Variability of solar UV radiation and vitamin-D synthetic capacity of sunlight

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Abstract

Terrestrial solar ultraviolet (UV) radiation (280-400 nm) plays a significant role for vital functions of biosphere including humans. In proper doses UV radiation is beneficial for people initiating vitamin D synthesis from its precursor 7-dehydrocholesterol in skin [1], but excessive UV doses lead to acute and chronic diseases, such as cataract, skin burn and cancer, immune system suppression, etc.

Significant variability of solar UVB radiation (280-315nm) caused by latitude, season, daily time as well as ozone layer thickness, clouds, aerosols and air pollutions affects biological activity of sunlight. It is evident that accepted UV dose causes beneficial or harmful effect on human health.

Usually biological activity of solar radiation and UV index are calculated by weighting of solar UV spectrum with erythema action spectrum. But the vitamin-D-synthetic capacity of sunlight cannot be correctly estimated from these data because of significant difference between the CIE erythema and vitamin-D synthesis action spectra [2, 3].

In view of crucial role of vitamin D for human health we developed reliable algorithm for direct calculation of 7-dehydrocholesterol conversion into previtamin D upon exposure to sunlight using mathematical model which describes photoreaction of vitamin D synthesis *in vitro* with solar UV spectrum at the model input [4]. Good agreement between experimentally measured and numerically simulated data allows the use of presented algorithm for prediction of the vitamin-D-synthetic capacity of sunlight [4].

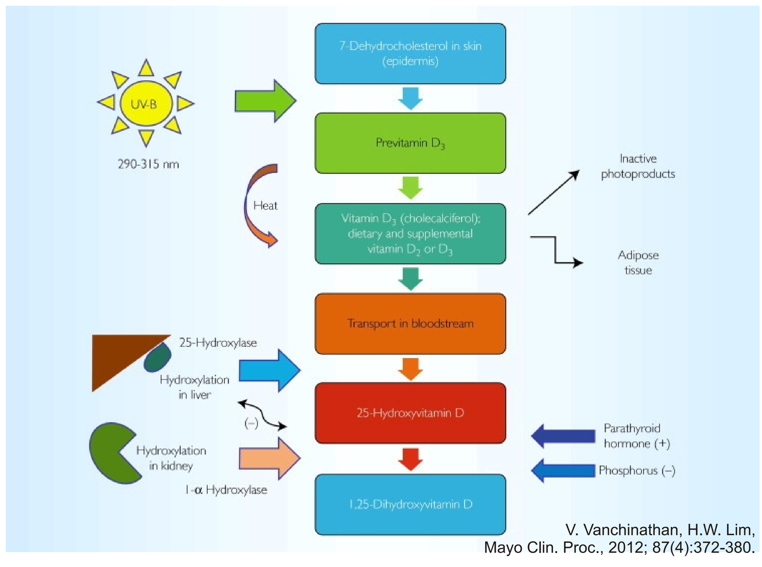
[1] W. Norman, R. Bouillon, *Exp. Biol. Med.,* 235 (2010), 1034-1045.

[2] I. Terenetskaya, *Proc. SPIE,* 4896 (2003), 144-150.

[3] M. Norval, L.O. Bjorn, F.R. de Gruijl, *Photochem. Photobiol. Sci.,* 9 (2010), 11–17.

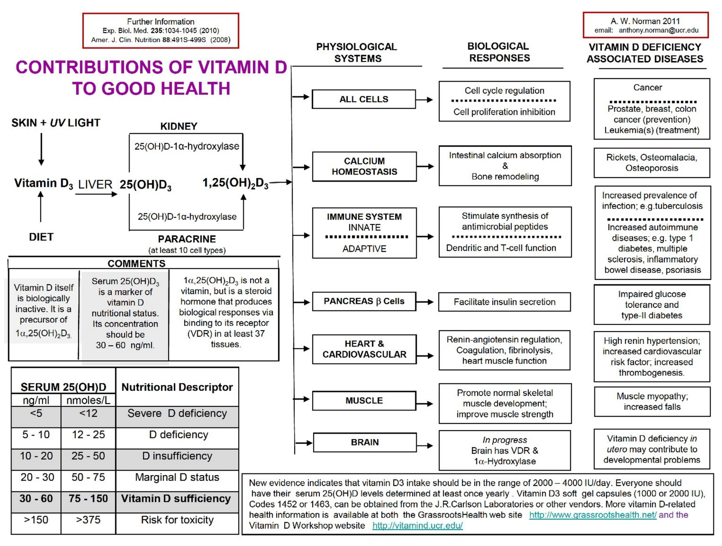
[4] I. Terenetskaya, T. Orlova, *Int. J. Remote. Sensing,* 32 (2011), 6205-6218.

