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Assessing the distribution of solar irradiation in Mbarara, Uganda

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With 8 Figures

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Summary

Careful measurements of surface radiation balance components provide, in principle, an important contribution to the understanding of the global energy cycle. They can be used to further improve climatologies of radiative flux components or in the validation of parameterization procedures in weather forecast and climate models. Existing literature lacks information on the distribution of global solar radiation and its two components for locations close to the Equator. The objective of this study is to identify and assess the distributions of global solar irradiation and the ratio of diffuse to direct solar irradiation at a site in Mbarara, Uganda, located at 00°37'S latitude, 30°39'E longitude and at 1413 m altitude. Results have shown that there are bigger and more frequent variations in daily global irradiation at the beginning and towards to the end of the year. The dominance of diffuse over direct solar radiation during the same periods has been demonstrated. The results have been compared with those from a similar measurement site and have shown some similarities and some differences.

1. Introduction

Solar energy, being a renewable and environmentally sound source of energy, is being used in a variety of applications such as lighting in homes, highways and warning signs, home appliances, telecommunication systems, solar heating, solar cooling and desalination (Alawaji and Hasnain,

1999). Selection, performance assessment and the improvement of solar design procedures of such solar applications require knowledge of the distribution and variability of the solar radiation resource (Chiguera, 2001; Santos et al., 2004). Further, the variability of solar radiation, being the principal energy source of the climate system, has implications for climate change at global, regional and local scales (Cubasch and Voss, 2000; Power, 2003; Power and Mills, 2005). Careful measurements of surface radiation balance components provide, in principle, an important contribution to the understanding of the global energy cycle. They can be used for the generation of improved climatologies of radiative flux components or for the validation of parameterization procedures in weather forecast and climate models.

Existing literature lacks information on the distribution of global solar radiation, and its two components, for locations close to the Equator. The objective of this study is to identify and assess the distribution of global solar irradiation and the ratio of diffuse to direct solar irradiation at a site in Mbarara, Uganda. Similar assessments have been carried out for locations at higher latitudes (e.g. Al-Riahi et al., 2003; Gonzalez and

Calbo, 1999; Hassan, 2001; Mosalam Shaltout et al., 2001).

2. Site description and instrumentation

The study site in Mbarara, Uganda, is located at $00^{\circ}37'S$ latitude, $30^{\circ}39'E$ longitude and has an altitude of 1413 m. Its vegetation is characterized by scattered bushes and short grass, and annual rainfall in this region can be as high as 2000 mm and as low as 875 mm.

The diffuse and direct components of solar radiation were measured for the period from July 2003 to June 2005. Diffuse solar irradiation was measured using the Kipp & Zonen CM6B Pyranometer with a shadow ring, while direct solar radiation was measured as an additional parameter on a Kipp & Zonen CSD-1 sensor with an accuracy of $\pm 50 \text{ W/m}^2$. The diffuse solar irradiation data were corrected for shadow ring effects using correction factors provided by the manufacturer. Ultimately, global solar irradiation data were obtained by summing diffuse and direct solar irradiation values, and validated using a service at the website: www.helioClim.net (Geiger et al., 2002).

3. Results and discussions

3.1 Distribution of sunshine duration, cloud cover and relative humidity

Figures 1–3 show the monthly mean daily distribution of sunshine duration, amount of cloud

