Sensitivity of UV Erythemally Effective Irradiance and Daily Dose to Spatial Variability in Total Ozone

Alois W. Schmalwieser*1, Thilo Erbertseder2, Günther Schaubberger1 and Philipp Weihs3

1Institute of Medical Physics and Biostatistics, University of Veterinary Medicine, Vienna, Austria
2Deutsches Fernerkundungsdatenzentrum, Deutsches Zentrum für Luft- und Raumfahrt, Oberpfaffenhofen, Germany
3Institute of Meteorology, University of Natural Resources and Applied Life Sciences, Vienna, Austria

Received 30 April 2007, accepted 1 December 2007, DOI: 10.1111/j.1751-1097.2007.00285.x

ABSTRACT

The total ozone column (TOC) is the most significant quantity for estimating the erythemally effective UV radiation under clear sky conditions. Uncertainties in TOC measurements and a limited spatial and temporal resolution therefore influence the quality of calculated erythemally effective radiation. The UV Index, the internationally accepted measure of the erythemally effective radiation, is used in public and the media to inform about current levels of UV radiation and builds the base for sun protection. Thus, the accuracy of the promoted values is essential. While in a preceding study we estimated the influence of measurement uncertainties, in this study we analyze the influence of spatial gaps and variability of TOC to the erythemally effective irradiance at noon and to the daily dose. The results allow defining the necessary spatial resolution of TOC values when a certain accuracy for the UV Index or for the purpose of sun protection is required. In case of the erythemally effective irradiance this study reveals that spatial gaps in TOC or the assumption of spatial invariability causes similar uncertainties independent of the geographic location. At higher latitudes the higher spatial variability of TOC counteracts the lower level of irradiance. For the daily dose gaps in TOC have an even higher impact at higher latitudes.

INTRODUCTION

During the past two decades public interest in exposure to sunlight has risen continuously. The publicity of the ozone hole and studies that documented the increase of skin cancer have contributed to the rise in interest. In many countries most of the UV exposure results from spare time activities and from holidays in southern destinations (1). The latter has increased in industrial countries strongly in the winter season when the skin is photoadopted to low levels of solar radiation (2). Information on the expected intensity level and recommendations for sun protection is therefore a helpful tool in health care.

More than 10 years ago the UV Index was introduced as a dimensionless number to indicate the intensity levels of solar UV radiation. Nowadays several international organizations and standards agree on the UV Index (International Commission on Nonionizing Radiation Protection, World Health Organization, World Meteorological Organization or European Commission [3–6]) and it is proposed to be used in public information. The UV Index is also a base for sun protection recommendations, risk assessment and health care (e.g., 4,7). Hence, the accuracy of promoted UV Index values is crucial. The promoted UV Index values are gained by measurements or by models sometimes including forecast calculations.

An ongoing process in model development and improvement has led to a variety of models where the main source of inaccuracy is no longer the radiative transfer calculation itself. In fact, the quality of the model output depends on the availability and accuracy of the input parameters. The most important parameters under cloudless sky conditions are the total ozone column (TOC) (e.g., 8,9) as well as the aerosol content (e.g., 10).

During the past years some studies were published which deal with the accuracy of calculated UV Index values. For example Koepke et al. (11) inter-compared different models with respect to the erythemally effective UV radiation and De Backer et al. (12) compared model results to ground-based measurements. Furthermore, several studies on the promotion and accuracy of the UV Index were carried out, like validations of worldwide forecasts of the erythemally effective irradiance (e.g., 13,14) as well as the daily dose (15). Recently, the uncertainty of the erythemally effective irradiance and daily dose resulting from uncertainties in TOC measurements was investigated (16).

