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Climatology of Ultraviolet Budgets using Earth Observation (CUBEO): mapping UV from the perspective of risk assessments

H. Slaper
Laboratory of Radiation Research
J. Matthijsen
Air Research Laboratory
P.N. den Outer
Laboratory of Radiation Research
G.J.M. Velders
Air Research Laboratory of National Institute of Public Health and the Enviroment (RIVM)

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Contents

Abstract

The use of satellite data to construct ground level UV-radiation maps offers a unique opportunity to investigate geographical and temporal variability of ground level UV-radiation levels related to atmospheric changes, like ozone depletion or cloud changes. The calculation of long term yearly UV-doses in combination with dose-effect models for UV-related effects, like skin cancer, further enhances the application of UV-maps as a powerful tool to support environmental assessments. This report describes the results obtained in the CUBEO-project: a Climatology of Ultraviolet Budgets using Earth Observation. The project aimed at the development and validation of UV-mapping methods that can be applied in environmental assessments. The results indicated that the satellite derived cloud correction provides accurate and representative results if the ground albedo is low. The comparison with ground based UV-measurements at different sites in Europe shows an agreement for the yearly UV-dose within 10%. An indication of the long term stability of the UV-mapping methods is obtained by means of a systematic comparison of UV-doses derived from ground based ozone and cloud data and doses derived from satellite observations over a period of nearly 20 years. The European maps of changes in UV-budgets at the ground and associated excess skin cancer risks have been reported in national and international state of the environment reports published by the National Institute of Public Health and the Environment (RIVM) and/or the European Environmental Agency (EEA). These state of the environment reports contribute to the provision of information necessary for framing and implementing sound and effective environmental policies.

Executive summary

The use of satellite data to construct yearly integrated ground level UV-radiation maps offers a unique opportunity to investigate geographical and temporal variability of ground level UV-radiation levels related to atmospheric changes, like ozone depletion or cloud changes. The combination with dose-effect models for UV-related effects, like skin cancer, further enhances the application of UV-maps as a powerful tool to support environmental assessments. Such assessments require the long term analysis of changes in yearly accumulated UV-doses. This report describes the results obtained in the CUBEO-project: a Climatology of Ultraviolet Budgets using Earth Observation. The project aimed at the development and validation of UV-mapping methods that can be applied in environmental assessments. The most important atmospheric components influencing the ground level UV are ozone and clouds. Ozone absorbs UV, especially at the shorter UV wavelengths and clouds scatter and reflect the UV-radiation.
Three different schemes for the calculation of cloud effects on UV-radiation are derived from satellite observations and are compared with a ground based empirical cloud correction in a large statistical analysis. The first scheme is based on three hourly cloud cover data obtained from satellites, the second scheme combines the cloud cover data with three hourly cloud optical thickness determinations derived from satellite data, and the third approach uses daily reflection data from the TOMS-satellite to derive the cloud effects. The empirical ground based method is based upon the link between the reduction in UV due to clouds and the reduction of ground level global radiation. The scheme using TOMS reflection data provides the best results for the six years of summer data analysed and on average agrees within 1-2% with the ground based analysis. On a day to day basis a relative standard deviation of 10% is observed between the ground based reduction factor, and the reduction factor derived from the TOMS reflection data. For the monthly values the standard deviation is reduced to 3%. The results indicate that the satellite derived cloud correction provides accurate and representative results if the ground albedo is low.
The comparison with ground based UV-measurements at different sites in Europe shows an agreement for the yearly UV-dose within 10%. Large deviations (40-50%) can occur when the ground is covered with snow, but for most of the European continent the influence on the yearly UV-dose is limited.
From the perspective of environmental assessments the determination of trends in relation to atmospheric changes are most relevant. This requires data on the relevant atmospheric changes obtained with sufficiently stable methods and available over prolonged periods. An indication of the long term stability of the UV-mapping methods is obtained by means of a systematic comparison of ground based and satellite derived UV-doses at the ground over a period of nearly 20 years. The squared correlation coefficient between the two methods is around 0.87 (increasing to 0.96 when omitting one year which is an outlier).
Yearly UV-doses based on ozone data from different satellite instruments (TOMS and GOME) show up to 8% differences over the European continent for the evaluated year 1998.

European maps of changes in yearly integrated UV-budgets at the ground and associated excess skin cancer risks are provided and have been reported in national and international state of the environment reports published by the National Institute of Public Health and the Environment (RIVM) and the European Environmental Agency (EEA). These state of the environment reports contribute to the provision of information necessary for framing and implementing sound and effective environmental policies.

1. Introduction

1.1 UV-maps and environmental assessments

Assessment of the effects of ozone depletion on biologically effective solar UV at ground level has greatly advanced through the use of remote sensing data. Satellite data on atmospheric properties allow the construction of geographically distributed surface UV radiation maps based on radiative transfer calculations [Bordewijk and Van der Woerd, 1997].

Stratospheric ozone is the major atmospheric absorber of solar UV-B (280-315 nm). For this reason, the decrease in ozone columns observed in the last few decades is expected to lead to increases in the UV-B doses at ground level. Increases in UV-B doses can lead to a wide variety of adverse health and environmental effects, among which increases in skin cancer incidence, cataracts and possible decrease in primary bio-mass production [United Nations Environmental Program (UNEP), 1998]. An assessment of environmental risks [e.g., Slaper et al., 1996] requires knowledge on the changes in spectral UV irradiances received at ground level. Apart from changes in the total ozone and solar elevation also clouds, aerosols, ground albedo and altitude play a role in the variability of UV doses at ground level. It has been well established that changes in the ozone column are anti-correlated with surface UV irradiances [Madronich, 1992; World Meteorological Organisation (WMO), 1995; WMO, 1999]. Recent studies established long-term upward changes in clear sky UV-radiation levels in relation to decreases in ozone (Zerefos et al 1998, McKenzie 1999). However, a long-term upward UV trend for yearly UV-doses at the ground in relation to the observed ozone depletion has not been established by means of direct ground-based UV-measurements. This is due to a lack of long-term ground-based UV monitoring data sets obtained with sufficiently stable instrumentation, and the variability in UV-radiation levels caused by year to year variations in cloud effects. Over the last years important progress has been made in deriving surface UV irradiances from satellite observations [e.g., Herman et al., 1996; Bordewijk and Van der Woerd, 1997; Meerkoetter et al., 1997; Krotkov et al., 1998]. The geographical distribution of surface UV doses or, so-called UV maps, are the result of radiative transfer calculations for a defined area and time period. The UV maps can be used to support risk assessments for health and environmental effects of past and future changes in the UV climate [e.g., Slaper et al., 1996; Slaper et al., 1998].

1.2 Requirements of UV-maps from the perspective of risk-assessments

Many of the adverse health effects associated with UV-exposure, like skin cancer, skin ageing and possibly cataracts, are related to doses received by individuals over prolonged time periods, i.e. exposure over many years up to a lifetime. Other effects like an impairment of the immune system can be related to doses received over a period of weeks to months. Some short term effects, like skin erythema (sunburn) and snowblindness, are primarily related to doses received over a day, but are influenced by the exposure history of the previous days to weeks. Adverse effects to plants and terrestrial and aquatic ecosystems are also primarily related to doses received over at least days to months, or in case of ecological changes years. Effects of UV on materials, especially polymers, and paints are also related to prolonged exposure periods.

In order to obtain relevant quantities for the effect assessment it is necessary to weigh the UV-spectrum with the appropriate, effect specific biological weighting factors. Primarily the wavelengths in the UV-B range (280-320 nm) contribute to the effective doses.
The main question to be answered within the context of environmental assessments: how will atmospheric changes lead to changes in risks associated with UV-exposure?
Therefore, it is most important to establish methods that can be used to analyse UV-changes over prolonged periods in time. Furthermore, from the perspective of environmental policies it is relevant to separate between effects due to man-made changes and natural variability, and to establish spatial variations in the changes.

1.3 Satellite data as a complementary source to ground based measurements

UV-radiation levels at the ground in relation to changes in ozone and clouds can be assessed by means of:

- direct spectral UV-irradiance measurements
- UV-transfer models in combination with ground based data on ozone columns and cloud observations
- UV-transfer calculations in combination with satellite observations on ozone and cloud properties

In addition a combination of satellite and ground based data could be used to analyse and model UV-budgets.

From the perspective of environmental (risk) assessments it is important to establish accurate location dependent estimates of changes in the UV-budgets over the past and coming decades. From that perspective it is important to assess the long term trends of time-integrated UV-doses, and not so much the day to day variability of the highest UV-irradiance levels at solar noon, as indicated by the widely used and communicated UV-index. The UV-index plays a role in communicating awareness of (potential) high exposure situations to the public, but is not directly applicable in environmental assessments.
The most direct way to assess the long term changes of UV-radiation levels at the ground is the direct measurement of spectrally resolved ground level UV-irradiance and the summation of these measured irradiance levels to obtain time-integrated yearly UV-doses. However, such measurements, obtained with sufficiently stable and accurate instruments, are not available over the required prolonged periods in time. The quality of UV-measurements in Europe is improving and the initiatives to design a European database for UV-measurements helps to establish a source of direct information on the UV radiation received at the ground. Important limitations of the datasets are: the limited number of years covered (5-10 years at the most) and the limited spatial information due to the very low number of sites that have continuous monitoring data available. Thus, the direct UV-radiation measurements can also in the future not fully cover the requirements from the perspective of environmental assessments. Furthermore, from the perspective of the evaluation of environmental policies it is important to separate the changes related to ozone changes from changes due to cloud effects. This implies that also the direct measurements of UV do not provide a direct answer to the policy related questions. The UV-measurements presently available can be used to validate and improve the UV-mapping methods.
Another (be it indirect) way of assessing ground level UV-doses, is the use of UV-transfer models in combination with ground based ozone measurements, and cloud observations. Ozone measurements are available over prolonged periods in time at a limited number of

stations, and the measurement techniques are regarded sufficiently accurate and stable over time. This approach provides results with a limited spatial coverage, but the approach enables trend analysis in time.

The use of satellite data to analyse UV-budgets offers a unique opportunity to investigate the spatial and temporal variability of changes over the European continent. However, it is essential to validate the methods for satellite derived UV-budgets by systematic comparison with ground based measurements, and by comparing with more detailed methods over shorter time periods. RIVM has focused on a methodology for the assessment of long term trends over the European continent, and the validation of this methodology. Comparison on a day to day basis with more detailed methods and measurements enables the study of limitations of the present methodology and helps to focus on the major issues for improvements.

1.4 Scope of the report

1.4.1 The project CUBEO and the connection to other projects

The report provides an overview of results and activities within the context of the project Climatology of Ultraviolet Budgets using Earth Observation, shortly CUBEO (project number 4.1/AP-03)). The CUBEO-project directly builds upon the results obtained in the BCRS-pilot project ‘Ultraviolet Dose Maps of Europe’ which was conducted at RIVM and has led to a pilot methodology for the determination of UV-maps using satellite data (Bordewijk and van der Woerd, 1997). This report describes the activities and results obtained in the CUBEO-project, which is focused on three major aspects of the UV-mapping methods:

- validation of the methodology by comparison with ground based UV-measurements and UV-transfer modelling using ground based input data,
- improvement of the pilot methodology, especially regarding the evaluation of cloud effects,
- incorporation of skin cancer risk models and the application of the methods in assessment studies.

Furthermore the (improved) methodology has been documented to arrive at a pre-operational method for UV-mapping: a prototype for the Assessment MOdel for Uv Radiation and Risks (AMOUR), which will be further improved to obtain a validated and documented demonstration method in the context of the RUBEO-project. The activities and analysis in the CUBEO project benefited from the EU-project MAUVE (Mapping UV by Europe) and the European UV-database that was developed in the EU-project SUVDAMA (Scientific UV DAta MAnagement).

The following RIVM activities were also relevant for the MAUVE-project:

- defining UV-map requirements from the perspective of Environmental (Risk) Assessments
- improving the RIVM UV-mapping method with the aim of long term assessments of UV-changes
- statistical validation analysis of cloud effects and participation in the validation of UV-mapping methods by comparing with ground based measurements
- submission of spectral UV-irradiation data for validation of UV-mapping methods, including: a full year of monitoring data for Bilthoven and participation in the MAUVE/CUVRA measurement campaign in March 1999.
- demonstrating the application of UV-maps in Environmental risk assessments, leading to contributions to a CUBEO and a MAUVE leaflet.

The MAUVE validation activities were also directly relevant for the CUBEO project and some results of these activities are included in this report, especially the comparison of monthly doses obtained using remote sensing data with the measured UV-doses at five different European sites. The activities in the CUBEO project focused on the effects of changes in total column ozone and the effects of clouds, the primary parameters determining the UV-doses. The influence of tropospheric parameters, like aerosol, SO_2 and tropospheric ozone has been investigated in the BCRS project SULPHATE. The results of the SULPHATE project will be used to further improve the methodology by including the ability to take into account the variations in tropospheric parameters. The RUBEO-project will implement the most relevant findings obtained in the SULPHATE-project.

1.4.2 Outline of the report

Following this introductory chapter the next chapter provides a brief description of the methodology and satellite data used to make the RIVM UV- and UV-risk maps for the European continent. The focus will be on three different methods to evaluate the effects of clouds on ground level UV-doses. Chapter 3 provides a description of the validation of these UV-mapping methods, focusing on a comparison with ground level measurements and a statistical analysis of cloud effects. Chapter 4 provides some results obtained using the mapping methods to analyse changes in the UV over the European continent in the past decades. The results are presented from the perspective of environmental assessments, and include examples of UV-risk maps in relation to the environmental changes. Chapter 5 summarises the main results obtained in the CUBEO and MAUVE projects and the conclusions on further improvements of the methodology.

2 UV-mapping methods at RIVM

2.1 Introduction

The method developed at RIVM is aimed at producing output to enable environmental risk assessments. From that perspective UV-maps are produced for the European continent which are integrated to obtain monthly and yearly summed doses of biologically weighted UV. Evaluating the changes over time in UV-doses received in Europe the UV-maps can be linked with risk-assessment models (Slaper et al., 1996), to obtain excess skin cancer risk maps that provide the excess skin cancer risks in Europe associated with the analysed UV-increases. The main activities within the context of the CUBEO and MAUVE-project were the improvement and validation of the UV-mapping methods. The work at RIVM focused on the improvement and evaluation of methods for the evaluation of cloud effects. This chapter will focus on a description of the presently available methods used to calculate UV-maps, and UV-risk maps. An outline of the UV-dose calculation method is given in section 2.2. Section 2.3 provides a description of the UV-transfer model and basic parameters used in this study. The three different methods that use satellite data to evaluate cloud effects are described in section 2.4. Section 2.5 gives an overview of the remote sensing data used, and section 2.6 outlines the risk assessment method. The methods are included in the pre-operational version of the Assessment Model for UV Radiation and Risks (AMOUR). The next chapter will provide validation activities and chapter 4 will provide some sample results using the methodology.

2.2 UV-dose calculations

First step in the calculation of the UV-doses received at the ground is the construction of a look up table, which provides cloudless sky effective UV irradiances in relation to solar zenith angle (SZA) and total ozone column (O_3). In the second step the look up table is used to interpolate the effective UV-irradiance for a certain location at a certain time using the specific ozone and SZA values. The UV-irradiance is corrected for the Earth Sun distance, the altitude of the location and if required for the effects of clouds. A subsequent summation of the corrected UV-irradiances over time leads to location specific doses. Usually daily, monthly and yearly ground level UV-doses are calculated.

A UV-transfer model (see section 2.3) is used to calculate spectral UV-irradiances ($E(\lambda,\theta,O_3)$) in relation to the total ozone column (O_3) and solar zenith angle SZA (θ). The spectral irradiances ($E(\lambda,\theta,O_3)$) are multiplied with a set of biological weighting factors, e.g. an action spectrum ($A(\lambda)$), to obtain effect weighted spectral irradiances. An integration of the weighted spectral irradiances over the full wavelength range provides effective the UV-irradiance in relation to the total ozone column and SZA ($UV_{eff}(\theta,O_3)$):

$$UV_{eff}(\theta,O_3) = \int E(\lambda,\theta,O_3) \times A(\lambda)\, d\lambda$$

The look up table is used to calculate the effective UV-irradiance for cloudless situations for a specific time and location. The effective UV-irradiance is corrected for: the earth-sun distance (ES, according to de Leeuw, 1988), altitude ($ALT = 1+0.06\times height$ (in km), in accordance with Bordewijk and van der Woerd, 1997) and clouds (CLD, obtained using one of the methods described in section 2.4):

$UV(t, loc) = UV_{eff}(\theta(t, loc), O_3(t, loc)) \times ES(t) \times ALT(loc) \times CLD(t, loc)$
where t -time, loc - location
A summation/integration of the corrected UV-irradiance over time provides the time-integrated UV-dose: $UV(loc) = \int UV(t, loc)\, dt$. The calculations are performed with hourly time-steps.

