A first approach in measuring, modeling and forecasting the vitamin D effective UV radiation

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ABSTRACT

There has been a growing interest in the connection of vitamin D and solar ultraviolet-B (UVB) radiation because numerous studies have shown that there is an anti-correlation between the vitamin D level and many types of cancer and various diseases. Additionally there is the well known anti-correlation with osteoporosis and its progress, a disease that affects approximately in 30% of all post-menopausal women. Information about the actual effectiveness of solar UVB radiation in producing vitamin D could therefore a very helpful tool for health care. Such information should base on well estimated parameters either measured or modeled. Therefore, we investigated the possibilities in measuring, modeling and forecasting the vitamin D effective radiation. Measurements were made with two different broadband devices. One is a hand-held radiometer which was designed as a personal dosimeter and another is a device which is in use world wide to measure the erythemally effective UV radiation. Further on we introduce a world wide forecast of the vitamin D effective UV radiation for clear skies together with its validation. Input parameters for the forecast are date and time, geographical position and altitude, total ozone, low aerosol content and neglected albedo.

Keywords: UV radiation, vitamin D, measurements, Model 501, Solarmeter Model 6.4, forecast, validation

1. INTRODUCTION

UV radiation (UVR) may cause a variety of damages in the human organism. However, there are numerous positive health effects generally related to the production of vitamin D. For most people on Earth, solar UVB is the primary source of vitamin D (Reichrath 2006). The importance of vitamin D in preventing rickets has been known for about a century (DeLuca 1988, Rajakumar 2003). However, it wasn't until the 1960s that the function of vitamin D in causing mineralization of the skeleton was known (DeLuca 1988). In 1980, the UVB/vitamin D/cancer hypothesis was proposed to explain the geographic variation of colon cancer mortality rates in the U.S. (Garland and Garland 1980). There are now about 20 types of cancer for which vitamin D is a risk reduction factor (Grant 2002, Giovannucci et al. 2006, Grant and Garland 2006). From the careful observations of vitamin D and cancer risk, it has been estimated that it takes 1000 to 1500 I.U. of vitamin D per day to reduce the risk of such cancers by 30-50% (Gorham et al. 2005, Garland et al. 2006, Giovannucci et al. 2006). Vitamin D has also been found to reduce the risk of autoimmune diseases such as multiple sclerosis (Hayes et al. 1997, Cantorna and Mahon 2004), acting through effects on the immune system, moving the balance of T-helper cells from Th1 (proinflammatory) to Th2 (antiinflammatory (Cantorna 2006). There are a number of recent reviews on the health benefits of solar UVB and vitamin D (Heaney, 2003, Grant et al. 2005, Peterlik and Cross 2005, Grant 2006a, Holick 2006).

UVR regulates the vitamin D level by degrading remaining vitamin D in the skin (Webb et al. 1988). Careful interaction with the sun especially during autumn could help to avoid vitamin D deficiency. However, for those whose geographic location or lifestyle does not permit adequate solar UVB irradiance, supplements present a safe alternate way to obtain vitamin D (Vieth et al. 2001).

Information about the actual effectiveness of solar radiation in producing Vitamin D could therefore a very helpful tool for health care. Such information should base on well estimated parameters either measured or modeled. In this paper we make a first approach for these. On the one hand we have examined two different measuring devices and on the other

hand we have introduced a forecast of the vitamin D effective UVR for a horizontally and a vertically oriented receiver for the next day which works on a global scale. While the horizontally oriented receiver corresponds to the mounting of most of the operational measuring devices for UVR, the vertically oriented surface correspond closer to the orientation of the human body, especially the face (Figure 1). The forecast is validated for the location of Vienna, Austria. At this station operational measurements are made by a broadband meter whereas measurements have to be converted in dependence of total ozone content (TOC) and solar height to correspond to the non-perfect fit of the device's spectral response to the action spectrum of pre-vitamin D3 photosynthesis.

