Surface Ultraviolet Irradiance From OMI

Aapo Tanskanen, Nickolay A. Krotkov, Jay R. Herman, and Antti Arola

***Abstract*—The Ozone Monitoring Instrument (OMI) onboard the NASA Earth Observing System (EOS) Aura spacecraft is a nadir-viewing spectrometer that measures solar reflected and backscattered light in a selected range of the ultraviolet and visible spectrum. The instrument has a 2600-km-wide viewing swath, and it is capable of daily, global contiguous mapping. We developed and implemented a surface ultraviolet (UV) irradiance algorithm for OMI that produces noontime surface spectral UV irradiance estimates at four wavelengths (305, 310, 324, and 380 nm). Additionally, noontime erythemal dose rate and the erythemal daily dose are estimated. The OMI surface UV algorithm inherits from the surface UV algorithm developed by NASA Goddard Space Flight Center for the Total Ozone Mapping Spectrometer (TOMS). The OMI surface UV irradiance products are produced and archived in HDF5-EOS format by Finnish Meteorological Institute. The accuracy of the surface UV estimates depend on UV wavelength and atmospheric and other geolocation specific conditions ranging from 7%to 30%. A postprocessing aerosol correction can be applied at sites with additional ground-based measurements of the aerosol absorption optical thickness. The current OMI surface UV product validation plan is presented.**

***Index Terms*—Algorithms, software verification and validation, solar radiation, ultraviolet radiation effects.**

I. INTRODUCTION

ATMOSPHERIC ozone is one of the key factors affecting surface ultraviolet (UV) radiation. Even though the Montreal protocol and its amendments have effectively cut down emissions of ozone-depleting chlorine and bromine compounds, the amount of stratospheric ozone is expected to stay below the pre-1980s level for the next couple of decades [1]. Excessive doses of UV radiation are known to cause health effects, such as skin cancer, eye problems and immunosuppression. Furthermore, UV radiation drives atmospheric photochemistry, and UV radiation can affect terrestrial and aquatic ecosystems, agriculture, and durability of materials [2].

The Ozone Monitoring Instrument (OMI) is a nadir-viewing spectrometer that measures solar ultraviolet and visible reflected and backscattered light in a selected range of the ultraviolet and visible spectrum [3]. OMI is designed to monitor ozone and other atmospheric species. It is a contribution of the Netherlands's Agency for Aerospace Programs (NIVR) in collaboration with the Finnish Meteorological Institute (FMI) to the EOS Aura mission. OMI contains two spectrometers that together cover the wavelength range from 270 to 500 nm. The width of the instrument's viewing swath, 2600 km, is large enough to provide global daily coverage of the sunlit portion of the atmosphere. The spatial resolution of the instrument is 13 × 24 km in nadir and larger toward the edges of the swath. OMI will continue the TOMS record for total ozone measurements. Coordinated OMI data processing, analysis, and validation efforts are carried out by scientists from KNMI, NASA, and FMI.

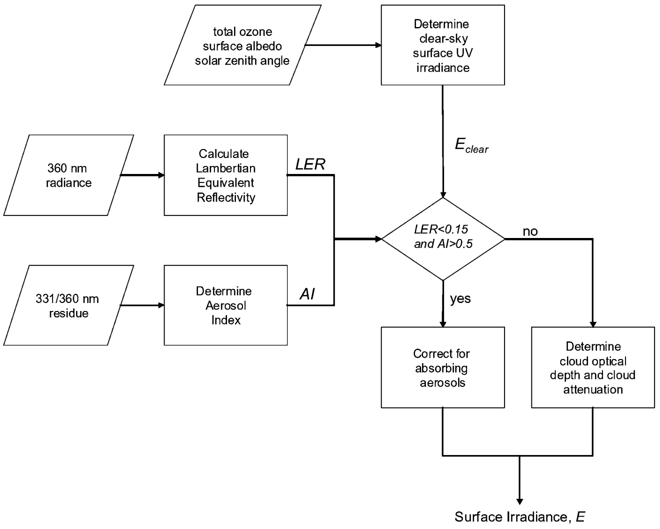

Fig. 1. Overview of the OMI surface UV algorithm.