2.3 Atmospheric UV-transfer model

2.3.1 Model description

The mapping method makes use of lookup tables for effective UV as a function of total ozone column and solar zenith angle. Values are for cloudless skies and have been calculated with our radiative transfer model UVTRANS version 5 (den Outer, 1999). The model UVTRANS makes use of a two stream algorithm. A two stream algorithm requires far less computing time than more advanced algorithms like discrete ordinate, and was used for that reason. A comparison with other model results is discussed in section 3.2. The model is an improved version of the model implemented by de Leeuw (1988). Improvements made include an implementation of anisotropic scattering by aerosols, flexibility with respect to wavelength interval and wavelength resolution, and flexibility regarding atmospheric height profiles, elevation level and choice of extinction cross sections used. The curvature of the earth surface is taken into account by using a pseudo spherical geometry correction. SO_2 absorption in the lower troposphere has been implemented in the model, but was ignored in the present evaluations. The effects of SO_2 absorption are studied in the BCRS-project SULPHATE.

2.3.2 Model input parameters

A fixed set of atmospheric parameters, given in table 2.3.1 is used to calculate the look-up-tables for effective UV. The set is taken from the SUVDAMA model comparison (van Weele et al., 2000) and applies to atmospheric conditions common in Bilthoven.

Table 2.1 Atmospheric parameters used to calculate the lookup tables.

Item	Value
Ozone min, ozone max Zone step	60-500 (Du), 10 Du
Angle min, angle max Angle step	0-90 (degrees) 1 degree
Aerosol optical thickness	0.28 (at 320nm)*
Anisotropy factor aerosols	0.7 *
Wavelength dependency aerosol scattering	1/wavelength
Albedo aerosols	0.95 *
Pressure	1013 (hPascal)
Ozone cross section	Bass&Paur 1984
Elevation	0 (km)
Ground albedo	0.02**
SO_2	0 (Du)

Profile	Source
Ozone	MLS***
Pressure	MLS***
Temperature	MLS***
Aerosol	Demerjian et al. 1980

*: height independent; ** wavelength independent; ***MLS –Mid latitude Standard atmosphere

2.4 Methods to describe effects of clouds on UV

2.4.1 Three approaches for cloud effects: introduction

Cloud cover (N) and cloud optical thickness (τ_{cld}) are dominant parameters in the determination of surface UV doses. The effect of clouds on instantaneous UV levels can vary from small enhancements to almost total reduction. Cloud information, cloud cover and cloud optical thickness, derived from satellite data represents an average in time and space with a relatively large variance and uncertainty. Averaged over time clouds will lead to a reduction of ground level UV-radiation levels compared to the clear sky values, and the cloud correction factor (CLD) for daily or monthly averages is therefore smaller than 1. In the text the cloud correction factor will also be indicated as the UV-reduction factor. Three different methods are considered to describe the effect of clouds on UV in the construction of UV maps:

1. a (pilot) method based on cloud cover data (N) from ISCCP (International Satellite Cloud Climatology Project); for this method NDF is the UV-reduction factor used, see section 2.4.2,
2. a new method based on ISCCP cloud cover and cloud optical thickness (τ_{cld}) , where SDF is the UV-reduction factor, see section 2.4.3
3. a method based on TOMS version 7 reflectivity data, where TDF is the UV-reduction factor, see section 2.4.4.

2.4.2 UV-reduction based on ISCCP cloud cover data

The pilot version of AMOUR (called Semi Empirical Model) uses an UV reduction factor due to clouds based on cloud cover only (Bordewijk and van der Woerd 1997). The UV reduction factor due to clouds is defined as the ratio of the daily integrated UV dose under the actual circumstances and the daily dose expected under cloudless circumstances ($UV_{cloudy}/UV_{cloudless}$). Figure 2.1 shows the monthly UV reduction factor (NDF) based on cloud cover. The UV-reduction factor

$$NDF = C_N(\overline{N})$$

C_N is an empirical relationship between the instantaneous cloud cover in octa (or cloud cover fraction) and the UV reduction factor. The dots and the interpolated line in figure 2.1 indicate the average reduction factor used in this approach. As shown by the error bars the actual reduction factor can vary quite a lot for a particular cloud cover, because the optical thickness of the clouds can vary independently from the cloud cover. The large variability of the optical thickness of the clouds is not taken into account, and limits the accuracy of this approach. Bordewijk and van der Woerd (1997) used monthly average cloud cover data (ISCCP-C2 satellite data) for cloud reduction calculations in the pilot methodology for UV-mapping. The non-linear relationship between the cloud cover and the UV reduction factor implies that time and area averages of the cloud cover give rise to errors in the determination of the monthly UV reduction factors. We therefore have improved the approach by using 3-hourly average ISCCP D1 cloud cover data. The intrinsic error, which is made using monthly average cloud cover, is therefore not introduced. Still, variations due to differences in cloud optical thickness are not represented. The UV reduction factor NDF is compared with a ground based UV-reduction factor and with other satellite derived UV-reduction factors (see next sections) in section 3.5.4.

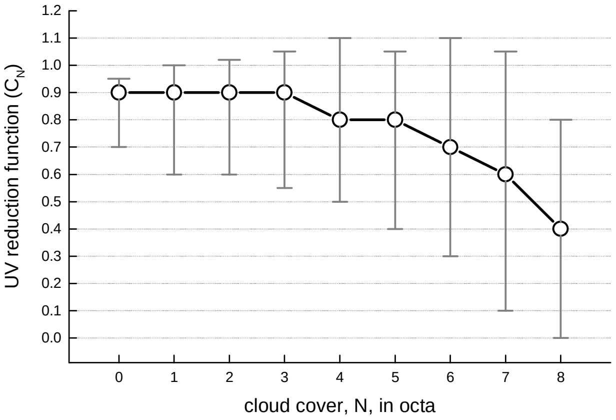


Figure 2.1 The existing cloud parameterisation. The large dots represent the average of the instantaneous UV reduction factors. The relationship shown is taken from Kuik and Kelder 1994.

2.4.3 UV-reduction based on ISCCP cloud cover and cloud optical thickness

To improve upon the cloud parameterisation in the previous section we developed a method using satellite derived cloud optical thickness in addition to the cloud cover data. The new method is based on high-resolution satellite data (3 hourly) for cloud cover (N) and cloud optical thickness (τ_{cld}) from ISCCP. The method uses a pre-calculated look-up table of instantaneous UV reduction functions and is discussed in detail in Matthijsen et al. 2000.

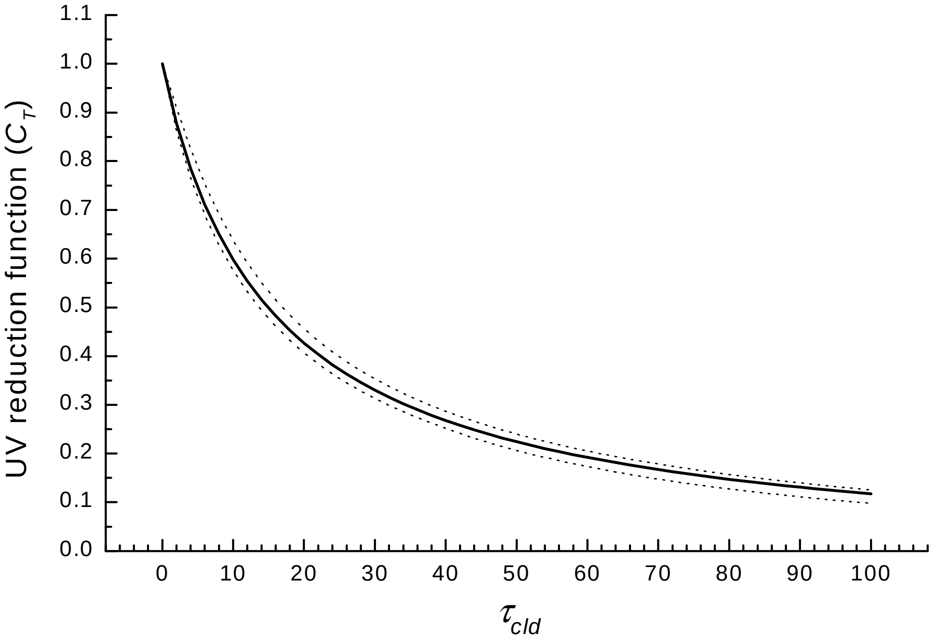


Figure 2.2 Calculated UV reduction functions due to clouds (C_T) as a function of the cloud optical thickness (τ_{cld}). The solid line represents the relationship calculated using base conditions at zenith angle 65° (see text), and the two dotted lines the upper and lower boundaries of this relationship, resulting from sensitivity tests for all relevant solar zenith angles.

A daily UV reduction factor (SDF = satellite derived daily reduction factor) is derived from $C_T(\tau_{cld},\theta)$ and N using the following equation:

$$SDF = \frac{\sum\left[\overline{UV_{cs}}\left(1-N(1-\overline{C_T(\tau_{cld},\theta)})\right)\right]}{\sum\overline{UV_{cs}}}$$

where the terms in the numerator make the daily UV dose, which includes the reduction due to clouds, and the term in the denominator is the daily UV dose for clear-sky conditions. The lines above symbols denote hourly average values and the subscript “cs” indicates that the hourly UV dose is for clear-sky conditions. N denotes the cloud cover fraction, and C_T the instantaneous reduction function due to clouds (see figure 2.2). Note that although τ_{cld} and N are in fact 3-hourly averages, we calculated SDF by summation over every hour (Σ). This approach renders better results because the variation of the solar zenith angle is described with a higher resolution. The SDF-based method described in this section is extensively tested with ground based UV-reduction factors in section 3.5.3 (results from Matthijsen et al. 2000) for sites all over the European continent. The UV reduction factor SDF is statistically compared with the UV reduction factors NDF (described in section 2.4.2) and TDF (described in section 2.4.4) in section 3.5.4.

2.4.4 UV-reduction based on TOMS7 reflectivity

The improved cloud parameterisation (SDF) gives good results for the UV reduction factor but is limited by the availability of the remote sensing data from ISCCP. ISCCP is a project, which continues at least until the year 2000. However the ISCCP D1 and D2 data sets are made available with a time delay of about 5 years, which makes UV dose calculations under the real cloudy conditions for recent years not (yet) possible (see figure 2.3).

Therefore we included in the application model an alternative cloud parameterisation, which is derived from daily TOMS7 reflectivity data. The UV reduction factor is described in detail by Eck et al. [1995] and is based on the assumption of conservation of radiation assuming that the ground albedo for UV is small (≈ 0.02). The daily TOMS UV reduction factor (TDF) is than defined by the following equation. Note that for optically thin clouds (reflectivity < 50%) a simple correction is included for the underlying surface contribution.

$$\begin{aligned} TDF &= 1-(R_\lambda - R_s)/(1-2R_s) \quad R_s \le 0.5 \\ TDF &= 1-R_\lambda \quad R_s > 0.5 \end{aligned} \qquad \textbf{(3)}$$

where R_λ is the reflectivity (0-1) at 380 nm for TOMS version 7/nimbus7 data and at 360 nm for TOMS version 7/earth-probe data. R_s is the surface reflectivity or ground albedo.

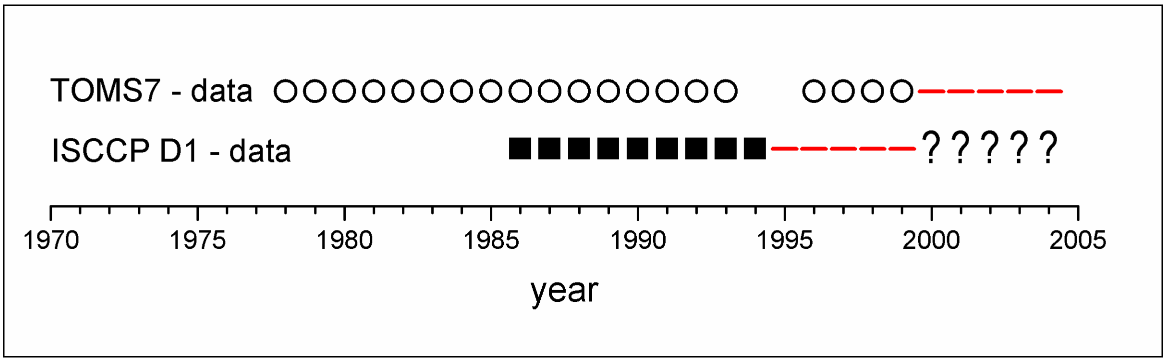


Figure 2.3 Data availability of TOMS7 data (circles) and ISCCP D1 data (squares). The dashed indicate planned availability. The continuation of the making of ISCCP D1 data or updates of satellite data after the year 2000 is probable but not sure now.

The method has as main advantage that the necessary remote sensing data is almost online and freely available (http://toms.gsfc.nasa.gov). Moreover the TOMS version 7 data covers a long period from November 1978 to now with some gaps of up to one year in the beginning of the nineties. Further the method is computationally simple and easy to include. The main disadvantage is that the time resolution is small (maximum of one overpass value per day, usually around 11 am local time). The monthly UV-doses derived using the UV reduction factor, TDF, which is derived from the TOMS7 reflectivity, are compared with ground based UV-measurements in four European sites in section 3.4. TDF is compared with a ground based reduction factor (GDF) and with the UV reduction factors described in the previous sections (NDF and SDF) in section 3.5.4.

2.5 Remote sensing data

2.5.1 Introduction

The UV-map method uses several sources of remote sensing data (from different platforms) for ozone, cloud parameters and aerosols. This section summarises the main remote sensing data sets used in this study.

2.5.2 Ozone column

The operational UV-map model can use daily and monthly mean data on the total ozone column. The model allows for ozone column data provided by either TOMS version 7 (level 3 gridded data) or for ozone column data from the Global Ozone Monitoring Experiment GOME (level 4, assimilated data). Both ozone data-files have the same data format. The total ozone values are given in Dobson Units in a $1.25^\circ \times 1^\circ$ longitude×latitude grid. It should be noted that the GOME pixels are larger than the TOMS pixels, and the full global coverage of GOME takes three days.

The daily mean and monthly mean ozone column data are obtained from the TOMS version 7 data set of NASA's Nimbus-7 satellite. The TOMS algorithm development, evaluation of instrument performance, ground-truth validation and data production are reported by McPeters et al. [1996], who show that the satellite-derived ozone column deviates no more than 5% from ground-based measured ozone columns.

The GOME level 4 total ozone column distributions as calculated with the Assimilation Model of the KNMI, AMK, (see Levelt et al, 1996)). The calculation is based on ozone observations from the Global Ozone Monitoring Experiment (GOME) onboard ESA's ERS-2 platform. The model makes use of the wind fields archived at the European Centre for Medium-range Weather Forecast. The AMK dynamical model is still under development, and therefore the GOME level 4 total ozone maps should be considered as a preliminary product. Results presented in this report are based up on the TOMS version 7 ozone data unless indicated otherwise.

2.5.3 Cloud parameters

The 3-hourly cloud cover and cloud optical thickness have been obtained from the ISCCP data base using the ISCCP D1 data set. As a separate method for evaluating the effects of clouds the TOMS7 reflectivity data (daily and monthly) are used to calculate UV cloud correction factors (see section 2.4.4 for details).

2.5.4 Additional parameters

Data on ground albedo and aerosol optical properties are not included in the basic calculations at present. Ground albedo is expected to have an important effect when the ground is covered with snow, with a variation in ground albedo from 0.9 with fresh snow down to 0.1 (old snow). It has been considered to use geographically distributed maps for the ground albedo. However UV ground albedo shows only small variations during the summer months when the UV dose is highest. The determination of aerosol optical properties from satellite remote sensing data is not yet operational and validated. The SULPHATE project focused on methods to include variability's in aerosol, SO2 and tropospheric ozone into the modelling of UV-maps. RIVM provided its improved UVTRANS UV transfer model for the SULPHATE analysis, and the results of the SULPHATE analysis will lead to an extension of the AMOUR-method, which will be implemented in the context of the RUBEO-project. A problem in the analysis of tropospheric changes is the limited availability of input data.
The TOMS version 7 reflectivity data include the reflection (not absorption) by aerosols. So by using TOMS version 7 reflectivity data to parameterise the effect of clouds on UV, the effect of aerosols is partly included. TOMS also provides for a freely available so called aerosol index (AI). However in absence of a thorough validation of AI it is not used in the present analysis.

2.6 UV risk assessment method

Excess skin cancer risks are calculated in relation to the changes in the yearly UV-doses received at a certain location. The excess risks represent the increase in skin cancer incidence which are expected if the observed increase in yearly UV-doses were prolonged for a lifetime. The changes of skin cancer incidence (ΔI) due to the changes of yearly UV over a period t_2-t_1 are derived by applying the yearly doses UV(x,y,t_1) and UV(x,y,t_2) and a reference yearly UV-dose (UV_0) to:

$$\Delta I = \sum_{i=1}^{3} I_i \left[\left(\frac{UV(x,y,t_1)}{UV_0} \right)^{C_i} - \left(\frac{UV(x,y,t_2)}{UV_0} \right)^{C_i} \right]$$

ΔI is the excess skin cancer incidence per million per year if the differences in yearly UV-doses UV(x,y,t1) and UV(x,y,t2) are prolonged for a lifetime. The summation is over three different types of skin cancer: basal cell carcinoma (BCC), Squamous Cell Carcinoma (SCC) and melanoma (MEL) (in line with Slaper et al., 1996). For each skin cancer type the incidences (I_i) provides the baseline incidence associated with the reference yearly dose (UV_0).
The calculations are performed assuming a population with the sensitivity and sun seeking habits of the Dutch population. In addition it is assumed that exposure habits and sensitivity do not change. Parameter settings are in accordance with Slaper et al. (1996), and are given in table 2.2. The excess mortality risk could be calculated from the excess incidences for each of the skin cancer types using:

$$\Delta S = \sum_{i=1}^{3} S_i \Delta I_i$$

where S_i indicates the fraction of the skin cancer cases which is lethal.

