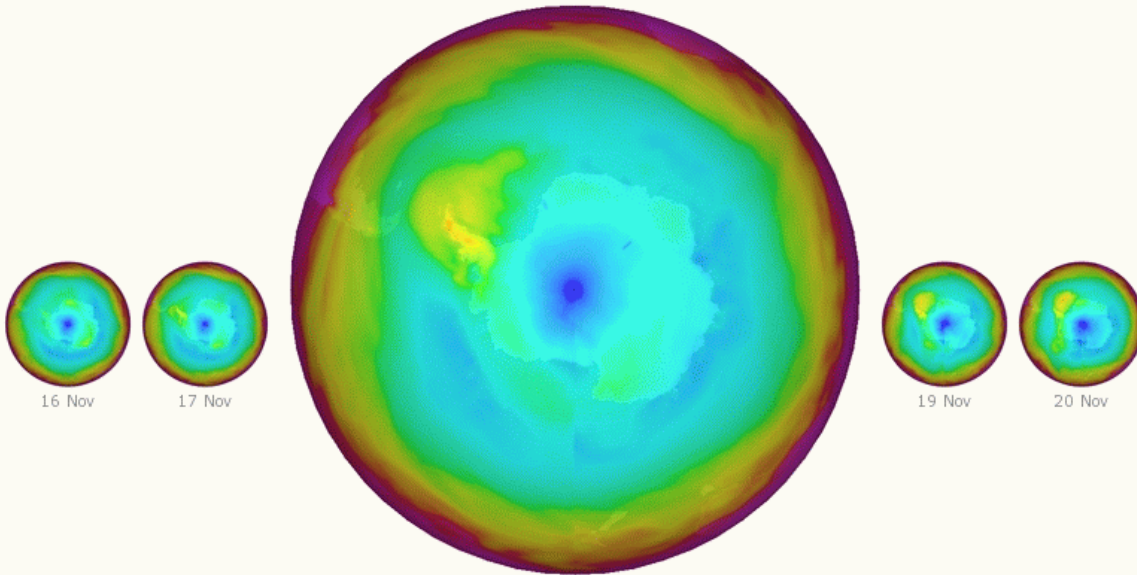
Organisation

Malta International Airport	Yonsei University, South Korea
Meteogratis, Italy	Geoex sas
L'Oreal, France	University of Manchester
KNMI	University of Magallanes, Chile
Storm Weather Service	Czech Hydrometeorological Institute
British Antarctic Survey	Deployment Health Clinical Center, US army
Pennsylvania State Un., Dep.of Anthropology	University of Iran
Marine Biology, Univ. Groningen	University of State of Rio de Janeiro, Brazil
Weill Medical Center of Cornell, New York	University of Magallanes, Chile
University of Cracow	Lakutaia, Chile
Indian Institute of Tropical Meteorology	St Xavier's College, India
GLOBE, EDUSPACE	Rostov meteo service, Russia
Sun-Gard Australia	Ministry of Health, Iraq
Maryland Science Center	Australian Radiation Protection and Nuclear Safety Agency
Bermuda Biological Station for Research	German Cancer Research Center (DKFZ)
Weather2 Ltd, Scotland	NCHGSR, India
Turkish State Meteorological Service	Loma Linda University, USA
Universidad de Costa Rica	Univ. of Colorado Health Sciences Center
Hall of Health (educational for children), US	McLean Hospital, USA

Table 2.1. List of users of the TEMIS UV products as developed in SUPREMACY. These are the users which are known because direct communications have taken place during the project.



18 Nov 2007



Pick a day: Year Month Day



Ronald van der A, Bas Mijling
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Figure 2.2. Images on the daily updated TEMIS ozone hole bulletins of the UV distribution over the Antarctic

3. Product and Algorithm Evaluation

3.1 UV products

The four SUPREMACY UV products are:

- The clear-sky UV index
- The daily UV dose for erythema
- The daily UV dose for Vitamin-D production
- The daily UV dose for DNA-damage

Daily UV doses for the three action spectra are given for Europe (-30W – 40E; 30-70N). The clear-sky UV index is given worldwide. Also cloud-free daily UV doses are provided globally. Time series for the UV index and all UV dose products are provided at selected locations in Europe (currently 46 locations). Time series for the UV index and cloud-free UV doses are provided at selected locations worldwide (currently 77 locations). The list of locations is increasing over time in response to incoming user requests for time series and forecasts at their specified locations.

3.1.1 Clear-sky UV index

Maps of the clear-sky UV index are produced for the forecasts based on the ozone forecasts and for the archive based on the ozone analysis. Nine forecast maps are produced daily for Europe, The Netherlands and the whole world. The maps that are based on the ozone analysis for yesterday are stored in the archive, together with the HDF data file including metadata (see section 3.4). Example figures are presented below.

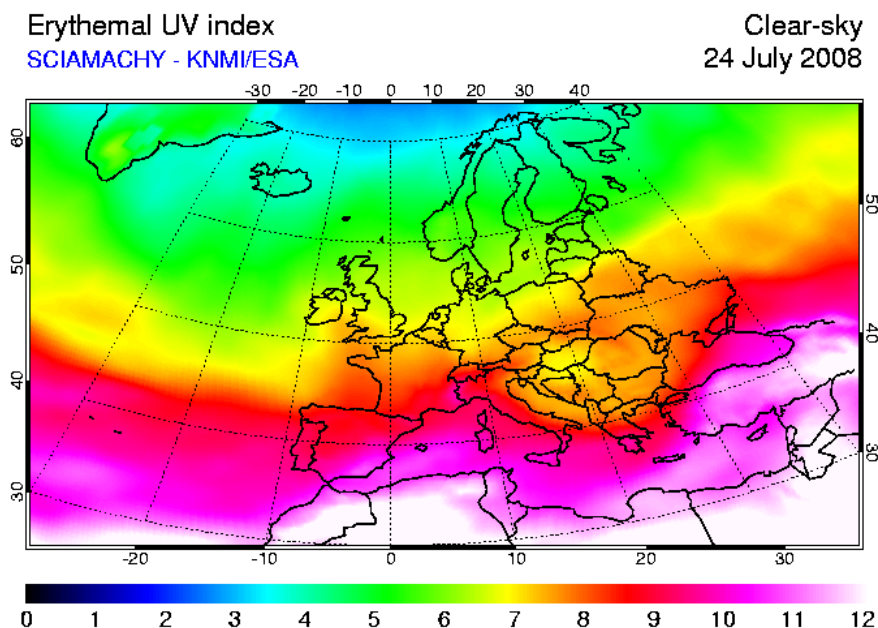


Figure 3.1. Example of the clear sky UV index forecast map for 24 July 2008 for Europe

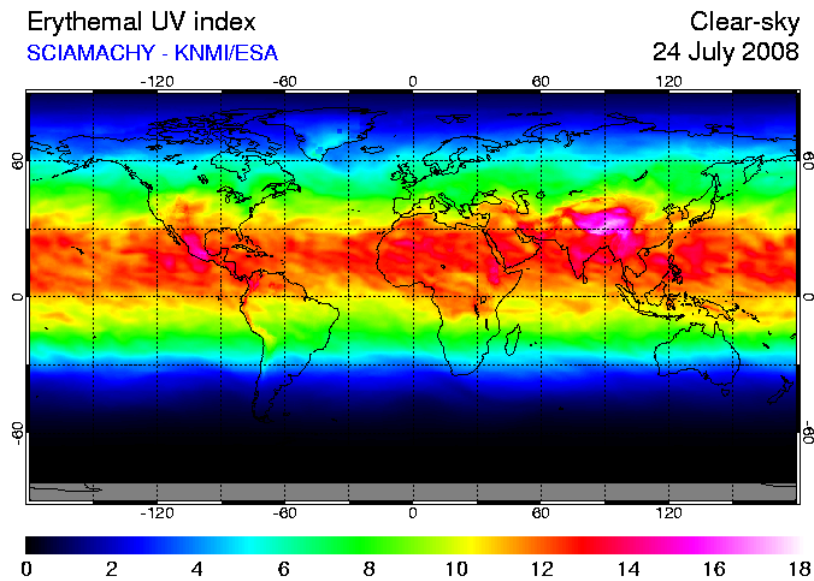


Figure 3.2. Example of the clear sky UV index forecast map for 24 July 2008 for the world