FMI is responsible for processing and archiving of the OMI surface UV irradiance (OMUVB) products. The input data for the processing is level 2 OMI total ozone product (OMTO3) from NASA/DAAC. The OMUVB products are offline products that are primarily intended for long-term monitoring of the surface UV irradiance. The OMUVB products will be released once they been validated against ground-based reference data. This paper describes the OMI UV algorithm, the OMUVB products and the validation plan.

II. OPERATIONAL OMI SURFACE UV ALGORITHM

A. Algorithm Overview

The OMI surface UV algorithm inherits from the TOMS UV algorithm developed by NASA/GSFC [4]–[7]. It is based on radiative transfer models whose input parameters are derived from the OMI measurement data. The speed of the algorithm is optimized using precalculated lookup tables. The calculation procedure depicted in Fig. 1 consists of two main parts: first the algorithm determines clear-sky surface UV irradiance, E_{clear}, that is subsequently corrected either for clouds and nonabsorbing aerosols or for absorbing aerosols. Aerosol correction is used only when the absorbing effect of aerosols can be estimated

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(ie. no significant cloudiness) and the effect exceeds a certain threshold level.

B. Clear-Sky UV Irradiance

Assuming that there are no clouds nor aerosols in the atmosphere and treating the surface of the Earth as a Lambertian reflector, the clear-sky surface UV irradiance, E_{clear} can be determined from

$$E_{\mathrm{clear}} = \frac{E_0}{d^2}\frac{E_{\mathrm{dir}} + E_{\mathrm{diff}}}{1 - A_s S_b} \tag{1}$$

where E_{dir} and E_{diff} are the direct and diffuse contributions to the surface irradiance for unit solar flux and zero surface reflectivity; d is the Sun-Earth distance; and E_0 is the extraterrestrial solar flux at 1 AU. The factor $(1 - A_s S_b)^{-1}$ accounts for the effect of surface reflection, where A_s is the surface albedo and S_b is the atmospheric backscatter ratio. The various terms of the (1) are determined from precalculated numerical solutions of the radiative transfer equation. The details of the clear-sky radiative transfer model are described in a previous publication [5].

C. Cloud Correction

The cloud correction of the OMI UV algorithm is based on radiative transfer calculations for a homogeneous, plane-parallel cloud model embedded in a scattering molecular atmosphere with ozone absorption [6]. The cloud optical thickness is assumed to be spectrally uniform and the effective cloud optical thickness is obtained by matching the calculational 360-nm radiance with the radiance measured by OMI. Modeling involves an assumption for surface albedo that is taken from a climatological database [8]. The same cloud model is used to determine wavelength-dependent cloud correction factor, C_T, and finally, the cloud-corrected surface UV irradiance is obtained from

$$E = E_{\mathrm{clear}} C_T. \tag{2}$$

The plane-parallel cloud model is one-dimensional, and three-dimensional effects of clouds or terrain inhomogeneity cannot be taken into account. Moreover, estimation of cloud effects is based on a single observation of the atmospheric conditions above the ground pixel that covers a relatively large area. The diurnal variation of the cloud conditions are not caught, and the satellite-retrieved estimate for the daily surface UV dose and ground-based UV measurements are not fully comparable.

D. Correction for Absorbing Aerosols

The aerosol correction of the OMI UV algorithm is based on the Aerosol Index (AI) that is used to detect the presence of absorbing aerosols [9]. According to radiative transfer studies absorbing aerosols yield a positive AI that increases with increasing optical depth of the aerosol layer. The absorbing aerosol correction [5], [7] of the OMI UV algorithm is determined from

$$E = E_{\mathrm{clear}} e^{-gAI} \tag{3}$$

where g is a conversion factor that depends on the aerosol distribution and type. In the current version of the OMI UV algorithm g is set to a constant value of 0.25. The current OMI UV algorithm applies a correction for absorbing aerosols if AI exceeds 0.5- and the 360-nm reflectivity is smaller than 0.15. A more sophisticated aerosol correction could be introduced in the future provided that more information about the aerosols was available from other OMI/Aura products or from auxiliary sources. A postprocessing aerosol correction based on a model of the attenuation of the surface UV as a function of the absorption optical thickness is described in Section IV.

