https://dx.doi.org/10.4314/ijs.v22i2.11

EVALUATION OF THE PERFORMANCES OF TWO REBS NET RADIOMETER DESIGNS DURING NIMEX AT A TROPICAL SITE IN ILE-IFE, NIGERIA

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(Received: 19th August, 2019; Accepted: 24th May, 2020)

ABSTRACT

In this study, the performances of two types of Radiation Energy Balance Systems (REBS) net radiometers, a domed (model Q-7.1) and domeless (model NR-LITE) against a reference, four-component net radiometer (model NR01), are evaluated during the conduct of Nigeria Micrometeorological Experiment (NIMEX) held between May 27 and June 12, 2013 at a tropical location in Ile-Ife, Nigeria. During the daytime, net radiation measurements made by NR-LITE and Q-7.1 showed good agreements with NR01, with coefficient of determination for both > 0.90. The values of the mean and standard deviation for daytime net radiation as measured by NR01, NR-LITE and Q-7.1 were 257.7 ± 174.7 W m^{-2}, 179.6 ± 129.3 W m^{-2} and 240.6 ± 153.1 W m^{-2}, respectively. At nighttime, NR-LITE net radiometer responded to longwave radiation better than Q-7.1. Adjustments made by linear regression of NR-LITE and Q-7.1 datasets with NR01 produced better fit. Though costs of the two REBS type net radiometers are comparatively the same, Q-7.1 performed better than NR-LITE. However, for long-term operation, the Q-7.1 type requires periodic (every 2-3 months) changing of the plastic domes due to ageing and cracking, unlike the NR-LITE. So, the NR-LITE is a preferred option to be adopted by the Weather Services in West African countries for routine measurements of net radiation because it does not require periodic changing of the plastic domes.

Keywords: Net radiation; REBS net radiometers; 4-component net radiometer; tropical location.

INTRODUCTION

Accurate and short-period (~1 min.) measurements of net (all-wave) radiation balance is very important to evaluate closure of all the energy fluxes (radiative, sensible, latent and ground heat) at the surface, and to determine the available energy driving the surface-atmosphere energy exchange processes (Foken 2008a).

In West Africa (and is generally true of the tropical areas), manifestations of transient convective clouds during daytime are indicative of short period fluctuations in the values of the net radiation (Jegede *et al.* 2006; Kothe and Ahrens 2010). As such, for micrometeorological investigations, measurements of absolute values of net radiation demand use of a fast response and accurate sensing system (net radiometers) and efficient datalogging. Presently in the sub-region, short periods (1 min. averages) net radiation data are still very scarce (Ayoola *et al.* 2014). This problem persists because of the inadequate technical infrastructures and low human capacity within the national meteorological services in the region. Added to this is lack of capacity to deploy, maintain and integrate digital data acquisition systems.

Net radiation at the surface, R_N can be determined as algebraic sum of the shortwave (~0.15 - 4.0 μm) and longwave (3.0 - 100 μm) radiation components; given as:

$$R_N = R_{S\downarrow} + R_{S\uparrow} + R_{L\downarrow} + R_{L\uparrow} \qquad (1)$$

where, R_N is the net (all-wave) radiation, $R_{S\downarrow}$ is the incoming short-wave (or solar) radiation, $R_{S\uparrow}$ is the outgoing (reflected) short-wave radiation, $R_L\downarrow$ is the incoming long-wave (sky) radiation and $R_{L\uparrow}$ is the outgoing (terrestrial) long-wave radiation. Using empirical models, calculations of net radiation determined by magnitudes of the terms appearing in Eq. (1) require dedicated and consistent datasets (Offerle *et al.* 2003; Jegede *et al.* 2006; Kjaergaard et al. 2009). This is still a challenge for most areas in West Africa.

Routine measurement of net radiation on component-by-component basis is elaborate and expensive to maintain on a long time basis. For the direct measurement of net radiation, basically there are two types of design for net radiometers: an all-wave (0.25 μm – 60 μm) radiometer or a combination of radiation sensors that measure individual components of the solar (shortwave) and atmospheric (longwave) radiation as shown in Eq. (1) above (see Fritschen and Fritschen 1991; Blonquist *et al.* 2009).

Several authors (Halldin and Lindroth 1992; Duchon and Wilk 1994; Kustas *et al.* 1998; Brotzge and Duchon 2000; Cobos and Baker 2003; Blonquist *et al.* 2009) have evaluated the performances of both types of net radiometers. The integrated net radiometers (commonly known as pyradiometers) are compact and reasonably affordable instrumentation by which measurements of net radiation can be made continuously on a long-term basis (Ayoola et al. 2014). Recent improvements, both in the design and in manufacturing, of pyradiometers show systematic error of less than 10 % of absolute values (Oliver and Wright 1990; Halldin 1991; Foken 2008b). It is highly recommended for micrometeorological investigations that separate measurements of solar and atmospheric radiation components be made for reliable and accurate determination of the value of net radiation (see Halldin and Lindroth 1992; Duchon and Wilk 1994; Kustas *et al.* 1998; Kohsiek *et al.* 2007; Foken 2008b; Blonquist *et al.* 2009). However, the 4-component varieties relatively are more expensive (Blonquist *et al.* 2009).

The Q-7.1 net radiometer (manufactured by Radiation and Energy Balance Systems (REBS), Inc., Seattle, WA, USA) is a fairly old sensor since the Campbell Scientific Inc. (CSI), USA commercially introduced it in mid 1990s (it has ceased to be marketed as from 2014). The sensing head is a 60-junction high output thermopile covered by clear plastic (polyethylene) domes and is unasphyrated (Manual for Q-7.1 net radiometer, 1996). The plastic domes require periodic replacements (2 - 3 months intervals) due to cracking. As such, it requires regular inspection to spot ageing/degradation of the plastic windshields (domes). To prevent dew condensation inside the domes, a dessicator tube is placed in the support frame to keep the air inside dry. The domed sensing head is integrated with a ball joint at its neck to allow for easy adjustment of the spirit level without disturbing the clamps to the mast. The manufacturer provides separate sensitivity factors for the positive and negative values of the net radiation (that is, for the daytime and nighttime conditions). In the case of strong wind conditions (> 5 m/s), a correction factor is provided to compensate for convective cooling of the detector surface. Application of this correction is not tangible at Ile-Ife in the sense that low wind regime persists (the mean wind speed is less than 1.5 m/s). A specification for the Q-7.1 net radiometer is listed in the Table 1.