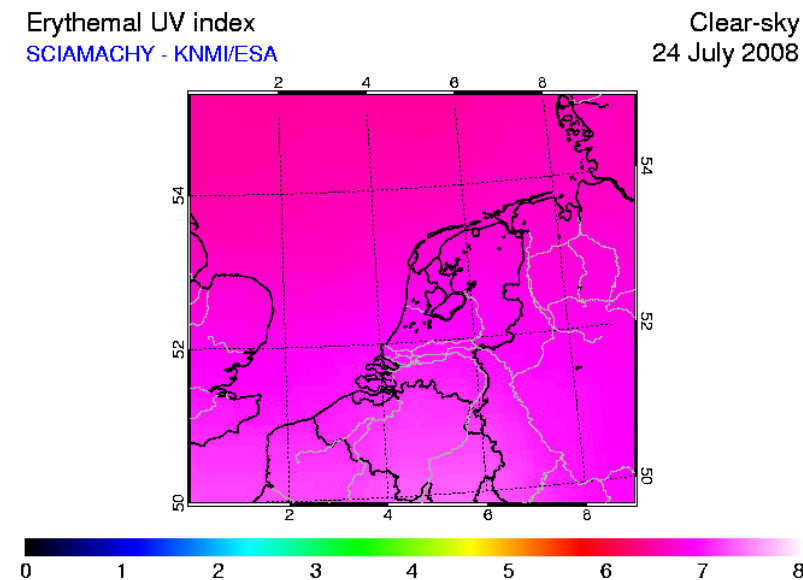


Figure 3.3. Example of the clear sky UV index forecast map for 24 July 2008 for The Netherlands

The quality of the clear sky UV index is primarily determined by the quality of the total ozone column data. The offset in the total ozone retrievals using the TOSOMI implementation (v0.32) is about -1.5% with respect to ground-based observations and GOME retrievals (Eskes et al., 2005). Continued validation of the TOSOMI total ozone observations is needed because the offset could change over time, e.g. caused by long-term drift in the instrument calibration. Day-to-day differences in aerosol mostly have a minor effect on the clear-sky UV index (see section 3.2), except for large aerosol optical thickness. Snow and ice surfaces are taken into account by a monthly climatology. Therefore, the UV index will be underestimated for places with incidental snow cover. For example, the UV index during winter will be underestimated in the Netherlands in case of snow cover. It should be realised that the UV index in the Netherlands is very small in winter (typically between 0 and 2).

3.1.2 Daily UV dose for erythema, DNA damage and Vitamin-D production

Maps of the daily UV dose for erythema, DNA damage, and Vitamin-D production are produced based on the ozone analysis and MSG cloud mask. Maps are produced daily for Europe, The Netherlands and the whole world and stored in the archive, together with the HDF data file including metadata (see section 3.4). Three example figures are presented below.

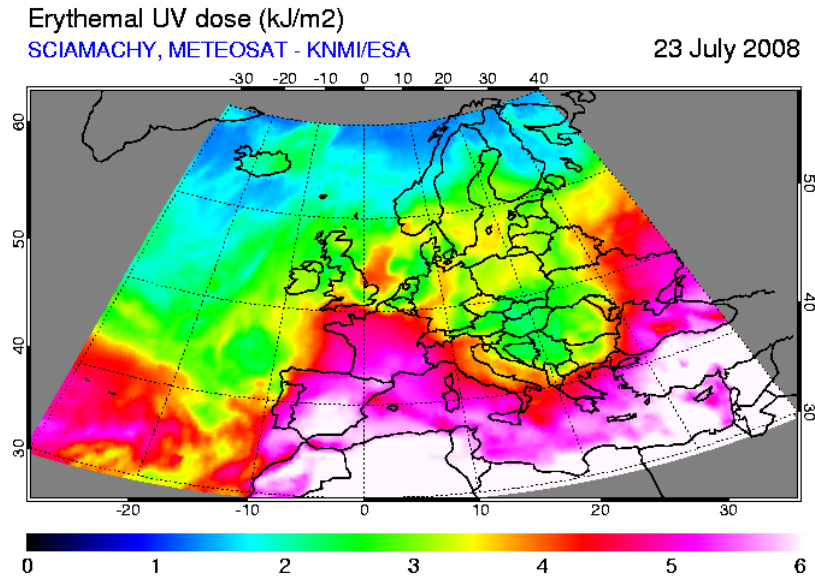


Figure 3.4. Example map of the daily UV dose for Europe for erythema

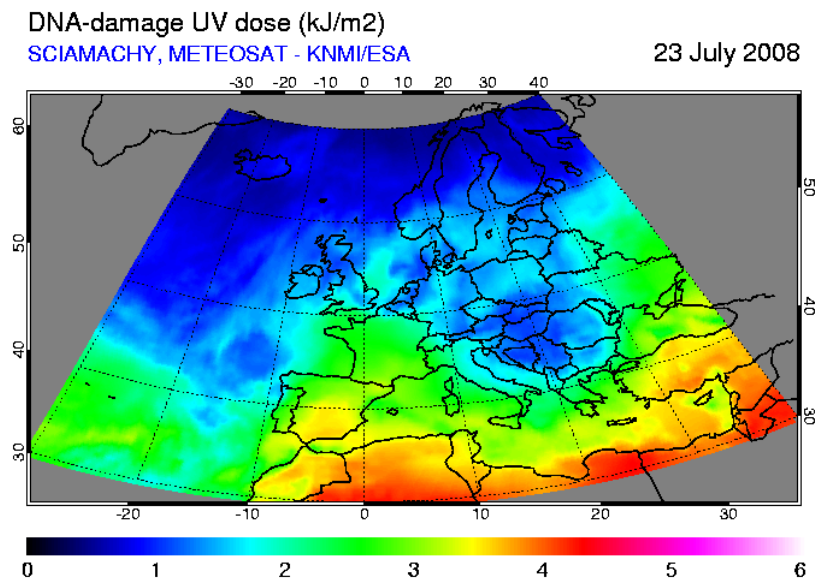


Figure 3.5. Example map of the daily UV dose for Europe for DNA damage

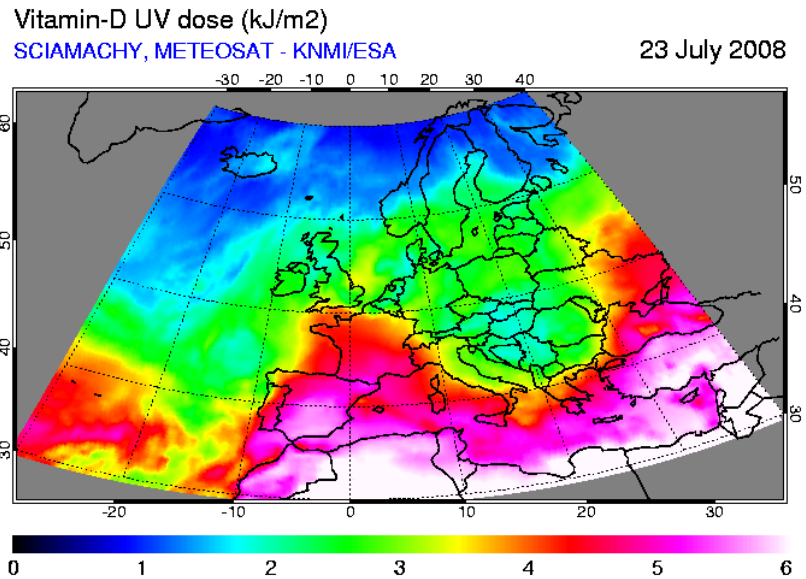


Figure 3.6. Example map of the daily UV dose for Europe for Vitamin-D production

In addition to the daily UV dose maps for Europe and the Netherlands, maps for the world are produced for the cloud-free daily UV doses. An example is given in Figure 3.7. The figure shows the cloud-free erythemal UV dose for 15 November 2006. Strongly enhanced UV doses are found at southern mid-latitudes and correspond to northern excursions of the ozone hole which is breaking up during southern spring.