Measurements of TOC are taken at a certain (discrete) location. When such a measured value is used to represent the surrounding region, one has to take into account an error which results from the assumption of spatial invariability of TOC. Consequently, spatial variability can be defined as a function of spatial distance and can be divided into a longitude, latitude and altitude component. Changes in TOC with topographic altitude are rather low (e.g., 17–19) and can be corrected in a satisfactory way (e.g., 20).
The latitudinal and longitudinal variability of TOC is caused by a variety of phenomena of different temporal and spatial scales (21). In general, the total ozone distribution is determined by photochemical production, transport and destruction (22). While in the tropics ozone variability can mainly be attributed to photochemical processes, at higher latitudes variability is mainly governed by atmospheric dynamics, i.e. planetary wave activity. Planetary waves are the dominating source mechanism for transport processes in the stratosphere. In polar regions they are responsible for the erosion and breakdown of the polar vortices, where effective ozone depletion is caused by complex chemical processes (23). In the mid-latitudes planetary waves are responsible for advection of tropical (ozone poor) or polar (ozone rich) air masses leading to steep gradients in TOC. There, the classical ozone–weather relationship (e.g. 24–26) dominates the spatial variability on the synoptic scale, as studied in this paper. As a result of these processes steep gradients with more than 100 DU per 1000 km in both latitudinal and longitudinal directions can occur in the TOC distribution at the polar vortex edge, at ozone mini-holes and whenever polar air masses are advected into mid- and subtropical latitudes and vice versa associated with planetary wave activity. In the tropics (<30°N, <30°S) there is hardly any gradient in longitude, i.e. zonal direction.

The global mean distribution of total ozone is characterized by a continuous latitudinal gradient (e.g. 27) increasing from the tropics to mid- and high latitudes. The latitudinal gradient strongly depends on the season. It is small in summer and autumn, but steep in winter and spring. This gradient varies with season and is on the order of 0.05–0.4% per 100 km.

In this paper we focus on quantifying the sensitivity of the erythemally effective UV radiation under clear sky conditions to spatial TOC variability. Hence we examine the effects caused by spatial gaps in TOC data or by assuming spatial invariability, i.e. neglecting spatial variability. We aim at quantifying the latitudinal and longitudinal contribution to the uncertainty.

The analysis is performed for calculated values of both irradiance at solar noon and daily dose as the length of the day varies significantly with latitude and therefore the ratio between irradiance and dose changes as well. The results of this study allow us further to stipulate requirements for the spatial resolution of TOC data when a certain accuracy in the UV Index or sun protection is demanded.

**MATERIALS AND METHODS**

The uncertainty of the erythemally effective UV radiation resulting from spatial gaps in TOC measurements or the assumption of spatial invariability is quantified by using satellite-borne observations from the Total Ozone Mapping Spectrometer (TOMS). These data are available in gridded form at a certain spatial discretization.

Starting with a fixed geolocation, we calculate the erythemally effective UV radiation using the according TOC measured at this site. Afterwards the erythemally effective UV radiation for this site is calculated by consecutively inputting TOC from distant grid points. The differences between the UV value derived for the geographically correct TOC and the UV values gained when using TOC from distant grid points allow us to estimate the uncertainty as a function of distance. The differences are calculated separately in latitudinal and longitudinal direction.

In connection to an earlier paper (16), where we estimated the influence of uncertainties in measured TOC, we selected the same three geolocations at 50°N, 1°E and 30°S representing the mid-latitudes, tropics and subtropics. The chosen geolocations have a similar longitude. This selection enables to estimate the influence of latitude regarding solar elevation, length of the day and TOC and exhibits the different statistical behavior over each site.

