UV Index and Forecast Model

1

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Abstract

Anthropogenic emissions of chlorine and bromine containing halocarbons have caused not only the well-known ozone hole over the Antarctica but also a global stratospheric ozone depletion. As a result, there is a significant increase in the solar UV radiation reaching the surface. High dosage of solar UV radiation is extremely harmful to human health, especially concerning the skin and eyes. In response to these health-related concerns, there are worldwide efforts to increase the public awareness of the harmful effects of daily exposure to excess UV radiation. A key process of these efforts is to evaluate and forecast the UV index as a measure of the surface level UV radiation. Currently there is no internationally agreed definition for the UV Index. But WMO Report #95 (1994) recommended strongly for a uniform index. In the following, I'll discuss the UV index adopted by the US EPA/NOAA (Long et al., 1996) which is based on the WMO recommendations, as an example to show how the index is calculated and forecasted. In addition, possible improvements of the index will be suggested.

1 Introduction

Since the discovery of the ozone hole over the Antarctica by Farman et al. (1985), extensive observations have shown that the reduction in ozone is a global phenomenon caused by anthropogenic emissions of chlorine and bromine containing halocarbons. As a result, there is asignificant increase in the solar UV radiation reaching the surface. It is well known that exposure to solar UV radiation over a prolonged period of time is extremely harmful to human health, especially to the skin, eyes, and even the immune system (Defabo and Noonan, 1983). In response to these health-related concerns, several countries have started to monitor the UV radiation and conducted education campaigns to increase the public awareness of the harmful effects of daily exposure to excess UV radiation. A key part of the education campaign is to broadcast the observed and/or predicted UV dosage (i.e. UV index) along with issuing "burning times" guideline for various types of skin

Currently there is no internationally agreed definition for the UV index. But WMO Report #95 (1994) recommended strongly for a uniform index. By 1994, about 8 countries (Canada, Germany, UK, New Zealand, Australia, Finland, Sweden, and USA) have developed UV indexes that are similar but with noticeable differences. USA alone has 3 different indexes.

WMO Report #95 (1994) made the following recommendations on the UV Index:

1. Publish a catalogue of UV monitoring activities,
2. Develop an international instrument calibration facility,
3. Produce a quality assurance protocol and coordinate data availability,
4. Utilize the CIE (1087) action spectrum normalized to 1.0 at 297 nm,
5. A minimum requirement is to report irradiance values at local solar noon, and
6. The index is expressed by multiplying the weighted irradiance in W/m2 by 40.0 (this will lead an index normally between 0 and 16).

In the following, the UV index adopted by US EPA/NOAA (Long et al., 1996) which is based on the WMO recommendations, will be presented as an example to show how the index is calculated and forecasted. In addition, possible improvements of the index will be discussed.

2. UV Index of the US NOAA/EPA

Unlike some countries, the NOAA/EPA UV Index is not based upon surface observations. Rather, it is computed using the forecasted ozone data, a radiative transfer model, forecasted cloud amounts and the elevation of the forecast cities. Total ozone amounts for the entire globe are obtained via the TOVS (TIROS Operational Vertical Sounder) or the SBUV/2 (Solar Backscatter UltraViolet/2) instruments on board NOAA polar orbiting satellites. The observed data of yesterday are then used to produce a forecast of the ozone data for tomorrow. This is done using the thermal-dynamical relationship between total ozone and heights at 100 and 500 hPa and temperatures at 50 hPa. The National Center for Environmental Prediction (NCEP, formerly NMC) provides the necessary analyzes and forecasts to be used to determine the forecasted ozone data. This is shown in the following equations

O3(tomorrow) = O3(yesterday) +ΔO3

$\Delta O3 = a\ \Delta Z500 + b\ \Delta Z100 + C\ \Delta T50 + d$

Where a, b, c, and d are regression coefficients. This forecasted ozone data has been shown to be more accurate than just using persistence (i.e. tomorrow's ozone equals yesterday's ozone) at mid-latitudes. However, near the tropics such as over Taiwan, this gain in accuracy is negligible because the daily total ozone variations are quite small (on the order of 1%). In this case, it is probably more appropriate to use the persistence approach.

A radiative transfer model is used to determine the UV irradiances from 290 to 400 nm, using the time of day (solar noon), day of year, and latitude. A constant ground albedo of 5% is assumed. The irradiances are weighted by the McKinlay-Diffey (1987) Erythema action spectrum, which is normalized to unit at 290 nm (Figure 1) so as to reflect the human skin's response to each wavelength. These weighted irradiances are integrated over the 290 to 400 nm resulting in the erythema dose rate (Figure 2). This rate is then scaled (divided) by the standard of 25 milliWatts per square meter and the result is the clear sky UV Index at sea level for the site.

