Methodology of the PROMOTE Integrated UV Record Service

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Contents

List of Acronyms

ACF	Aerosol Correction Factor
ASCII	American Standard Code for Information Interchange
CACF	Cloud and Aerosol Correction Factor
CF	Cloud Fraction
CIE	International Commission on Illumination
CMF	Cloud Modification Factor
CS	Clear-sky
DEM	Digital Elevation Map
EUVDB	European UV Database
FMI	Finnish Meteorological Institute
FTP	File Transfer Protocol
GADS	Global Aerosol Data Set
GMES	Global Monitoring for Environment and Security
GMT	Generic Mapping Tools
GOME	Global Ozone Monitoring Experiment
GrADS	Grid Analysis and Display System
GTOPO30	is a digital elevation model for the world, developed by United States Geological Survey
HDF	Hierarchial Data Format
IPA	Independent Pixel Approximation
ISCCP	International Satellite Cloud Climatology Project
KNMI	Royal Dutch Meteorological Institute (Koninklijk Nederlands Meteorologisch Instituut)
LUT	Look-Up-Table
MSG	Meteosat Second Generation
MTW	Moving Time Window
OMI	Ozone Monitoring Instrument
PROMOTE	PROtocol MOniToring for the GMES Service Element on Atmospheric Composition
SCIAMACHY	SCanning Imaging Absorption spectroMeter for Atmospheric CartograpHY
SDISORT	radiative transfer solver based on the pseudospherical discrete ordinates method
TEMIS	Tropospheric Emission Monitoring Internet Service
TOMS	Total Ozone Mapping Spectrometer
USGS	United States Geological Survey
UTC	Coordinated Universal Time
UV	ultraviolet
WCRP	World Climate Research Programme
WMO	World Meteorological Organization

1 Introduction

PROMOTE, PROtocol MOniToring for the GMES Service Element on Atmospheric Composition, delivers policy-relevant services on multiple atmospheric issues to end-users. It provides GMES services relevant to the ozone layer, UV-exposure on the ground, air quality, climate change and special applications. These services are directed at the needs for information on environment and climate by public authorities and governmental agencies. Some services are directed at the general public. More than 50 users from 16 countries and international organisations have signed Service Level Agreements for the PROMOTE services. In the current Consolidation Phase (Stage 2, 2006-2009) the PROMOTE strategy calls for an incremental enhancement of the ozone and UV services by providing more products of better quality. The methodology advocated in PROMOTE calls for the integration of surface data and space data into models. PROMOTE will further demonstrate the need for integration of space data in these models as well as the need for nesting these models in order to establish the connection between global, regional, and local scales.

The UV Record service provides long-term records of surface ultraviolet radiation data. University of Manchester is the core user of the service with the mandate of WMO. The starting point for Stage 2 of PROMOTE was a set of individual UV monitoring services developed in Stage 1 of PROMOTE. These are the TEMIS UV radiation archive that provides UV records based on GOME, SCIAMACHY and MSG data; and UV Record service that provides UV records based on Nimbus-7 and Earth Probe TOMS instruments. The Stage 1 services provide daily maps and local time series of UV index and daily dose data. In Stage 2 the UV Record service will be upgraded to become an integrated service that provides global and homogeneous surface UV time-series. This document describes the scientific methodology of the new integrated UV Record service. A prototype of the new integrated service will be available in 2008. The service will be completed in year 2009. Validation of the UV Record service will be based on utilization of ground-based spectral measurement data from the European UV Database (EUVDB) and UV time series obtained using reconstruction methods.

2 Sources of Input Data

The integrated UV Record is based on several sources of data based on multiple satellite instruments. This section describes them.

2.1 Assimilated Total Column Ozone

The source of total column ozone data is the PROMOTE assimilated long-term ozone record from TOMS, GOME, SCIAMACHY and OMI provided by KNMI. The assimilation system is called TM3DAM. The paper of Eskes et al. (2003) provides a more detailed discussion of the model, assimilation approach and references to related work. The assimilated data are in a regular grid whose dimensions are 181 and 240 in latitude and longitude, respectively. The available datasets are OMI (2004-present), SCIAMACHY (2002-present), GOME (1995-2003), and TOMS (1978-1993). The ozone data are converted into GrADS compatible binary format in prior of use.

2.2 ISCCP-D1 Cloud Data

International Satellite Cloud Climatology Project (http://isccp.giss.nasa.gov/, ISCCP) was established in 1982 as part of the World Climate Research Programme (WCRP) to collect and analyze satellite radiance measurements to infer the global distribution of clouds, their properties, and their diurnal, seasonal, and interannual variations. The resulting datasets and analysis products are being used to improve understanding and modeling of the role of clouds in climate, with the primary focus being the elucidation of the effects of clouds on the radiation balance. There are many versions of the ISCCP data, and for the PROMOTE UV Record service it was decided to use the ISCCP-D1 data. ISCCP-D1 contains merged spatial averages of satellite-derived cloud properties. The ISCCP-D1 data are given in a global 280 km equal-area grid with a time resolution of 3 hr. All the data are given in UTC time. The cloud information that are extracted from the ISCCP-D1 data are cloud fraction and the cloud optical depth for the cloudy part of the pixel. In prior of use of the ISCCP-D1 data for estimation of the transmission of UV radiation to the surface of the Earth, the extracted cloud fraction and cloud optical depth data are converted into a regular grid of 1 by 1 degrees. The time resolution as well as the spatial resolution of the data may not be optimal for the UV Record. However, it would be much more laborious to utilize the ISCCP-DX data set, as the data from different satellites have not been merged.

2.3 GADS Aerosol Climatology

Global Aerosol Data Set (http://www.lrz-muenchen.de/~uh234an/www/radaer/gads.html, GADS; Koepke et al., 1997) is a global aerosol climatology. The atmospheric aerosol particles are described by 10 main aerosol components which are representative for the atmosphere and characterized through their size distribution and their refractive index depending on the wavelength. These aerosol particles are based on components resulting from aerosol emission, formation and removal processes within the atmosphere, so that they exist as mixture of different substances, both external and internal. Typical components include water-soluble, water-insoluble, soot, sea-salt and mineral. The sea-salt particles are defined in two classes and the mineral particles in four. GADS version 2.2 was used. The optical properties of the aerosols were extracted on a 5 by 5 degrees regular grid for winter and summer for the wavelength of 300 nm assuming a relative humidity of 70%. The GADS climatology may not be representative globally, because in some regions the current aerosol emissions differ greatly from the emissions of the past. This has been taken into account in development of the integrated UV Record service, so that the UV Record time series can be updated if more accurate aerosol data become available.

