Imaging the environmental ultraviolet

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Abstract

A technique has been developed to visually represent measured environmental ultraviolet radiation using a digital photograph and measurements of the UV and visible light intensity. The method involves the use of a personal pocket UV meter, an optional lux meter and a simple image processing technique to present visual images that are weighted to the ambient ultraviolet, providing images that highlight regions of high ultraviolet intensity that can be compared with a visible photograph. The technique described, provides a method students can follow to better develop an understanding of the potentially harmful ultraviolet irradiance with respect to visible daylight, indicating that the ambient ultraviolet and visible environment are not directly related, with ultraviolet intensity being dependent on many different factors and not the visual brightness of the location alone.

Introduction

The ultraviolet radiation (UV) incident at the Earth's surface that has the potential to cause harm to humans falls within the range of 280 to 400 nm. Visible radiation incident at the Earth's surface lies within the range of 400 to 700 nm, with peak human visual acuity and colour sensitivity varying according to brightness and individual perception. Peak visual sensitivity can be taken in daylight to be in the green region and quoted tentatively at 555 nm (CIE 1931) although it should be noted that there are different human eye responses to visible radiation (Schanda et al 2002, Sharpe et al 2005). Sunlight incident at the Earth's surface does not have the same irradiance over all wavelengths and is dependent upon absorption at certain wavelengths by various chemical elements in both the Sun's and Earth's atmosphere. Furthermore, scattering and absorption in the Earth's atmosphere varies with wavelength over the continuum. Oxygen absorbs almost completely all UV radiation below 280 nm, with the absorption of UV light above 280 nm being moderated by stratospheric ozone (O_3). Atmospheric Rayleigh scattering plays a major role in the intensity of the radiation received from the sky, with the shortest wavelengths being scattered more prominently than longer wavelengths with the degree of scatter defined proportionately:

$$\propto \frac{1}{\lambda^4} \qquad (1)$$

For visible light, the sky appears blue due to increased scattering of shorter wavelengths, likewise in the shorter ultraviolet range the degree of scatter is greater than in the visible. Typically, depending on the position of the sun, scattered (or diffuse) skylight makes up about half of the total

Figure 1. Year 11 Hervey Bay State High School Students, Natalie Marsh, Brittney MacDougall, David McKie, and Samantha Dos-Santos photograph and measure global UV and visible light intensity using a personal pocket UV meter and a lux meter.

received UV radiation incident at the Earth's surface, with the remainder coming from direct sunlight. Measurements of the total received UV and visible light therefore contain both a direct (solar beam) and diffuse (skylight) component. Measurements made on a horizontal plane, take both the direct and diffuse components into account. Such measurements are referred to as Global measurements. For the activity presented here, global measurements of UV and visible light are made with sensors held in a horizontal position. The sensors used were an Edison personal pocket UV meter and a lux meter. Both meters are available commercially from electronics suppliers.

Measurements of UV or visible light radiation at the Earth's surface depend on the local environment. Reflections and absorption by various surface objects can reduce or enhance the measured surface radiation and affect the rate at which humans sunburn. Due to variation in absorption, reflection and scatter in both the atmosphere and at the surface, visual perception of brightness has no direct relationship with the received UV. Likewise the feeling of heat due to incoming solar infrared radiation has no bearing on the received short wavelength UV. For these reasons, humans have difficulty in perceiving the UV environment and have no internal mechanism that can be relied upon to determine excessive UV exposure beyond noticing a sunburn which occurs post-exposure.

Measurements made by instruments calibrated to record radiation in the UV waveband are the only reliable way to determine the UV intensity in any given location. Measurements made by the Edison personal pocket UV meter employed for this activity were made in the sunburn weighted UV in units of mW/m^2 to replicate the response of the human sunburn (or erythema) reaction to incident global UV (CIE 1987). Such a measurement is known as an Erythemal Irradiance, and measures the erythemally effective UV incident over a square meter. The received erythemally effective energy can be determined:

$$\frac{mJ}{m^2} = \frac{mW \times s}{m^2} \qquad (2)$$

A Standard Erythema Dose (SED) is further defined as 100 J/m^2 of erythemally effective UV (Diffey et al 1997), where 2 SED is approximately the erythemally effective UV required to cause a mild sunburn in fair skin 8 to 24 hours following the UV exposure (Diffey 1992). Thus the measured unit of mW/m^2 can also be expressed as:

