Original Research Article

Measurements of Meteorological Variables in a Tropical Location, Ile-Ife, Nigeria

ABSTRACT

This study observed six meteorological variables at a tropical location from 2016 to 2019. The measurement was performed at the meteorological station (7.55 ^{0}N; 4.56 ^{0}E) of Obafemi Awolowo University, Ile-Ife, Nigeria. The variables that were measured are: incoming solar radiation, net radiation, air temperature, surface temperature, relative humidity and wind speed. The results obtained showed that the maximum daytime monthly mean values of the incoming solar radiation (S) and net radiation (Rn) were recorded in March (782.0 and 545.4 Wm^{-2}, respectively), which is the transition month from dry to wet season. The minimum daytime monthly mean values of S and Rn were recorded in August (443.9 and 330.4 Wm^{-2}, respectively) which is at the peak of the wet season. The daily air and surface temperatures (Ta and Ts, respectively) varied between 19.7 and 35.8 ^{0}C; 20.9 and 45.6 ^{0}C, respectively. The daytime maximum values peaked at about 15:00 LT with the maximum monthly mean values recorded in January (35.8 and 45.6 ^{0}C, respectively) and the daytime minimum monthly mean values recorded in August (28.9 and 33.3 ^{0}C, respectively). The daily values of relative humidity (Rh) ranged between 29 % and 98 % with a mean value of 47 %. The diurnal trend of the wind speed (u) recorded at the study location ranged between 0.48 ms^{-1} to 2.10 ms^{-1}.

Keywords: Measurements, Solar radiation, Net radiation, Air temperature, Surface temperature, Relative humidity, Wind speed

1. INTRODUCTION

Meteorological variables are indispensable in the development of geographical climatology, agricultural meteorology and in the interpretation of physical processes in the lower atmosphere. They are essential for the monitoring and prediction of weather and climate; and for the management of natural resources. These observations are important for the short term decision of activities such as monitoring of natural disaster, farming response, early warning of pests and diseases, etc. Meteorological variables are also imperative in the long term prediction of weather forecast [1]. Knowledge of meteorology is the basis of scientific weather forecast which is the prediction of the state of the atmosphere at a given location. This helps in the determination of the physical and chemical characteristics of the atmosphere. Therefore, standard and high quality observations of climatic variables are fundamental necessity [2]. Meteorological variables are usually measured in meteorological stations. A meteorological station is a collection of different instruments or sensors that measures different meteorological variables such as temperature, solar radiation, precipitation, humidity, wind speed, atmospheric pressure, rainfall, etc. The instruments used for the collection of the variables depend on the weather condition of a particular location. A meteorological station can either be analog (where the weather data are physically collected and recorded by humans) or digital [3].

Mean meteorological variables are often called routinely-measured meteorological variables because they are easily and commonly measured. As such, they are readily available for the immediate weather or climatic determination of local and regional atmosphere. In this study, six meteorological variables were routinely measured at the meteorological station located at the Teaching and Research Farm of the Obafemi Awolowo University, Ile-Ife, Nigeria. The variables are solar radiation, net radiation, air temperature, surface temperature, relative humidity and wind speed. These variables are consistently used for the monitoring of the weather, farming response and description of the atmosphere at the study location.

1.1 Radiation

Solar radiation is the direct radiation received at the earth's surface. It determines the energy available at the surface for physical and biological processes [4]. Net radiation is the algebraic sum of incoming and outgoing solar and atmospheric radiation [5]. The measured radiation (solar and net radiation) is dependent on season, surface temperature, geographical location, time of the day, cloudiness, type and conditions of the surface as indicated by albedo and emissivity [6]. Observation of radiation is applicable in the study of land-surface processes, simulation of crop growth models, solar voltaic technology, solar electrical applications, among others [7]. Solar radiation can be measured using a pyrheliometer or a pyranometer while net radiation can be measured with a net radiometer.

1.2 Temperature

Temperature is the thermodynamic state of a body. It describes the mean random motion of molecules in a physical body. Air temperature is a measure of the heat content in the atmosphere as a result of the combined effects of absorbed solar radiation by the surface, convection of air by the vertical fluxes of turbulent heat and horizontal advection of warm and cold air masses [8]. Increase in air temperature increases the rate of heat transfer at the surface which consequently results in higher evaporation rates. In sunny conditions, the maximum air temperature is usually observed between 12:00 and 14:00 hr, while the minimum air temperature is obtained between 04:00 and 06:00 hr. The time required for air to rise from the minimum temperature to the maximum temperature is usually less than 10 hr, but the time requirement for air at the maximum temperature to reach the minimum temperature is more than 14 hr.

