Increasing Intensity of Solar Radiation in the Continental United States 1979 to 2011: Implications for Skin Cancer
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Abstract
Importance: Skin cancer rates continue to escalate in the United States, yet little is known about changes in climatologic contributors to this epidemic.

Objectives: To assess whether there has been a change in solar radiation over time.

Methods: This manuscript analyzes extant climatologic data on measured solar radiation from the North America Land Data Assimilation System Daily Sunlight available from the Centers for Disease Control and Prevention. Data for the Continental United States was analyzed from 1979 to 2011. In addition to descriptive statistics, to test the hypothesis that sunlight energy is changing, a series of regressions was performed on data on National, Regional, and Divisional levels. Also, the relationship between total sunlight energy and ultraviolet B radiation was explored.

Results: The average daily sunlight was 16,432MJ/m² across the Continental United States. Over the 32 year study period, the Continental United States experienced a 2.4% increase in average daily radiation, which translates to a 0.076% per year increase. Although all 9 United States Census Bureau Geographic Divisions saw an increase in their average daily radiation over the study period, for two of these Divisions, Pacific and West North Central, the change was not significant. The Geographic Division with the greatest numeric increase in daily sunlight energy, New England, experienced a 6% increase, translating to a 0.19% increase per year. Daily sunlight energy was an excellent predictor for UVB energy (p=.0001, R²=.97)

Conclusions: Solar radiation demonstrates increases over time, which may have profound implications for a continuously increasing risk of nonmelanoma skin cancer.

INTRODUCTION
Nonmelanoma skin cancer and melanoma continue to increase in frequency in the United States. Health behaviors certainly may modify an individual’s or group’s risk of skin cancer, but environmental factors may also play a role in this trend. Ultraviolet light exposure remains the most important contributor to the pathogenesis of nonmelanoma skin cancer, but its effect on melanoma is not as clear. Most human diseases are multifactorial, and understanding all of the factors contributing to a condition helps guide public health efforts aimed at prevention and control.

Around the world, climatologic data are being accumulated on an ongoing basis, and there are now large amounts of these data available for investigators to perform hypothesis testing. Specifically, The North America Land Data Assimilation System (NLDAS) Daily Sunlight data are available from the Centers for Disease Control and Prevention. NLDAS is an impressive collaboration project among several groups: the National Oceanic and Atmospheric Administration National Centers for Environmental Prediction Environmental Modeling Center, the National Aeronautics and Space Administration Goddard Space Flight Center, Princeton University, the National Weather Service Office of Hydrological Development, the University of Washington, and the NCEP Climate Prediction Center. The NLDAS data are archived and distributed by the Goddard Earth Sciences Data and Information Services Center. Detailed information about the NLDAS project can be found online.
The current study examines the question as to whether there has been a change in the amount of sunlight reaching the United States and to characterize any observed changes.

**METHODS**

The NLDAS Daily Sunlight data available on CDC WONDER are daily sunlight (insolation or solar radiation) observations over the years 1979 to 2011. Reported measures include but are not limited to the average daily solar radiation, reported in kilojoules per square meter (KJ/m2). Sunlight data are available by location and can be assessed at the county, State, geographic division, geographic region, or combined 48 contiguous (continental) states plus the District of Columbia as defined by the United States Census Bureau are presented in Table 1.

To relate total solar radiation to ultraviolet B radiation (UVB), comparisons were made between 3 separate surface radiation (SURFRAD)10 sensing sites were chosen for data extraction. SURFRAD does not have available data over the entire study period from 1979 to 2011. From 1995 to 2011, monthly average UVB was obtained from Bondville, IL, Fort Peck, MT and Goodwin Creek, MS and compared with NLDAS sunlight energy data over the same period for these three US States.

Data were extracted from the CDC WONDER system, and then analyzed by Microsoft Excel 2013 or by SAS 9.3.

All regressions reported are linear and significance was achieved when p<.05. There were no human nor animal subjects so this study was not subject to IRB review.

**RESULTS**

Figure 1 presents the average daily sunlight energy to each State in the Continental United States over the 32 year study period from 1979 to 2011. Note that the readings refers to all light energy and is not strictly limited to light in the ultraviolet light spectrum. Table 2 presents the average solar radiation over the entire study period for the Continental United States, as well as each Geographic Region and Division. In terms of extremes, the West Region has 23% more average daily sunshine intensity than the Northeast Region. Similarly, the West South Central Division experienced 28.5% more average solar radiation than New England. The lowest recorded observation was 849 KJ/m2 whereas the highest recorded observation was 37,714 KJ/m2.

Figure 2 shows that over this study period, sunlight energy in the United States triples in Summer compared with Winter. Figure 3 depicts the monthly average daily solar radiation by geographic region. Note that the West Region Consistently produces the highest amounts of solar radiation in April through September, whereas the South Region produces the highest amounts of solar radiation in October through March.

To test the hypothesis that sunlight energy is changing from 1979 to 2011, a series of regressions was performed on data on a National, Regional, and Divisional levels. Table 2 presents the change in average daily sunlight energy obtained with linear regression from 1979 to 2011. Note that the number of KJ/m2 significantly increased on a National basis and for all of the Geographic Regions. Although all 9 Geographic Divisions saw an increase in their energy over the study period, for two of these Divisions, Pacific and West North Central, the change was not significant. For both of these Divisions, the regression coefficient of determination (R-Squared) was lower than for any other of the Divisions. Graphic presentations of the change in energy over these study periods is presented for the Nation (Figure 4), Geographic Regions (Figure 5), and Geographic Divisions (Figure 6). Linear regression estimates are depicted for these figures.

