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ESTIMATE EARTH SURFACE ULTRAVIOLET RADIATION EXPOSURE FROM ISCCP-D1 AND TOMS MEASUREMENTS

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1. INTROUDUCTION

The response of the biosphere to UV radiation is proportional to both instant high and daily-accumulated amounts of UV exposure (*Tevini, 1993*). Hence, a "snapshot" of UV intensity derived from a single satellite measurement is insufficient to understand the ecological impact of increased surface UV radiation. By combining TOMS total ozone amount with ISCCP-D1 3-hourly reflectance measurements, we have obtained global diurnal and daily-integrated UV data over a long period (1983-1994). The inversion algorithm of Li et al. (2000) was employed with a newly developed VIS-UV reflectance conversion model. The data were validated against ground–based measurements at 6 stations. Finally, The effect of diurnal variation in atmospheric opacity, due primarily to cloud, on the estimation of daily erythemal UV doses is investigated with both ground-based and ISCCP-D1 data.

2. METHODOLOGY

2.1. UV Inversion Algorithm

The retrieving algorithm developed by Li et al. (2000) is adopted. This algorithm is particularly tailored for processing large amount of satellite data due to its simplicity and few input parameters required. The algorithm has been validated using Canadian UV measurements (Wang et al, 2000). This algorithm is valid for retrieving surface UV flux at any integrated wavelength, such as UVB and erythemal UV dose rate. Some of the coefficients in the algorithm need to be adjusted accordingly. The required input parameters are UV band-mean TOA albedo without ozone absorption, total ozone amount and surface albedo.

2.2. Relationship Between UV Band-mean TOA Albedo and TOA Albedo at 360nm

Since no satellite measurement cover the entire UV spectrum, band-mean TOA UV albedo must be estimated from narrowband measurements, either in UV or in Visible. In the previous studies (Li et al., 2000; and Wang et al.2000), the UV band-mean TOA albedo is converted from TOMS measured TOA albedo at 360nm with a linear relationship. However, after close examination with radiative transfer calculations, it is found that more accurate estimation may be achieved using a non-linear relationship to account for the strong wavelength dependence of Rayleigh scattering. This is clearly illustrated in Figure 1. The new relationship is:

$$R_{UVB} = a + bR_{360}{}^{C} \qquad (1)$$

where R_{UVB} and R_{360} denote band mean TOA albedo at UVB and TOA albedo at 360nm, respectively. a , b and c are coefficients. They are functions of solar zenith angle and the optic depth of Rayleigh scattering.

As seen from Figure 2, applying the simple linear relation may induce –10 to 20% error in the estimated atmospheric transmittance for scattering. Modification of the relationship reduce the majority of errors to within 5%. The outliers (around –20%) only appear at the very low transmittance and thus very small absolute errors.

2.2. Relationship Between visible TOA Albedo and TOA Albedo at 360nm

As there are more satellite measurements in the visible

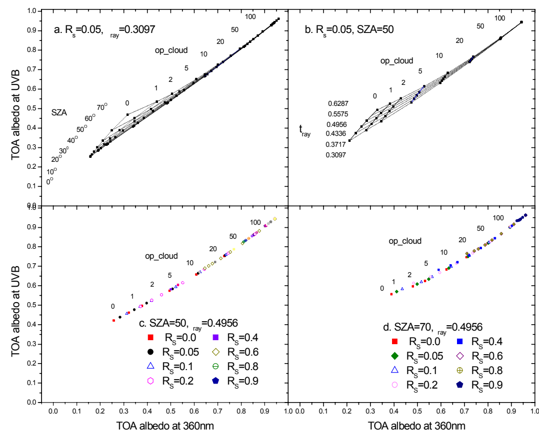

Figure 1. Relationship between TOA albedo at 360nm and mean TOA albedo in UVB. Rs denotes surface albedo. τ_{ray} represents the optical depth of rayleigh scattering. Op_clo is cloud optical depth.