2.4 MTW 360 nm Surface Albedo Climatology

The moving time-window (MTW) method (Tanskanen et al., 2003) is based on the assumption that the reflectivity values within a certain time-window around the day of interest form a sample of the reflectivity distribution whose lower tail corresponds to the clear sky case. An estimate of the surface albedo is obtained by fitting a linear function to the lower tail of the cumulative distribution of the sample. The wider the time-window is, the more information is available about the reflectivity distribution. However, use of a very wide time-window leads to underestimation of the surface albedo in case the surface albedo experiences a transient within the time-window. In order to account for the surface albedo transients the MTW algorithm aims at choosing an optimum time-window by narrowing and shifting the window during transients. The MTW algorithm was applied to the TOMS 360 nm Lambertian Equivalent Reflectivity (LER) time-series to construct daily surface albedo estimates for the Nimbus-7 period. Prior to the use of the MTW method the LER data were gridded to a 1 by 1 degree regular grid defining the grid cell value as the daily minimum LER value. Finally, the surface albedo climatology was constructed by averaging the resulting surface albedo estimates for the years 1979-1992.

2.5 GTOPO30 Digital Elevation Map

GTOPO30 is a digital elevation model (DEM) for the world, developed by United States Geological Survey (USGS). Elevations in GTOPO30 are regularly spaced at 30-arc seconds. However, for the UV Record service a DEM with a spatial resolution of 1 by 1 degrees is used. This DEM is based on GTOPO30 and it was downloaded from the TEMIS website (http://www.temis.nl/data/topo/dem2grid.html).

3 Method

The fundamental quantity of interest for the UV Record Service is the erythemal irradiance, that is defined as the spectral irradiance (W/m^2/nm) on a horizontal surface weighted with the CIE erythemal (sunburning) action spectrum. The erythemal irradiance (*E*) is estimated using the Independent-Pixel-Approximation, and it is calculated from

$$E = E_{cs}(z, \Omega, R_s, \theta) \times \left((1 - CF) \times ACF(\tau_a, \omega, R_s, \theta) + CF \times CACF(\tau_c, \theta, R_s, \tau_a, \omega)\right)$$

where E_{cs} is the clear-sky irradiance, *(1-CF)*ACF* is the contribution of the cloud-free part of the satellite pixel, and *CF*CACF* is the contribution of the cloudy part of the satellite pixel. *CF* is cloud fraction, *ACF* represents the attenuation of the UV radiation due to the aerosols, and *CACF* denotes the attenuation of the UV radiation due to the combined effect of the clouds and aerosols. The above described quantities (E_{cs}, *ACF*, and *CACF)* are determined by interpolation using precalculated Look-Up-Tables (LUTs) produced with SDISORT radiative transfer code within the libRadtran program package. The multidimensional LUTs depend on several parameters: altitude (z), total column ozone (Ω), surface albedo (R_s), solar zenith angle (θ), aerosol optical depth (τ_a), aerosol single scattering albedo (ω), and cloud optical depth (τ_c). The dimensions and the nodes of the three LUTs are summarized in Tables 1, 2, and 3. The erythemal irradiance is calculated using satellite data for every hour (UTC time) and the daily erythemal dose is determined from the hourly irradiances using the trapezoid integration method.

Table 1. CS LUT for the clear-sky erythemal irradiance, 24960 nodes

Parameter	N	Unit	Nodes
altitude (z)	4	Km	0, 2, 4, 9
total column ozone (Ω)	24	Dobson	100, 125, 150, 175, 200, 225, 250, 275, 300, 325, 350, 375, 400, 425, 450, 475, 500, 525, 550, 575, 600, 650, 700, 800
surface albedo (R_s)	13		0, 0.05, 0.10, 0.20, 0.30, 0.40, 0.50, 0.60, 0.70, 0.80, 0.90, 0.95, 1.00
solar zenith angle (θ)	20	Degrees	0, 10, 20, 30, 40, 50, 55, 60, 64, 67, 70, 73, 76, 78, 80, 82, 84, 86, 88, 89

Table 2. ACF LUT for the aerosol effect, 8190 nodes

Parameter	N	Unit	Nodes
aerosol optical depth (τ_a)	7		0, 0.1, 0.2, 0.4, 0.7, 1.0, 1.6
single scattering albedo (ω)	9		0.60, 0.70, 0.75, 0.80, 0.85, 0.90, 0.95, 0.98, 1.00
surface albedo (R_s)	13		0, 0.05, 0.10, 0.20, 0.30, 0.40, 0.50, 0.60, 0.70, 0.80, 0.90, 0.95, 1.00
solar zenith angle (θ)	10	Degrees	0, 10, 20, 30, 40, 50, 60, 70, 80, 88

Table 3. CACF LUT for the combined cloud and aerosol effect, 122850 nodes

Parameter	N	Unit	Nodes
aerosol optical depth (τ_a)	7		0, 0.1, 0.2, 0.4, 0.7, 1.0, 1.6
single scattering albedo (ω)	9		0.60, 0.70, 0.75, 0.80, 0.85, 0.90, 0.95, 0.98, 1.00
surface albedo (R_s)	13		0, 0.05, 0.10, 0.20, 0.30, 0.40, 0.50, 0.60, 0.70, 0.80, 0.90, 0.95, 1.00
solar zenith angle (θ)	10	Degrees	0, 10, 20, 30, 40, 50, 60, 70, 80, 88
cloud optical depth (τ_c)	15		0, 0.1, 0.3, 1, 3, 6, 10, 20, 30, 50, 70, 100, 150, 200, 250

4 Verification of the Look-Up-Tables

The LUTs were verified using a test program that generated random test cases that were solved using both full radiative transfer calculation and the look-up-table approach. The test method enabled a systematic way to verify that the look-up-table interpolation method gives erythemal irradiance with anticipated accuracy. The comparison also revealed small systematic biases caused by the interpolation method. The verification was carried out by comparing 10 thousand cases with randomly selected input parameters. The erythemal surface UV irradiances determined using one of the two combinations of the look up tables (either CS+ACF or CS+CACF) were compared to the ones calculated with a radiative transfer model.