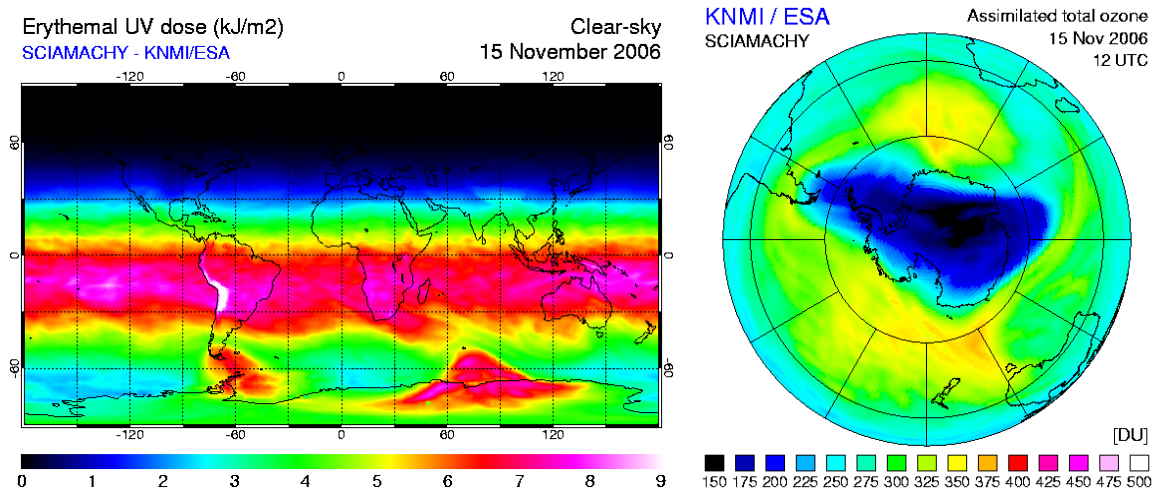


Figure 3.7a,b. Figure (a) on the left shows the cloud free daily UV dose on 15 November 2006 for the whole world. The figure shows the strongly enhanced cloud-free UV dose at southern mid-latitudes which correspond to northern excursions of the ozone hole, which is breaking up during southern spring. The corresponding assimilated total ozone columns are shown in Figure(b) on the right.

The quality of the daily UV doses over Europe is principally determined by the quality of the cloud correction factor, which is investigated in detail in section 3.3. Apart from the cloud correction, the quality of the (cloud-free) daily UV doses are determined by the quality of the total ozone column data, similar to the UV index. The offset in the total ozone retrievals using the TOSOMI implementation (v0.32) is about -1.5% with respect to ground-based observations and GOME retrievals (Eskes et al., 2005). Continued validation of the TOSOMI total ozone observations is needed because the offset could change over time, e.g. caused by long-term drift in the instrument calibration.

Day-to-day differences in aerosol mostly have a minor effect on the daily UV dose (see section 3.2), except for large aerosol optical thickness. Snow and ice surfaces are taken into account by a monthly climatology. Therefore, the daily UV dose will be underestimated for places with incidental snow cover. It should be realised that the daily UV dose in, e.g., the Netherlands is very small in winter.

3.1.3 Time series at selected locations

Time series of all UV products are produced based on the ozone analysis and the MSG cloud mask. The cloud-corrected daily UV doses are only available for locations in Europe. Example figures of the available time series are presented below for De Bilt and Punta Arenas, respectively. The data for Punta Arenas, a small town in southern Chile [-53S, 71W] show the enhanced UV index levels in southern spring when the ozone hole is breaking up and ozone poor air makes northward excursions towards the inhabited areas in the southern part of the South-American continent.

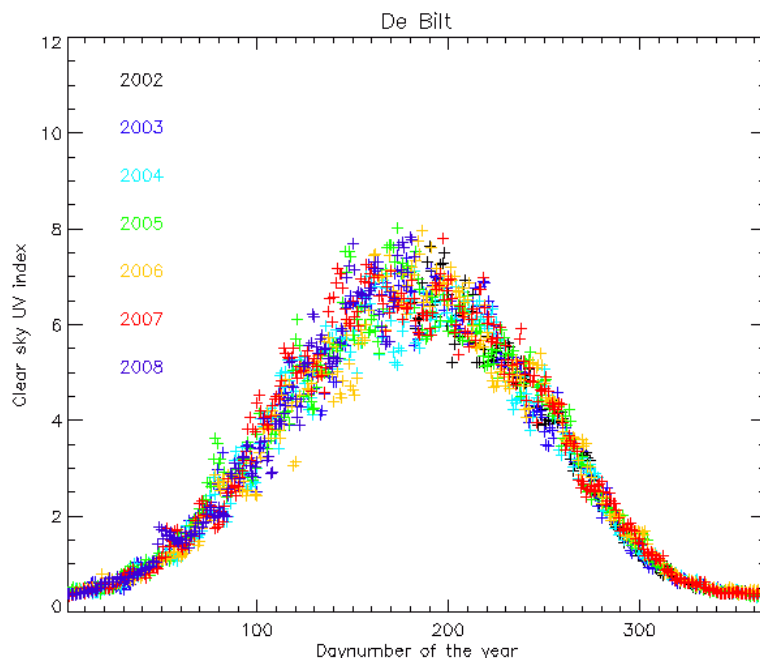


Figure 3.8. Satellite-based long-term time series [July 2002 – July 2008] of the clear-sky UV index for De Bilt, The Netherlands [52N, 5E]

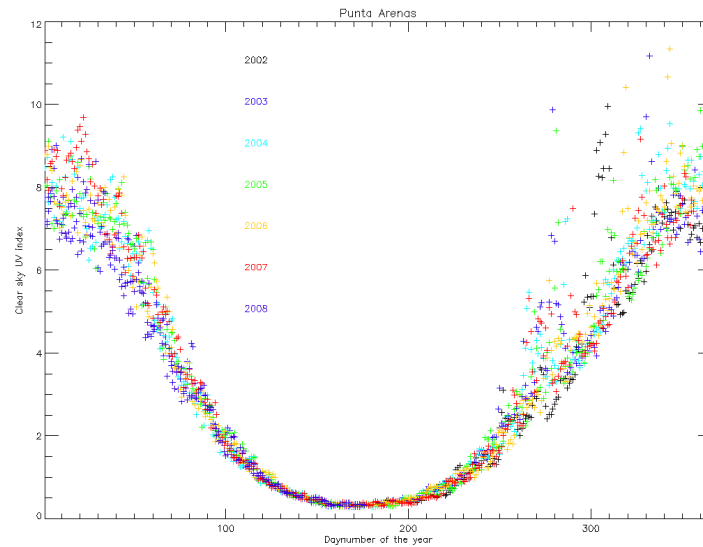


Figure 3.9. Satellite-based long-term time series [July 2002 – July 2008] of the clear-sky UV index for Punta Arenas [53S, -71W] showing regular enhanced UV index values during southern spring

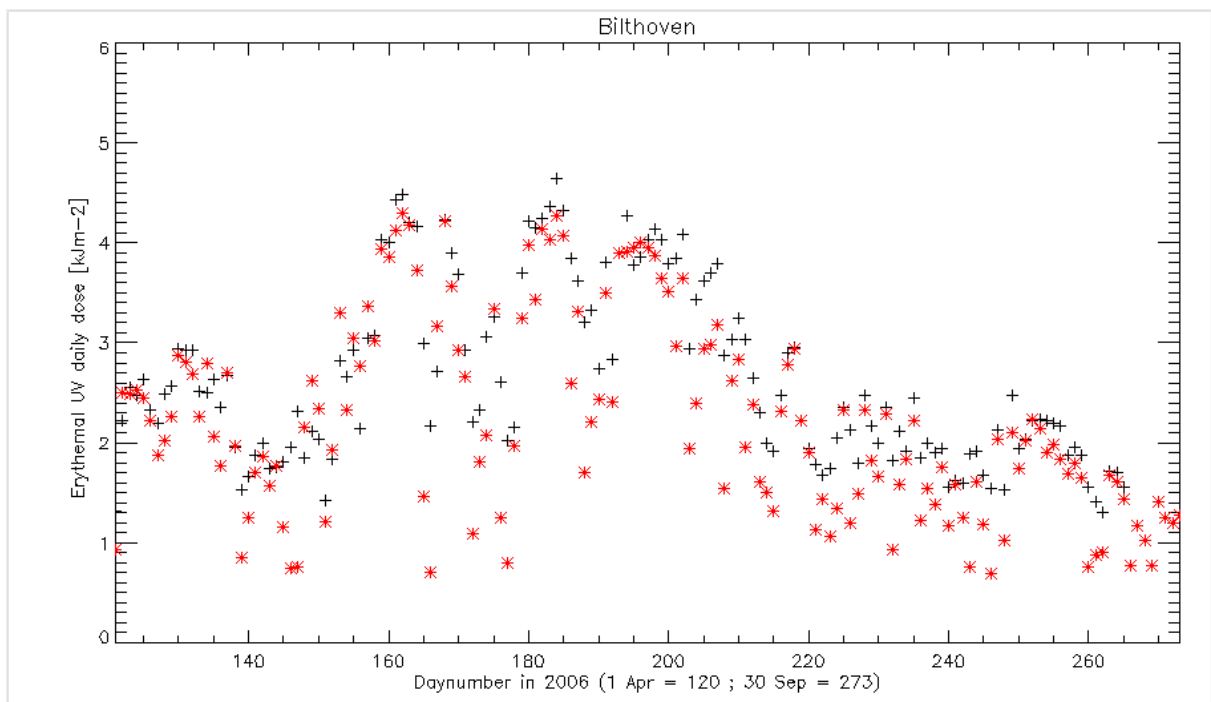


Figure 3.10. Day-to-day comparison of the satellite-based daily UV dose (in red asteriks) with the observed daily UV dose (in black plus signs) at the UV measurement site at RIVM in Bilthoven, The Netherlands (courtesy Peter den Outer, RIVM, The Netherlands) showing the best agreements on days with a highest UV dose, illustrating that the main uncertainty in the satellite retrieved UV dose is caused by the cloud correction.