Table 2.2 Parameters in the skin cancer risk calculations

I	Cancer type	I_i	C_i	S_i
1	BCC	900	1.4	0.003
2	SCC	160	2.5	0.030
3	MEL	110	0.6	0.250

Where I_i is the incidence per million inhabitants per year for the Dutch population

3 Validation of the UV-mapping methods

3.1 Introduction

3.1.1 Validation: requirements and limitations

Ground based measurements and satellite observations are complementary sources of information in the determination of UV-doses relevant for effect evaluations. Ground based measurements of UV-irradiation can provide detailed information for a specific location and a specific time, but it is not clear how representative the information is for larger areas. Satellite derived information is usually less specific for a certain location and is not available at all times, but it enables an evaluation of geographical variability. This difference in spatial and temporal resolution poses difficulties in the direct comparison of ground level UV-measurements and satellite derived UV-radiation levels. Here, we will focus on the validation of UV-maps from the perspective of effect evaluations. From that perspective it is most relevant that time integrated doses are calculated accurately on a time scale from days to years. Skin cancer evaluations require primarily yearly doses and a stability of the assessments over the years, whereas sunburn evaluations require daily doses primarily.

An optimal comparison between satellite derived UV-irradiance and ground based measurements requires many measurement sites within the grid cells representing the view of the satellite, or a very narrow view of the satellite. A high density of UV-measurement stations is not available and a direct comparison with ground based UV-measurements over prolonged time periods, is often not possible for lack of long term data. Therefore, we have separately analysed various steps in the map making methodology. The next section provides a brief overview of the various validation activities.

3.1.2 Outline of validation activities

The maps produced at RIVM are used for environmental and effect assessments and focus on changes occurring over a period of years. The maps are not intended to produce a very high local precision and are not used to evaluate UV-levels with a high temporal resolution. RIVM therefor focused the validation activities on the statistical analysis of available data sets, and a step wise validation for the various steps involved in the map-making. The major steps in the map-making are described in the previous chapter and involve: the use of a UV transfer model and the determination of the relevant parameters that determine the UV-doses. The next two sections are focused on an evaluation of the UV-transfer model used in the RIVM map-making. In section 3.2 we evaluate the UV-transfer model by comparing with several other transfer models. This comparison focuses on cloud free situations. In section 3.3 we include an empirical model for ground based evaluations of cloud effects on the UV-doses and we use ground based input parameters for the transfer model to compare modelled yearly UV-doses with measured ground based UV-doses over a period of five years in Bilthoven. In section 3.4 we use input data obtained from satellites to calculate ground based UV-doses and compare with measured monthly UV-doses at different locations in Europe. The satellite data provide spatial averages of the cloud optical parameters and thus a statistical evaluation of the accuracy is required to investigate how representative the data are for the area covered. This type of analysis requires a systematic comparison with ground based data. The empirical model for cloud effects uses ground based measurements of global radiation to calculate the UV-reduction by clouds on a daily basis. The global solar radiation measurements are widely available at many locations in Europe and thus this ground based method allows for a direct statistical comparison with cloud effects calculated from satellite observations. This statistical analysis is provided in section 3.5, where the three different methods for calculation of cloud

effects are compared with the ground based method for the summer period. Section 3.6 provides a comparison of the difference in the yearly UV-doses comparing 1997 and 1984. The relative change in effective UV is analysed with and without using cloud corrections. For the location de Bilt we have studied the long term stability of the satellite derived UV-doses as compared to UV-doses derived from ground based data on ozone and global radiation. Results are also provided in section 3.6. In section 3.7 we compare the yearly UV-doses obtained using ozone data from two different satellite platforms: TOMS and GOME.
A summary of the validation results and limitations of the present methodology are outlined in section 3.8 using further information from the MAUVE validation strategy, and findings from the SULPHATE project.

3.2 Comparison of UVTRANS model with other UV-transfer codes

The UVTRANS model was compared with other UV transfer codes in the context of the SUVDAMA model intercomparison. In that study six cloudless sky cases were studied with a set of twelve UV-transfer models, and a benchmark value was calculated for each case. The main results of the comparison of UVTRANS with the benchmark values for these cases are summarised in the table 3.1. At low Solar Zenith Angles (SZA), typical around noon at mid latitudes in the summer, the agreement with results obtained with other codes was within 3% for the erythemally weighted UV-irradiance, and within 3 to5% for the spectral irradiance (300-400 nm). For SZA above 65 degrees the deviations between the model benchmark and the UVTRANS value are between –1 to +7% for the erythemally weighted UV and for the 300-310 nm range the deviations from the benchmark can amount up to 10-20%. Deviations between the model benchmark and measured spectra were usually in the range of 0-13% (see Van Weele et al., 2000).

Table 3.1 Comparing UVTRANS model with benchmark calculations from other UV transfer codes

Comparing erythemally weighted (CIE) irradiances obtained for six cases in the model benchmark (van Weele et al.2000) with results obtained using the UVTRANS model

Case	Location	SZA (^{o})	Ozone (DU)	Aerosol optical thickness*	Benchmark value (mW m-2)	UVTRANS (mW m-2)	relative deviation
1	Ispra	62.7	318	1.563	22.7	22.5	-1%
2	Ispra	25.1	318	1.563	140	136	-3%
3	Garmisch P	68.3	399	0.016	24.9	27	+7%
4	Garmisch P	29.9	327	0.016	193	199	+3%
5	Garmisch P	69.7	319	0.156	20.9	22	+6%
6	De Bilt	32.4	295	0.250	186	189	+2%

* aerosol optical thickness at 320 nm for the boundary layer aerosol, assuming a single scattering albedo of 0.90 for cases 1 and 2, and 0.95 for the other cases; surface albedo is 0.40 for case 3 and 0.02 for all other cases; other parameters as in van Weele et al., 2000.

The conclusions from these results can be that the effective UV-irradiance for the erythemally weighted UV are in line with other UV-transfermodels. Deviations are occurring at high solar zenith angles in the wavelength range 300-310 nm.

3.3 Model-Measurement comparison at the RIVM site

3.3.1 Introduction to comparisons including cloud effects

To further investigate if the UVTRANS model could be used to analyse doses accumulated over a year we have compared modelled yearly UV-doses with measured yearly doses at the RIVM site, using data from the RIVM UV-monitoring system (den Outer et al., 2000). In order to compare measurements with modelled UV-doses directly the effects of clouds need to be taken into account. An empirical cloud correction was developed at RIVM (Bordewijk et al., 1995, Slaper et al., 1994) and improved recently (den Outer et al., 2000) to calculate cloud reduction effects in the UV from global radiation measurements. This method will be briefly outlined in the next section, and then applied to Bilthoven in the years 1994-1998 in section 3.3.3.

3.3.2 Empirical model for reduction of UV by clouds

The effects of clouds on the UV-irradiance are highly variable, which is related to the large variability of relevant cloud parameters like: cloud cover, cloud shapes, cloud optical thickness, water content etc.). The effects of clouds on the UV-irradiance can vary from (small) enhancements on the short time scale under partly clouded conditions to large decreases under full cloud cover with clouds with a large optical thickness. From the perspective of effect evaluations the short time-scales are not relevant, and on average the clouds are bound to have a reducing effect on the UV-irradiance. In line with previous studies (Bordewijk et al., 1995, Bodeker and McKenzie, 1996) we analysed the effects of clouds on daily integrated UV-doses and daily integrated global radiation (being the broadband integrated radiation from UV up to infrared). It is found that the reduction of UV compared to the cloudless situation correlates to the reduction in UV (see figure 3.1).
Global radiation is measured as a standard meteorological parameter at many meteorological sites and these measurements are therefor widely available (see next section).
Reduction factors for global radiation were determined dividing the measured daily sum of global radiation by daily sums calculated using a clear sky empirical model. We used daily integrated global radiation measurements from a nearby meteorological station (KNMI in de Bilt) and compared the calculated reduction of global radiation with the cloud-induced reduction in the daily integrated weighted UV-dose. The latter reduction is obtained dividing the measured daily UV-dose by the modelled UV-dose for the cloudless sky case. The cloudless sky values are obtained using the UVTRANS model with a standard (cloudless) atmosphere, using measured ozone values and integrating the weighted spectral irradiance over the day.

The UV radiation measurements were made with a Robertson-Berger (RB) UV biometer at the measurement site of the National Institute of the Public Health and the Environment (RIVM). The spectral sensitivity of the RB-meter approximates the spectral sensitivity of Caucasian skin to sunburn (i.e. the erythema action spectrum).
In Figure 3.1 the reduction factor in the daily effective UV-dose is plotted versus the reduction factor for the global radiation for the summer months in 1994 and 1995 in Bilthoven. The solid line represents the optimum power-law fit: $C_F = a\ (G/G_{cs})^b = UV/UV_{cs}$ (as in Bodeker and McKenzie, (1996)) with a = 1.05 and b = 0.84. The dotted lines represent an upper and a lower limit of the plotted data.

We concentrate in this report on summer periods for several reasons. Summer periods yield the major contribution to the yearly UV-load, and measurements over Europe are more comparable during summer periods. High ground albedo due to snow will be absent as well as extreme difference in solar zenith angles. Bodeker and McKenzie (1996) have reported a solar zenith angle dependence of the relationship between the reduction of pyranometer readings and the reduction of UV. Our findings confirm a solar zenith angle dependence, leading to a more linear shaped relation with low solar zenith angles and a more curved relation for high solar zenith angles (den Outer et al., 2000). In the next section we will use the seasonally (=zenith angle dependent) cloud correction functions obtained by den Outer et al. (2000). In the sections thereafter the satellite derived cloud correction factors are compared without taking the seasonal influence into account.

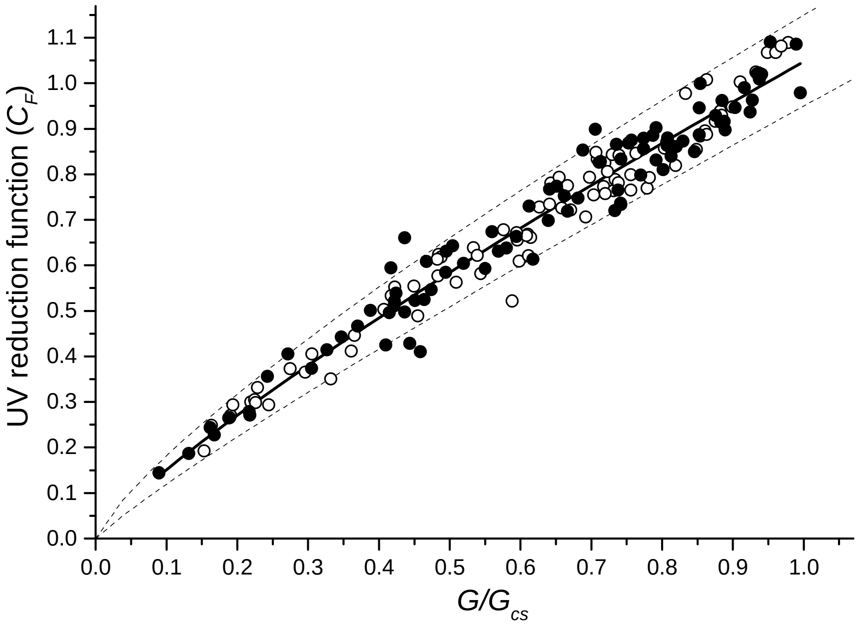


Figure 3.1 Daily mean UV reduction functions (C_F) as a function of daily mean global solar radiation ratios (G/G_{cs}). The relationship is based on UV and global solar radiation measurements at RIVM in Bilthoven in the Netherlands during the months of May, June and July of 1994 (solid circles) and the same period in 1995 (open circles). The solid line represents the best fit with a power-law function and the surrounding dotted lines the upper and lower limits of C_F.

3.3.3 Comparing modelled and measured yearly UV-doses using ground based data

We use the reduction in global radiation to determine the UV-cloud correction, applying the cloud correction function described in the previous section. This is done in two ways:

- Multiplying the daily UV-dose, obtained applying the UVTRANS model, with the daily cloud correction factor we obtain a modelled daily dose for the clouded situation which can be directly compared with the daily dose calculated from the UV-measurements. Summing over all days in the year we obtain the yearly UV-dose.
- Dividing the measured yearly UV-dose by the modelled yearly UV-dose for the clouded situation yields a correction factor between model and measurement. This factor is multiplied with the modelled cloudless sky dose to obtain an estimate of the 'measured' yearly sum for the cloudless sky.

Figure 3.2 shows the results for the cloud-included analysis and the cloudless analysis. As can be seen there is good agreement between the modelled and measured UV. Most relevant from the perspective of effect assessments is the fact that the relative changes from year to year are well matched. This implies that the model itself is suited for an analysis of yearly doses for Bilthoven provided that the correct input data are used. In this case we used local ground based daily data for global radiation and ozone values averaged from two ground based stations and the TOMS satellite (if available), and all other atmospheric parameters were fixed (see chapter 2).

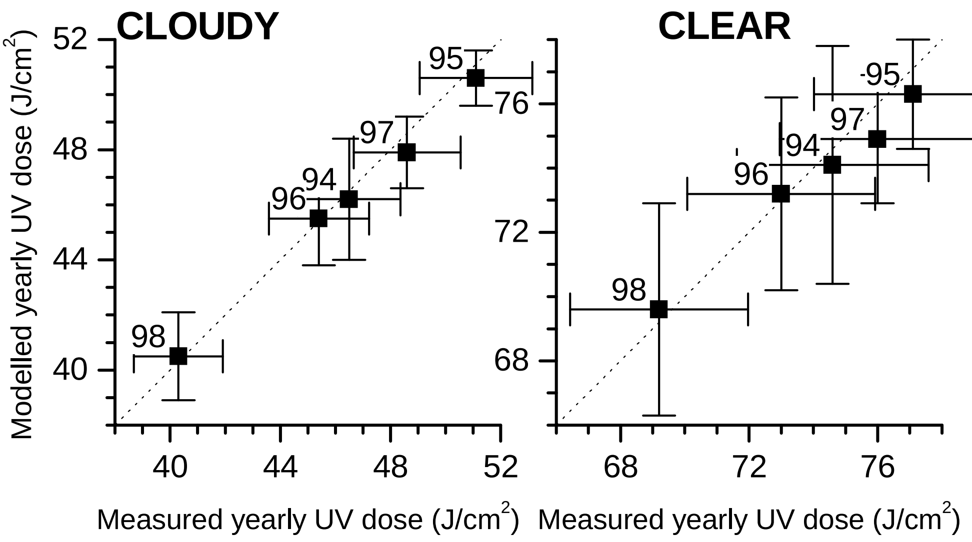


Figure 3.2 Modelled yearly UV dose related to the measured yearly UV dose, obtained from spectral UV-measurements and weighted with the CIE erythemal action spectrum (McKinlay Diffey, 1987). Dotted lines depict full agreement between measured and modelled UV-doses.

3.4 Comparing measured UV-doses and modelled UV using satellite data

3.4.1 Model and measurement comparison in Bilthoven in 1997

In this section we compare UV doses measured on the ground at Bilthoven in 1997 with modelled UV using ground based input parameters and modelled UV using input parameters based on satellite information. The comparison is provided in figure 3.3. The method based on TOMS reflectivity measurements is used to calculate reduction due to clouds (TDF, section 2.4.4). Integrated over the year the model based on ground based input parameters compares very well with measurements (within 1%). It should be noted that this agreement in absolute values is partly due to the choices of some atmospheric parameters and the cloud corrections, which are specifically fitted for the Bilthoven situation.

The modelled yearly UV-dose based on TOMS overpass data are also in close agreement with the measured yearly UV-dose: the modelled values being +0.7% higher than the measured values. Using the gridded TOMS-data the modelled yearly dose is +4.3% higher than the measured yearly dose. The overall agreement is therefore at the 1-5% level.

