P1.3 PHOTOSYNTHETICALLY ACTIVE RADIATION IN ZAMBIA

D. A. Finch [1] *, W. G. Bailey [2], L. J. B. McArthur [3] and M. Nasitwitwi [2]
1. Queen's University, Kingston, Ontario, Canada
2. Simon Fraser University, Burnaby, British Columbia, Canada
3. Meteorological Service of Canada, Downsview, Ontario, Canada

1. INTRODUCTION

The accurate determination of photosynthetically active radiation (PAR) is important in many ecological applications, such as net primary productivity and carbon cycle modelling (Pinker and Laszlo, 1992; Frouin and Pinker, 1995). High quality, continuous solar radiation data are limited for many locations. For example, reliable and long-term measurements of global solar radiation (K↓) and PAR are practically nonexistent in most parts of Africa. With the exception of Udo and Aro (1999a, 1999b) and Miskolczi *et al*. (1997), most observations of PAR in Africa are short-term (e.g., Stigter and Musabilha, 1982; Eck *et al*., 2001). Therefore, the need for long-term high quality radiation data for locations in Africa is evident. In addition, the ability to determine PAR from more widely measured variables such as K↓ has merit. The present study contributes to the knowledge of solar radiation in southern Africa through an examination of the temporal variation of K↓, PAR and the PAR/K↓ ratio within a savanna environment. Both the roles of the Hadley circulation system and local climate influences, such as regional biomass burning, are considered and shown to be significant.

2. METHODS

The observations were conducted in Lusaka, Zambia on a rooftop at the University of Zambia (15° 24´ S, 28° 18´ E, 1154 m above mean sea level) from April through December 2000. An Eppley Precision Spectral Pyranometer (PSP) was used to measure K↓ and a LICOR LI-190 quantum sensor was used to measure PAR (photosynthetic photon flux density (PPFD)). The instruments were calibrated at the National Atmospheric Radiation Centre of Canada prior to deployment. The instruments were scanned at 1Hz with a Campbell Scientific 21X datalogger. Daily radiation totals were derived from 1-minute averages. Supplemental meteorological data were obtained from the Zambian Meteorological Department.

* *Corresponding author address*: D. A. Finch, Department of Geography, Queen's University, Kingston, Ontario, Canada K7L 3N6; email: finchd@post.queensu.ca

3. RESULTS AND DISCUSSION

3.1 *Seasonal trends*

Figure 1 shows the seasonal trend in daily K↓ and this can be compared with extraterrestrial radiation (K_{ex}). In Zambia, there are three distinct seasons: the cool-dry season, the hot-dry season which is associated with the sub-tropical anticyclones (STACs) and the warm-wet season which is associated with the Intertropical Convergence Zone (ITCZ). Overall, K↓ tracks the trend in K_{ex}, with the large day-to-day variability mainly due to cloudiness. This is quite apparent during the warm-wet season when intense convective activity associated with the ITCZ prevails. The least variability is found during the hot-dry season when cloudless conditions associated with the STACs dominate.

Figure 1 also presents the seasonal trend in daily PAR and the PAR/K↓ ratio. The seasonal trend in daily PAR tracks the trend in K↓, with the lowest PPFD values occurring during the cool-dry season and the highest values at the end of the hot-dry season. Similar to K↓, the greatest variability in the daily PAR occurs during the warm-wet season and the least variability is in the hot-dry season. Daily PAR/K↓ ratios range between 1.778 mol MJ^{-1} and 2.414 mol MJ^{-1}. Values tended to decrease during the cool-dry season, decrease and then increase during the hot-dry season, and increase during the warm-wet season.

Table 1 provides monthly and seasonal means of the daily PAR/K↓ ratio. Monthly and seasonal regimes are apparent in the mean daily ratios. The mean daily PAR/K↓ ratio for the hot-dry season was considerably lower than the mean daily ratios for the cool-dry season and the warm-wet season. Primarily cloudless conditions occurred frequently during the hot-dry season. In more cloudy and humid conditions, the absorption of solar radiation in the infrared portion of the solar spectrum is enhanced, whereas absorption in the PAR waveband does not vary significantly. Thus, an increase in the PAR/K↓ ratio under cloudy skies and a decrease under cloudless skies is found. During the warm-wet season, when cloudy and very cloudy conditions prevailed due to the position of the ITCZ, increases in the mean daily ratio were considerable. The mean daily PAR/K↓ ratio for the whole experiment period (1.992 mol MJ^{-1}) was probably slightly lower than the actual annual value, as a portion of the warm-wet season was not included in this study. If these data were included, an increase in the mean annual value of the daily PAR/K↓ ratio would likely be found.