$$\frac{mJ}{m^2} \times \frac{1}{s} = \frac{mSED}{s} \div 100 \qquad (3)$$

This unit conversion is useful and has been employed throughout this activity as measurements are given as the equivalent number of SEDs received per second allowing for a simple calculation to determine the length of time required to receive 1 SED by finding the reciprocal of the determined SED/s. That is, to determine the time to receive 1 SED based on any given global UV measurement made with the personal pocket UV meter:
1. Measure UV irradiance in mW/m² (includes automatic erythema weighting)
2. Convert to mSED/s by dividing by 100
3. Convert to SED/s by dividing by 1000
4. Invert the result to determine the time in seconds required to receive 1 SED

The units used for the measurement of UV irradiance, however are not the same as those used to measure visible light intensity. The reason is due to the measurement of visible light intensity being weighted to the human eye response (photometric response), such that measurements of visible light intensity provide a reasonable estimate of light intensity as seen by the human eye. The unit of visible light intensity is the lux, where 1 lux is the equivalent of 1 lumen / m² of visible light intensity.

Comparisons between UV (radiometric) measurements and visible (photometric) measurements are difficult and cannot be made directly. The two are generally considered separately but are provided here to determine variation in image brightness in the two wavebands. There is no direct relationship that can be found between the two measurements of visible and UV radiation intensity and for this reason, the use of UV meters is required to determine estimates of the local ambient UV. This is an important outcome that students should gain from the activity.

Specifically the aims of this paper are to:
1. Provide students with experience in measuring visible and UV light intensity;
2. Develop an understanding of simple image processing techniques;
3. Compare visible and UV radiation intensity and;
4. Draw conclusions about the local visible and UV environments.

Method
Photographs, being digital or otherwise are made with visible light and cannot easily be taken with standard cameras in the UV light range. The method presented here uses both

measurements of the global visible and global UV intensity to convert standard visible images into UV image estimates. Such a technique is valuable in determining regions of high UV intensity that may not be immediately obvious in visible light. Further, comparisons between visible and UV images highlight variations in the nature of light received at the Earth's surface and emphasise the narrow range of the human eye response.

Visible measurements will be presented here, although they are not required for the successful completion of the activity and may be ignored if the only purpose is to produce UV images. It should also be noted that although a simple image processing technique was applied to digital photographs for this activity, similar results can be achieved using a photograph and overhead transparency film, making the activity easily accessible to large classes that do not have ready access to computers.

Selecting the study site and initial measurements
The activity requires students to photograph a site of interest. This may be a typical playground setting, or an image taken near buildings. Heavily shaded sites should be avoided, as UV measurements may not register. The activity is best suited to groups of three or four students, depending on whether or not visible lux measurements are required. Students will need:
1. A personal UV meter
2. A lux meter (optional)
3. A digital camera
4. Access to computer (or alternatively felt pens and transparency film)
5. Hat and sunscreen protection

Figure 1 shows a group of high school students taking a photograph of a site of interest while on excursion. A standard digital camera with a set infinite focal depth was used in automatic shot mode. Note that while the photograph was being taken, global measurements of the visible and UV were also being recorded. For this activity, it is important to take all measurements within as short a time period as possible to eliminate variations that may be caused by changing cloud conditions. Global measurements should be taken so that the light sensitive areas of each recording instrument are orientated in a horizontal position and held as far from the body as possible to eliminate shadow and increase instrument sensitivity to the sky view at the location.

Processing the image
Following the initial measurements, both lux meter and UV meter readings were taken with instrument sensors oriented toward the approximate middle top, bottom, left and right

