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Inferring UV intensity from visible light or solar warmth

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Abstract. People can neither see nor physically sense erythemal UV, so perceptions of its intensity can be very inaccurate. We are probably more conscious of direct solar irradiance, but it varies little over much of the day. Correlation is much closer with global horizontal irradiance, as measured at over 150 sites in New Zealand. In conjunction with ozone data and clear sky models, the measurements can be used to predict UVI reliably, even under varying cloud as the effects of cloud attenuation or enhancement of radiation are averaged. The recent development of solar-tracking UV spectrometry at Lauder will enable further elucidation. Unlike solar energy flux, diurnal air temperature is very misleading about UV.

Motivation

Without the benefit of reliable UV information, people attempting to follow safe sun practice tend to base their behaviour on perceived UV intensity. If these perceptions come just from physical senses – how bright the light seems to be, how warm sunlight feels, or air temperature – they can be very inaccurate. Here we use precise measurements of global horizontal (*G*) and direct normal incident (*R*) radiation, spectral UV and its erythemal intensity (as UVI), and climate parameters to illustrate and explore the relationships.

Data

The NIWA station at Lauder (45° S, 169.7° E) is the southern hemisphere mid-latitude site of the international Network for the Detection of Atmospheric Composition Change (NDACC), measuring atmospheric constituents mostly by spectroscopy of transmitted solar radiation. Spectral measurements of solar UV, to the highest global standards of stability and absolute accuracy, traceable via FEL lamps to NIST, are one component of NDACC. In turn, they provide reliable calibration of erythemal sensors measuring at higher time resolution (Seckmeyer et al. 2001; 2008).

Lauder is also a Baseline Surface Radiation Network (BSRN) site, measuring solar energy flux to Earth's surface at clean sites for satellite data validation and long-term monitoring of Earth's radiative balance. Solar tracking instruments measure global horizontal, diffuse, and direct normal-incident radiation to the best available accuracy; currently 5, 3, and 1.5 W m^{-2} respectively. Data at 1 Hz provide 1-minute statistics .

Standard meteorological data are recorded as 10-minute averages. Here they are interpolated to all (2.93 million) minutes from 1 Oct 2012 to 31 Dec 2013 with valid BSRN and UV measurements (Badosa et al. 2014).

Analysis

Figure 1 compares the diurnal variation of the different radiation measures on a clear day. Solid lines denote measurements, as labelled, and dotted lines show values from a simple clear sky model.

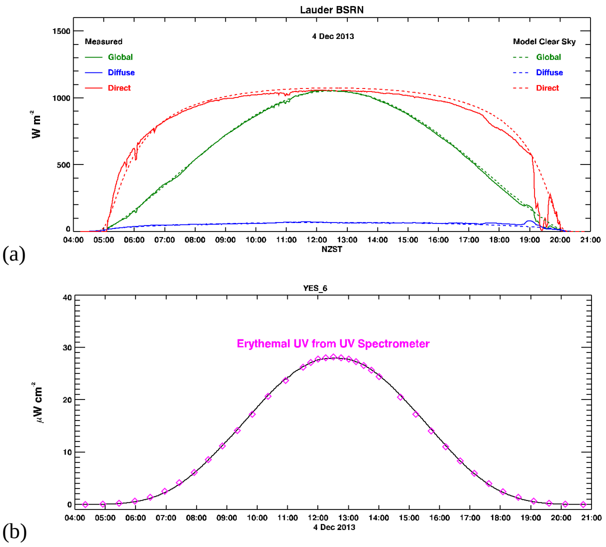

Figure 1. (a) Global, diffuse and direct normal radiation from BSRN instruments at Lauder on 4 Dec 2013, and model clear sky values. (b) Erythemal UV on the same day, from an NDACC standard spectrometer and a Yankee Environment Systems UVB-1 RB meter.

Both direct and diffuse radiation have very broad distributions that vary little over 10 to 12 hours centred around solar noon. This accords with our perception that daylight is nearly uniformly bright over this period. Facing the sun at low solar elevation, or behind a window with that aspect, we perceive even more radiant energy and light than under high sun. Correspondingly, winter sun seems equally bright, even though its noon elevation and intensity are comparable to values 2-3 hours after dawn or before dusk in summer. If winter sun does not feel as warm on our skin, it is only because of the combination with our temperature. We sense not the radiant heat, but the net heat flux at our skin.

In contrast, the common measurement of solar energy flux is the global irradiance of a horizontal surface, as shown in green in Figure 1(a). Though most solar energy is in the direct beam on a clear day, only the downward component, the 'cosine-weighted' part, contributes to the global irradiance. Data of this type, at hourly or 10-minute resolution, are available from the NIWA climate database for over 150 sites around New Zealand, from pyranometers or, more commonly, inexpensive silicon photodiodes that measure only part of the 300 nm to 3 μm nominal range but show good proportionality.

The erythemal UV irradiance, as shown in Figure 1(b), is even more strongly peaked around solar noon, because at low sun elevation the longer path through stratospheric ozone increases absorption by (roughly) the secant (reciprocal cosine) of zenith angle. The similarity of the two profiles is further illustrated in Figure 2, with UV now represented by the familiar UV Index (1 UVI = 2.5 μW cm^{-2} = 25 W m^{-2} erythemal UV).