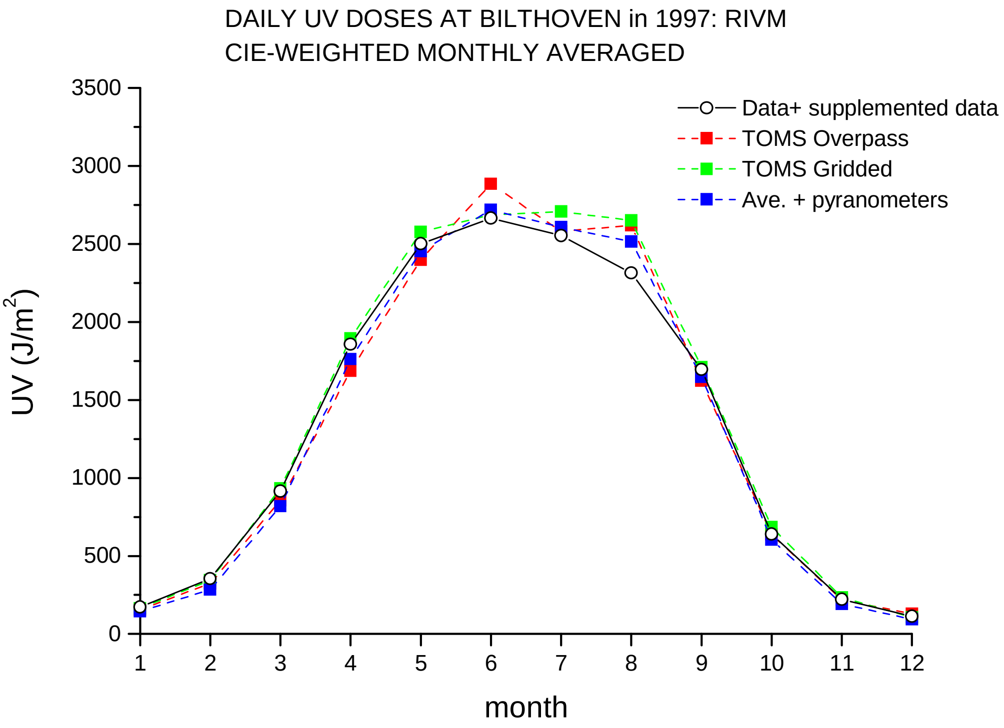


Figure 3.3 Modelled monthly averaged daily UV-doses using input data from satellite observations in comparison with measured monthly averaged daily UV-doses in Bilthoven in 1997 and with modelled UV using ground based input data. Data + supplemented data refers to measured UV (missing spectral measurements are supplemented by modelled data, correcting the modelled data for average differences observed between model and measurements). TOMS overpass refers to modelled UV using the TOMS overpass ozone values and reflection data. TOMS gridded uses the gridded ozone and reflection data; Ave. + pyranometers refers to the methods using ground based ozone and global radiation (pyranometer) readings.

3.4.2 Modelled UV using satellite data and measured UV-doses at four European sites

Satellite derived UV-doses (monthly and daily sums) for 1997 have been compared with ground based spectral measurements for five different stations in Europe, as part of the MAUVE validation strategy (Kalliskota et al., 1999, Peeters et al., 1999): Garmisch-Partenkirchen, Brussel, Bilthoven, Jokioinen and Tromsoe. Modelled values are based upon the overpass data from TOMS, using the TOMS version 7 reflectivity measurement to derive the cloud correction factors (TDF). Figure 3.4 provides the results for four sites (results provided by A Arola from the Finnish Meteorological Institute (FMI)). The modelled yearly UV-dose exceeds the measured UV-dose for the four sites shown: +0.7% in Bilthoven, +4.6% in Garmisch-Partenkirchen, +8.8% in Brussels, and +10.3% in Jokioinen. It should be noted that the measured data from Brussels and Jokioinen have not been corrected for cosine errors of the instrumentation. Accounting for the cosine error would probably result in a 4-9 % increase of the measured UV-doses. It is therefor probable that the agreement between modelled and measured yearly UV-doses is within 6% for the four stations in figure 3.4. Looking at seasonal differences an overestimation in the summer period and an underestimate in the winter period is observed especially during periods with snow cover. In line with these findings the results for Tromsoe (above 69° N) show much larger relative errors than for the other sites. The deviation due to snow cover in the winter is easily understood since in the TOMS reflection measurements are not corrected for high albedo effects due to snow, which implies that snow cover is mistaken for clouds. For Tromsoe (at 69° N) the snow cover period expands into May leading to a nearly 40-50% underestimate in the period up to May.

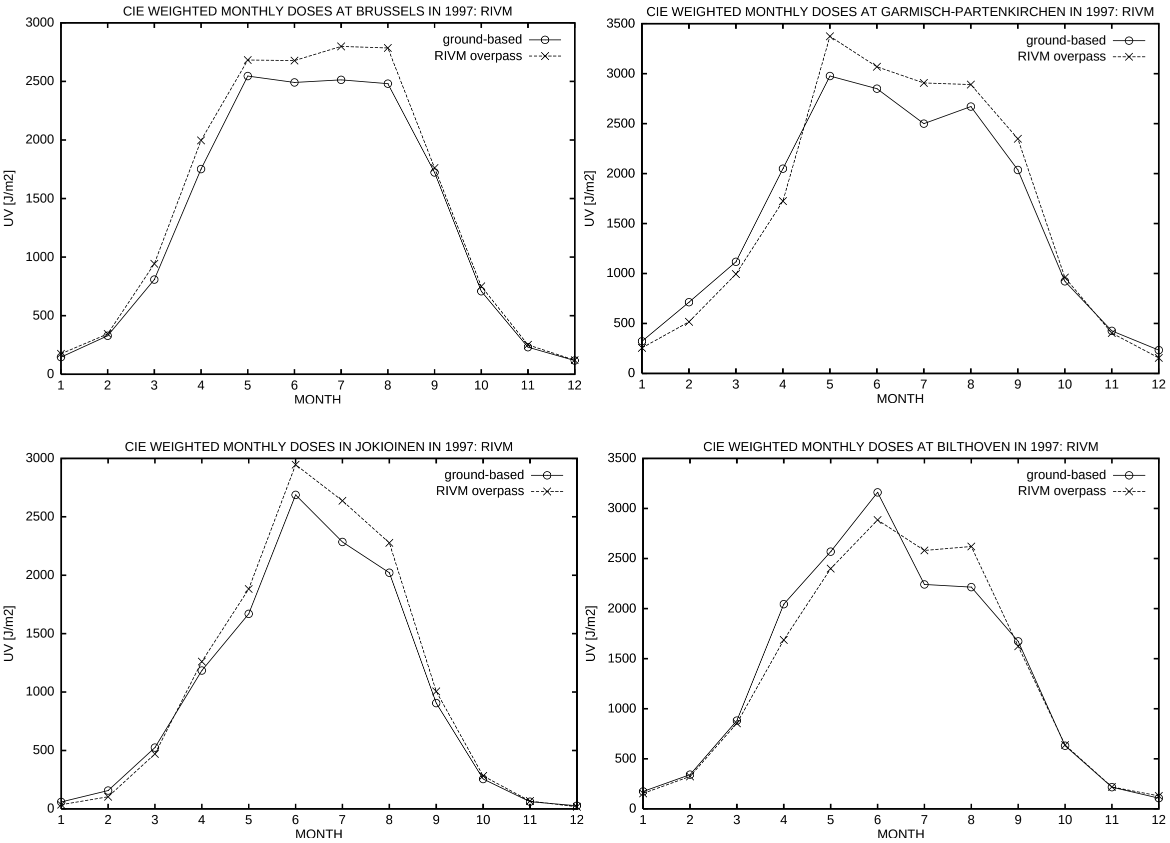


Figure 3.4 A comparison of modelled monthly UV-doses at ground level using input data from satellites (TOMS-reflection for cloud effects) with measured monthly UV-doses (results obtained from the MAUVE-validation, provided by A Arola (FMI, Finland)). NB: days for which spectral measurements are missing, are supplemented by using the average daily dose of the days with measurements in the month.

3.5 UV-reduction by clouds: comparing satellite and ground based methods

3.5.1 Statistical analysis of cloud effects: introduction

Clouds are a dominant factor in the determination of ground level UV-doses and the high temporal and spatial variability complicates the validation of satellite derived cloud effects since satellite data provide averages over time and viewing area. Using the empirical cloud correction method described in section 3.3.2 we can use global radiation measurements at the ground to investigate cloud effects on UV on a local scale. The availability of global radiation measurements at many meteorological sites makes it possible to investigate the validity of the geographical averaging of cloud effects estimated from satellite observations. In sections 3.5.2 and 3.5.3 we present the major results from a statistical comparison between ground based and satellite derived cloud effects on UV, using the SDF-method described in section 2.4.3 (further details are reported in Matthijsen et al., 2000). The investigation is limited to the summer periods to avoid additional complications from high albedo situations due to snow cover. In section 3.5.4 we compare the three methods for satellite derived cloud effects as described in chapter 2 (sections 2.4.2, 2.4.3 and 2.4.4) with the ground based analysis.

3.5.2 Ground based stations used in the statistical analysis

The map in figure 3.5 indicates the 125 sites for which global radiation measurements are used in the statistical analysis. Data are obtained from the World Radiation Data Center (WRDC) database. From that database all European sites are selected which meet the following criteria:

- available data for the studied period (May-June-July 1990, 1991, 1992)
- altitude is below 500 meter
- at least three selected stations are situated in one ISCCP grid cell

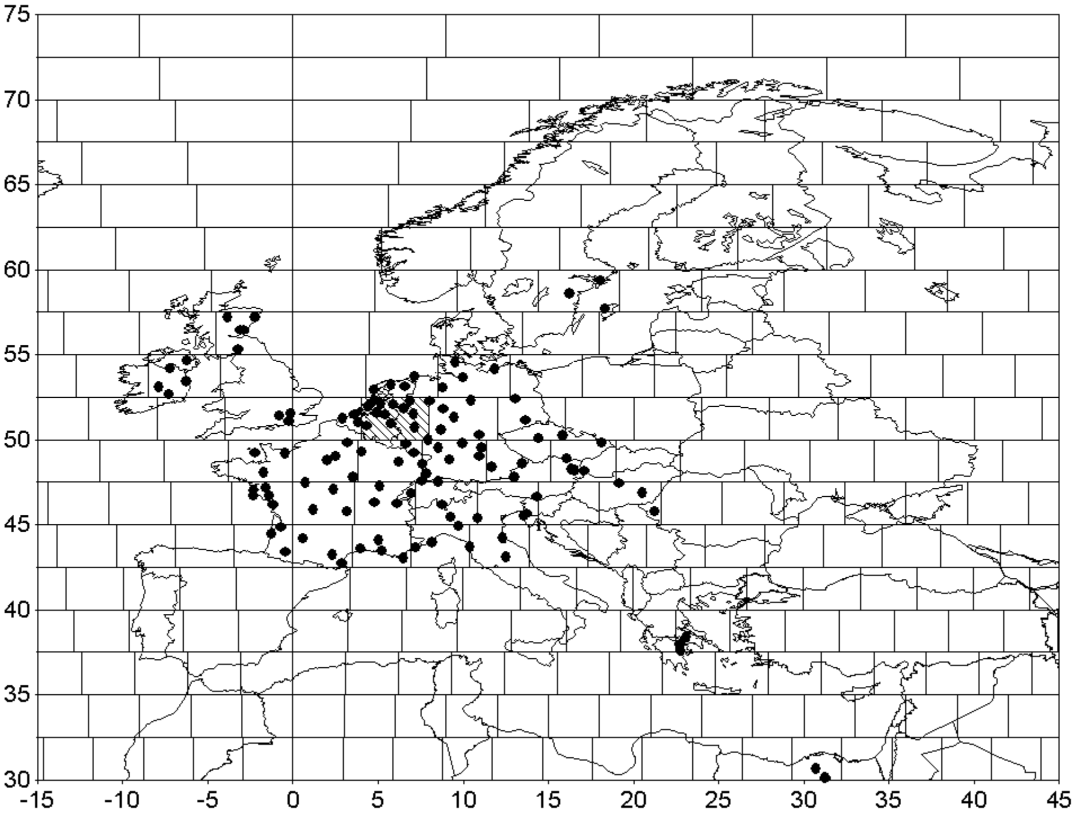


Figure 3.5 Area considered comprising 280 km equal-area ISCCP grid-cells (thin lines). The dots denote the location of the selected WRDC stations supplying global solar radiation data for the period considered. Stations were selected if their altitudes were less than 500 m and if the ISCCP grid-cell contained at least two more WRDC stations. Results of the hatched grid-cell are shown in Figure 3.6.

3.5.3 UV-reduction from ISCCP cloud cover and cloud optical thickness (SDF) and ground based stations (GDF)

Figure 3.6 shows the temporal behaviour of SDF and GDF for the ISCCP grid-cell covering a small part of Germany, most of Belgium and a large part of the Netherlands (hatched grid-cell at approximately 6˚E and 51˚N in Figure 1). This specific ISCCP grid-cell contains the highest number of WRDC stations (12) having a relatively even distribution. Moreover, the relationship used to calculate GDF is derived from measurements at a site in the same grid-cell. The results for this grid-cell are therefore believed to be the most reliable. The thick solid baseline represents GDF values obtained by using the best-fit relationship (Figure 3.1). The upper and lower boundaries of the grey area are obtained by using instead the upper and lower limit fit, respectively. From Figure 3.6 we see that the contours of GDF and SDF (dotted lines) are very similar; however, SDF does not always fall within the range of GDF. For reasons of clarity we have not pictured the standard deviation in GDF, which is for this grid-cell always ≤ 0.1. For the same reason we did not include the estimated error of approximately 7% in SDF. When these uncertainties are taken into account both UV reduction factors agree except for a few very low values. Further, the results for this specific grid-cell indicate small systematic differences between SDF and GDF, SDF is slightly higher than GDF.

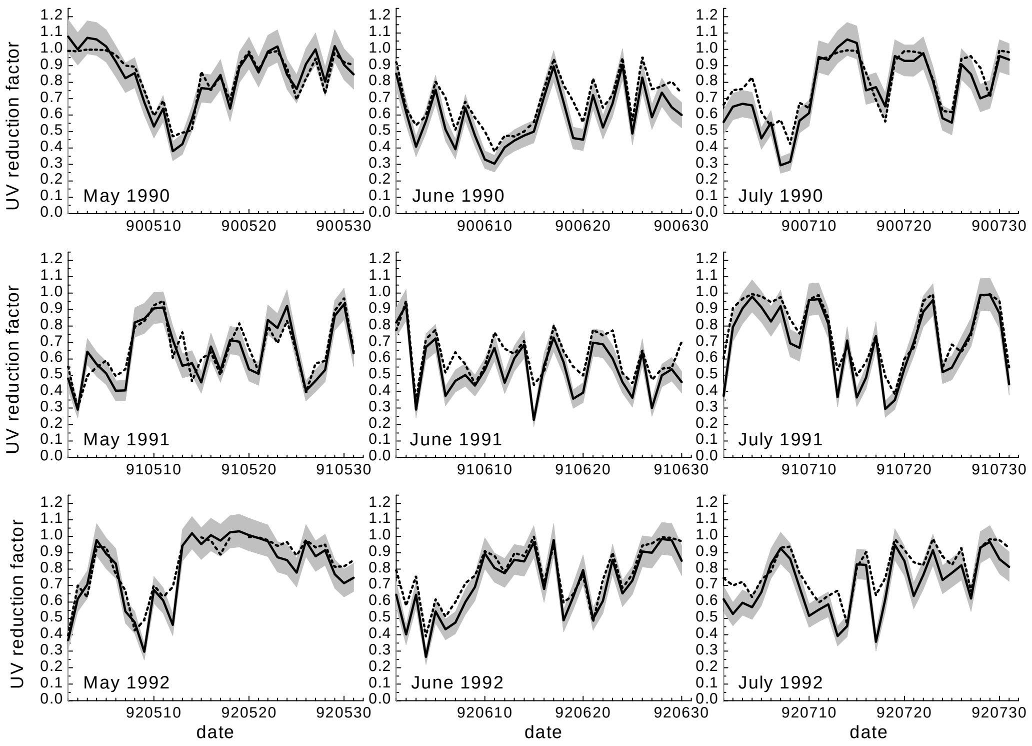


Figure 3.6 Temporal development of daily mean UV reduction factors for the ISCCP grid-cell at approximately 6˚ longitude and 51˚ latitude (hatched grid-cell in Figure 1). The thick solid line is the daily mean UV reduction factor derived from ground-based measurements (GDF) and the dotted line is the daily mean UV reduction factor derived from satellite observations (SDF). The grey area represents GDF values, which can be obtained using any C_F value within the range of the upper or lower limit (see Figure 3.1).

We determined for all grid cells the daily UV-reduction factor based on the global radiation measurements (GDF, averaged over the stations in a grid cell) and the satellite derived reduction factor using the ISCCP cloud cover and cloud optical thickness data (SDF). All daily values are grouped according to the solar zenith angle at local noon. Figure 3.7 shows the results of this analysis where the data are binned according to the SDF and the variation in the GDF is shown. The results do not indicate a significant zenith angle dependence for the summer period considered. A systematic shift of 0.05 is observed in the reduction factors (SDF being larger than GDF) and a standard deviation between SDF and GDF values of 0.06 with a 90% confidence interval from –0.09 up to 0.19 when comparing daily values. The standard deviation for 10 day averaged reduction factors is smaller: 0.03, which indicates that averaging over longer periods improves the agreement.