3.2 The aerosol correction factor

The aerosol correction factor for the clear sky UV index and daily UV dose calculations is a fixed factor. Using radiative transfer calculations it has been determined that the implicit assumption for aerosols in the SUPREMACY UV products corresponds with an aerosol optical thickness of about 0.3 at 368 nm, for a single scattering albedo of 0.9.

The relationship between the aerosol optical thickness and the clear-sky UV index has been investigated in detail in the work by (Badosa and van Weele, 2002). The effect of aerosols has been found independent of the total ozone column and limited dependent on solar zenith angle. The absolute sensitivity of the UV index to a change in aerosol optical thickness of 0.3 ± 0.2 , is ± 0.5 for a solar zenith angle of 30 degrees (minimum in the Netherlands) and $+0.2/-0.1$ for a solar zenith angle of 60 degrees. Therefore, the aerosol corrections are of marginal importance for the clear-sky UV forecasts in the Netherlands. On the other hand, long-term changes in aerosols are important for long-term changes in the daily UV dose.

A parameterization was developed as a function of aerosol optical thickness, single scattering albedo and solar zenith angle. In comparison to radiative transfer model calculations the maximum relative and absolute errors of the parameterization are $\pm 3\%$ and ± 0.2 , respectively. The parameterization for the aerosol correction factor could not yet be implemented in the UV products, because both the required aerosol optical parameters (optical thickness and single scattering albedo) that are needed are not (yet) available in forecast mode, and also not (yet) in long-term time series for the recent past.

3.3 The cloud correction factor

The cloud correction algorithm for the daily UV dose is based on the Meteosat-8 near-real time cloud mask (CMA, version 1.2), developed within the Nowcasting Satellite Application Facility (NWC-SAF; <http://nwcsaf.inm.es/>).

The central aim of the CMA is to delineate all cloud-free pixels in a satellite scene with a high confidence. In addition, the product provides information on the presence of snow/sea ice, dust clouds and volcanic plumes. Every 15 minutes a cloud mask field is available for the MSG-N region (Europe, North Africa and adjacent seas). The algorithm is based on a multi-spectral threshold technique applied to each pixel of the image. The channels from SEVIRI that are applied to derive the CMA product include R0.6 μm , R0.8 μm , R1.6 μm , T3.9 μm , T8.7 μm , T10.8 μm , and T12.0 μm . The CMA product distinguishes 6 categories: 0=non-processed; 1=cloud-free; 2=cloud-contaminated; 3=cloud-filled; 4=snow/ice-contaminated; 5=Undefined).

From the CMA product we derive a 0.5×0.5 degrees cloud cover field by using a cloud cover of 0 for CMA=1 and 4, a cloud cover of 1 for CMA=3, and a cloud cover of 0.5 for CMA=2. The latter choice reflects the inherent uncertainty in cloud cover for the category of cloud-contaminated pixels (CMA=2), which maybe as well close to transparent, partly cloudy or close to cloud filled, all with substantial different effects on UV cloud transmission. Because the application of a 15-minute update of the CMA field did not give significant other results than using a 30-minute update for the daily UV dose, we implemented standard a 30-minute cloud mask update, which time scale is also more in line with spatial integration to a grid of 0.5×0.5 degrees.

UV transmission from cloud mask (C_f)

In the standard operational mode the cloud correction factor (CCF) is calculated for each time step from the C_f field by application of an empirical relationship that relates UV cloud transmission to a Meteosat cloud cover on a 0.5 × 0.5 degrees grid (C_f). Note that an accurate physically-based relation between a satellite-based cloud cover and UV cloud transmission is difficult to establish, as it may depend on various unknown factors such as the cloud pattern and morphology in combination with the solar angle. A cloud cover smaller than 0.02 has been labelled cloudfree (100% cloud transmission) and a cloud cover larger than 0.98 has been labelled overcast. Except for the cloudfree and overcast situations the following empirical relationship is being applied (see also Figure 3.11)

$$\text{CCF} = 0.9651 + 0.2555 C_f \quad (1)$$

This empirical relationship has been derived by comparison of one full year (2002 AD) of hourly Meteosat MVIRI cloud cover on 0.5 × 0.5 degrees with spectral surface UV observations with the Brewer #100 spectrometer at the roof of the KNMI building at De Bilt, The Netherlands (52.1 N; 5.18W). Spectral surface UV measurements with the Brewer #100 have been performed since 1994 with only a few data gaps, e.g. during instrument intercomparison campaigns. The data have been evaluated to be of constant high quality, e.g. within the European UV data evaluation exercise of the European EDUCE project (2000-2003; contract number EVK2-CT-1999-00028) in which KNMI participated.

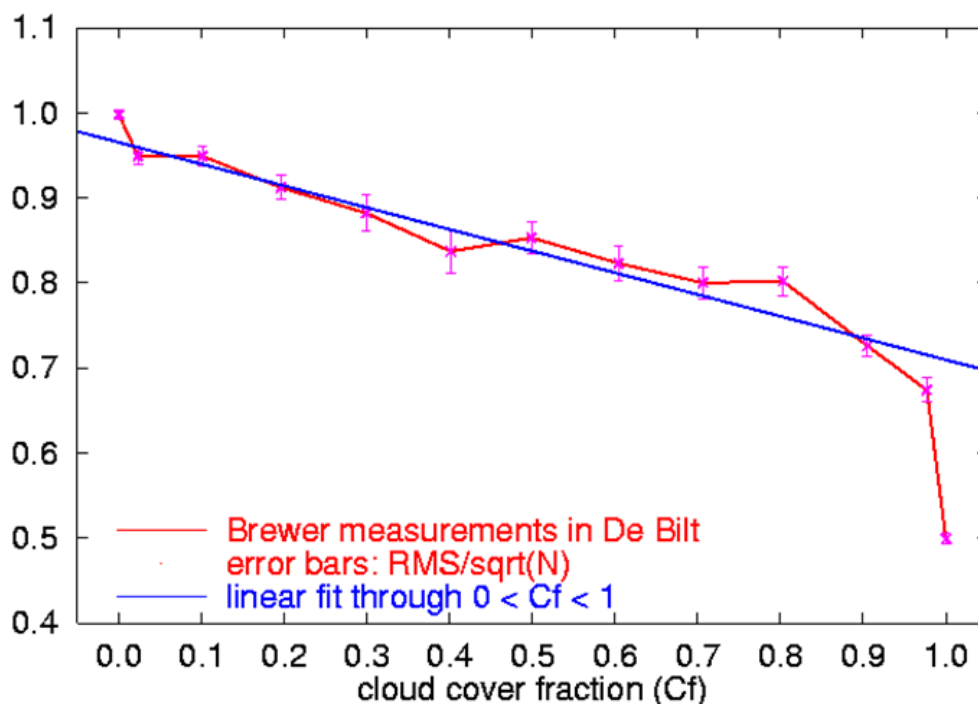


Figure 3.11. The empirical cloud correction factor (straight line; slope = 0.2555; y-intercept = 0.9651) for a given Meteosat cloud cover fraction ($\neq 0$ (cloud free) and $\neq 1$ (overcast)) over a 0.5 x 0.5 degrees grid box as derived using ground-based observations of spectral surface UV radiation at KNMI in De Bilt, The Netherlands (line with ticks). The cloud correction factor is 1 for cloud cover fractions < 0.02 (“cloud free”) and 0.5 for cloud cover fractions > 0.98 (“overcast”).

