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Action Spectrum Conversion Factors that Change Erythemally Weighted to Previtamin D_3-weighted UV Doses†

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ABSTRACT

Many solar UV measurements, either terrestrial or personal, weight the raw data by the erythemal action spectrum. However, a problem arises when one tries to estimate the benefit of vitamin D_3 production based on erythemally weighted outdoor doses, like those measured by calibrated R-B meters or polysulphone badges, because the differences between action spectra give dissimilar values. While both action spectra peak in the UVB region, the erythemal action spectrum continues throughout the UVA region while the previtamin D_3 action spectrum stops near that boundary. When one uses the previtamin D_3 action spectrum to weight the solar spectra (D_{eff}), one gets a different contribution in W m^{-2} than what the erythemally weighted data predicts (E_{eff}). Thus, to do proper benefit assessments, one must incorporate action spectrum conversion factors (ASCF) into the calculations to change erythemally weighted to previtamin D_3-weighted doses. To date, all benefit assessments for vitamin D_3 production in human skin from outdoor exposures are overestimates because they did not account for the different contributions of each action spectrum with changing solar zenith angle and ozone and they did not account for body geometry. Here we describe how to normalize the ratios of the effective irradiances (D_{eff}/E_{eff}) to get ASCF that change erythemally weighted to previtamin D_3-weighted doses. We also give the ASCF for each season of the year in the northern hemisphere every 5° from 30°N to 60°N, based on ozone values. These ASCF, along with geometry conversion factors and other information, can give better vitamin D_3 estimates from erythemally weighted outdoor doses.

INTRODUCTION

Solar terrestrial UV radiation (290–400 nm) affects human health in both detrimental and beneficial ways. Sunburn (1) is among the detrimental health effects (2,3), while vitamin D_3 production (4) is among the beneficial health effects (5–7). The erythemal action spectrum can estimate the risk of getting a sunburn (8); however, it cannot correctly estimate the benefit for making vitamin D_3. Erythemally weighted terrestrial UV doses are available worldwide from calibrated R-B meters and Brewer spectrophotometers. Erythemally weighted personal UV doses are readily available from calibrated polysulphone badges and minimum erythemal dose (MED) meters. Most outdoor UV measurements are weighted by the erythemal action spectrum so that action spectrum conversion factors (ASCF) are needed to convert those doses to previtamin D_3-weighted doses (9) in order to do accurate benefit assessments. Because most benefit assessments for vitamin D_3 production from solar UV exposures are based on erythemally weighted data, they are incorrect overestimates (10). These estimates also do not account for human body geometry, which can decrease the amount by 50% or more, because the UV doses used in the calculations are relative to the horizontal plane. Furthermore, most estimates also do not account for the declining ability to make vitamin D_3 with age (11), which can reduce the amount by 50% or more after the age of 60. Thus, the estimates for vitamin D_3 production currently available are much higher than what people actually make from casual outdoor UV exposures.

Although both action spectra peak in the UVB region, the previtamin D_3 action spectrum stops near the UVA boundary (9) while the erythemal action spectrum continues throughout the UVA region to 400 nm (8). If one uses the previtamin D_3 action spectrum to weight the solar UV spectra, one finds it contributes a different amount toward vitamin D_3 production than what the erythemally weighted UV doses predict. Thus, to do proper benefit assessments for making vitamin D_3, the difference between the contributions of these action spectra must be accounted for by using ASCF that change erythemally weighted UV doses to previtamin D_3-weighted UV doses. Simply weighting solar spectra by the previtamin D_3 action spectrum to get the effective irradiance (eff) will not render useable data because the original studies used MEDs produced from tanning lamp exposure to measure the amount of circulating 25-hydroxyvitamin D_3 produced in humans. Thus, those human studies actually weighted the tanning lamp's spectral output by the erythemal action spectrum. To get accurate ASCF for solar erythemal UV doses, one must normalize the ratios between the effective irradiances of previtamin D_3 and erythema by the ratio of the effective irradiance delivered by the tanning lamp's spectral emission that was used to get a given amount of that biologic effect

†The opinions and/or conclusions expressed are solely those of the authors and in no way imply a policy or position of the Food and Drug Administration.
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(previtamin D_3 here [12]). Thus, before calculating the amount of vitamin D_3 a person makes from outdoor erythemal UV exposures, one must first weight the solar spectrum by the erythemal action spectrum, if it is not already weighted, and then multiply by the correct ASCF.

Here we describe a method to formulate ASCF that change erythemally weighted to previtamin D_3-weighted solar UV doses. We calculate ASCF for each season of the year in the northern (45°N) and southern (35°N) United States taking into account differences in ozone levels at those latitudes during each season. We also calculate ASCF for different ozone levels every 5° from 30°N to 60°N, and provide equations for calculating new ASCF at other ozone levels so that better calculations can be made for vitamin D_3 production from erythemally weighted terrestrial and personal UV doses in the northern hemisphere.

