Instituto de Ciências da Terra
Institute of Earth Sciences

Preliminary analysis of irradiance data for the

Generation of a Typical Solar Radiation Year for Évora, Portugal

Technical Report

Paulo Canhoto

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Paulo Canhoto
Physics Department and Institute of Earth Sciences
School of Sciences and Technology, University of Évora
Rua Romão Ramalho 59, 7000 – 671 Évora, Portugal

Institute of Earth Sciences
University of Évora

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Introductory note

This report presents the preliminary results of a work under progress aiming the generation of a Typical Solar Radiation Year (TSRY) and a Typical Meteorological Year (TMY) for Évora, Portugal. The final results will be published in a detailed report and in scientific journals, so that the results presented in this report can be used for preliminary calculations only and should not be included in any technical or scientific publication.

Summary

This report presents the generation of a mean solar radiation year using the 2003-2015 data series of solar global and diffuse irradiances on a horizontal surface in Évora, Portugal. The selection of the months/years to be included in the mean solar radiation year is based on the simple comparison of the mean daily solar global irradiation of each month/year with the mean value of the entire series, for each month of the calendar. Additionally, the direct normal irradiance is estimated and compared with the measurements taken at the same location since 2015. These are preliminary results that will be extended in the next step to the generation of a Typical Solar Radiation Year and a Typical Meteorological Year for Évora.

Terms of reference

Acronym	*Description*
DNI	Direct normal irradiance
RDIF	Diffuse irradiance on a horizontal surface
RGBL	Global irradiance on a horizontal surface

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b	Shadow band width (cm)
K	Total correction factor of diffuse irradiance
K_a	Fraction (percentage) of blocked diffuse radiation due to non-isotropic conditions
L	Latitude (°)
r	Shadow band radius (cm)
X	Fraction of blocked diffuse radiation in isotropic conditions
δ	Solar declination (°)
ε	Parameter of the $\cos\phi$ regularization function (Equation (4))
ϕ	Solar zenith angle (°)
ψ_s	Solar azimuth angle at sunrise (°)

1. Introductory remarks

The generation of Typical Solar Radiation Years (TSRY) and Typical Meteorological Years (TMY) are widely used in the calculations associated with renewable energy systems [1-5] and it is well established that good results are obtained by using the Finkelstein- Schafer (FS) statistics [6]. An example is the Sandia method [7]. This report presents a preliminary processing of irradiance data aiming the later generation of a Typical Solar Radiation Year (TSRY) for Évora, Portugal.

2. Location of the measuring stations, instruments and sampling rates

The measuring station is located in Évora, Portugal (Lat.: 38,567773, Long.: -7,911419, H: 290 m) and comprises two Eppley pyranometers for measuring the solar global irradiance on a horizontal surface and a Eppley pyranometer with shadow band for measuring the diffuse irradiance. The data acquisition started in 2002. The sampling rate is 5 seconds and the mean values are recorded every 10 minutes. A new measuring station was installed in 2015 at the same location including one Kipp&Zonen pyrheliometer with suntracking (direct normal irradiance) and two other pyranometers from Kipp&Zonen (global and diffuse irradiances). In this case the sampling rate is 1 second and the mean, maximum, minimum and standard deviation values are recorded every minute.

3. Sensors calibration

The pyranometers were periodically calibrated by direct comparison with reference pyranometers according to the standard ISO9847:1992 while the pyrheliometer was calibrated once by comparison with a new pyrheliometer of the same model according to the standard ISO9059:1990. The pyranometers must be recalibrated during 2016 in order to correct data.

4. Data filtering and quality tests

The irradiance rawdata were filtered to detect inconsistent values and missing data. Additionally, the present analysis also includes the data filtering using the same quality tests that are recommended for the measuring stations integrated in the Baseline Surface Radiation Network [8, 9]. A supplemental quality filter will be also included in the next step of the analysis to check for the correct alignment of the shadow band while the missing data (data gaps) will be estimated through interpolation and correlations with other nearby stations.

5. Correction of the zero offset of the instruments

The voltage outputs of the instruments were corrected for the zero offset through a linear interpolation of the one hour mean values of the output signal from before and after astronomical twilight (solar zenith angle = 108°) in each day. This assumes that the infrared response of the instrument, which greatly determines its zero offset, remains constant throughout the day [8].