In Figures 1, 2, 3, 4, 5, and 6 are shown the verification results for the cloud-free case. Figures 1, 2, 3, 4, and 5 show the percentage error (or deviation of the LUT given result from the reference calculation) of the erythemal surface UV irradiance as a function of total column ozone, solar zenith angle, surface albedo, aerosol optical depth, and single scattering albedo. Figure 6 shows the distribution of the percentage error. Figures 7, 8, 9, 10, 11, 12, and 13 show the results for the verification of the combined cloud and aerosol case. Figures 7, 8, 9, 10, 11, and 12 show the percentage error (or deviation of the LUT given result from the reference calculation) of the erythemal surface UV irradiance as a function of total column ozone, solar zenith angle, surface albedo, cloud optical depth, aerosol optical depth, and single scattering albedo. Figure 13 shows the distribution of the percentage error. The results show that the erythemal surface UV irradiances determined with the LUT approach (both CS+ACF or CS+CACF) agree well with the ones obtained using a radiative transfer model. The LUT method causes a minute systematic positive bias and some nearly random deviation from the reference method. The error statistics of the verification are summarized in Table 4. For the cloud-free case the behavior of the percentage error as a function of solar zenith angle shows some systematic features: the method tends to cause underestimation at small solar zenith angles and overestimation at large solar zenith angles. The method could be further improved by adding more nodes to the LUTs, but the overall performance of the method was considered fit for the purpose.

Table 4. Error statistics of the verification of the LUTs.

LUT Combination	Bias (%)	Std (%)
CS + ACF	0.46	1.21
CS + CACF	0.71	1.74

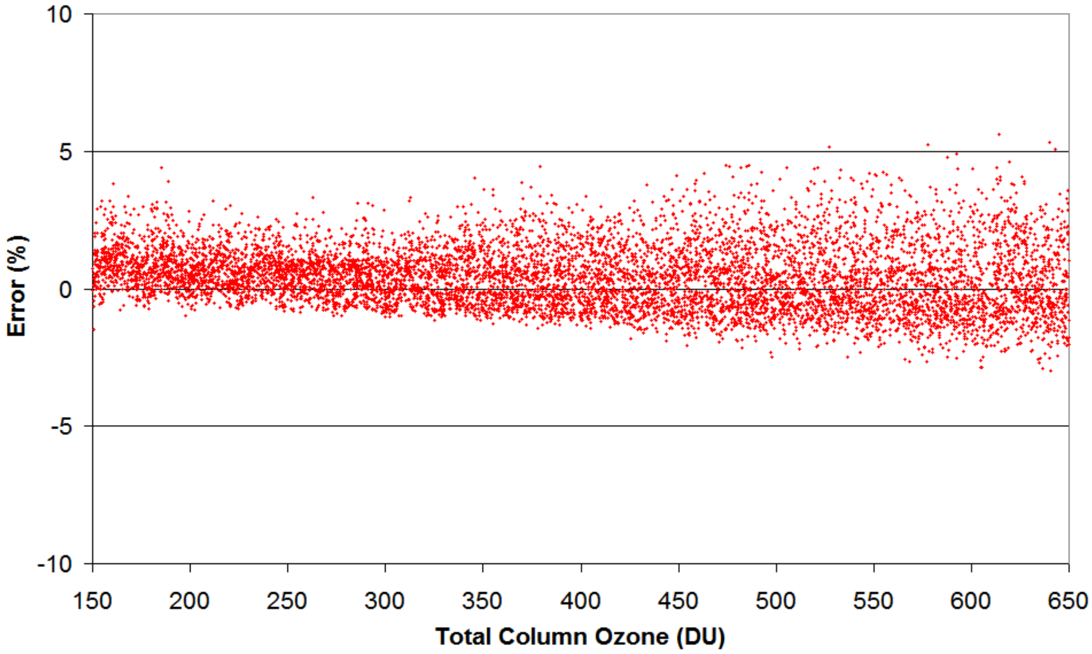

Figure 1. The error percentage of the product of the CS and ACF LUTs as a function of the total column ozone.

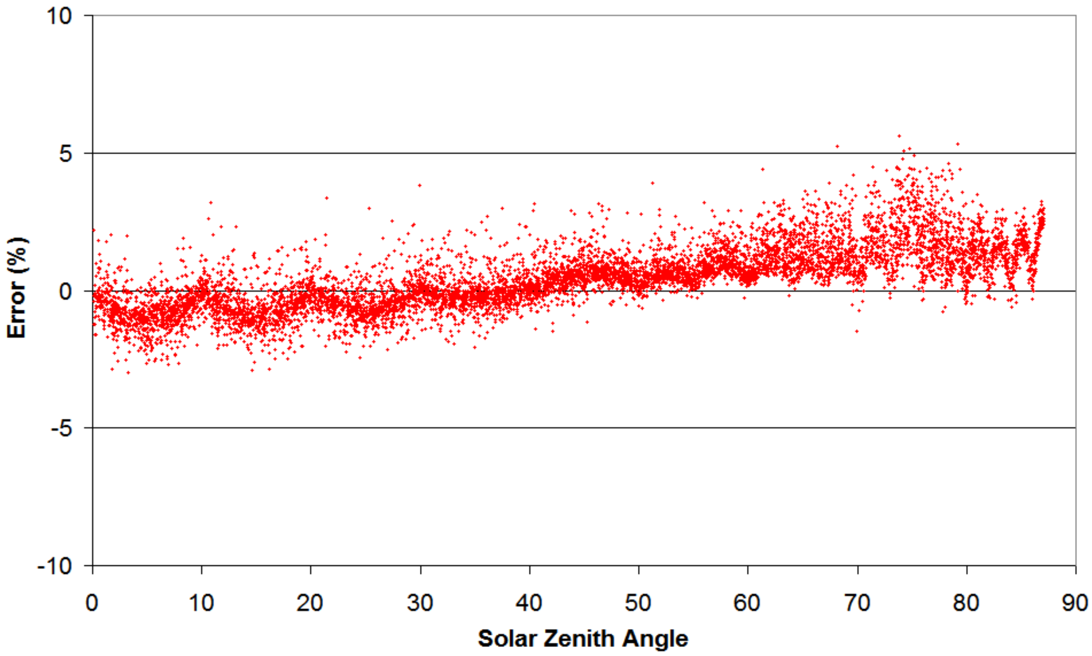

Figure 2. The error percentage of the product of the CS and ACF LUTs as a function of the solar zenith angle.