The NR-LITE net radiometer is a domeless-type manufactured by Kipp & Zonen B.V., Delft, Netherlands and marketed by CSI. The year of its introduction was ca. 2003 and currently, it has been replaced by the NR-LITE2, retaining essentially the same design as the previous model. The sensor is a thin thermopile with slightly cone shaped, up- and down-ward looking surfaces. It is relatively easy to maintain (cleaning-wise) because the sensor surface is coated with *Teflon*. Therefore, it is suitable for relatively long term unattended operations. The slim design of the sensor head ensures minimal radiative heat loss and thermal convection (Manual for NR-LITE net radiometer 2006). The flattened top and bottom surfaces make for improved cosine response. The manufacturer supplies a sensitivity factor for both positive and negative measurements of net radiation by the sensor. An equation is provided to correct for the measurement errors (adjustment) occasioned by the sensitivity of the sensor to the high wind speeds. The NR-LITE is slightly less accurate than the more traditional type net radiometers which use plastic domes due to the Teflon coating of its sensor surface (Manual for NR-LITE net radiometer, 2006). Details of the NR-LITE net radiometer are contained in Table 1.

Table 1: Specifications sheet for NR-LITE, Q-7.1 and NR01 (4-component type) net radiometers.

Model/Type of Net Radiometer	Costs (approx.)	Sensitivity/Accuracy	Response time (s)	Serial No.	$^{+}$Response to SW (0.2 - 1.0 μm)	$^{+}$Response to LW (1.0 - 100 μm)
Q-7.1 (REBS) Campbell Scientific	\$1200	9.6 Wm^{-2}/mV (+ve values); 11.9 Wm^{-2}/mV (-ve values)	~30	Q94193	good	poor
NR-LITE (REBS) Hukseflux	\$1600	14.00μV/Wm^{-2}	~30	093242	good	good
NR01 (4-component) Hukseflux	\$4200	SR01-Up (15.5 μV/Wm^{-2}) & SR01-Down (15.6 μV/Wm^{-2}). IR01-Up (9.9 V/Wm^{-2}); IR01-Down (8.2 μV/Wm^{-2})	18	1182	good	Very good

Notes

REBS: Radiation Energy Balance System

+ Instrument manual

In the present study, two different designs of commercially available REBS type net radiometers described above: one with polystyrene domes (model Q-7.1) and another, domeless (model NR-LITE), were set up in the field. Measurements with these instruments were compared to that made by the four-component net radiometer, model NR01, chosen as the reference. The aim of the field study was to determine which of the two REBS types of net radiometers (domed and domeless) has better accuracy and performance. Another objective was to test the reliability of integrated (all-wave) net radiometers in use in West Africa.

Net radiation measurements at the NIMEX site

The Nigeria Micrometeorological Experiments (NIMEX) is a series of field investigations of the mean and turbulent characteristics of atmospheric surface layer conducted at selected sites in Obafemi Awolowo University campus, Ile-Ife, Nigeria (Jegede *et al.* 2004). Ile-Ife is in the "tropical wet and dry" zone of West Africa with an annual average rainfall between 1000 and 1500 mm. The NIMEX research, which started in 2004, has as objectives determination of balance of the surface energy fluxes (radiative, sensible, latent and ground heat) at the land-surface atmosphere at a tropical location.

As part of NIMEX project held in May/June 2013, surface radiation energy balance system comprising of three net radiometers: NR01, NR-LITE and Q-7.1, respectively, were set up at measurement site (7.52° N, 4.52° E) near the main bowl of the University sports complex. Arrangement of the radiation balance instrumentation on site is shown in the Fig. 1. Co-located within the same study area were the eddy covariance (EC) and Bowen ratio energy balance (BREB) systems. In addition, weather conditions observed during the period of study were recorded.

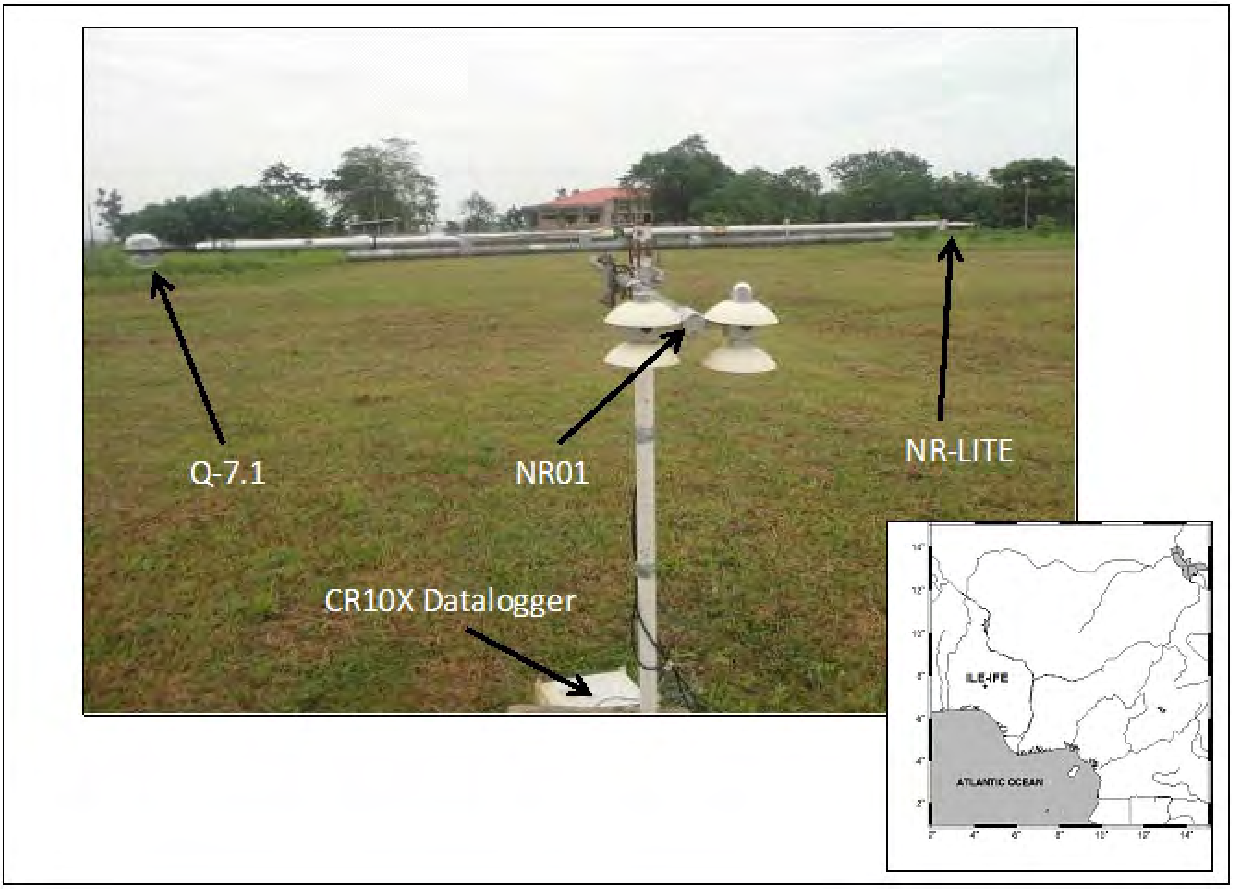
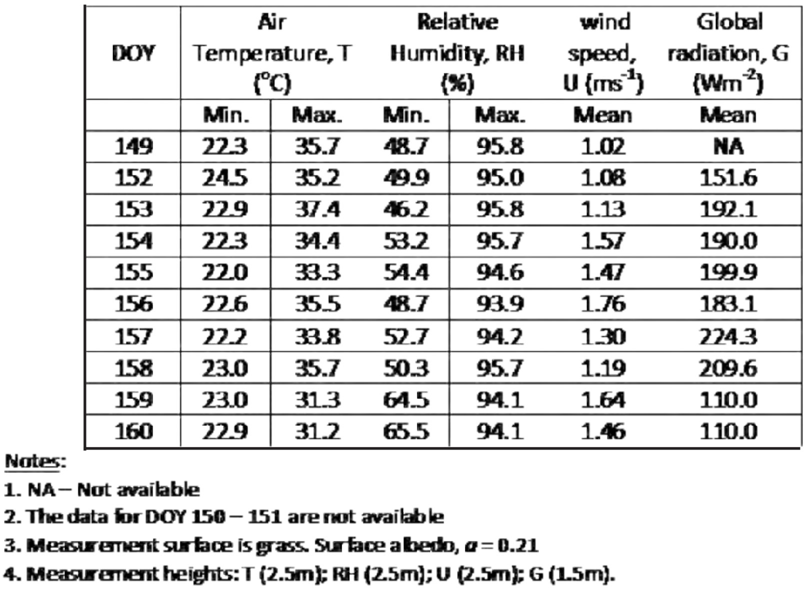