2. MATERIALS AND METHODS

2.1 Model to calculate the vitamin D effective UV radiation

The core procedure is a fast spectral model, also called the physical model with simple parameterization. The general idea traces back to a suggestion of Diffey (1977): spectral measurements are parameterized to solar height and TOC. The basing spectral measurements were made by Bener (1972) over many years at the alpine observatory (46°48′N, 9°49′E, 1590 m above sea level (a.s.l.)) of Davos, Switzerland. Splines are introduced for parameterization. This procedure delivers the global spectral irradiance as the sum of the diffuse and direct component. From this the irradiance is calculated for 16 discrete wavelengths between 297.5nm and 400nm with higher resolution in the UVB (290-315 nm) than in the UVA (315-400 nm). To correspond to the altitude dependence of UV radiation a wavelength dependent factor gained by Blumthaler et al. (1997) is applied. The resulting spectral irradiance is weighted by the action spectrum of vitamin D photosynthesis (MacLaughlin et al. 1982). This action spectrum is shown in Figure 2. Integration over the UVB range delivers the vitamin D effective irradiance for a plane horizontally oriented receiver.

$$E = \int E_\lambda \cdot w_\lambda \, d\lambda$$

This part of the model was validated in the past in respect to the erythemally effective UV radiation by a comparison to other models (Köpke et al. 1998, Schmalwieser and Schauberger 2000, De Baker et al. 2001) as well as by a comparison with measurements made at 4 continents for irradiance (Schmalwieser et al. 2002) and daily dose (Schmalwieser et al. 2005).

A further feature allows the calculation of the biologically effective irradiance on inclined planes. It was developed by one of us (Schauberger 1990, 1992) and takes into account the anisotropy of the diffuse irradiance. This feature has another advantage. It enables to calculate the biologically effective irradiance on inclined planes by inputting measurements from a horizontally oriented device. For the vertically oriented plane receiver we assume that the receiver has no preferable orientation relative to the sun; that means a continuously rotation around its vertical axis whereas the rotational velocity is much faster than the azimuth change of the sun. Irradiance on a vertical oriented receiver is than:

$$E_v(t) = \frac{1}{360°} \int_{\alpha=azi-180°}^{\alpha=azi+180°} E_\alpha(t) \cdot d\alpha$$

Temporal integration of the effective irradiance from sun rise to sun set delivers than the effective radiant exposure over the whole day Hdaily (daily dose).

$$H_{daily} = \int_{t=sunrise}^{sunset} E(t) \, dt$$

2.2 Forecast procedure

The forecast of Vitamin D effective UVR is done for clear sky because of the unavailability of an appropriate world wide cloud forecast. Input parameters for the forecast are therefore time and date, geographical co-ordinates, elevation, and the

TOC of the atmosphere. Since showing both, spatial and temporal variability, appropriate TOC values have to be provided to ensure high accuracy of UV model calculations (e.g. Schwander et al.1997). As shown by Schmalwieser et al. (2003), TOC measurements from satellites can be prepared to deliver TOC values appropriate for a forecast of the erythemally effective UV radiation. For the presented forecast the TOC base were data from NASA's Earth Probe TOMS (EPTOMS) (McPeters et al. 1998) and NASA's latest Aura Ozone Monitoring Instrument (OMI) (http://aura.gsfc.nasa.gov/instruments/omi/index.html).

Details on this simple global TOC forecast scheme can be found in Schmalwieser et al. (2003). By its use, daily mean TOC values for the day of forecast, for certain sites or on a global grid were gained. The later consists of 360x180 values, which correspond to a spatial resolution of 1.0° in latitude and longitude.

The forecast procedure was also already validated for the erythemally effective UV radiation on a horizontally oriented plane receiver by comparisons to other models (Schmalwieser and Schauberger 2000) and by measurements made at 4 continents (Schmalwieser et al. 2002, Schmalwieser et al. 2005).

In this paper we have compared model and forecast calculations to measurements of the vitamin D effective UVR.
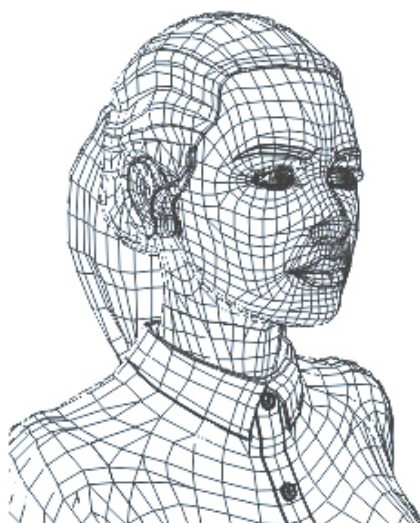

Fig. 1. Detail of a human mesh model which can be equipped with different clothes.