Surface temperature is the skin temperature of the earth's surface [9]. It describes processes such as the rate and timing of plant growth, the exchange of energy and water between the earth's surface and atmosphere. Surface temperature is sensitive to soil moisture and vegetation, therefore, it can be used for the identification of land use/land cover changes. Surface temperature can also be used in the estimation of radiation budgets and as a control for climate models [10].

Temperature can be measured at various levels: near the earth's surface, at the upper atmosphere, at the ground surface, surface levels of sea and lakes and various depths of the soil. Instruments for measuring temperature are: thermistors, thermocouples, platinum resistors, liquid-in-glass thermometers, sonic and radiometric sensors.

1.3 Relative humidity

Relative humidity is the ratio of vapour pressure observed in a location, to the saturation vapour pressure at the same temperature and pressure, in percentage [11]. It is a percentage of the total amount of moisture that air can hold. A relative humidity of 50 % signifies that the air is half saturated with moisture. The significance of relative humidity to a particular application depends on the knowledge of both the dry-bulb temperature and the relative humidity. The humidity of air in cool temperate regions varies between 45 and 55 %, while in tropical regions, a values as high as 80 % can be obtained. Measurements of relative humidity can be applied in environmental studies, aeronautical services, agriculture, hydrology and climatic studies. Relative humidity can be measured with a psychrometer. A psychrometer is a device that contains two thermometers, each for the measurement of dry air and moist air [12].

1.4 Wind Speed

Wind is caused by the uneven heating of the surface by the incoming solar radiation. Wind speed is the small-scale random fluctuations of air in space and time. Wind measurements are required for the determination of wind energy, estimation of wind damage, estimation of surface fluxes, monitoring and forecasting of weather. Wind speed can be measured using a wind gauge or anemometer.

Despite the relatively simple instrumentation for the measurements of mean meteorological variables, the observational data is still scarce in West Africa. Although, the availability of satellite data has the potential to complement the paucity of these measurements, the data cannot provide the spatial or temporal resolution compared to in-situ sensors, especially for local weather-dependent activities. Therefore, this study presents the measurements of six meteorological variables at a tropical location in Ile-Ife, Nigeria.

2. METHODOLOGY

2.1 Site Description

The study site is located at the Obafemi Awolowo University Meteorological Station, Ile-Ife (7.53 ^{0}N; 4.54 ^{0}E), Nigeria. The climate of the area can be characterized by two seasons: the wet and the dry seasons. The wet season is between March and October while the dry season spans between November and February. The change of season is as a result of the meridional movement of the Inter-Tropical Discontinuity (ITD) which separates the dry and hot North-Easterly trade winds from the moist and warm South-Westerly trade wind at the surface [13]. The onset months of the wet season is within the weather zone B that extends from 200 - 400 km south of the surface position of the ITD. This zone can be described by its suppressed convection which results into the formation of cumulus clouds. Hence, precipitation is limited to light showers. At the peak of the wet season (July), the study area falls within the weather zone D and it is characterized by stratus cloud which is associated with light rains and drizzles with occasional thunderstorm activities [5]. The field measurement was conducted between 2016 and 2019.

2.2 Instrumentation

The sensors used for the measurements of the meteorological parameters in this study were mounted a 6-m meteorological mast. A wind cup anemometer (034B) was mounted at a height of 6 m to measure wind speed, a temperature and relative humidity probe (HMP45) was located at a height of 4 m for the measurement of air temperature and relative humidity. At a height of 2 m, a pyranometer (CS300) and a four-component net radiometer (NR01) were mounted for the measurements of incoming solar radiation and the components of net radiation, respectively. A 110PV-L temperature probe was placed on the surface to measure the surface temperature.

2.2.1 CS300 Pyranometer

The CS300 pyranometer which comprises of a silicon photovoltaic detector mounted in a cosine-corrected head was used for the measurement of solar radiation. The CS300 was installed from all reflective surfaces and obstructions that might affect measurement. It has a spectral range of 360 - 1120 nm, measurement range of 0 – 2000 Wm^{-2} and accuracy of ±5 % for daily total radiation. The operational temperature of CS300 is between -40 ^{o}C and +70 ^{o}C.

