WORLD ATLAS OF ULTRAVIOLET A AND B RADIATION FOR MELANOMA RESEARCH

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ABSTRACT

Ultraviolet B (UVB) has high biological importance, but its geographic distribution is not adequately described in the biomedical literature. UVB is needed for photosynthesis of vitamin D, which is associated with lower incidence rates of some cancers, but may have adverse effects. Ultraviolet A (UVA) may play a role in melanoma. Data on ozone and UV radiation from the National Aeronautics and Space Administration Total Ozone Mapping Spectrometer satellite packages were combined with cloud cover and sulfate air pollution data from other satellite sensors. Geographic information systems (GIS) were used to produce comprehensive world maps of UVA and UVB. GIS provided an essential tool for creation of a preliminary epidemiological atlas of UV radiation.

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INTRODUCTION

Many epidemiological studies of the geographic correlates of disease depend on the availability of authoritative information on geophysical factors, such as ultraviolet irradiance. This is particularly important for studies of cancers related to deficiency of ultraviolet B (UVB) and vitamin D, such as colon (1-15), breast (13-20) and ovarian (14, 15, 21) cancer. It is also useful for studies of diseases that may be due largely to excessive exposure to ultraviolet A (UVA), such as cutaneous melanoma and basal cell carcinoma of the skin (22-25).

The worldwide geographic distribution of UVA and UVB was poorly characterized before satellites became available that could provide more geographically comprehensive estimates than were available from the relatively few ground measurement sites equipped with Brewer spectrophotometers. Unfortunately, existing networks based on broadband Robertson-Berger meters did not provide data per nanometer, and were of limited use for determination of high-resolution spectral UVB or UVA irradiance since their spectrum included UVB and a portion of the shorter UVA.

Relevant data from satellites have been collected by the National Aeronautics and Space Administration (NASA) remote sensing platforms and spectrophotometric measurements at ground level provided by other organizations. However, accessibility of the data to medical scientists has been limited, to some degree by the format.

A new use for geophysical information regarding ultraviolet irradiance by country has been created by the availability of the GLOBOCAN database of the International Agency for Research on Cancer, which provides estimated age-adjusted incidence rates of cancer for 175 countries (26).

Studies of diseases that may be prevented or induced by solar radiation require accurate knowledge of the distribution of UVA and UVB irradiance by country. UVB has high biological importance because it is needed for photosynthesis of vitamin D, which, in turn, is associated with lower incidence rates of some types of cancer (2-20). UVA, on the other hand, is important from an epidemiological standpoint because it may play a central etiological role in melanoma (22-24). Geographic information systems (GIS) have been useful in the creation of maps by country of UVB and UVA radiation.

METHODS

Data from satellite-derived data resources were used to develop maps of UVB and UVA for 175 countries. The UVB data points that were used were obtained from Daniel Lubin and associates of the University of California, San Diego, Scripps Institution of Oceanography (27). These data were extracted from the Total Ozone Mapping Spectrometer (TOMS) (28) and Earth Radiation Budget Experiment (ERBE) satellite databases (29). Data on the global distribution of UVA were obtained from Dr. Jay Herman of the Goddard Space Flight Center, Laboratory for Atmospheres (30).

In order to provide an understanding of cloud cover related to ultraviolet B irradiance, maps were created of the annual mean total cloud amount, expressed as a proportion, during the interval 1983-2001, using data from the NASA International Satellite Cloud Climatology Project (ISCCP) (31). These data were for the winter solstice. Data for December were used for the Northern hemisphere, and data for June were used for the Southern hemisphere. Contours for cloud cover over large countries were coded to estimate the cloud cover over the most heavily populated areas. For example, the contours used for Australia were for the southern coastal region, where the majority of the population resides, and those used for Brazil were for the eastern coastal region, where the majority of the population resides. Tropospheric anthropogenic sulfate optical depth data were obtained from the Moderate-resolution Imaging Spectroradiometer (MODIS) instrument carried aboard the Terra spacecraft (32). Anthropogenic aerosols were differentiated from aerosols derived from vegetation fires and volcanism based on a determination for each country of whether there were industrial sources of sulfate aerosols present. Anthropogenic aerosols were of particular interest since industrial aerosols persist over decades, while aerosol plumes from vegetation fires and volcanism are typically sporadic.