2.3 Measurements of vitamin D effective irradiance in using broad band devices

The action spectrum for pre-vitamin D3 photosynthesis decreases by 2 orders from the maximum at 297 nm down to 0.002 at 320 nm (see Figure 2) (McLaughlin et al. 1982). Therefore the effective irradiance is very sensitive to changes in TOC. Since the sensitivity of broad band device do not fit the action spectrum perfectly and the shape of the solar spectrum at the earth's surface changes, it is necessary to apply correction factors on measured effective irradiance values. These correction factors for a device at a certain location depend in first order on TOC and solar height. Such a correction matrix can be gained by modeling the vitamin D effective UV irradiance EvitD using the action spectrum wVitD of vitamin D photosynthesis and by modeling the device effective UV irradiance EDevice using the spectral sensitivity curve sDevice of the device as weighting function. Their ratio in dependence of TOC (O3) and solar height (sh) delivers a correction matrix.

$$Cf\left(O_3, sh\right) = \frac{E_{VitD}\left(O_3, sh\right)}{E_{Device}\left(O_3, sh\right)}$$

With that the measurements M of a device can be corrected by

$$M_{Device} \cdot Cf\left(O_3, sh\right) = E_{VitD}$$

Two different instruments were used to measure the vitamin D effective UVR. One is the well known Model 501 from SolarLight Inc. (Philadelphia, USA) which was originally designed to measure the erythemally effective UV radiation (Berger 1976, Berger and Moris 1992) following the action spectrum of the human erythema (CIE 1987). Its spectral sensitivity is given in Figure 2. Several national monitoring networks use this device like the Austrian one. The properties of this instrument are well known and described (e.g. Bais et al. 2001). This device is part of the Austrian UV Network (Schmalwieser and Schauberger 2001). The quality of the participating instruments is checked twice a year by a comparison to a reference meter (Silbernagel and Blumthaler 1998).
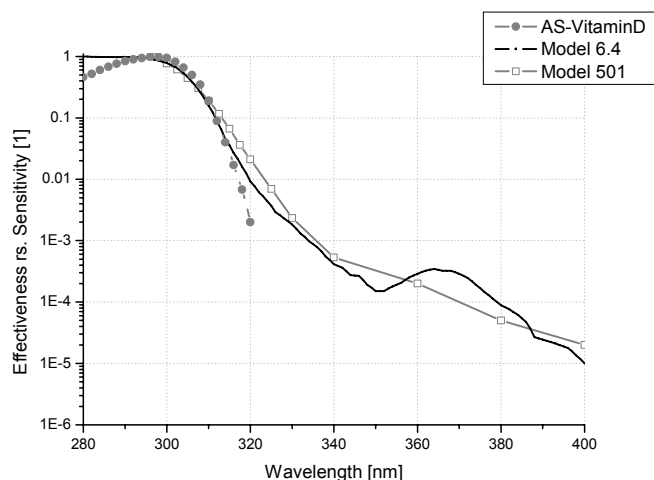

Fig. 2. The red line shows the action spectra of pre-vitamin D_3 photosynthesis (MacLaughlin et al. 1982). Further shown are the spectral sensitivity of the Model 501 (Solar Light Inc.)(green line) and the Solarmeter Model 6.4 (blue line).
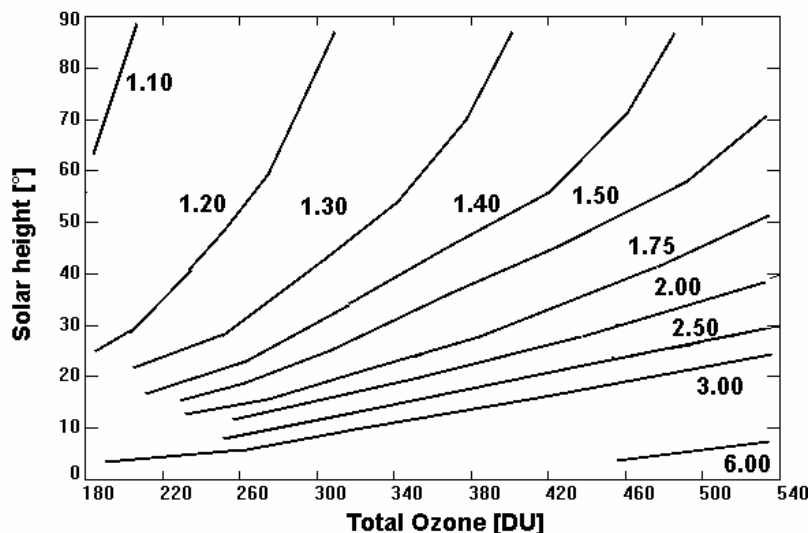

Fig. 3. Conversion matrix to gain values of vitamin D effective UV radiation from measurements of a broadband meter (Model 501, Solar Light) in dependence of total ozone column and solar height.