2.2.2 NR01 Net Radiometer

The net radiation was measured by the NR01 net radiometer (Campbell Scientific, Inc.). The sensor is a high-output thermopile which measures the algebraic sum of the incoming radiation (0.2 - 0.7 µm) and outgoing radiation (0.7 – 100 µm). The balance of both the shortwave and longwave radiation is known as the net radiation. The sensor is passive, hence, it requires no power supply. Its upward-facing side measures the incoming solar energy and far infrared radiation received from the whole hemisphere (180° field of view). Its downward-facing side measures the energy received from the surface. The values obtained from the two sides are subtracted and the outcome is interpreted as a single output signal. NR-LITE is designed for constant outside use, it has a temperature range from about -30 ^{o}C to +70 ^{o}C and its sensitivity is 10 µVW^{-1}m^{2}. The surface of the sensor is spectrally black, hence, it absorbs radiation from all wavelengths. This enhances the stability of the sensor and its life time.

2.2.3 HMP45 Air Temperature/Humidity Probe

HMP45 Air Temperature/Humidity Probe was used for the measurement of air temperature and relative humidity. It comprises of a Platinum Resistance Temperature detector (PRT) and a Vaisala INTERCAP capacitive relative humidity sensor. It is a simple, durable, cost-effective and miniature-size humidity probe. The probe has a length of about

7.1 cm and a diameter of 1.2 cm. Its low power consumption of about < 2 mA makes it suitable for battery-powered applications. HMP45 has an operational temperature between -40 and +60 ^{0}C and it is designed to fit for rough conditions.

2.2.4 110PV-L Surface Temperature Probe

A 110PV-L surface temperature probe was used to measure the surface temperature. The 110PV-L has a thermistor which is enclosed in an aluminum disk. The aluminum disk shields the thermistor and stimulates heat transfer from the surface. The probe measures temperature within the range of -40 and +135 ^{0}C.

2.2.5 034B Wind Cup Anemometer

The horizontal wind speed was measured with a Campbell scientific 034B cup anemometer and was located away from obstructions such as trees. The rotation of the cup wheel opens and closes a reed switch at a rate proportional to wind speed. The operating range was between 0 and 75 ms^{-1} with a threshold of 0.4 ms^{-1}. Its output signal is contact close (reed switch) and its resolution is 0.7998 ms^{-1} per scan rate in seconds. The cup has an accuracy of 0.1 ms^{-1} and an operating temperature of -30 to 70 ^{0}C.

2.3 Data Acquisition and Reduction

A Campbell Scientific datalogger system (CR10X) was employed for data acquisition during this experiment. All the sensors were connected directly to the datalogger through the SE or DIFF channels. The datalogger measured signals as voltages and stores them. The data was collected via a retrieval system (a serial cable connecting a computer with the datalogger). Sampling of the data was done every 10 seconds, saved as 1-minute averaged values and subsequently, the data were reduced to produce 30-minutes statistics. Microcal Origin 7.0 (data analysis software package) was used for graphing and analysis of the variations of the meteorological variables.

3. RESULTS AND DISCUSSIONS

3.1 Diurnal Variations of Incoming Solar Radiation and Net Radiation

The hourly averaged values of incoming solar radiation (S) and net radiation (Rn) from January to December at the study location are presented in Fig. 1. From sunrise, the magnitudes of S increased steadily from zero to reach maxima at about the local noon (13:30 Local Time, LT) when there was maximum intensity of incoming solar radiation. From sun set (about 18:00 LT), the values of S dropped gradually to zero throughout the night.

At dawn, the magnitudes of Rn were negative and relatively constant. As the sun rises, the values became positive and reached maxima at about 13:30 LT when the sun was overhead. As the sun sets, the values of Rn reduced steadily to negative throughout the night. The negative values were within the range of -4.4 and -40.4 Wm^{-2}, indicating radiative cooling at the surface.

It was observed that the values of the solar radiation were about 36 % higher than that of the net radiation. This is due to the fact that the solar radiation is mainly the direct energy from the sun received at the surface while net radiation is the algebraic sum of incoming and outgoing solar and atmospheric radiation.

In Fig. 1, the maximum values of S (S_{max}) and Rn (Rn_{max}) in January were 664.5 and 389.7 Wm^{-2}, respectively. These values are relatively lower than the values obtained in February (672.6 and 418.5 Wm^{-2}, respectively) due to the highly turbid atmosphere since the dry season peaks around this period. S_{max} and Rn_{max} increased considerably in March to 782.0 and 545.4 Wm^{-2}, correspondingly, as the highest values of radiation obtained in the study period. March is usually a transition month between the dry and wet season. The period is characterised with occasional rain showers which leads to washouts and significant reduction in atmospheric turbidity [14]. Consequently, there is less attenuation of the incoming solar radiation hence, the high values obtained.