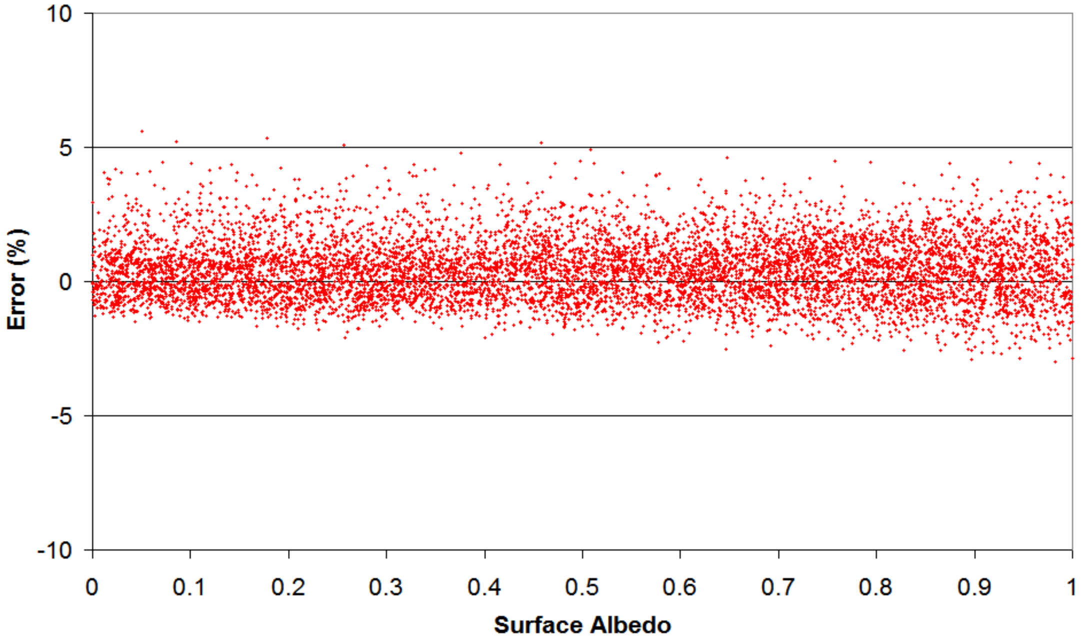

Figure 3. The error percentage of the product of the CS and ACF LUTs as a function of the surface albedo.

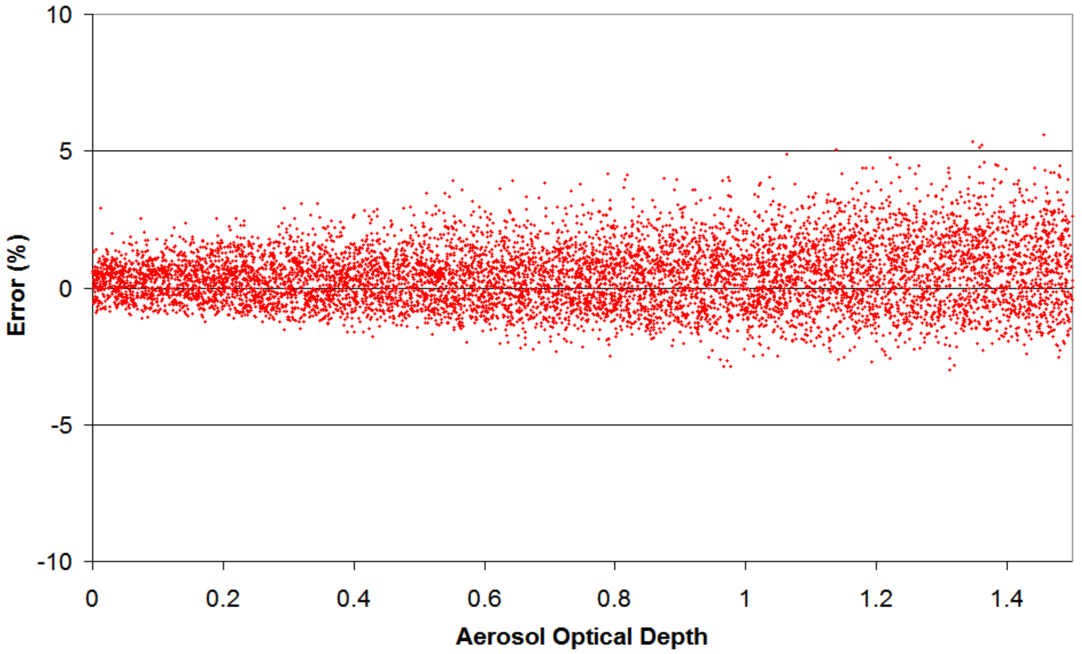

Figure 4. The error percentage of the product of the CS and ACF LUTs as a function of the aerosol optical depth.