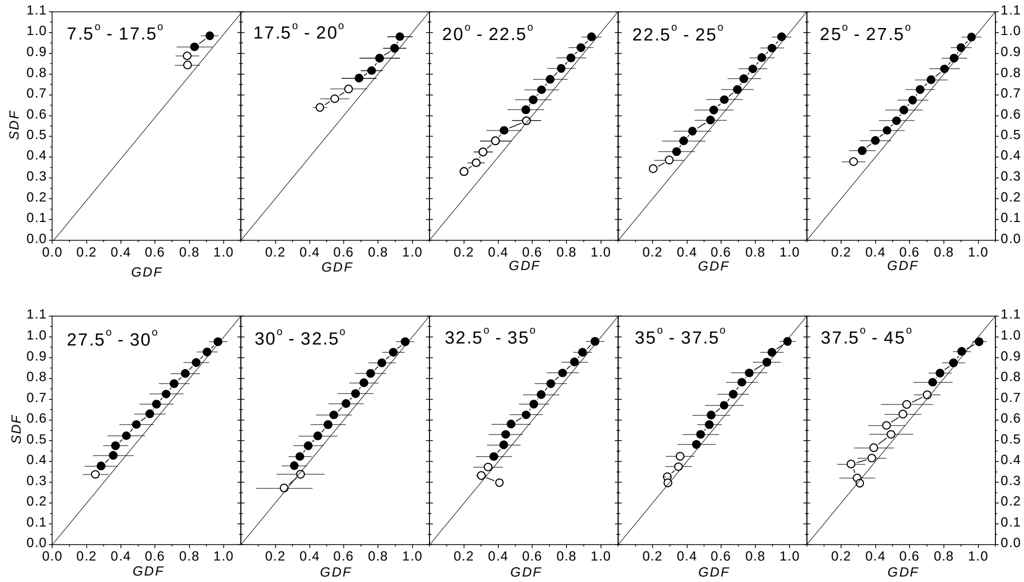


Figure 3.7 Mean GDF versus mean SDF as a function of local noon solar zenith angle of an ISCCP grid-cell. Each dot denotes an average of the values GDF and SDF within a bin size of 0.05 for SDF. The horizontal bars are the standard deviations of GDF in each bin. Open dots are used when there were less than 12 combinations of GDF and SDF available for the average. The range of local noon zenith angles is found in the left corner of each graph.

3.5.4 Comparing three approaches for cloud effects with ground based data

Three methods for assessing UV-reduction by clouds through the use of satellite observations are compared with ground based UV-reduction factors as obtained using global radiation measurements (GDF)(Matthijsen et al., 1999):

- UV-reduction based on ISCCP cloud cover data, NDF (section 2.4.2)
- UV-reduction based on ISCCP cloud cover and cloud optical thickness, SDF (section 2.4.3)
- UV-reduction based on TOMS7 reflectivity, TDF (section 2.4.4)

Over 730 daily values of GDF were compared with the three methods using satellite data. Results of the comparison are summarised in table 3.2.Figure 3.8 shows the correlation of the daily UV-reduction factors for each of the three methods data with the ground based analysis (GDF).

Table 3.2 Comparison of satellite derived NDF, SDF and TDF daily cloud reduction factors with ground based GDF factors. Results are obtained for over 730 days during the summer months May-August in the years 1986, 1988, 1989, 1990, 1991 and 1992.

		Daily values			Monthly averaged values		
Method	Mean reduction	Correlation R^2	Method-GDF	st.dev	correlation R^2	Method-GDF	st.dev
GDF	0.658	1	0	0	1	0	0
NDF	0.604	0.68	-0.053	0.116	0.79	-0.046	0.04
SDF	0.769	0.88	0.112	0.075	0.87	0.115	0.03
TDF	0.673	0.91	0.015	0.063	0.93	0.022	0.02

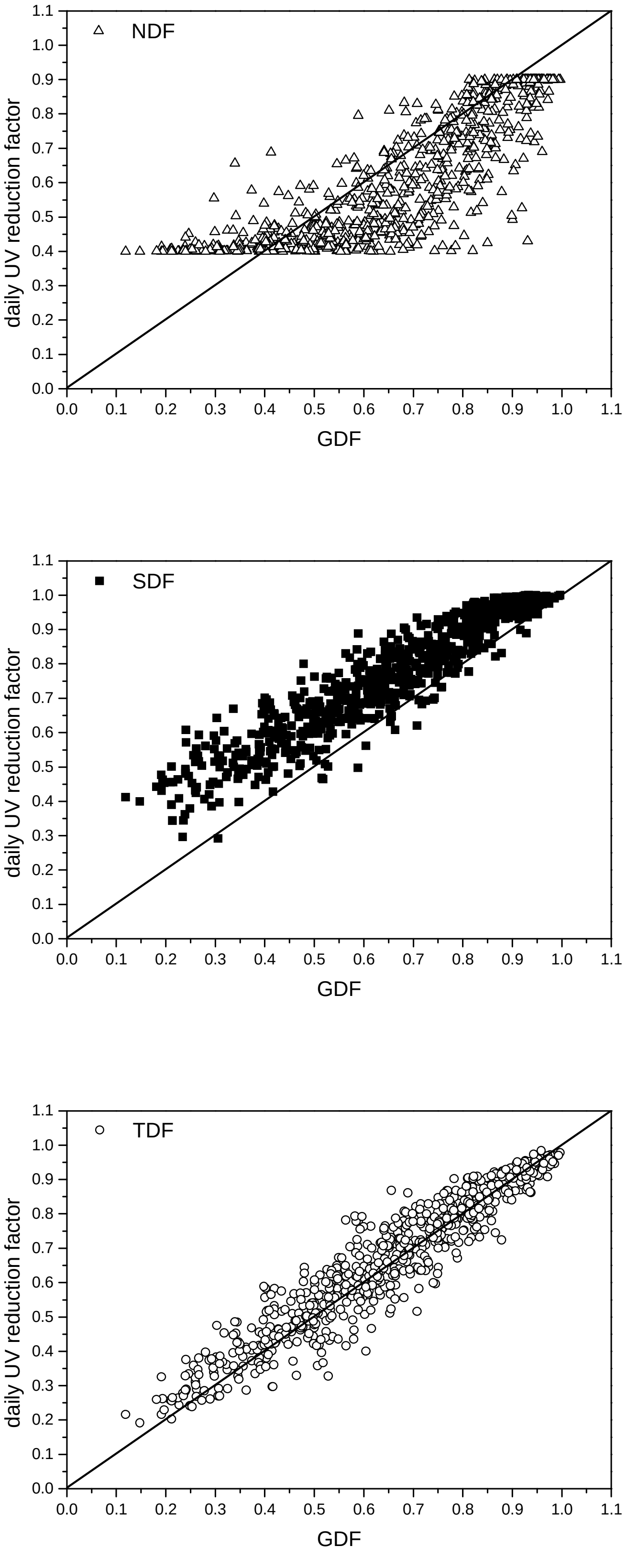


Figure 3.8 Daily UV reduction factors based on ground based global radiation measurements (GDF) versus NDF (top), SDF (mid) and TDF (bottom) for the ISCCP grid cell which contains part of The Netherlands, Belgium and Germany (Hatched grid cell in figure 3.5).

Figure 3.9 shows the correlation between the monthly mean values for GDF and NDF, SDF and TDF respectively. Again it can be seen that the TDF closely matches the GDF values as illustrated by the least square linear fit: TDF = 0.045(± 0.035)+ 0.963(±0.053)×GDF.
For the grid cell and period of the year (May-August) considered in this analysis the day to day standard deviation between TDF and GDF is 0.063 (9-10% relative error), whereas the monthly standard deviation between TDF and SDF is 0.02 (less than 3% relative error).

We conclude from these results that the method based on the TOMS-reflection data provides the best comparison with the ground based reduction factors. This result is surprising since the TOMS reflection measurement is based on a single overpass for each day, whereas the ISCCP data are determined every 3 hours during the day.

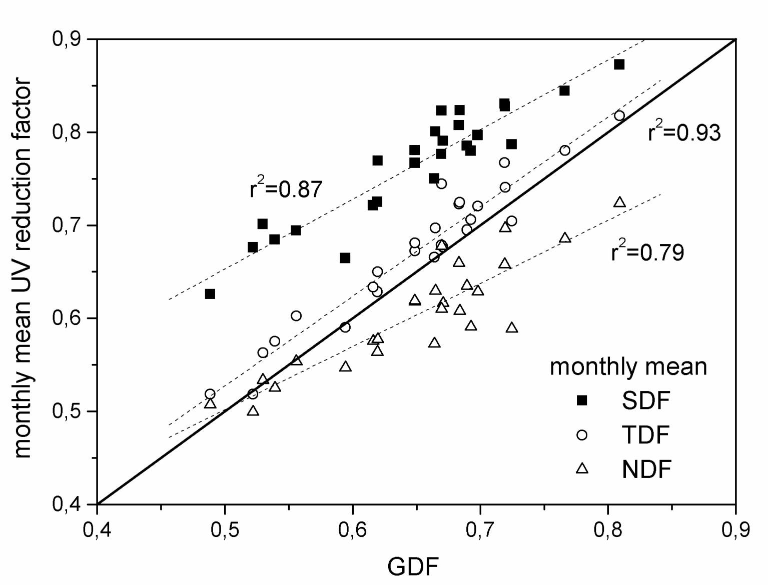


Figure 3.9 Monthly mean UV reduction factors based on ground based global radiation measurements (GDF) versus NDF (triangles), SDF (squares) and TDF (circles) for the ISCCP grid cell which contains part of The Netherlands, Belgium and Germany (hatched grid cell in figure 3.5). The solid line denotes an optimal match between the reduction factors derived from satellite observations and the ground based reduction factor (GDF); the dotted lines are linear best fits.

3.6 Long term changes in yearly UV-doses, including and excluding the influence of clouds

3.6.1 Long term comparison of changes in UV: introduction

In the previous sections UV-doses obtained with ground based data have been systematically compared with methods using satellite observations. However, the analysis was restricted to five to six years of data at the most. From the perspective of environmental assessments long term evaluations of the changes are required, which put high demands on the stability and availability of the data sets. As an example of the study of long term changes we calculate differences in UV doses for the years 1997 and 1984 (section 3.6.2). In section 3.6.3 we study the long term stability of the satellite derived UV-budgets by comparing with UV-budgets derived from ground based measurements on ozone and global radiation.

3.6.2 Differences in yearly UV-doses in Europe comparing 1997 and 1984

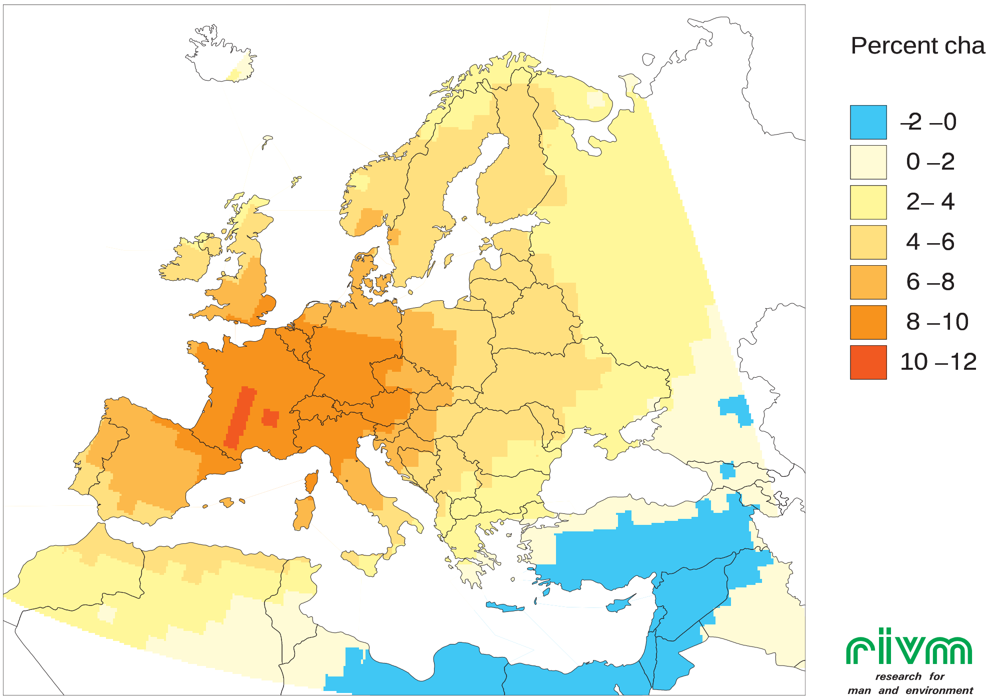
In this section we compare changes in the yearly UV-doses for 1997 with the yearly UV-dose in 1984 in two different ways: one without accounting for the effects of clouds and the other accounting for cloud effects using the TOMS reflectivity method (TDF, section 2.4.4). It should be noted that this comparison is not an analysis of a systematic trend but an example of changes between years. The comparison is based on CIE-weighted erythemal UV and uses TOMS version 7 ozone data and reflection data (TDF method). Figure 3.10 top shows the change in the UV-dose without taking the cloud variability into account. For the Netherlands the doses in 1997 are 8.1±0.4 % higher than the doses in 1984. Using ground based ozone data from KMI in Uccle (Belgium) the difference between 1997 and 1984 is 9.6 % (ozone data kindly provided by de Muer and de Backer (KMI)). Including the cloud effects (fig. 3.10 bottom) increases the variability of the changes over Europe. For the Netherlands we find that the UV-dose is 21.0±3.7% higher in 1997 than in 1984, when using the TDF method (TOMS reflectivity, using gridded data). This matches with the ground based analysis (GDF) which provides a change of 17.8 % (using KNMI global radiation in combination with KMI-Uccle ozone measurements). In the following section we have studied the year to year changes comparing ground based analysis of the yearly UV-dose with satellite derived UV-doses over a prolonged period.

3.6.3 Long term comparison of modelled yearly UV-doses: ground based versus satellite based

The evaluation of long term changes requires that input data are available over prolonged periods and that the instrumentation and techniques are sufficiently stable. In figure 3.11 we compare two methods to calculate yearly UV-doses at the ground in de Bilt for the period 1979-1998: one method uses input data from ground based measurements (ozone and global radiation) and the second method uses satellite observations (total ozone and reflectivity measurements from TOMS). Ground based ozone measurements are obtained from KMI Uccle and are used as input in model calculations to obtain the clear sky UV-doses in de Bilt. TOMS overpass data for Amsterdam is used for total column ozone data in the method using satellite data. In the ‘clear’ evaluation of figure 3.11 clouds are not taken into account and the overall result shows a good correlation (R^2=0.872) between the two methods with on average 2.5% lower values for the satellite based analysis. The absolute difference of 2.5% is probably due to the difference in location for the ozone determinations. A similar difference of nearly 3% is observed comparing yearly UV-doses calculated for de Bilt for the past five years using the KMI-Uccle data with UV-doses obtained using ground based ozone measurements from KNMI in de Bilt. Yearly UV-doses are also calculated for both methods including the effects of clouds (cloudy panel in figure 3.11). The satellite derived cloud effects are obtained using the TOMS-reflection measurements for the Amsterdam overpass, and the ground based cloud effects on UV are calculated from the ground based global radiation measurements obtained from KNMI in de Bilt (applying the method described in section 3.3.2). The results of the satellite based analysis are in good agreement with the ground based analysis: the squared correlation coefficient (R^2) equals 0.873 when all evaluated years are used and increases to 0.964 if the 1982 data are excluded. As can be seen the clouded data for 1982 show a deviation of about 4-5%, which is much larger than for all other years evaluated.

We can conclude that the results for the yearly UV-dose derived using satellite data agree quite well with the ground based analysis of the UV-dose for the site in de Bilt for the period 1979-1998. This result gives confidence that the satellite methodology is sufficiently stable to analyse trends and changes over time.