MATERIALS AND METHODS

We calculated solar spectra to get the ratio changes between the W m^{-2} needed for previtamin D_3 production and the W m^{-2} needed for erythema throughout an average day during each season. We used Fast RT (13), which utilizes the radiative transfer model LibRadTran (14), to calculate solar spectra every two degrees of solar zenith angle (SZA) for the middle of each season on 15 July, 15 October, 15 January and 15 April. We generated calculated spectra using different ozone values in Dobson units (DU) averaged for each season at different latitudes in the northern hemisphere (15). The ozone values used in the calculations for the northern (45°N) and southern (35°N) U.S. are:

U.S. latitude	Summer	Fall	Winter	Spring
North (45°N)	325 DU	285 DU	325 DU	375 DU
South (35°N)	285 DU	260 DU	285 DU	310 DU

We calculated clear-sky spectra using an albedo of 3% for the middle of the United States at Little Rock, Arkansas (35°N) and Minneapolis, Minnesota (45°N), and used Central Standard Time. From these data, we calculated the previtamin D_3 effective irradiance (D_{eff}) and the erythemal effective irradiance (E_{eff}) by multiplying each solar spectrum by each action spectrum and integrating the area under the curves to get the total effective irradiance in W m^{-2}. We used the original previtamin D_3 action spectrum in human skin (9), which stops around 320 nm and is normalized at 297 nm, and the Commission Internationale de l'Eclairage (CIE) erythemal action spectrum (8), normalized at 298 nm, to weight every wavelength of the solar irradiance to get the D_{eff} and the E_{eff}, respectively, according to Eq. (1).

$$\int_{290}^{400} I(\lambda)w(\lambda)\,d\lambda \qquad (1)$$

where λ is the wavelength in nm, $I(\lambda)$ is the irradiance in W m^{-2} nm^{-1} and $w(\lambda)$ is the action spectrum weighting function.

We chose not to use the CIE previtamin D_3 action spectrum in human skin because the committee mathematically extended it from 320 to 330 nm without any supporting experimental data (16) and because our digitization of the original previtamin D_3 action spectrum (9) does not match the CIE's; however, our digitization matches Sayre and Dowdy's (17).

We calculated the D_{eff} and E_{eff} in W m^{-2} for every 1/10th degree of SZA and matched each 15-min time interval throughout the day with its corresponding SZA and effective irradiance. We then normalized those ratios using the averaged ratio between the two lamps used to produce vitamin D_3 in humans (D_{eff}/E_{eff} ~1.5 ± 0.1) and then matched that spectral ratio of D_{eff}/E_{eff} with a solar spectrum that gave a similar ratio. We used the solar noon (35.2° SZA), mid-April ratio at 45°N and 375 DU (ratio is 1.51). We must do this because, unlike tanning lamps that have a fixed spectral irradiance, the solar irradiance changes with SZA and ozone, so that the contributions in W m^{-2} nm^{-1} toward each endpoint changes throughout the day and year (and latitude). We normalize the seasonal ratios by dividing by 1.51 because, in previous studies, the international units (IU) of vitamin D_3 made (about 15 000 [12]) from exposing people (90% body area) with skin Type II (18) to 1 MED (320 J m^{-2}) was delivered using either a tanning bed (Wolff Eurosun S3 lamps with added UVB phosphor [19]) or a UVB booth (FS lamps [20]). We matched the averaged ratio of D_{eff}/E_{eff} of these two types of lamps to a point reference solar spectrum with a similar ratio, called the "Standard Sun." The exact character of the spectral emission is not as important as the ratio of D_{eff} to E_{eff} produced from that source. We should mention a caveat; no solar spectrum can match the output of either of these lamps because they emit wavelengths below 290 nm, while the solar UV reaching the earth's surface is negligible below 290 nm. This causes an overrepresentation of weighted shortwave UVB (< 290 nm), when compared with solar spectra. Nevertheless, our so-called "Standard Sun" or normalizing solar spectrum generates D_{eff}/E_{eff} ratios that are within 10% of these two source spectra values. In addition, if one uses the CIE previtamin D_3 action spectrum, one will get slightly larger D_{eff}/E_{eff} ratios, a slightly larger normalization constant, and slightly larger ASCF as well.

We calculated the ASCF to change solar UV irradiances weighted by the erythemal action spectrum to solar UV irradiances weighted by the previtamin D_3 action spectrum by forming a ratio between the two effective irradiances (D_{eff}/E_{eff}) throughout one representative day in the middle of each season. The normalized ratio of D_{eff}/E_{eff} is the ASCF. Thus, to convert from an average daily erythemal dose in J m^{-2} to an average daily vitamin D_3-producing dose in J m^{-2} throughout 1 day during a season, one multiplies the erythemal dose in J m^{-2} by the corresponding ASCF for that season.