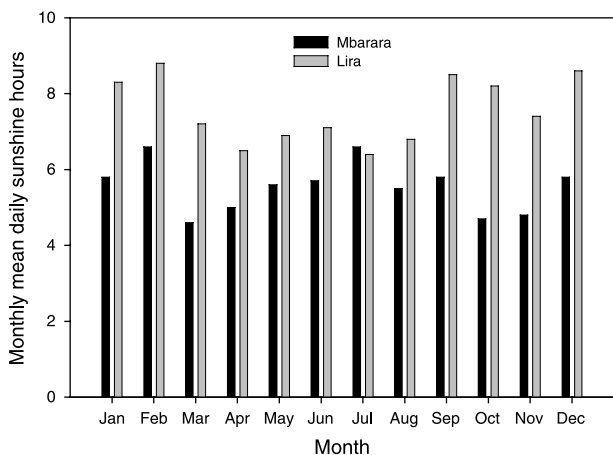


Fig. 1. Distribution of monthly mean daily sunshine hours at Mbarara and Lira

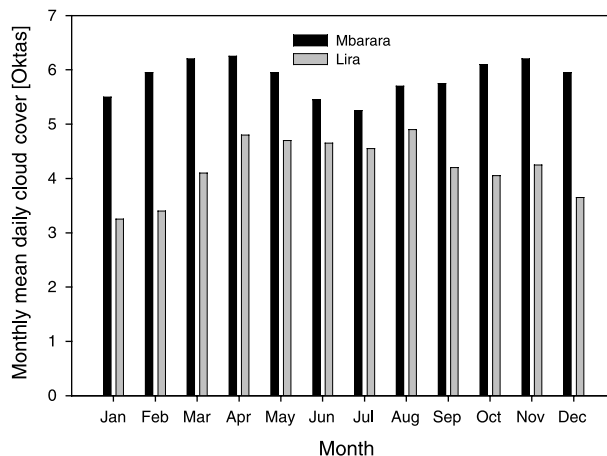


Fig. 2. Distribution of monthly mean daily cloud cover at Mbarara and Lira

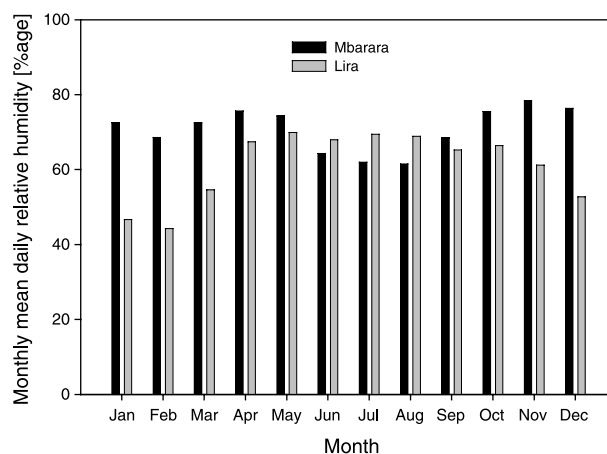


Fig. 3. Distribution of monthly mean daily relative humidity at Mbarara and Lira

and relative humidity for both Mbarara and Lira. Data from Lira are used for comparison purposes. The site is located at $02^{\circ}17'N$ latitude, $32^{\circ}56'E$ longitude and has an altitude of 1189 m. Figures 1–3 are based on data collected (over ten years) from the Meteorological Department of Uganda. Monthly mean daily sunshine duration varies between 4 and 7 hours with the maximum duration found in July and February and the minimum in March and October, in Mbarara. The Lira site exhibits higher values of sunshine hours than at Mbarara. The region within which Lira is located has more clear sky days, according to information obtained from the website: <http://eosweb.larc.nasa.gov/sse/> (NASA, 2006).

Monthly mean daily cloud cover in Mbarara, varies between 5 and 7 oktas, and is highest at the

beginning and towards the end of the year, during March, April, October and November whilst minimum cloud cover is observed mid-year (June, July). In contrast, the site at Lira exhibits lowest values of cloud cover at the beginning and towards the end of the year. It is worth noting that the study site in Mbarara is south of the Equator while Lira is located north of the Equator. The pattern of the monthly mean daily relative humidity is almost similar to the pattern of cloud cover for both sites.

3.2 Variability of global solar irradiation

Figure 4 shows the distribution of monthly mean hourly global solar irradiation where the highest values of $\geq 2.0 \text{ MJ/m}^2$, occur in each month of the year, between 10.00 and 16.00 hours local time. The distribution at Lira shows high variability of hourly global solar irradiation during the same time intervals. A location at higher latitude, such as that demonstrated by Al-Riahi et al. (2003), exhibits highest values of hourly global solar irradiation between May and July, from 12.00 to 13.00 hours. This difference is due to the latitudinal positions of the stations. Global solar irradiation values decrease towards the morning and evening hours.