An estimation of cutaneous vitamin D3 synthesis on an instantaneous basis can be determined with the handheld radiometer Solarmeter® Model 6.4 D3, recently introduced by Solartech Inc. This radiometer displays the effective

irradiance in International Units (IU) per minute for skin type two II when 10% of the body surface is exposed. The radiometer's spectral response is a "hybrid" of the CIE action spectrum for the human erythema (CIE 1987) and the action spectrum for pre-vitamin D_3 photosynthesis, falling about halfway between the two (Figure 2). A interactive software provided with the meter enables adjustment of readouts based on several parameters including skin type, percent body exposure, age, base tan level, sun protection factor (SPF) if any and gives also exposure in units of MED (minimal erythemal dose) to enable sunburn prevention.

3. RESULTS

3.1 Measurements

Figure 3 visualizes the conversion matrix for the broadband meter Model 501 which enables the conversion of the readings to vitamin D effective UVR in dependence of TOC and solar height. It can be seen that conversion factors will become high especially with decreasing solar height and increasing TOC. Figure 3 visualizes measurements vitamin D-effective UVR made with the Solarmeter 6.4 at Vienna, Austria on August 9th, 2006. Measurements normal to the sun went up to 43 IU/min and measurements of the vertically oriented receiver to 30 IU/min. During this day the sky was partly covered by clouds whereas cloud cover increases with the time of the day. The height of the horizon was close to 5°. While in the morning cloud cover was within 30% to 40%, in the afternoon clouds covered up to 80% of the sky.

Shown are measurements made normal to the sun, measurements oriented to South and inclined by 45° and measurements made oriented to South and to the theoretical horizon which corresponds to a vertically oriented receiver. Results using the Solarmeter 6.4 in San Francisco over a period of a year are given in Grant 2006b.
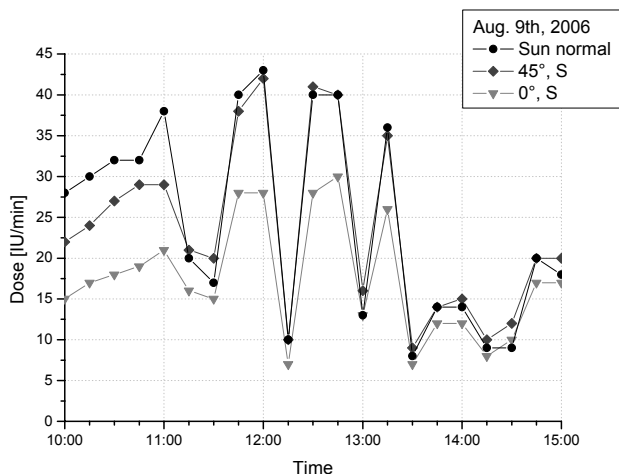

Fig. 4. Measurements of the Vitamin D effective UV irradiance at noon made at Vienna (Austria) on August 9th, 2006.

3.2 Forecast and validation

The operational forecast of the vitamin D effective daily dose has been done daily since October 2004 at the Institute of Medical Physics and Biostatistics, University of Veterinary Medicine Vienna, Austria. The forecast system generates the global distribution of the vitamin D effective daily dose for the next day for a vertically and a horizontally oriented plane receiver. While the vertical orientation corresponds closer to the human face (Figure 1), the horizontal one is today's standard orientation for operationally measurements. Forecast visualization is done by maps (Figure 5). The levels are indicated by colors in the legend. To overcome the unavailability of a world wide cloud forecast the legend provides the numbers in dependence of cloud cover which are indicated by four classes of cloud cover symbols. The figures are