The ASCF are calculated using Eq. (2).

$$\left(\int_{i=1}^{n} D_{eff} / \int_{i=1}^{n} E_{eff}\right) / N\,dn \qquad (2)$$

where n is the number of increments of data (15 min intervals of solar irradiance from 290–400 nm), D_{eff} is the previtamin D_3 effective irradiance (in W m^{-2}), E_{eff} is the erythemal effective irradiance (in W m^{-2}) and N is the normalization constant (1.51 for previtamin D_3), which is unitless, as are the ratios of D_{eff}/E_{eff} and the ASCF.

The ASCF are weighting factors. Here they convert seasonal, daily erythemal doses to seasonal, daily previtamin D_3 doses. Thus, a person with skin Type II will make about 15 000 IU of vitamin D_3 when they get 1 MED (320 J m^{-2}) on 90% of their body from a tanning source that has a spectral output yielding a D_{eff}/E_{eff} ratio of 1.5 ± 0.1, when the ASCF is unity. If another source with a different spectral output is used, such as the sun, the ASCF will convert those erythemally weighted doses to previtamin D_3-weighted doses. One weights the erythemal dose prior to calculating how much vitamin D_3 a person makes from that particular previtamin D_3 dose because the ASCF are independent of all other variables, such as skin type, age, dose received and the percent of the body area exposed.

To show how the ASCF change during a summer day, we measured every nm of the outdoor solar UV irradiance from 290 to 400 nm. We took measurements every other hour at 10:00 A.M., 12:00 P.M., 2:00 P.M. and 4:00 P.M. on 29 June 2004, in Silver Spring, MD (39°N, 77°W and < 0.1 km above sea level) using a double-grating portable spectroradiometer (Optronics Model OL 754; Optronic Laboratories, Inc., Orlando, FL). We calibrate our spectroradiometer using a 1000 W standard lamp that is traceable to the National Institute of Standards and Technology.

RESULTS

In Fig. 1a we show the action spectra for previtamin D_3 (9), normalized at 297 nm, and erythema (8), normalized at 298 nm. Notice that erythema has a lower contribution in W m^{-2} nm^{-1} than previtamin D_3 from 299 to 315 nm, and extends throughout the UVA region to 400 nm, whereas the previtamin D_3 action spectrum stops near the UVA boundary. The differences between these action spectra become apparent when used to weight the solar spectra (for a 12:00 P.M. and 4:00 P.M. example of solar spectra during June, see Fig. 1b) to get the contribution in W m^{-2} nm^{-1} toward each respective endpoint. Figure 1c shows the product of each action spectra with the 12 pm solar spectrum. The contributions at noon on 29 June 2004 (39°N; < 0.1 km, 325 DU) are 0.2901 W m^{-2} for previtamin D_3 and 0.1672 W m^{-2} for erythema. The ratio is 1.734 at noon, so that the ASCF is 1.15 (1.734/1.51). Figure 1d shows the product of each action spectra with the 4:00 P.M. solar spectrum. The contributions at 4:00 P.M. on the same day are 0.0878 W m^{-2} for previtamin D_3 (3.3 times lower than noon) and 0.1231 W m^{-2} for erythema (only 1.36 times lower than noon). The ratio is 1.4 at 4:00 P.M., so that the ASCF is about 0.93 (1.4/1.51). This illustrates how the ratios and ASCF change with time during the day, but note that this is also true for different seasons and latitudes because the ASCF are dependent on the SZA.

Figure 2a shows the calculated solar spectra for SZA from 6° to 86° every 4° using Fast RT (13). These calculated solar spectra, created for the middle of each season, are first weighted by each of the action spectra shown in Fig. 1a, separately totaled for that season's day, then a daily ratio for that season is formed (D_{eff}/E_{eff}), and finally the ratios for each season are normalized by the "Standard Suns" (solar noon, mid-April value at 45°N) D_{eff}/E_{eff} ratio (1.51). Note how the shortest wavelength reaching the Earth's surface (290 nm around noon) increases with decreasing SZA or increasing time away from solar noon. Figure 2b shows the changing D_{eff} and E_{eff} during the summer's representative day (middle of July) and during the winter's representative day (middle of January), while Fig. 2c shows how the ASCF change during the summer's representative day (middle of July) and during the winter's representative day (middle of January). For clarity, we did not show the spring and fall seasons.

Figure 3 shows the normalized daily ratios of D_{eff}/E_{eff} or the ASCF obtained throughout the year (from winter to winter) in the middle of each season in the southern (35°N) and northern (45°N) United States.