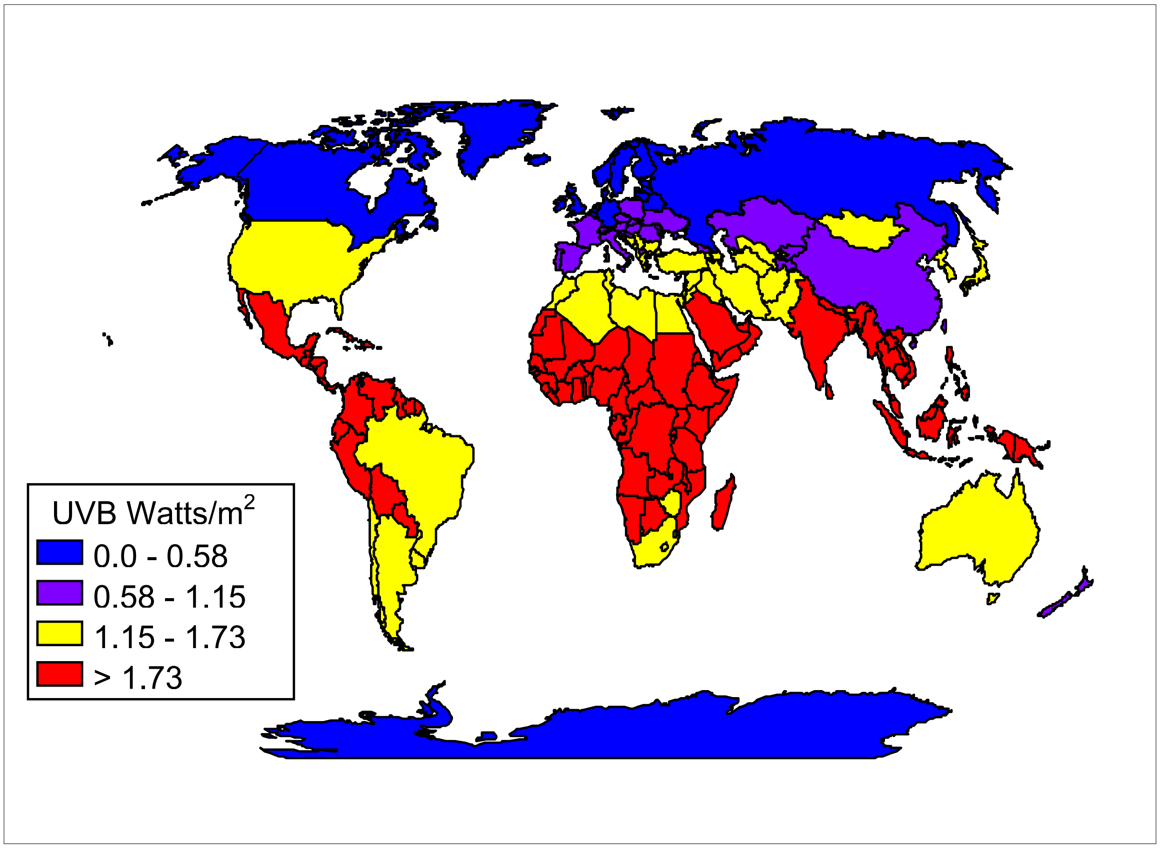
UVA and UVB irradiance were separately plotted against sex-stratified melanoma incidence rates for 175 countries and multiple regression was performed using JMP 5.1.2 (Cary NC: SAS Institute). The regression assessed the relationship among UVB, skin pigmentation, migration, and melanoma incidence rates. Data on skin pigmentation were obtained from a study by Jablonski and Chaplin (33) and incidence rates by country for melanoma were obtained from the GLOBOCAN database (26). A variable for migration was created to account for the effect of countries where the majority of the population migrated from distant latitudes. This was done by subtracting the absolute latitude of the capital city of the destination country from that of the capital city of the country of origin. Coefficients of determination shown in the titles for Figures 6-9 excluded Australia and New Zealand since they were outliers. However, all 175 countries were included in the multiple regression tables.

RESULTS

There was considerable variation in UVB (Figure 1) and UVA (Figure 2) irradiance among countries. Both types of ultraviolet radiation predominated in areas near the equator and were markedly lower in areas distant from it. The difference in irradiance between Australia and New Zealand was more noticeable for UVB than for UVA.

