HONG KONG OBSERVATORY

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SOLAR ULTRAVIOLET INDEX IN HONG KONG

1999 - 2003

by

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摘要

本報告簡介香港太陽紫外線指數的測量及列舉每日及每小時紫外線指數的統計分析結果。研究顯示紫外線指數具有明顯的季節與日際變化，日與日之間的波動亦頗大。季節變化和日際變化均與太陽的仰角有關。每日平均及最高紫外線指數的季節平均最大值均在夏季出現。日際變化方面，中午至下午一時的每小時紫外線指數在每季中都是最高。日與日之間紫外線的變化主要受本地的因素影響，例如雲的覆蓋、空氣微粒和臭氧等都會令到達地面的紫外線減弱，因而降低紫外線指數。

Abstract

This report introduces the measurement of solar UV Index in Hong Kong and presents the results of statistical analysis on the daily and hourly UV Indices. It was found that there were distinct seasonal and diurnal variations as well as significant day-to-day fluctuations in the UV Index. Solar elevation accounts for both the seasonal and diurnal variations. The highest seasonal averaged values of the daily mean and the daily maximum UV Indices were both attained in the summer months. Diurnally, the hourly UV Index was the highest between noon to 1 p.m. in all seasons. Local conditions such as cloud cover, aerosol and total ozone contribute to the day-to-day fluctuations in the UV Index by reducing the intensity of UV radiation from reaching the ground.

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1. Introduction

Solar ultraviolet (UV) radiation has significant effects on both the atmosphere and human beings. The absorption of UV radiation is the main reason for the increase of air temperature in the stratosphere. At ground-level, excessive exposure to UV radiation may bring about health effects such as painful sunburns, wrinkling and premature ageing of the skin as well as the increased risk of developing skin cancers and cataracts. Since the early 1970s, a marked increase in skin cancers has been observed in populations worldwide and about 80% of skin cancers may be attributable to excessive exposure to sunlight (World Health Organization (WHO), 2002a). WHO also estimates that up to 20% of cataracts are caused by UV over-exposure.

To raise the public awareness on the potential harm of UV radiation, the Hong Kong Observatory (HKO) installed an instrument at the King's Park meteorological station for measuring UV Index and launched a UV Index Advisory Service in 1999 to provide the information on the intensity of solar UV radiation in Hong Kong.

This report documents the measurement of UV Index in Hong Kong from August 1999 to July 2003, provides a statistical analysis and a climatological description on the recorded daily and hourly UV Indices, and discusses astronomical and meteorological factors affecting the UV Index. Section 2 provides the background information of UV radiation, and how the UV Index is defined and measured in Hong Kong. The results on the statistical analysis of the daily mean and maximum UV Indices as well as the hourly mean UV Index are presented in Section 3. The astronomical and meteorological factors that may affect the UV Index are discussed in Section 4. Section 5 compares the erythemally weighted UV radiation with the total solar radiation measured in Hong Kong. Conclusions are given in Section 6.

2. Measurement of UV Index

2.1 UV Index and its derivation

Within the spectrum of solar radiation, UV is a form of electromagnetic wave with wavelength ranging from 100 nm to 400 nm and can be classified into three bands: UV-A (315-400 nm), UV-B (280-315 nm) and UV-C (100-280 nm). As sunlight passes through the atmosphere, all the UV-C and about 90% of the UV-B are absorbed by various gaseous components such as ozone and water vapour in the atmosphere. Of the UV radiation reaching the surface of the Earth, most of it comes in the form of UV-A.

UV-B is most damaging to human health. Human skin has different sensitivity to different wavelengths of UV radiation. The International Commission on Illumination (CIE) adopted the erythemal action spectrum shown in Figure 1 to represent the average skin response to different wavelengths of UV radiation. The erythemal action spectrum is a composite curve obtained by statistical analysis of many research results on the response of many different types of human skin to UV radiation (Long *et al*., 1996). In Figure 1, the erythemal weighting factor, representing the damaging effect to human skin, is in log scale. It shows that the damaging effect of UV-B is much larger than that of UV-A.

In order to measure the potential harm of UV radiation on the human skin, an index called the solar UV Index was defined. Definition of the UV Index and its derivation were standardized by the World Health Organization (WHO), the World Meteorological Organization (WMO), the United Nations Environment Programme (UNEP), the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the German Federal Office for Radiation Protection (World Meteorological Organization, 1997). UV index, I_{UV} , is formulated by using the CIE's erythemal action spectrum and is given by the equation:

$$I_{UV} = k_{er} \int_{250}^{400} E_{\lambda} S_{er}(\lambda) d\lambda$$

where λ is the wavelength in nanometer, E_{λ} the UV irradiance in Watt/(metre^2 nanometre) at wavelength λ, $S_{er}(\lambda)$ the weighting factor at wavelength λ in the erythemal action spectrum, and k_{er} a constant equal to 40 metre^2/Watt (World Health Organization, 2002a).

Some organizations calculate the UV Index by carrying out integrations from 280 nm instead of 250 nm. The two integrations are practically the same as radiation of wavelengths from 250 nm to 280 nm are all absorbed by the atmosphere without reaching the ground.

In general, the higher the UV Index the more likely will be the damage to the human body. The World Health Organization (2002a) classifies the UV Index as “Low”, “Moderate”, “High”, “Very High” and “Extreme” based on the UV Index values (Table 1). This definition is adopted for use in Hong Kong.

2.2 Instrumentation and measurement

The measurement of the UV Index can be made by two approaches. The first method is to use a spectroradiometer to measure UV irradiances at different wavelengths and then calculate the UV Index by applying the formula stated in Section 2.1. The second method is to use a broadband detector that has been calibrated and programmed to output the UV Index directly.

The Hong Kong Observatory employs the second method and uses a Yankee Environmental Systems broadband UVB-1 ultraviolet pyranometer (Figure 2) for measuring the UV Index in Hong Kong. The pyranometer is sited at the King’s Park meteorological station (latitude

22°19'N, longitude 114°10'E), an urban site of altitude 65 m above mean sea level. This kind of instrument has been employed in UV Index measurements in various countries. It measures the global solar UV-B irradiance or power per unit area of UV-B radiation received by a horizontal surface from the entire hemisphere of the sky. This includes both the UV radiation transmitted directly through the atmosphere and that scattered by atmospheric gases and aerosols. UV-A radiation is not measured since its erythemally weighted irradiance is very small compared to UV-B.

The UVB-1 pyranometer makes use of a fluorescent phosphor to convert incoming UV-B radiation to visible light, which in turn is measured by a solid state photodiode to output a voltage. The pyranometer has a spectral response similar to the CIE's erythemal response spectrum and gives the total erythemally weighted UV irradiance in Watt/metre^2 with an accuracy of ±4% for solar elevation angle larger than 25 degrees (Yankee Environmental Systems, 1997). The UV Index is then obtained by multiplying this erythemally weighted UV irradiance by 40. Details of the principle of operations of the pyranometer and the radiative transfer calculations used to convert the output voltage to the erythemally weighted UV irradiance are given in Dichter *et al*. (1993).

Figure 3 shows the data flow in the HKO's UV Index observation and dissemination system. The pyranometer is interfaced with a data logger which stores raw voltage outputs from the pyranometer. The voltage signal is extracted every 5 minutes by a software installed on a personal computer at the King's Park meteorological station. The voltage readings are then transmitted via the personal computer to HKO's main computer system where it is converted to the 5-minute mean UV Index. The 5-minute UV Index values are used to compute the 15-minute mean, the hourly mean, the daily mean and the daily maximum values of the UV Index for dissemination to the public through the HKO's website and the broadcasting media. To ensure data availability, a redundant observation system has also been installed at King's Park to serve as a hot back up.

3. Statistical analysis of UV Index

Daily and hourly UV Indices have been recorded by HKO since August 1999. Statistical analysis was carried out on 4 years of UV Index data collected between August 1999 and July 2003. In the present study, spring refers to the months from March to May, summer from June to August, autumn from September to November and winter from December to February.