Photobiosynthesis of vitamin D_3



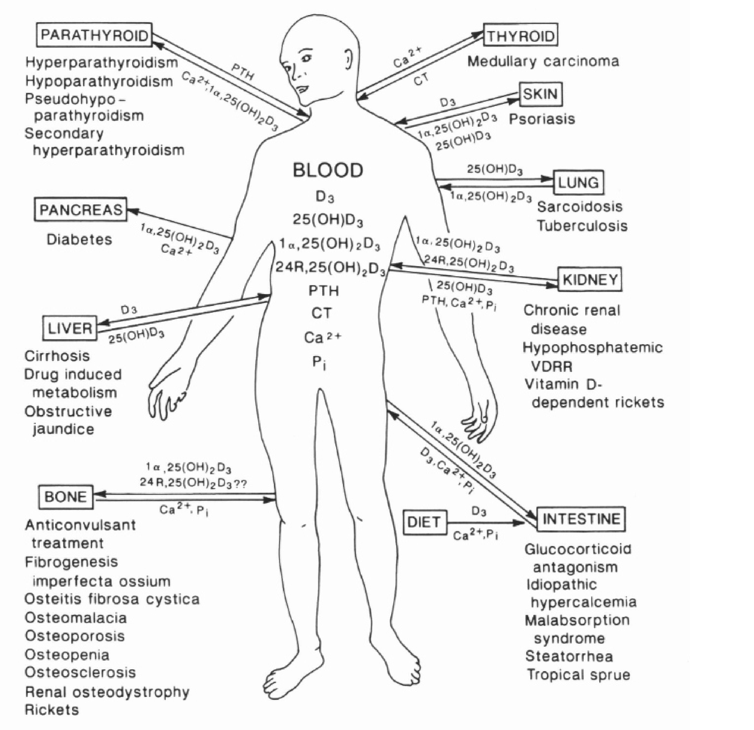
V. Vanchinathan, H.W. Lim, Mayo Clin. Proc., 2012; 87(4):372-380.