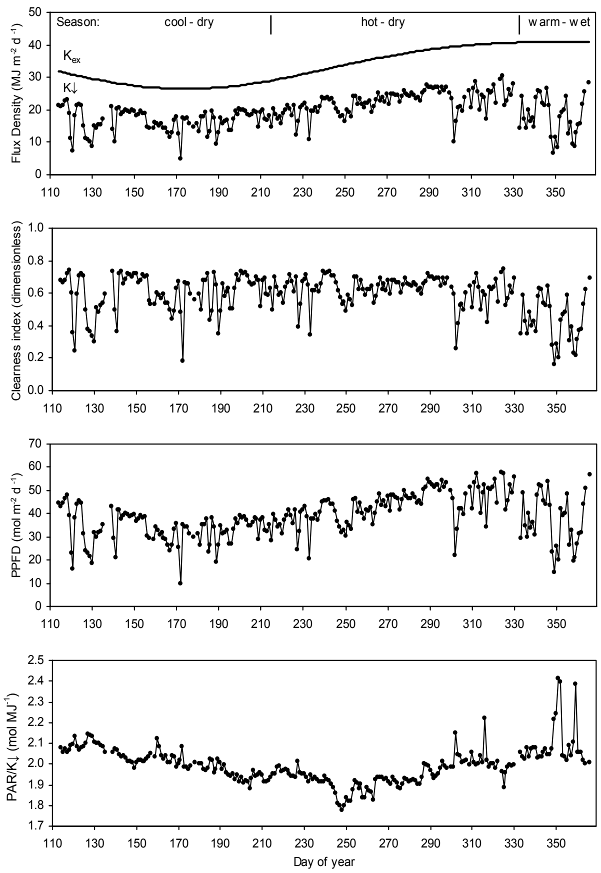

Figure 1. The trend in daily extraterrestrial radiation (K_{ex}), global solar radiation (K↓), clearness index (K↓/ K_{ex}), photosynthetically active radiation (PPFD) and the PAR/K↓ ratio at Lusaka, Zambia from April to December 2000.

Table 1. Monthly and seasonal PAR/K↓.

Period of observation	Mean daily PAR/K↓ (mol MJ $^{-1}$)	Standard deviation (mol MJ ^{1})	Maximum daily PAR/K↓ (mol MJ $^{-1}$)	Minimum daily PAR/K↓ (mol MJ $^{-1}$)
April*	2.081	0.024	2.131	2.056
May	2.063	0.044	2.146	1.978
June	2.021	0.035	2.122	1.975
July	1.952	0.036	2.026	1.881
August	1.943	0.027	2.013	1.886
September	1.876	0.049	1.936	1.778
October	1.961	0.057	2.148	1.879
November	2.009	0.055	2.223	1.887
December	2.097	0.114	2.414	2.003
Cool-dry season*	2.014	0.061	2.146	1.881
Hot-dry season	1.945	0.067	2.223	1.778
Warm-wet season*	2.097	0.114	2.414	2.003
Whole period	1.992	0.089	2.414	1.778

* Based on incomplete data for period indicated

3.2 *The clearness index and the PAR/K↓ ratio*

The daily clearness index (the ratio of K↓ to K_{ex}) accounts for the attenuation of solar radiation by all atmospheric constituents. Figure 1 shows the seasonal trend in the daily clearness index. The variability in the clearness index was mainly due to cloudiness. Decreases in the daily clearness index did not usually translate into large changes in the PAR/K↓ ratio. This demonstrates the conservative nature of the latter ratio, as decreases in K↓ are accompanied by somewhat proportional decreases in PAR. However, during periods when there were very low clearness indexes (<0.30), the PAR/K↓ ratio tended to increase significantly, especially during the warm-wet season. Cloudy and very cloudy conditions were mainly associated with the warm-wet season. During the dry season, between day 245 and 255, there was a decrease in the daily clearness index and a considerable decrease in the daily PAR/K↓ ratio. Predominantly cloudless conditions were associated with this period. The decrease in the clearness index during this period can be accounted for by an increase in the atmospheric turbidity due to widespread regional biomass burning which occurs for various agricultural purposes. This trend suggests that the pyrogenic aerosols present absorb more effectively at PAR wavelengths than in the infrared portion of the solar spectrum.