Figure 1: Arrangement of net radiometers (NR01, NR-LITE and Q-7.1) at the measurement site near the Sports Complex of Obafemi Awolowo University (OAU), Ile-Ife, Nigeria. In the insert is the map of Nigeria showing Ile-Ife (7.52° N, 4.52° E).

The period while the radiation measurement was taken among other meteorological parameters is May 27th to June 12th, 2013. The general weather pattern showed cloudy-sky conditions in daytime and devoid of appreciable precipitation despite being the peak of the rainy season in Ile-Ife. In the same period of observation, the atmospheric condition was warm and humid with the daily ranges for air temperature and relative humidity recorded as 22° C - 37.4° C and 46.2 %-95.8 %, respectively. For the period, the wind speed was low and the mean value ranged between 1.0 ms^{-1} and 1.8 ms^{-1}. The daily average of global radiation at the surface ranged between 110.0 W m^{-2} and 224.3 W m^{-2}. The measurement surface was short-grass ($\leq$ 5 cm) and the albedo, *a*, was 0.21. The weather summary is detailed in Table 2.

Table 2: Meteorological variables recorded at the measurement site in Ile-Ife (7.52° N, 4.52° E) during the observation period, May 29th to June 9th, 2013 (DOY 149 - DOY 160).



DOY	Air Temperature, T (°C)		Relative Humidity, RH (%)		wind speed, U (ms^{-1})	Global radiation, G (Wm^{-2})
	Min.	Max.	Min.	Max.	Mean	Mean
149	22.3	35.7	48.7	95.8	1.02	NA
152	24.5	35.2	49.9	95.0	1.08	151.6
153	22.9	37.4	46.2	95.8	1.13	192.1
154	22.3	34.4	53.2	95.7	1.57	190.0
155	22.0	33.3	54.4	94.6	1.47	199.9
156	22.6	35.5	48.7	93.9	1.76	183.1
157	22.2	33.8	52.7	94.2	1.30	224.3
158	23.0	35.7	50.3	95.7	1.19	209.6
159	23.0	31.3	64.5	94.1	1.64	110.0
160	22.9	31.2	65.5	94.1	1.46	110.0

Notes:

1. **NA – Not available**
2. **The data for DOY 150 – 151 are not available**
3. **Measurement surface is grass. Surface albedo, $\alpha = 0.21$**
4. **Measurement heights: T (2.5m); RH (2.5m); U (2.5m); G (1.5m).**

The three net radiometers were placed at the same height of 1.5 m above grass surface. Orientation of the net radiometers was a T-like formation (see Fig. 1), with the NR01 being in the middle position and facing the north direction. The Q-7.1 and NR-LITE were oriented in east-west direction. The siting of the net radiometers was distant from tall trees, structures and buildings, so as to prevent shadows falling on the sensors. With the aid of integrated spirit level on the housing of the net radiometers, careful adjustments of the sensing heads were done to ensure proper alignment with the horizontal. Every morning, the top and bottom surfaces were cleaned with soft brush and lint-free cloth to remove the fine dust particles settling on the sensing heads.

For Q-7.1 net radiometer, the sensitivities for positive and negative values of net radiation were 9.60 W m^{-2}/mV and 11.90 W m^{-2}/mV, respectively. The sensitivity quoted for NR-LITE net radiometer was 14.00□ μV/W m^{-2}. In the case of NR01, the sensitivities for the top and bottom pyranometers (SR01) were 15.50 μV/W m^{-2} and 15.60 μV/W m^{-2}, respectively. The sensitivities of the two pyrgeometers (IR01), were 9.90 μV/W m^{-2} and 8.20 μV/W m^{-2}, for top and bottom sensors respectively (specifications of the net radiometers are contained in the Table 1).

The net radiometers were connected to a datalogger (Campbell Scientific, CR10X) and programmed using LOGGERNET® software for data acquisition. The data were sampled every 10 secs. and stored as 2-min. averages. Once daily, the data, which is stored in the logger memory, was collected by a portable computer for further processing. The net radiation data was screened for erroneous values due to the instrument malfunctioning (electrical spikes) or out-of-range measurement values were flagged off. Stringent QA/QC procedure was introduced to remove spurious data.

The net radiation data acquired by NR01 (chosen as reference) was compared to measurements obtained both by NR-LITE and Q-7.1 net radiometers. For the comparison, two quantitative parameters *BIAS* and *DIFF* defined below as;

$$BIAS = \frac{\sum_i \left| R_{NR01,i} - R_{REBS,i} \right|}{N} \qquad (2)$$

$$DIFF = \frac{\sum_i \left(R_{NR01,i} - R_{REBS,i} \right)}{N} \qquad (3)$$

were chosen to test the goodness of fit for the data. In Eqs. (2) $R_{NR01,i}$ and $R_{REBS,i}$ respectively represent net radiation data values as measured by NR01 net radiometer and the REBS (i.e., Q-7.1 and NR-LITE) net radiometers. N is the total number of the data points. Linear regression of the measured data by REBS net radiometers with NR01 net radiometer was performed using data analysis software, MicroCal Origin®. The net radiation data acquired for this study covered the period beginning from May 27th to June 12th, 2013 (DOY 147-163).

RESULTS AND DISCUSSION

Two-minute averages (as time series) of net radiation at the study site in Ile-Ife showing the diurnal course for the three net radiometers, Q-7.1, NR-LITE and NR01, are plotted in Fig. 2 for the measurement period May 27th to June 12th 2013. A specific day, May 29th, 2013 (DOY 149) shown in Fig. 3 showed detailed diurnal variation for the three net radiometers. In both figures, the diurnal trends obtained for the three net radiation sensors are similar, both in magnitudes and tendencies. Generally, measurements made with both NR-LITE and Q-7.1 net radiometers were found to show good agreement with values obtained by NR01 net radiometer.