Contributions of vitamin D_3 to good health



The role of vitamin D_3 in human health

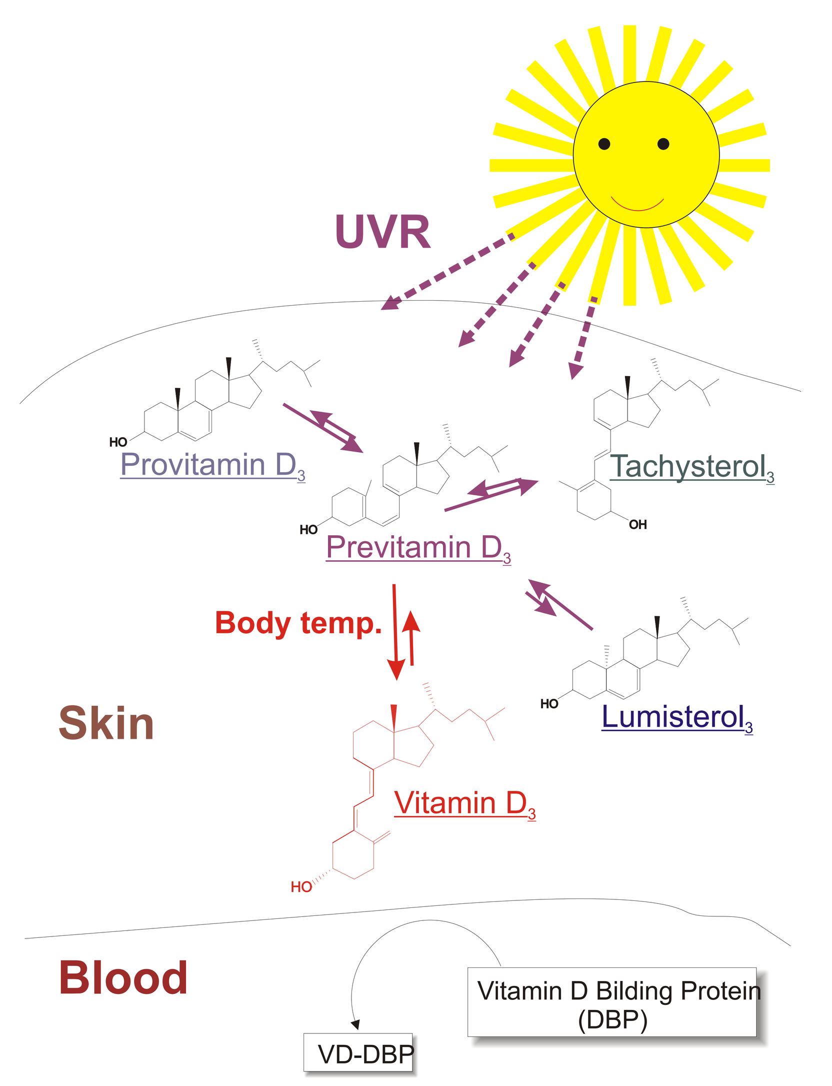
Vitamin D synthesis is well-known beneficial effect of solar UVB radiation. Natural exposure to sunlight is responsible for adequate vitamin D nutrition for most of the population in the world.



VITAMIN D, traditionally perceived as an antirachitic vitamin essential for regulation of calcium homeostasis, is now acknowledged as the orchestrater of a wide array of biological responses via mechanisms analogous to classical steroid hormones.

(Encyclopedia of Human Biology, Acad.Press, NY, 1991)

First stage of photobiosynthesis in details: production of vitamin D_3 in the skin



Mathematical model of the photoreaction

The kinetics of previtamin D photosynthesis is described by the system of differential equations that enables calculation of the photoreaction course for any mono- or polychromatic UV source using its spectroradiometric data at the model input.

$$\frac{dC_1}{dt} = \int d\lambda I^*(\lambda)\left[-\varepsilon_1(\lambda)C_1\phi_{12} + \varepsilon_2(\lambda)C_2\phi_{21}\right]$$

$$\frac{dC_2}{dt} = \int d\lambda I^*(\lambda)\left[-\varepsilon_2(\lambda)C_2\phi_{21} + \varepsilon_1(\lambda)C_1\phi_{12} - \varepsilon_2(\lambda)C_2\phi_{23} + \varepsilon_3(\lambda)C_3\phi_{32} - \varepsilon_2(\lambda)C_2\phi_{24} + \varepsilon_4(\lambda)C_4\phi_{42} - \varepsilon_2(\lambda)C_2\phi_{25}\right]$$

$$\frac{dC_3}{dt} = \int d\lambda I^*(\lambda)\left[-\varepsilon_3(\lambda)C_3\phi_{32} + \varepsilon_2(\lambda)C_2\phi_{23}\right]$$

$$\frac{dC_4}{dt} = \int d\lambda I^*(\lambda)\left[-\varepsilon_4(\lambda)C_4\phi_{42} + \varepsilon_2(\lambda)C_2\phi_{24}\right]$$

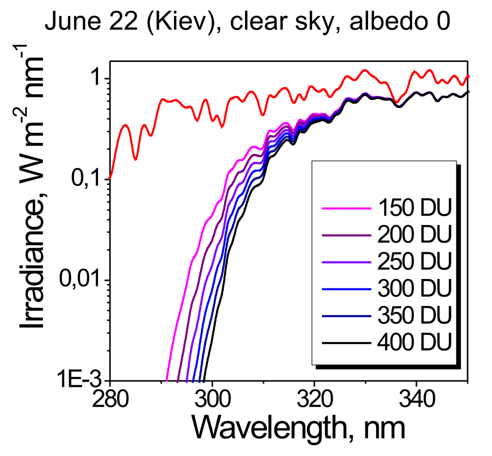
$$\frac{dC_5}{dt} = \int d\lambda I^*(\lambda)\left[\varepsilon_2(\lambda)C_2\phi_{25}\right]$$