6. Correction of the diffuse irradiance

The correction of the diffuse irradiance was carried out by determining the fraction of diffuse radiation blocked by the shadow band, X, in isotropic conditions [10]

$$X = \frac{2b}{\pi r} cos^3(\delta) \left[\left(\frac{\pi}{180} \psi_s \right) \sin(L) \sin(\delta) + \cos(L) \cos(\delta) \sin(\psi_s) \right] \quad (1)$$

in which b is the width of the shadow band, r is the radius of the shadow band, ψ_s is the azimuth angle of the sun at sunrise, L is the latitude and δ is the declination of the sun. The correction factor was then calculated as follows

$$K = \frac{1}{1 - X} + K_a \quad (2)$$

where K_a represents the anisotropy effect. A value of $K_a = 0.04$ (partly cloudy skies) was used [10] in this preliminary analysis. The calculation of the parameter K_a will be improved in a next step through the estimate of the cloud coverage as function of the raw measurements of global and diffuse irradiances. Additionally, a filter was included to set the diffuse irradiance equal to the solar global irradiance if the corrected values of diffuse irradiance were higher than the global irradiance measurements, which can occur in the case of overcast skies and/or during the twilight (sunrise and sunset), due to the fact of using a constant value of K_a and due to the instrumental error.

7. Determination of the direct normal irradiance

The direct normal irradiance (DNI) was estimated based on the 10-minute-mean values of solar global (RGBL) and diffuse (RDIF) irradiances by using [11]

$$DNI = (RGBL - RDIF) R(\overline{\cos\phi}, \varepsilon) \quad (3)$$

in which $R(x, \varepsilon)$ is a regularization function of the 10-minute-mean cosine of the solar zenith angle, $\overline{\cos\phi}$, defined as [11]

$$R(x, \varepsilon) = \begin{cases} 1/x, & x > \varepsilon \\ \varepsilon, & x \leq \varepsilon \end{cases} \quad (4)$$

A value of $\varepsilon = 0.03$ was used in the present work. The estimated values of DNI were compared with the values measured by the pyrheliometer since 2015 and the preliminary result of this validation is shown in Figure 1.

8. Analysis of the irradiance data

In order to obtain a mean solar radiation year the monthly average of the daily solar global irradiation was calculated. The differences in percentage between those values and the respective mean values considering the entire data series for each calendar month are presented in Table 1.

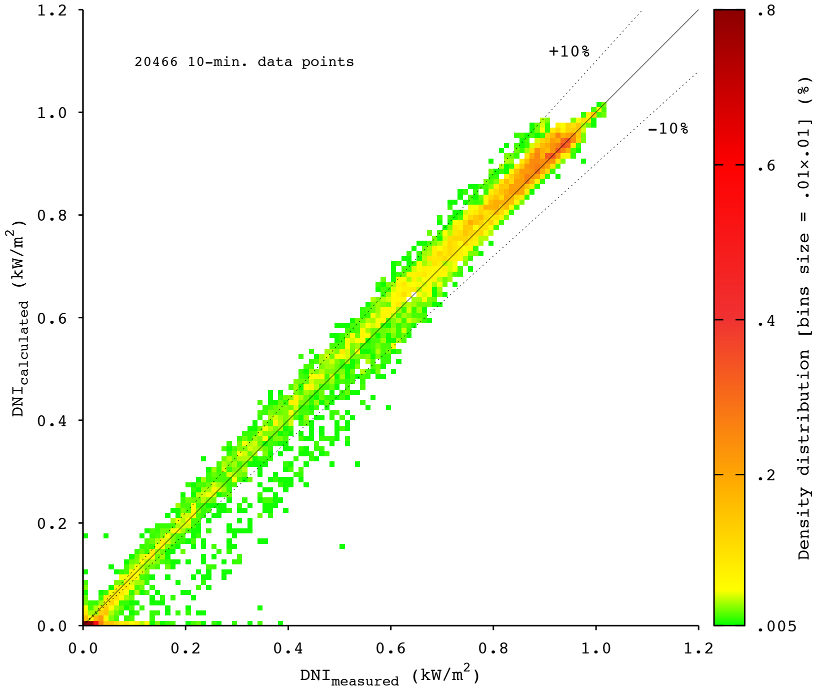

Fig. 1 – Comparison between calculated and measured values of DNI.