To verify that the NLDAS total solar energy levels represent UVB levels, a regression was performed for the monthly averages of total solar energy from 3 US States compared with ground-based UVB recordings from SURFRAD. Although the SURFRAD recordings were from a single site and the NLDAS was from entire States, there was a highly significant relationship between total solar energy and UVB (p<.001, R2=.97). Thus, the observations about total solar energy relate closely to UVB (Figure 7).
Figure 1
A 32 year average of the average daily solar radiation by State in the Continental United States. The West and South display the highest daily radiation whereas New England displays the lowest.

Figure 2
A 32 year average of the average daily solar radiation by day of the year in the Continental United States. The solar radiation on the peak Summer days is more than three-fold higher than the lowest Winter days.

Figure 3
The intensity of daily solar radiation by Month and Geographic region for the Continental United States.

Figure 4
The change in the average daily solar radiation by year for the Continental United States with linear regression line. The mean daily increased solar radiation over the study period was 393 KJ/m2.

Figure 5
The change in the average daily solar radiation by year for the Continental United States by Geographic Region with linear regression lines. All Regions demonstrate significant increases in average daily solar radiation, with the greatest increases in the South.

Figure 6
The change in the average daily solar radiation by year for the Continental United States by Geographic Division with linear regression lines.
**DISCUSSION**

For the Continental US as measured by the NLDAS Daily Sunlight data, this paper finds that solar radiation reaching the Earth's surface significantly increases over the 32 year study period. It should be emphasized that the measures contained within this dataset are not exclusively ultraviolet radiation. Rather these measures portray all wavelengths of sunlight, only a fraction of which are the oncogenic UVA and UVB wavelengths. Nevertheless, since NLDAS solar energy levels are closely aligned with UVB levels, it is likely that UVB radiation is increasing over the past three decades.

Readers should note that over the entire study period, the magnitude of increase on a National basis is only estimated to be 2.4% in units of KJ/m2, which translates to a 0.076% per year increase in KJ/m2. In the Geographic Division with the greatest numeric increase in daily sunlight energy, New England, there was a 6% increase, translating to a 0.19% increase per year. In the West North Central Division, the area with the smallest numeric (and statistically nonsignificant) increase, the increase over 1979 to 2011 was 1.0% translating to 0.032% change in KJ/m2 per year. The increase in the rate of nonmelanoma skin cancer has been far
greater than this increase,12 so the radiation change may not be
the primary driver of change.

Those people residing in higher solar radiation areas such as
the South or West Regions experience a larger dose of
potentially harmful radiation than those in other areas.
Hypothetically, if the increase in New England Division
continues at 6% every 32 years, we would need to wait 132
years for New England to achieve the current average daily
solar radiation of the Pacific Division.

There also appears to be marked year to year variations
nationally and on a more local basis that contribute to the
observed variability in the data. Just as some climate
variability makes some seasons display more extreme
temperatures than others,13,14 solar irradiation may display
similar variability. This observation is likely the reason that,
although all measures indicate that the average daily solar
radiation is rising, the various observed coefficients of
determination are all less than or equal to 0.50.

The implications of this study regarding increasing health
risks from yearly increasing solar radiation are patently
apparent. Nonmelanoma skin cancer rates continue to
inexorably rise in the US and most such skin cancer has
ultraviolet radiation as a cause.5,15,16 Any increase in
ambient ultraviolet levels poses incremental increased risk
over time. Threshold effects have been observed in at least
one animal model suggesting that further radiation, around
the oncogenesis threshold, increases risk.17 Recent
evaluation and recommendations by the United States
Surgeon General appear prudent.18 Clearly, since the data
depicted in Figure 1 are typical of UV Index data published
on a continuous basis, prudent solar protection approaches
are required. With respect to the skin, further vigilance is
required as ambient radiation rates increase over time.

At the same time, the issue of sunlight and health remains a
complex one. Ultraviolet radiation increases could result in
diminished vitamin D deficiency, with the possibility of
diminished systemic risks of many conditions linked to
hypovitaminosis D states. The literature on the benefits of
ultraviolet radiation is extensive19 and beyond the scope of
this discussion.

This author is not able to comment upon the methodologic
limitations inherent in the measurements and estimations and
algorithms employed by governmental climatologic and
space agencies that generated this data. It is also beyond the
scope of this author to speculate upon mechanisms such as

ozone depletion and other factors noted to contribute to
increasing solar radiation. It is certainly possible that despite
an increase in overall radiation, that there may not be as
large of a magnitude in change in ultraviolet radiation. There
is no a priori reason to assume that the ultraviolet light
proportion in the total radiant flux has changed, but this
author could find no evidence scholarly activity related to
this topic in the United States.

This manuscript finds evidence of a consistent and sustained
increase in solar radiation over the past three decades.
Whether the magnitude of this increase is sufficient to be a
major factor in our current skin cancer epidemic is unclear.

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