# Analysis of Data on Net Longwave, Shortwave, and Global Radiation During a Transition Period in a Tropical Station in Southwestern Nigeria.

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## ABSTRACT

This paper examines the distribution of the surface radiation balance components measured during the Nigerian Micrometeorological Experiment (NIMEX-1), a field study conducted to measure surface heat fluxes in the boundary layer during the transition period which marks the end of dry season and the onset of wet season (February 15 and March 10, 2004) in the southwestern part of Nigeria. Regression equations were obtained using the daily average values and hourly mean values between net shortwave and net longwave radiation, respectively, with the global radiation. Higher correlations with low standard error of measurement were obtained for daily mean values than the hourly mean. It was also observed that the peak values of each type of radiation during the period occurred, on average, two hours after noon when it was expected to occur.

(Keywords: Nigerian Micrometeorological Experiment, NIMEX-1, heat fluxes, regression, equations)

## INTRODUCTION

Radiation balance at the surface of the Earth is composed of four spectral radiant fluxes; the incoming shortwave (0.15 - 4μm) radiation that arrives from sun ($R_S\downarrow$), the amount of this energy that is reflected from the surface ($R_S\uparrow$), the incoming longwave (less than 4 μm) radiation from the atmosphere ($R_L\downarrow$), and the amount of longwave radiation emitted from the surfaces ($R_L\uparrow$). The net radiative flux, Rn, is represented as follows:

$$Rn = (R_S\downarrow - R_S\uparrow) + (R_L\downarrow + R_L\uparrow) \quad \textbf{(1)}$$

Out the four terms, the two incoming fluxes ($R_S\downarrow$ amd $R_L\downarrow$) are relatively independent of surface conditions (vegetation, bare soil). On a cloud-free day, solar radiation and the atmospheric longwave radiation are approximately the same and are often used interchangeably such that (at the same elevation and air mass) either measurement of the incoming radiation could be considered representative for the entire area. However, the outgoing terms are highly dependent on surface conditions (Al-Riahi et al., 1988; Jackson et al., 1985; Jegede et al., 2004).

The purpose of this work was to investigate the pattern of variation of the global and net shortwave radiation ($R_S\downarrow$ - $R_S\uparrow$) and net longwave radiation ($R_L\downarrow$ + $R_L\uparrow$) and further develop the empirical regression equations between global radiation and net solar radiation; and net longwave radiation respectively during a transition period over tropical and research agricultural farm in the southwestern part of Nigeria.

The climate of the tropical West Africa is characterized by the interplay between monsoon and Harmattan winds which meet at the Intertropical Convergence Zone. Moist south-westerly winds transport rainfall into Nigeria from the Atlantic Ocean across the Gulf of Guinea coast. Close to the surface, this moist airstream has the potential to penetrate beyond Nigeria as far as the southern border of the Sahara Desert near $20^o$ latitude and however diminishes in intensity as it moves away from the Gulf of Guinea.

This airstream is overlain by a hotter and drier north-easterlies airstream which originates from above the Sahara. Globally, the zone at the surface which separates the south-westerlies from the north-easterlies has been variously called Intertropical Convergence Zone (ITCZ), the Inter Tropical Front (ITF), and the Inter Tropical Discontinuity (ITD). The position of the ITD fluctuates seasonally. In this context we speak of the wet season, which roughly lasts from April to

October in this area. The dry season from November to March is determined by winds blowing from NE directions, bringing a cold, dry and often dusty continental air mass from the Saharan desert or Sub-Saharan regions. These north-easterly trade winds are locally known as Harmattan (Adedokun 1978; Balogun 1981; Nieuwolt 1982).

## DATA COLLECTION AND INSTRUMENTATION

The data was collected during one of the first series of field investigations of surface heat flux measurements (NIMEX-1,-2 and -3) conducted by the Nigerian Micrometeorological Experiment (acronym name is NIMEX).

The experiment was conducted between February 15 and March 20, 2004 (which were Julian days from 56 to 70), a transition period that was characterized with a feature of dry season changing to wet season.

The study was carried out at the Teaching and Research Farm of the Obafemi Awolowo University, Ile-Ife located on Latitude 7.77$^o$N and Longitude 4.56$^o$E. At the commencement of the field measurement, the bushy surface was almost cleared and prepared for the investigations. But towards the end of the measurement period, about 2$^{nd}$/3$^{rd}$ March 2004, the study surface was covered by a short grass (growing). This definitely meant that the surface roughness, $z_o$, varied during the period from about 0.5cm to 3.0cm. The surface conditions of the site can simply be characterized as a typical agricultural farmland in a rural location. The surface albedo ranged from 0.10 and 0.20.