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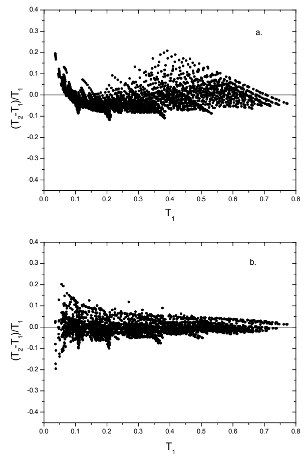

Figure 2. Relative errors in estimated atmospheric transmittance as a function of atmospheric transmittance using (a) linear; and (b) nonlinear relationships.

visible band than in the UV, it is desirable to take advantage of visible information for UV inversion. As such, the relationship between TOA visible albedo (R_{VIS}) and TOA albedo at 360nm (R_{360}) is also developed. The long separation in wavelength requires surface albedo be considered in terms surface type. Following comprehensive radaitive transfer calculations over 10 different surface types, we derived the following relationship:

$$R_{360} = d + eR_{VIS}{}^{f} \tag{2}$$

where d, e and f are coefficients. They are parameterised as functions of SZA given in Table 1 (not shown) for four distinct surface types: vegetation, water, desert and snow.

As shown in Figure 3. The relative differences are small (<±10%) for all surface types under most conditions. Relatively large errors occur over snow surface and thick cloud (~100) or large SZA.

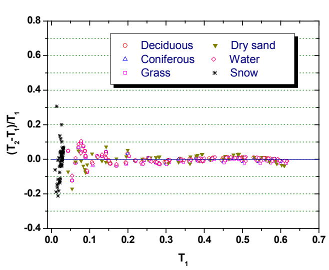

Figure3.Same as Fig. 2 but for using visible reflectance R_{VIS} (about 640nm) and Eq. (2).

3. RESULTS AND DISCUSSIONS

3.1. Effect of Diurnal Variation of Clouds

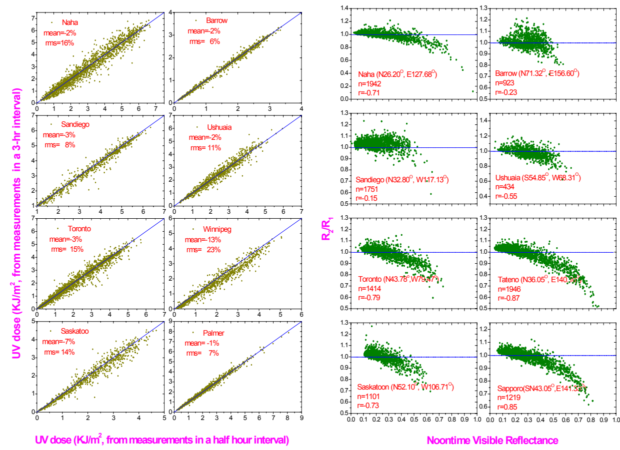

Figure 4. Left: Comparisons of daily-integrated erythemal UV doses calculated from ground-based measurements in 0.5h interval against those of 3 hours, together with mean and root mean relative differences. Right: Ratio of R_2 vs R_1 as a function of TOA noontime visible reflectance. n is the number of samples. r denotes correlation coefficient. R_2 and R_1 is defined as:

$$R_1 = \sum_{i=1}^{n}\left[T_{O_3}(i) * \left(1 - a - b * R_{360}(j)^c\right) * \mu_0(i)\right] \quad R_2 = \sum_{i=1}^{n}\left[T_{O_3}(i) * \left(1 - a - b * R_{360}(noon)^c\right) * \mu_0(i)\right]$$

Among all the factors controlling the UV radiation reaching the earth surface, cloud cover exhibits the largest diurnal variation. Hence, it may not be sufficient to calculate the daily-integrated exposure from a single "snap shot". The right panel in Figure 4 shows the ratio of R_2 to R_1 as a function of TOA noontime visible reflectence (hereinafter referred to as α_{vis}) for pixels covering the 8 ground stations that are used in this study. There is a clear tendency that the ratio generally decreases with increasing α_{vis}. Except for Barrow, San Diego and Ushuaia, the correlation coefficients between the ratio and α_{vis} are fairly high, ranging from –0.71 to –0.85. Yet, the ratio is generally larger (less) than 1 for α_{vis} less (larger) than 0.15, implying that daily erythemal UV dose would be overestimated using a single noontime ISCCP-D1 measurement made under clear or low cloud cover conditions. The opposite is true for overcast or thick cloud cover conditions. These results are similar to those obtained by Martin et al. (2000) with ground-based measurements.