Relative change yearly UV dose 1997/1984, clear



Relative change yearly UV dose 1997/1984, cloudy

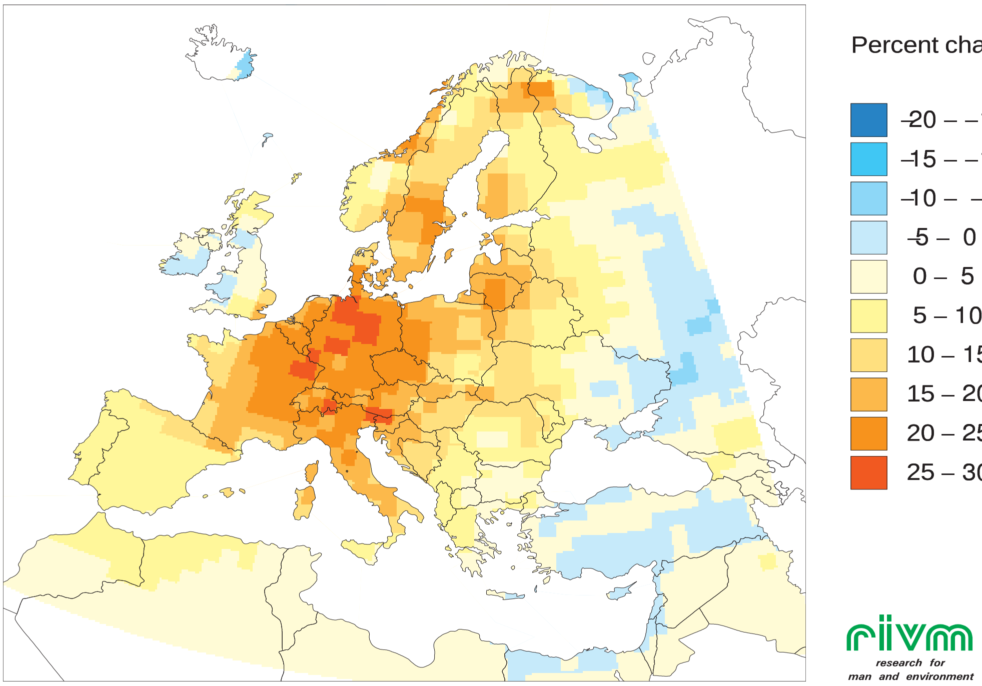


Figure 3.10 Relative change in yearly UV-dose (CIE) for 1997/1984 without (top) and with cloud effects

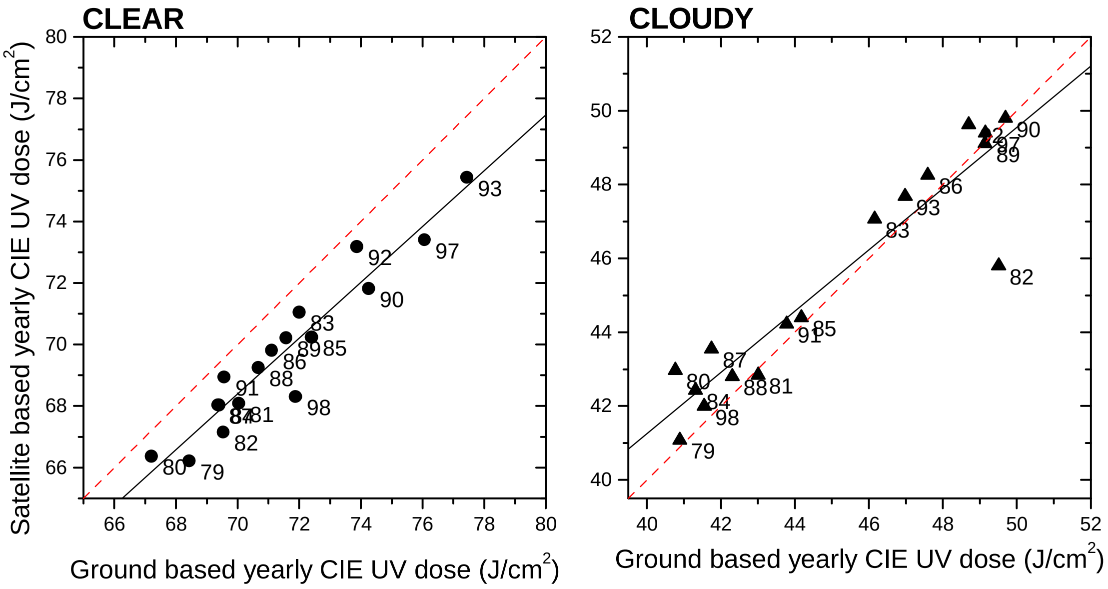


Figure 3.11 Comparing yearly UV-doses at ground level based on ground based ozone and global radiation measurements with UV-doses from satellite data, using TOMS derived ozone and reflection data. The left plot shows the results for cloudless (clear) yearly totals, the right plot includes the analysis of cloud effects. Satellite derived doses use TOMS ozone and reflection data for Amsterdam overpass. The ground based analysis uses ozone from KMI in Uccle to calculate UV at the ground for Amsterdam. The global radiation measurements from KNMI in de Bilt are used to calculate cloud effects for Amsterdam.

3.7 Comparing yearly UV-doses using TOMS and GOME ozone data

In order to compare the use of different platforms we have compared the yearly total UV-dose obtained for 1998 using TOMS and GOME ozone data respectively. Figure 3.12 shows the results for the relative difference between the yearly UV-doses obtained using both platforms. We used the GOME level 4 data, and the relative difference is obtained calculating: (GOME-based UV – TOMS-based UV)/(TOMS-based UV). The results indicate a difference between 0 and 8% in the yearly UV-doses obtained over the European continent. The relative deviations are smallest in Scandinavia <4%, and increase to 7-8% in some areas in the Mediterranean (Greece and northern Africa). The difference for large parts of central Europe is around 5%.

In view of these differences between the TOMS and GOME derived UV-doses it can be concluded that in trend assessments it is not straightforward to combine different satellite instruments for retrieval of ozone columns. Furthermore, the variation over the continent shows that the comparability of results in one region does not mean that the agreement is equally well in other regions.

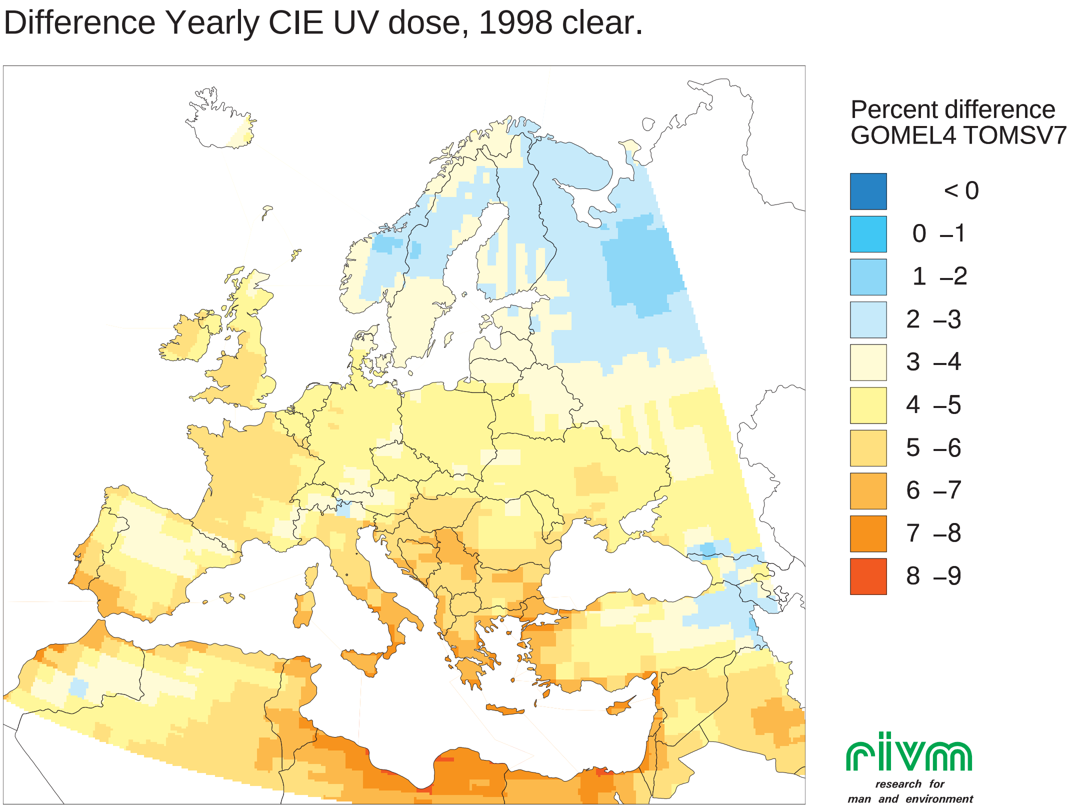


Figure 3.12. Relative difference in modelled yearly UV-doses comparing the use of TOMS total ozone data with GOME level 4 total ozone data.

3.8 Overview of validation activities and results

Sources of error in the production of UV-maps relate to the UV-transfer modelling, the time and spatial averaging and the errors and uncertainties in the input data. We investigated the uncertainties in the UV-transfer modelling by comparing calculated effective UV-irradiances for specific cloudless sky situations with results obtained using other transfer models and with measurements. For low solar zenith angles (SZA<35^o) the agreement with other models was within 3%, for larger SZA (> 65^o) the deviation was in the range –3 up to +7%. The comparison with measurements showed a deviation between –3 up to +10% for the low SZA, and for the high SZA the deviation was between –10 and +15%. We further analysed yearly UV-doses in Bilthoven comparing measurements and models, using ground based input data, and found good average agreement between measurements and models for 5 years of data (within 3% for the yearly totals). Yearly measured UV-doses for four locations in Europe with latitudes from 47^o N up to 61^o N are compared with UV-doses obtained with modelling using satellite observations (TOMS ozone and reflectivity data are used). Deviations found range from 1 to 10%, but are likely to be smaller (probably to 1-6%) following cosine corrections for two of the measured data sets. The deviations show a seasonal dependence, especially when snow cover is involved. The use of reflectivity measurements from the satellites for the estimation of cloud effects can only give meaningful results if the ground albedo is properly estimated. Without snow the albedo is usually low (around 0.02) and of limited influence, but the albedo can be much higher when the ground is covered with snow (albedo between 0.1 and 0.9). A correct estimate of the snow albedo is required because otherwise the snow reflections are interpreted as clouds leading to too low values for the modelled UV-irradiance. The average deviations during periods with snow cover can amount to 40-50% errors. This was observed for Tromsoe in north Norway situated at 69^o N where the snow cover can remain until May, and thus the yearly UV-dose in that case is considerably underestimated. For Garmisch-Partenkirchen (at 47^o N and 730 m altitude) a similar underestimate was observed during winter, including the MAUVE-campaign period in March 1999 due to large amounts of snow. The under estimation of yearly UV-doses due to the omission of the snow albedo has limited influence on the yearly total UV-dose for Garmisch-Partenkirchen and Jokioinen (at 60 N) since the winter half year contributes no more than 10-20% to the yearly UV-dose. Snow albedo plays no role whatsoever for Bilthoven and Brussels. The variation between measured daily doses and modelled daily doses for Bilthoven and Brussels is typically around 30%. This variation reflects the local daily variability in clouds and the variation in other atmospheric parameters like aerosol and tropospheric ozone, which are not included in the dynamic variables in the present model.

Three different cloud correction schemes using satellite observations were compared in a large statistical analysis with a ground based empirical cloud correction for the UV-irradiance. The empirical method was based upon the link between the reduction in UV due to clouds and the reduction of ground level global radiation. The scheme using TOMS reflection data provided the best results for the six years of summer data analysed and on average agrees within 1-2% with the ground based analysis. On a day to day basis a relative standard deviation of only 10% is observed between the averaged ground based reduction factor for an ISCCP grid cell and the reduction factor derived from the TOMS reflection data. For the monthly values the standard deviation is reduced to 3%. These results indicate that the satellite derived cloud correction provides highly accurate and representative results for the grid cell analysed if the ground albedo is low.

The analysis of long term trends requires that data are available over prolonged periods in time and that the input data are acquired with sufficiently stable methods. An analysis over nearly twenty years of yearly UV-doses shows that the TOMS-based analysis agrees well with the ground based analysis indicating a good stability of the satellite based and ground based data. This holds for the cloudless sky analysis as well as for the cloud-included analysis for the central part of the Netherlands. An extension to other areas would be useful.

It should be noted that in the present analysis systematic changes in tropospheric ozone and aerosols have not been included. Results obtained in the context of the SULPHATE project indicate that these tropospheric changes do probably not have a considerable influence on the changes in yearly UV-doses calculated for the past two decades. For longer time-scales the influences might be relevant (Guicherit et al 2000).

A comparison between UV-doses derived from TOMS and GOME ozone data shows differences in yearly doses between 0-8% over the European continent. This indicates that one could expect stepwise changes in a trend analysis when combining data from different sources in a single UV-trend analysis.

4. The application of UV- and UV-risk maps in environmental assessments

4.1 Introduction

UV-maps can be an important tool to study the geographical variability of changes in the yearly UV-doses in relation to environmental changes, and thus can support environmental assessments. Connected to dose-assessment models the UV-maps can be used to estimate UV-radiation risks. This chapter shows some examples of UV-radiation and risk maps, which are relevant for environmental assessments. The analysis is focused on maps that show the effects of changes in ozone and do not include the changes due to clouds and other atmospheric parameters. In view of the important modifying role of clouds this is a limitation when it comes to fully assessing the changes in the UV-climate, but it does enable the separated analysis of different factors influencing the UV. For environmental assessments this separation is relevant. Clouds introduce a large year to year variability in ground level UV and thus can obscure the observation of the trends due to ozone depletion. An analysis of trends due to changes in clouds would, in view of the large year to year variability, require an analysis over at least thirty years. From the perspective of skin cancer risk assessments the increases over longer time periods are important and not so much the year to year variability. The next sections will give some examples of UV-maps and UV-risk maps related to ozone changes.

4.2 Changes in UV-doses

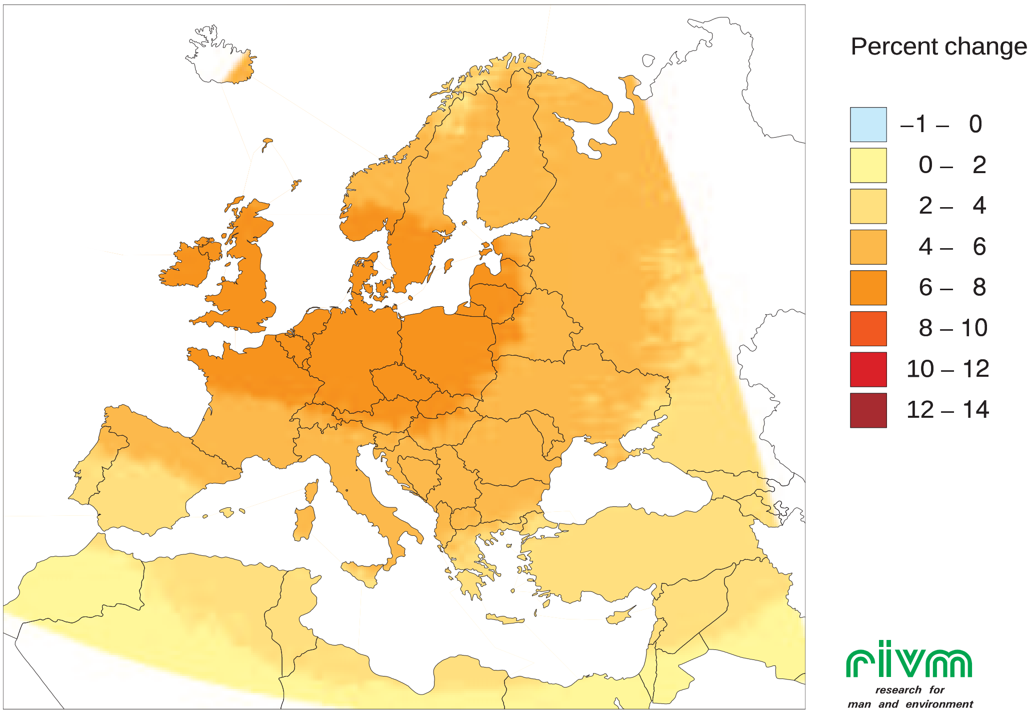
Figure 4.1 provides an analysis of UV-changes in relation to ozone changes over the European continent since 1980. To avoid a large year to year variability the 1980 UV-doses are obtained by averaging UV-doses over the years 1979-1981. The 1991 UV-radiation levels are also calculated as an average over three years (1990-1992). The 1997^1/1980 and 1998^1/1980 maps show the differences between the year indicated (1997 and 1998) and the average over three years for 1980. The 1998^2/1980 map shows the average over 1997 and 1998. The maps show the relative percent increase calculated for each location using:
UVrel = 100×(UV(199x) – UV(1980)) / UV(1980)

The results indicate that the largest relative changes in UV due to ozone changes are seen in North western Europe. Around 1991 the increase was maximally around 7%, in 1997 the increases were maximally around 11%, but a remarkable drop was observed in 1998 where the relative increase compared to 1980 was maximally around 4%. Averaged over the two years 1997 and 1998 the increases observed compared to 1980 are roughly similar to the changes over the period 1991/1980: maximally around 7%.

4.3 Changes in skin cancer risks

Figure 4.2 shows the excess skin cancer cases per million per year if the UV-increases observed were maintained for a lifetime. Compared to the relative changes in UV the excess risk maps show higher excess risks in the more southern regions of Europe. The calculations are based on the sensitivity and behaviour of the Dutch population. Maximum increases are around 200 excess cases per million per year. If the ozone layer starts to recover in the next decades the risks might be somewhat lower than indicated in this analysis.