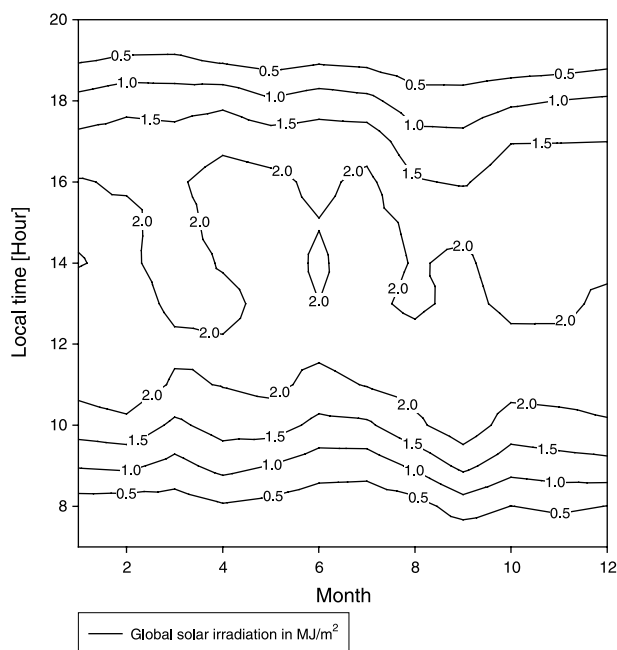


Fig. 4. Monthly mean hourly distribution of global solar irradiation at Mbarara

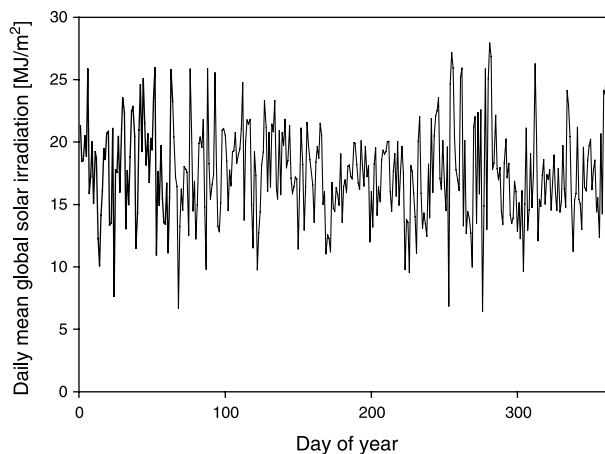


Fig. 5. Distribution of daily mean global solar irradiation at Mbarara

Figure 5 shows the distribution of daily mean global solar irradiation during the year. Daily mean global irradiation varied between 5 and 28 MJ/m^2 and it can be seen that this variation is centered along 18 MJ/m^2 . Furthermore, the amplitude in the global irradiation values is wider at the beginning and towards the end of the year. This can be attributed to the prevalence of a more extensive and ever-shifting cloud cover, and the atmosphere above this site being more humid during these times of the year.

Figure 6 shows that daily mean global irradiation varied between 5 and 30 MJ/m^2 and is centered along 22 MJ/m^2 for the site at Lira. Clearly, the Lira site exhibits higher average global irradiation values than at Mbarara. This is attributed to the longer average monthly sunshine duration in Lira, as demonstrated in Fig. 1. The difference