Here $I(\lambda)$ is the intensity of the incident light at the wavelength λ, C_i are concentrations of the photoisomers at time t, $\varepsilon_i(\lambda)$ - molar absorption coefficients, φ_{ij} - quantum yield of the reaction in the channel *i ->j*

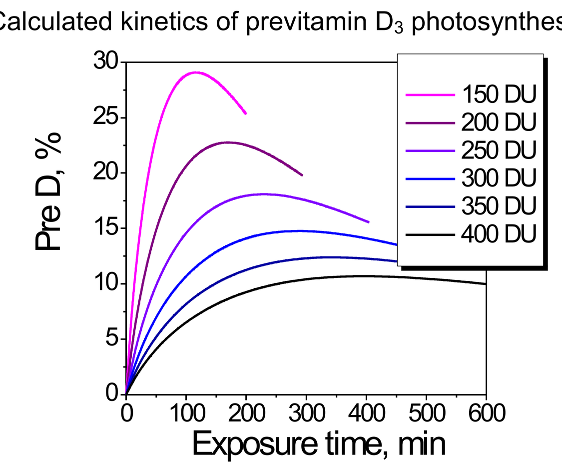
At the initial time t = 0 C_1 = 1 (only Provitamin D is presented), and concentrations of all other photoisomers are zero ($C_2 = C_3 = C_4 = C_5 = 0$).

Double effect of the stratospheric ozone layer thickness on previtamin D_3 synthesis: photoreaction rate + maximum concentration

Solar UV spectra for SZA = 26[0]79', corresponding to 10:00 GTM, June 22 (Kiev), clear sky, albedo 0

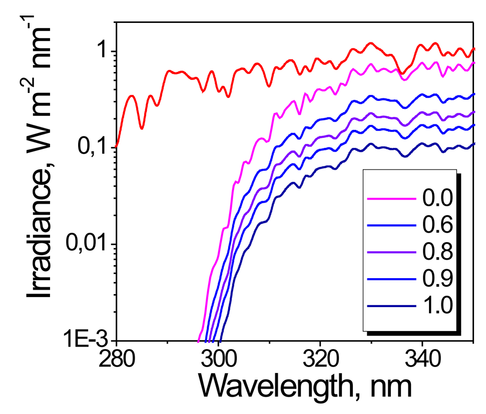


Calculated kinetics of previtamin D_3 photosynthesis

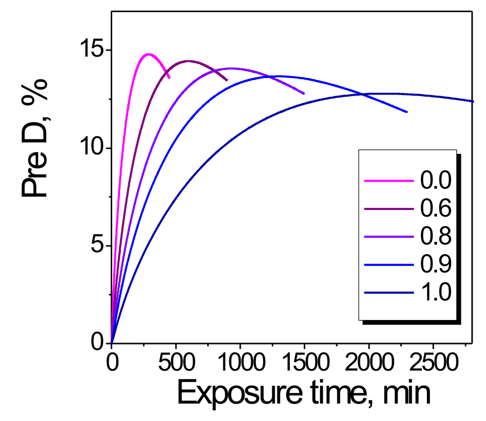


Effect of cloudiness and albedo changes on previtamin D_3 synthesis: photoreaction rate only

Solar UV spectra at different scattered clouds fraction for ozone 300DU, SZA = 26[0]79', corresponding to 10:00 GTM, June 22 (Kiev)