Figure 4 shows how the ASCF change with changing time (or SZA) during a summer day (29 June 2004, Silver Spring, MD, latitude 39°N, 77°W, < 0.1 km). Note that at noon (SZA 21.8°) the ASCF is slightly more than unity (1.15), while it is

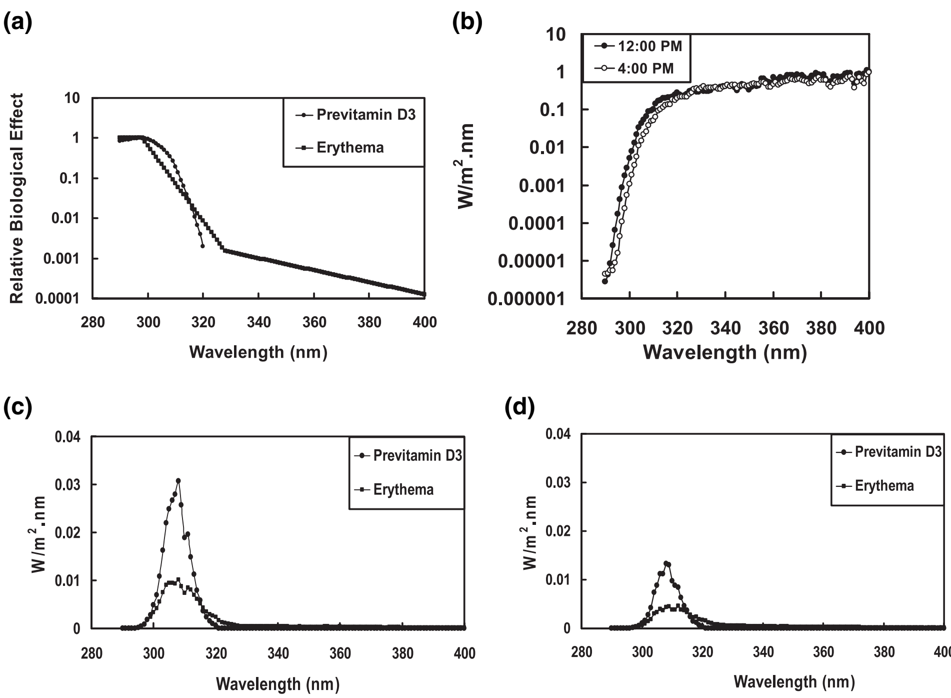

Figure 1. (a) Semi-log plot of the action spectra for previtamin D_3 production in human skin (8) and erythema in human skin (7). Note that the CIE normalized the erythemal action spectrum at 298 nm, and we normalized the previtamin D_3 action spectrum at 297 nm. (b) Semi-log plot of two solar UV spectra measured in Silver Spring, MD (39°N, 77°W, < 0.1 km, 325 DU) at 12:00 P.M. (SZA 21.81°) and 4:00 P.M. (SZA 38.9°) on a clear day in June (29 June 2004). (c) The 12:00 P.M. solar UV spectrum in (b) weighted by the previtamin D_3 (8) and erythemal (7) action spectra shown in (a). Note that the shortest wavelength reaching the earth's surface was 293 nm and the peak contribution from the sun occurs near 308 nm. The integrated numbers under the curves or contributions toward each biologic endpoint are 0.2901 W m^{-2} for previtamin D_3 and 0.1672 W m^{-2} for erythema. The D_{eff}/E_{eff} ratio is 1.734. The normalized ratio or ASCF is about 1.15 (1.734/1.51) at noon on 29 June 2004 and is unity at 10:00 A.M. (d) The 4:00 P.M. solar UV spectrum in (b) weighted by the previtamin D_3 (8) and erythemal (7) action spectra shown in (a). Note that the shortest wavelength reaching the earth's surface was 295 nm while the peak contribution from the sun still occurs near 308 nm. The integrated numbers under the curves or contributions toward each biologic endpoint are 0.1231 W m^{-2} for previtamin D_3 (about 3.3 times less than at noon) and 0.0878 W m^{-2} for erythema (only about 1.35 times less than at noon). The D_{eff}/E_{eff} ratio is about 1.4. The normalized ratio or ASCF is about 0.93 (1.4/1.51) at 4:00 P.M. on 29 June 2004.