**TOC data.** The TOC data are taken from the TOMS on board NASA’s Earth Probe satellite, hereafter called EPTOMS (28). The EPTOMS instrument is essentially similar to its three TOMS predecessors, flown aboard Nimbus 7 (from October 1978 to May 1993),
aboard Meteor 3 (August 1991 to December 1994) and on Adeos (September 1996 to June 1997)—a single, fixed monochromator, with exit slits at six near-UV wavelengths, which measures the incident solar radiation and backscattered UV sunlight. TOCs are retrieved from these measurements at a horizontal resolution of typically 50 × 50 km at nadir. Measurements are taken close to solar noon. For this study we use gridded Level 3 near real-time data, which are delivered on a 1°/1.25° latitude by 1°/1.25° longitude grid and are disseminated a few hours after overpassing (29). For reason of consistency with a preceding paper (16), we apply near real-time data from 2000 to 2004, which was processed at the time of acquisition by TOMS Version 7.

The data domains are also chosen in correspondence to the abovementioned paper (16). There we estimated the uncertainties of TOC measurements and the limitation of accuracy in UV index calculations resulting from these uncertainties. The region on the northern hemisphere covers the latitudinal range from 50° N to 60° N and 16° E to 26° E and includes the location of the Solar and Ozone Observatory of Hradec Kralove (50.183° N, 15.83° E, Figure 2).

**Figure 2.** Fiftieth percentiles for absolute amount of differences in total ozone $p_{50}\Delta TOC$ (a, b), irradiance at solar noon $p_{50}\Delta E$ (c, d) and daily dose $p_{50}\Delta H$ (e, f) for the region from 50° N to 60° N and 16° E to 26° E for certain spatial distances in latitude (left panels) and in longitude (right panels).
The region at the equator ranges from 5°S to 5°N and from 26°E to 26°E and includes the ozone observatory near Nairobi, Kenya (1.3°S, 36.8°E). The southern region around Springbok (29.7°S, 17.9°E), Republic of South Africa is between 30°S and 19°S and between 16°E and 28°E.

For our analysis we included all available EPTOMS data between 1 January 2000 and 31 December 2004. Since 2002 there has been an ongoing problem in calibration of EPTOMS data especially for the mid-latitudes (30). However, statistical descriptors (see below) estimated for 1 January 2000 to 31 December 2001 do not show a systematic difference to those when estimated for 1 January 2002 to 31 December 2004. With the end of the year 2004 EPTOMS data delivery was terminated and replaced by data from the new Ozone Mapping Instrument onboard NASA’s Aura satellite launched in July 2004 (31).

Uncertainty from spatial gaps and variability. In order to quantify the error introduced in the erythemally effective radiation by assuming spatial invariability or spatial gaps in TOC data, model calculations were performed with a fast spectral UV radiation model. This model was developed by some of us in 1995 in order to forecast the erythemally effective radiation on a global scale. The development...
followed a suggestion of Diffey (32) incorporating several improvements. The radiation model calculates the spectral irradiance at 17 discrete wavelengths between 297 and 400 nm with a higher resolution in the UVB than in the UVA range. The database from Bener (33), which was obtained from spectral measurements made over several years at Davos (46°49′N, 9°49′E, 1590 m a.s.l.), was used for parameterization. A detailed description of the model can be found in Schmalwieser et al. (13). The model was validated considering the erythemally effective UV radiation in the past by a comparison with other models (11,12,34) as well as by a comparison with measurements made on four continents for irradiance (13) and daily dose (15).

The erythemally effective irradiance is derived using the Commission Internationale de l’Eclairage (CIE) action spectrum of the erythema (35) for weighting, followed by the integration over the whole spectral range. The erythemally effective irradiance is expressed in units of the UV Index, gained by multiplying the effective irradiance given in W m⁻² by 40. The erythemally effective daily dose is expressed in units of UV Index hours (UVIh) following a suggestion of Saxebøl (36). The daily dose is gained by integrating the daily course of the effective irradiance from sunrise to sunset. A received dose of 1 UVIh is equal to 90 J m⁻² or 0.9 standard erythemal dose (37).