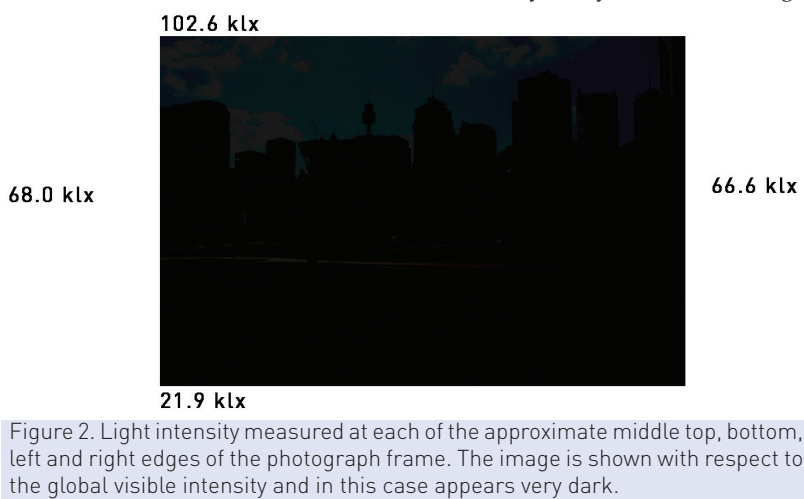**102.6 klx**

68.0 klx

66.6 klx

21.9 klx

Figure 2. Light intensity measured at each of the approximate middle top, bottom, left and right edges of the photograph frame. The image is shown with respect to the global visible intensity and in this case appears very dark.

	1	2	3	4	5	6	7	8	9
A	102.6	102.6	102.6	102.6	*102.6*	102.6	102.6	102.6	102.6
B	94.0	93.9	93.9	93.8	93.8	93.7	93.7	93.6	93.6
C	85.3	85.2	85.1	85.0	85.0	84.9	84.8	84.7	84.6
D	76.7	76.5	76.4	76.3	76.1	76.0	75.9	75.7	75.6
E	*68.0*	67.8	67.7	67.5	67.3	67.1	67.0	66.8	*66.6*
F	56.5	56.3	56.2	56.1	56.0	55.8	55.7	55.6	55.4
G	45.0	44.9	44.8	44.7	44.6	44.5	44.4	44.3	44.3
H	33.4	33.4	33.3	33.3	33.3	33.2	33.2	33.1	33.1
I	21.9	21.9	21.9	21.9	*21.9*	21.9	21.9	21.9	21.9

Table 1a. Interpolated light intensity matrix for each numeric horizontal image position and alpha-numeric vertical image position based on the measurements in figure 2. The bold Italic numbers are actual measurements. The units of measurement are klx.

frame regions of the taken photograph. The sensors need to point toward the frame regions of the photograph and are not global measurements in this case. Typically frame measurements will be lower than the global measurements taken previously.

In some cases, frame measurements may be higher than the recorded global measurements. This may be due to changing atmospheric conditions or frame orientations being taken closer to the direct solar beam. This will not affect the results and such measurements should be accepted. Figure 2 shows the photograph taken in figure 1, with lux measurements taken oriented toward the photograph frame edges. Units are given in kilolux. For later comparison with the UV image the visible image brightness requires adjustment with respect to the global visible lux measurement. For the case shown, the maximum image brightness was recorded at 102.6 klx (image top) compared with a global measurement of 970 klx, therefore the image brightness was reduced by 89% to depict the scene relative to the global visible measurement and the image appears darker than the scene would have appeared originally. Image adjustment can be performed by adjusting the brightness setting using any digital image software. In the figure 2 image, the city skyline can just be

	1	2	3	4	5	6	7	8	9
A	11	11	11	11	*11*	11	11	11	11
B	10	10	10	10	10	10	10	10	10
C	9	9	9	9	9	9	9	9	9
D	8	8	8	8	8	8	8	8	8
E	*7*	7	7	7	7	7	7	7	*7*
F	6	6	6	6	6	6	6	6	6
G	5	5	5	5	5	5	5	5	5
H	3	3	3	3	3	3	3	3	3
I	2	2	2	2	*2*	2	2	2	2

Table 1b. Interpolated light intensity matrix expressed as a percentage of the measured global visible light intensity (970 klx) for the interpolated intensity estimates of table 1a.

made out. In some cases image brightness may need to be increased depending on the maximum image brightness with respect to the measured global visible intensity.