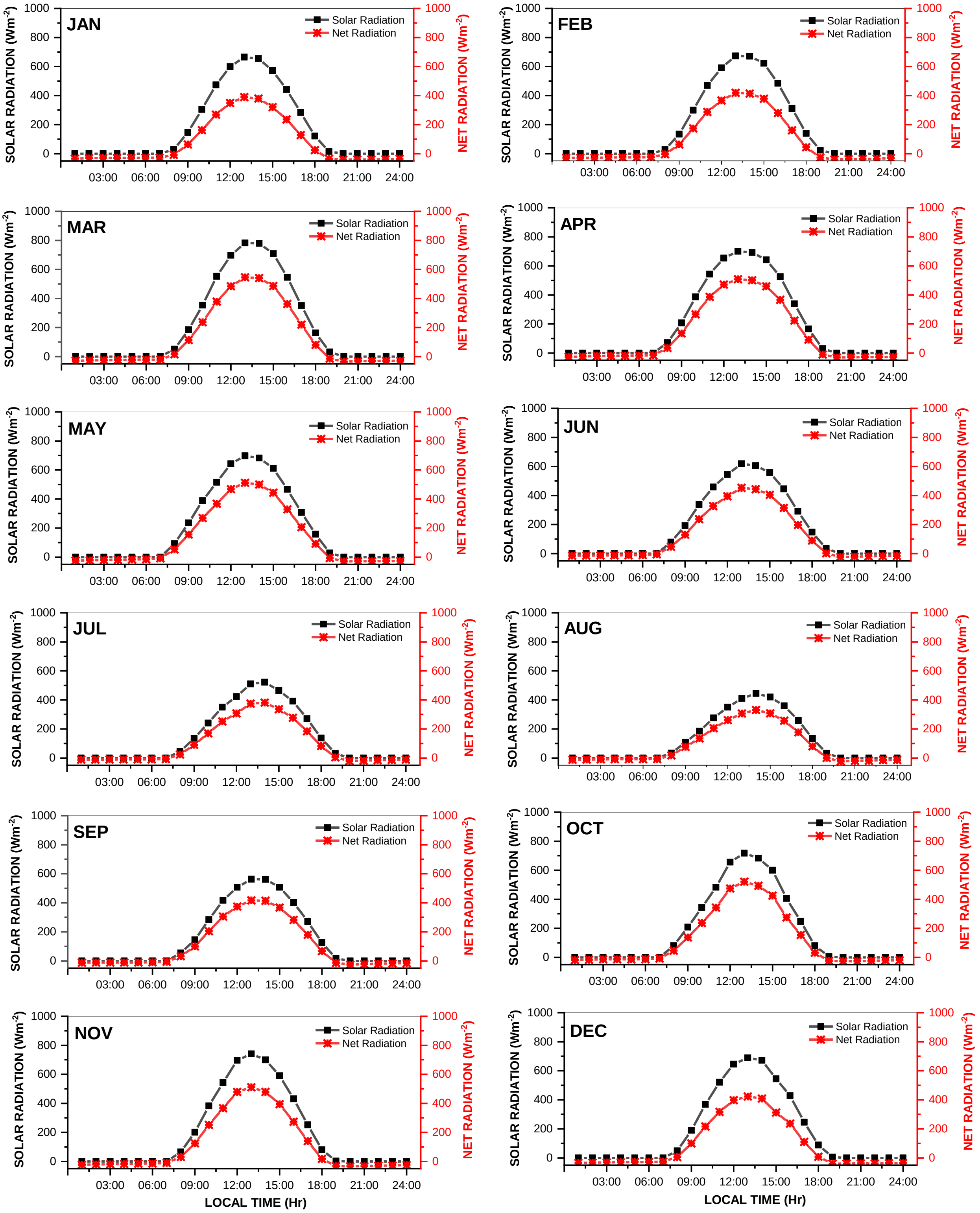

Fig. 1: Diurnal Variations of Monthly Mean of Solar Radiation and Net Radiation from January to December (2016 -2019)

At the start of the wet season in April, S_{max} and Rn_{max} decreased from 710.9 and 507.7 Wm^{-2}, respectively, to 697.6 and 511.9 Wm^{-2}, respectively in May and continued to decrease through June and July till they reached the lowest values in August. In August, the lowest daytime maximum values of S and Rn were recorded as 443.9 and 330.4 Wm^{-2}, correspondingly. These values were attributed to cloudiness and high atmospheric moisture content. S_{max} and Rn_{max} increased progressively from 562.1 and 417.3 Wm^{-2}, respectively in September to 740.5 and 510.8 Wm^{-2}, respectively in November as the wet season concludes and then dropped to 689.1 and 422.9 Wm^{-2}, respectively in December as the dry season kicks off.