Figure 4. Hundredth percentiles for absolute amount of differences in total ozone p100ΔTOC (a, b), irradiance at solar noon p100ΔE (c, d) and daily dose p100ΔH (e, f) for the region from 50°N to 60°N and 16°E to 26°E for certain spatial distances in latitude (left panels) and in longitude (right panels).
For this work an aerosol-free atmosphere and cloud-free sky are assumed to point out the influence of the TOC only. Therefore, the input parameters comprise date, time, geographic position, altitude and TOC.

The influence of spatial variability and data gaps in TOC is estimated by using TOC data from different grid points to calculate the erythemally effective radiation for a selected fixed geolocation. The erythemally effective radiation is calculated for the selected initial point and a certain day. Step by step TOC from distant grid points is applied to calculate the erythemally effective radiation at the initial point for the same date. Due to the spatial variability of TOC the calculated erythemally effective radiation differs. Consequently, the absolute differences between the outcome when using the geographically correct TOC and the outcome when using TOC from a distant geolocation are calculated. These differences build the base for the statistical analysis. It is expected that the differences become larger with increasing distance. The influence of spatial gaps or assumed spatial invariability in TOC is estimated up to distances of 1000 km for longitude and latitude.

Analysis of the differences was performed using the 50th percentile (p50), the 95th percentile (p95) and the 100th percentile (p100) of absolute differences for each month of the year. p50 denotes that every second day the difference is larger, p95 denotes that on one day in a month the difference is larger than this one. p100 denotes simply the highest difference which was found for this month within the 5 year period.

The percentiles of differences in longitude and latitude were interpolated to distances to multiples of 100 km for comparability in latitude and longitude at all locations. At Hradec Kralove 1°C corresponds to 65 km, at Springbok 88 km and at Nairobi 101 km whereas the longitudinal resolution of gridded EPTOMS total ozone data is 1.25°C.

RESULTS

Influence of spatial total ozone variability at 50°N

At 50°N the TOC exhibits high variability not only during the year but also within a few days. The latter mainly coupled to the planetary wave activity and the associated advection of tropical (ozone poor) or polar (ozone rich) air masses in the stratosphere into mid-latitudes TOC values can be found between 200 DU and 500 DU (Fig. 1a) and may change by more than 100 DU within a month. The erythemally effective irradiance at solar noon modeled for clear sky (Fig. 1b) changes from 0.5 UVI in winter to 7 UVI in summer. The length of the day undergoes large changes of more than 8 hours. The modeled daily dose (Fig. 1c) may be below 2 UVIIh in winter and can reach 50 UVIIh near the summer solstice.

The error in TOC arising from assuming a spatially homogeneous ozone distribution is presented in Figs. 2a,b, 3a,b and 4a,b. At the p50, p95 and p100 level the differences in TOC show an annual cycle which develops with increasing distance. For a distance of 100 km differences are only somewhat higher between November and March than between April and October. Through a distance of 1000 km the values are two times higher in winter than in summer. This means that the atmospheric structures responsible for spatial variability are stronger in winter. Differences are similar in latitudinal and longitudinal directions, which denotes that the atmospheric structures which are responsible for spatial variability are of circlet extension. Higher values in the annual course occur when the temporal variability of TOC is also high as it can be estimated from the annual course of TOC measurements (Fig. 1a).

Figure 5. (a) Total ozone content of the atmosphere (TOC), (b) modeled erythemally effective irradiance at solar noon (E) and (c) daily dose (H) for the location of 0.0°S, 36.6°E (near Nairobi, Kenya) under clear skies.
All percentiles in irradiance (Figs. 2c,d, 3c,d and 4c,d) reveal a clear annual cycle related to solar elevation. However, the influence of TOC is quite obvious especially in the first months of the year and the few months after the summer solstice (August, September). The p100 values in irradiance (Fig. 4c,d) are strongly influenced by TOC, especially for longer distances.

Within the first 100 km the p50 values are below 0.1 UVI and are below 0.5 UVI even for distances of 1000 km. Gaps in TOC up to 200 km do not cause a p95 value of 0.5 UVI; a p95 of 1 UVI is caused by distances of 1000 km in June.