The visible measurements recorded above provide an indication of the light intensity received by the camera when the picture was taken. The image was then divided into even areas or segments and the approximate light level given for each segment. Although only four measurements are provided here, additional measurements could be taken oriented within the photograph frame, to supplement the frame measurements and improve accuracy in subsequent segment averaging. For the data presented here, the image was divided into a 9 by 9 segment grid. Simpler grids could also be used. In table 1a, it was assumed that the light intensity would be the same across the entire top and bottom of the image, therefore these segments are all of the same value. The left and right frame edges were interpolated vertically. All inner segments were then interpolated horizontally from the left and right frame edge interpolations. The method of interpolation is left to individual teachers, with a simpler averaging technique being perhaps more beneficial to lower year levels and more complex techniques being suited to senior students. Obviously different results can be achieved for different

102.6 klx

8.0 klx
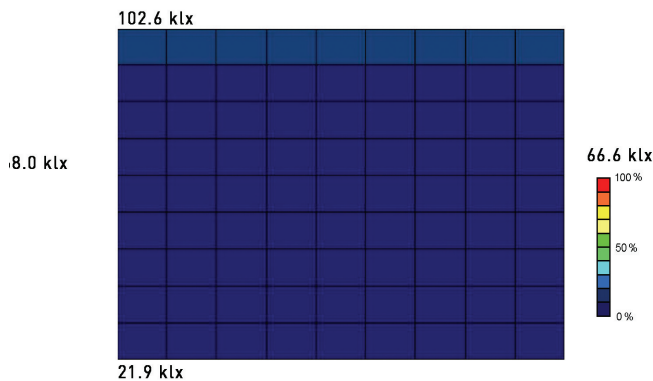
66.6 klx
100 %

50 %

0 %

21.9 klx

Figure 3. Visible intensity divided over a 9 by 9 element matrix. Colour levels are determined as a percentage of the global visible light intensity and are listed in table 1b. The coloured matrix indicates regions of greatest brightness relative to the received global intensity for the location photographed in figure 2 which for this case was below 11 %.

1.88 mSED/sec

1.59 mSED/s
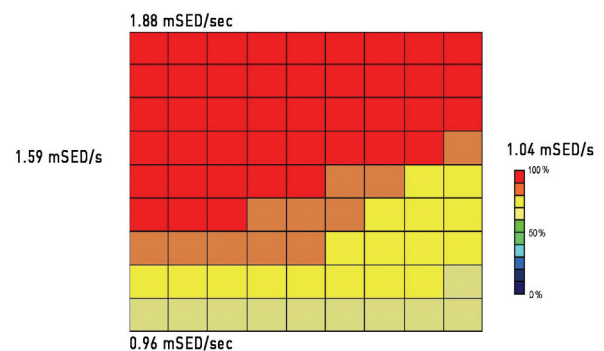
1.04 mSED/s
100 %

50 %

0 %

0.96 mSED/sec

Figure 4. UV intensity for the location photographed in figure 2 divided over a 9 by 9 element matrix. Colour levels are determined as a percentage of the global UV measurement and are listed in table 2b.

	1	2	3	4	5	6	7	8	9
A	1.88	1.88	1.88	1.88	*1.88*	1.88	1.88	1.88	1.88
B	1.81	1.79	1.77	1.76	1.74	1.72	1.70	1.69	1.67
C	1.74	1.70	1.67	1.63	1.60	1.56	1.53	1.49	1.46
D	1.66	1.61	1.56	1.51	1.46	1.41	1.35	1.30	1.25
E	*1.59*	1.52	1.45	1.38	1.32	1.25	1.18	1.11	*1.04*
F	1.43	1.38	1.33	1.28	1.23	1.18	1.12	1.07	1.02
G	1.28	1.24	1.21	1.17	1.14	1.10	1.07	1.03	1.00
H	1.12	1.10	1.08	1.07	1.05	1.03	1.01	1.00	0.98
I	0.96	0.96	0.96	0.96	*0.96*	0.96	0.96	0.96	0.96

Table 2a. Interpolated UV intensity matrix for each numeric horizontal image position and alpha-numeric vertical image position based on measurements made by the personal pocket UV meter at the approximate middle top, bottom, left and right edges of the photograph frame of figure 2 (Units of measurement are mSED/s).

methods of interpolation. This may be useful to trial with different student groups for further discussion.

Image segments were then converted into percentages relative to the received global lux measurement. For the case shown the received global measurement was 970 klx.

The light intensities in each interpolated segment of table 1a were then expressed as percentages of this measurement (table 1b).