UV transmission from cloud optical thickness (COT)

So far, we have assumed for overcast situations a fixed cloud correction factor of 0.5. However, this assumption neglects the possibly large variability in cloud optical thickness (COT) of overcast cloud fields. While the cloud cover fraction is the most important parameter determining variations in UV cloud transmission for non-overcast situations, the cloud optical thickness is the most important parameter determining variations in UV cloud transmission in overcast situations. Information on the daily mean cloud optical thickness over Europe is available via the Web User Interface of the Climate Monitoring Satellite Application Facility (CM-SAF) (<http://www.dwd.de/en/FundE/Klima/KLIS/int/CM-SAF/index.htm>). The CM-SAF generates, archives and distributes satellite-derived products relevant for climate monitoring in operational mode.

One of the CM-SAF cloud algorithms retrieves cloud optical thickness and effective radius on the basis of the 0.6 and 1.6 micron channel of SEVIRI on Meteosat-8/9. The underlying principle of the method is that cloud reflectances at a channel in the visible wavelength region are primarily a function of the optical thickness, whereas the reflectances at a channel in the near-infrared are primarily a function of cloud particle size. The retrieval cloud optical thickness is logarithmically averaged to the 0.5 x 0.5 degrees grid to account for the quasi-logarithmic relationship between cloud transmission and COT. More details on the COT retrievals and their application are presented in (Roebeling et al., 2006).

A cloud correction factor is calculated from the daily mean cloud optical thickness by a delta-Eddington type relationship (van Weele and Duynkerke, 1993) that relates UV cloud transmission to cloud optical thickness (τ) for non-absorbing overcast clouds:

$$\text{CCF} = [1 + 0.058 \tau]^{-1} \quad (2)$$

In this equation the numerical factor is a tuning parameter that has been adjusted to reach (within a couple of %) agreement between this parameterisation and 8-stream plane-parallel radiative transfer calculations of cloud transmission for the UV index as a function of cloud optical thickness for solar zenith angles up to 70 degrees and cloud optical thicknesses up to 40. If uncertainties in the retrieval of cloud optical thickness would get sufficiently small, i.e., to the level of a few percent, this would make the use of accurate radiative transfer calculations appropriate and replace the computationally cheap application of equation (2).

3.4 Verification: comparisons with ground data

We have analyzed the impact of different assumptions for the cloud correction factor (CCF) on the UV dose over the period April – July 2006. Monthly mean daily erythemal UV doses have been calculated over this time period using various choices for the CCF. The resulting UV doses are intercompared and evaluated for De Bilt, The Netherlands (52.1 N; 5.18 E). We also present the time series of the UV doses on a day-to-day basis. First the different options for the CCF that have been made are shortly discussed. All options are summarized in Table 3.1.

Option I	CCF =1 for the cloud-free UV dose
Option II	CCF = 0.5 for the completely overcast UV dose
Option III	CCF based on the gridded NWC SAF CMA product and using equation (1) for the UV cloud transmission
Option IV	As (III) but using the CM SAF COT in combination with equation (2) for the UV cloud transmission
Option V	As (III) but using the CM SAF COT in combination with equation (2) but only for overcast conditions
Option VI	CCF based on the gridded Meteosat-7 cloud-mask product and using equation (1)
Option VII	As (III) but using the noontime CMA product throughout the day to simulate cloud information from a polar orbit

Table 3.1 The various options for the cloud correction factor (CCF) that have been investigated.

The results using Option I are included to show the maximum possible daily UV dose for the measured total ozone column, i.e. without cloud corrections. Option II is to show the minimum daily UV dose that can be obtained from the standard near-real time UV dose processing, i.e. with CCF=0.5. The standard near-real time processing using the NWC-SAF cloud mask and eq. (1) is Option III. Option IV shows the results that are based on equation (2) and using the CM-SAF cloud optical thickness for UV cloud transmission. In Option V we also use the cloud optical thickness data of the CM-SAF to improve upon Option III, but only in overcast situations. Note that Option III neglects any variability in cloud transmission for overcast conditions. Note also that in Option IV and V the NWC-SAF cloud mask is still used to diagnose if any cloud correction needs to be made. The NWC-SAF CMA product is considered more advanced, i.e. based on more spectral channels of SEVIRI, to detect cloud-free pixels than the cloud detection that is applied in the two-channel COT-algorithms.

Option VI represents the former near-real time UV dose processing, which was based on a Meteosat-7 cloud mask, (data from earlier years are still presented at <http://www.temis.nl>). For this option we can present results until the 11th of June 2006 when the Meteosat-7 satellite was switched off by EUMETSAT. Finally, option VII is included to illustrate the effect of using only noon-time cloud information to calculate the daily UV dose, which is common practice in satellite-based retrievals based on polar-orbiting satellites such as, e.g., TOMS (Eck et al., 1995; Herman et al., 1999).

Monthly-mean daily UV dose (kJm ⁻²)	Based on Brewer #100 UV spectra	Option I	Option II	Option III	Option IV	Option V	Option VI	Option VII
April 2006	1.48 (0.75)	1.94	0.973	1.46 (0.75)	1.49	1.50	1.49	1.41
May 2006	2.03 (0.67)	3.03	1.51	2.30 (0.76)	2.32	2.32	1.97	2.27
June 2006	2.95 (0.74)	4.09	2.04	3.30 (0.81)	3.33	3.29	n/a	3.20
July 2006	3.13 (0.80)	4.18	2.09	3.74 (0.89)	3.64	3.66	n/a	3.60

Table 3.2. Monthly mean daily UV dose calculated for De Bilt, The Netherlands (52.1 N; 5.18 E) over the period April 2006 – July 2006. Based on ground-based Brewer #100 UV spectra as well as for satellite-based calculations using 7 different options (I-VII) for the cloud correction factor. The various options are detailed in Table 1. In the column with the Brewer data between brackets the observed cloud correction factor for the monthly-mean daily UV dose. In the column with Option III between brackets the cloud correction factor as applied for this option (CCF = Option III / Option I).

Table 3.2 shows the calculated monthly mean doses over the period April-July 2006 for the choices I-VII together with the monthly UV dose based on Brewer #100 spectral surface UV irradiance observations. Measurements have been performed regularly on every day in this time period and we can use for each day about 20 UV-scans that are evenly distributed over the day to calculate the daily integral.

From Table 3.2 we can read that the monthly-mean UV dose retrievals based on Meteosat-8 data tend to overestimate the UV dose. The satellite-based retrievals for different options are systematically higher, except in April. The cloud correction factor that is calculated from the Brewer observations varies between 0.67 in May and 0.80 in July. Especially July 2006 was a relatively hot and sunny month in De Bilt with two heat-waves occurring during the month. The CCF calculated with the standard processing (Option III) is 0.89 for July 2006. The bias with the Brewer for this month is quite significant, and it has been only slightly reduced by the introduction of the cloud optical thickness (Options IV and V) in combination with equation (2). Below we investigate the differences in the monthly means UV doses further on a day-to-day basis.

Option VI, which is based on Meteosat-7 shows less bias (only in April and May; June/July not available). This is not very surprising because equation (1) has been derived on relating Meteosat-7 cloud cover with Brewer data, although for the year 2002. More surprising is probably that Option IV, which is based on equation (2) and as such fully independent, gives values for the UV dose which are very similar to the UV doses of Option III.

Option VII, which based on noontime cloud mask data only, shows only slightly lower monthly UV doses than Option III. This result indicates that noontime cloudiness, which is most important for the daily integral, is reasonably representative of cloudiness over the day at this site. On the other hand, we think that there will be for most sites little guarantee that noontime cloud observations are representative for a whole day and therefore we prefer the use of cloud data with diurnal variations as available from geostationary platforms.