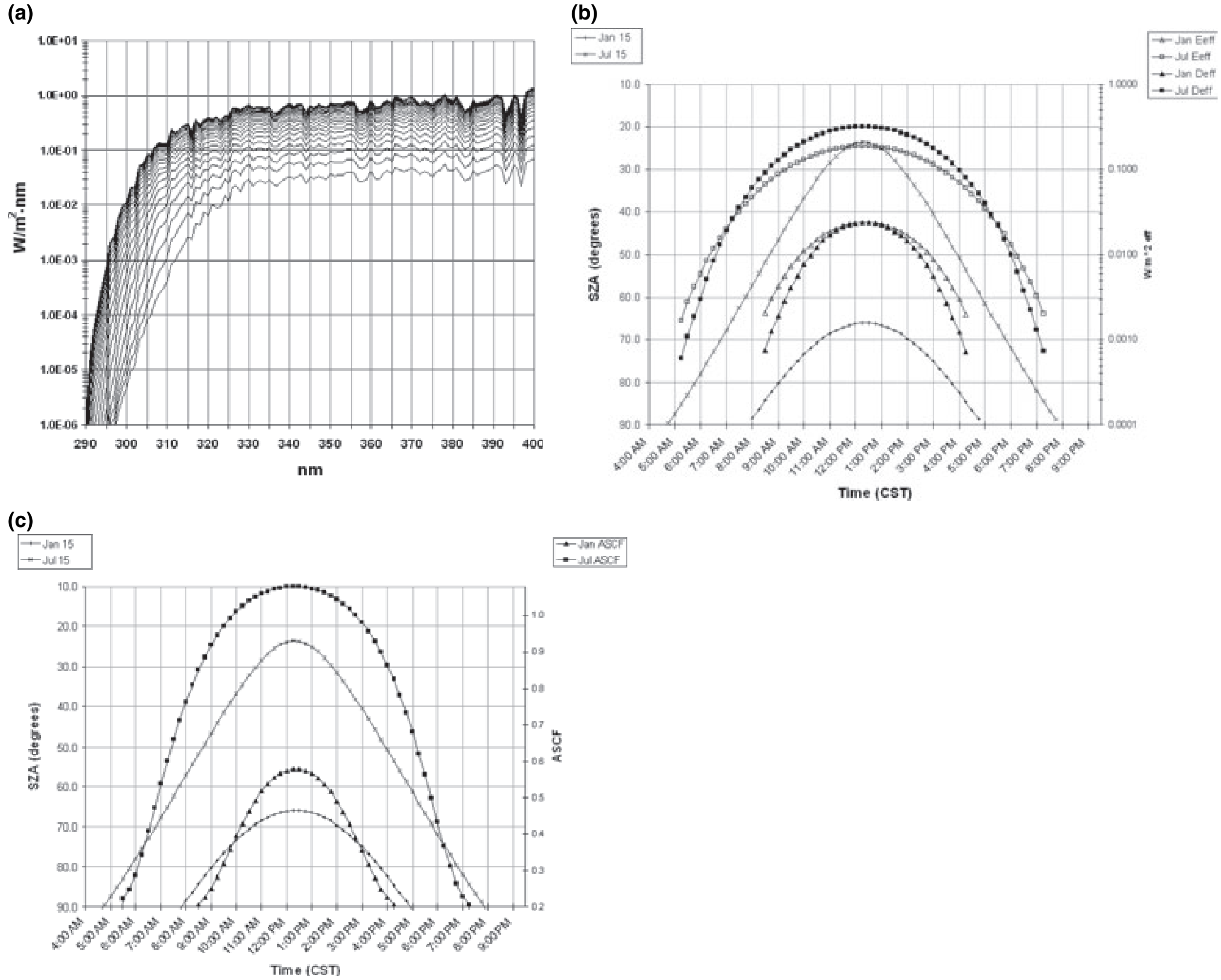

Figure 2. (a) Semi-log plot of the calculated solar spectra comprising every 4° of SZA from 6° to 86° at 45 °N (300 DU). (b) SZA labeled on the left (primary) *Y*-axis for diurnal periods in the middle of January and July with the middle of July having the lowest SZA (or highest peak solar altitude angle). W m^{-2} nm^{-1} labeled on the right (secondary) *Y*-axis (log scale) shows curved lines with solid and hollow data markers. These curves represent the changing E_{eff} and D_{eff} irradiances for different SZA during the day in the middle of January and July at 45°N (325 DU). (c) SZA labeled on the left (primary) *Y*-axis for diurnal periods in the middle of January and July with the middle of July having the lowest SZA (or highest peak solar altitude angle). ASCF labeled on the right (secondary) *Y*-axis shows curved lines with solid data markers. These curves represent the changing normalized D_{eff}/E_{eff} irradiances or incremental ASCF throughout the day during the middle of January and July at 45°N (375 DU).

unity or less in the morning (*e.g.* at 10:00 A.M. it is 1.0 with SZA of 43.3°) and in the afternoon (*e.g.* at 4:00 P.M. it is about 0.93 with SZA of 38.9°). During the winter, the ASCF ratio is noticeably less than unity at solar noon (about 0.57 mid-Jan) and changes rapidly during the day, as shown in Fig. 2c. We also calculated the Fast RT solar spectrum for 10:00 A.M. on 29 June 2004 using measured ozone levels of 325 DU, which gave a D_{eff}/E_{eff} ratio of 1.01, within 1% of our measured values.