Estimated segment percentages can be expressed as specific colours on the 9 by 9 (or appropriately selected) grid. Note that the grid selected should match the dimensions of the printed photograph, allowing for easy comparison with the image. This can be done using a prepared grid and computer or performed more simply using a segment grid drawn onto overhead transparency film. The grid was divided into 10 % colour levels. Depending on the desired detail, finer colour levels could be chosen. A coloured representation of the visible image brightness of the figure 2 image is shown in figure 3. Note that higher image brightness occurs along the top of the image as expected with decreasing brightness found toward the bottom of the photograph. This is to be expected as visible light intensity decreases with absorption by surface objects. For this case there is little variation in visible brightness as is evident in table 1b. The coloured analysis is however a good representation of the photograph's changing brightness levels with respect to the measured global visible intensity.

	1	2	3	4	5	6	7	8	9
A	131	131	131	131	*131*	131	131	131	131
B	126	125	124	123	122	120	119	118	117
C	121	119	117	114	112	109	107	105	102
D	116	113	109	105	102	98	95	91	87
E	*111*	106	102	97	92	87	82	78	*73*
F	100	97	93	89	86	82	79	75	71
G	89	87	84	82	80	77	75	72	70
H	78	77	76	75	73	72	71	70	69
I	67	67	67	67	*67*	67	67	67	67

Table 2b. Interpolated UV intensity matrix as a percentage of the measured global UV (1.43 mSED/s) and interpolated intensity estimates of table 2a.

The process is repeated for measurements made in the UV. Note that meter readings presented here were converted to mSED/s. This is a convenient unit to use as the time to receive an exposure of 1 SED is easily calculated. The time for an equivalent exposure of 1 SED for the location and time in figure 2 was calculated as follows:
Global measurement of UV: 143 mW/m² = 1.43 mSED/s
Global time for 1 SED = 1 / (1.43x10⁻³) = 699 s = 12 mins

Such a calculation is a suitable way of evaluating the UV in each photographed environment. Processed images were then compared with this value to show locations within the image of high UV intensity. To calculate the UV irradiances over the image, tables 2a and 2b were produced. Figure 4 is the estimated image segment percentages relative to the received global UV.

Using a similar process to that used to produce the figure 4, the visible photograph can be further divided into a 9 by 9 segment grid and the brightness of individual segments adjusted according to the percentage levels given in table 2b. Figure 5 represents the same location photographed in figure 2 as it might appear in UV light. Individual image segments were adjusted in brightness according to the percentage levels provided in table 2b using a simple cut and past method that can be replicated with standard photo-adjustment software.

1.88 mSED/s

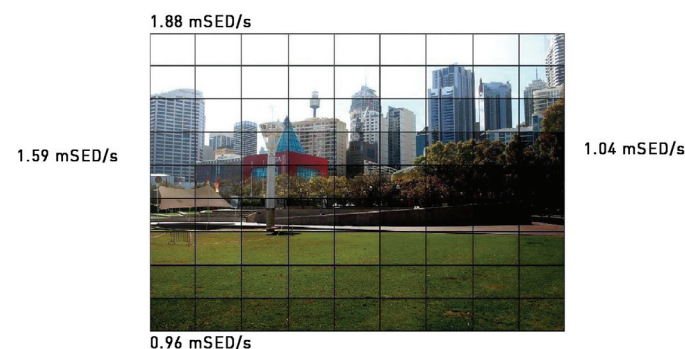1.59 mSED/s

1.04 mSED/s

0.96 mSED/s

Figure 5. Estimated UV intensity imaged over a 9 by 9 element grid. The relative brightness of each element was determined by adjusting element brightness according to the percentages listed in table 2b. The image is an estimate of what the above location might look like in UV light and highlights regions of greatest UV intensity.