All percentile values in daily dose (Figs. 2e,f, 3e,f and 4e,f) are related to the length of the day with obvious features caused by TOC, especially in August. Within the first 100 km the p50 values are below 0.75 and 3.5 UVIh for distances of 1000 km. For distances shorter than 100 km the p95 value is below 2.5 UVHIh and does not overstep 10 UVHIh within distances of 1000 km.

Figure 6. Fiftieth percentiles for absolute amount of differences in total ozone p50ΔTOC (a, b), irradiance at solar noon p50ΔE (c, d) and daily dose p50ΔH (e, f) for the region from 5°S to 5°N and from 26°E to 38°E for certain spatial distances in latitude (left panels) and in longitude (right panels).
Influence of spatial total ozone variability at the equator

At the equator the TOC does not vary much during the year and lies between 230 and 310 DU (Fig. 5a). This range is on the order of changes that can easily occur within a few days at 50°N.

As photochemistry is the dominating process in the tropics, spatial variability of TOC is mainly a function of the solar zenith angle, i.e. latitudinal. However, wave disturbances like Kelvin waves may create some spatial variability (latitudinal and longitudinal) on time scales of some days. The change in solar zenith angle at noon is within ±23°. Therefore, clear sky irradiance at solar noon (Fig. 5b) varies by 3 UVI during the year exhibiting two peaks (March and September) around 10.5 UVI. Similar to this, the daily dose (Fig. 5c) undergoes smooth changes within 45 and 65 UVIh.

Figure 7. Ninety-fifth percentiles for absolute amount of differences in total ozone p95ΔTOC (a, b), irradiance at solar noon p95ΔE (c, d) and daily dose p95ΔH (e, f) for the region from 5°S to 5°N and from 20°E to 38°E for certain spatial distances in latitude (left panels) and in longitude (right panels). The gray areas indicate the p95 of uncertainties of TOC measurements and the corresponding p95 for irradiance and daily dose as given in Schmalwieser et al. (16).
The p50 values of differences in TOC are characterized by a different pattern in latitude (Fig. 6a) and longitude (Fig. 6b). In longitude there is only a slight annual cycle with high values around October and November. In latitude, however, a peak develops with increasing distance between June and August, where the highest values have more than doubled compared with the lowest p50 values found in March. This peak is also obvious in p50 for irradiance (Fig. 6c) and daily dose (Fig. 6e).

The variability of TOC dominates these annual courses and neither a dependency of the annual course from solar elevation nor from the length of the day is evident. This peak occurs in every single year and can thus not be attributed to one extreme event. This enhanced latitudinal gradient around July can also be seen in the zonal averaged TOC distribution (e.g. 27).

The annual patterns of the investigated quantities at p95 levels (Fig. 7) are similar to those of p50. The peak from June...
to August is weaker than in the p50 values. Values do not increase much with distance going up to 0.8 UVI and 5 UVIh, respectively, for distances of 1000 km.

The p95 values for differences in irradiance in longitude indicate a smooth annual cycle with maxima around October and November. The values are slightly lower than those for latitudinal distances.

The increase in the p100 levels of differences (Fig. 8) in TOC with distance is only obvious within the first 200 km. For larger distances almost no increase can be found. Additionally, the annual pattern as evident in the p50 and p95 values is weaker. For gaps up to 100 km the p100 values for irradiance are below 0.5 UVI and below 4 UVIh for the daily dose.

Influence of spatial total ozone variability at 30°S

At 30°S the TOC ranges between 225 and 375 DU. A clear annual cycle can be seen (Fig. 9a) with low values around the winter solstice (June) and high values in spring. The spatial variability still follows photochemical processes similar to that in the tropics. Some spatial variability of TOC on time scales of days can be induced by displacements of the subtropical barrier and the episodic advection of air masses from the tropics or mid-latitudes. The erythemally effective irradiance at solar noon under clear sky (Fig. 9b) is within 2 and 10 UVI. Daily dose (Fig. 9c) varies within 10 and 65 UVIh during the year.