The measurement of the components of both the incoming and outgoing short- and longwave radiation by using a well-calibrated Kipp and Zonen CNR-1 net radiometer while the global radiation measurement was obtained by a Kipp and Zonen Pyranometer (model CM21).

The response time of the radiometer is about 30seconds. The field data was collected by the use of a datalogger (Campell Scientific, model CR10X) as an half an hour (30 minutes) averages.

## DISCUSSION/ DATA ANALYSIS DISTRIBUTION PATTERN OF VARIATION OF RADIATION

Figures 1, 2, and 3 represent the distribution of the daily average of mean hourly global radiation, Rg, net longwave, Rnl and net shortwave radiation, Rns measured respectively from a bare surface interspersed with short grasses, during the transition period from the dry season to wet season in a tropical humid station (February 15 – March 16).

The time of occurrence of the peaks of the global radiation for all the days under consideration staggered between 13.00Hr and 14.00Hr (see Figure 1). The maximum value of 972.5Wm$^{-2}$ was recorded on the 62$^{nd}$ (i.e. March 3, 2004). On this day there was a slight drizzle at about 19.30Hr. The minimum value of about 4.25Wm$^{-2}$.(except on the 62$^{nd}$ day when we have 0.0Wm$^{-2}$) was recorded for almost all the days (about 69% of the days) in the early morning (07.00Hr) while an average of 28.5Wm$^{-2}$ was recorded in the late afternoon. The respective values for the late afternoon were observed to be higher than that of the early morning for each of the transition period.

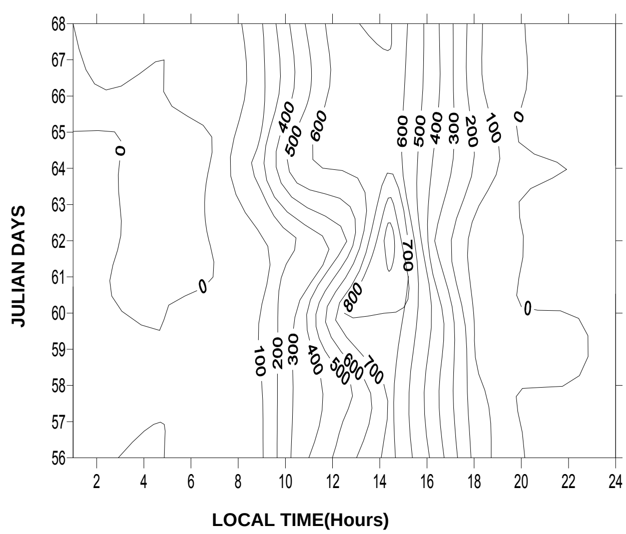


**Figure1:** Distribution of Daily Average of the Hourly Global Radiation (wm$^{-2}$hr$^{-1}$) During the Transition Period (February 15–March 10, 2004).

Figure 2 shows the distribution pattern of the net shortwave radiation ($k^* = k_\downarrow - k_\uparrow$ ). This is similar to the pattern of global solar radiation. In the early morning, it was observed that the upward flux ($k_\uparrow$) predominate during the period with the minimum values ranging between 0.33Wm$^{-2}$ and 1.94Wm$^{-2}$ (except on the days 60$^{th}$ (0.0337 Wm$^{-2}$) and 65$^{th}$ (0.13144 Wm$^{-2}$). The values appreciate to different maximum values occurring between 1300Hr and 1400Hr for all the days during the period of this study. The maximum value for each day ranges between 452.16 Wm$^{-2}$ and 795.90 Wm$^{-2}$.

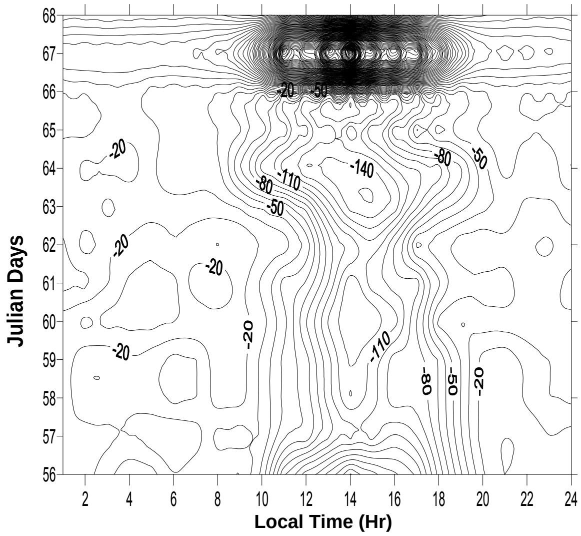


**Figure 2:** Distribution of Daily Average of the Hourly Net Longwave Radiation (wm$^{-2}$hr$^{-1}$) During the Transition Period (February 15-March 10, 2004).