3.1 Daily UV Index

There are two types of daily UV Index records, the daily mean UV Index (DMEAN) and the daily maximum UV Index (DMAX). DMEAN for a given day is defined as the averages of all the 15-minute mean UV Index values between 7 a.m. and 6 p.m. in the day while DMAX refers to the maximum of all the 15-minute mean UV Index values recorded during the period on that day.

The daily values of DMEAN and DMAX for the whole period from August 1999 to July 2003 are shown in Figure 4 and 5. Clear seasonal cycles can be seen from the two figures. In both DMEAN and DMAX, maximum values were attained in summer. DMEAN and DMAX for the same day and month but averaged over the 4-year period from August 1999 to July 2003 were also computed respectively. Figure 6 and 7 show the annual variation of the daily and monthly mean values of DMEAN and DMAX respectively. Seasonal variations as well as large day-to-day fluctuations of both DMEAN and DMAX are shown.

A summary of the monthly statistics of DMEAN and DMAX can be found in Table 2 and 3. Individual daily values of DMEAN ranges from 0.28 to 7.24 while that of DMAX ranges from 0.74 to 15.36. Maximum values of both monthly mean DMEAN and DMAX were attained in July while minimum values in January. This seasonal variation is primarily due to the difference in solar elevation angle which determines the length of atmospheric attenuation of the solar UV radiation in different seasons and the amount of radiation incident on the Earth's surface, and thus the solar UV irradiance on the Earth's surface. The day-to-day variability is mainly due to meteorological factors, such as cloud cover, aerosol and ozone etc., and will be discussed in Section 4.

The ten highest DMEAN and DMAX occurring during the period under study are shown in Table 4 and 5. The ten highest DMEAN were all recorded in the summer months of July and August. The ten highest DMAX occurred in late spring and summer months between May and August, all recorded shortly after noon time. The highest DMEAN and DMAX on record are 7.24 and 15.36, recorded on 7 July 2003 and 23 July 2003 respectively.

The frequency distributions of DMEAN and DMAX in different exposure categories are shown in Table 6 and 7 as well as in Figure 8. For operational use, the UV Index is rounded off to the nearest integer if it is greater than 1 before classifying according to exposure categories. From Figure 8, it can be seen that DMEAN was "Low" and "Moderate" on about 92% of the time and was never "Very High" or "Extreme". For DMAX, about 44% is "Extreme" or "Very High" (17% for "Extreme" and 27% for "Very High"). From Table 6 and 7, the "High" cases in DMEAN and the "Extreme" cases in DMAX were mostly attained during summer months and never occurred in winter months.

3.2 Hourly UV Index

Hourly mean UV Index is taken as the average of the four 15-minute mean UV Index values in the past hour. The annual and seasonal averaged values of the hourly mean UV Index are shown in Figure 9. The figure indicates clearly the diurnal variation of the Index. For all seasons, the hourly mean UV Index at 1 p.m. was the highest. It is due to the fact that during the period from noon to 1 p.m., the solar elevation in Hong Kong reaches its maximum. A summary of the hourly mean UV Index statistics for different seasons can be found in Table 8. It can be seen that the hourly mean UV Index observed at 1 p.m. ranges from 0.08 to 13.79 for the period under study. Seasonal values range from 0.20 to 12.95 in spring, 0.08 to 13.79 in summer, 0.40 to 11.80 in autumn and 0.50 to 8.56 in winter.

4. Astronomical, meteorological and other factors affecting UV Index

Long *et al*. (1996), Mantis *et al*. (2000) and the World Health Organization (2002a) listed out some factors that may influence UV radiation level. These elements are discussed below.

4.1 Sun elevation

In general, the higher the sun in the sky, the higher the UV radiation level will be. Hence, the UV Index depends on the solar elevation angle which varies with the solar time of day and also time of year. The diurnal and seasonal variations of the UV Index in Hong Kong have been presented in Section 3. Figure 10 shows a three dimensional plot of hourly mean UV Index averaged for different months. Maximum values of UV Index occurred at 1 p.m. and in the summer month of July. Similar diurnal and seasonal variations were observed in many other places such as Macau, Taiwan, Canada and the United States. Spatially, the UV Index for a given place depends also on its latitude. Generally speaking, for regions closer to the Equator, in other words with higher solar zenith angle, higher UV Indices are expected.

4.2 Cloud cover

Made up of water droplets, clouds absorb, reflect and scatter portions of incoming UV radiation, reducing the amount reaching the ground. Scatter diagrams showing the relationship between the daily mean UV Index and the corresponding daily mean cloud amount for the four seasons is given in Figure 11. The correlations for spring, summer, autumn and winter are -0.58, -0.66, -0.47 and -0.60 respectively. All these correlations are statistically significant at 5% level indicating that in general, the greater the cloud amount, the lower the UV Index. It is interesting to note from Figure 11 that the UV Index drops rapidly for all seasons as the cloud amount increases to over 85%.

Apart from cloud amount, UV irradiance also depends strongly on cloud types (Bais *et al*., 1993). In general, attenuation of UV radiation by cirrus is weak. On some occasions, broken clouds can enhance the intensity of UV radiation by reflection from their sides (Madronich, 1993). This effect was observed on 15 May 2000. Between 9 a.m. and 6 p.m. on that day, there were 1 okta to 2 oktas of cumulus and 3 to 5 oktas of altocumulus. The visibility at the Observatory stayed above 13 kilometres and 9.5 hours of sunshine were recorded. On 16 May 2000, it was fine apart from a few cumulus clouds (mostly 1 okta) and the sky became cloudless after 4 p.m. The visibility at the Observatory was above 14 kilometres and there were 11.7 hours of sunshine. Despite more cloud amount and less sunshine hours on 15 May 2000 as compared with that on 16 May 2000, the UV Index rose to a maximum of 12.9, which is higher than 10.2 on the sunny day of 16 May 2000 by more than 20%.

4.3 Aerosol

Surface UV irradiance and hence the UV Index can be reduced by atmospheric aerosols through absorption, reflection and scattering. Aerosols can also play an indirect role in the attenuation of UV intensity through an increase in cloud lifespan, amounts and albedo.

As an illustration, during a sunny day on 18 August 1999, the UV Index rose to over 10 near noon time (Figure 12a). The mean cloud amount for that day was 4 oktas and the visibility at HKO was 16 kilometres or above during the day. The following day was a hazy day with the mean cloud amount (3 oktas) nearly the same as the day before but the visibility dropping to around 7 kilometres during day-time under light wind conditions. The UV Index on that day only rose to about 6 near noon time (Figure 12b), a reduction of over 40% compared with the previous day.

4.4 Atmospheric ozone

Ozone is the atmospheric constituent which dominates UV depletion. It absorbs some of the erythemal UV radiation that would otherwise reach the ground.

As a contribution to the World Meteorological Organization's (WMO) Global Atmospheric Watch (GAW) programme, HKO has been launching ozonesondes at King's Park since October 1993. Details of the ozonesonde operations can be found in Shun and Leung (1993). Total ozone over Hong Kong can be obtained from the ozone profile by integrating ozone concentrations with height or pressure. To ensure that ozone throughout the depth of the atmosphere was included as far as possible for the computation of total ozone, only flights that reached 30 km or above are used. In the computation, the amount of ozone above balloon-burst altitude is estimated by extrapolating the ozone mixing ratio at burst altitude to the top of the whole atmosphere. Details of the computation can be found in Leung *et al*. (2003).