TABLE I
PRIMARY CONTENTS OF THE OMI SURFACE UV IRRADIANCE PRODUCT

Product	Units
Irradiance at 305 nm at local solar noon	W/m^2/nm
Irradiance at 310 nm at local solar noon	W/m^2/nm
Irradiance at 324 nm at local solar noon	W/m^2/nm
Irradiance at 380 nm at local solar noon	W/m^2/nm
Erythemally weighted irradiance at local solar noon	W/m^2
Erythemally weighted daily dose	J/m^2

III. OMI SURFACE UV IRRADIANCE PRODUCTS

A. Product Overview

The OMI surface UV irradiance products (OMUVB) follow the HDF5-EOS format. Each product granule corresponds to a single OMI orbit containing data for some 10^5 observations. The nominal size of a single product granule is 8.5 Mb. Thus, some 120 Mb of OMUVB data will be produced per day. The OMUVB products are produced and archived at FMI's Satellite data center in Sodankylä. The archive is a relational database that enables powerful product search and filtering according to the product metadata.

B. Product Contents

The primary contents of the OMUVB granules are local solar noon irradiances at 305, 310, 324, and 380 nm, as well as erythemally weighted irradiance. Additionally, the erythemally weighted daily surface UV dose is included. The archive files also contain various auxiliary data and metadata used for archive maintanance and control of the processing quality. Table I summarizes the primary contents of the OMUVB products.

C. Product Examples

The combination of the sunsynchronous orbit of Aura and the wide-viewing swath of OMI enable daily global monitoring of the Earth's atmosphere. Figs. 2–4 show distribution plots obtained by combining data from several OMUVB product granules. Fig. 2 shows the global distribution of the clear-sky UV Index at local solar noon on June 3, 2005. UV Index is a unitless quantity that is linearly related to the erythemally weighted

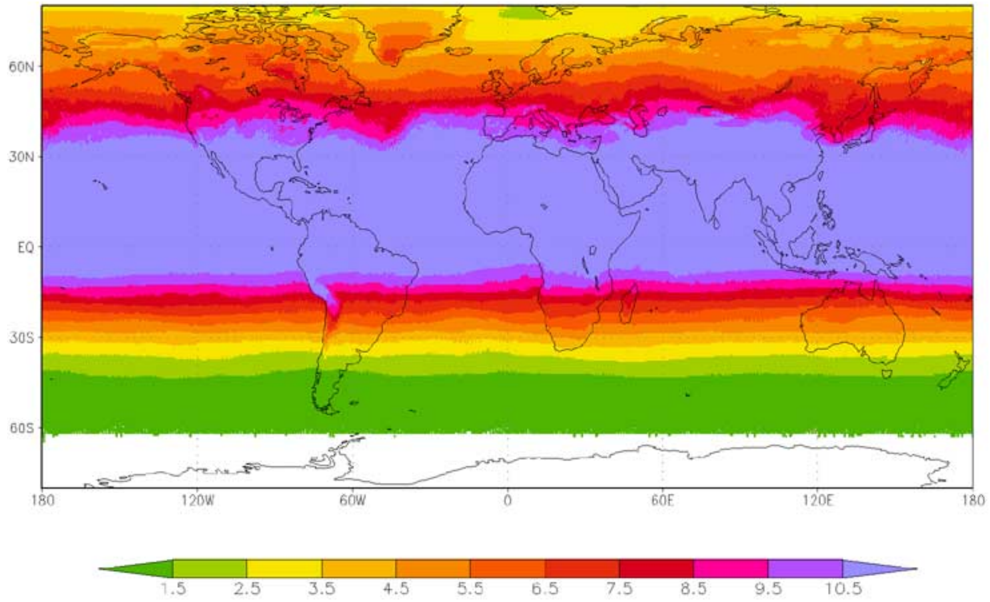

Fig. 2. Global distribution of the clear-sky UV index at local solar noon on June 3, 2005 derived from OMI measurement data.

dose rate. Fig. 3 shows the global distribution of the cloud corrected erythemal daily dose on June 3, 2005, while in Fig. 4 is shown the distribution of the cloud corrected erythemal dose rate in Europe at local solar noon (milliwatts per square meter) on the same day.