Figure 5 shows the average ozone values in DU for each season in the northern hemisphere every 5°N from 10°N to 80°N (plotted from the data in Ilyas [15]).

Figure 6a–d shows how the ASCF change with different ozone levels at various latitudes (every 5°N from 30 to 60°N; equations are adjacent to the latitude) each season: (a) summer, (b) spring, (c) fall, (d) winter.

Table 1 shows the estimates of the seasonal ASCF every 5°N from 30 to 60°N based on average ozone levels during each season (see Fig. 5). To correct these estimates for differences in ozone, one should use the equations in Fig. 6a–d.

DISCUSSION

We describe a method to get ASCF to convert solar E_{eff} to solar D_{eff} and give seasonal estimates for every 5° of latitude from 30 to 60°N. Note that the ASCF are only weighting functions (unitless) that change a solar erythemal dose to a solar previtamin D_3 dose. They are independent of all other variables, such as age, skin color and area exposed. One uses the other variables to calculate the amount of vitamin D_3 a person makes from an outdoor exposure after one weights the solar erythemal dose by an appropriate ASCF to get the "relative" D_{eff}. All outdoor D_{eff}/E_{eff} ratios have to be normalized by the UV lamps' D_{eff}/E_{eff} ratio (N = 1.5), so that the other variables can be properly used to calculate the amount of vitamin D_3 a person produces.

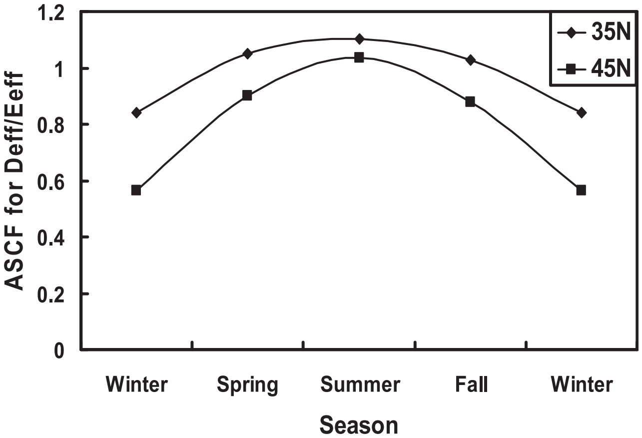

Figure 3. Annual pattern of the changing seasonal average ASCF from calculated solar spectra in the southern (35°N) and northern (45°N) United States.

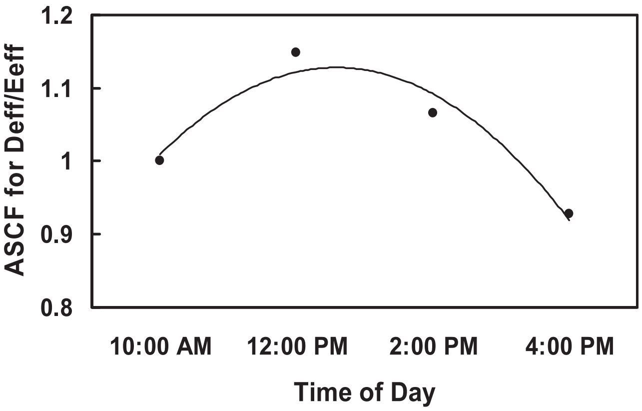

Figure 4. The ASCF for D_{eff}/E_{eff} calculated from spectrophotometric measurements of the sun every other hour from 10:00 A.M. to 4:00 P.M. on 29 June 2004 at 39°N (77°W, < 0.1 km, 325 DU). Note that at noon during the summer, the ratio is a little above unity (1.15), but is noticeably less than that before or after 12:00 P.M. For example, at 10:00 A.M. (SZA 43.3°) the ratio is unity (another "Standard Sun"), while at 4:00 P.M. it is only about 0.93.

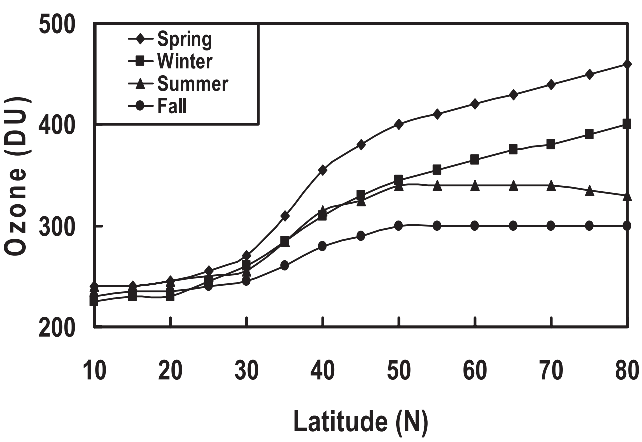

Figure 5. Average seasonal ozone levels in the northern hemisphere every 5°N from 10°N to 80°N, plotted from the data in Ilyas (15).