Relative change yearly UV dose 1991/1980



Relative change yearly UV dose 1997[1]/1980

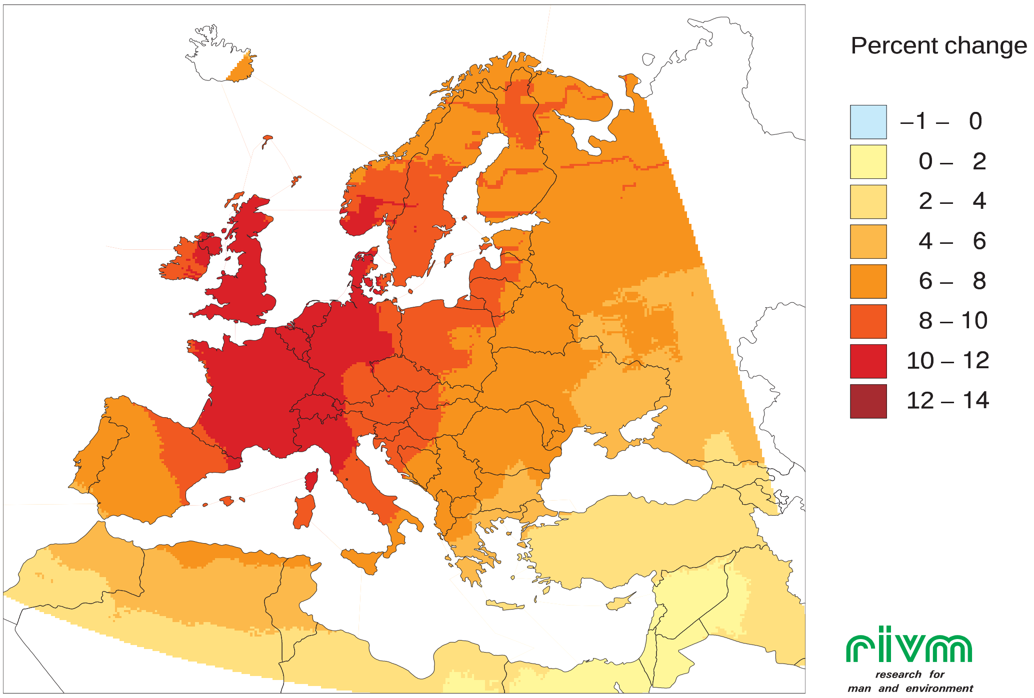
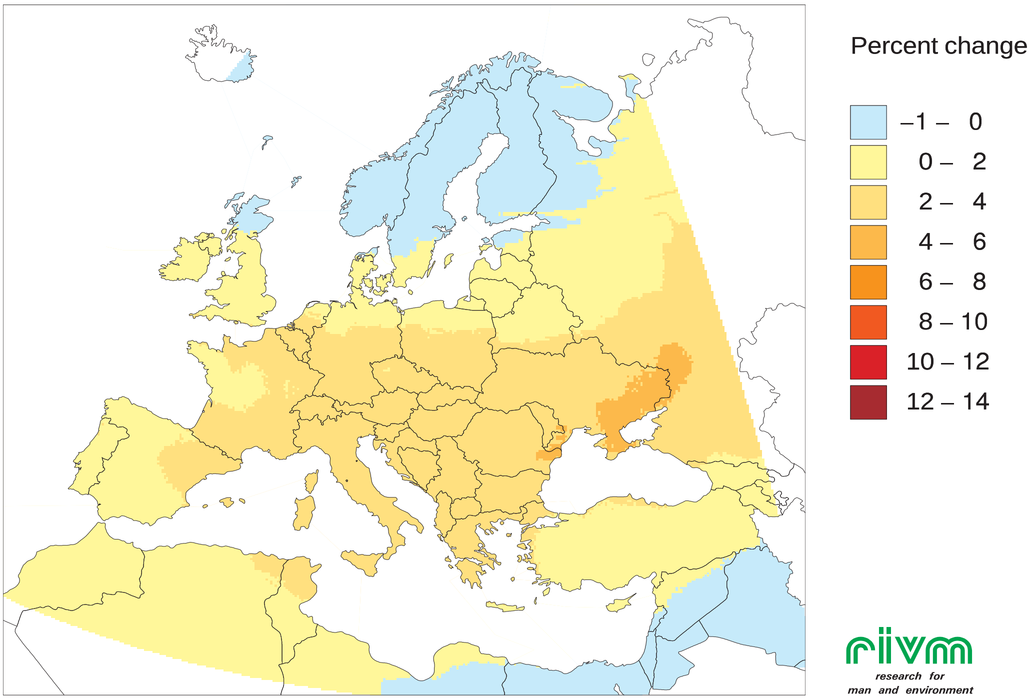
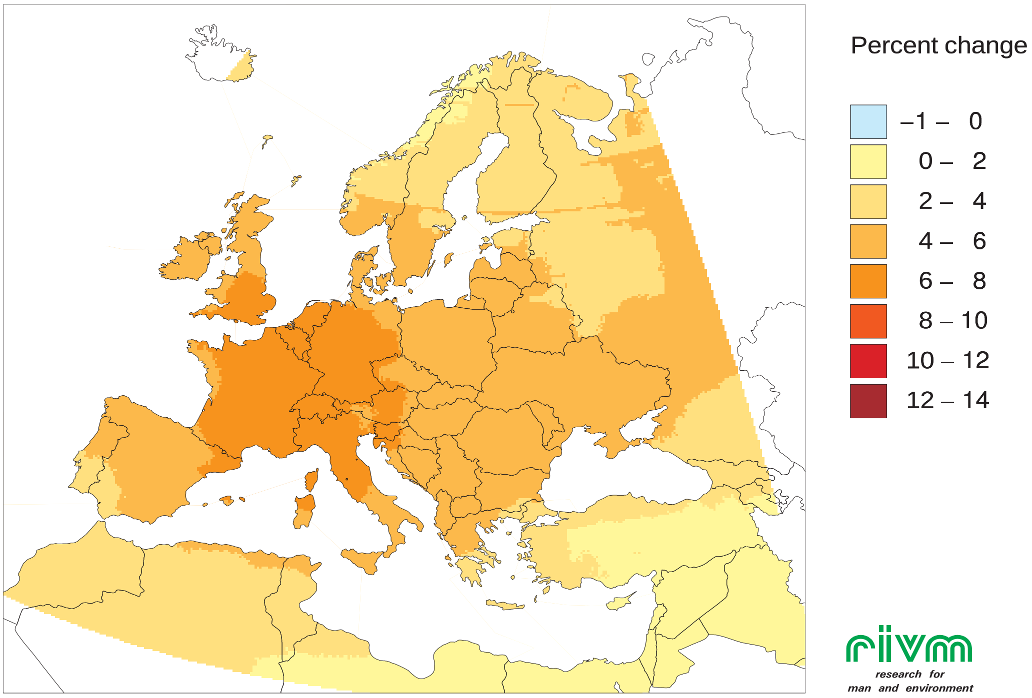


Figure 4.1A Relative change in yearly effective UV-dose (SCUPh): 1991-1980 (top), 1997-1980 (bottom)



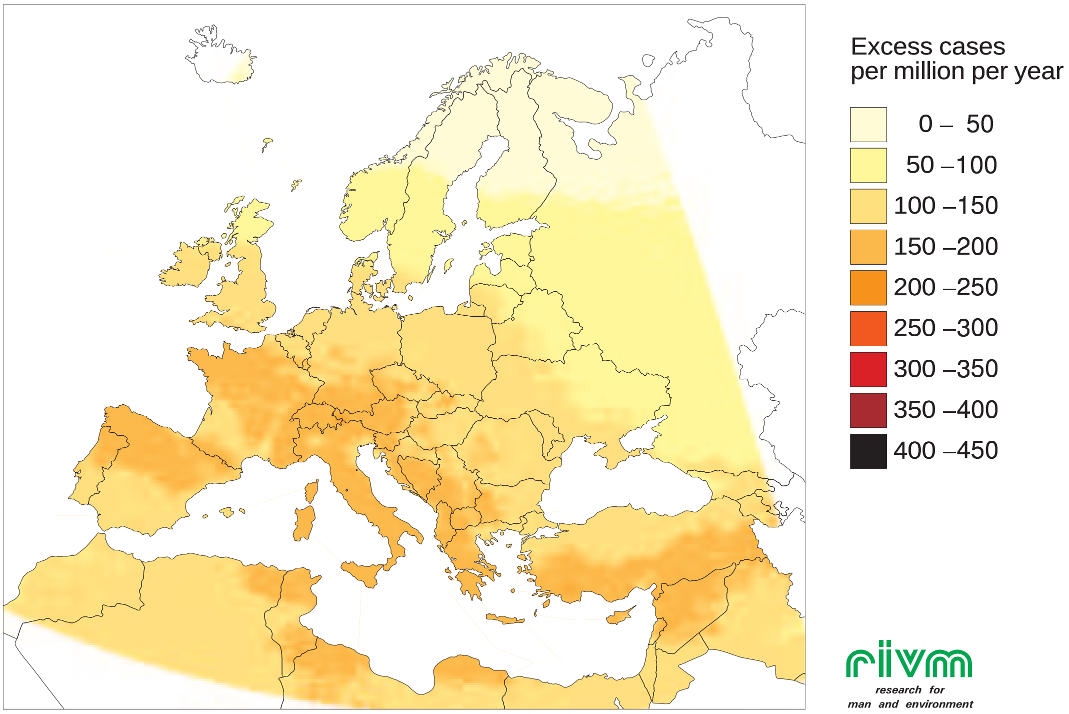
Relative change yearly UV dose 1998^1/1980



Relative change yearly UV dose 1998^2/1980

Figure 4.1B Relative UV-change: 1998-1980 (top), average 1997/1998 versus 1980

Excess skin cancer risks based on 1991/1980 UV change



Excess skin cancer risks based on 1998^2/1980 UV change

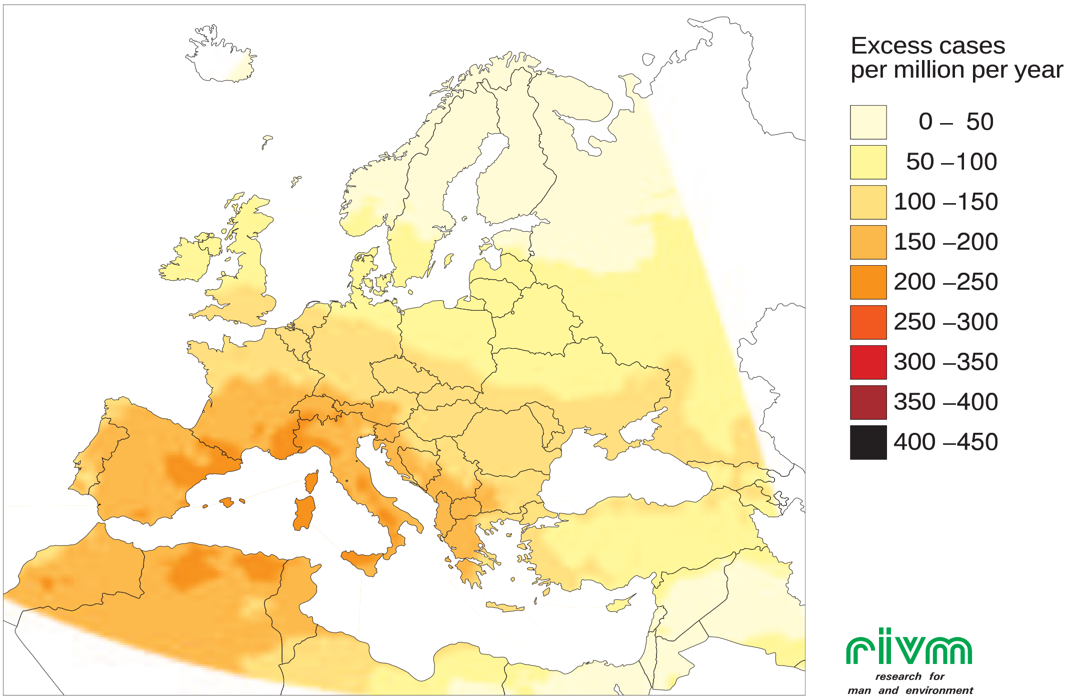


Figure 4.2 Excess skin cancer cases due to ozone depletion

4.4 Application of results

4.4.1 Excess UV-maps and UV-risk maps in environmental assessment studies

The UV- and UV-risk maps, obtained using the methods developed in the CUBEO-project, have been included in a number of key publications on integrated environmental assessments from the European Environmental Agency (EEA) and the National Institute of Public Health and the Environment (RIVM). These key publications directly relate to the core tasks of the EEA and RIVM. The contributions to these integrated assessment reports show the increases in yearly UV-doses over the European continent related to decreases in ozone and/or the possible increases in skin cancer incidence associated with these changes. The results support the conclusions that it is very important to fully and globally comply with the countermeasures as described in UNEP's strictest Amendments of the Montreal protocol on Substances that Deplete the Ozone Layer, which were agreed upon in the context of the Vienna Convention to protect the ozone layer.

We will briefly summarise the role of RIVM and EEA and the position of the core assessments, and give an overview of these integrated core assessments which include results obtained in the CUBEO-project.

The core responsibilities of RIVM are specified in the RIVM Act of 21 October 1996 and include:

- To carry out supportive research for governmental policy development and supervision of public health, nature, and the environment.
- To report periodically about the state of, and outlook for public health, nature, and the environment.

A statutory regulation in the Environmental Protection Act makes RIVM the environmental planning agency for the Dutch ministry of Housing, Physical Planning and the Environment (VROM). In this capacity RIVM compiles an annual Environmental Balance (Sheet), which describes to what extent changes in environmental quality development correlate to the environmental policy pursued, and an Environmental Outlook issued every four years, describing the environmental quality outlook in relation to policy goals for a period of at least the next ten years. The Environmental Outlook serves as scientific basic document for the National Environmental Program.

In addition to these national tasks RIVM serves as a Thematic Centre Air Quality, as part of the European Environmental Agency (EEA). The aim of the European Environment Agency is to establish a seamless environmental information system. This is done to assist the Community in its attempts to improve the environment and move towards sustainability, including the EU's efforts to integrate environmental aspects into economic policies.

UV- and or UV-risk maps obtained with methods developed in the context of the CUBEO project were reported in several environmental assessment reports, and a selection is available on the world wide web:

http://themes.eea.eu.int/toc.php/issues/ozone (EEA-site)

http://www.rivm.nl/milieucompendium (RIVM-site; in Dutch): C (milieudruk), subject C3.6 Increase in UV-radiation above Europe, and subject E effects E2.10: Additional skin cancer Risk caused by increased UV-radiation.

The following integrated assessment reports use the results from RIVMs UV-(risk-)mapping:

- Environment in the European Union at the turn of the century, Environmental Assessment report no 2; European Environmental Agency, Luxembourg ISBN-92-9157-202-0, 1999
- Data Issues of Global Environmental Reporting: experiences from GEO-2000, Jaap van Woerden (ed),UNEP/DEIA&EW/TR.99-3, RIVM 402001013, ISBN 92-807-1823-1, 1999.
- Europe’s Environment: the second assessment, European Environmental Agency, Oxford, ISBN 92-828-3351-8, 1998
- MB99, Dutch national environmental assessment study 1999
  Milieubalans 1999, Het Nederlandse milieu verklaard, ISBN 90 140 62273, RIVM, Bilthoven 1999
- MC99, Dutch national overview of environmental facts 1999
  Milieucompendium 1999, Het milieu in cijfers, ISBN 90 14062 29 X, RIVM, Bilthoven 1999
- MB98, Dutch national environmental assessment study 1998
  Milieubalans 1998, Het Nederlandse milieu verklaard, ISBN 90 422 02262, RIVM, Bilthoven 1998

4.4.2 Scientific reports and publications

Further papers and reports with contribution from map-making activities in the MAUVE/CUBEO period:

Matthijsen, J., Slaper, H. and Velders, G. J.M., 1998. A method to map UV climatology using earth observation. European Conference on Atmospheric UV Radiation, 29 June – 2 July 1998 Helsinki, Finland. Abstract, oral presentation

Matthijsen, J., Slaper, H., Reinen, H.A.J.M., and Velders, G. J.M., 2000. Reduction of solar UV by clouds: A comparison between satellite-derived effects and ground-based radiation measurements. J. Geophys. Res., 105, 5069-5080, 2000

Matthijsen J., P.N. den Outer, H. Slaper, 1999. Reduction of Solar UV by Clouds: A Remote Sensing Approach Compared with Ground Based Measurements, EGS XXIV General Assembly April '99, The Hague, The Netherlands, abstract and oral presentation.

Matthijsen J., P.N. den Outer, H. Slaper, G. Velders 1999c. Reduction of Solar UV by Clouds: A Remote Sensing Approach using TOMS reflectivity versus ISCCP-D1 cloud data, IRCTR symposium; remote sensing of cloud parameters: retrieval and validation, October 1999 Delft, The Netherlands. Abstract and oral presentation

Peeters, P., P. Simon, G. Hansen, R. Meerkoetter, J. Verdebout, G. Seckmeyer, P. Taalas, H. Slaper, 1999. MAUVE: a European initiative for developing and improving satellite derived UV maps, NRPB International Workshop on UV radiation, exposure, measurements and protection, October 1999 Oxford, UK.