3.2 Diurnal Variations of Air Temperature and Surface Temperature

The hourly averages of the air temperature (Ta) and surface temperature (Ts) obtained for the same period of study are presented in Fig. 2. Generally, in the mornings (00:00 LT – 07:00 LT), the values of the air and surface temperatures were low and fairly constant (with values in the range of 20 and 25 ^{0}C; 21 and 27 ^{0}C, respectively) due to the radiative cooling at the surface. The values of Ta and Ts steadily increased from about 07:30 LT reaching maxima (35 ^{0}C and 46 ^{0}C, respectively) at about 15:00 LT and 14:00 LT, respectively. The lag between the two variables was predominant in the dry months (January, February, March, November and December). That is, the surface temperature reached maxima faster than air temperature in the aforementioned months. This is as a result of high solar heating at the surface due to the intense incoming solar radiation that is prevalent at this period. Consequently, the surface heats faster than the overlying air. Also, there was significant difference in the daytime values of Ta and Ts in the dry months unlike in the wet months.

As the surface gradually cooled from about 17:30 LT, the values of Ta and Ts steadily decreased to minimum (in the range of 21 and 22 ^{0}C and 22 to 28 ^{0}C, respectively) from 20:00 LT to 24:00 LT. The daily air and surface temperatures varied between 19.7 and 35.8 ^{0}C; 20.9 and 45.6 ^{0}C, respectively.

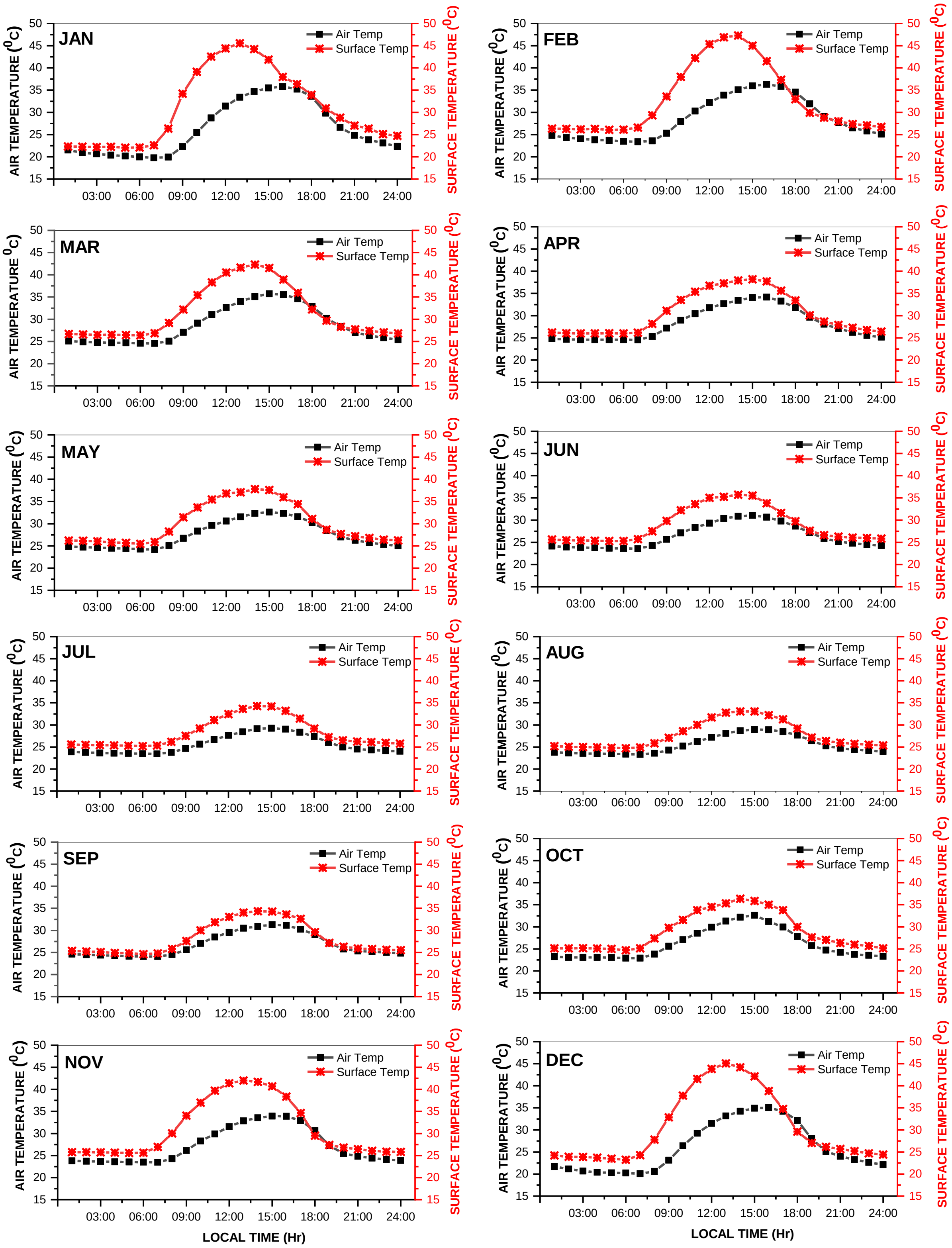

Fig. 2: Diurnal Variations of Monthly Mean of Air Temperature and Surface Temperature from January to December (2016 -2019)

