Asian Journal of Research and Reviews in Physics

3(4): 35-42, 2020; Article no.AJR2P.62814
ISSN: 2582-5992

Characteristic Variation of Ground Heat Flux and Net Radiation at Tropical Station in Ile-Ife, Osun State, Nigeria

A. Usman[1*], B. B. Ibrahim[1] and L. A. Sunmonu[2]

[1]Department of Science Laboratory Technology (Physics/ Electronics Unit), Kwara State Polytechnic, Ilorin, Kwara State, Nigeria.
[2]Department of Physics, Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria.

Authors' contributions

This work was carried out in collaboration among all authors. Author AU designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors BBI and LAS managed the analyses of the study. Author LAS managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJR2P/2020/v3i430127
Editor(s):
(1) Prof. Shi-Hai Dong, National Polytechnic Institute, Mexico.
Reviewers:
(1) Ali Habeeb Askar, University of Technology, Iraq.
(2) Manar S. M. Al-Jethelah, Tikrit University, Iraq.
(3) P. Rajarajeswari, Kingston Engineering College, India.
Complete Peer review History: http://www.sdiarticle4.com/review-history/62814

Original Research Article

Received 05 September 2020
Accepted 12 November 2020
Published 03 December 2020

ABSTRACT

Characteristic variation of ground heat flux and net radiation enhances the understanding of the significance of indicated trends of variability to everyday life and factors that might be responsible for such variations. This research work critically analyses some specific days with field data over grass-covered surface at Ile-Ife, Nigeria between ground heat flux and net radiation. For the field observations, an instrumented meteorological mast was set up at an experimental site (7°33ʹN, 4°35ʹE) located at Obafemi Awolowo University campus, Ile-Ife, Nigeria for a period of two weeks (31st May-14th June, 2013). The soil heat flux, net radiation and soil temperature from the soil heat flux plate; an all-wave net radiometer, and soil thermometer were recorded every 10 seconds and averaged over 2 minutes interval. The sampled data was stored in the data logger (Campbell Scientific, Model CR10X) storage module. After the removal of spurious measurement values (Quality Assurance and Quality Control), the data stored was further reduced to 30 minutes

**Corresponding author: E-mail: usbash2009@yahoo.com;*

averages using the Microcal Origin (version 7.0) data analysis software. The results showed that the measured ground heat flux, H_{GM} during the daytime increases until 1400 hrs with maximum value of about 136.86 Wm^{-2} and minimum value of about -72.87 Wm^{-2} at 0830 hrs (DOY 156). The measured net radiation, R_n value of 649.65 Wm^{-2} observed at 1400 hrs (DOY 156), represented the maximum value for the entire period of the study. -10.75 Wm^{-2} value observed at1800 hrs (DOY 154), represented the minimum value for the entire period of the study due to the cloudy condition of the sky which reduces the amount of incoming solar radiation reaching the earth surface.

Keywords: Ground heat flux; net radiation and soil temperature.

1. INTRODUCTION

Net radiation and ground heat flux are two important components of earth surface energy balance. This is because the difference between them which is the available energy is the primary term for the formulation of evapotranspiration Davies, [1]; Idso et al*.,* [2]; Dugas et al*.,* 1991). The soil derived its heat almost entirely from the sun and loses much of its radiation into the sky. The heterogeneity of soil properties in the scale of 10^{-3} – 10^{-2} m is ignored, and the soil is assumed to be nearly homogeneous for the given meteorological scale Foken, [3]. In addition, conductive heat fluxes in the soil and latent heat fluxes in large pores are ignored. The ground heat flux, (H_{GM}) is based mainly on molecular heat transfer and is proportional to the temperature gradient multiplied by the thermal molecular conductivity (a_G). This molecular heat transfer is so weak that during the day only the upper decimeters are heated. When considering the annual cycle of ground temperature, maximum temperature is at the surface during the summer, but 10 – 15 m below the surface during winter (Lehmann and Kalb, 1993).

Due to the generally smaller magnitude of H_{GM} compared to the other energy fluxes its determination in energy balance studies at the earth's surface is often handled rather simply, parameterizing H_{GM} as a constant fraction of the net radiation.

However, this is not suitable for specific surfaces such as bare soil, non-natural materials or urban surfaces where H_{GM} is a dominant part of the energy budget and can amount to more than 50% of the net radiation Oke et al., [4]; Jauregui et al., [5].

Ground heat flux is normally measured with heat flow sensors and soil temperature probes buried beneath the soil surface. But, since H_{GM} is highly dependent on surface conditions (wet or dry and bare or vegetated), it cannot be reliably approximated for large areas. On a daily basis, H_{GM} is generally small relative to the other fluxes and sometimes has been ignored in energy balance models Hatfield et al., [6].

The ground surface (including plants and urban areas) is heated during the day by the incoming shortwave radiation. During the night, the surface cools due to long-wave up-welling radiation, and is cooler than the air and the deeper soil layers. High gradients of temperature are observed in layers only a few millimeters thick Foken, [3].