Slaper, H., Velders, G. J.M., and Matthijsen, J., 1998. Ozone depletion and skin cancer incidence: a source risk approach. J. Hazardous Mat., 61, 77-84.

Termorshuizen, F., J.Garssen, J.J. Maas, W.G. Goettsch, J. Matthijsen, H.Houweling, H. van Loveren, 1999. UVB and infectious diseases: exposure assessment by means of a retrospective questionnaire for an epidemiological study: presentation of first results, RIVM-report nr. 640300 001, Bilthoven.

Weele, M. van, T. J. Martin, M. Blumthaler, C. Brogniez, P. N. den Outer, O. Engelsen , J. Lenoble, G. Pfister , A. Ruggaber, B. Walravens, P. Weihs, H. Dieter, B.G. Gardiner, D. Gillotay, A. Kylling, B. Mayer, G. Seckmeyer, W. Wauben, 2000. From model intercomparison towards benchmark UV spectra for six real atmospheric cases, J.Geophys. Res., 105, 4915-4925, (2000).

5. Conclusion

The construction of UV-(risk-) maps can be a valuable tool in assessing changes in the UV-climate in relation to environmental changes. The major parameters that influence the effective UV at ground level are: solar zenith angle, total ozone column (and ozone profile), cloud optical properties, altitude, atmospheric aerosol concentrations (and aerosol optical properties), and ground albedo. The relative importance of these factors varies with season and from place to place. An accurate detailed determination of these parameters with sufficient temporal and spatial resolution is often not possible, and thus the validation of UV-radiation maps is a challenging task. This report, in combination with additional information gained in the MAUVE project, provides only first steps in the validation and error budget determination of UV-radiation maps. The results can not be regarded as fully conclusive, but provide a first indication of the uncertainties involved. The identification of the main uncertainties has led and will lead to further improvements of the UV-mapping methods.

We focused in this report on the validation of methods that are used in environmental assessments. These methods are designed to analyse UV-radiation levels over prolonged time periods, and thus less focused on high accuracy on a local scale at a high temporal resolution. The latter determinations require input with higher temporal and spatial resolution, whereas for environmental assessments time and spatial averages are sufficient, and the focus is on proper identification of changes over a time- period of many years. This implies that availability of the data sets used in the derivation of the UV-maps over longer time periods is very important. The fact that a time span of years needs to be covered implies that the calculations must be sufficiently fast, because the determination of yearly effective UV-radiation levels over the full European continent requires time and wavelength integrated calculations for each grid cell.
Yearly UV-doses at four locations in Europe ranging from 47 N to 61 N compared within 10% with the calculated UV-doses using the TOMS ozone data and TOMS reflection measurements. Given the fact that two ground based instruments were not corrected for cosine errors it is likely that the agreement is within 6% for these four sites. For the northerly station Tromsoe, at 69 N, the yearly total is not as accurate due to the omission of snow albedo in the present approach. It was found that during periods of snow cover the UV-dose could be underestimated by 40-50%. Similar deviations, due to snow albedo, were observed during the MAUVE campaign in Garmisch-Partenkirchen in March 1999. However, the yearly UV-doses for Garmisch-Partenkirchen and Jokioinen (Finland) were not underestimated, despite the errors due to snow cover in the winter period.

The reduction of UV by clouds was analysed in a large statistical study comparing ground based reduction with reductions based on three different methods using satellite observations. The method using TOMS reflectivity measurements was found to be in close agreement with the ground based analysis. For six years of summer data the agreement was on average within 2% and the relative standard deviations for monthly averages is 3%. These results indicate that the satellite derived cloud correction provides good average agreement with ground based cloud corrections and representative results for the grid cell if the ground albedo is low. Changes over time are important from the perspective of environmental assessments. The direct comparison of changes derived from modelling using ground based input data with an analysis using the satellite data shows good agreement. The 1997 UV-dose in Bilthoven was calculated to be 18% higher than the 1984 UV-dose using the ground based analysis and 21%

higher using the satellite based analysis. Half of this change is due to the change in ozone and the other half due to the variation in clouds. These figures should be seen as an example to indicate the accuracy of the calculated changes and not as a trend assessment.

Further improvements of the methodology should focus on an improved incorporation of ground albedo in the analysis, and the inclusion of additional atmospheric parameters in the dynamical modelling (like aerosols and tropospheric ozone). The BCRS supported project SULPHATE has studied the methods that can be used to include tropospheric changes in the UV-mapping methodology. This improvement of the methodology will be included in the RUBEO-project, which follows the CUBEO project.
Further statistical comparison of UV-mapping methods with ground based measurements and other mapping techniques can lead to improvement of the UV-mapping methods and to a better understanding of the uncertainties involved in UV-mapmaking. The UV-database that is presently being developed in the context of the fifth framework EU-project EDUCE (European Database for Ultraviolet radiation Climatology and Evaluation) offers a unique opportunity for further validation and improvement of the UV-mapping methods. The combination of the ground based UV-measurements at a limited number of sites with the geographically explicit UV-mapping obtained from satellite observations supports the determination of the (European) UV-climatology.
Long term environmental assessments require accurate data, obtained with sufficiently stable instrumentation. The comparison between UV-maps based on GOME and TOMS total ozone data shows that changing from one instrument to another is not-trivial. In that respect it is important to further study the comparability and use of various satellite sources from the perspective of future trend assessments.

UV-maps have been used in European and national environmental assessment studies to analyse the change in the UV-doses in relation to ozone depletion. The combination with dose-effect models for skin cancer incidence enables the evaluation of UV-related skin cancer risks in relation to environmental change. Changes in cloud effects were thus far not included in assessment studies. The results obtained in this study indicate that including cloud effects is feasible in future assessment studies. A link with prognostic models for environmental change might further enhance the use of UV-maps in environmental policy evaluations.

Acknowledgements

This study was financially supported by the Netherlands Remote Sensing Board (BCRS) as part of the project CUBEO and by the EU as part of the project MAUVE. The improvement of the UV-transfer model was partly supported by the BCRS as part of the SULPHATE project. We thank dr H de Backer and dr D de Muer (KMI) for providing the ozone data for Uccle. The ISCCP-D1 data were obtained from NASA Langley Research Center EOSDIS Distributed Active Archive Center. The global solar irradiance data were obtained from the World Radiation Data Center (WRDC) and the total column ozone data by NASA's Nimbus 7 TOMS database. GOME level 4 ozone data were provided by dr Levelt (KNMI). The UV-measurements for different European sites were obtained within the context of the EU-project MAUVE, using the database developed in the SUVDAMA-project. Spectral UV-measurement data are from dr G Seckmeyer (presently at University of Hannover), dr P Taalas (FMI), dr D Gillotay (IASB) and dr H. Reinen (RIVM). A Arola (FMI) kindly provided plots of the monthly UV-doses. We thank dr H Reinen (RIVM) for his review of the manuscript.

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APPENDIX A: relation with MAUVE-work packages

Main contribution of RIVM to the MAUVE project:

1. A streamlined version of the UV MAP-producing program has been developed. The program provides for automatically logging of parameters sets and programs version.
2. Building of ISCCP-D1 and ISCCP-D2 cloud data set (cloud cover and cloud optical thickness) for the period 1986 to 1994 has been completed. Further TOMS and GOME column ozone data sets have been set up and are continuously updated.
3. Delivered 1 full year of monitoring spectral data to the MAUVE-database
4. Participated in the joint CUVRA-MAUVE validation campaign March 8 to 28 1999.
5. Analysed and distributed the results of spectral data for all 8 participating spectral instruments during the joint CUVRA- MAUVE campaign
6. Delivered UV-maps for the MAUVE leaflet, and Web–page.
7. Delivered model calculations for the CUVRA-MAUVE campaign, CIE-UV-maps monthly averaged daily dose for April 1984 and April 1994 clear sky and cloud, local noon dose rates for April 15, 16 and 17 1997 and March 18, 19 and 20.
8. Delivered model calculations, spectral and wavelength integrated dose rates and daily sums, required for the MAUVE validation Strategy.
9. Validation of cloud reduction method has been extended. J. Matthijsen et.al. Paper accepted for publication in J. Geophys. Res.
10. UV-maps have been used in national annual reports on the UV climate and trends

Description of RIVM contributions with respect to the Work Program

WP 1000: Capture of requirements
Is addressed in section 1.1 and 1.2.
RIVM has contributed to the Statement of User Requirements by specification of UV-maps from the perspective of environmental assessments.

WP 1123: Building of initial data: TOMS/ISCCP maps
Is addressed in section 2.3 and 2.5.
Building of ISCCP-D1 and ISCCP-D2 cloud data set (cloud cover and cloud optical thickness) for the period 1986 to 1994 has been completed. Further TOMS and GOME column ozone data sets have been set up.

WP 1125: Building of initial data: TOMS/ISCCP maps
Is addressed in section 3.3

WP 1200: Requirements of the pilot products
Is addressed in section 1.1 and 1.2.

WP 2112: Improvements of products: Broken cloud field
Is addressed in section 2.4.
In the existing UV mapping method a cloud parameterisation was employed using satellite data of cloud cover only. Based on literature studies and radiative transfer model studies we found that the parameterisation could be much improved by accounting also for the optical thickness of clouds. The cloud optical thickness is, like cloud cover, a property which can be derived from satellite measurements. Cloud cover and cloud optical thickness applied in the improved parameterisation are obtained from the International Satellite Cloud Climatology

Project (ISCCP) D1/D2 satellite data sets. The D1 and D2 sets consist of the most recent updates of atmospheric observation from an ensemble of satellites mapped to a 3-hourly global 280 km equal-area grid. The characteristics of the cloud cover and cloud optical thickness in the ISCCP D1/D2 satellite data sets can be found in the elaborate documentation by *Rossow et al.* [1996].

The UV-mapping method developed at RIVM is further improved especially with respect to the cloud parameterisation. The methodology is aimed at long-term assessments, focusing on trends in the UV-budgets and will in the future be connected to the UV-chain model, which enables prognostic risk evaluations. We have documented a new and updated version of our UV mapping method, which serves as a basis for future developments. Furthermore, we have extended the UV mapping method to include usage of level 4 ozone data of the global ozone monitoring experiment (GOME, platform: ERS-2 satellite) in addition to the existing usage of ozone data from the total ozone monitoring spectrometer (TOMS, platforms: Nimbus-7, Meteor-3 and Earth Probe). The implementation of the method now also allows the use of TOMS reflectivity measurements for cloud parameterisation.

WP 3130: Produce pilot products: Produce TOMS/ISCCP maps
Is addressed in section 4.2 (UV-maps) and 4.3 UV-risk maps).
The first UV maps have been constructed based on TOMS total column ozone data from the Nimbus-7 and Earth-probe satellites. Relative surface UV changes over the period 1980-1991 and over the period 1980-1997 have been calculated using the satellite data for ozone in combination with a UV-transfer model. The increases are largest in NW-Europe: around 8% (1980-1991) and around 12% (1980-1997). Results for 1998 show much smaller enhancements 3-4% maximally. In addition to the UV-change maps UV-risk maps have been produced and were used in assessment studies. Section 4.4 provides a summary of assessments reports and publications in which the UV-mapping methodology was used and validated.

WP 3160: Produce pilot products: Validation campaign
Measurement campaign (WP3160)
RIVM has participated in the joint MAUVE-CUVRA 3 weeks validation campaign, March 1999, with a mobile spectrometer, broad band UV and global radiation detectors. RIVM analysed and distributed the spectral readings for all 8 participating spectral instruments during the campaign. Good agreement was found between the readings of RIVM and IFU, University of Innsbruck (at 3-5% irradiance calibration). RIVM performed an on line data-analysis during the campaign, thus the campaign benefited from the use of the SHICrivm package which was developed in the context of the EU-project SUVDAMA. Details on the validation campaign are found in the IFU contribution.

Model calculations
Addressed in section 3.6 and 3.4
RIVM performed model calculations for all days in march 1999 embedding the measurement campaign period. Dose rates at local noon as well as daily integrated doses were calculated. The standard RIVM settings for atmosphere and ground properties were used. A clear underestimation of the UV dose was obtained in comparison to measurements and other models. Results for RIVM are indicated in section 3.7.
In the year round analysis of UV-doses the use of the reflection measurements provided good agreement with the measured values for four locations ranging from 47^{o} N up to 61^{o} N (1-10%, probably at 1-6%; section 3.4).

WP 3220: MAP inter-comparison

Is addressed in sections 3.4 and 3.5.

RIVM has contributed in the map inter-comparison by producing monthly averaged daily UV dose maps for the full years 1984 and 1997 (section 3.6). The difference in yearly effective UV-doses between 1984 and 1997 matched well with a ground based analysis for Bilthoven.

Preliminary results have been delivered and compared with IASB for dose rates at local noon in April 15th 16th and 17th 1997 and dose rates in March 18th 19th and 20th 1999.

In the year round analysis of UV-doses the use of the satellite reflection measurements provided good agreement with the ground based measured values for four locations ranging from 47° N up to 61° N (1-10%, probably at 1-6%; section 3.4).

WP 3230 Analysis of pilot products (section 3.5)

A large scale statistical analysis has been performed comparing three methods for the calculation of cloud effects on UV using satellite data with a ground based analysis. The results were obtained for six years of summer data and revealed very good agreement between the TOMS-reflection approach and the ground based analysis.

WP 4000: Exploitation of results

Is addressed in section 4.1, 4.2 and 4.3,

RIVM has contributed to the MAUVE leaflet, and the internet page.

Within the (inter)national tasks of RIVM contributions have been made with UV-maps and UV-risk maps to several national and international ozone assessments and risk assessment studies. An overview is given in section 4.4.

Appendix B: List of acronyms

AMK	-Assimilation Model KNMI, calculates daily ozone values from GOME measurements
AMOUR	-Assessment MOdel for Uv Radiation and Risks, (pre-operational) model under development in the context of CUBEO and RUBEO projects from BCRS.
BCRS	-BeleidsCommissie voor Remote Sensing, the Netherlands Remote Sensing Board
CUBEO	-Climatology of Ultraviolet radiation Budgets using Earth Observation, project at RIVM financially supported by the BCRS
CUVRA	-Characteristics of UV-radiation in the Alps; fourth framework EU-project
EDUCE	-European Database for Ultraviolet radiation Climatology and Evaluation; fifth framework EU-project; follow up of the SUVDAMA project
EEA	-European Environmental Agency
ESA	-European Space Agency
EU	-European Union
FMI	-Finnish Meteorological Institute
GDF	- Ground Derived UV-reduction Factor for the evaluation of cloud effects on ground level UV, using an empirical relationship based on ground-based pyranometer data (see section 3.3.2)
GOME	-Global Ozone Monitoring Experiment on board ESA’s ERS-2 satellite;
IASB	-Institut d’Aeronomie Spatiale de Belgique
ISCCP	-International Satellite Cloud Cover Project
KNMI	-Koninklijk Nederlands Meteorologisch Instituut
KMI	-Koninklijk Meteorologisch Instituut voor België
MAUVE	-Mapping UV by Europe, EU-project within the fourth framework program
NASA	-National Aeronautics and Space Administration
NDF	-UV-reduction factor derived from satellite derived cloud cover data, which are obtained from ISCCP; in the present analysis 3 hourly average cloud cover data are used ISSCP D1 data set (see section 2.4.2).
RB	-Robertson Berger UV-biometer, instrument applied at RIVM to measure erythemally weighted UV-irradiances
RIVM	-Rijks Instituut voor Volksgezondheid en Milieu, National Institute of Public Health and the Environment
RUBEO	-Risks and Ultraviolet Budgets using Earth Observation, project at RIVM financially supported by the BCRS
SDF	-Satellite Derived UV-reduction factor for the evaluation of cloud effects on ground level UV, using 3 hourly cloud cover data and cloud optical thickness data from ISCCP (D1 data set)(see section 2.4.3).
SULPHATE	-Surface Ultraviolet Levels; Prediction and History from Atmospheric Trends over Europe
SUVDAMA	-Scientific UV DAta Management, EU-project within the fourth framework program; spectral UV-measurements are used from the European UV-database designed within this project
SZA	-Solar Zenith Angle
TDF	-TOMS derived UV-reduction factor for the evaluation of cloud effects on ground level UV, using daily reflectivity measurements from the TOMS satellite instrument (see section 2.4.4)

TOMS	-Total Ozone Monitoring System, on board of NIMBUS 7, METEOR and Earth Probe satellites; source for total ozone measurements
UNEP	-United Nations Environmental Programme
UV	-Ultraviolet radiation (wavelength range 100-400 nm)
UV-A	-Ultraviolet radiation in the wavelength range 315-400 nm
UV-B	-Ultraviolet radiation in the wavelength range 280-315 nm
UV-C	-Ultraviolet radiation in the wavelength range 100-280 nm
UVTRANS	-Two stream atmospheric UV-transfer model developed at RIVM
VROM	-ministerie van Volkshuisvesting Ruimtelijke Ordening en Milieu; Dutch Ministry of Housing, Physical Planning an the Environment
WMO	-World Meteorological Organisation
WRDC	-World Radiation Data Center, data center from which the global radiation measurements were obtained