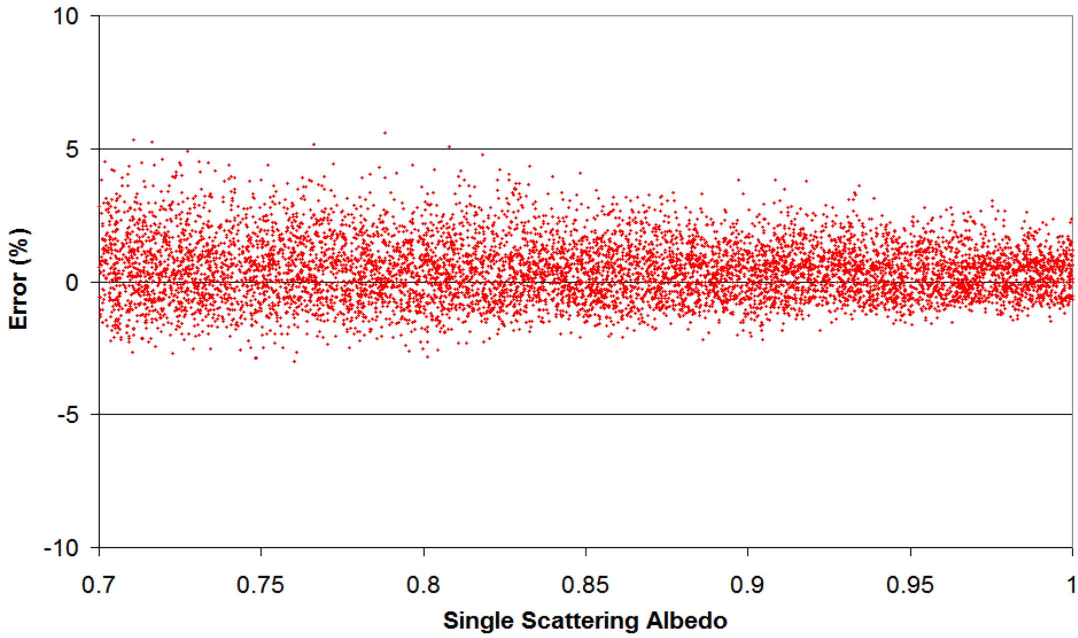

Figure 5. The error percentage of the product of the CS and ACF LUTs as a function of single scattering albedo.

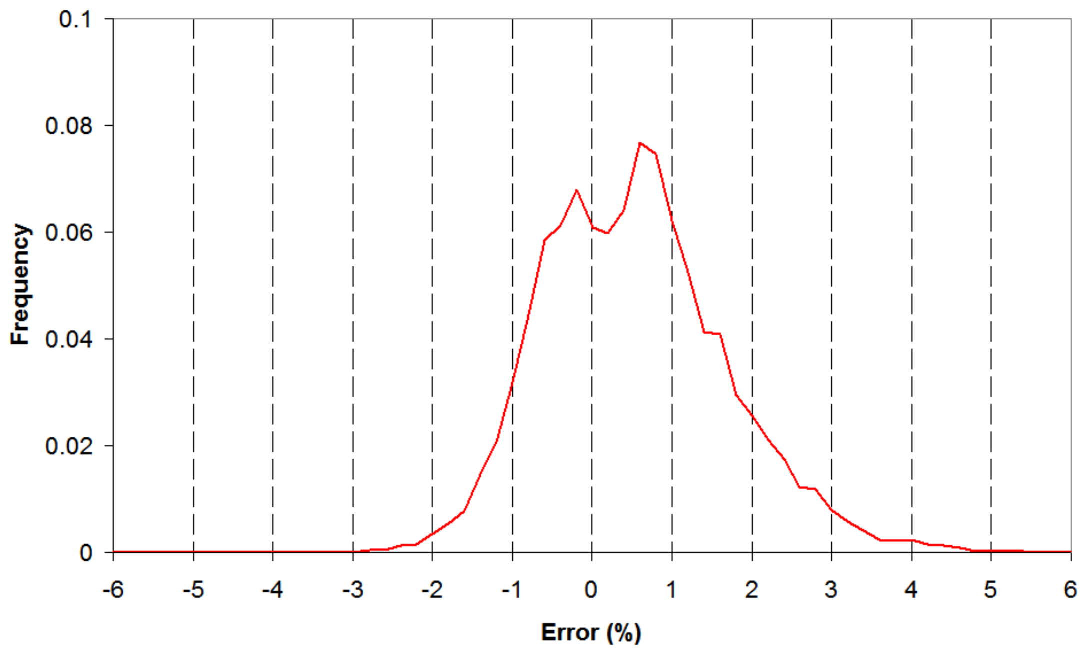

Figure 6. The percentage error distribution of the product of the CS and ACF LUTs.

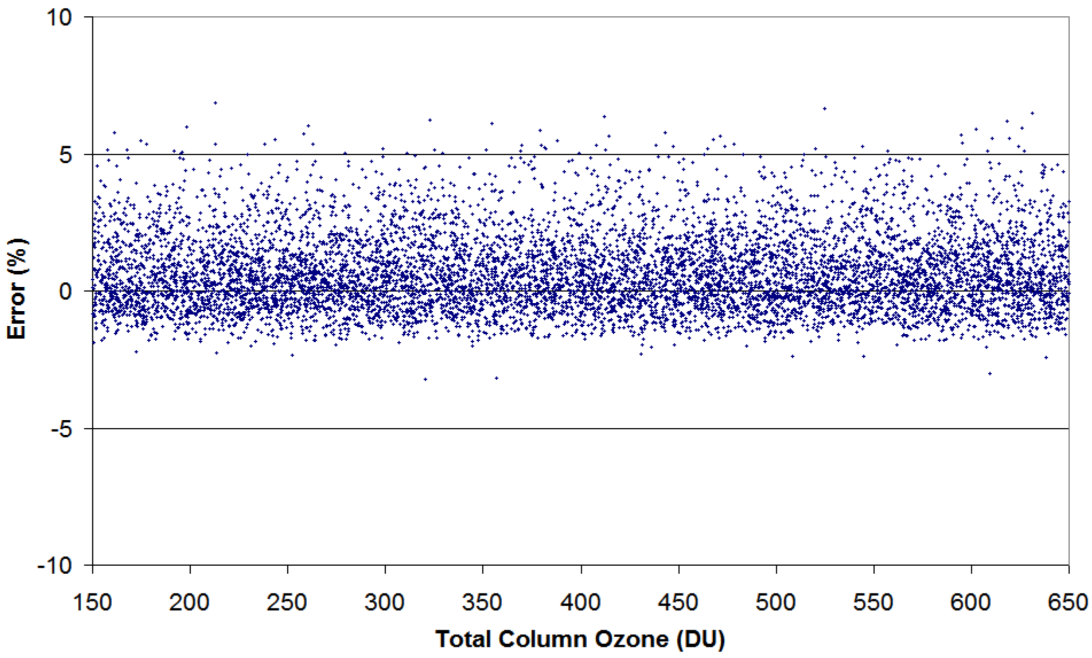

Figure 7. The error percentage of the product of the CS and CACF LUTs as a function of the total column ozone.

Figure 8. The error percentage of the product of the CS and CACF LUTs as a function of the solar zenith angle.