Figure 1

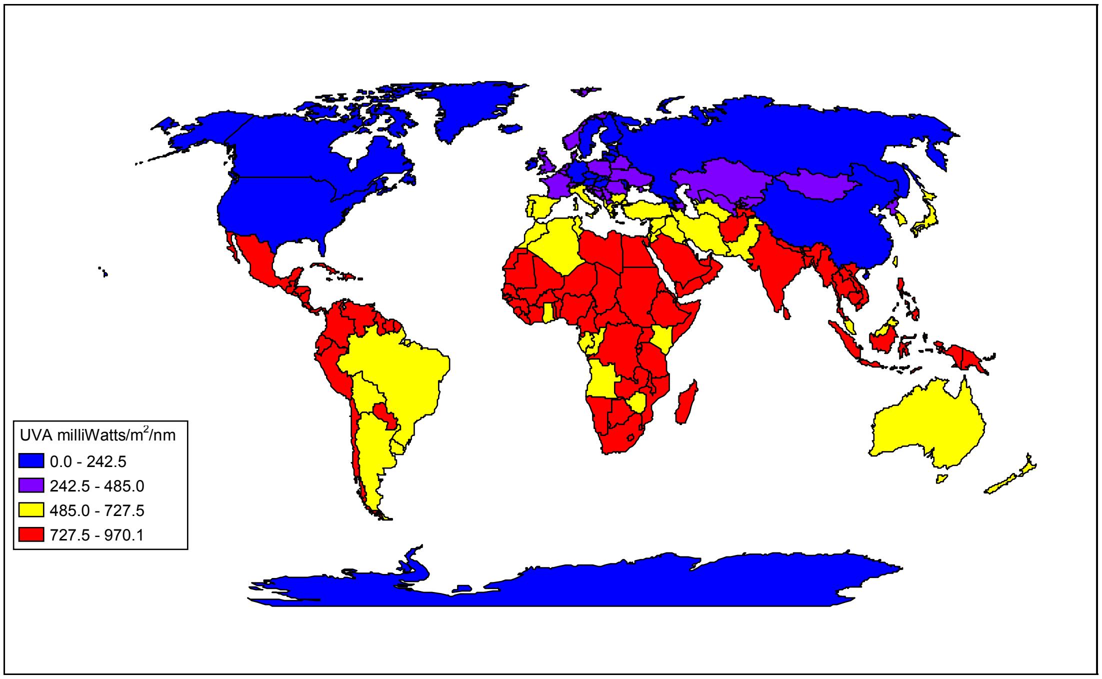
Estimated equinoctial ultraviolet B irradiance (280-315 nm) at ground level, solar noon, Watts/meter^2



Source of data used for creation of this map: Dan Lubin and associates, California Space Institute, Scripps Institution of Oceanography, University of California San Diego (27)

Figure 2

Estimated equinoctial ultraviolet A irradiance (380 nm) at ground level, solar noon, milliWatts/meter^2/nm



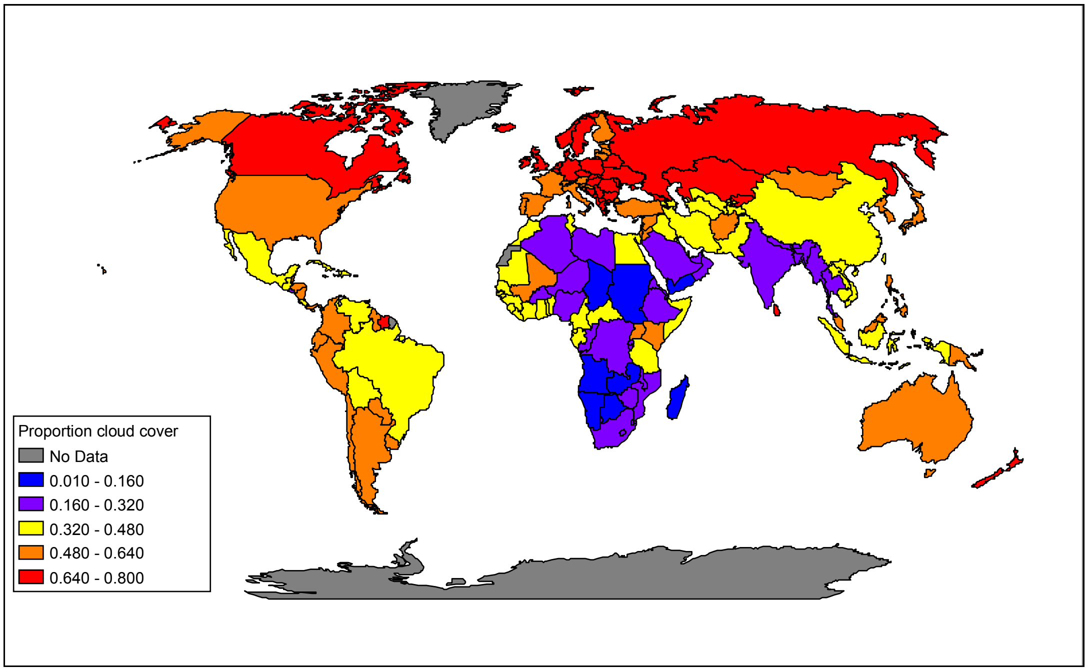
Source of data used for drawing this map: Dr. Jay R. Herman and NASA Goddard Space Flight Center, Laboratory for Atmospheres (30).

Some of the variation in UVB and UVA was due to variations in cloud cover (Figure 3), which varied from a low of <16% in most of sub-Saharan Africa to a high of 64-80% in Eastern and Southeastern Europe, Scandinavia, Russia, Ukraine, and Kazakhstan. A continuous contour map of total amount of clouds is shown in Appendix Figure 1, based on data from the International Satellite Cloud Climatology Project (31).

Some of the variation in UVB was due to variations in anthropogenic sulfate aerosols (Figure 4), whose optical depth varied from a low of 0.01-0.14 in most of sub-Saharan Africa and Saudi Arabia to a high of 0.56-0.70 in China.