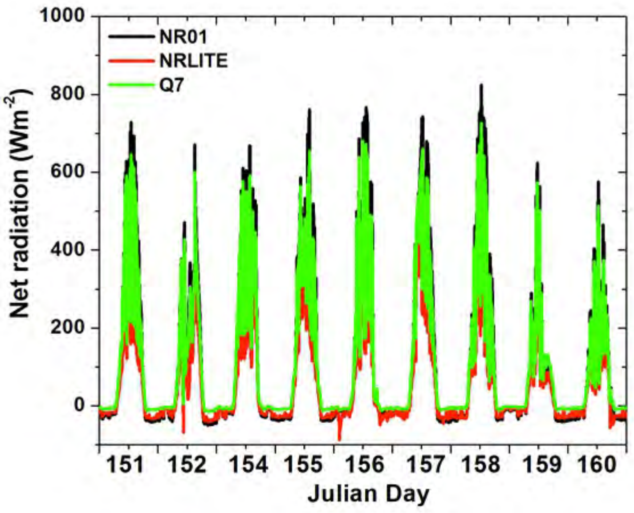


Figure 2: Diurnal variation of net radiation measurements with NR01 (4-component type), NR-LITE and Q-7.1 net radiometers at the measurement site for the period 27th May – 12th June 2013.

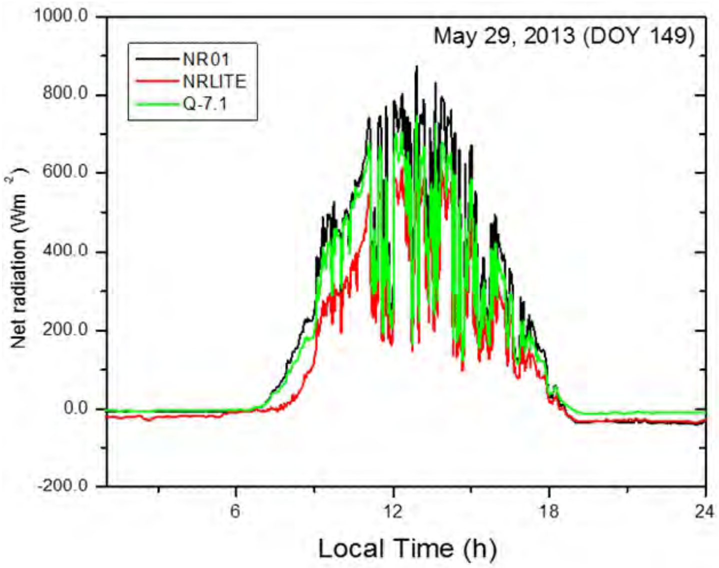


Figure 3: Diurnal variation of net radiation measurements with NR01 (4-component type), NR-LITE and Q-7.1 net radiometers at the measurement site on 29th May 2013 (DOY 149).

For daytime conditions when $R_N > 0$, the values of net radiation measured by the REBS net radiometers (Q-7.1 and NR-LITE) were found to be lower than those obtained by NR01. The percentage errors in the values obtained for Q-7.1 and NR-LITE net radiometers were respectively (0-30 %) and (10-50 %) lower than for NR01. The maximum daytime values of net radiation measured by NR01 was 872.0 W m^{-2} at about 13:00 h. and this was the highest value of the three net radiometers compared. At the same time, the corresponding values of net radiation for Q-7.1 and NR-LITE were 747.0 W m^{-2} and 645.3 W m^{-2} respectively. For nighttime periods, the NR-LITE net radiometer performed better than Q-7.1. The performance by Q-7.1 sensor is found to be poor at nighttime, which suggests that the net radiometer does not show a good sensitivity in the longwave bands (Manual for Q-7.1 net radiometer, 1996).

Comparison of measurements of net radiation by Q-7.1 and NR-LITE with NR01 (reference sensor) for the observation period, June 1st to 9th, 2013 (DOY 152 - 160) are shown as scatter plots in Figs. 4 and 5 for daytime ($R_N > 0$) and nighttime ($R_N < 0$) conditions respectively. The 1:1 line drawn and linear regression relationships were obtained to compare the values of domed and domeless-type net radiometers with NR01. In daytime cases plotted in Figs. 4(a)-(i), it is observed that measurements by Q-7.1 net radiometer compared more favorably to benchmark values of NR01 than values obtained from NR-LITE. The dispersion and outliers in NR-LITE data were worse than what was obtained from Q-7.1 values, which is similar to the observations made by Brotzge and Duchon (2000) and Blonquist et al. (2009). This resulted in lower means and standard deviation in NR-LITE values when compared to NR01 values.