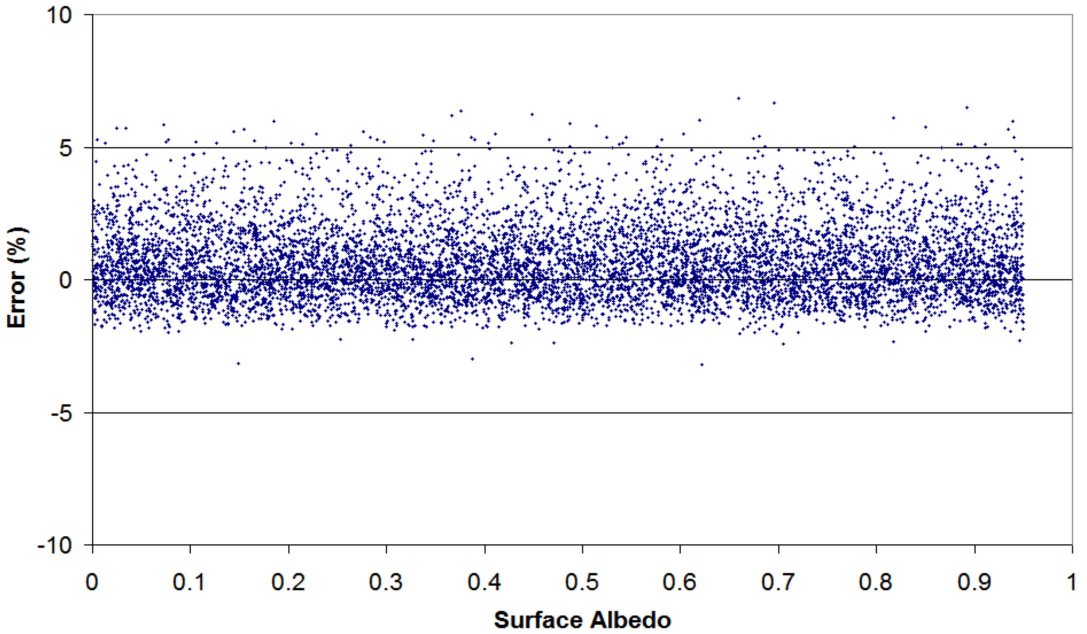

Figure 9. The error percentage of the product of the CS and CACF LUTs as a function of the surface albedo.

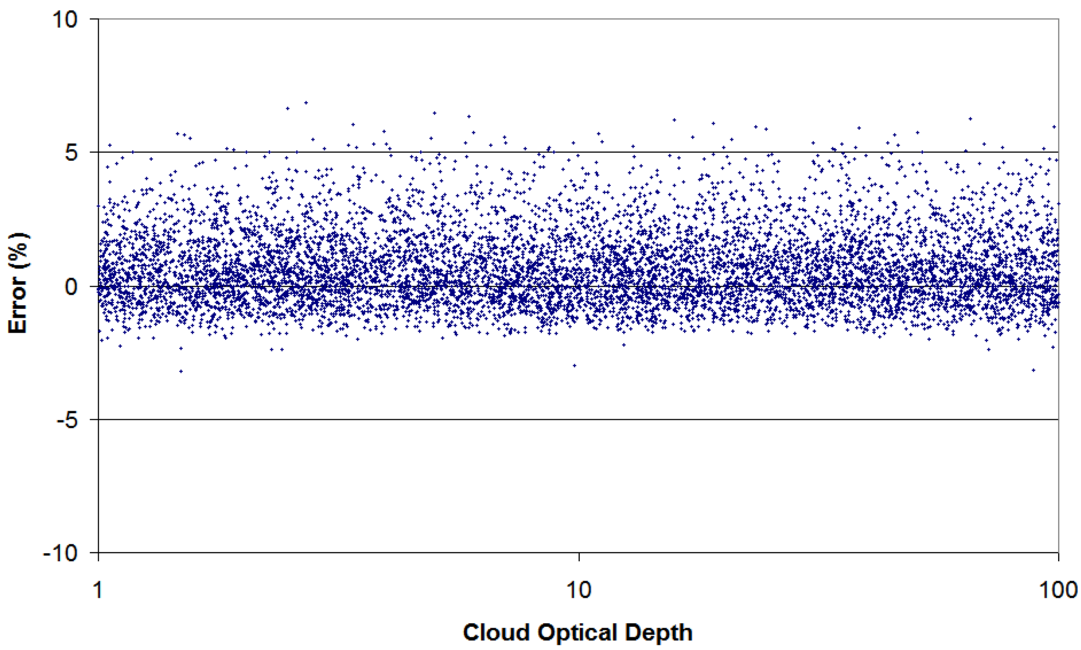

Figure 10. The error percentage of the product of the CS and CACF LUTs as a function of the cloud optical depth.

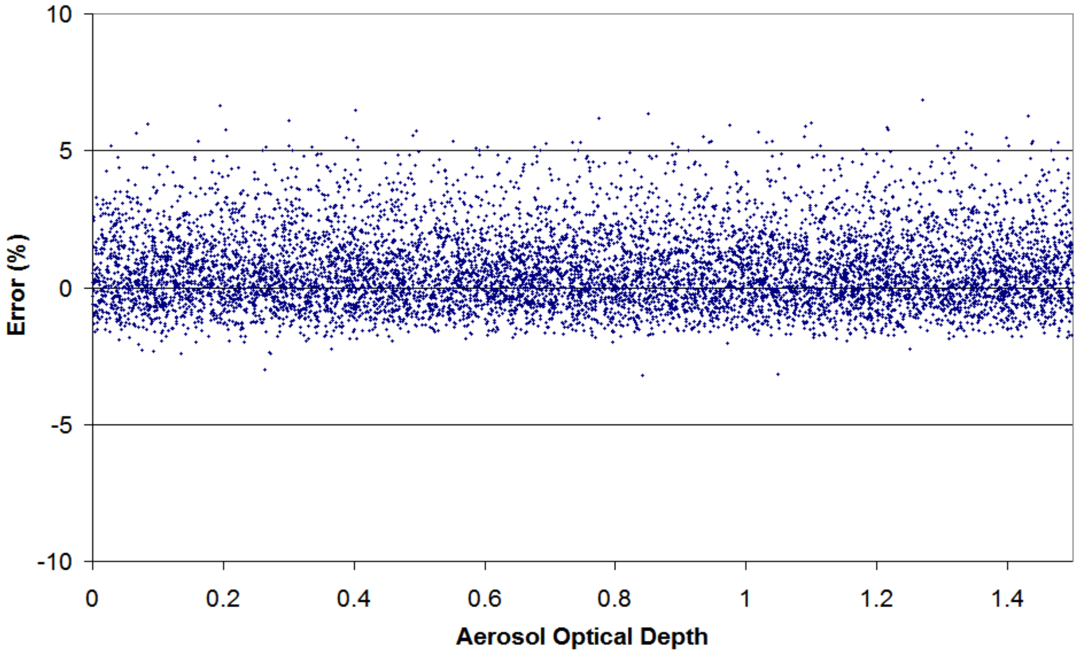

Figure 11. The error percentage of the product of the CS and CACF LUTs as a function of the aerosol optical depth.