Figure 3 depicts the distribution pattern for the net longwave radiation for the transition period. As it is expected, net longwave radiation unlike the global and net shortwave radiations prevails throughout the day, that is, it occurs both during the daytime and the nighttime. It is extremely low during the nighttimes and high during the daytimes. All through the period, the net longwave is directed upwards. At nighttime, the minimum value was 5.7 Wm$^{-2}$ and this appreciates to 11.3 Wm$^{-2}$ as the day break (0700Hr). The maximum value for each day ranges from 111.96 Wm$^{-2}$to 171.57 Wm$^{-2}$and the time of occurrence was not exactly the noon time but staggered between 1300Hr and 1400Hr. At the evening time the value has decreased to values between 28.70 Wm$^{-2}$ and 82.8 Wm$^{-2}$ (the decrease continue into the night period).

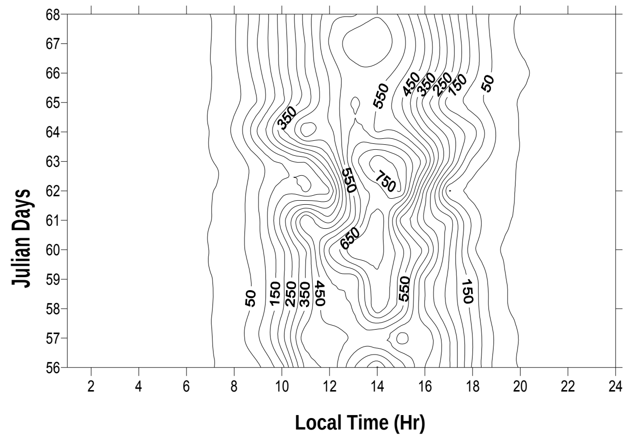


**Figure 3:** Distribution of Daily Average of the Hourly Net Shortwave Radiation (wm$^{-2}$hr$^{-1}$) During the Transition Period (February 15-March 10, 2004).

The diurnal variation of the mean daily ambient temperature, global, net solar and net longwave radiation is plotted and shown in Figure 4. It is seen from the figure that the ambient temperature and net shortwave radiation follow the same pattern of variation with the global radiation but the net longwave radiation gave an inverse variation with global radiation. The highest values of 219.90 Watt/m$^2$, 178.05 Watt/m$^2$ and 75.25Watt/m$^2$, respectively, obtained both for global radiation, the net shortwave radiation and net longwave radiation occurred on the 65$^{th}$ day.

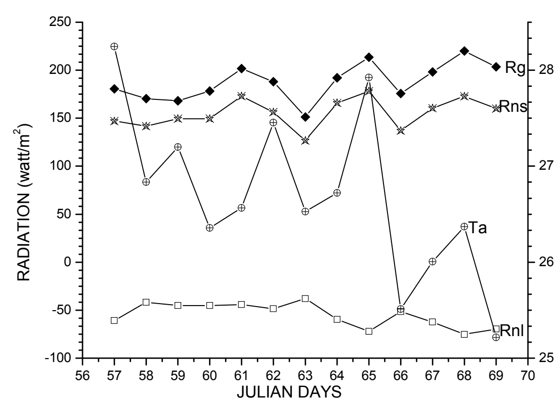


**Figure 4:** Daily Average of the Mean Hourly Distribution of (a) Global Radiation (b) Net Shortwave Radiation (c) Net Longwave Radiation and (d) Ambient Temperature.

The ambient temperature attains a maximum value of 28.2$^{o}$C on the 56$^{th}$ day. The minimum value of 25.0$^{o}$C was recorded on the 66$^{th}$ day; on this day, the synoptic condition for this day reveals a turbid condition, characterized by an all day low-level fog in the morning with cool stratus cloud.