The interval of 3 hours appears to be coarse in resolving cloud diurnal variation. The left panel in Figure 4 is an examination of the suitability of using ISCCP 3-hour sampling interval to compute daily-mean values. It shows that the comparisons made between the daily erythemal UV doses calculated from ground-based measurements in two different sampling intervals, namely 3 hours and less than an hour, for 8 station. Overall, the two quantities are very close with small mean and RMS differences. Note that these comparisons are based on ground-based measurements. Both the mean and RMS differences would be smaller in the estimates of daily erythemal UV dose over a satellite grid for reduced cloud variability. It

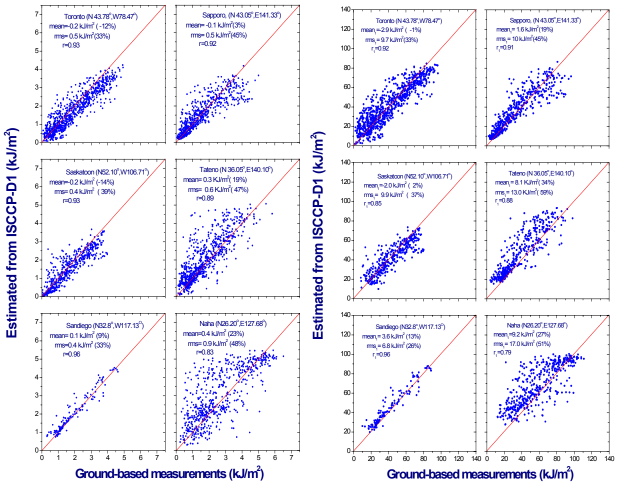

Figure 5. Scatterplots of the daily-integrated erythemal UV dose (left) and UVB (right) estimated from ISCCP-D1 and TOMS measurements against those measured by ground-based instruments at 6 different stations.

is thus concluded that 3-hour sampling intervals suffice for estimating daily UV dose.

3.2.Validation Against Ground-based Measurement

The quality of the estimated daily-integrated surface UV radiation from ISCCP-D1 satellite measurements is investigated by comparing against those measured by ground-based instruments. Figure 5 shows the comparisons of daily values for 6 stations of latitude ranging from 26°N to 52°N. These stations were selected for match in space and time with ISCCP-D1 3-hourly measurements. Mean and RMS difference between ISCCP-D1 estimated and ground-based data are also given in the figure, in both absolute (kJ/m^2) and relative magnitudes (%). It is seen that the estimates are closely correlated with the ground-based measurements, the correlation coefficient ranging from 0.79 to 0.96. The systematic mean biases for UV dose are also generally small, ranging from –0.2 to 0.4 kJ/m^2 and from –12 to 23% respectively in absolute and relative values. The slopes of liner fit are shown to vary from 0.72 to 0.96. However, data scattering is rather significant with RMS from 33 to 48%. The scattering appears to be larger in low latitude stations such as Tateno and Naha, than those in high latitudes such as Toronto and Saskatoon. This is presumably because of more frequent presence of broken clouds in low latitudes than in high latitudes. Among the six stations shown in Figure 5, San Diego has the highest correlation coefficient (0.96), a moderate mean difference (9%) and the lowest RMS of difference (33%), as a result of prevailing clear sky condition over this station.

This is not surprising considering large differences in areas represented by ISCCP data (about 280 km by 280 km) and ground-based measurements (single point), and strong spatial variation in the optical property of the atmosphere and cloud. Therefore, instant values measured by ground-based instrument at a single spot may deviate significantly from those estimated from satellite as a result of sampling errors. This is demonstrated by the finding that the RMS error in the comparisons of the satellite-estimated with ground measured surface radaition decreases substantially with increasing density of surface sites within a satellite grid cell (Li et al., 1995). It also bodes well with a comparison of instantaneous UVB irradiances between satellite estimation and ground-based observation, for which more scattering is found under all sky conditions than under clear sky conditions (Wang et al., 2000). To check if this is the case for daily-integrated UV doses, Figure 6 shows the variation of estimated-to-measured UV dose ratio against daytime mean cloud amount. The latter was calculated from daytime 3-hourly cloud statistics in ISCCP-D1 data, and the method for cloud detection was described by Rossow et al. (1999) in detail. Mean and RMS differences between the estimated and measured daily erythemal UV doses for different bins of daytime mean cloud amount are also given. It is clearly seen that, except for Naha, the ratio is much more spread at the high end of cloud amount than that at the low one, with RMS differs by a factor of 2.