The months/years with lower differences were selected to the mean solar radiation year (underlined values in the table), except in the cases in which the months with lower difference values also presents significant data gaps. The comparison between the selected months and the entire series in terms of the mean daily solar global irradiation is shown in Figure 2.

Table 1 – Selection of months/years for the mean solar radiation year.

Year	***Jan***	***Feb***	***Mar***	***Apr***	***May***	***Jun***	***Jul***	***Aug***	***Sep***	***Oct***	***Nov***	***Dec***
2003	0,63	14,17	16,53	15,51	9,58	**0,09**	3,28	6,60	3,86	4,10	19,63	21,13
2004	13,18	10,01	2,45	8,21	12,09	8,38	1,41	7,30	2,79	8,81	**2,16**	13,53
2005	27,27	14,75	5,67	6,15	1,75	1,35	0,40	1,16	8,82	7,39	2,23	11,47
2006	5,49	**0,53**	12,90	3,23	4,94	3,92	5,34	3,60	1,22	**1,05**	31,59	51,30
2007	40,95	17,28	62,98	44,41	17,31	6,10	2,71	2,47	8,58	12,47	20,43	3,83
2008	**0,37**	11,52	3,41	**0,15**	23,88	6,61	1,53	0,26	3,17	4,63	12,73	12,94
2009	21,96	6,22	10,19	0,78	3,43	5,88	5,25	2,48	3,34	12,20	8,36	25,27
2010	22,05	24,11	17,14	1,21	**0,31**	2,60	**0,07**	**0,24**	2,00	1,61	5,99	19,51
2011	11,10	4,63	8,27	1,49	4,81	5,28	1,41	3,84	2,92	15,49	12,20	**3,36**
2012	17,54	29,47	6,16	23,58	8,05	1,20	3,72	3,07	2,42	1,25	19,13	11,79
2013	13,60	2,40	28,19	5,34	2,24	0,15	2,57	4,22	**0,01**	3,51	10,27	6,90
2014	20,12	19,08	**0,43**	12,46	5,97	4,57	2,15	5,05	13,28	4,05	20,15	11,60
2015	9,75	3,61	7,98	8,12	7,43	0,31	2,87	1,97	0,09	15,52	10,38	11,35

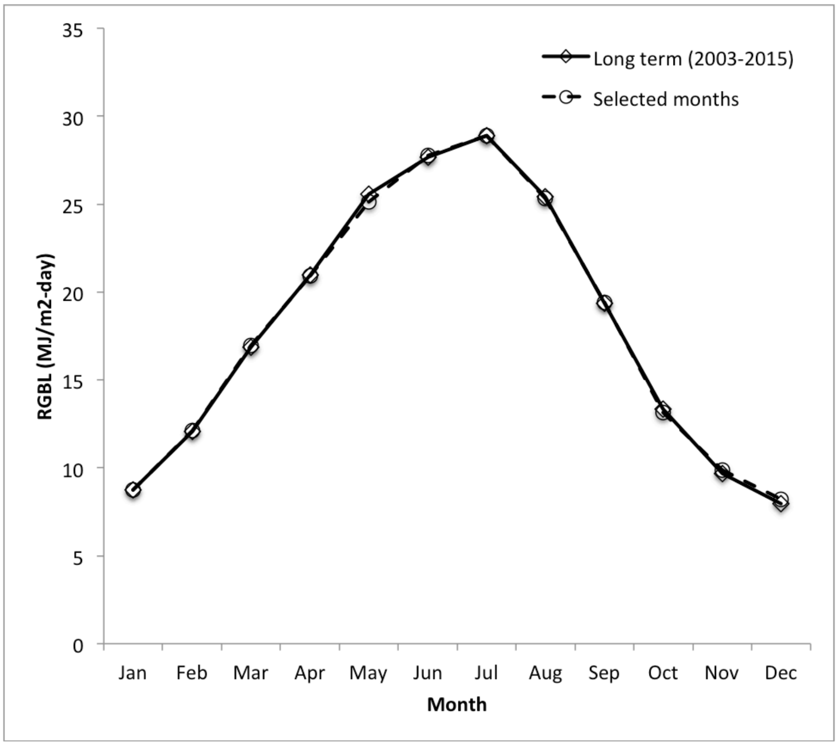

Fig. 2 – Comparison of mean values of daily solar global irradiation.