D. Anticipated Product Accuracy

The accuracy of the various UV irradiance data of the OMUVB product differ: the low wavelength irradiances are more sensitive to modeling errors. The accuracy of the UV irradiance estimates have been assessed using a radiative transfer model [10]. The results of this study are summarized in Table II. In a clear sky, snow and aerosol free case the accuracy of the surface UV irradiance can be as good as 7% at 380 nm, while it is of the order of 10% at 305 nm. However, snow cover or episodic aerosol plume can result in product accuracy of some 20% or 30%.

IV. POSTPROCESSING AEROSOL CORRECTION

Multiyear comparisons of the TOMS UV data with ground-based Brewer measurements revealed a positive bias at many locations [12], [13]. The bias can be seen at all wavelengths in clear-sky conditions, which suggests that the difference is not related to ozone absorption. The current OMI UV algorithm applies a correction for absorbing aerosols when AI exceeds 0.5 and the 360-nm reflectivity is smaller than 0.15. The operational OMI UV algorithm does not distinguish between thin clouds and aerosols. This causes a typical C_T error of the order of 2% for nonabsorbing sulfate or sea salt aerosols. On the other hand, absorbing aerosols in the boundary layer attenuate UV irradiance more strongly causing cloud correction to underestimate their attenuation of surface UV irradiance. Because pollution aerosols are typically located in the boundary layer, they yield a negative AI, and cannot be distinguished from nonabsorbing aerosols or thin clouds. This results in underestimation of attenuation of the UV radiation by pollution aerosols.

The positive bias of the surface UV estimates produced by the operational OMI UV algorithm can be corrected provided that the aerosol absorption optical thickness τ_{abs} for the specific UV wavelength is known from an auxiliary source [11]. The aerosol corrected surface UV irradiance, E_{ac} is obtained from

$$E_{\mathrm{ac}}(\lambda) = \frac{E(\lambda)}{1 + b\tau_{\mathrm{abs}}(\lambda)} \qquad (4)$$

where b is a constant whose value is around 3. This correction can be applied at sites where τ_{abs} is obtained from ground-based measurements. An alternative is to use climatological values for aerosol absorption optical thickness.

V. OMUVB VALIDATION PLAN

Coexistent surface UV products from other satellite instruments (EP-TOMS, GOME, SCIAMACHY) will be used to obtain the first impression of the quality of the OMI surface UV data. However, the ultimate reference data for validation are the ground-based spectral UV irradiance measurements. Validation is planned to rely on the existing UV monitoring sites with high-level instrument QA/QC. The validation sites shall represent various latitudes, climatic conditions, land cover types and altitudes. Some validation sites provide concurrent measurements of aerosol optical depth and single scattering albedo that can be used to validate surface UV algorithm to account for aerosols. The ultimate validation goal is to establish the OMUVB product uncertainty in different atmospheric conditions and to obtain insight for further development of the OMI surface UV irradiance algorithm.

VI. CONCLUSION

The OMI surface UV algorithm has been implemented at the Sodankylä satellite data center and the first surface UV irradiance distribution plots imply that the algorithm functions in accordance with the specifications. The true accuracy of the