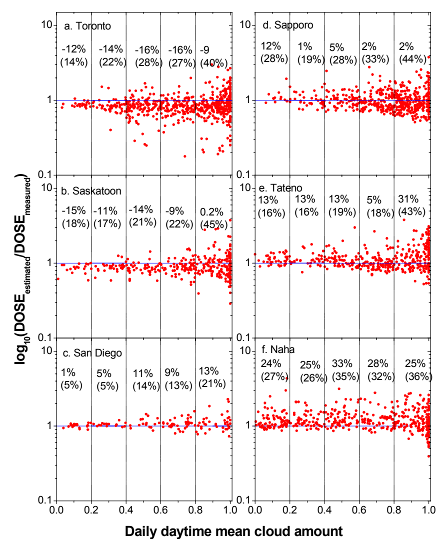

Figure 6. Ratio of ISCCP-D1 estimated daily erythemal UV doses to ground-based measurements as a function of daily mean cloud amount in the ISCCP-D1 pixel over the ground stations. Mean and rms difference (in parentheses) for the different bins of daily mean cloud amount are also shown.

The sampling error discussed above is reduced by averaging over a week or a month period. This has been demonstrated for both TOMS-estimated UV irradiance (Herman et al., 1999) and TOMS-estimated daily erythemal UV doses (Kalliskota et al., 2000). The same is true for ISCCP-estimated erythemal UV doses, as are shown in Figure 7, which presents the daily variations of erythemal UV doses estimated from ISCCP-D1 for the grid-cell encompassing Toronto in 1991, in comparison with ground measurements. Individual dots (solid for ground observations and open for satellite estimation) correspond to daily mean values, while the curves are for 7-day running means. As the interval of temporal averaging increases from one day to seven 7 days, the correlation coefficient increases from 0.92 to 0.97 and RMS difference decreases from 0.54 kJ/m^2 to 0.41 kJ/m^2, nearly 25% reduction.

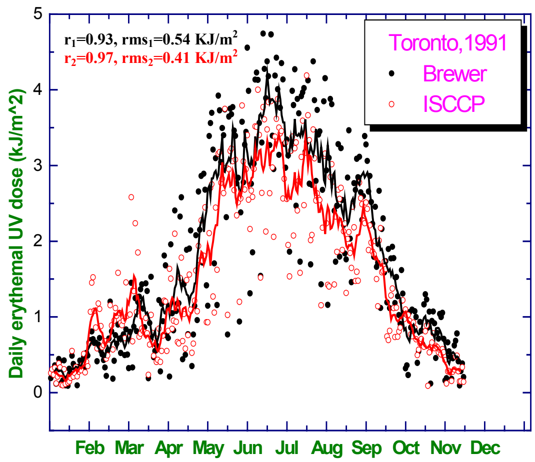

Figure 7. ISCCP-estimated daily erythemal UV doses (open dots) and ground-based measurements (solid dots) in 1991. The solid lines represent 7-day running average. r_1 (or rms_1) and r_2 (or rms_2) denote correlation coefficient (or root mean square error), with and without running average.

4. SUMMARY

In this study, we presented a method that enables us to derive daily UV exposure by combining ISCCP-D1 and TOMS measurements. This method accounts for the effect of diurnal cloud variation on the total amount of UV radiation reaching the surface. Errors in the estimates of daily-integrated UV exposure from a single noon time "snap shot" were also investigated. In summary, it can be concluded as follows:

1. Daily erythemal UV doses estimated from only a noontime satellite "snapshot" may incur errors larger than 20%, which may be reduced for long-term averages.
2. A general good agreement between estimated and measured daily UV exposure is found at most stations, with relative mean and root mean square (RMS) differences ranging from –12 to 23% and 33 to 48% respectively. Among them, a fairly low mean difference (9%) and the lowest RMS difference (33%) was observed at San Diego, owing to the prevailing clear sky condition. A large portion of the differences originated from the mismatch between satellite and ground-based measurements.
3. A new long-term global dataset of surface UV radiation was generated, which shall be useful for studying the biological and ecological effect of UV radiation reaching the Earth's surface.

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