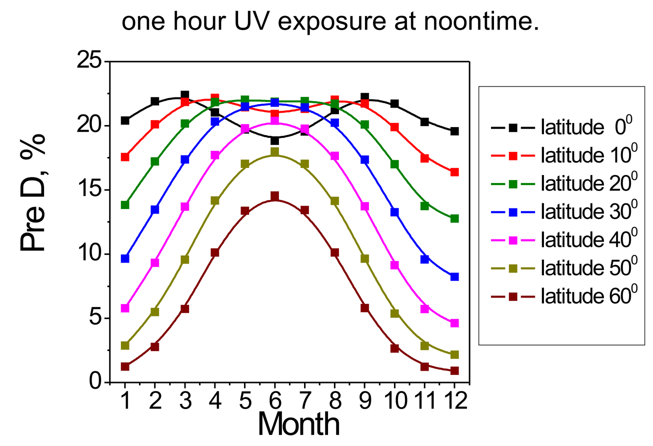


Calculated kinetics of previtamin D_3 photosynthesis

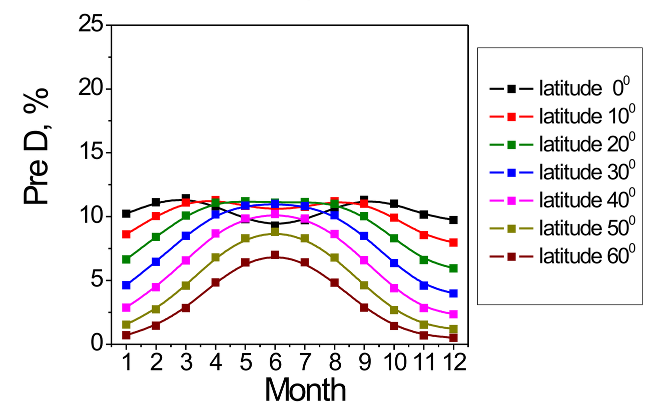


Effect of latitude and seasonal changes on previtamin D_3 synthesis

Clear sky, ozone 200 DU, albedo 0, one hour UV exposure at noontime.



Clear sky, ozone 300 DU, albedo 0, one hour UV exposure at noontime.



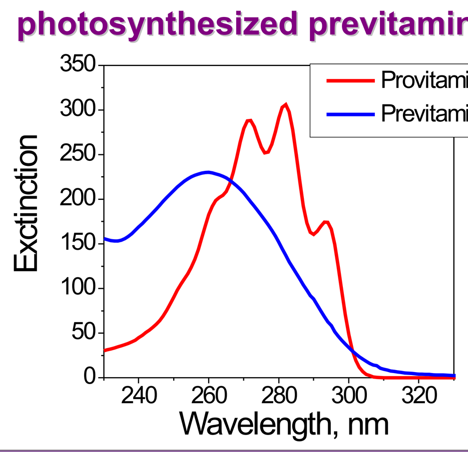
Experimental method

'D-dosimeter' uses the first – photochemical – step of vitamin D_3 synthesis. Solution of provitamin D_3 in ethanol (*in vitro* model of vitamin D_3 synthesis) is irradiated in standard rectangular quartz cuvette. As a result of UV irradiation, a multicomponent photoisomer mixture is formed from the initial provitamin D_3, and UV absorption spectrophotometry is used for concentration analysis *in situ*.

The absorption spectra of the solution are recorded by a spectrophotometer before and after an UV exposure within spectral range 230÷330 nm and the photo-isomers concentrations are derived from the spectra by computer processing using specially designed software.

The decay of starting provitamin D_3 is analogous to biological response of many biodosimeters in the form of some damage caused by UV radiation, but 'antirachitic' dose is determined by measuring previtamin D_3 accumulation depending on the exposure time.