The p50 of differences for TOC as a function of depending on distance reveals very different patterns in latitude and longitude (Fig. 10a,b). For latitudinal effects a strong annual cycle develops with distance. The highest p50 values are found in August and September, the lowest in March. The pattern of p50 in TOC for latitudinal gaps can be seen as well in the p50 of irradiance (Fig. 10c,d) and daily dose (Fig. 10e,f). The influence of solar elevation and the length of the day weaken the TOC pattern but the highest values can be still seen around September.

The weak pattern of p50 in TOC for longitudinal gaps almost vanishes when changing to irradiance and daily dose. The p50 value reaches up to 0.5 UVI and 2.5 UVIh only during a few months for latitudinal gaps larger than 600 km. For longitudinal gaps the p50 are all below 0.5 UVI and 2.5 UVIh within 1000 km.

The patterns of the p95 levels are similar to those evident for the p50 levels. The p95 levels for TOC (Fig. 11a,b) show an almost linear ascent with increasing distances of up to 600 km. Depending on the time of the year the increase is larger (around August) or smaller (around February). With that, the almost constant course for 100 km changes to a clear annual cycle for 1000 km. The spatial variability in longitude is less apparent.

The peak of TOC variability for larger distances around August is not outweighted by solar elevation and is therefore also obvious in the p95 for irradiance (Fig. 11c,d). For p95 in daily dose (Fig. 11e,f) the length of the day weakens this peak further but only to a certain extent.

In longitude the influence of distance is lower than that in latitude for distances larger than 300 km. Contrary to the p95 levels in latitude the p95 levels in longitude stay below 1 UVI. The patterns of p95 in daily dose are similar to those in

Figure 9. (a) Total ozone content of the atmosphere (TOC), (b) modeled erythemally effective irradiance at solar noon (E) and (c) daily dose (H) for the location of 30.0°S, 18.1°E (near Springbok South Africa) under clear skies.
irradiance but higher values are shifted to summer solstice (December).

The pattern of the p100 in TOC (Fig. 12a,b) is similar to those of the p50 and p95 but weaker. The annual pattern in TOC can be seen to a certain extent in the p100 for irradiance (Fig. 12c,d) and daily dose p50ΔH (e, f).

A value of 0.5 UVI and 5 UVIh is exceeded in half of the year for a distance of 100 km. Within 1000 km a value of 2 UVI is not exceeded.

In daily dose the highest p100 (Fig. 12e,f) for distances of 1000 km reach 14 UVIh in latitudinal direction and only 10 UVIh in longitudinal direction.

**DISCUSSION**

In this paper we have estimated the influence of spatial variability and data gaps in TOC on (calculated) clear sky erythemally effective UV radiation with special emphasis on
the UV Index and sun protection. It is proposed that the UV Index should be given as integer (3,4). For this, one could use a value of 0.5 and 1 UVI as limit value for inaccuracy. For radiant exposure—in our case the daily dose—one could use an equivalent to the minimal erythemal dose (MED) for melano-compromised (fair-skinned) persons (Fitzpatrick skin Types I and II) (4,38) and its multiples as limit values for accuracy. Expressed in units of UV Index hours 1 MED is close to 2.5 UVIh.

Considering these limit values an application-related estimation of the maximum size of spatial gaps in TOC can be made. For this, the p95 of absolute differences can be chosen as the measure of uncertainty because it indicates the error which occurs on one day in a month.