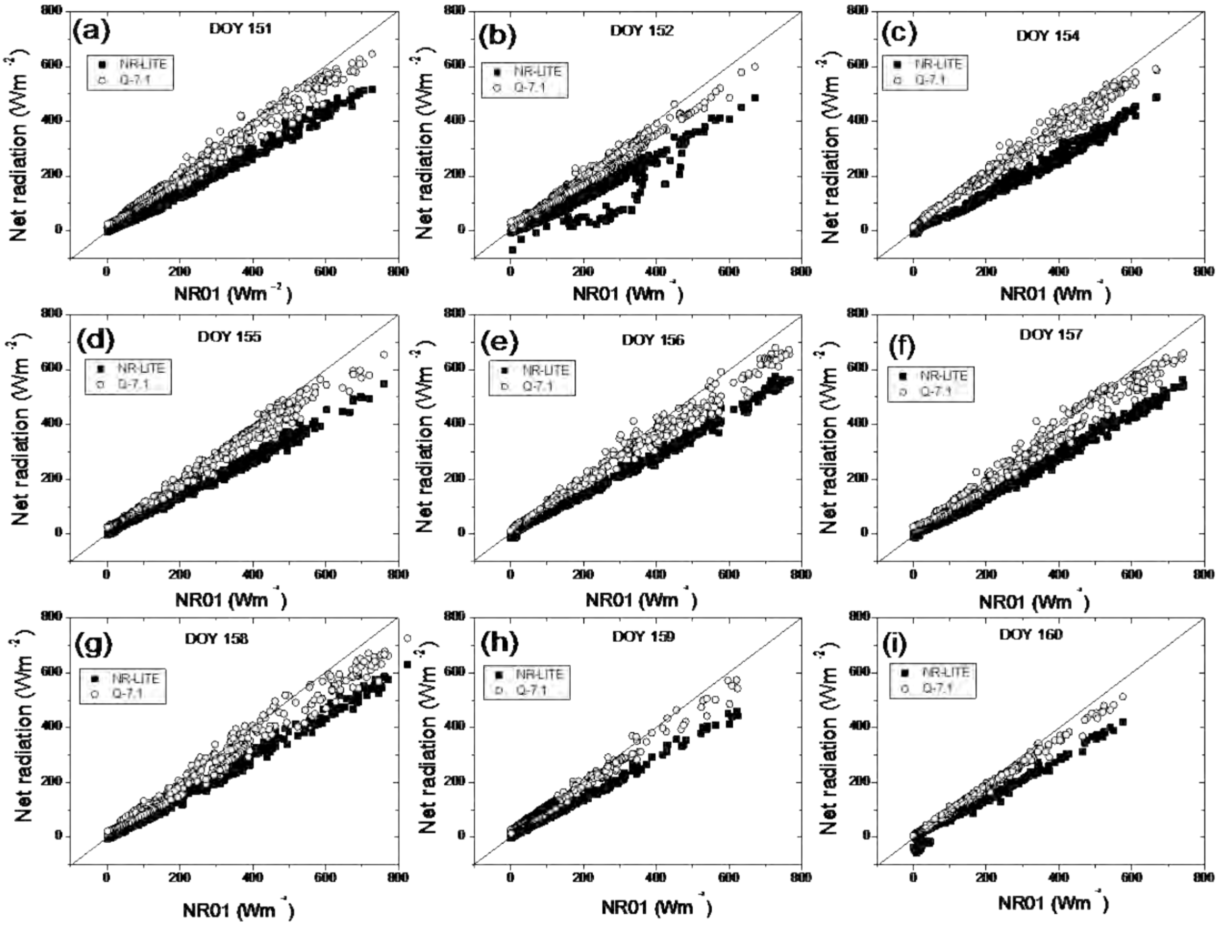


Figure 4: Scatter plots of net radiation measurements for NR-LITE and Q-7.1 net radiometers with NR01 (as reference) for the period: May 31st – June 9th, 2013 (DOY 151 – DOY 160) during daytime ($R_N > 0$).

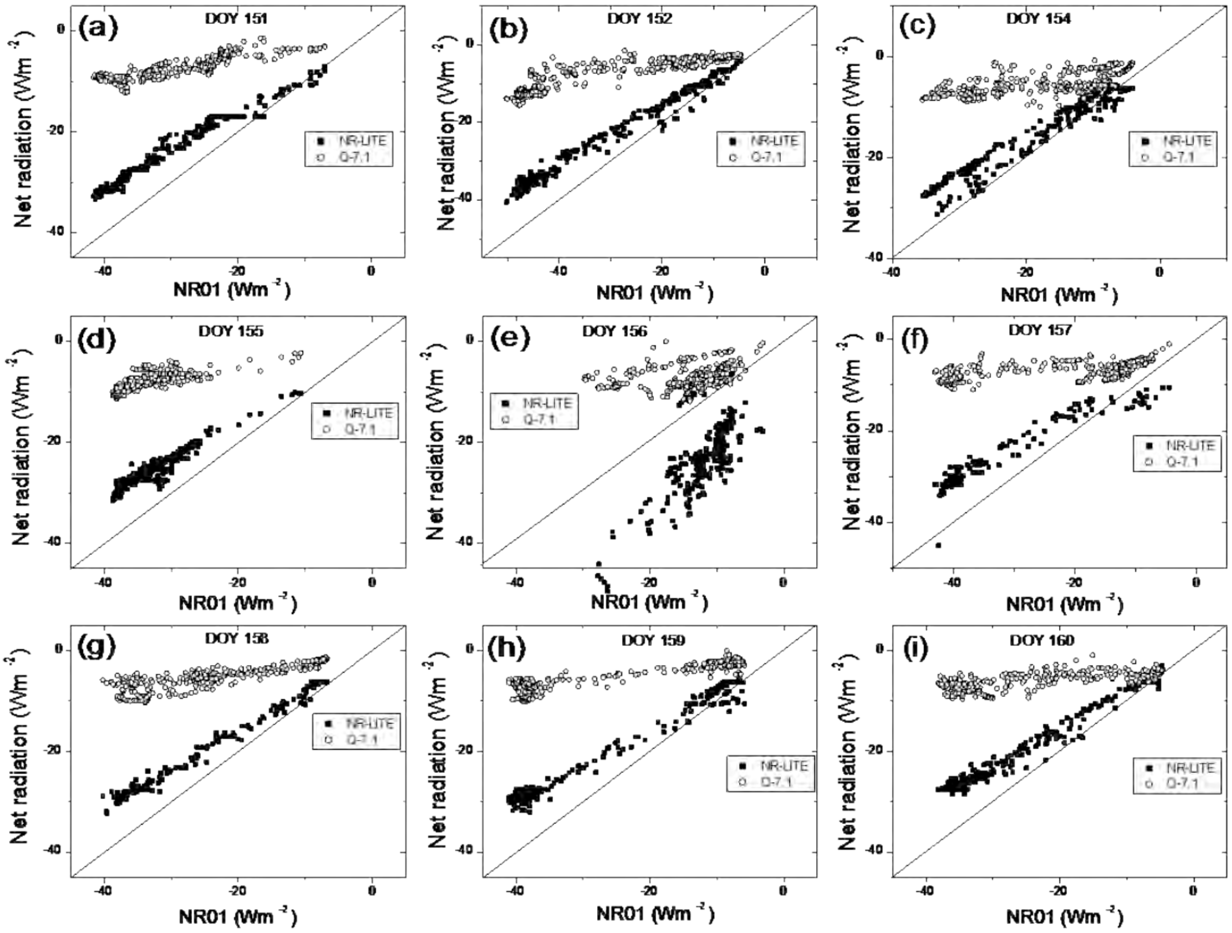


Figure 5: Scatter plots of net radiation measurements for NR-LITE and Q-7.1 net radiometers with NR01 (as reference) on May 31st – June 9th, 2013 (DOY 151 – DOY 160) during nighttime ($R_N < 0$).

For nighttime conditions shown in Figs. 5(a)-(i), the scatter was worse than the daytime for both NR-LITE and Q-7.1. The Q-7.1 data does not show a significant correlation to the NR01.

Fig. 6 shows the scatter plots of residuals of net radiation measurements for (*a*) NR-LITE and (*b*) Q-7.1 net radiometers for the period of May 31st – June 9th, 2013 (DOY 151 – DOY 160) during nighttime conditions. The coefficient of determination, R^2 for the residual of NR-LITE was 0.9639 while that of Q-7.1 was 0.6972. This reinforced the fact that, during the nighttime conditions, NR-LITE closely mirrored the reference measurement of NR01 than Q-7.1 net radiometer.