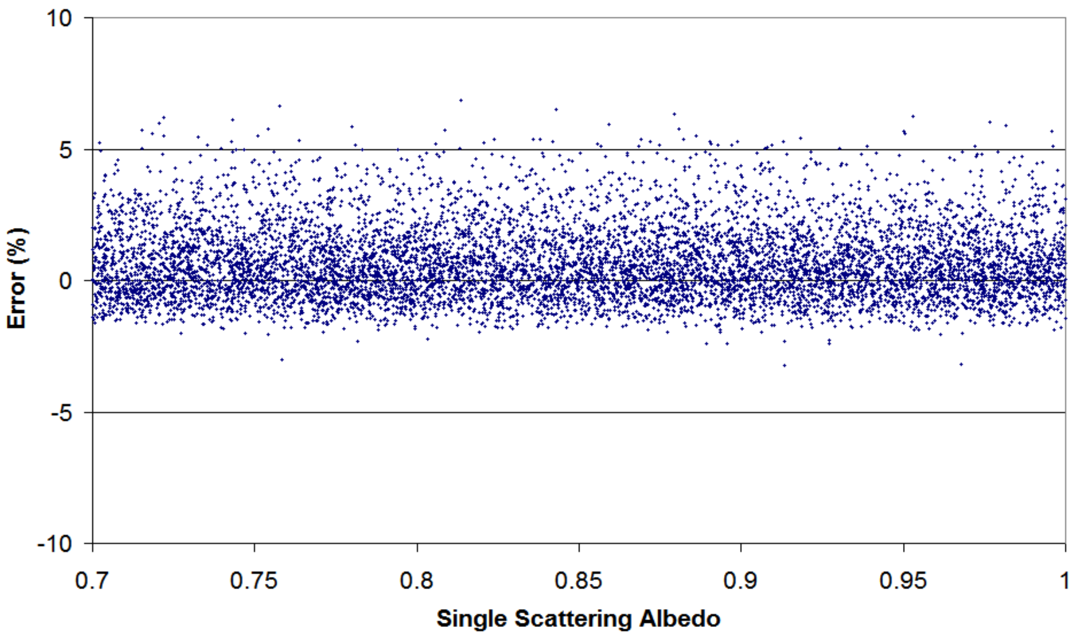

Figure 12. The error percentage of the product of the CS and CACF LUTs as a function of single scattering albedo.

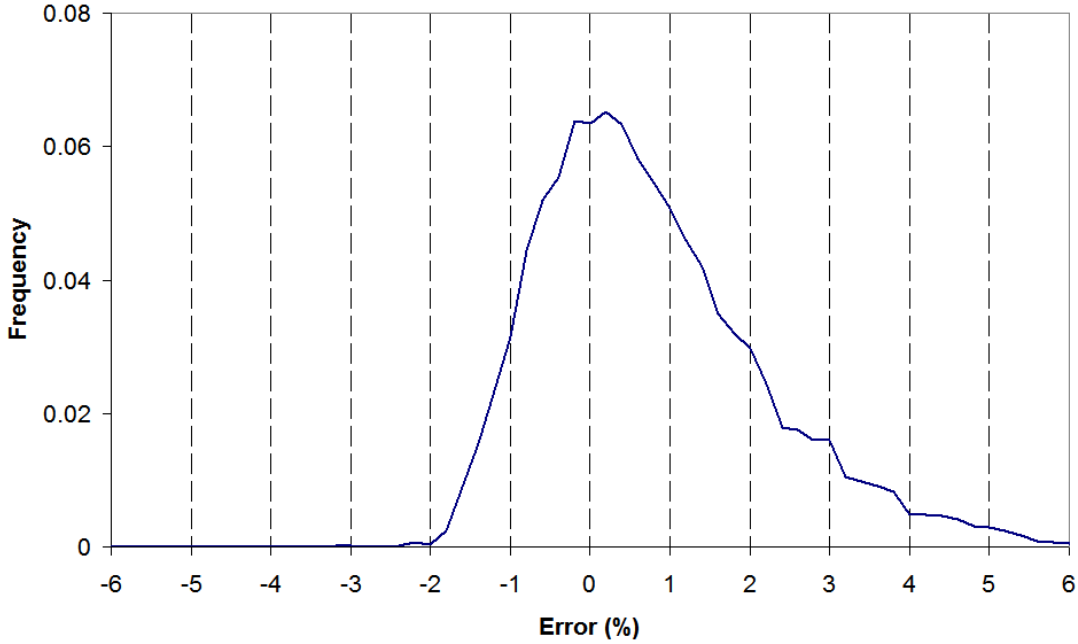

Figure 13. The percentage error distribution of the product of the CS and CACF LUTs.

5 Processing Scheme

The processing scheme of the UV Record service is depicted in Figure 14. It consists of six processing steps labeled in the scheme. The processing steps are described in more detail in the following sections.