updated daily at 0:00 GMT, for up to 48 hours in advance. They are available via the world-wide-web: http://i115srv.vu-wien.ac.at/uv/uv_online.htm. This web-page provides also some general information about vitamin D.
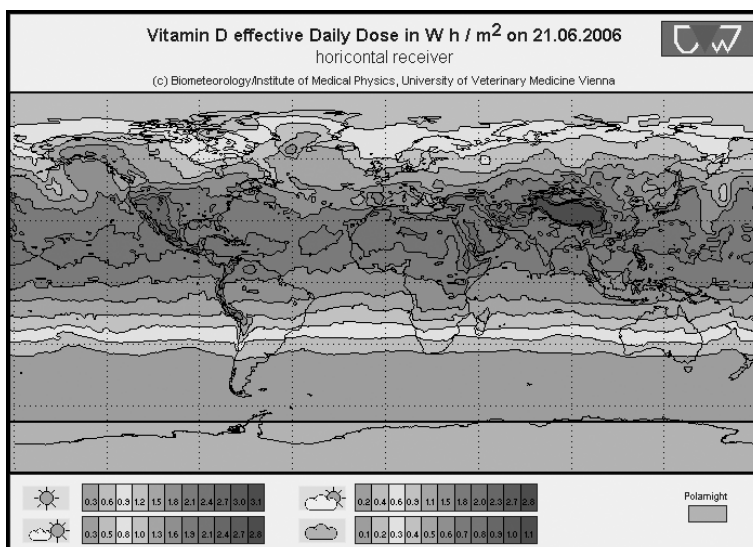

Fig. 5. Forecasted global distribution of the Vitamin D effective daily dose for a horizontally oriented plane receiver for June 22, 2005.
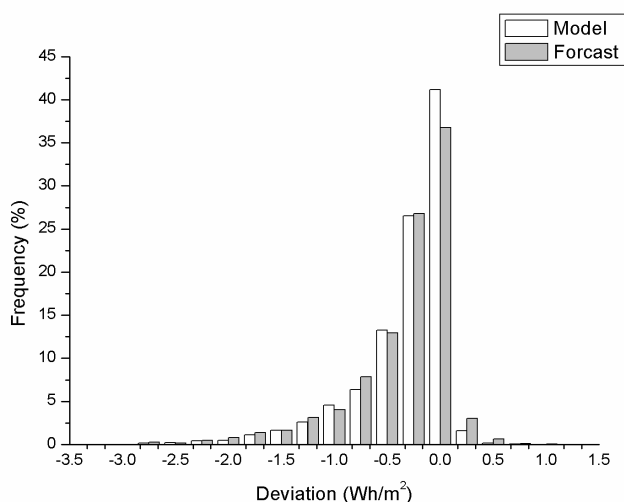

Fig. 6. Validation of modeled and forecasted values of the Vitamin D effective daily dose by a comparison to measurements made by a horizontally oriented broadband meter (Model 501, SolarLight, Inc.) for the location of Vienna (48.26°N, 16.43°E, 153m a.s.l.), Austria.

The validation of model calculations and forecast can be done by comparisons to measurements of a broadband meter. The spectral sensitivity of the chosen device (Model 501, SolarLight Inc.) is as similar to the action spectrum of the vitamin D initiation as the CIE action spectrum of the erythema (Figure 2). The application of conversion factors depending on solar height and total ozone delivers satisfactory agreement. In this manner we have converted the broadband meter readings from our measuring station in Vienna (48.26°N, 16.43°E, 153m a.s.l.) made from January

2003 to December 2005. The validation was done for the daily dose for all sky conditions. The hit rate for the model is 42% and for the forecast 38% (Figure 6). As hit we count deviations less than ± 0.125 $W_{VitD}h/m^2$. This value corresponds to approximately 2 MED for skin type 2. Overestimation results mainly through cloudiness which is not an input parameter for the model and the forecast.

4. DISCUSSION AND CONCLUSION

Modern lifestyle may lead to an improper interaction with the sun. During holidays and spare time many people tend to overexpose themselves (by solar UV or sun beds), while at other times, people may underexpose themselves. During the past years many efforts were undertaken to inform the public to avoid health damage due to overexposure on solar UVR (e.g. Vanicek et al. 2000). For this purpose some of us established a freely available world wide forecast of the UV Index in 1995 (Schauberger et al. 1997) in the world wide web together with information for sun protection and recommendations of sun protection factors for different skin types.

During the last years there was a rising concern on the vitamin D status of people since many studies have shown that vitamin D level is inversely correlated with the risk of several types of cancer, autoimmune diseases and aged-related weakening of the skeleton and corresponding injuries.

Low serum vitamin D levels were reported e.g. by van der Wielen et al., 1995 for the European population. However a satisfactory vitamin D level should be ensured to reduce the risk for several diseases and types of cancer.