In January, the maximum values of Ta (Ta_{max}) and Ts (Ts_{max}) recorded were 35.8 ^{0}C and 45.6 ^{0}C, respectively. These high values were attributed to the intense solar heating at the earth's surface during this period.

As the time progresses in February and March, Ta_{max} and Ts_{max} increased to 36.3 ^{0}C and 35.7 ^{0}C; 47.7 ^{0}C and 42.4 ^{0}C, respectively. Therefore, the peak values of Ta and Ts were obtained in February.

As the wet season commences in April, the peak values of Ta_{max} and Ts_{max} gradually dropped to 34.2 ^{0}C and 38.3 ^{0}C, respectively. The values continued to decrease throughout May, June and July to reach the minimum of 28.9 ^{0}C and 33.3 ^{0}C, respectively in August.

The low values obtained in August are due to cloudiness, high moisture content in the atmosphere and low intense of solar radiation as distinct features during the wet season. These characteristics are in agreement with the report of [14]. The air and surface are highly moist, therefore, the temperatures are of the lowest during this period. As the wet season recedes by October, the daytime values of Ta_{max} and Ts_{max} increased steadily from 32.6 ^{0}C and 36.7 ^{0}C; to 33.9 ^{0}C and 42.2 ^{0}C, respectively in November. Thereafter, Ta_{max} and Ts_{max} increased to 35.0 ^{0}C and 45.1 ^{0}C, respectively in December when the dry season was again re-established.

3.3 Diurnal Variation of Relative Humidity

The hourly averages of relative humidity (Rh) from January to December observed at the study location are presented in Fig. 3. Going by the mean diurnal trend, from 00:00 LT to 08:00 LT, the values of Rh were high (> 80 %). The high values of Rh are indicative of the atmosphere being humid which consequently lead to condensation due to radiative cooling. From 09:00 LT onwards, Rh gradually decreased and reached minimum at about 15:00 LT. The observed minimum values are due to the occurrence of insolation during the daytime, hence, reduction in atmospheric moisture content. Afterwards, from about

20:00 LT, Rh progressively increased to reach maximum. The daily values of relative humidity (Rh) ranged between 29 % and 98 % with a mean value of 47 %.

In January, the daytime minimum value of Rh (Rh_{min}) at about 15:00 LT was observed to be 29 %. This was the lowest value of Rh_{min} recorded at the study location. This observation is an indication that in January, which is the peak of the Harmattan period [15], the air is dry suggesting low moisture content. As the transition month approaches in March, Rh_{min} gradually increased from 49 % to 57 % in April; 63 % in May; 67 % in June; 73 % in July and 74 % in August which is the peak of the wet season. The value of Rh obtained in August (74 %) is a consequence of increased rate of precipitation and high atmospheric moisture content that are prevalent about this time. From October, Rh_{min} steadily decreased from 61 % to 33 % in December.

3.4 Diurnal Variation of Wind Speed

Fig. 4 shows the hourly averages of the wind speed (u) observed at the study location from January to December. Typically, the observed wind speeds were low (0.8 ms^{-1}) at about dawn and reached maxima (1.9 ms^{-1}) at noon and dropped off to near calm conditions around dusk. Generally, the values of the wind speed observed during the study period were relatively low (< 2 ms^{-1}). This is typical of the wind speed distribution in the tropics. The low wind speed values are as a result of the convergence of the trade winds (south-westerly and north-easterly) at the surface which generates weak horizontal pressure gradients at the surface.