To demonstrate the relationship between ozone concentration and the UV Index, two one-hour time intervals of quite different total ozone levels were selected for which the solar elevations were similar, visibilities were greater than 15 km and the cloud amounts were low in both instances (Table 9), thereby minimizing respectively the possible impact of astronomical and meteorological factors on the UV Index. As given in Table 9, total ozone levels were 247.1 Dobson Units (DU) on 18 August 1999 and 345.1 DU on 17 May 2000. The corresponding hourly total erythemally weighted UV radiation doses were 999 Joule/metre^2 and 729 Joule/metre^2 respectively. These observations show that a decrease of 1% in total ozone contributes to an increase of erythemally weighted UV radiation dose by about 1.3%. This result is compatible with the value of 1.37% observed in Mauna Loa, Hawaii (Climate Monitoring and Diagnostics Laboratory, 1996), whose latitude is similar to Hong Kong.

The above discussion serves only as an example of the effect of total ozone on the erythemally weighted UV radiation or the UV Index. The relationship between total ozone and the UV Index under clear sky condition can best be studied by using an advanced radiative transfer model such as those adopted by the National Weather Services of the United States (Long *et al*., 1996), which is beyond the scope of this study.

4.5 Altitude and ground reflection

At higher altitudes, the atmosphere is thinner and hence less UV radiation is absorbed by the atmosphere. In general, dose of erythemally weighted UV radiation increases by 6% per kilometer increase in altitude (U.S. National Weather Service, 2004).

UV radiation is reflected or scattered in varying degree by different surfaces. Snow can reflect as much as 80%, beach sand 15%, grass, soil and water less than 10% of the UV radiation (World Health Organization, 2002b). As a result, the UV Index is higher for surfaces covered with snow or beach sand.

5. Comparison between erythemally weighted UV radiation and global solar radiation

UV Index is a measure of the intensity of erythemally weighted UV radiation and hence the UV Index collected can be used to determine the amount of erythemally weighted UV radiation energy in Hong Kong. Daily mean UV Index can be converted easily to the daily dose of erythemally weighted UV radiation in Joule/metre^2 by dividing the daily mean UV Index by 40 and then multiplying it by 39,600 (the number of seconds from 7 a.m. to 6 p.m.). It is interesting to compare the daily dose of erythemally weighted UV radiation with that of global solar radiation to see how large the portion of solar radiation energy contributes to erythema. Data for the daily total global solar radiation measured at King's Park are also available from HKO for analysis. Details of the measurement on global solar radiation in Hong Kong can be found in Lau (1989).

Figure 13 shows the very high positive correlation (r = 0.93, significant at 5% level) between the daily mean UV Index (or the daily total erythemally weighted UV radiation) and the daily total global solar radiation. The variation of the ratio "daily total erythemally weighted UV radiation to daily total global solar radiation" against daily total global solar radiation is shown in Figure 14. It can be seen that this ratio lies mainly between 1.3×10^{-4} and 3.5×10^{-4}. This range is the same in the lower limit but about twice as much in the upper limit when compared with the range 1.3×10^{-4} to 1.6×10^{-4} observed in Greece (Mantis *et al.*, 2000). The ratio generally decreases (though only slightly on average) as the daily total global solar radiation increases up to about 15 MJ/m^2, but generally increases for total solar radiation greater than 15 MJ/m^2. Similar decreasing trend in the ratio was found in Valencia, Spain for total solar radiation up to about 15 MJ/m^2 (Martinez-Lozano and Casanovas, 1994). Martinez-Lozano and Casanovas (1994) concluded that cloud cover reduces global solar radiation more than solar UV radiation, and this is due to absorption by water vapour being much stronger in the near infra-red region than in the shorter wavelengths.

6. Conclusion

The instrumentation and methodology used by the Hong Kong Observatory in the observation of UV Index for Hong Kong were described. Statistical analysis of the UV index data was carried out and results showed that there were marked seasonal and diurnal variations as well as large day-to-day fluctuations in the UV Index.

Seasonal and diurnal variations of UV Index are related to the elevation of the sun in the sky for which larger UV Index will be attained for higher elevation. The highest seasonal averaged values of the daily mean and the daily maximum UV Indices were both attained in the summer months while the lowest were attained in the winter months. The ten highest daily mean and daily maximum UV Index were all recorded in late spring and summer between May to August. In exposure categorization, the daily mean UV Index was classified as “Low” and “Moderate” on over 90% of the time and was never “Very high” or “Extreme”. For the daily maximum UV Index, about 40% was “Very high” or “Extreme” and the “Extreme” cases were mostly attained during summer months and never occurred in winter months. Diurnally, seasonal averaged values of the hourly mean UV Index was the highest between noon to 1 p.m. in all seasons. The ten highest daily maximum UV Index were also recorded between noon and 1 p.m.

Factors such as cloud cover, aerosol and ozone contribute to the day-to-day fluctuations in both the daily mean and the daily maximum UV Index. These factors generally modulate the UV radiation reaching the ground and extensive cloud cover, high aerosol and ozone concentrations contribute to the lowering of the UV Index.

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Table 1. UV Index and the corresponding exposure level as categorized by the World Health Organization (WHO).

UV Index	Exposure level
0–2	Low
3–5	Moderate
6–7	High
8–10	Very high
≥ 11	Extreme

Table 2. A summary of the monthly statistics of daily mean UV Index (DMEAN).

Month	Mean	Standard deviation	Range
Jan	1.81	0.66	0.36–2.90
Feb	2.25	0.99	0.40–4.16
Mar	2.53	1.14	0.40–4.90
Apr	2.78	1.58	0.35–6.20
May	3.83	1.48	0.60–6.60
Jun	3.77	1.80	0.28–6.70
Jul	4.38	1.78	0.40–7.24
Aug	3.76	1.73	0.31–6.90
Sep	3.32	1.32	0.40–6.10
Oct	2.92	0.98	0.30–4.50
Nov	2.35	0.72	0.40–3.80
Dec	1.84	0.60	0.40–3.00

Table 3. A summary of the monthly statistics of daily maximum UV Index (DMAX).

Month	Mean	Standard deviation	Range
Jan	4.42	1.36	1.20–6.70
Feb	5.61	1.98	1.00–8.63
Mar	6.35	2.43	0.98–11.02
Apr	7.00	3.19	1.24–12.60
May	9.02	2.75	1.00–13.89
Jun	8.93	3.33	1.20–13.90
Jul	10.05	2.93	1.60–15.36
Aug	8.97	3.18	1.02–13.70
Sep	8.00	2.45	1.60–12.40
Oct	7.07	2.00	0.74–10.50
Nov	5.61	1.47	1.20–8.30
Dec	4.54	1.24	1.20–6.90

Table 4. The ten highest daily mean UV Index (DMEAN) recorded from 1 August 1999 to 31 July 2003.

Rank	Daily mean UV Index	Recorded on
1	7.24	7 July 2003
2	7.23	13 July 2003
3	7.2*	13 July 2000
4	7.13	3 July 2003
5	6.97	5 July 2003
6	6.95	14 July 2003
7	6.93	16 July 2003
8	6.9*	1 August 1999
9	6.85	17 July 2003
10	6.84	15 July 2003

* UV Index data are in one decimal place before 1 August 2002.

Table 5. The ten highest daily maximum UV Index (DMAX) recorded from 1 August 1999 to 31 July 2003.

Rank	Daily maximum UV Index	Recorded on	Time recorded
1	15.36	23 July 2003	12:30-12:45
2	14.04	12 July 2003	12:45-13:00
3	13.9*	17 June 2001	12:15-12:30
4	13.90	30 June 2003	12:45-13:00
5	13.89	15 May 2003	12:45-13:00
6	13.7*	5 August 2001	12:15-12:30
7	13.67	13 May 2003	12:45-13:00
8	13.64	9 July 2003	12:00-12:15
9	13.51	14 May 2003	12:45-13:00
10	13.45	7 July 2003	12:30-12:45

*UV index data are in one decimal place before 1 August 2002.