We show here how to get an average ASCF for each season of the year, but one can use this approach to get ASCF for any period, *e.g.* year, month, week, several days, 1 day or for any time during a day, so that one can use ASCF for different purposes. To get the correct ASCF, one must use the original action spectra for both erythema (8), normalized at 298 nm, and previtamin D_3 (9), normalized at 297 nm (or 298 nm [17]), and the normalization constant of 1.5 ± 0.1. The average seasonal ASCF values can then be used to convert average seasonal, erythemally weighted solar doses to average, seasonal previtamin D_3-weighted solar doses, as we did for vitamin D_3 production in the U.S. (D. E. Godar, S. J. Pope, W. B. Grant and M. F. Holick, in preparation), because we have averaged personal erythemally weighted UV doses for each season in the northern (45°N) and southern (35°N) United States (21,22). Note that one can also use this approach to convert from erythemally weighted doses to any other weighted doses using the appropriate action spectrum, normalized to the proper wavelength. However, one must know the UV dose needed to achieve a given amount of that biologic effect and the spectral output needed to get it, so that one can normalize the data by a suitable "Standard Sun." Unfortunately, no one can calculate the ASCF needed to change erythemally weighted data to photocarcinogenically weighted data because no one knows the photocarcinogenic dose needed to produce a squamous cell carcinoma or the solar spectrum (or other UV-emitting source) required to produce that UV dose, so that the data cannot be normalized (J.C. van der Leun, personal communication).

The ASCF seem counterintuitive when one compares the effective irradiances because the D_{eff} is usually larger than the E_{eff}. The amount of previtamin D_3 one can make at solar noon is more than one can make during the rest of the day for a set amount of time or erythemic dose (see Fig. 4), because more of the shorter wavelength photons of UVB are present during the midday than during the morning or afternoon (see Fig. 2a). In fact, in the early morning and late afternoon there is hardly any UVB present to make previtamin D_3, while sufficient UVA is present to cause erythema. Thus, for most days of casual UV exposure outdoors, the contribution of E_{eff} toward an erythemal dose is actually more than the contribution of D_{eff} toward a previtamin D_3 dose, leading to a fraction of the daily erythemal dose effective toward previtamin D_3 production, and conversion factors that are usually less than unity (see Table 1).

Although one can calculate D_{eff} and E_{eff}, form ratios (17) and divide by the largest ratio or any other ratio, one cannot formulate accurate ASCF without proper normalization. One can properly normalize another source, as we did for the sun, by forming the ratio of D_{eff}/E_{eff} from a lamp source (like the FS lamps where the D_{eff}/E_{eff} is ~1.5) that is used under "standardized conditions." Here the "standardized conditions" are 90% of a human body area exposed to 1 MED or 320 J m^{-2} for skin Type II, which produces 15 000 ± 5000 IU of vitamin D_3. Although one does not need these standardized conditions for formulation of the ASCF, one uses them after a D_{eff} dose is obtained to calculate the amount of vitamin D_3 made from any UV dose humans get while outdoors. When the ratios of D_{eff}/E_{eff} from the source and the Sun "match," the ASCF is unity and one has a matching solar spectrum or normalizing "Standard Sun." Many so-called "Standard Suns" exist that give a D_{eff}/E_{eff} ratio of about 1.5 ± 0.1. For example, besides our two Standard Suns, solar noon on 15 April at 45°N in Minneapolis, Minnesota (375 DU) and