Figure 3

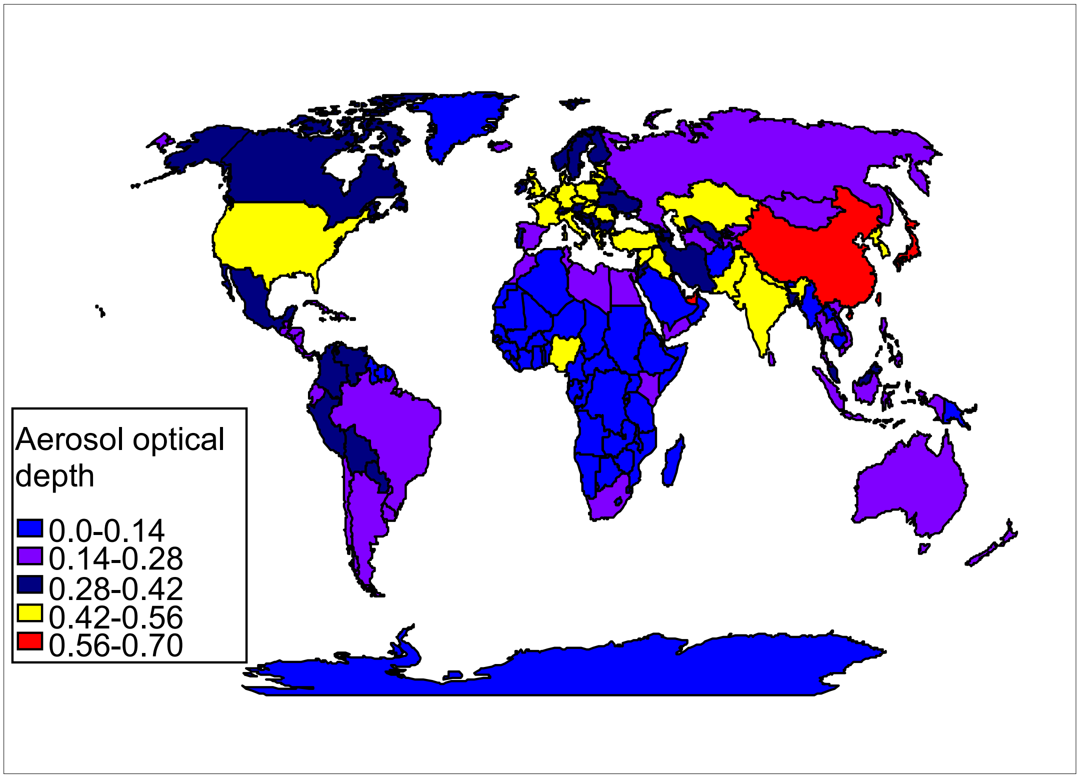
Mean total amount of clouds, expressed as a proportion



Source of data used for drawing this map: National Aeronautics and Space Administration. International Satellite Cloud Climatology Project database (31). Data were annual means during 1983-2001.

Figure 4

Mean optical depth of anthropogenic aerosols



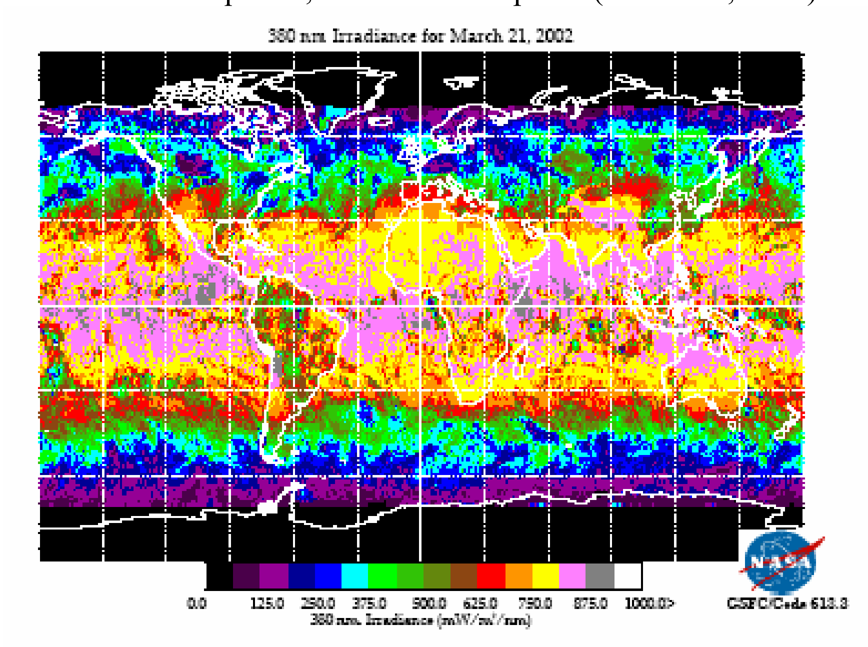
Source of data used for creation of this map. National Aeronautics and Space Administration. Moderate Resolution Imaging Spectroradiometer (MODIS) MOD 08 Images (32). Data were for August 2000. Aerosol optical depths for countries with sporadic vegetation fires and volcanism were estimated from data for adjacent countries.