We have made the first approach in forecasting the vitamin D effective daily dose. The forecast provides the global distribution of the vitamin D effective daily dose for a horizontally and a vertically oriented plane receiver visualized by maps. The forecast is freely available via the Internet and can be found at: http://i115srv.vu-wien.ac.at/uv/uv_online.htm. The validation for Vienna, Austria has shown that the forecast values are in good agreement with converted measurements from a broadband meter (Model 501, Solar Light, Inc.) and from a hand held meter. The next challenge will be to give the forecasted or modeled effective UVR a deeper meaning so that people can adapt their behavior. Such recommendations however have to be given only in conjunction with sun care information. Those people aged 50+ could particularly benefit from vitamin D care recommendations.

To give modeled or measured values of effective irradiance a meaning it is necessary to convert them to a quantity of vitamin D like the International Units (IU) (1 IU = 40 µg). The conversion has to work at least 5 levels:

Level 1: Calculated or measured effective irradiance together with the orientation of the receiver and the duration of exposure delivers the effective exposure.

Level 2: The received total surface exposure depends on the exposed body area. The area depends at least on body size and shape, age (age related changes of the body shape) and gender.

Level 3: The received total surface exposure is not transmitted 1:1 through the outer layer of the skin. Transmission depends on skin type, facultative tan and possible applied sun protection tool. After taking these absorbers into account one gets the subcutaneous irradiance.

Level 4: UV radiation is used in the next layers of the skin whereas the efficiency of photosynthesis from 7-dehydrocholesterolxx to pre-vitaminD3 depends strongly on age (Webb, 2006). Pre-vitaminD3 is thermoisomerized into vitamin D_3, a temperature-dependent process.

Level 5: Vitamin D3 (either from photosynthesis or from diet) is than transported via the blood to the liver where it is converted to 25-hydroxyvitamin D [25(OH)D] (calcidiol) and the kidney where the active form 1,25 di-hydroxyviatmin D [1,25(OH)2D] (calcitriol) is processed. This active form can also be produced from calcidiol by many organs in the body (Zehnder et al., 2001). The effectiveness of these processes depends also on many variables like personal conditions, gender or age.

A possibility is to use the IU of vitamin D as the quantity reported. With this unit, the measured or calculated values can be compared to vitamin D from dietary sources of supplements. This is the concept of the Solarmeter Model 6.4D software design. Advantage of the use of IU is that this unit is not new for the public since already known from the package texts of several foods and food supplements and may find easy acceptance.

REFERENCES

1. A. Bais, C. Topaloglou, S. Kazadtzis, M. Blumthaler, J. Schreder, A. Schmalwieser, D. Henriques and M. Janouch, *Report of the LAP/COST/WMO Intercomparison of Erythemal Radiometers (Thessaloniki, Greece, 13-23 September 1999)*, WMO-Report No.141, Geneva, Switzerland, 2001.

2. P. Bener, *Approximate values of intensity of natural radiation for different amounts of atmospheric ozone*, Eur. Res. Off., US Army, London, United Kingdom, 1972.

3. D. S. Berger, "The sunburning ultraviolet meter: design and performance," *Photochem. Photobiol.* 24, 587–593 (1976).

4. D. Berger and M. Moris, "UV-Biometer—a broad-band instrument complementing ozone measurements with ground based UV exposure," In: *Ozone in the Troposphere and Stratosphere, Proceedings of the Quadrennial Ozone Symposium, Charlottesville VA, 1992* (Edited by R. D. Hudson), 4–13, NASA Conference Publication 3266, Greenbelt, MD, USA, 1994.

5. M. Blumthaler, W. Ambach and R. Ellinger, "Increase in solar UV radiation with altitude," J. *Photochem. Photobiol. B: Biol.* 39, 130–134 (1997).

6. CIE (Commission Internationale de l'Eclairage), "A reference action spectrum for ultraviolet induced erythema in human skin," *CIE J.* 6, 17-22 (1987).

7. H. De Backer, P. Koepke, A. Bais, X. de Cabo, T. Frei, D. Gillotay, Ch. Haite, A. Heikkilä, A. Kazantzidis, T. Koskela, E. Kyrö, B. Lapeta, J. Lorente, K. Masson, B. Mayer, H. Plets, A. Redondas, A. Renaud, G. Schauberger, A. Schmalwieser, H. Schwander and K. Vanicek, "Comparison of measured and modelled uv indices for the assessment of health risks," *Meteor. Appl.* 8, 267-277 (2001).