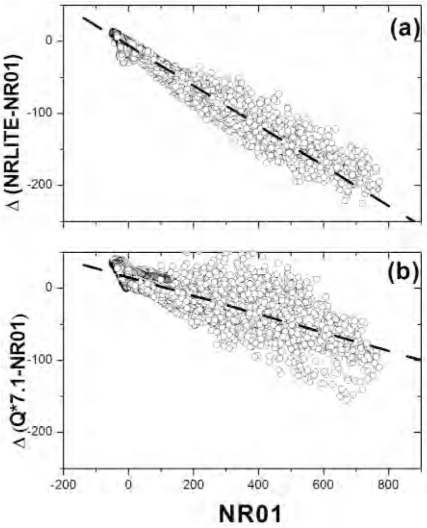
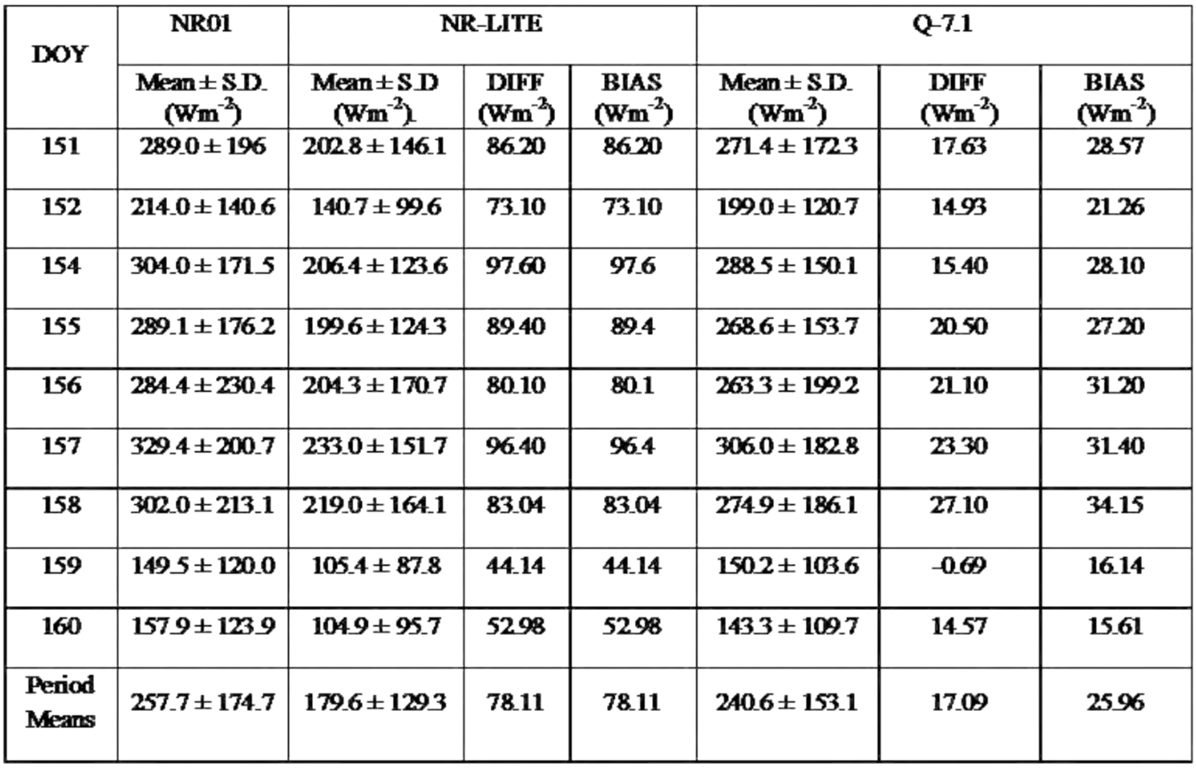


Figure 6: Scatter plots of residuals of net radiation measurements for (a) NR-LITE and (b) Q-7.1 net radiometers for the period: May 31st – June 9th, 2013 (DOY 151 – DOY 160) under nighttime conditions.

For daytime ($R_N > 0$) and nighttime ($R_N < 0$) conditions, computed statistical measures of *DIFF* and *BIAS* (as defined in Eqs. (2) and (3) above) and the mean values with their respective standard deviations from the net radiation dataset (2-min. averages for DOY 151 to DOY 160) are given in the Tables 3 and 4. In daytimes (see Table 3), the mean value of net radiation obtained by Q-7.1 net radiometer (240.6 ± 153.1 W m^{-2}) compared better to NR01 value (257.7 ± 174.7 W m^{-2}) than NR-LITE value (179.6 ± 129.3 W m^{-2}). This then suggests that Q-7.1 values have smaller dispersion than NR-LITE when compared with the NR01 dataset during daytime conditions. The statistical measures, *DIFF* and *BIAS* given in the same Table 3 for the NR-LITE net radiometer were the same value 78.11 W m^{-2}, while for the Q-7.1 net radiometer, these values estimated were 17.09 W m^{-2} and 25.96 W m^{-2} respectively. The lower *BIAS* and *DIFF* obtained for Q-7.1 values clearly indicate a lower departure from the mean benchmark values. These measures (*DIFF* and *BIAS*) quantitatively showed that the performance of Q-7.1 was better than NR-LITE for net radiation measurement during daytime condition.

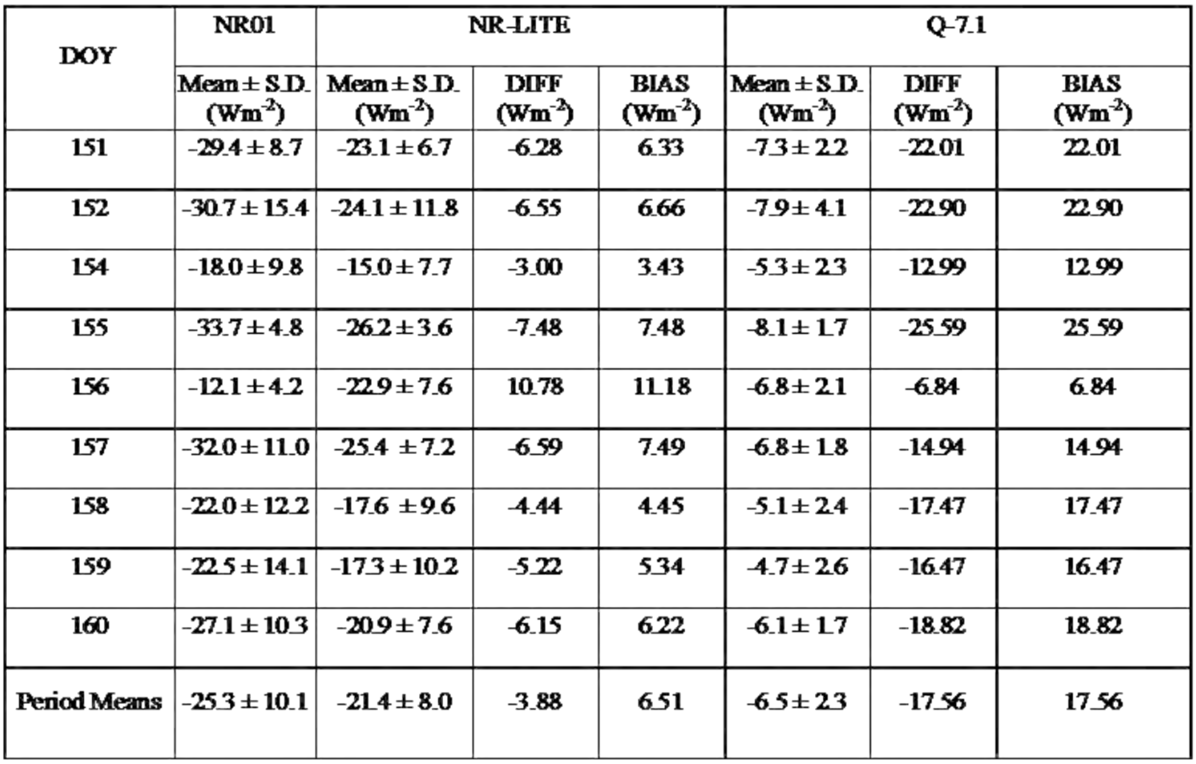
In Table 4 obtained for nighttime conditions ($R_N < 0$), it is observed that net radiation values measured by NR-LITE net radiometer have better agreement with the NR01 compared to Q-7.1 net radiometer. This observation is in agreement with the findings made by Samani et al. (2005) and Blonquist et al. (2009). The mean value obtained by NR-LITE was -21.4 ± 8.0 W m^{-2}, while that of Q-7.1 was -6.5 ± 2.3 W m^{-2}. For NR01, the mean value was -25.3 ± 10.1 W m^{-2}. The *DIFF* and *BIAS* for the NR-LITE were -3.88 W m^{-2} and 6.51 W m^{-2} respectively, while these values for the Q-7.1 were -17.56 W m^{-2} and 17.56 W m^{-2} respectively. The larger *DIFF* and *BIAS* value reported for Q-7.1 measurements indicate significant deviation from NR01 values suggesting that its performance at nighttime was inconsistent and poor.