Continuous contour maps of 380 nm UVA irradiance at the vernal equinox in the northern and southern hemispheres were provided by Dr. Jay R. Herman of NASA Goddard Space Flight Center, Laboratory for Atmospheres, Greenbelt MD (30). These maps are shown in Figure 5.

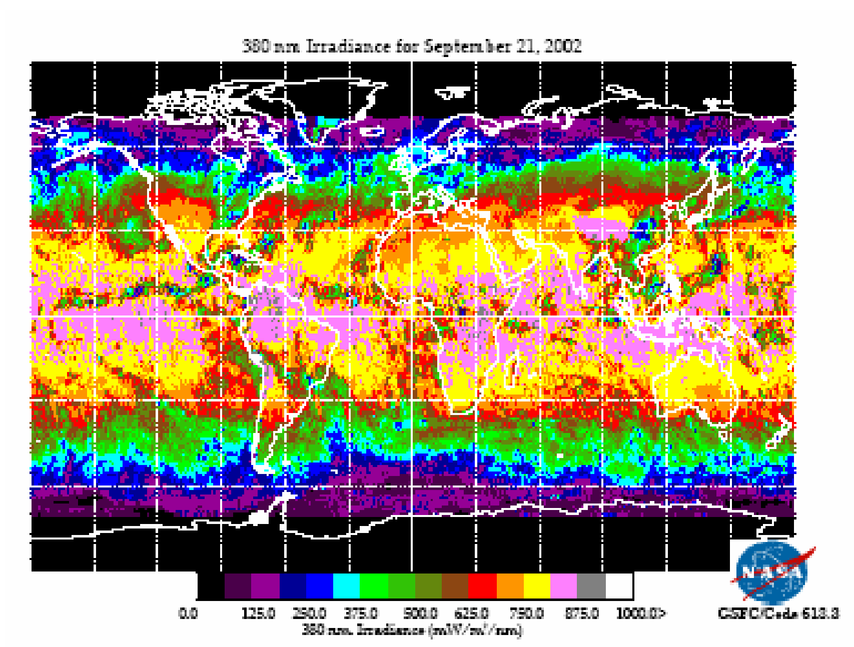
Figure 5

Estimated equinoctial ultraviolet A irradiance, solar noon, $mW/m^2/nm$

A. Vernal equinox, northern hemisphere (March 21, 2003)



B. Vernal equinox, southern hemisphere (September 21, 2003)

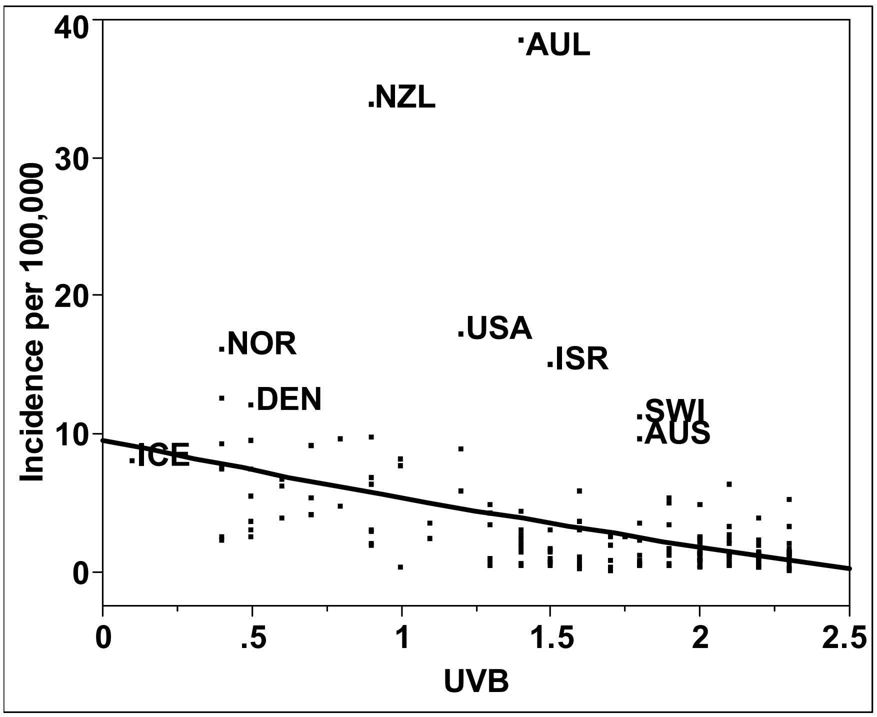


Source: Dr. Jay R. Herman, NASA Goddard Space Flight Center, Laboratory for Atmospheres (30).

Age-adjusted melanoma incidence rates were lowest in areas with the highest levels of UVB in men (Figure 6) and women (Figure 7). The rates were also inversely associated with UVA in both sexes (Figures 8 and 9).