Table 6. Frequency distribution of daily mean UV Index (DMEAN) in different exposure categories and months (1 August 1999 - 31 July 2003).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Percentage
Low (UV Index 0-2)	101	63	58	58	23	32	24	31	30	33	57	110	620	42.70%
Moderate (UV Index 3-5)	22	49	66	57	83	61	60	65	83	91	63	14	714	49.17%
High (UV Index 6-7)	0	0	0	5	18	27	40	25	3	0	0	0	118	8.13%
Very High (UV Index 8-10)	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00%
Extreme (UV Index ≥11)	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00%

Table 7. Frequency distribution of daily maximum UV Index (DMAX) in different exposure categories and months (1 August 1999 - 31 July 2003).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Percentage
Low (UV Index 0-2)	16	12	12	10	3	7	3	10	4	5	8	11	101	6.96%
Moderate (UV Index 3-5)	77	32	30	34	13	16	10	8	17	20	33	87	377	25.96%
High (UV Index 6-7)	30	43	35	20	16	15	12	13	18	31	74	26	333	22.93%
Very High (UV Index 8-10)	0	25	45	35	52	29	28	39	65	67	5	0	390	26.86%
Extreme (UV Index ≥11)	0	0	2	21	40	53	71	51	12	1	0	0	251	17.29%

Table 8. A summary of the hourly statistics of UV Index (1 August 1999 – 31 July 2003).

	Spring			Summer			Autumn			Winter			Annual		
Hour	Mean	Standard deviation	Range	Mean	Standard deviation	Range	Mean	Standard deviation	Range	Mean	Standard deviation	Range	Mean	Standard deviation	Range
8 am	0.40	0.31	0.00–1.20	0.69	0.32	0.00–1.30	0.34	0.19	0.00–0.80	0.07	0.05	0.00–0.20	0.37	0.33	0.00–1.30
9 am	1.26	0.80	0.00–3.55	1.94	0.92	0.00–3.50	1.26	0.59	0.06–2.60	0.52	0.24	0.00–1.20	1.25	0.85	0.00–3.55
10 am	2.64	1.58	0.10–7.17	3.72	1.82	0.08–6.77	2.75	1.23	0.00–5.80	1.45	0.65	0.10–3.00	2.64	1.61	0.00–7.17
11 am	4.18	2.32	0.30–10.06	5.61	2.76	0.09–9.99	4.40	1.88	0.10–9.30	2.68	1.18	0.10–5.41	4.22	2.36	0.09–10.06
noon	5.37	2.96	0.10–12.28	6.83	3.43	0.00–12.56	5.58	2.30	0.20–11.50	3.72	1.57	0.50–7.69	5.38	2.88	0.00–12.56
1 pm	5.88	3.24	0.20–12.95	7.26	3.72	0.08–13.79	5.83	2.41	0.40–11.80	4.16	1.78	0.50–8.56	5.79	3.10	0.08–13.79
2 pm	5.42	2.98	0.00–12.00	6.61	3.47	0.08–12.46	5.00	2.10	0.30–11.30	3.78	1.64	0.23–7.95	5.21	2.84	0.00–12.46
3 pm	4.11	2.27	0.10–9.00	5.17	2.75	0.05–10.03	3.45	1.53	0.13–8.20	2.76	1.27	0.38–6.12	3.88	2.23	0.05–10.03
4 pm	2.57	1.36	0.00–6.35	3.34	1.75	0.10–6.70	1.85	0.91	0.08–5.20	1.57	0.77	0.14–3.70	2.34	1.44	0.00–6.70
5 pm	1.16	0.64	0.00–2.70	1.69	0.88	0.00–3.48	0.66	0.39	0.00–2.10	0.58	0.34	0.09–1.51	1.03	0.75	0.00–3.48
6 pm	0.31	0.19	0.00–0.80	0.57	0.28	0.00–1.11	0.10	0.11	0.00–0.50	0.08	0.09	0.00–0.32	0.27	0.27	0.00–1.11

Table 9. Hourly total erythemally weighted UV radiation and total ozone on 18 August 1999 and 17 May 2000.

Date	Hourly total erythemally weighted UV radiation (noon – 1 p.m.) (Joule/metre^2)	Total ozone measured by ozonesonde (Dobson Units)	Solar elevation at 1 p.m. (Degree)	Total cloud amount (Oktas)	
				Noon	1 p.m.
18 August 1999	999	247.1	78	2	3
17 May 2000	729	345.1	80	4	4

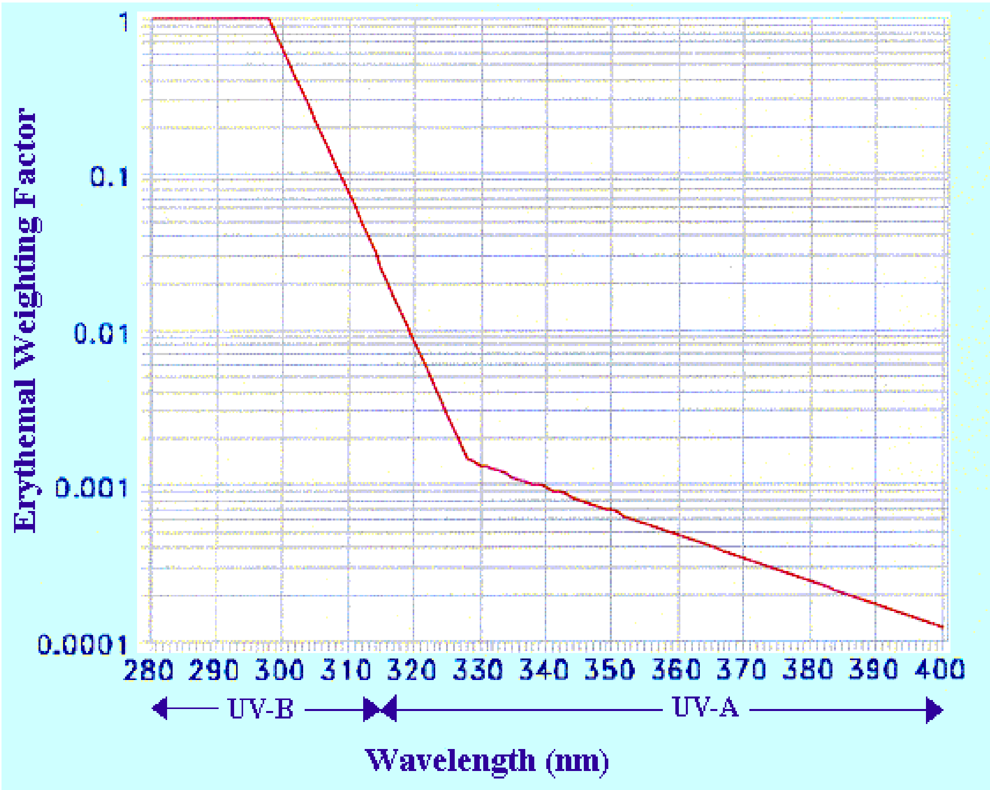


Figure 1. Erythemal action spectrum adopted by the International Commission on Illumination.

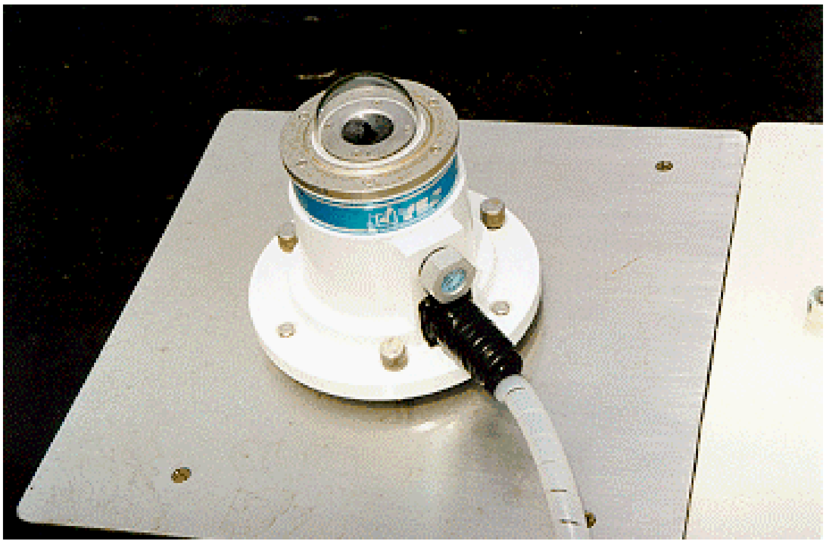


Figure 2. A picture of the broadband UVB-1 ultraviolet pyranometer used by the Hong Kong Observatory.