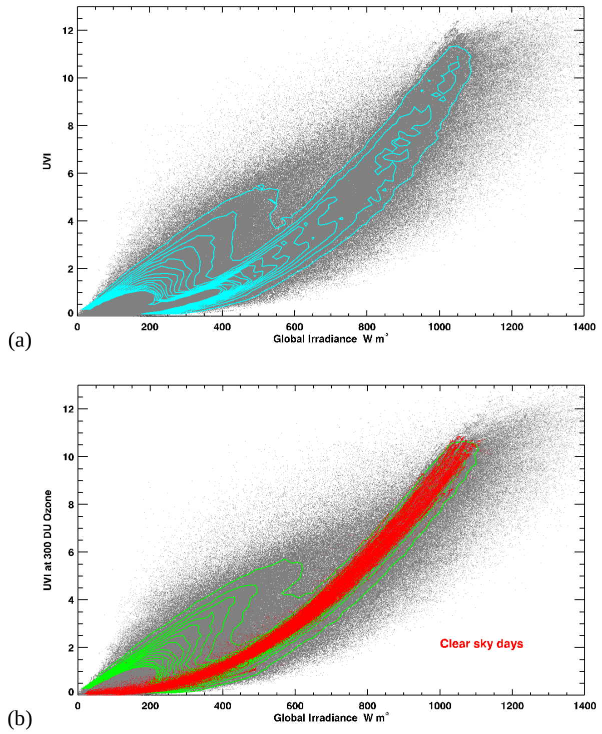

Figure 2. Global irradiance vs. UVI; 11 years of 1-minute data at NIWA Lauder. (a) Raw data, with contours of data density. (b) Scaled to fixed ozone column, and with clear sky data highlighted in red.

The compact relationship between broadband and UV irradiance can be used to predict UVI. Ozone variation makes about 9% difference, mostly as seasonal variation (less ozone, more UV in autumn; vice versa in spring). Scaling to constant ozone leaves about 8% coefficient of variation for clear sky UVI predictions. Residual correlation with pressure, humidity, and even aerosol optical depth is negligible in the Lauder data, but may be apparent at more polluted sites.

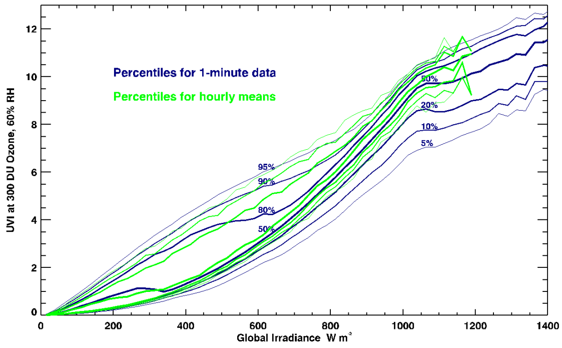

Figure 3. Averaging 1-minute data to hourly preserves the compact relationship, but removes cloud enhancement.

The NIWA UV Atlas (http://www.niwa.co.nz/our-services/online-services/uv-and-ozone/uv-atlas) exploits this relationship, scaling clear-sky UVI by a 'cloud modification factor' computed from the ratio of measured to clear sky hourly global irradiance. From Figure 3, hourly averages of 1-minute data show the same compact relationship, but cloud enhancement largely disappears as an hour of bright sunshine in a sky of broken cloud is rare.

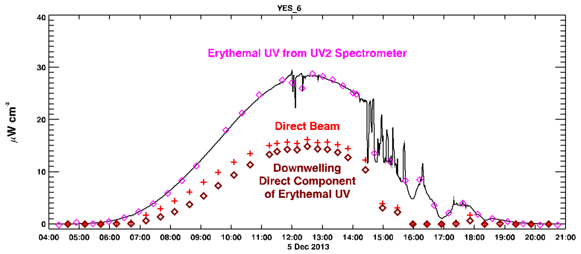

Figure 4. Alternate global and direct erythemal UV from fibre-optic feed to UV2 spectrometer at Lauder.

A recent development at Lauder uses a quartz fibre optic to couple the BSRN tracker to a 280 - 600 nm spectrometer. This will enable further research into the UV climate, as illustrated in Figure 4 which compares direct beam UV with global. Even without the cosine weighting of its downward component, direct UV is strongly peaked around solar noon, unlike the flat diurnal shape of broadband direct radiation in Figure 1(a). For the midday period, downward direct radiation makes up only about half of the global erythemal UV.

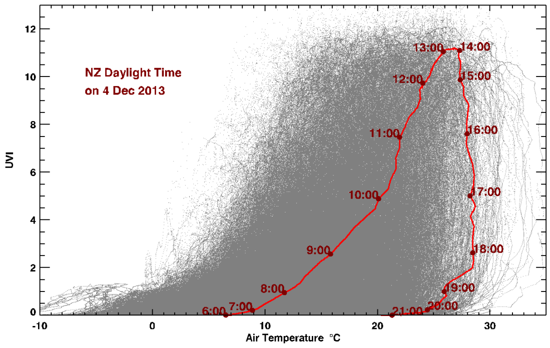

Figure 5. Dry air temperature vs. UVI for 11 years at Lauder, highlighting the day shown in Figure 1.

Even more than broadband direct radiation, which can look brighter and feel warmer on an upright surface like a face, air temperature gives a very misleading impression, as shown in Figure 5. The small overall correlation is a result just of seasonal change. Within a given day, especially under clear sky, the air temperature continues to rise through the day to a peak in late afternoon when UVI is back to very low levels. Well-informed public advice is required to counter any perception that temperature is a valid indicator of UV Index.

References

Badosa, J., Calbó, J., McKenzie, R., Liley, B., González, J.-A., Forgan, B., Long, C.N. 2014. Two methods for retrieving UV index for all cloud conditions from sky imager products or total SW radiation measurements. Photochemistry and Photobiology; doi:10.1111/php.12272.

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