Figure 11. Ninety-fifth percentiles for absolute amount of differences in total ozone p95ΔTOC (a, b), irradiance at solar noon p95ΔE (c, d) and daily dose p95ΔH (e, f) for the region from 30⁰S to 19⁰S and 16⁰E to 28⁰E for certain spatial distances in latitude (left panels) and in longitude (right panels). The gray areas indicate the p95 of uncertainties of TOC measurements and the corresponding p95 for irradiance and daily dose as given in Schmalwieser et al. (16).
At first glance, one could expect that the uncertainty of the erythemally effective radiation resulting from gaps in TOC is highest where the erythemally effective irradiance is highest. However, the results of this study show that the uncertainties are even somewhat higher at mid-latitudes than in the tropics. This results from the fact that at higher latitudes the spatial variability of TOC is highest. The increase in variability is more effective than the decrease in irradiance level. For the erythemally effective irradiance at 50°N an uncertainty (p95) of 0.5 UVI has to be taken into account when gaps in TOC of 200 km are present or invariability of the same distance is assumed. The uncertainty resulting from distances of 1000 km peaks up to 1 UVI. The uncertainties in longitude and latitude are similar. At 30°S gaps can be as large as 300 km to cause an uncertainty of 0.5 UVI. Depending on direction a p95 of 1 UVI is caused by TOC gaps of 600 km (latitude) and 1000 km (longitude). At the equator one has to take into account an uncertainty of 0.5 UVI from missing or invariable

Figure 12. Hundredth percentiles for absolute amount of differences in total ozone p100ΔTOC (a, b), irradiance at solar noon p100ΔE (c, d) and daily dose p100ΔH (e, f) for the region from 30°S to 19°S and 16°E to 28°E for certain spatial distances in latitude (left panels) and in longitude (right panels).
TOC values within 300 km. Contrary to the other locations an uncertainty of 1 UVI is not reached by distances of up to 1000 km.

For the daily dose we found that at 50°N uncertainties of 2.5 UVIh result from gaps or distances in TOC of 100 km, 5 UVIh from distances of 300 km and 7.5 UVIh from distances of 700 to 800 km. At 30° the uncertainties in latitudinal direction are similar; gaps of 100 km may result in a p95 of 2.5 UVIh, of 400 km in 5 UVIh and of 1000 km in 7.5 UVIh. In longitudinal direction 7.5 UVIh are not reached even when gaps are as large as 1000 km. At the equator the influence of gaps in TOC does not increase much with size. A p95 of 2.5 UVIh is caused by missing TOC up to 200 km and 5 UVIh are not exceeded by gaps up to 1000 km.

In general, the results of this study show that a spatial resolution of approximately 100 km enables calculations of the erythemally effective irradiance with an accuracy higher than 0.5 UVI and 2.5 UVIh for skin Type 1.

In a recent study (16) the influence of uncertainties in TOC to the erythemally effective UV radiation was quantified. The p95 of absolute differences resulting from measurement uncertainties in TOC, maximum daily irradiance and daily dose are taken from this study and added to Figs. 3, 7 and 11 as gray shaded areas (data from TOVS are excluded). Their lower limits are at the level of those p95 which would result from a spatial gap of 100 or 200 km. The level of the upper limits of uncertainty differs quite significantly between the different locations. At 50°N they are comparable to distances of 400–500 km, at 30°S to distances of 500 and 600 km and at the equator they are larger than uncertainties from distances of 1000 km. The annual courses of the uncertainties from measurement uncertainties and from spatial variability may differ significantly for certain months of the year.

In order to reduce the uncertainty of the erythemally effective irradiance and eventually to improve UV index calculation we conclude that the spatial variability of TOC has to be considered especially for the mid-latitudes where high gradients on smaller spatial scales occur. Data gaps can be avoided and spatial ozone variability better taken into account by means of data assimilation procedures where total ozone measurements are assimilated into global chemistry-transport models driven by meteorological fields (e.g. 39, 40). This results in synoptic TOC distributions which build a basis for improving the derivation of erythemally effective irradiance, daily dose and the UV index.

In a follow-up paper the influence of the temporal variability to the erythemally effective irradiance and daily dose will be studied.

REFERENCES