9. Preliminary results

The Figure 3, the Figure 4 and the Figure 5 show the mean solar radiation year of hourly solar global, diffuse and direct normal irradiation, respectively, generated from the selected months. The graphics were constructed from matrices of 24 by 365 elements of hourly irradiation obtained from the 10-minutes-mean irradiance values, and represented in colour scale as shown. The lower and upper limiting lines represent the sunrise and sunset hours, respectively. The various months were simply joined together in the sequential order of the calendar without any numerical interpolation in the hours before and after the end of each month, because during the night all the irradiance values are zero.

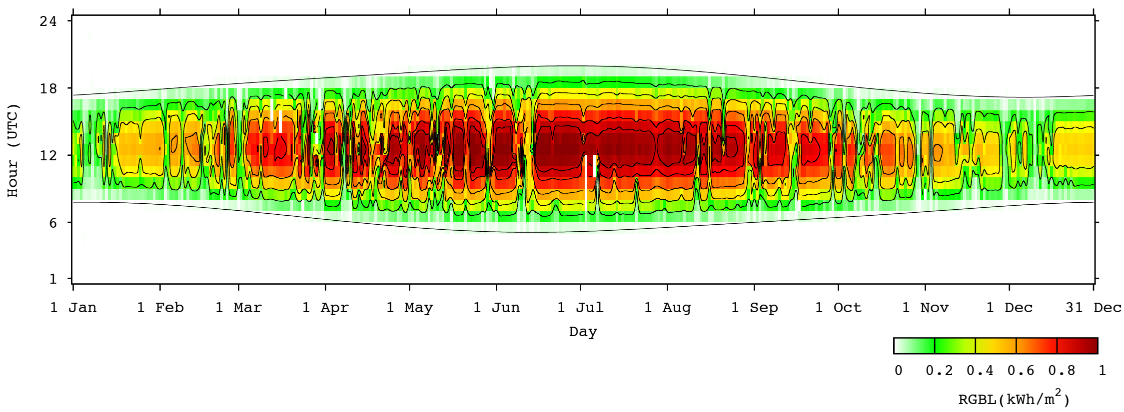

Fig. 3 – Mean solar radiation year: hourly solar global irradiation on a horizontal surface.

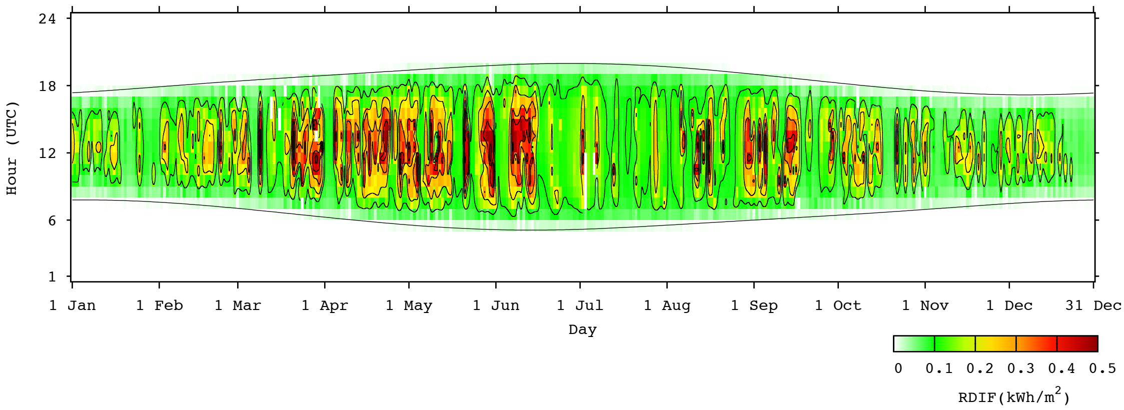

Fig. 4 - Mean solar radiation year: hourly diffuse irradiation on a horizontal surface.