The dynamic of the atmosphere particularly in terms of cloud formation is obvious in the variation pattern of the radiations. The investigation was carried out during a transition from the dry season to wet season. This change of season occurs in association with the Meridional movement of the International tropical Discontinuity (ITD) line and associated with it are the recognized weather zones (Hastenrath, 1991). During the months of May/June, which, is at the onset of the wet season, Ile-Ife, which is at about latitude 7$^{o}$N lies within the Zone B (extends 200-400Km south of the surface position of the ITD) which is characterized by suppressed convection resulting into cumulus clouds and precipitation which is limited to light showers (Jegede, Ogolo and Aregbesola,2004). The weather manifestation at this period explains adequately the reason for the observation in both the daytime and nocturnal values.

## DEVELOPMENT OF CORRELATION

In this work regression equations and correlation coefficients were developed between global and net longwave; shortwave radiation, respectively. Correlation between global and net longwave radiation have been reported in literatures (Omar, 1971; Reddy, 1971; Guerrini, 1978) and that between global and net shortwave radiation (Al-Riahi, 1988).

Figure 5 is the correlation of the mean hourly values of (a) global radiation and the net longwave radiation (b) global radiation and the net shortwave radiation during the transition period. From the diagram the correlation between daily average of the mean hourly net longwave radiation and net shortwave radiation respectively with global radiation during the transition period is established in this work as follows:

(1) The mean hourly global, Rg and net longwave, Rnl radiation during the transition period between dry and wet season are correlated (see Figure 6a). Using a computerized linear regression technique, an equation describing the relationship between the net longwave and global radiation was determined as:

$$Rnl = -0.0445-25.526Rng\ (Wm^{-2}) \qquad \textbf{(2)}$$

While a weak and negative correlation coefficient of -0.29 was obtained; however, a better correlation was obtained between the mean hourly global, Rgh and net shortwave, Rnsh radiation. Also, by the same mean of linear regression, an equation is found to be

$$Rns = 0.833 - 0.937\ Rng\ (Wm^{-2}) \qquad \textbf{(3)}$$

Unlike the net longwave radiation, a high and a positive correlation of 0.993 was obtained.

Figure 6(a) is the correlation of the daily average of the mean hourly between (a) global radiation and the net longwave radiation (b) global radiation and the net shortwave radiation during the transition period.

(2) The daily average of the mean hourly global radiation, Rg was plotted respectively with net longwave, Rnl and net shortwave radiation (see Figure 6(a) and (b), the resulting regression equations and correlation coefficient are given below:

Figure 6a is the scatter plot of the net longwave (Rnl) against the global (Rg) radiation, and an equation establishing a relationship between the two was found to be:

$$Rnl = -0.0445 - 25.526Rng\ (Wm^{-2}) \qquad \textbf{(4)}$$

with an improved negative correlation coefficient, R of -0.83 having a negative intercept of 0.04454 This indicates the fact that there is an inverse relationship between net longwave radiation and net shortwave radiation.

Figure 6b is the scatter plot of net shortwave against global radiation for the period. The regression equation deduced is:

$$Rns =- 2.81228 + 0.8417Rng\ (Wm^{-2}) \qquad \textbf{(5)}$$

While the correlation coefficient, R is 0.999 which is approximately better than that for the mean hourly variation.

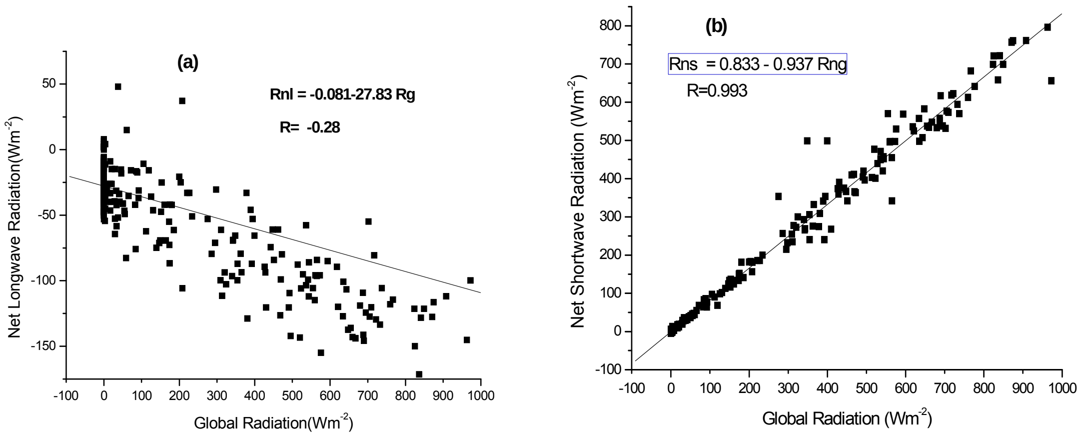


**Figure 5:** The Correlation of the Mean Hourly (a) Global Radiation and the Net Longwave Radiation (b) Global Radiation and the Net Shortwave Radiation During the Transition Period.