8. B.L. Diffey, "The calculation of the spectral distribution of natural ultraviolet radiation under clear day conditions," *Phys. Med. Biol.* 22, 309-316 (1977).

9. C.F. Garland and F.C. Garland, "Do sunlight and vitamin D reduce the likelihood of colon cancer?," *Int J Epidemiol.* 9, 227-231 (1980).

10. C.F. Garland, F.C. Garland, E.D. Gorham, M. Lipkin, H. Newmark, S.B. Mohr and M.F. Holick, "The role of vitamin D in cancer prevention," *Am. J. Public Health* 96, 252-261 (2006).

11. E. Giovannucci, Y. Liu E.B. Rimm, B.W. Hollis, C.S. Fuchs, M.J. Stampfer and W.H. Willett, "Prospective study of predictors of vitamin D status and cancer incidence and mortality in men," *JNCI* 98, 451-459 (2006).

12. E.D. Gorham, C.F. Garland, F.C. Garland, W.B. Grant, S.B. Mohr, M. Lipkin, H.L. Newmark, E. Giovannucci , M. Wie and M.F. Holick, "Vitamin D and prevention of colorectal cancer," *J. Steroid Biochem. Mol. Biol.* 97, 179-194 (2005).

13. W.B. Grant, "An estimate of premature cancer mortality in the United States due to inadequate doses of solar ultraviolet-B radiation," *Cancer* 94, 1867-1875 (2002).

14. W.B. Grant, "Epidemiology of disease risks in relation to vitamin D insufficiency," *Progress Biophys. Molec. Biol.* 92, 65-79 (2006a).

15. W.B. Grant. **"**Rates of vitamin D production from solar ultraviolet B irradiance in San Francisco during one year," *Citizen Scientist*. June 2, 2006b (http://www.sas.org/tcs/weeklyIssues_2006/2006-06-02/feature1/index.html)

16. W.B. Grant and C.F. Garland, "The association of solar ultraviolet B (UVB) with reducing risk of cancer: multifactorial ecologic analysis of geographic variation in age-adjusted cancer mortality rates," *Anticancer Res.* 26, 2687-2700 (2006).

17. W.B. Grant and M.F. Holick, "Benefits and requirements of vitamin D for optimal health: a review," *Altern. Med. Rev.* 10, 94-111 (2005) (ww.thorne.com/altmedrev/.fulltext/10//94.pdf)

18. C.E. Hayes, M.T. Cantorna MT, DeLuca HF. Vitamin D and multiple sclerosis," *Proc. Soc. Exp. Biol. Med.* 216, 21-27 (1997).

19. R.P. Heaney, "Long-latency deficiency disease: insights from calcium and vitamin D," Am. J. Clin. Nutr. 78, 912-919 (2003).

20. M.F. Holick, "High prevalence of vitamin D inadequacy and implications for health," *Mayo. Clin. Proc.* 81, 353-373 (2006).

21. P. Koepke, A. Bais, D. Balis, M. Buchwitz, H. de Backer, X. de Cabo, P. Eckert, P. Eriksen, D. Gillotay, T. Koskela, B. Lapeta, Z. Litynska, J. Lorente, B. Mayer, A. Renaud, A. Ruggaber, G. Schauberger, G. Seckmeyer, P. Seifert, A. Schmalwieser, H. Schwander, K. Vanicek and M. Weber, "Comparison of models used for UV index calculations," *Photochem. Photobiol.* 67, 657-662 (1998)

22. J.A. MacLaughlin, R.R. Anderson and M.F. Holick. "Spectral character of sunlight modulates photosynthesis of previtamin D3 and its photoisomers in human skin," *Science*. 216, 1001-1003 (1982).

23. M. Peterlik and H.S. Cross, "Vitamin D and calcium deficits predispose for multiple chronic diseases," *Eur. J. Clin. Invest.* 35, 290-304 (2005).

24. K. Rajakumar, "Vitamin D, cod-liver oil, sunlight, and rickets: a historical perspective," *Pediatrics* 112:e132-135 (2003).

25. J. Reichrath, "The challenge resulting from positive and negative effects of sunlight: how much solar UV exposure is appropriate to balance between risks of vitamin D deficiency and skin cancer?," *Prog. Biophys. Mol. Biol.* 92, 9-16 (2006).