3.3 *The relationship between daily PAR and K↓*

Figure 2 presents the linear relationship between daily PAR and K↓. The mean daily ratio for the entire observation period, 1.992 mol MJ^{-1}, finds agreement with other authors. Considering that the mean value presented in this work does not include all of the warm-wet season, the actual annual PAR/K↓ ratio is probably higher. The seasonal and monthly values tend to agree well with those of Udo and Aro (1999a) from Nigeria, which is likely due to similar measurement techniques, as well as the tropical locations. In this study, the mean daily PAR/K↓ ratio for the warm-wet (rainy) season was 2.097 mol MJ^{-1}, comparing favourably with the rainy season value reported by Udo and Aro (2.12 mol MJ^{-1}). During the hot-dry season, when conditions were not only generally cloudless, but also under the influence of pyrogenic aerosols from regional biomass burning, the mean daily value was 1.945 mol MJ^{-1}. Udo and Aro present a value of 1.94 mol MJ^{-1} for the portion of the dry season at Ilorin, Nigeria that was under the influence of the Harmattan dust and pyrogenic aerosols from local biomass burning. It is known that high dust and aerosol loading tends to decrease the PAR/K↓ ratio (Miskolczi *et al.*, 1997). However, Udo and Aro note that the attenuation of global solar radiation by Harmattan dust is known to be non-waveband selective, and thus would not influence the PAR/K↓ ratio. This helps confirm the role played by pyrogenic aerosols in reducing the magnitude of the PAR/K↓ ratio. Therefore, the combination of reduced cloudiness and the influence of pyrogenic aerosols led to substantially reduced PAR/K↓ values during the hot-dry season at Lusaka.

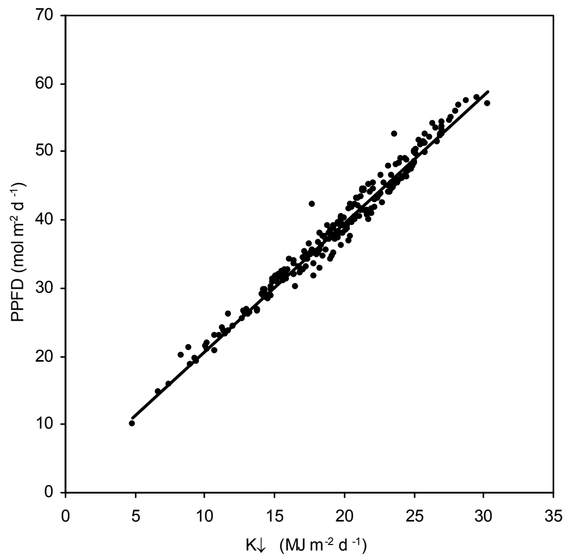

Figure 2. The relationship between daily PAR and K↓ at Lusaka, Zambia from April to December 2000. The best fit line is given by y = 1.8807x + 1.9749, r^2 = 0.9761, n =241.

4. CONCLUSIONS

This study presents the temporal variation in K↓ and PAR at Lusaka, Zambia. A strong positive correlation between them is demonstrated. The mean daily PAR/K↓ ratio decreased during the cool-dry season, decreased then increased during the hot-dry season, and increased in the warm-wet season. This variation was mainly due to trends in cloudiness and the associated atmospheric moisture associated with the movement of the Hadley cell circulation system. However, the role of pyrogenic aerosols is found to be unequivocal and considerable. Although the magnitude of the clearness index affects the PAR/K↓ ratio, it cannot be used as a predictive tool by itself. When present, pyrogenic aerosols tended to influence the PAR/K↓ ratio, resulting in considerable decreases in the ratio during the peak biomass burning period. Local climatic factors are major determinants of the temporal trend in the PAR/K↓ ratio, and the role of cloudiness, atmospheric water vapour and aerosols merit attention in PAR and PAR/K↓ regimes at this location.

5. ACKNOWLEDGMENTS

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