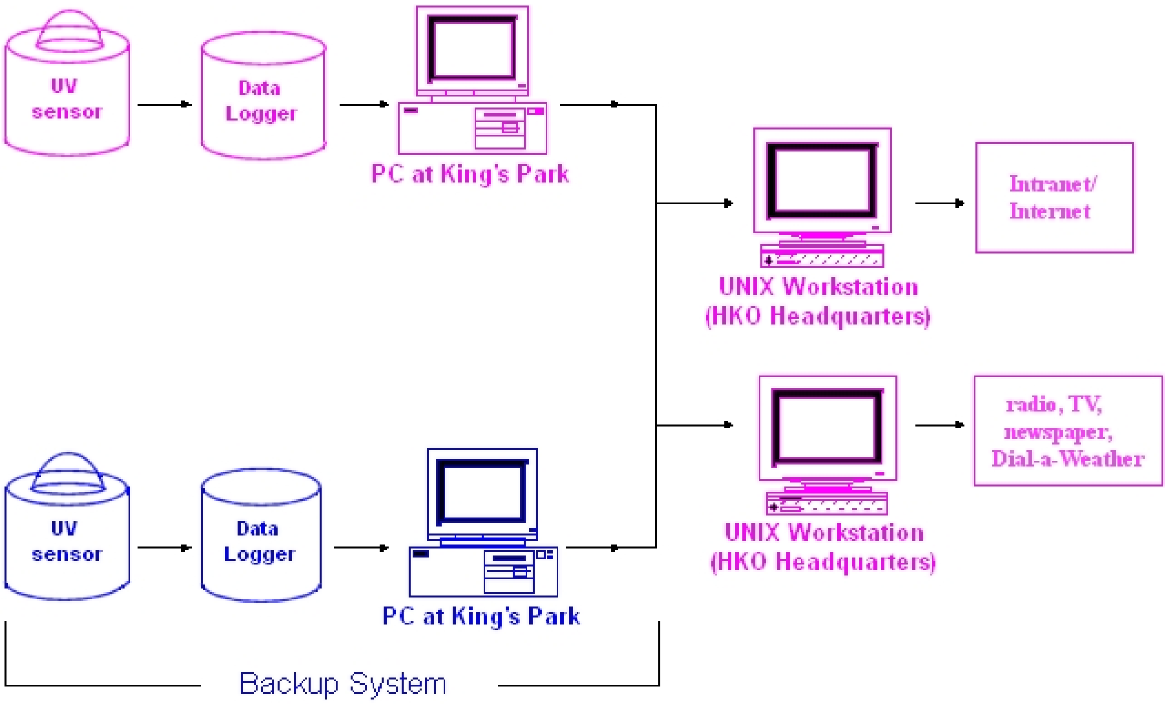


Figure 3. A schematic diagram showing the Hong Kong Observatory's UV Index observation and dissemination system.

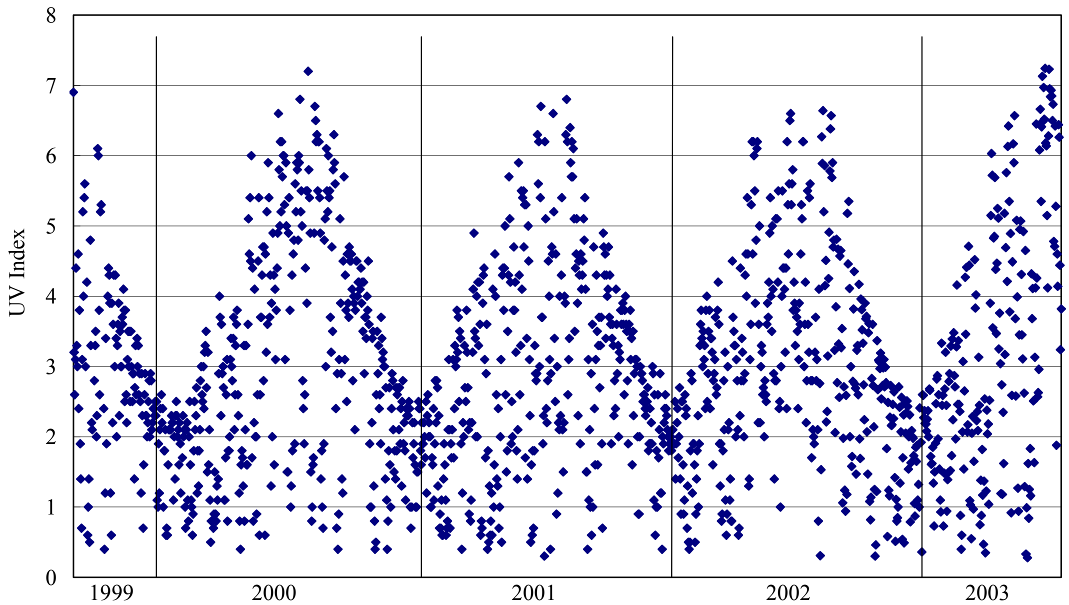


Figure 4. Daily mean UV Index (DMEAN) from 1 August 1999 to 31 July 2003.

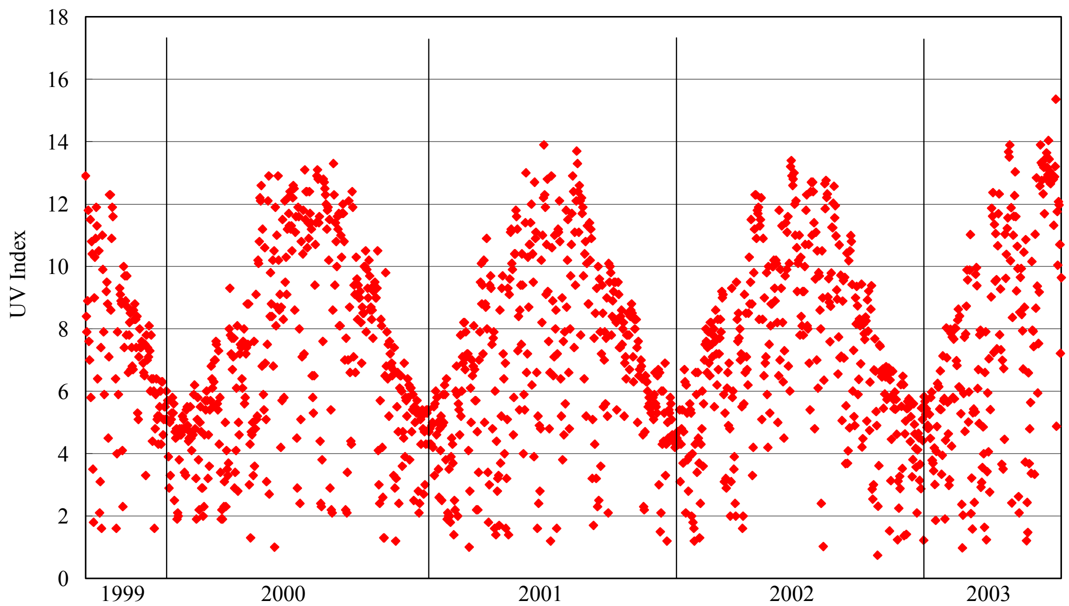


Figure 5. Daily maximum UV Index (DMAX) from 1 August 1999 to 31 July 2003.