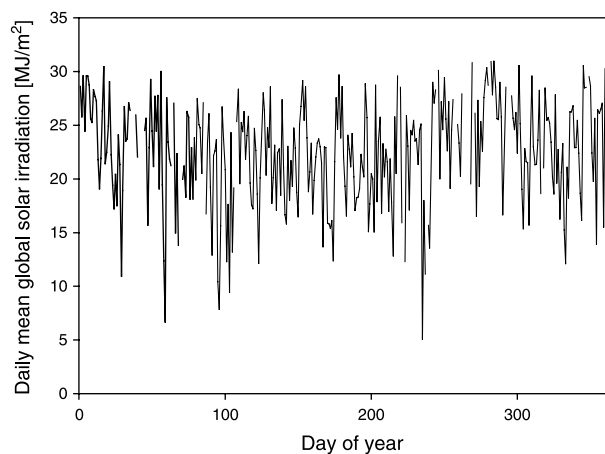


Fig. 6. Distribution of daily mean global solar irradiation at Lira, Uganda

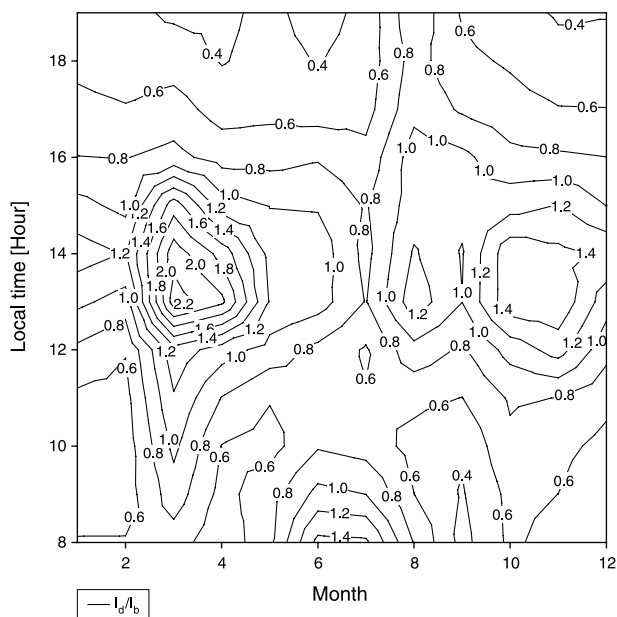


Fig. 7. Distribution of (\bar{I}_d/\bar{I}_b) at Mbarara

in the patterns of daily mean global irradiation for the two sites is due to differences in the magnitude of some meteorological parameters, such as cloud cover, humidity and sunshine duration.

3.3 Variability of the ratio of diffuse to direct solar irradiation

Figure 7 shows the distribution of the ratio of monthly mean hourly diffuse to direct solar irradiation (\bar{I}_d/\bar{I}_b) for Mbarara. \bar{I}_d and \bar{I}_b are the monthly mean hourly diffuse and direct solar irradiation, respectively. The amount of diffuse is equal to the direct solar irradiation for periods where $(\bar{I}_d/\bar{I}_b) = 1.0$. Values of $(\bar{I}_d/\bar{I}_b) > 1.0$ signify the dominance of diffuse over direct solar irradiation and were observed from February to May, between 11.00 and 16.00 hours and from August to December, between 12.00 and 15.00 hours local time. This occurrence is attributed to the higher values of cloud cover. A similar pattern is observed when distributions of (\bar{I}_d/\bar{I}_b) are drawn for the study period. There is an isolated case of $(\bar{I}_d/\bar{I}_b) > 1.0$ at mid-year, between 8.00 and 9.00 hours, in the morning. The same phenomenon is observed across the study period. This can be attributed to hazy conditions experienced during this period and time of the year.

The comparison site at Lira exhibits traces of similarity in the patterns of peak values of the ratio

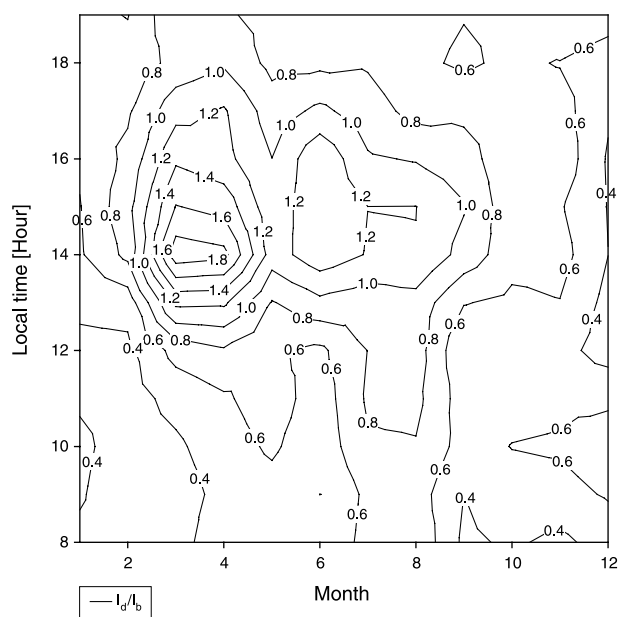


Fig. 8. Distribution of (\bar{I}_d/\bar{I}_b) at Lira, Uganda

(\bar{I}_d/\bar{I}_b) from February to May, between 13.00 and 17.00 hours local time (see Fig. 8). The dominance of diffuse over direct solar radiation during this period, at this site, can be attributed to longer sunshine duration leading to prolonged scattering of solar radiation, despite the lower cloud cover.

4. Conclusions

This study was inspired by the lack of information in the existing literature regarding the distribution of global solar radiation and its two components for locations close to the Equator. This study has attempted to identify and assess distributions of global solar irradiation and the ratio of diffuse to direct solar irradiation at a site at Mbarara, Uganda. The results have shown that there are bigger and more frequent variations in daily mean global irradiation at the beginning and towards to the end of the year. The dominance of the diffuse over the direct component of solar radiation during the same periods has been demonstrated. These periods are characterized by higher values of cloud cover and humidity. Results have been compared with those from a similar measurement site at Lira, and have shown both similarities and differences. The above results are a contribution to the understanding of the global energy cycle in a sample location close to the Equator. Furthermore, the present study

can be used to encourage similar studies in near equatorial African or non-African regions.

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