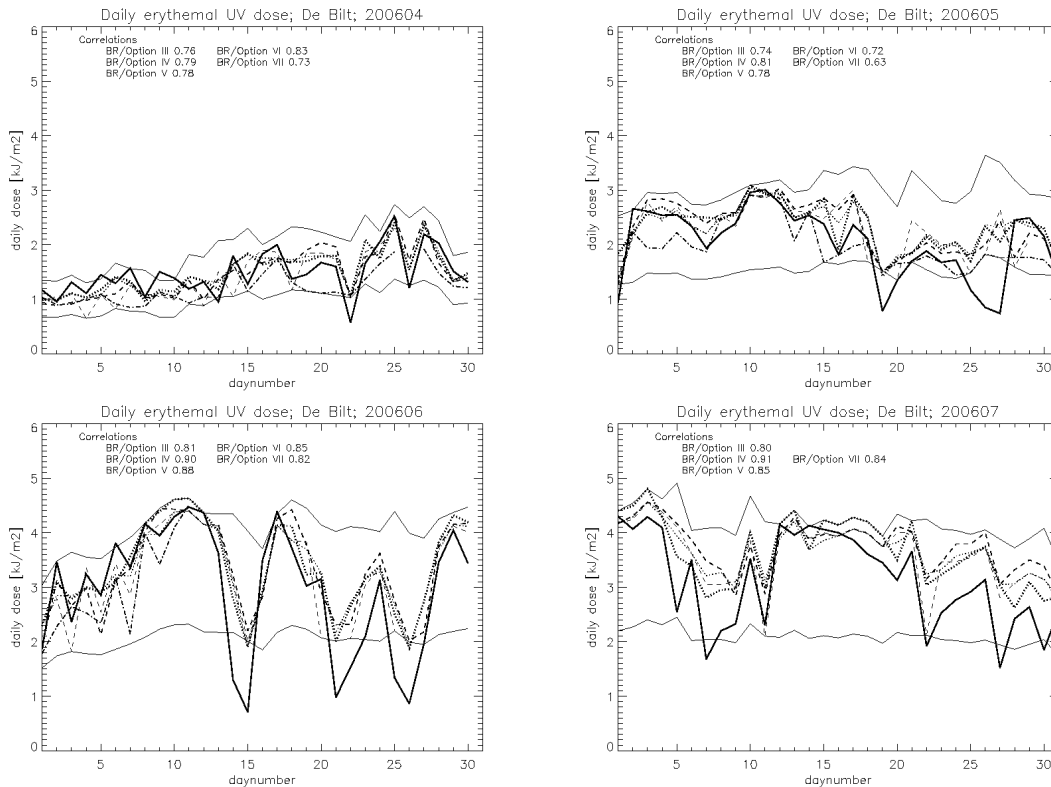


Figure 3.12. The day-to-day evolution of the daily UV dose in De Bilt, The Netherlands, for the period April-July 2006. The upper thin solid line shows the cloud-free UV dose (Option I) and the lower thin solid line shows the overcast UV dose with CCF=0.5 (Option II). The thick solid line represent the Brewer observations. The thick-dashed line shows the standard near-real time processing using Meteoast-8 (Option III). The thick and thin dotted line shows the use of COT (Option IV and Option V, resp.). The dot-dashed line shows the former near-real time processing based on Meteosat-7 (Option VI, until 11th of June). The thin dashed line shows Option VII, simulating cloud information from polar orbit. Upper left: April 2006; Upper right: May 2006; Lower left: June 2006; Lower right: July 2006. Also the respective correlations with the Brewer observations are shown in the figures.

We have also made day-to-day evaluations of the UV dose over the four-month time period. Figure 3.12 shows the time evolution of the daily UV dose per month. The upper and lower thin solid lines in the figures show the variability in daily UV dose that is caused by the day-to-day variations in the total ozone column. Although the total-induced variability is quite significant at this mid-latitude site the day-to-day variability in UV dose is dominated by the variations in cloud transmission. Note that on some days the ground-based observations fall well below the lower

thin solid line. This suggests that on these days the cloud correction factor should in fact be less than 0.5. Even though this is principally possible using the CCF that is based on cloud optical thickness (Option IV and V), very low values do not occur, which implies that the retrieved cloud optical thickness did not exceed about 17 (eq. 2) in the considered time period. At this stage it should be remembered that the retrieved COT values are diurnal mean values and have been logarithmically averaged over 0.5×0.5 degrees grid. Possible explanations for the UV dose bias therefore include, apart from a possible bias in the COT retrievals themselves, either the averaging in time or the averaging in space. The results would need to be further analyzed on a case-by-case basis to better diagnose the differences.

A study of a longer time period will help to find out what may be the cause of the bias. It is expected that more clarity can come from the application of 15-minute average cloud optical thickness data instead of diurnal-mean values. The cloud optical thickness around noontime is more relevant than the values in early morning or late evening, while nighttime cloudiness is irrelevant for the UV dose. Unfortunately the 15-minute data however are currently only available for a limited domain around and including The Netherlands.

Finally it is noteworthy that the inclusion of the COT in combination with Equation (2) as was applied for Options IV and V (thick and thin dotted lines, respectively) had a measurable positive effect on the correlations with the ground-based observations. Especially in May, June and July, the correlations using, e.g., Option IV are very good, 0.81, 0.90 and 0.91, respectively, which compares to reduced correlations of 0.74, 0.81 and 0.80 for Option III. The correlations between the ground-based observations are typically highest with Option IV, even though the bias in the monthly mean is still quite large. Especially from the time series in June it can be seen that largest contributions to the overestimation of the monthly dose stem from days with low cloud transmission / thick clouds. Therefore these situations should be focus of further investigation using data including the diurnal variation in cloud optical thickness.

In conclusion, it is shown that clouds impact dramatically on the daily-integrated UV radiation levels transmitted to the Earth's surface. Diurnal variations in cloud amount and cloud optical thickness over the day need to be captured by observations for an accurate cloud correction of the daily UV dose. Sampling of the diurnal variations in clouds is most efficiently done from a geostationary platform. A disadvantage of cloud information from a geostationary platform is the regional coverage.

3.5 Archives and Webservice

Apart from the near-real time delivery of the UV products, the new UV service provides archives of the different UV products. A complete overview of the archives that have been produced is presented in Table 3.3 below.

SCIAMACHY-based UV products	Time Coverage
Clear-sky UV index	Jul 2002 – Yesterday
Daily UV dose for Europe based on MSG (Erythema, DNA damage, and Vitamin-D production)	Jul 2005 – Yesterday
Daily UV dose for the World (cloud-free) (Erythema, DNA damage, and Vitamin-D production)	Jul 2002 – Yesterday
Daily UV dose for Europe based on Meteosat-7 (Erythema, DNA damage, and Vitamin-D production)	Jan 2004 – Jun 2006
GOME-based UV products	
Clear-sky UV index	Aug 1995 – May 2003
Daily UV dose for Europe based on Meteosat-7 (Erythema and DNA damage)	Aug 1995 – May 2003

Table 3.3. Complete overview of the TEMIS / SUPREMACY UV archives that have been made available. The archives include for each of the products maps for Europe, The Netherlands and/or the World, HDF4 data files, and ASCII time series for a set of locations worldwide. Note that the GOME-based UV products do not yet include the daily UV dose for Vitamin-D production. Also note that UV doses are missing because of a cloud data gap in the second half of 2003.

The metadata that has been included in the Hdf datafiles allows users to correct the products delivered by TEMIS. For example, using a high-resolution topography map the elevation correction can be adapted for regional application in mountainous areas.

On the next page a few snapshots are presented of the renewed operational TEMIS UV webservice. For an overview of the complete web service one should visit

<http://www.temis.nl/uvradiation> .

4. Cost Benefit Analysis

In the SUPREMACY project a near-real time processing chain has been developed and implemented in an operational software environment, displaying the output products on the publicly accessible TEMIS website (www.temis.nl).

The benefits of the SUPREMACY project are substantial, despite the relatively small scale of the project. The TEMIS UV index forecast is among the most popular products of TEMIS. Via the TEMIS feedback forms about each month specific requests are being made by new users from around the world for UV time series and/or UV dose climatologies at specific locations or for certain regions/countries. The user requirements and user statistics are summarised in Chapter 2.

Being a complicated system with several data interfaces, regular maintenance has been required to keep the system operational after the development and implementation phase. During the last years automatic processing failed about once as month because of e.g. satellite data delivery delays, changes in satellite instrument (e.g. from Meteosat-8 to Meteosat-9), changes in data processing software, system changes, etc. Mostly the interruptions could be repaired in a few hours. In order to fill in data gaps and also to make use of later improved versions of the input satellite data it is recommended to perform manual reprocessing over the whole time period to complete long-term records and improve climatologies. It is estimated that the automated operational processing can be maintained with an investment of about half a working day per month or one week per year.

4.1 Costs

Maintenance costs of the service are estimated to be minimal € 4000 per year, if no substantial upgrades in the architectural design are needed. Costs for maintenance are estimated to be 2 hours per week for a post-doc position. Costs for hardware (computing costs, storage costs) are marginal, since the processing will be part of the TEMIS operational environment. TEMIS is funded by ESA till 31 December 2009, where after new funding will be looked for.