Figure 6

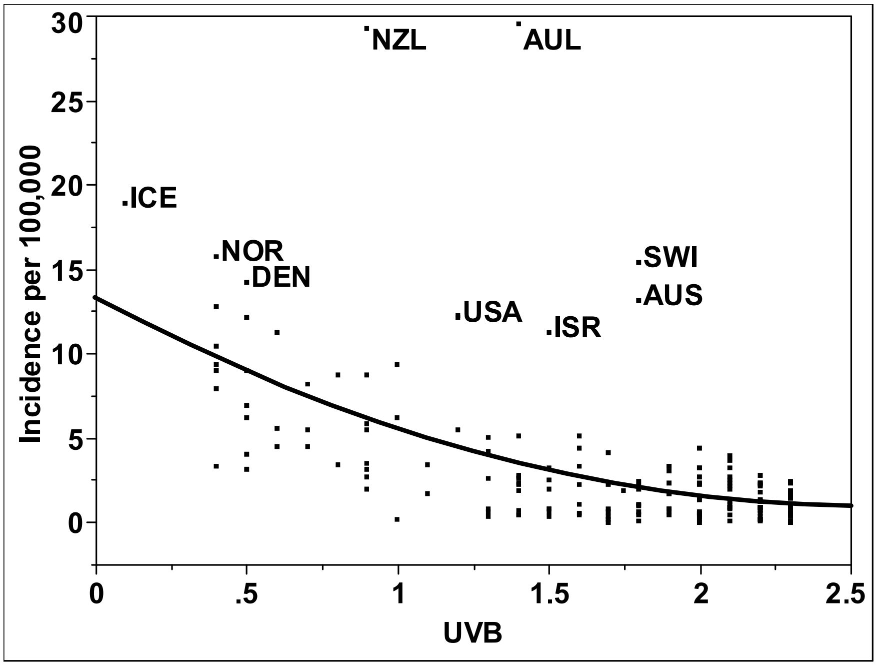
Age-adjusted melanoma incidence rate per 100,000 males, by equinoctial UVB (280-315 nm) irradiance at solar noon, Watts/m^2, 175 countries, 2000 (R^2 = 0.34)



Sources of data: GLOBOCAN (26) for melanoma data and Lubin et al. (27) for UVB data. Abbreviations for labeled data points: AUL Australia, AUS Austria, DEN Denmark, ICE Iceland, ISR Israel, NOR Norway, NZL New Zealand, SWI Switzerland, USA United States of America

Figure 7

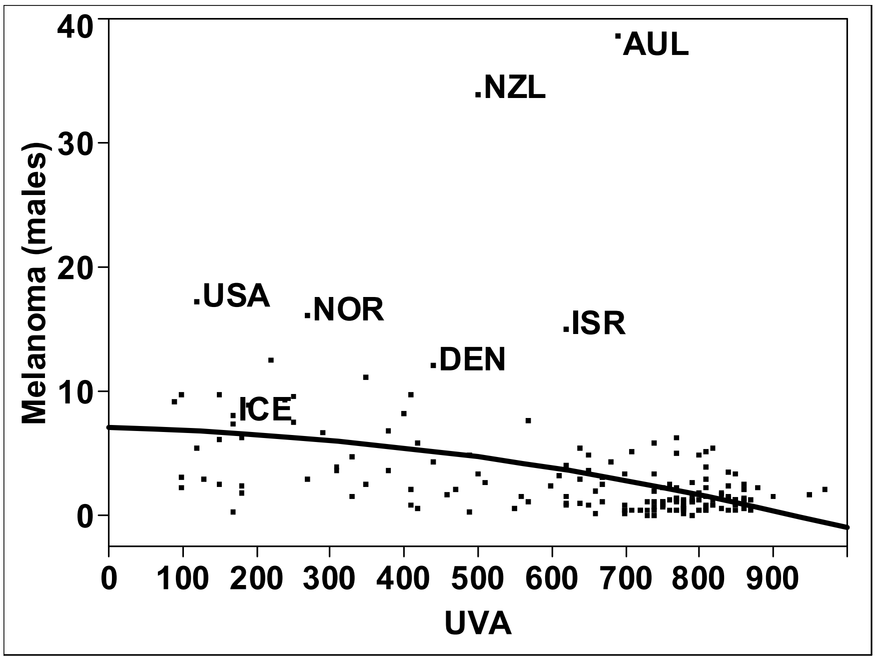
Age-adjusted melanoma incidence rate per 100,000 females, by equinoctial UVB (280-315 nm) irradiance at solar noon, Watts/m^2, 175 countries, 2000 (R^2 = 0.48)



Sources of data: GLOBOCAN (26) for melanoma data and Lubin et al. (27) for UVB data. Abbreviations for labeled data points: AUL Australia, AUS Austria, DEN Denmark, ICE Iceland, ISR Israel, NOR Norway, NZL New Zealand, SWI Switzerland, USA United States of America