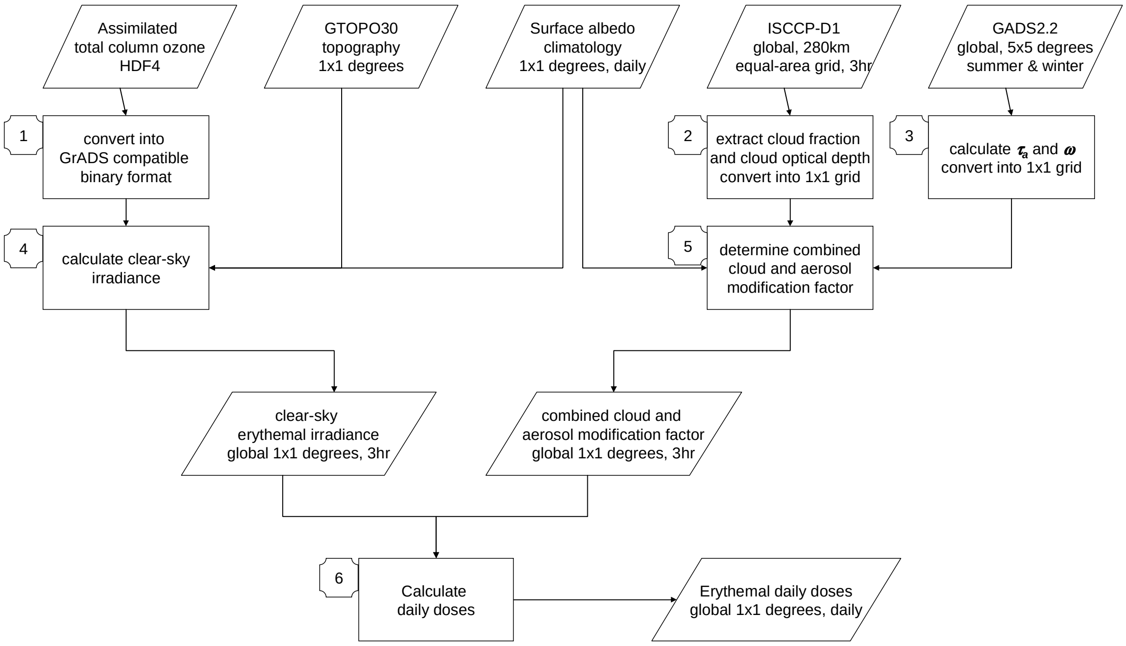

Figure 14. The processing scheme of the UV Record service.

5.1 Step 1: preprocessing of the assimilated total column ozone data

In this processing step the assimilated total column ozone data in the HDF4 format is downloaded and converted into the GrADS compatible binary format. The input data is downloaded from the TEMIS website to a temporary file, and the ***read_hdf*** tool is used to extract the data and write it into a temporary ASCII file. Next the ASCII data is converted into GrADS compatible binary data. One year of GrADS compatible total column ozone data amounts to some 60 Mbytes.

5.2 Step 2: preprocessing of the ISCCP-D1 data

This processing step consist of extraction of cloud fraction and cloud optical thickness information from the ISCCP-D1 data set, conversion of the data given in equal area grid into a regular grid of 1 by 1 degrees, and writing of the cloud information into a GrADS compatible binary file. The input data is downloaded from the FTP server of National Climatic Data Center to a temporary file. It is read with a ***D1READ*** Fortran code provided by the ISCCP project. The resulting ASCII file is parsed with Perl scripts to extract the cloud fraction and cloud optical depth data, and a simple ASCII file is produced with data in three columns: longitude, latitude, and cloud fraction (or cloud optical depth). Next the data is converted into a regular grid of 1 by 1 degrees using the ***nearneighbor*** and ***grd2xyz*** tools of the Generic Mapping Tools (GMT). Finally the data is written in a GrADS compatible binary format. Only the end product of the processing step is preserved. One year of GrADS compatible cloud cover and cloud optical thickness data occupies some 1.5 Gbytes of disk space, and the total amount of data after this step is of the order of 35 Gbytes.

5.3 Step 3: preprocessing of the GADS data

The GADS data is used by calculating the fundamental global optical properties: aerosol optical depth and single scattering albedo at 300 nm in 5 by 5 degrees regular grid. The data are available for two seasons: summer and winter. In prior of use the GADS data are converted by oversampling into the regular grid of 1 by 1 degrees. This is accomplished using the ***surface*** and ***grd2xyz*** tools of GMT.

5.4 Step 4: calculation of the clear-sky erythemal irradiance

The erythemal clear-sky surface UV irradiance is determined with linear interpolation using the CS Look-Up-Table. The clear-sky irradiance is calculated for every UTC hour and for the global grid of 1 by 1 degrees. The process step is initiated by reading the surface albedo climatology and total column ozone data of the day of interest as well as the digital elevation map. Next the eccentricity factor is determined in order to take into account the annual variation of the Sun-Earth distance. Finally the erythemal surface UV irradiance is calculated for every cell of the 1 by 1 degree regular grid involving calculation of the local solar zenith angle, and the result is written to a binary file that is compatible with GrADS.

5.5 Step 5: determination of the combined effect of clouds and aerosols

The combined effect of the cloud and aerosols is determined for every UTC hour with linear interpolation using the ACF and CACF Look-Up-Tables. The result of this step is a combined cloud and aerosol modification factor that is multiplied with the clear-sky irradiance in order to achieve the erythemal surface UV irradiance. The combined cloud and aerosol modifcation factor is calculated for every UTC hour and for the global grid of 1 by 1 degrees. The process step is initiated by reading the surface albedo climatology of the day of interest and the seasonal aerosol climatology. Next the cloud fraction and cloud optical depth data corresponding to the nearest UTC hour available are read. Finally the combined cloud and aerosol modification factors are determined for every cell of the 1 by 1 degree regular grid involving calculation of the local solar zenith angle, and the result is written to a binary file that is compatible with GrADS.

5.6 Step 6: calculation of the daily dose

In this final step the surface UV irradiances calculated for every UTC hour in a regular grid of 1 by 1 degrees are summed up to calculate the cumulative erythemal daily dose. The process step is relatively complicated and slow because the surface UV irradiances correspond to the UTC time, while daily dose corresponds to local solar time.

6 Summary

This document presents the methodology applied to calculate erythemally weighted daily UV doses for the Promote UV Record Service. The methodology is based on a look-up-table approach for radiative transfer simulations, taking as input the assimilated total ozone column fields provided by KNMI in the Ozone Record Service of Promote. Cloud information is taken from the ISCCP data set that provides cloud fraction and cloud optical depth (of the cloud covered part of the pixel) every three hours. Furthermore, the methodology uses climatological values for both the surface albedo and the aerosol loading of the atmosphere.

Verification results of the look-up-table, comparing the surface UV irradiance retrieved from the look-up-table with that obtained using a full radiative transfer calculation under various atmospheric conditions were presented, showing satisfactory results. Validation results of the satellite UV algorithm will be presented elsewhere.

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