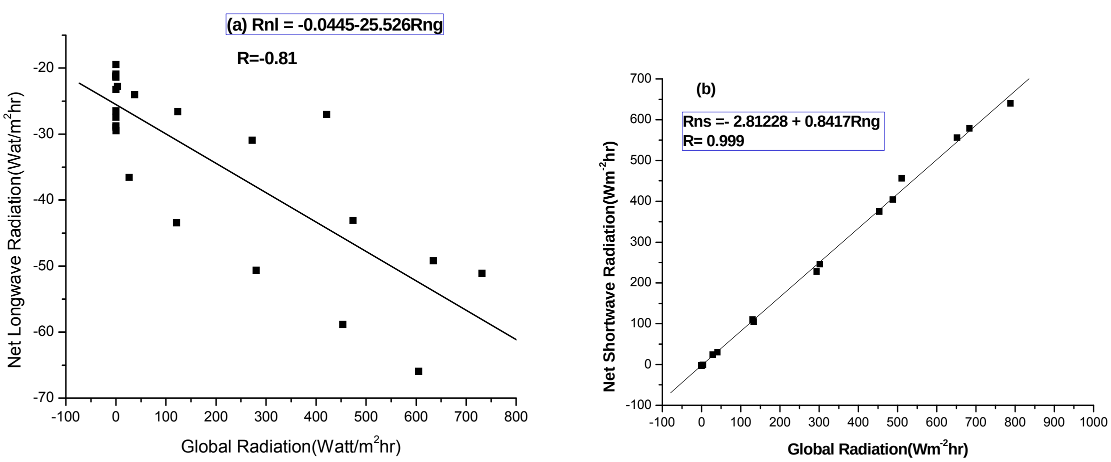


**Figure 6:** The Correlation of the Daily Average of the Mean Hourly (a) Global Radiation and the Net Longwave Radiation (b) Global Radiation and the Net Shortwave Radiation During the Transition Period.

From the above results, it is observed that on the hourly basis, the correlation coefficient between global radiation and net longwave radiation is extremely low (R =- 0.28) when compared with the average daily value which is -0.83. Both the correlation coefficients of 0.993 and 0.999 were found between the net shortwave and the global radiation for hourly means and daily means respectively. It is also observed that the daily means relatively compete effectively with the hourly means but with an insignificance difference, unlike the case between global and net shortwave just discussed above. In addition to the higher correlation coefficients observed for the daily mean, the standard error of measurement too, for both radiations were low (see Table 1 and 2). The reason for this observation may be attributed to the combined effect of the mean weather condition which represents both the clear and the cloudy days.

The observed high correlation between global radiation and net shortwave is an indication of low cloud covers and a strong dependence on albedo (Chacko et al., 1968; Chacko, 1973, Binattacharya et al., 1996) during the period and that the net shortwave radiation may be taken as an approximate representation of global radiation for the area (because correlation coefficient is approximately equals unity). It is also observed from the results (Tables 1 and 2) that a better relationship of a relatively high correlation coefficient is obtained for a daily average values than for hourly mean values between both radiations (net shortwave and net longwave) and global radiation. This observation also agree with a similar study which confirmed that the correlation between the daytime net radiation and shortwave radiation is better for monthly mean values than for clear day values (Polavarapu, 1970).

The net longwave radiation is function of air temperature, cloud cover and emissivity of the earth surface and the severe effect of any of these factors is assumed to determine their mean values for any given period of time. The synoptic weather observations recorded during the period shows that the average temperature is 26.7$^{o}$C with a high frequent occurrence of turbidity. During the period, low level fog and the associated poor visibility were experienced in the early morning hours. The net longwave loss from the surface from the surface is lower on a mean weather day than on a clear day for a given shortwave radiation. This due to the additional radiation from clouds in the atmosphere window thus, increasing the atmosphere radiation.