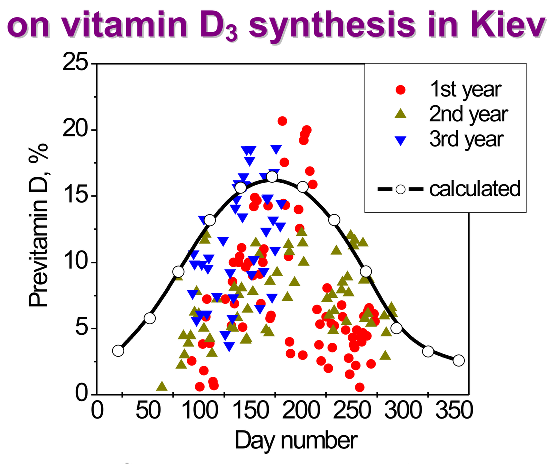
UV absorption spectra of initial provitamin D_3 and photosynthesized previtamin D_3



Monitoring of the vitamin D_3 synthetic capacity of sunlight in Kiev (50[0]23' N, 30[0]32' E)

Dr. T.Orlova and Prof. I.Terenetskaya adjust the UV measuring device 'D-dosimeter'.

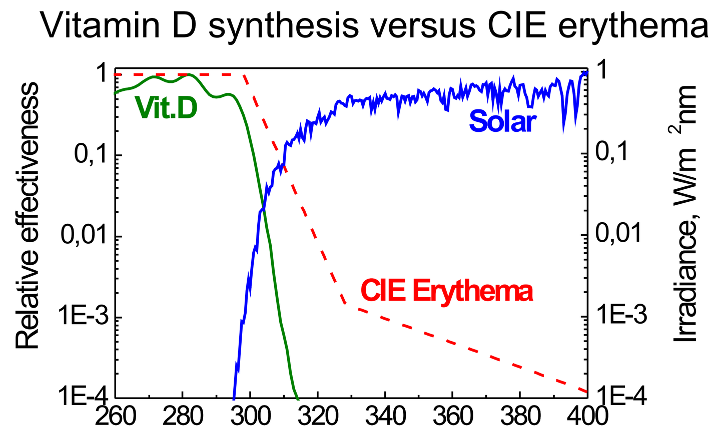
Effect of season and clouds on vitamin D_3 synthesis in Kiev



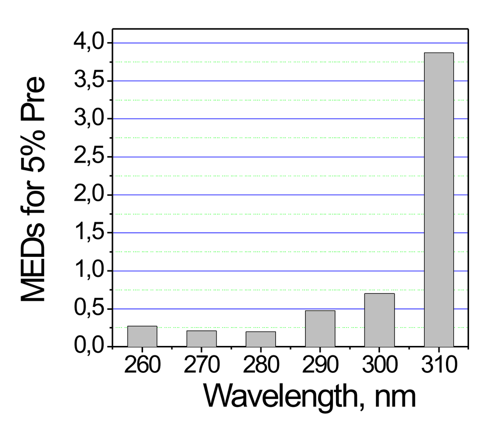
Symbols – measured data,
line – calculated data (clear sky, ozone content 300 DU).

Relationship between CIE erythema and vitamin D_3 synthesis action spectra

Vitamin D synthesis versus CIE erythema



The wavelength dependence of the MEDs quantity required to yield 5% of previtamin D_3



Conclusions

In view of recent findings on the substantial role of vitamin D on human health, it becomes widely recognized now that the monitoring of the vitamin D synthetic capacity of sunlight is keenly needed in addition to permanent standard measurements of its erythemal activity.

Although there are both beneficial and detrimental UV effects, it is an increase in the detrimental effects, associated with climate change, attract most attention. Concerns range from human health (increases in the incidence of skin cancer (van der Leun et al, 2008), to agriculture (reduction in crop yields), and to aquatic ecosystems (changes in the world's oceans) (Cracknell and Varotsos, 2007). As was mentioned above, in view of the remarkable difference between the CIE erythema and 'Vitamin D' action spectra, the UV index introduced by WHO in 1994 to raise public awareness and to provide information about potential risks of solar UV exposure, is not attributable to the vitamin D synthetic capacity of sunlight.

Since anticipated direct health consequences of climate change include increases in air pollution-related illness, we think that global UV mapping as well as annual and daily forecasts should consider both erythemal and 'antirachitic' solar indices. We believe the presented algorithm is useful for predictions of climate change effects on the vitamin D synthetic capacity of sunlight and provides a means for introduction of the new UV 'D-index'.

Should the weather forecast inform about vitamin D-synthetic capacity of sunlight? Please indicate your opinion!