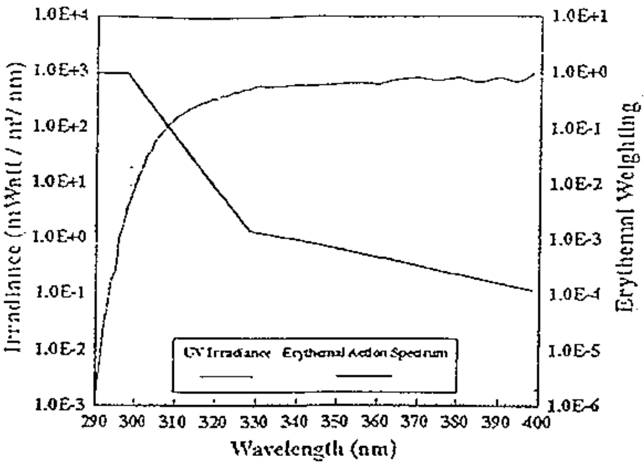

FIG. 1. The UV spectral irradiances (thin line) from 290 to 400 nm at summer solstice, 40°N, and solar noon, with 300 DU of ozone overhead. For the same wavelengths but using the opposite y axis, the erythemal action spectrum (bold line) is plotted.

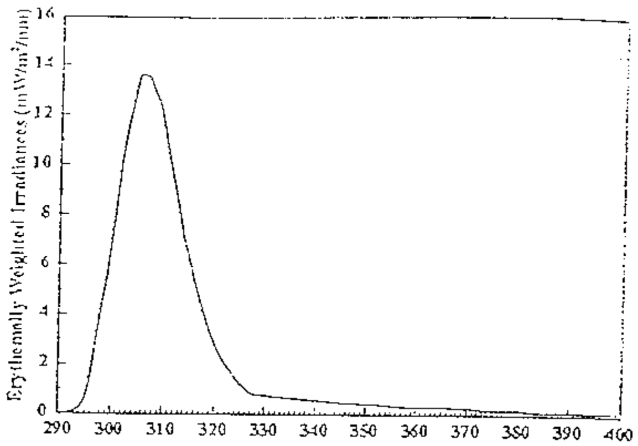

FIG. 2. The product of spectral irradiances and the erythemal action spectrum is plotted. Note that the peak occurs between 308 and 310 nm.

The actual UV Index for the site is calculated by adjusting the clear sky UV Index at sea level for the effects of elevation and cloudiness. The adjustment for elevation is done according to the result of the radiative transfer model that gives about 6% increase in the UV Index per kilometer. Cloud cover at the site is derived from the National Weather Service (NWS) Medium Range Forecast Model outputs. It is quantified to four single-layer cloud cover conditions (Erickson, 1988): clear for 0 – 0.1 cloud cover, scattered for 0.2 – 0.5 cloud cover, broken for 0.6 – 0.8 cloud cover, and overcast for 0.9 – 1.0 cloud cover. The adjustment to cloud cover is then calculated according to the following empirical factors: clear sky conditions allow 100% transmission of UV radiation to the surface, scattered cloud conditions allow 89% transmission, broken cloud conditions allow 73% transmission, and overcast cloud conditions allow 32% transmission. The UV Index calculated this way has values ranging from zero to the mid-teens. Table 1 shows the US EPA general guidelines of protective actions for various UV Indexes.

Table 2 gives an example of the output of the UV Index forecasts for 58 cities over the US for June 22, 1997. It can be seen that most of the values of the UV Index are in the High and Very High categories in this summer day. The lower values and most of the variability in the UV Index among the cities are the result of different cloud cover conditions. This clearly indicates that forecasting cloud conditions is most important in the forecast of the UV Index.

Table 1

The EPA has devised general guidelines as far as what to do to protect oneself from overexposure to UV radiation. These are shown in the table below.

Exposure Category	UV Index	Protective Actions
Minimal	0, 1, 2	Apply skin protection factor (SPF) 15 sun screen.
Low	3, 4	SPF 15 & protective clothing (hat)
Moderate	5, 6	SPF 15, protective clothing, and UV-A&B sun glasses.
High	7, 8, 9	SPF 15, protective clothing, sun glasses and make attempts to avoid the sun between 10am to 4pm.
Very High	10+	SPF 15, protective clothing, sun glasses and avoid being in the sun between 10am to 4pm.