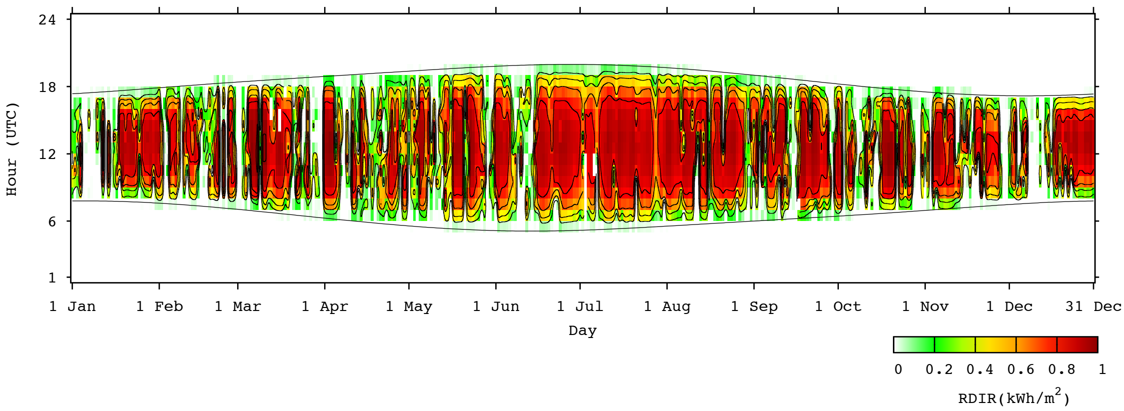

Fig. 5 - Mean solar radiation year: hourly direct normal irradiation.

10. Conclusions

This preliminary analysis allowed obtaining a mean solar radiation year for Évora including the solar global irradiance on a horizontal surface, the diffuse irradiance on a horizontal surface and an estimate of the direct normal irradiance. This analysis will proceed with the generation of a Typical Solar Radiation Year and a Typical Meteorological Year according to a more complete statistical procedure and including other meteorological variables.

References

[1] Pissimanis D, Karras G, Notaridou V, Gavra K. The generation of a "Typical Meteorological Year" for the city of Athens. Solar Energy 1988; 40: 405–11.

[2] Skeiker K. Generation of a typical meteorological year for Damascus zone using the Filkenstein–Schafer statistical method. Energy Conversion and Management 2004;45:99–112.

[3] Jin Z, Yezheng W, Gang Y. Generation of typical solar radiation year for China. Renewable Energy 2005.

[4] Kalogirou SA. Generation of typical meteorological year (TMY-2) for Nicosia, Cyprus. Renewable Energy 2003; 28:2317–34.

[5] Chan ALS, Chow TT, Fong SKF, Lin JZ. Generation of a typical meteorological year for Hong Kong. Energy Conversion and Management 2006; 47:87–96.

[6] Finkelstein, J. M., Schafer, R. E., Improved goodness of fit tests. Biometrika 1971; 58: 641-645

[7] Wilcox, S., Marion, W., Users Manual for TMY3 Data Sets, Derived from the 1991–2005 National Solar Radiation Data Base, NREL/TP-581-43156, Golden, CO: National Renewable Energy Laboratory, 2008.

[8] L. McArthur, Baseline Surface Radiation Network, Ontario: World Climate Research Programme, 2005.

[9] C. Long e E. Dutton, "BSRN Global Network recommended QC tests," BSRN Technical Report, 2002.

[10] M. Iqbal, An Introduction to Solar Radiation, Academic Press, 1983.

[11] MACC-II, Report on direct normal irradiance standards, 2013

Appendix

The moving averages of the hourly irradiation values considering the entire series (2003-2015) are shown in the Figure 6, in the Figure 7 and in the Figure 8, respectively for the solar global, diffuse and direct normal irradiation.