4.2 Benefits

The TEMIS/SUPREMACY UV data products spin off from existing satellite data products. In comparison to the costs of the satellite instruments and processing the marginal costs are very limited, while the benefits are large. By making space borne UV data publicly available via the TEMIS website scientists and other interested parties from all over the world are able to benefit from the unique combination of SCIAMACHY ozone data and operational METEOSAT cloud data. The TEMIS/SUPREMACY UV products are also made available as SCIAMACHY scientific products via the SCIAMACHY product website: <http://www.sciamachy.org>.

Table 2.1 in Chapter 2 provides an overview of known users of the TEMIS UV data. The overview shows that the UV data are used by researchers and for applications all over the world. Of special interest is the use of the data in many countries with less well-developed infrastructures. Clearly, the processing as set up by SUPREMACY has helped them to get

direct access to near-real time UV data.

Apart from the actual data, the TEMIS website now also hosts archives of UV maps and data sets. Time series are available for a list of stations/locations where UV radiation is being monitored. By making the data and the images easily accessible on the TEMIS website the UV data are attractive for comparison by any person measuring UV radiation somewhere on this world.

On a national level the TEMIS UV processing chain as maintained during the SUPREMACY project is used to produce daily predictions of the UV index ('zonkracht'). These predictions are made available on the internet and via national television on NOS teletekst page 708. In case of UV index predictions larger than 7 a warning is added to the weather bulletins and a free SMS service becomes active (<https://www.alarmbericht.nl/sms-diensten.html>).

The largest benefits from SUPREMACY are related to the huge medical costs that are related to excessive UV exposure. Unfortunately these are also the benefits which are most difficult to quantify. Skin cancer related to too much exposure to UV is estimated to cause 60,000 deaths a year worldwide (WHO, 2006). In the EU25 half a million new cases of non-melanoma skin cancer are diagnosed each year and 10.000 dies of skin cancer every year (Annals of Oncology, Editorial, 2004). Other health risks from too much UV radiation are cataracts and suppressed immune responses. Changes in behavior of individual people caused by regular information on UV exposure such as delivered by SUPREMACY will lead to health and cost benefits that easily exceed the project costs.

The exact costs are difficult to estimate and depend on assumptions for cost-of-illness, including costs for hospital care, primary care, pharmaceuticals, mortality, and morbidity, and also on assumptions on the possible reduction in the number of patients by providing better information to the general public. Recent studies on the cost-of-illness for skin-cancer resulted, for example, in \$33 million a year for New Zealand, in excess of £190 million a year for England (Morris et al., 2005), and approximately 0.4% of the overall health-care costs for hospital care and primary health care in the area around Stockholm (Nilsson et al, 2003). The Netherlands has spent about 36 billion euro on health care in 1999 (Polder et al., 2004). If we use the number of 0.4 % from Nilsson as rough assumption for the Netherlands, the estimated costs-of-illness from skin-cancer will be 144 million euro.

With the improved information on the UV index not only for the Netherlands but also for all holiday destinations, SUPREMACY might reduce a fraction of this cost-of-illness, which will certainly exceed the annual € 4000 needed for maintenance of the UV products.

Conclusions and outlook

Within the SUPREMACY project a semi-operational monitoring service for surface UV radiation reaching the Earth's surface has been established by combining ozone information of the SCIAMACHY instrument on ENVISAT with cloud information of the SEVIRI instrument on Meteosat Second Generation (MSG). The SUPREMACY project has improved upon daily UV dose products for Europe that are most relevant for UV monitoring as well as on global cloud-free UV products that are most relevant for worldwide UV forecasting.

With the SUPREMACY UV products an extension has been provided of the TEMIS UV products based on GOME and Meteosat for the time period 1995-2003. Based on the requirements by TEMIS users new products have been added to the UV service, including the Vitamin-D UV dose and the archive of the clear-sky UV index. Feedback of the end users has also been used to optimize the UV products and the presentation formats. The correction algorithms for clouds as well as for aerosol optical thickness have been evaluated and the SUPREMACY products have been compared with surface measurements. The service has been integrated in the TEMIS services hosted by KNMI on <http://www.temis.nl> .

UV index forecast

The TEMIS UV service to provide worldwide UV index forecasts has been continued based on SCIAMACHY assimilated total ozone observations. These forecasts are freely used by many customers around the world. For the Netherlands the UV index forecasts are published on the KNMI internet site and on television via NOS Teletekst page 708. Continued validation of the TOSOMI total ozone observations is needed because the offset could change over time, e.g. caused by long-term drift in the instrument calibration.

UV monitoring

The automated long-term UV monitoring that has been established within SUPREMACY includes the following products:

- Maps and data of the clear-sky UV index worldwide at local solar noon
- Maps and data of the daily UV dose for Erythema, DNA-damage and Vitamin-D production over Europe
- Maps and data of the cloud-free daily UV dose worldwide
- Time series of the UV products at selected locations

Archiving of the clear-sky UV index from the SCIAMACHY ozone analyses was started and extended backward to 1 July 2002 (based on SCIAMACHY). In combination with the UV index archive based on GOME the complete UV index archive currently spans 14 years (1 August 1995 – 1 August 2008). The clear-sky UV index algorithm includes a fixed correction for aerosols and no corrections for clouds. Therefore any long-term changes in the archived UV index time series can be caused only by long-term changes in total ozone. The clear-sky UV index archives are also relevant for the operational forecasting, because these provide a year-round long-term climatology to which forecasts can be compared and exceptional forecasts flagged.

The UV daily dose monitoring includes the daily UV dose weighted with three different action spectra: Erythema, DNA-damage, and Vitamin-D production. A three-year homogeneous time series (July 2005 – July 2008) based on MSG has been obtained from which a UV daily dose climatology has been developed. Large differences were found between the operational cloud masks based on MSG and the earlier Meteosat satellites for the overlapping period in spring 2006. Therefore, a long-term homogeneous data set for the daily UV dose could not be constructed. A climatology based on the combination of the two inhomogeneous data sets would not make sense. Furthermore, a data gap exists in the daily UV dose records between the end of the GOME/Meteosat UV dose records until May 2003 and the start of the SCIAMACHY/MSG records in July 2005. This data gap can only be partly (Feb 2004 – July 2005) closed using operational MSG cloud mask data from the period before the SUPREMACY project. The monitoring and archiving of the daily UV dose is most relevant for assessments of long-term health risks and benefits, and to study long-term effects of UV radiation on the environment.

Service Evaluation

Over the project period 2005-2008 the automated near-real time service has been working properly with only a limited set of days missing for the UV daily dose, and a complete data set for the clear-sky UV index. Automatic processing failed about once a month because of, e.g., satellite data delivery delays, changes in satellite instrument (e.g. from Meteosat-8 to Meteosat-9), changes in data processing software, system changes, etc. Mostly, the interruptions could be repaired within a few hours. In order to fill in data gaps and also to make use of later improved versions of the input satellite data it is recommended to perform manual reprocessing over longer time period to complete and improve the long-term records which is important for the development of climatologies. It is estimated that the automated operational processing can be maintained with an investment of about half a working day per month, or about one week per year. A prerequisite is that the TEMIS infrastructure in which the SUPREMACY products are embedded is also being maintained. In conclusion, at the time of writing of this final report in July/August 2008 the extended and improved UV service has been implemented and it has been maintained for a period of 3 years.

Outlook

The TEMIS UV services including the extensions provided by SUPREMACY can be continued during the coming years with minimal effort. During the years the time records will get longer and improve upon the UV climatologies. Based on the long-term monitoring investigations can be performed on interannual variations and long-term changes in the surface UV climate caused by, respectively, variations and long-term changes in the total ozone column and cloud amount over Europe. In 2009 European UV climatologies will become available as derived within the European COST-726 action “Long term changes and climatology of UV radiation over Europe” (<http://www.cost.esf.org>). It will be useful to compare the UV products based on SCIAMACHY and MSG with these newly developed climatologies.

For quality control of the services is it important that validations of the satellite-derived UV products with surface observations such as performed at KNMI (from 1994 onward, but stopped recently) and RIVM (from 1994 onward) are being continued. The continuation of the surface UV measurements at at least one location in the Netherlands is therefore strongly recommended, also in view of obligations in the framework of the Montreal Protocol.

The fixed correction for aerosols in the UV index algorithm has been evaluated. The correction corresponds with an aerosol optical thickness of about 0.3 (at 368 nm) and a single scattering albedo of about 0.9. The algorithm to correct the UV index for other aerosol loadings is available. Improved aerosol corrections can be implemented as soon as reliable forecasts and/or analyses of the aerosol optical properties would become available.