Figure 8

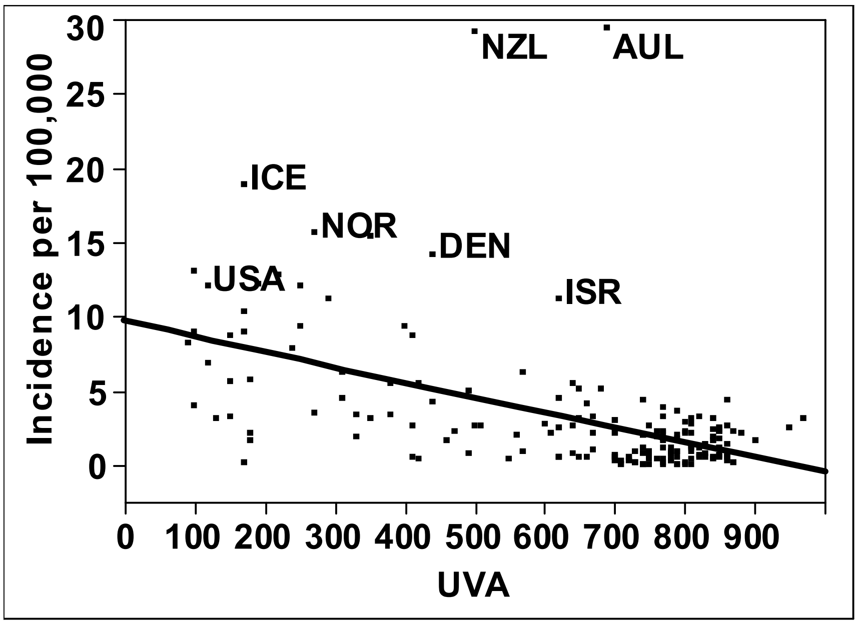
Age-adjusted melanoma incidence rate per 100,000 males, by equinoctial UVA (380 nm) irradiance at solar noon, milliWatts/m^2/nm, 175 countries, 2000 (R^2 = 0.36)



Sources of data: GLOBOCAN (26) for melanoma data and Dr. Jay R. Herman, NASA Goddard Space Flight Center, Laboratory for Atmospheres (30) for UVA data. Abbreviations for labeled data points: AUL Australia, DEN Denmark, ICE Iceland, ISR Israel, NOR Norway, NZL New Zealand, USA United States of America

Figure 9

Age-adjusted melanoma incidence rate per 100,000 females, by equinoctial UVA (380 nm) irradiance at solar noon, milliWatts/m^2/nm, 175 countries, 2000 (R^2 = 0.44)



Sources of data: GLOBOCAN (26) for melanoma data and Dr. Jay R. Herman, NASA Goddard Space Flight Center, Laboratory for Atmospheres (30) for UVA data. Abbreviations for labeled data points: AUL Australia, DEN Denmark, ICE Iceland, ISR Israel, NOR Norway, NZL New Zealand, USA United States of America

In regression models for males and females (Tables 1 and 2 respectively), UVB irradiance, migration, and pigmentation all were statistically significantly associated with age-adjusted melanoma incidence rates.

Table 1. Associations of covariates with age-adjusted incidence rates of melanoma per 100,000 males, 175 countries, 2000

Variable	Regression coefficient	Standard error	*t*	*p*
Ultraviolet B irradiance, Watts/m^2*	-1.7316	0.592	-2.93	0.004
Migration, degrees of latitude†	1.3056	0.088	14.87	< 0.0001
Pigmentation score‡	-1.1721	0.358	-3.28	0.001

R^2 for model = 0.69

p for model < 0.0001

*Solar noon equinoctial ultraviolet B irradiance integrated over the range 280-315 nm

†Difference between absolute latitude of country of origin and absolute latitude of country of migration

‡Jablonski – Chaplin pigmentation score (33) was adapted for this analysis

Table 2. Associations of covariates with age-adjusted incidence rates of melanoma per 100,000 females, 175 countries, 2000

Variable	Regression coefficient	Standard error	*t*	*p*
Ultraviolet B irradiance, Watts/m^2*	-2.431	0.6028	-4.03	< 0.0001
Migration, degrees of latitude†	0.9612	0.0894	10.74	< 0.0001
Pigmentation score‡	-1.2476	0.3646	-3.42	< 0.001

R^2 for model = 0.64

p for model < 0.0001

*Solar noon equinoctial ultraviolet B irradiance integrated over the range 280-315 nm

†Difference between absolute latitude of country of origin and absolute latitude of country of migration

‡Jablonski – Chaplin pigmentation score (33) was adapted for this analysis

DISCUSSION

Despite their public health importance, the geographic distributions of UVB and UVA irradiance are poorly understood. This is beginning to change as a result of satellite remote sensing technology. The equinox was chosen for these maps as the optimal date for measurements of the importance of ultraviolet radiation in human health. Differences in ultraviolet irradiance between countries are greatest at the equinox. Spring, the season containing the vernal equinox, is the time of year when vitamin D deficiency diseases often appear. A classic example is the historically high occurrence of rickets in springtime (H. L. Newmark, personal communication, 2005).