Table 3: Statistical measures of mean, standard deviation, *DIFF* and *BIAS* for NR-LITE and Q-7.1 net radiometers with NR01 (reference net radiometer) determined for the observation period: May 31st to June 9th, 2013 (DOY 151 - DOY 160) for daytime ($R_N > 0$).



DOY	NR01	NR-LITE			Q-7.1		
	Mean ± S.D. (Wm^{-2})	Mean ± S.D (Wm^{-2})	DIFF (Wm^{-2})	BIAS (Wm^{-2})	Mean ± S.D. (Wm^{-2})	DIFF (Wm^{-2})	BIAS (Wm^{-2})
151	289.0 ± 196	202.8 ± 146.1	86.20	86.20	271.4 ± 172.3	17.63	28.57
152	214.0 ± 140.6	140.7 ± 99.6	73.10	73.10	199.0 ± 120.7	14.93	21.26
154	304.0 ± 171.5	206.4 ± 123.6	97.60	97.6	288.5 ± 150.1	15.40	28.10
155	289.1 ± 176.2	199.6 ± 124.3	89.40	89.4	268.6 ± 153.7	20.50	27.20
156	284.4 ± 230.4	204.3 ± 170.7	80.10	80.1	263.3 ± 199.2	21.10	31.20
157	329.4 ± 200.7	233.0 ± 151.7	96.40	96.4	306.0 ± 182.8	23.30	31.40
158	302.0 ± 213.1	219.0 ± 164.1	83.04	83.04	274.9 ± 186.1	27.10	34.15
159	149.5 ± 120.0	105.4 ± 87.8	44.14	44.14	150.2 ± 103.6	-0.69	16.14
160	157.9 ± 123.9	104.9 ± 95.7	52.98	52.98	143.3 ± 109.7	14.57	15.61
Period Means	257.7 ± 174.7	179.6 ± 129.3	78.11	78.11	240.6 ± 153.1	17.09	25.96

Table 4: Statistical measures of mean, standard deviation, *DIFF* and *BIAS* for NR-LITE and Q-7.1 net radiometers with NR01 (reference net radiometer) determined for the observation period: May 31st to June 9th, 2013 (DOY 151 - DOY 160) for nighttime ($R_N < 0$).



DOY	NR01	NR-LITE			Q-7.1		
	Mean ± S.D. (Wm^{-2})	Mean ± S.D. (Wm^{-2})	DIFF (Wm^{-2})	BIAS (Wm^{-2})	Mean ± S.D. (Wm^{-2})	DIFF (Wm^{-2})	BIAS (Wm^{-2})
151	-29.4 ± 8.7	-23.1 ± 6.7	-6.28	6.33	-7.3 ± 2.2	-22.01	22.01
152	-30.7 ± 15.4	-24.1 ± 11.8	-6.55	6.66	-7.9 ± 4.1	-22.90	22.90
154	-18.0 ± 9.8	-15.0 ± 7.7	-3.00	3.43	-5.3 ± 2.3	-12.99	12.99
155	-33.7 ± 4.8	-26.2 ± 3.6	-7.48	7.48	-8.1 ± 1.7	-25.59	25.59
156	-12.1 ± 4.2	-22.9 ± 7.6	10.78	11.18	-6.8 ± 2.1	-6.84	6.84
157	-32.0 ± 11.0	-25.4 ± 7.2	-6.59	7.49	-6.8 ± 1.8	-14.94	14.94
158	-22.0 ± 12.2	-17.6 ± 9.6	-4.44	4.45	-5.1 ± 2.4	-17.47	17.47
159	-22.5 ± 14.1	-17.3 ± 10.2	-5.22	5.34	-4.7 ± 2.6	-16.47	16.47
160	-27.1 ± 10.3	-20.9 ± 7.6	-6.15	6.22	-6.1 ± 1.7	-18.82	18.82
Period Means	-25.3 ± 10.1	-21.4 ± 8.0	-3.88	6.51	-6.5 ± 2.3	-17.56	17.56

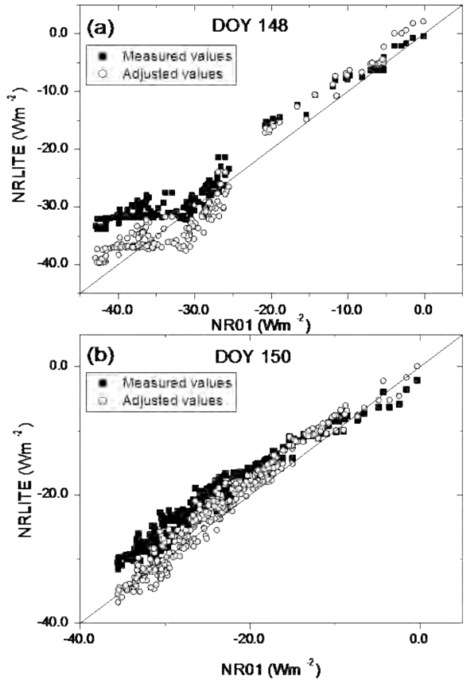


Figure 8: Scatter plots of measured and adjusted values of net radiation for (a) NR-LITE net radiometer with NR01 on May 28th, 2013 (DOY 148) for nighttime. Figure 8(b) same as DOY 148, but for DOY 150.