26. G. Schauberger, "Model for the global irradiance of the solar biologically-effective ultraviolet-radiation on inclined surfaces," *Photochem. Photobiol.* 52, 1029–1032 (1990).

27. G. Schauberger, "Anisotropic model for the diffuse biologicallyeffective irradiance of solar UV-radiation on inclined surfaces," *Theor. Appl. Climatol.* 46, 45–51 (1992).

28. G. Schauberger, A.W. Schmalwieser, F. Rubel, Y. Wang and G. Keck, "UV-Index: Operationelle Prognose der solaren, biologisch-effektiven Ultraviolett-Strahlung in Österreich," *Zeitschrift für Medizinische Physik* 7, 153-160 (1997).

29. A.W. Schmalwieser and G. Schauberger, "Validation of the Austrian forecast model for solar, biologically-effective ultraviolet radiation - UV Index for Vienna, Austria," *J. Geophys. Res.* 105, 26661-26668 (2000).

30. A. W. Schmalwieser and G. Schauberger, "A monitoring network for erythemally-effective solar ultraviolet radiation in Austria: determination of the measuring sites and visualisation of the spatial distribution," *Theor. Appl. Climatol.* 69 (3/4), 221-229 (2001).

31. A.W. Schmalwieser, G. Schauberger, M. Janouch, M. Nunez, T. Koskela, D. Berger, G. Karamanian, P. Prosek and K. Laska, "Global validation of a forecast model for irradiance of the solar, erythemally effective UV radiation," *Opt. Eng.* 40, 3040-3050 (2002).

32. A.W. Schmalwieser, G. Schauberger, P. Weihs, R. Stubi, M. Janouch, J.R. Coetzee and S. Simic, "Preprocessing of total ozone content as an input parameter to UV Index forecast calculations," *J. Geophys. Res.* 108 (D6), 4176- 4189 (2003).

33. A.W. Schmalwieser, G. Schauberger, M. Janouch, M. Nunez, T. Koskela, D. Berger and G. Karamanian, "Global Forecast Model to Predict the Daily Dose of the Solar Erythemally Effective UV Radiation," *Photochem. Photobiol.* 81, 154-162 (2005).

34. R. Silbernagl and M. Blumthaler, "First Experiences with the Austrian UV-Monitoring Network," In: *Proceedings of the European Conference on Atmospheric UV Radiation, Helsinki, June 29–July 2 1998*, P75, p. 88. European Commission/COST713, Brussels, Belgium, 1998.

35. H. Schwander, P. Koepke and A. Ruggaber, "Uncertainties in modeled UV irradiances due to the limited accuracy and availability of input data," *J. Geophys. Res.* 102, 9419–9429 (1997).

36. R.P. van der Wielen, M.R. Lowik, H. van den Berg, L.C. de Groot, J. Haller, O. Moreiras, and W.A. van Staveren, "Serum vitamin D concentrations among elderly people in Europe," *Lancet*, 346, 207-210 (1995).

37. K. Vanicek, Z. Lytinska, T. Frei and A. Schmalwieser, *UV Index for the public*. Publication of the European Communities, Brussels, Belgium, 2000.

38. R. Vieth, "Vitamin D supplementation, 25-hydroxyvitamin D concentrations, and safety," *Am. J. Clin. Nutr.* 69, 842-856 (1999).

39. R. Vieth, P.C. Chan and G.D. MacFarlane, "Efficacy and safety of vitamin D3 intake exceeding the lowest observed adverse effect level," *Am. J. Clin. Nutr.* 73, 288-294 (2001).

40. A.R. Webb, B.R. DeCosta and M.F. Holick, "Sunlight regulates the cutaneous production of vitamin D3 by causing its photodegradation," *J. Clin. Endocrinol. Metab.* 68, 882-887 (1989).

41. A.R. Webb, "Who, what, where and when-influences on cutaneous vitamin D synthesis," *Prog. Biophys. Mol. Biol.* 92, 17-25 (2006).

42. D. Zehnder, R. Bland, M.C. Williams, R.W. McNinch, A.J. Howie, P.M. Stewart and M Hewison., "Extrarenal expression of 25-hydroxyvitamin d(3)-1 alpha-hydroxylase," *J. Clin. Endocrinol. Metab.* 86, 888-894 (2001).