Table 2

NOAA/EPA ULTRAVIOLET INDEX /UVI/ FORECAST
CLIMATE PREDICTION CENTER NCEP
NATIONAL WEATHER SERVICE WASHINGTON DC
205 PM EDT SUN JUN 22 1997

VALID JUN 23 1997 AT SOLAR NOON /APPROXIMATELY NOON
LOCAL STANDARD TIME OR 100 PM LOCAL DAYLIGHT TIME/

CITY	STATE	UVI	CITY	STATE	UVI
ALBUQUERQUE	NM	11	LITTLE ROCK	AR	9
ANCHORAGE	AK	4	LOS ANGELES	CA	10
ATLANTA	GA	9	LOUISVILLE	KY	9
ATLANTIC CITY	NJ	9	MEMPHIS	TN	9
BALTIMORE	MD	9	MIAMI	FL	8
BILLINGS	MT	5	MILWAUKEE	WI	9
BISMARCK	ND	6	MINNEAPOLIS	MN	8
BOISE	ID	7	MOBILE	AL	8
BOSTON	MA	8	NEW ORLEANS	LA	9
BUFFALO	NY	9	NEW YORK	NY	9
BURLINGTON	VT	7	NORFOLK	VA	9
CHARLESTON	SC	8	OKLAHOMA CITY	OK	8
CHARLESTON	WV	9	OMAHA	NE	8
CHEYENNE	WY	10	PHILADELPHIA	PA	9
CHICAGO	IL	9	PHOENIX	AZ	10
CLEVELAND	OH	9	PITTSBURGH	PA	9
CONCORD	NH	8	PORTLAND	ME	8
DALLAS	TX	8	PORTLAND	OR	4
DENVER	CO	10	PROVIDENCE	RI	8
DES MOINES	IA	9	RALEIGH	NC	9
DETROIT	MI	8	SALT LAKE CITY	UT	9
DOVER	DE	9	SAN FRANCISCO	CA	10
HARTFORD	CT	8	SAN JUAN	PU	11
HONOLULU	HI	12	SEATTLE	WA	3
HOUSTON	TX	8	SIOUX FALLS	SD	9
INDIANAPOLIS	IN	8	ST. LOUIS	MO	9
JACKSON	MS	9	TAMPA	FL	8
JACKSONVILLE	FL	8	WASHINGTON	DC	9
LAS VEGAS	NV	10	WICHITA	KS	7

3. Comparison with Observations

The UV Index forecasts need to be tested by comparison with measured UV radiation. This was done for measurements taken at 21 sites in the contiguous United States in 1994. Most of the measurements were done by RB instrument, some by spectral instrument, and one by Brewer instrument. Some scaling of the data was necessary to take care of the uncertainty in the calibration of the instruments. The result of the comparison is summarized in a histogram of the differences between the forecast UV Index and noontime observations (Figure 3). The forecasts are accurate (within 0.5 unit) 31.8% of the time, within 1 unit 75.9% of the time, and within 2 units 91.5% of the time. This is a very good verification of the forecast.

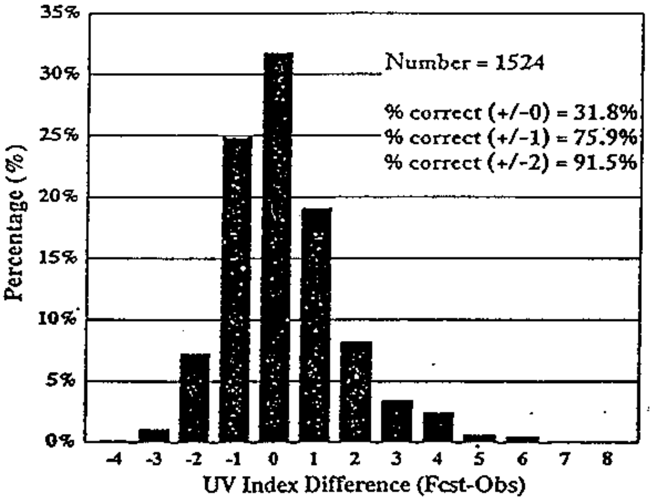

Fig. 3. Histogram of the (UVI forecast–UV observation) differences in whole UVI units for all 21 sites between July and October 1994.

Because of the harmful health effects of high UV radiation, it is important for the forecast to be accurate when the observed UV Index falls into the High (H) and Very High (VH) categories. For such cases, accurate H and VH forecasts were made 517 times (X), while the observed H and VH were underestimated 105 times (Y). These numbers give a probability of detection of H and VH (PoD = X divided by X+Y) of 0.831, indicating a high detection rate of harmful cases. This is comparable to, or better than, the PoD's of other types of severe weather forecasts that the NWS issues. For instance, in the case of severe local storm forecasts, the national average PoD for 1993 was 0.70.

4. Possible Improvements

Currently, the computation of the UV Index does not include the effects of variable surface albedo, atmospheric pollutants or haze. These effects should be included, particularly the effect of aerosols that can reduce the UV radiation significantly in populated areas of industrialized countries (Liu et al., 1991). Because of the importance of cloud cover, it may be necessary to include multi-layer clouds. In addition, for countries other than the US, TOMS total ozone data are more appropriate to use as they are readily available and probably better calibrated. Finally, it may be valuable to take advantage of surface UV observations and various meteorological parameters to derive correlation coefficients and use them to improve the calculation of UV Index. For example, the correlation of UV radiation with various cloud cover conditions can be used to improve the calculation of the dependence of UV Index on the forecasted cloud covers.

5. References

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