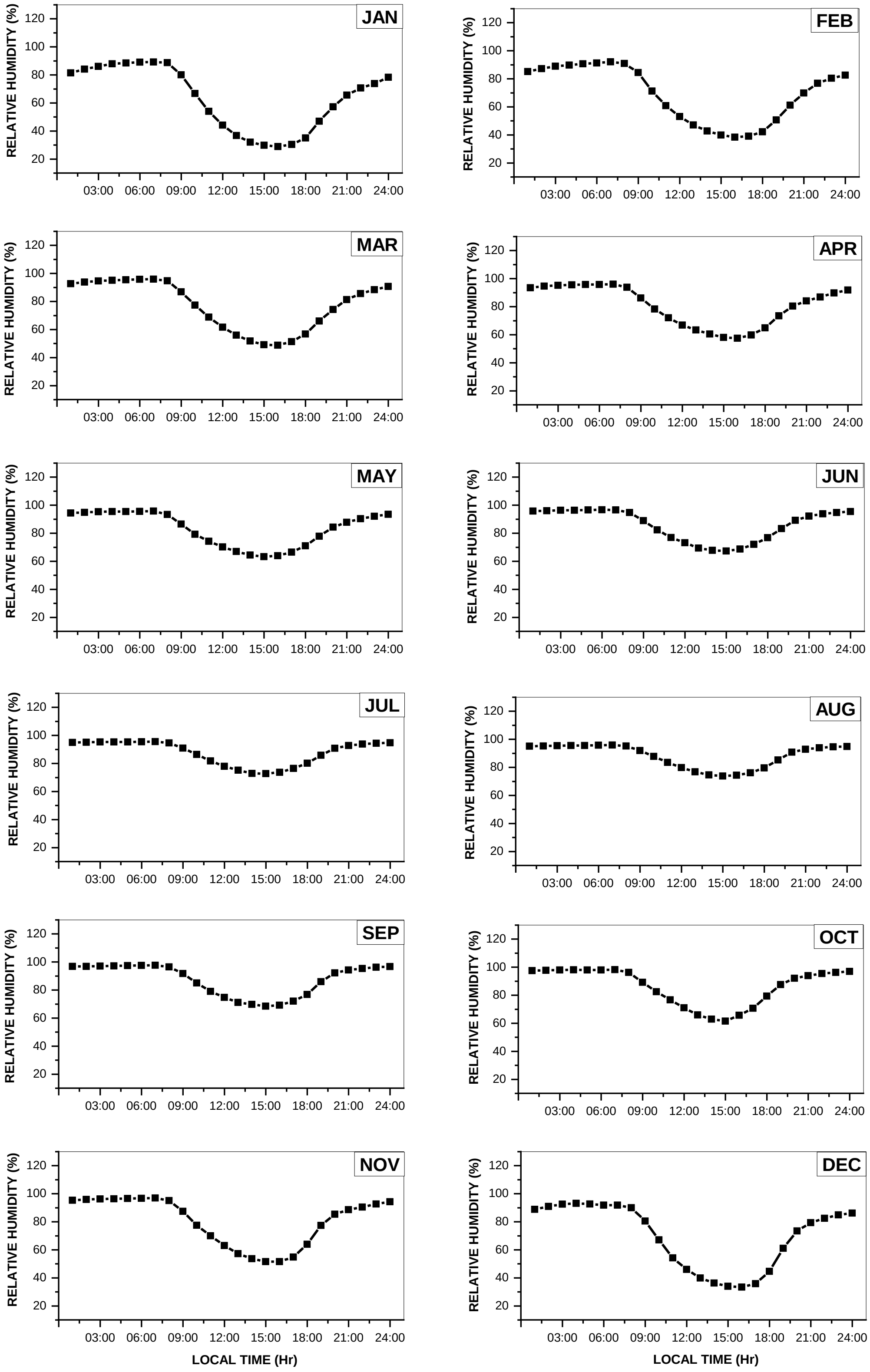

Fig. 3: Diurnal Variation of Monthly Mean of Relative Humidity from January to December (2016 -2019)