## CONCLUSION

The above results represent typical relationships between the components of net radiation (net shortwave and net longwave radiation) and global radiation. The study was carried out during a transition from the dry period to wet period in a tropical humid environment, that is, Ile-Ife, Nigeria. An empirical relationship was obtained between net shortwave (and net longwave) radiation and global radiation. Higher correlations with low standard errors were observed for the daily mean values than the hourly means. The albedo was recorded during the period was low. The following environmental conditions as regards the radiation balance components and ambient temperature were established for the location, during the transition period (see Table III):

- ❖ net shortwave and the net longwave radiation during the period covered a range of about (2.70-795.90) W/m$^2$ and (7.31-150.05) W/m$^2$, respectively.
- ❖ The global radiation varied between 0 and 972.50 W/m$^2$
- ❖ The ambient temperature was between 20.60 and 38.00 $^{o}$C.

**Table 1:** The Statistical Relationship Between Global Radiation and Net Longwave Radiation.

| | Correlation Coefficient | Regression Constants | | Standard Error |
|---|---|---|---|---|
| | | A | B | |
| Hourly means | -0.29 | -0.081 | -27.83 | ±72.981 |
| Daily means | -0.83 | -0.046 | -25.52 | ±7.288 |

**Table 2:** The Statistical Relationship Between Global Radiation and Net Shortwave Radiation.

| | Correlation Coefficient | Regression Constants | | Standard Error |
|---|---|---|---|---|
| | | A | B | |
| Hourly means | 0.933 | 0.833 | -0.937 | ±26.55 |
| Daily means | 0.999 | -2.812 | 0.842 | ±5.939 |

**Table 3:** Minimum and Maximum Occurrences of Net Shortwave, Net Longwave, Global Radiation and the Ambient Temperature.

| Julian Day | Net Shortwave Radiation (W/m²) | | Net Longwave Radiation (W/m²) | | Global Radiation (W/m²) | | Ambient Temperature (°C) | |
|---|---|---|---|---|---|---|---|---|
| | Min. | Max | Min. | Max | Min. | Max | Min. | Max |
| 56 | 3.25 | 658.1 | 9.79 | 171.56 | 0 | 836.00 | 22.87 | 36.07 |
| 57 | 3.05 | 457.18 | 10.07 | 111.96 | 0 | 544.05 | **20.60** | 34.59 |
| 58 | 4.88 | 699.12 | 12.31 | 121.40 | 0 | 823.50 | 20.89 | **38.00** |
| 59 | 5.13 | 675.44 | 14.88 | 116.85 | 0 | 849.00 | 21.83 | 34.03 |
| 60 | 3.05 | 761.47 | 9.08 | 116.36 | 0 | 908.00 | 22.62 | 34.22 |
| 61 | 2.85 | 757.01 | **7.31** | 127.68 | 0 | 871.00 | 22.87 | 25.47 |
| 62 | **2.70** | 760.91 | 9.08 | 116.36 | 0 | **972.50** | 22.96 | 33.55 |
| 63 | 3.46 | **795.90** | 24.81 | **150.05** | 0 | 963.00 | 23.65 | 32.88 |
| 64 | 3.20 | 616.75 | 13.48 | 145.84 | 0 | 689.90 | 22.41 | 34.56 |
| 65 | 3.15 | 612.27 | 22.73 | 118.04 | 0 | 759.50 | 22.41 | 34.56 |
| 66 | 3.10 | 576.26 | 26.22 | 127.43 | 0 | 709.70 | 23.07 | 35.17 |
| 67 | 3.41 | 641.02 | 38.43 | 114.03 | 0 | 794.50 | 21.23 | 31.21 |
| 68 | 4.41 | 594.30 | 34.75 | 136.18 | 0 | 732.50 | 20.06 | 33.68 |

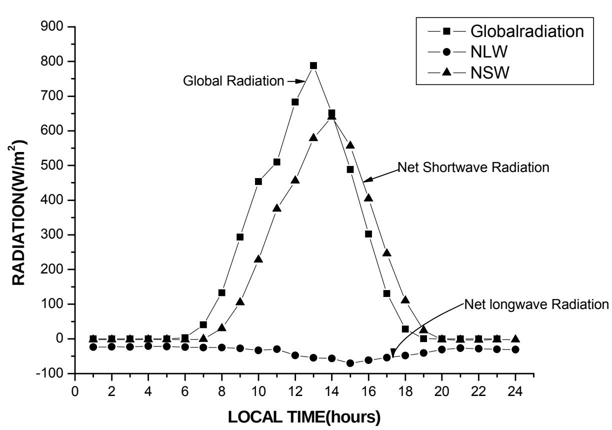


**Figure 7:** Distribution of Daily Average Hourly Global, Net Shortwave and Net Longwave Radiation ($Wm^{-2}hr^{-1}$) During the Transition Period (February 15-March10, 2004).

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## SUGGESTED CITATION

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