Discussion

The technique that has been presented here allows visible images to be converted with the use of real UV measurements into UV intensity estimates in a scene to provide a permanent visual record of the UV intensity. Comparisons between the UV intensity and visible image brightness can also be made. Images of the UV environment
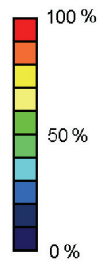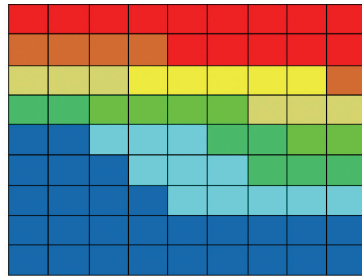
Figure 6. Near Building: Top left: visible photograph, top right: light intensity as a percentage of the measured global visible intensity (7.6 klx), bottom left: UV image, bottom right: UV intensity as a percentage of the measured global UV (1.06 mSED/s)
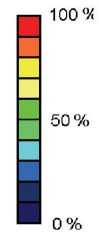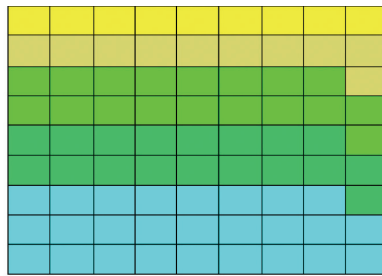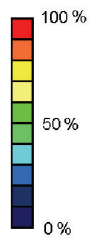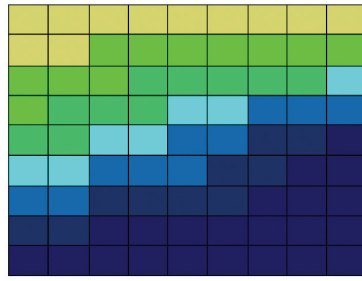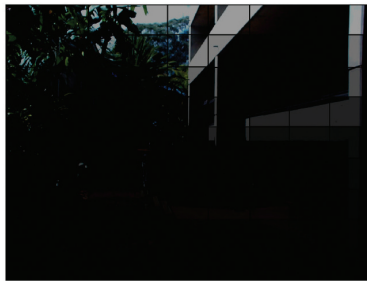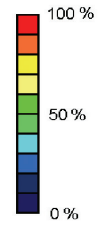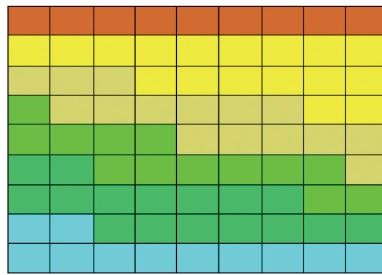

Figure 7. Tree shaded area: Top left: visible photograph, top right: light intensity as a percentage of the measured global visible intensity (33.2 klx), bottom left: UV image, bottom right: UV intensity as a percentage of the measured global UV (0.73 mSED/s)

are possible for a variety of different settings and locations. Figures 6 and 7 highlight variation in the visible and UV environment near buildings and in a lightly shaded environment. Both the figures show variation in the distribution of UV intensity compared with visible measurements. Regions of high UV intensity are indicated by higher brightness levels in photograph segments. For the cases shown here, UV intensity near the building site appears darker than the corresponding photographed visible image, while for the tree shade site, UV intensity is higher (brighter) than its respective visible image. However, comparing with global measurements of the UV, the environment photographed near the building recorded a higher UV intensity compared to the tree shade location. This indicates that image brightness is solely an indicator of the UV intensity at each specific location and should not be taken as an absolute indicator of the UV intensity in each environment for direct comparison. That is, UV images taken in different locations should not be directly compared to each other as images are shown relative to the respective global UV measurement recorded at each site.

Further detail of each environment could be examined by photographing each location in a series of photographs taken at the same site facing different directions. In this case, UV images could be directly compared with each other provided location images were shown relative to the same global UV measurement recorded at a particular site.

Conclusions
- A technique has been developed to present visible photographic images in UV light using measurements of UV and visible radiation.

- The activity enables students to evaluate both the visible and UV radiation intensity and draw conclusions about the local environment and its potential to cause harm due to excessive UV exposure.

- The activity provides students with an understanding of simple image processing techniques and has been designed to supplement the high school science curriculum studies of environmental and physical sciences and can further benefit students studying computational and statistical methods.

Acknowledgements

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Nathan Downs is a professional engineer, teacher and PhD research candidate at the University of Southern Queensland. His primary research interests include modelling the environmental solar ultraviolet.
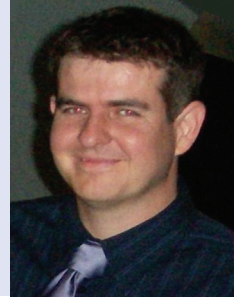
Alfio Parisi

Alfio Parisi is an associate professor in the Faculty of Sciences at the University of Southern Queensland. His research interests include developing techniques to better understand the solar ultraviolet environment that humans are exposed to during their normal daily activities.