Future continuity of the TEMIS UV services is foreseen because the semi-operational ozone forecasts based on assimilation of SCIAMACHY total ozone observations will be replaced before the end-of-life of SCIAMACHY by an operational data stream such as provided by Eumetsat using the GOME-2 instrument on the MetOp polar platform, or by total ozone assimilated fields provided by ECMWF.

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Appendix 1.

Publications, presentations and relevant websites

Scientific publications

- Roebeling, R.A., A.J. Feijt, and P. Stammes, Cloud property retrievals for climate monitoring: implications of differences between SEVIRI on METEOSAT-8 and AVHRR on NOAA-17, J. Geophys. Res., 111, D20210, doi:10.1029/2005JD006990, 2006
- Van Weele. M., R.J. van der A, J. van Geffen, and R. Roebeling, 2005: Space-Based surface UV monitoring for Europe using SCIAMACHY and MSG, Conference proceedings of SPIE Europe 2005, 19-22 September 2005, Brugge, Belgium
- Van Weele. M., and R.J. van der A, 2006: On the Use of Quantitative Diurnal Cloud Information for the Calculation of Daily UV Dose Maps over Europe, Conference proceedings of SPIE Europe 2006, 11-14 September 2006, Stockholm, Sweden
- Van Weele, M. van, 2007, Spaceborne surface UV radiation products as available from TEMIS, Proceedings of the UV conference, "One Century of UV Radiation Research", Ed. J. Groebner, 18-20 September, 2007, Davos, Switzerland

Presentations

- Geffen, J. van, Surface UV radiation monitoring based on GOME and SCIAMACHY, ENVISAT and ERS Symposium, 6-10 September 2004, Salzburg, Austria
- Weele, M. van, Space-Based surface UV monitoring for Europe using SCIAMACHY and MSG, ICB 2005, 5 September 2005, Garmisch-Partenkirchen, Germany
- Weele, M. van, Space Based surface UV monitoring for Europe using SCIAMACHY and MSG, SPIE Europe 2005, 19-22 September 2005, Bruges, Belgium
- Weele, M. van, On the Use of Quantitative Diurnal Cloud Information for the Calculation of UV Daily Dose Maps over Europe, SPIE Europe 2006, 11-14 September 2006, Stockholm, Sweden
- Weele, M. van, On the Use of Quantitative Diurnal Cloud Information for the Calculation of UV Daily Dose Maps over Europe, KNMI, 31 May 2007, De Bilt, The Netherlands
- Weele, M. van, 2007, Spaceborne surface UV radiation products as available from TEMIS, Envisat Symposium, 23-27 April 2007, Montreux, Switzerland
- Weele, M. van, 2007, Spaceborne surface UV radiation products as available from TEMIS, European UV Symposium "One Century of UV Radiation Research", 18-20 September, 2007, Davos, Switzerland
- Weele, M. van, COST action 726: "Long term changes and climatology of UV radiation over Europe", KNMI, 5 November 2007, De Bilt, The Netherlands
- Weele, M. van, 2007, Spaceborne surface UV radiation products as available from TEMIS, Quadrennial Ozone Symposium, 29 June – 5 July 2008, Tromso, Norway

Relevant Websites

- COST – European Cooperation in the field of Scientific and Technical Research
<http://www.cost.esf.org>
- COST action 726: "Long term changes and climatology of UV radiation over Europe"
<http://i115srv.vu-wien.ac.at/uv/COST726/Cost726.htm>
- KNMI daily UV index forecast 'zonkracht'
http://www.knmi.nl/kodac/weer_en_gezondheid/zonkracht.html
- SCIAMACHY products and their validation
<http://www.sciamachy.org>
- SMS Alarmbericht UV Index
<http://www.alarmbericht.nl>
- TEMIS UV service
<http://www.temis.nl/uvradiation>

Appendix 2.

SUPREMACY - list of activities by work package

In the SUPREMACY project proposal it was foreseen to hire a post-doc for the period of two years. The project was granted, but with a reduced funding (18 month). This implied a reduced effort and a post-doc was not hired. Instead the work was performed on part-time basis by KNMI personnel. This extended the project duration by one year. The project had a duration of 30 months, from 1 January 2005 until 30 June 2007, and the service was further maintained at no further costs over the period July 2007 – July 2008. The work was conducted in part-time by dr. Michiel van Weele, and the project was coordinated by Ronald van der A. The reorganisation at KNMI in October 2006 further delayed the progress of the project. The end report could not be finished before August 2008.

During the project duration quarterly reports were sent to NIVR to report on the progress. Below is an overview of activities and work performed, for each of the work packages. This overview is largely translated from the content of the quarterly reports that were written in Dutch.

WP0: Management

The project was executed within the constraints of the agreed technical scope and depth and within financial budget. The time schedule was not maintained as explained above. The end-date of the project was extended until 20 June 2007. The delivery of the final report took place in August 2008. Quarterly reports were sent to NIVR for the 3-month periods between January 2005 and June 2007.

WP1.1: Ozone and UV monitoring and forecasting

The ozone and UV monitoring and forecast services via TEMIS were developed for SCIAMACHY assimilated total ozone and continued for the duration of the project. The UV service provides the KNMI UV index forecast published daily on the internet and on Dutch national television via NOS Teletekst 708.

WP1.2: MSG cloud monitoring

MSG cloud mask data was stored at KNMI since July 2005. Cloud optical thickness was calculated for a limited area around the Netherlands using the same software as applied in the CM-SAF. De UV-dose service op basis van MSG became operational in the first half of 2006. The TEMIS UV dose service based on Meteosat-7 stopped on 12 June 2006 with the end of services by Meteosat-7, as was announced by EUMETSAT. Some overlap between both services occurred in spring 2006. For the implementation of the operational UV dose processing over Europe based on MSG clouds it was decided to use as input the operational NWC-SAF cloud mask data.

WP2.1: Algorithm development and improvement

Relations between total ozone, solar zenith angle and UV radiation levels were established for DNA-damage and Vitamin-D production similar to the relation for the erythemal UV index described in (Allaart et al., 2004). Different options to correct the UV doses for cloudiness were investigated. Empirical algorithm using cloud mask data were compared with more physical corrections using cloud optical thickness. Also the use of different cloud masks as derived from Meteosat-7 and MSG was intercompared for spring 2006 and evaluated against surface observations. The possibilities for aerosol corrections were evaluated.

WP2.2: Processing of UV dose

The TEMIS UV dose processing was adapted to the use of MSG cloud data. MSG cloud mask data was stored at KNMI since July 2005. After the UV dose processing based on MSG became operational in the beginning of 2006 reprocessing took place to have the MSG-based time series starting in July 2005. Daily variation in cloud optical thickness as derived from the CM-SAF is not (yet) available. At KNMI the same data processing as in the CM-SAF was taking place, including daily variations, though not for the whole of Europe. The use of a daily-mean cloud optical thickness as available from the CM-SAF was not found to give a significant improvement over the use of the NWC-SAF cloud mask. The UV dose processing for the whole of Europe was continued based on the NWC-SAF cloud mask.

WP2.3: Processing of solar irradiance product

The algorithm to determine solar irradiance from quantitative cloud products including cloud optical thickness and cloud cover was tested and very considered useful for the determination of the UV dose. However, because of the limited area around the Netherlands over which the solar irradiance could currently be calculated, a further integration of the software for solar irradiance and the UV dose for Europe was not further investigated in the project.

WP3: Product verification

Differences in UV dose based on the different methods that had been developed within the project have been analysed. Comparisons were made between the operational data streams based on Meteosat-7 and MSG, respectively, products based on the daily-mean CM-SAF cloud optical thickness, as well as with surface observations in De Bilt and Rome.

WP4: user service and reporting

The TEMIS UV webservice web-environment has been completely updated. Metadata has been included in the hdf files containing the UV data products. Explanations on data formats and use have been improved where necessary. Worldwide cloud-free UV dose products for erythema, DNA-damage and Vitamin-D have been added. Time series have been compiled for a list of stations/locations where UV radiation measurements are, or have been, performed. UV dose climatologies have been compiled based on three years of UV dose data (July 2005 – June 2008) and a UV index climatology based on 6 years of data (July 2002 – June 2008). Presentations have been given at several scientific conferences throughout the project period to promote the TEMIS UV service and the improvements accomplished in the SUPREMACY project. The draft final report was written in July-August 2008 and finalized in November 2008.