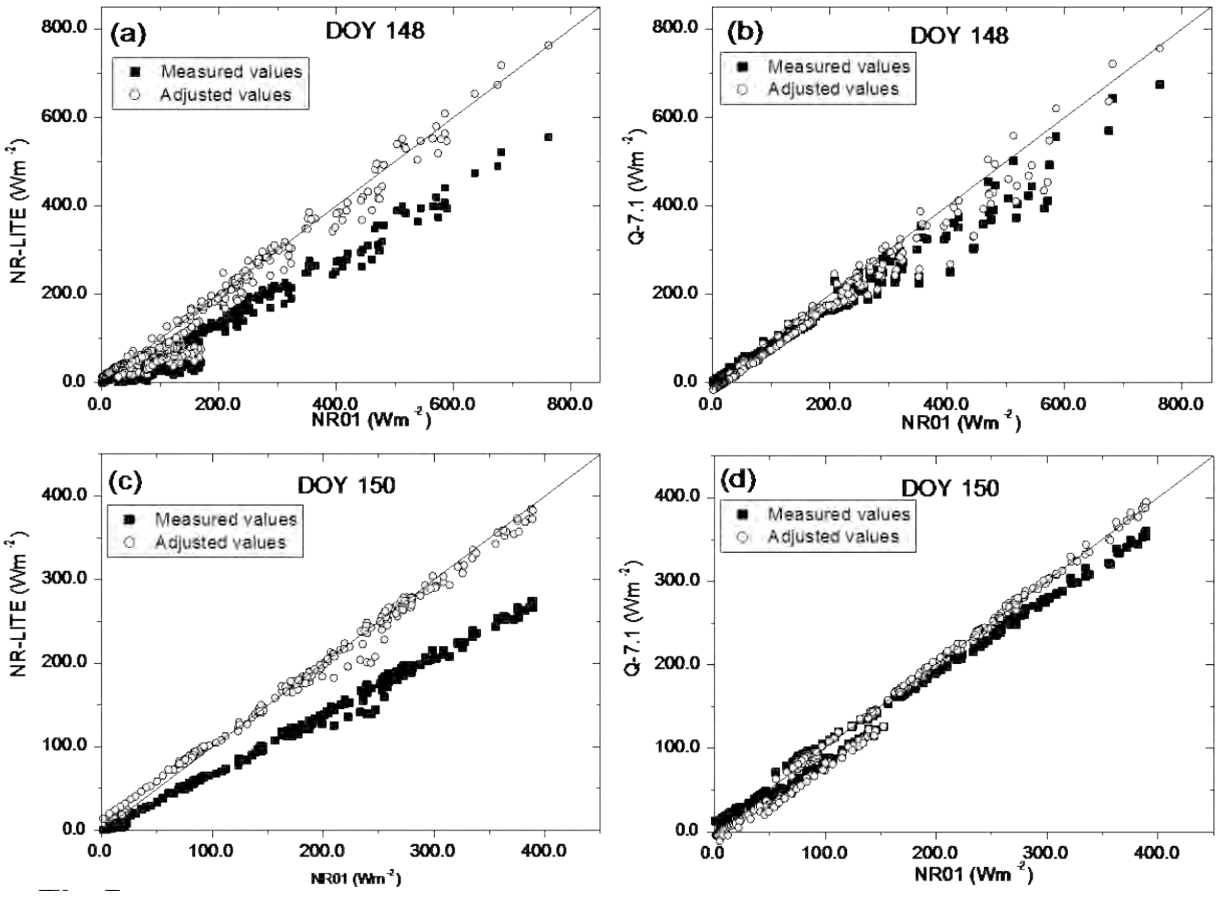


Figure 7: Scatter plots of measured and adjusted values of net radiation for (a) NR-LITE and (b) Q-7.1 net radiometers with NR01 on May 28th, 2013 (DOY 148) for daytime. Figures 7 (c) and (d), same as DOY 148, but for DOY 150.

The net radiation data for May 28th and 30th, 2013 (DOY 148 and DOY 150) have been used to validate linear regression both for NR-LITE and Q-7.1 taking with the NR01 measurements separately in Figs. 7 and 8 for daytime ($R_N > 0$) and nighttime ($R_N < 0$) conditions respectively. Using the regression coefficients in Table 5 (R^2 is 0.913 for NR-LITE and 0.989 for Q-7.1 for the daytime), the scatter plots of the adjusted data are shown in Figs. 7(a) and (b) for DOY 148. Similarly, the adjusted data for DOY 150 are plotted in Figs. 7(c) and (d). It can be seen that with simple linear regression, the 1:1 correspondence of both NR-LITE and Q-7.1 data can be maintained.

CONCLUSIONS

In this study, performances of two commercially available REBS type net radiometers: models Q-7.1 (domed) and NR-LITE (domeless), have been compared against a reference, four-component net radiometer, model NR01 using two-minute average data obtained during the Nigeria Micrometeorological Experiment (NIMEX) at Ile-Ife, Nigeria, between May 27th and June 12th, 2013. It was observed that, under daytime conditions, both NR-LITE and Q-7.1 measurements consistently showed good agreements with NR01, but Q-7.1 has better correlation (R^2= 0.99) than NR-LITE (R^2 = 0.91). Also, the departure of Q-7.1 values from benchmark values of NR01 were smaller than those of NR-LITE values, which makes it better. This is indicated by a lower *DIFF* of 17.09 W m^{-2} between Q-7.1 and NR01 values as compared to 78.11 W m^{-2} obtained between NR-LITE and NR01 values. At nighttime, the *DIFF* value between NR-LITE and NR01 net radiation measurements were small, -3.88 W m^{-2}, unlike -17.56 W m^{-2} obtained for Q-7.1 and NR01. In the same period, NR-LITE net radiometer responded better to longwave radiation than Q-7.1. Adjustments made by linear regression of both NR-LITE and Q-7.1 with NR01 datasets produced better fit for the case studies on DOY 148 and 150. Based on these results, it can be concluded that Q-7.1 net radiometer model performed better than NR-LITE model for daytime measurements of net radiation for a tropical location. Also, with proper recalibration in the field, the two REBS type of net radiometers can be deployed for routine measurements of net radiation because their costs are comparatively the same. However, for long-term operation, the Q-7.1 type requires periodic (every 2-3 months) changing of the plastic domes due to ageing and cracking, unlike the NR-LITE. So, the NR-LITE is a preferred option to be adopted by the Weather Services in West African countries for routine measurements of net radiation because it does not require periodic changing of the plastic domes.

ACKNOWLEDGEMENTS

The Nigeria Micrometeorological Experiments (NIMEX) was funded by the following organisations: International Programmes in the Physical Sciences (IPPS), Uppsala University, Sweden and Alexander von Humboldt Foundation, Germany.

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