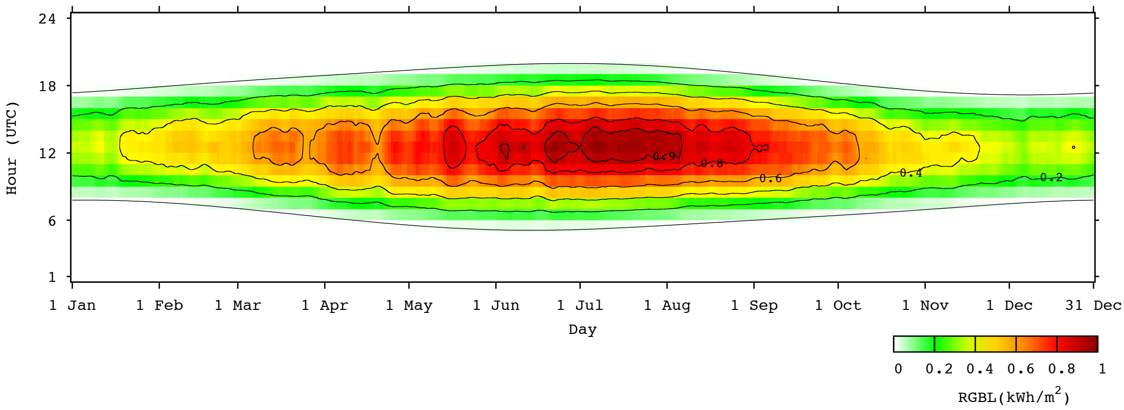

Fig. 6 - Solar global irradiation on a horizontal surface: five days centred hourly moving average.

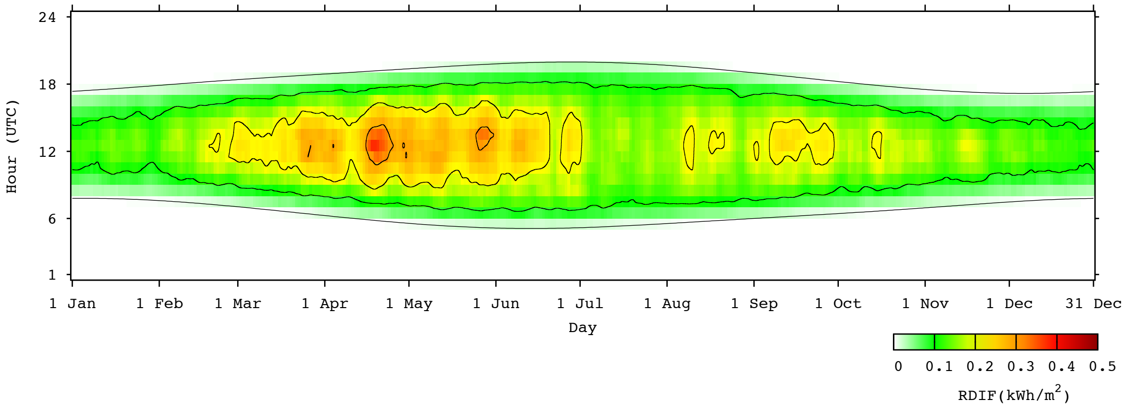

Fig. 7 - Diffuse irradiation on a horizontal surface: five days centred hourly moving average.

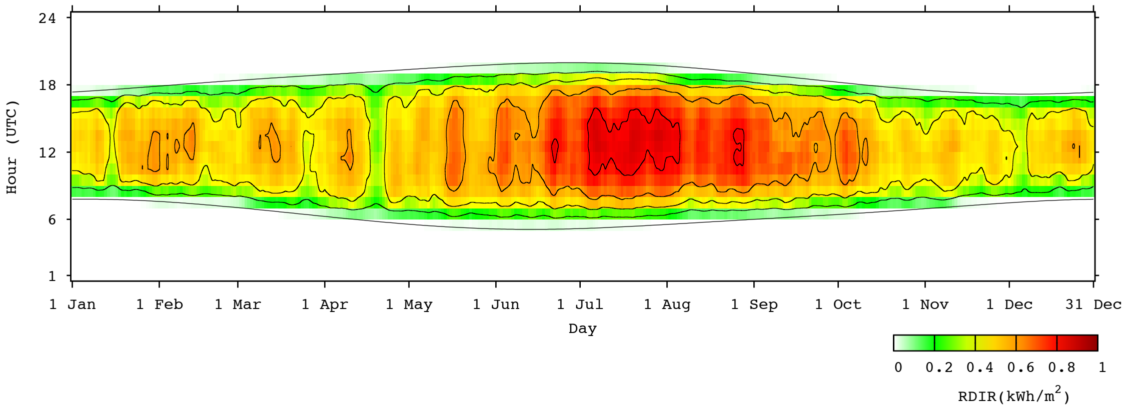

Fig. 8 – Direct normal irradiation: five days centred hourly moving average.