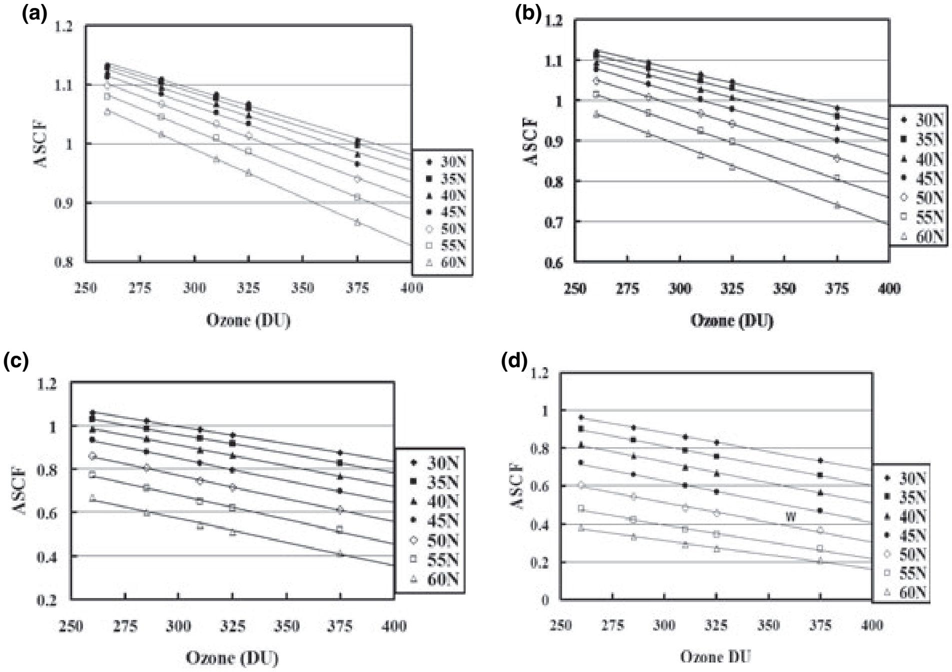

Figure 6. (a–d) Ozone levels change ASCF values at different latitudes (30–60°N every 5°N) each season: (a) summer, (b) spring, (c) fall, (d) winter. Equations for calculating new ASCF for different ozone levels are adjacent to the latitude in each figure.

Table 1. Calculated seasonal action spectrum conversion factor (ASCF) values every 5°N for latitudes between 30 and 60°N (one can generate other ASCF values for different ozone levels using the equations in Fig. 6).

Latitude	Summer	Fall	Winter	Spring
Previtamin D_3 (ASCF)				
60°N	0.951	0.601	0.269	0.742
55°N	0.986	0.71	0.344	0.805
50°N	1.013	0.802	0.453	0.857
45°N	1.034	0.879	0.565	0.9
40°N	1.067	0.963	0.7	1.008
35°N	1.104	1.029	0.842	1.049
30°N	1.11	1.061	0.91	1.065

10:00 A.M. on 29 June at 39°N in Silver Spring, Maryland (325 DU), Webb and Engelsen (23) calculated another Standard Sun with a D_{eff}/E_{eff} ratio similar to ours, solar noon on 21 March at 42.2°N in Boston, Massachusetts (350 DU).

Once one has a Standard Sun, one can weight it by each action spectra to calculate D_{eff} and E_{eff} and form the correct normalization ratio. However, one must also use correctly digitized action spectra (previtamin D_3 stops around 320 nm), normalized at the correct wavelength, because if one uses incorrectly digitized and/or one renormalizes either or both action spectra, one will get incorrect contributions to each biologic endpoint, incorrect ratios of D_{eff}/E_{eff} and incorrect ASCF. For example, if one uses the CIE previtamin D_3 action spectrum (16), one will get larger D_{eff}/E_{eff} ratios and larger ASCF. However, if one uses a properly digitized and normalized previtamin D_3 action spectrum, truncated at 320 nm, as did Sayre and Dowdy (17), one will get values within 3% of ours. For example, they got a D_{eff}/E_{eff} ratio of 1.78 at 30°N (SZA about 20° [17]) and we get a ratio of 1.74 (< 3% difference); we calculate their ASCF as 1.18 (1.78/1.51). The reason our ASCF value for 30°N in Table 1 is lower (1.11) than theirs is because we calculated averages for the entire day in the middle of each season. When we calculate the value at 30°N (SZA of 20°), we get an ASCF of 1.15 (1.74/1.51), within 3% of their value.

To calculate accurately how much vitamin D_3 a person makes at different latitudes during each season, or other time frame, one also needs to use the proper geometry conversion factors (GCF) because almost all of the erythemally weighted doses are relative to the horizontal plane. The human body is not on the horizontal plane, even while lying down, because the body is not completely flat as are the cosine-response detectors. People not only lie down, but sit and stand while outdoors and are also oriented at different aspects to the sun during changes in the SZA. Thus, we also calculated the GCF at different latitudes for each season of the year (S. J. Pope, J. J. Streicher and D. E. Godar, in preparation), so we can make better risk and benefit calculations for sunburn and vitamin D_3 production from solar exposures.

Using GCF in combination with ASCF, age-related changes (11), percent body exposed and skin type, it will be possible to get good estimates of how much vitamin D_3 a person makes from erythemally weighted solar UV doses relative to the horizontal plane. Now that this method for calculating ASCF to change erythemally weighted UV doses to previtamin D_3-weighted UV doses exists, we can get much better estimates of the benefits associated with solar UV exposures worldwide (24).

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