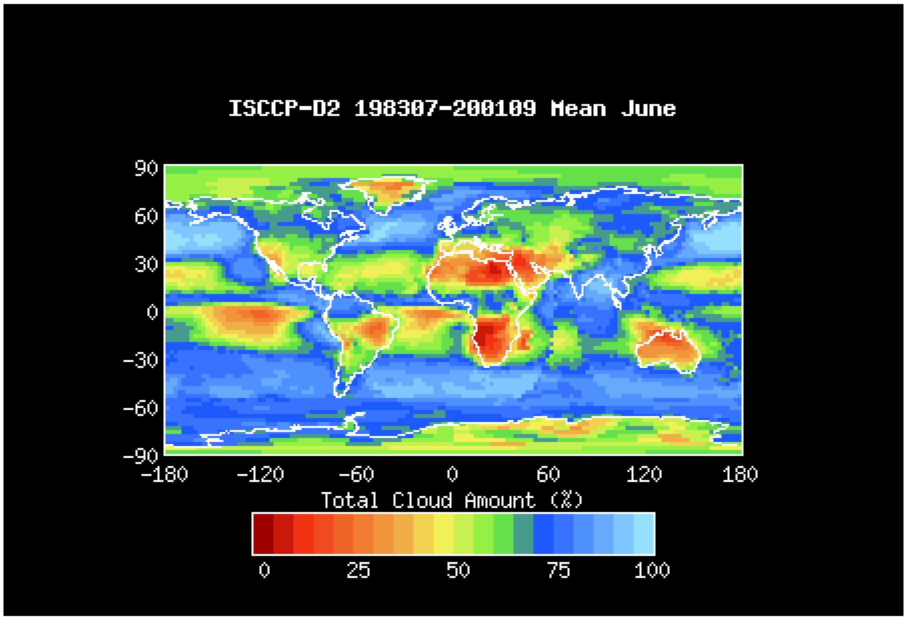
The melanoma findings are consistent with greater photoprotective pigmentation in populations living in regions of high ultraviolet irradiance. They should not be interpreted to mean that overexposure to ultraviolet A radiation is harmless. A previous international comparison study revealed that, after adjustment for level of pigmentation of the skin, level of exposure to UVA, but not UVB, was positively related to risk of melanoma (25). Other studies have suggested that UVB may, paradoxically, be protective against melanoma through a mechanism involving photoprotective accommodation and photosynthesis of vitamin D in the skin (22-25, 34, 35).

Distributions of UVA and UVB by latitude were similar. The latitude of the median irradiance for both UVA and UVB occurred at approximately 37 degrees north of the equator for land masses in the northern hemisphere, and at 39 degrees south of the equator for land masses in the southern. GIS facilitated creation of these epidemiologically oriented maps of UV irradiance. Such maps may facilitate the emerging understanding of the role that solar ultraviolet B irradiation plays in reduction of incidence of human disease.

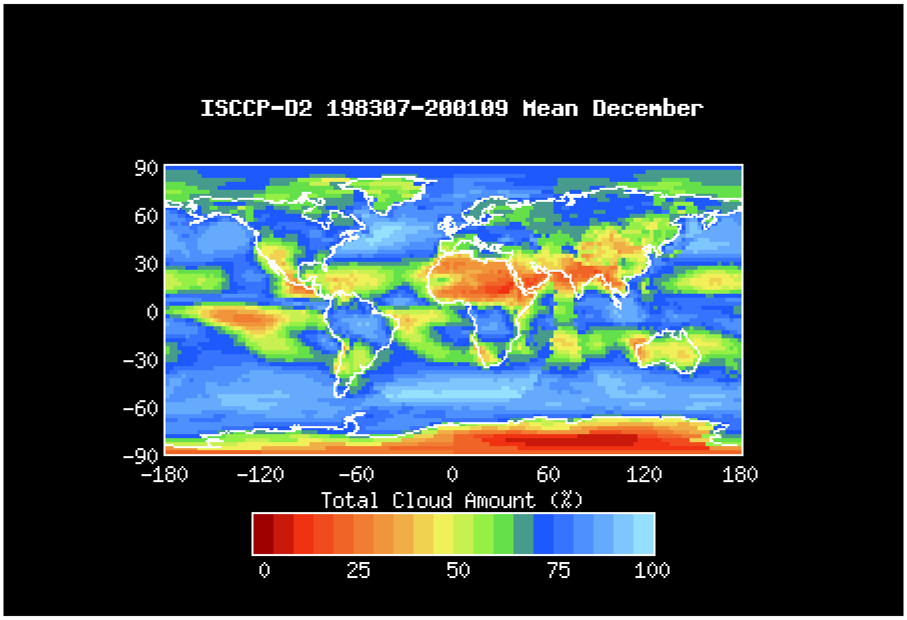
APPENDIX

Appendix Figure 1. Total mean amount of clouds, expressed as a proportion

A. June, 1983-1991



B. December, 1983-1991



Source: NASA International Satellite Cloud Climatology Project (31).

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