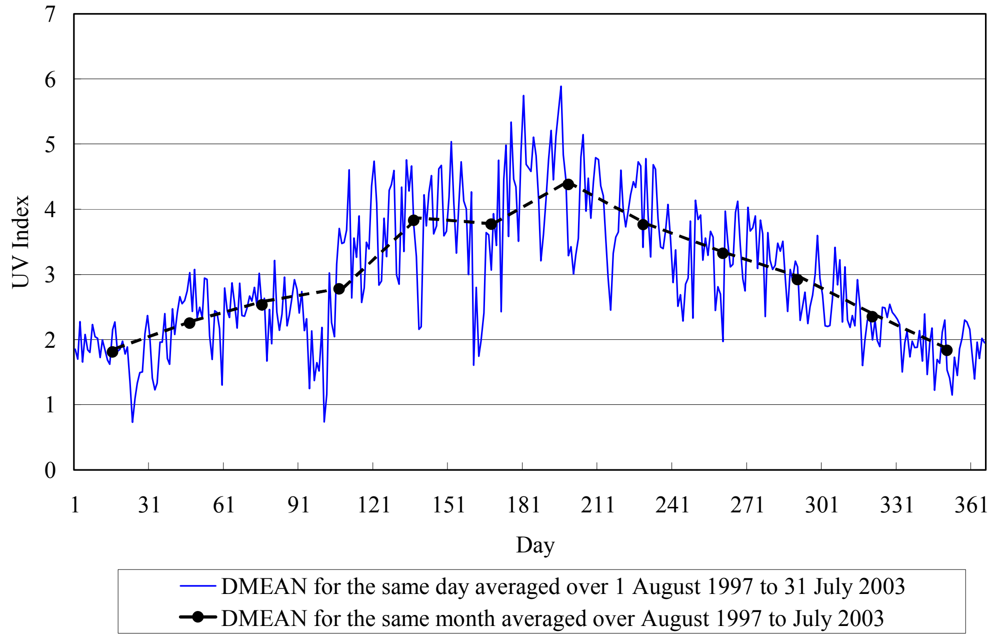


Figure 6. Annual variation of the daily and monthly mean values of DMEAN.

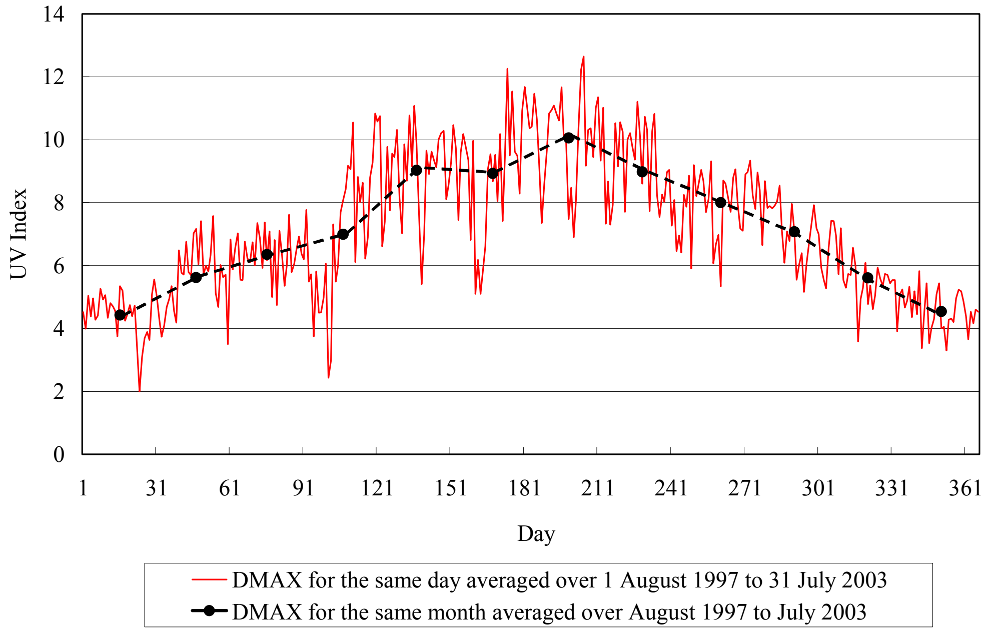


Figure 7. Annual variation of the daily and monthly mean values of DMAX.

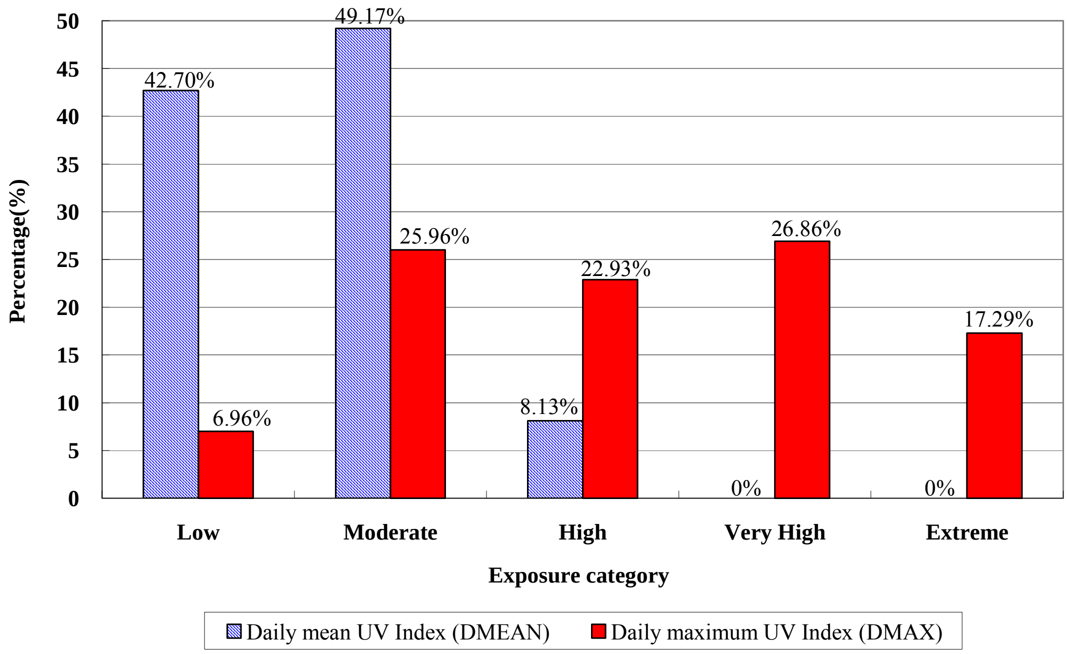


Figure 8. Frequency distributions of daily mean UV Index (DMEAN) and daily maximum UV Index (DMAX) in different exposure categories (1 August 1999 to 31 July 2003).

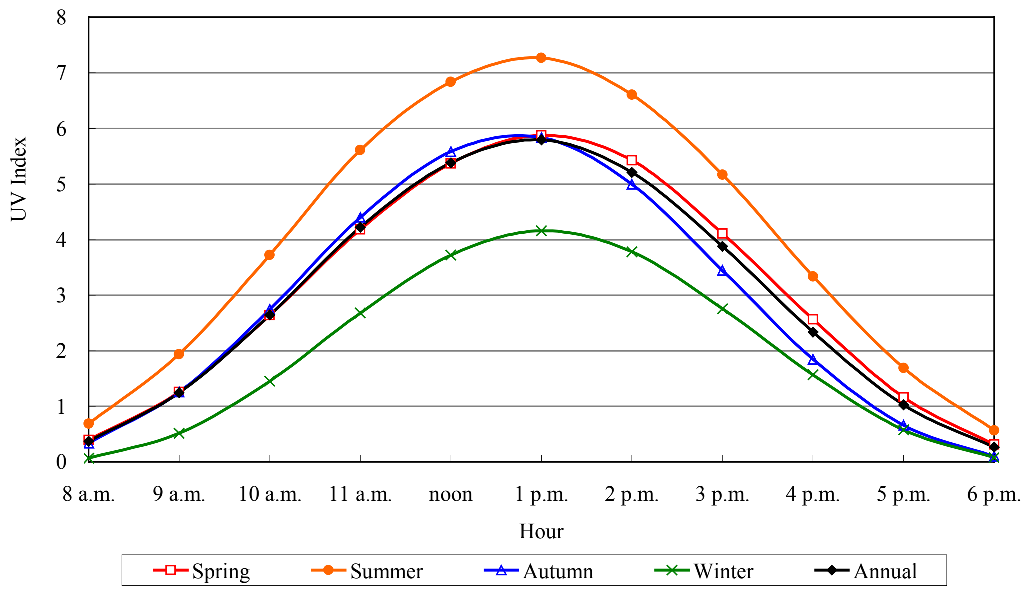


Figure 9. The annual and seasonal averaged values of hourly mean UV Index (1 August 1999 to 31 July 2003).