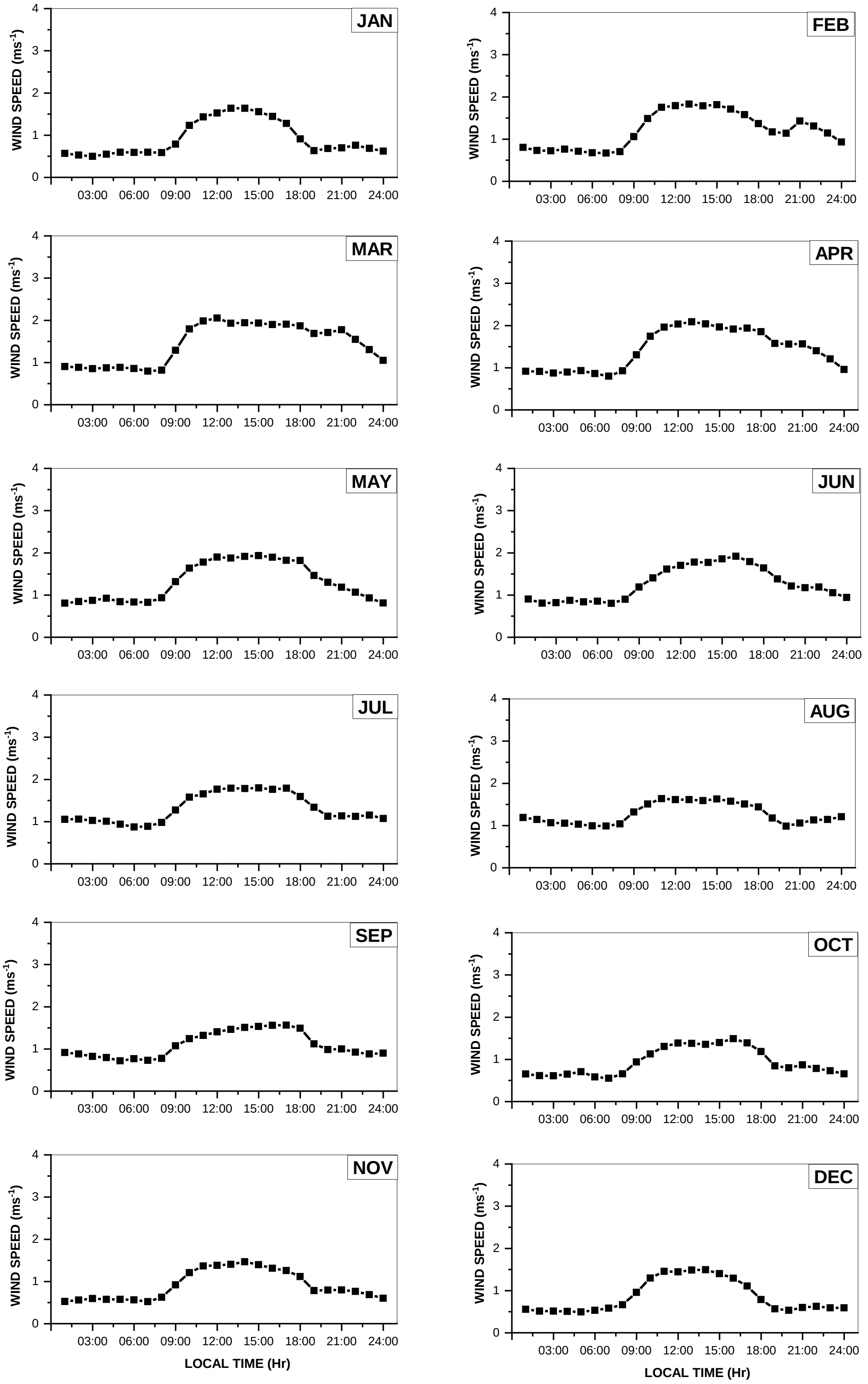

Fig. 4: Diurnal Variation of Monthly Mean of Wind Speed from January to December (2016 -2019)

4. SUMMARY AND CONCLUSION

In this study, measurements of six meteorological variables were observed from 2016 to 2019. The measurement was performed at the meteorological station (7.55 ^{o}N; 4.56 ^{o}E) of Obafemi Awolowo University, Ile-Ife, Nigeria. The measurements of the meteorological parameters (incoming solar radiation, net radiation, air temperature, surface temperature, relative humidity and wind speed) were carried out on a 6-m micrometeorological mast centrally positioned at the station using slow response sensors. The measurements were controlled by a programmable module CR10X datalogger. The raw data were reduced subsequently to 30-minutes average values.

The results obtained revealed that the maximum daytime monthly mean values of the incoming solar radiation (S) and net radiation (Rn) were recorded in March (782.0 and 545.4 Wm^{-2}, respectively), which is the transition month from the dry to wet season. The minimum daytime monthly mean values of S and Rn were recorded in August (443.9 and 330.4 Wm^{-2}, respectively) which is at the peak of the wet season. The daily air and surface temperatures (Ta and Ts, respectively) varied between 19.7 and 35.8 ^{0}C; 20.9 and 45.6 ^{0}C, respectively. The daytime maximum values peaked at about 15:00 LT with the maximum monthly mean values recorded in January (35.8 and 45.6 ^{0}C, respectively) and the daytime minimum monthly mean values recorded in August (28.9 and 33.3 ^{0}C, respectively). The daily values of relative humidity (Rh) ranged between 29 % and 98 % with a mean value of 47 %. The diurnal trend of the wind speed (u) recorded at the study location ranged between 0.48 ms^{-1} to 2.10 ms^{-1}.

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