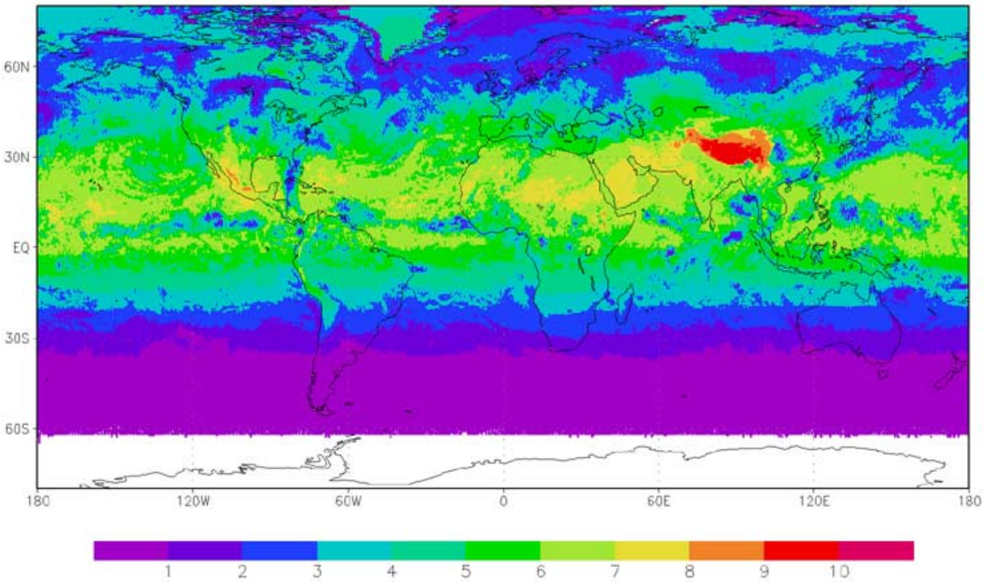

Fig. 3. Global distribution of the cloud corrected erythemal daily dose (kilojoules per square meter) on June 3, 2005 derived from OMI measurement data.

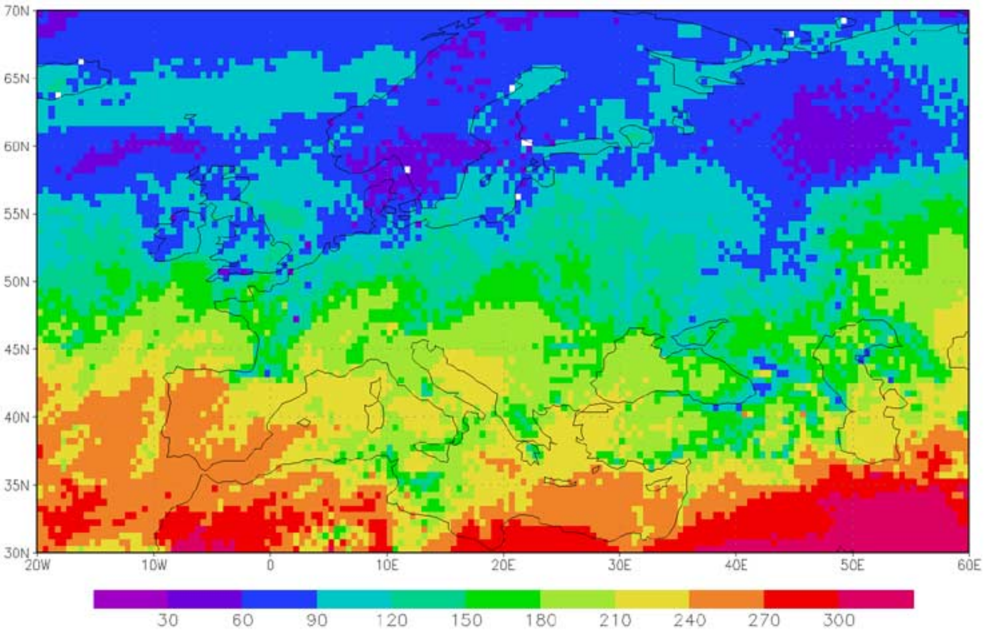

Fig. 4. Distribution of the cloud corrected erythemal dose rate in Europe at local solar noon (milliwatts per square meter) on June 3, 2005 derived from OMI measurement data.

TABLE II
ANTICIPATED ERRORS OF THE OMI SURFACE UV IRRADIANCE PRODUCTS [10]

Atmospheric scenario	305 nm	310 nm	324 nm	380 nm
Background, snow free	10%	8%	7%	7%
Seasonal snow	27%	26%	25%	25%
Permanent snow	30%	30%	30%	30%
Smoke plume	22%	21%	21%	22%
Dust plume	15%	13%	11%	15%
Urban pollution	20%	15%	10%	10%

OMUVB products will be established with a comprehensive validation study.

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