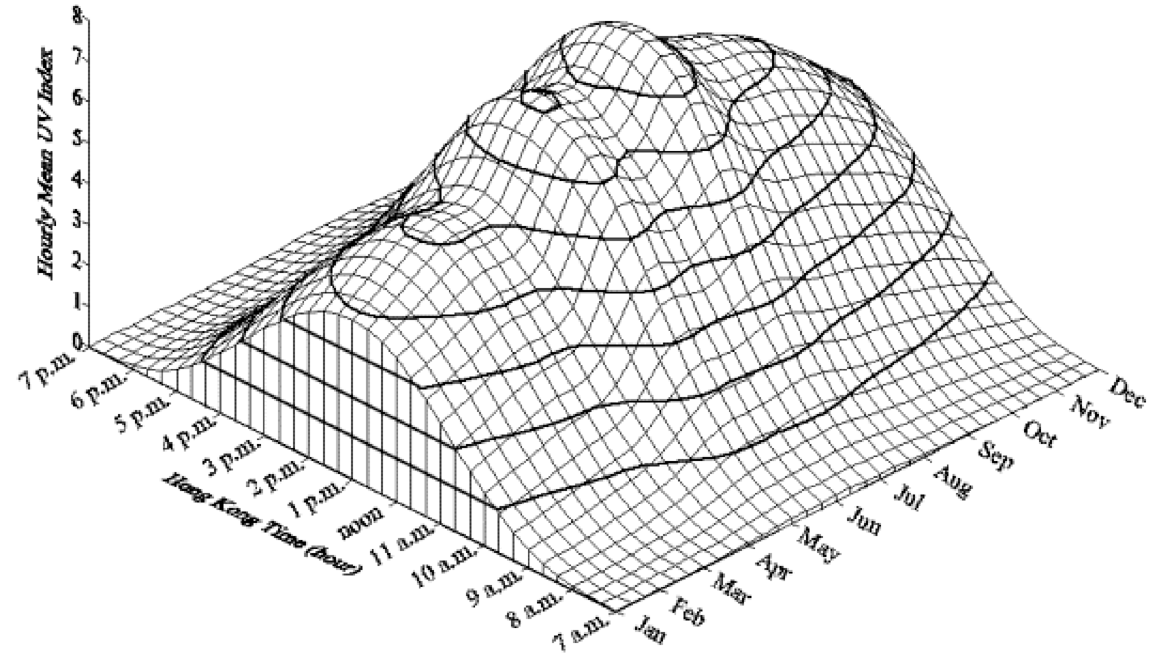


Figure 10. A three dimensional plot of hourly mean UV Index averaged for different months (1 August 1999 to 31 July 2003).

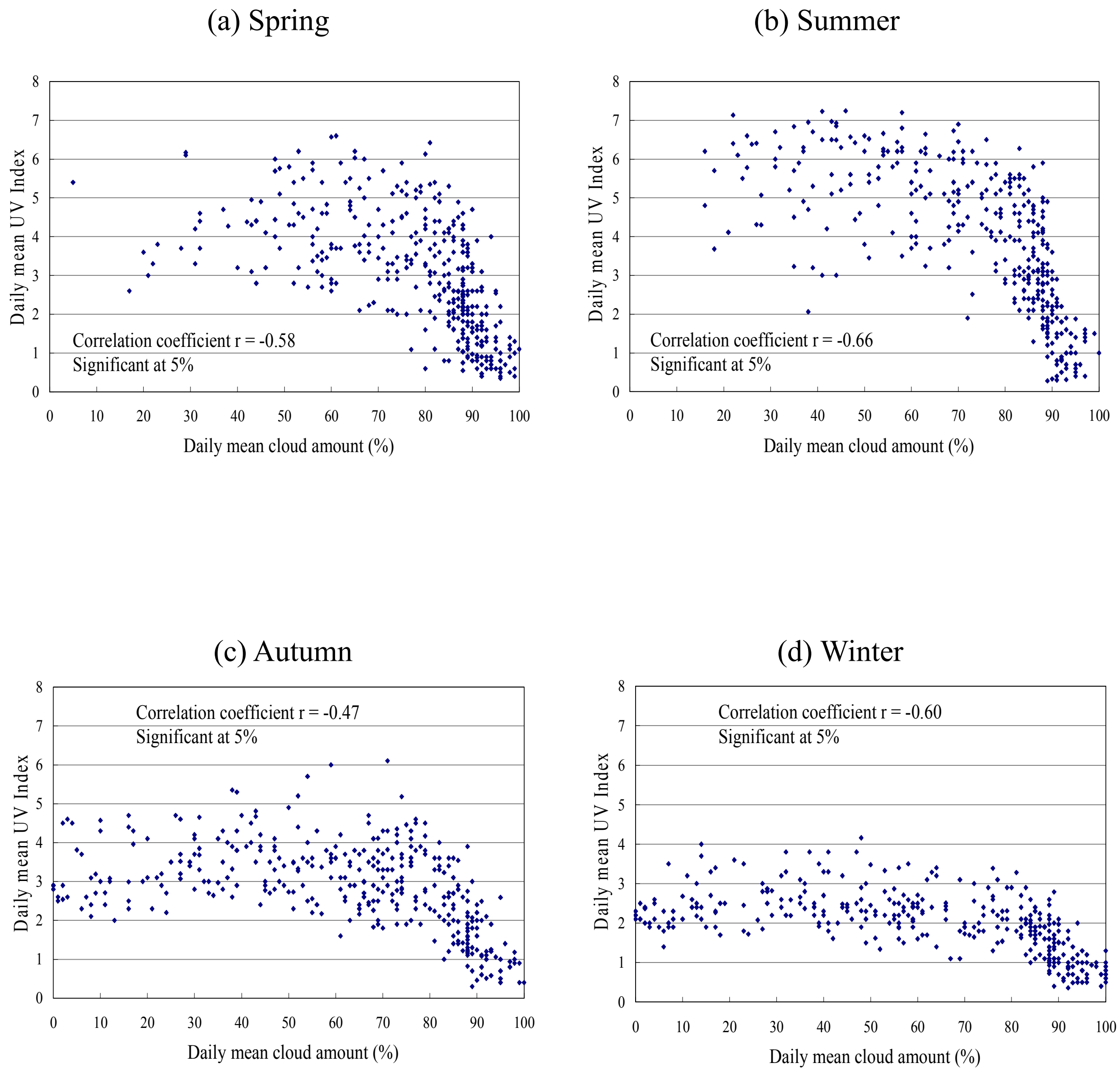
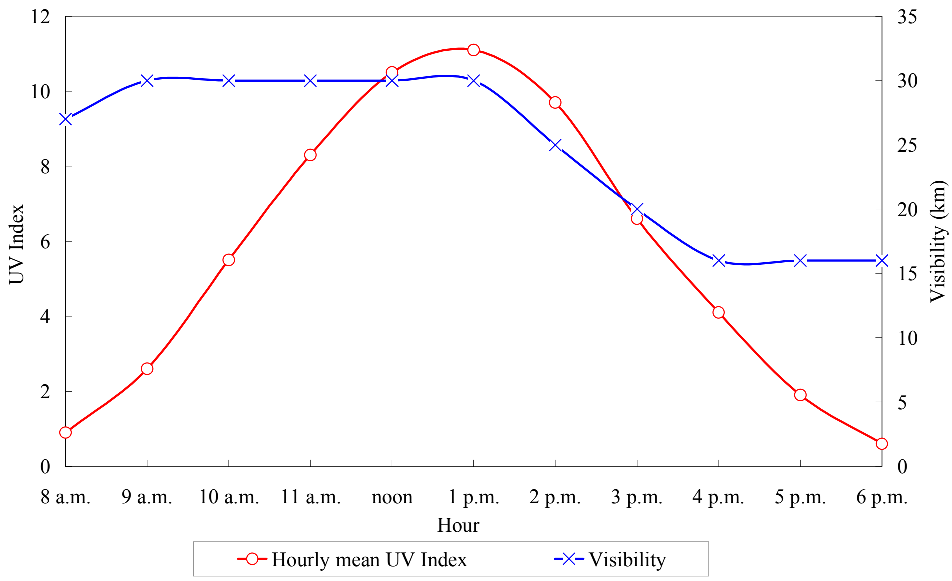


Figure 11. Scatter diagrams showing the relationship between the daily mean UV Index and the daily mean cloud amount in (a) spring, (b) summer, (c) autumn and (d) winter (1 August 1999 to 31 July 2003).

(a) 18 August 1999



(b) 19 August 1999

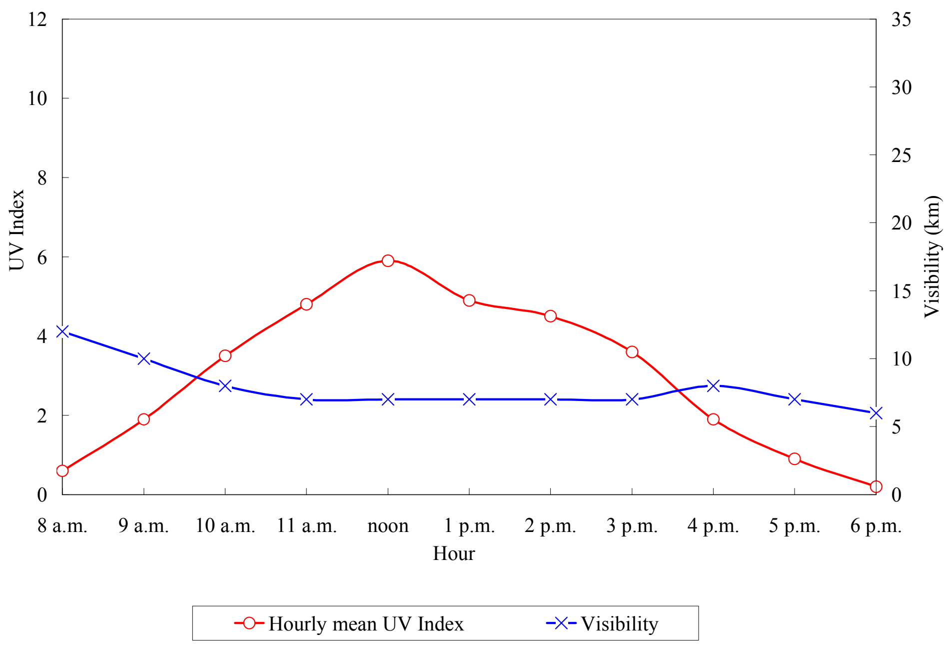


Figure 12. Hourly mean UV Index and visibility at HKO on (a) 18 August 1999 and (b) 19 August 1999.

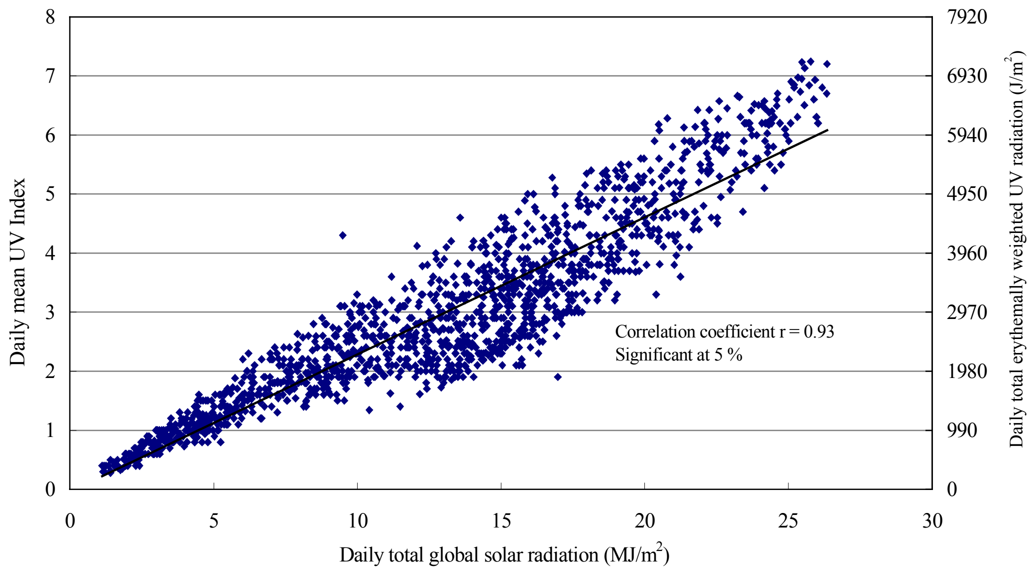


Figure 13. A scatter diagram showing the relationship between the daily mean UV Index (or daily total erythemally weighted UV radiation) and the daily total global solar radiation (1 August 1999 to 31 July 2003).

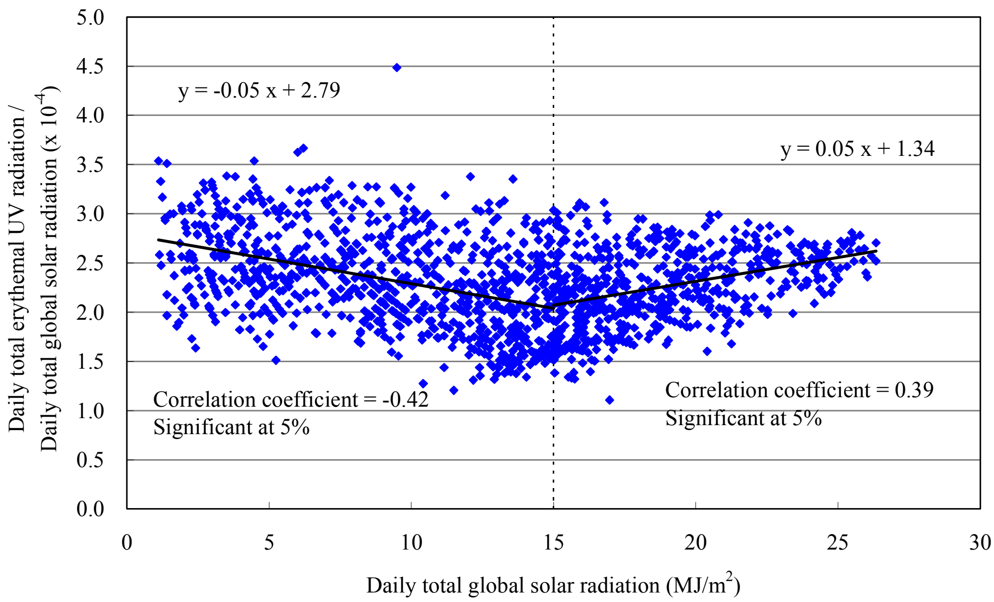


Figure 14. Variation of the ratio "daily total erythemally weighted UV radiation to daily total global solar radiation", against daily total global solar radiation (1 August 1999 to 31 July 2003).