It is a basic task of micrometeorology to provide correct and reliable estimates of H_{GM}, for the other components of the energy balance, there are widely accepted measurement procedures as well as numerous sensor comparisons Foken et al., [7]; Halldin, [8]; Mauder and Foken, [9]; Kohsiek et al., [10]. There are numerous publications dating from the 1970s and 80s on how to measure the ground heat flux correctly (Kimball and Jackson, [11]; Fuchs, [12].

It is intended in this research to present some results of measurements and characteristic variation of ground heat flux and net radiation over grass covered surface in Ile-Ife.

2. MATERIALS AND METHODS

The ground heat flux, H_{GM}, is based mainly on molecular heat transfer and is proportional to the temperature gradient times the thermal molecular conductivity a_G.

$$H_{GM} = a_G \frac{\partial T}{\partial Z} \tag{1}$$

This molecular heat transfer is so weak that during the day only the upper decimeters are heated. On a summer day, the ground heat flux is about 50–100 Wm^{-2}. A simple but not reliable calculation (Liebethal and Foken, 2006) is: $H_{GM} = -0.1R_n$ or $H_{GM} = 0.3\ R_n$ Stull, [13]. The determination of the ground heat flux according to Eq. (1) is not practicable because the temperature profile must be extrapolated to the surface to determine the partial derivative there.

However, the ground heat flux (H_{GM}) at the surface can be estimated as the sum of the soil heat flux measured at some depth using soil heat flux-plates and the heat storage in the layer between the surface and the plate:

$$H_{GM} = SHF + \Delta S \quad (2)$$

Where SHF is the soil heat flux and ΔS is the storage term.

The storage term ΔS is given as

$$\Delta S = \frac{\Delta T_s C_s d}{t} \quad (3)$$

Where, ΔT_s is the change in soil temperature, C_s is the heat capacity of the soil, d is the depth and t is the output interval.

Net radiation (R_n) at the surface is given as the algebraic sum of the downward flux of emitted solar radiation (R_{sd}) from sun and sky (i.e. global radiation), the downward infrared or thermal radiation flux (R_{id}) from the atmosphere, the upward flux of reflected solar radiation (R_{su}), and the upward infrared radiation flux (R_{iu}) from the surface. Thus, sum of these terms altogether represent the net radiative energy balance at the surface and is given as:

$$R_n = R_{sd} - R_{su} + R_{id} - R_{in} \quad (4)$$

The compositing terms of the net radiation, which appear on the right hand side of equation (4), are parameterized individually Jegede et al., [14].

2.1 Methodology

An all-wave net radiometer (Kipp and Zonen, model NR-LITE), two soil thermometers (Campbell Scientific, model T108) and a soil heat flux plate (Campbell Scientific, model HFP01) were set up on site to measure net radiation, soil temperature and soil heat flux respectively over a grass covered surface. The instruments are collated at an experimental site near the Sports Complex in Obafemi Awolowo University, Ile-Ife for a period of two weeks (31st May-14th June, 2013). The NR-LITE net radiometer was mounted on a 2.7 m tall mast and aligned at 1.41 m above the grass-covered surface. One of the T108 soil thermometers was buried at 2 cm and the other was buried together with the soil heat flux plate at 10 cm below the soil surface. Measurements were taken every 10 seconds and averaged over 2 minutes intervals. The sampled data was stored in the datalogger (Campbell scientific, model CR10X) storage module. The data stored was further reduced by using the Microcal Origin (version 7.0) data analysis software.

3. RESULTS AND DISCUSSION

On 1st June, 2013 (DOY 152), there was rain and the sky was partly cloudy with no insolation in the afternoon (see Appendix I). The daytime variation of both the ground heat flux and net radiation on this day was depicted in Fig. 1. The ground heat flux varies between -32.63 and +131.08 Wm^{-2}. It was observed that from 900 hrs to 1000 hrs there was slight fluctuations between the ranges of +7.91 to +45.93 Wm^{-2}, a sharp decrease between 1000 hrs to 1030 hrs i.e. (+45.93 to -23.75 Wm^{-2}) was observed due to a decrease in the amount of solar radiation reaching the earth surface. From the 1400 hrs, the curve shows an increase in the value due to the amount of insolation reaching the surface. The maximum ground heat flux value, +131.08 Wm^{-2} was observed at about 1600 hrs. The net radiation value varies between +35.39 to 537.41 Wm^{-2} which is due to an increase in the amount of solar radiation reaching the surface. The maximum value of net radiation measured was 537.41 Wm^{-2} at about 1530 hrs and it fell to 107.09 Wm^{-2} around 1800 hrs due to no insolation at that particular period.

On 3rd June, 2013 (DOY 154), there was cloudiness with no insolation in the early morning and afternoon (see Appendix I). The daytime variation of both the ground heat flux and net radiation on this day was depicted in Fig. 2. It was observed that from 0830 hrs to 1200 hrs, there was an increase in the value between +7.89 and +76.55 Wm^{-2}, until around 1400 hrs where a decrease was seen due to cloud cover which in turn reduces the intensity of solar radiation reaching the earth's surface. The day has a maximum and minimum value of +101.81 and -55.22 Wm^{-2} respectively.

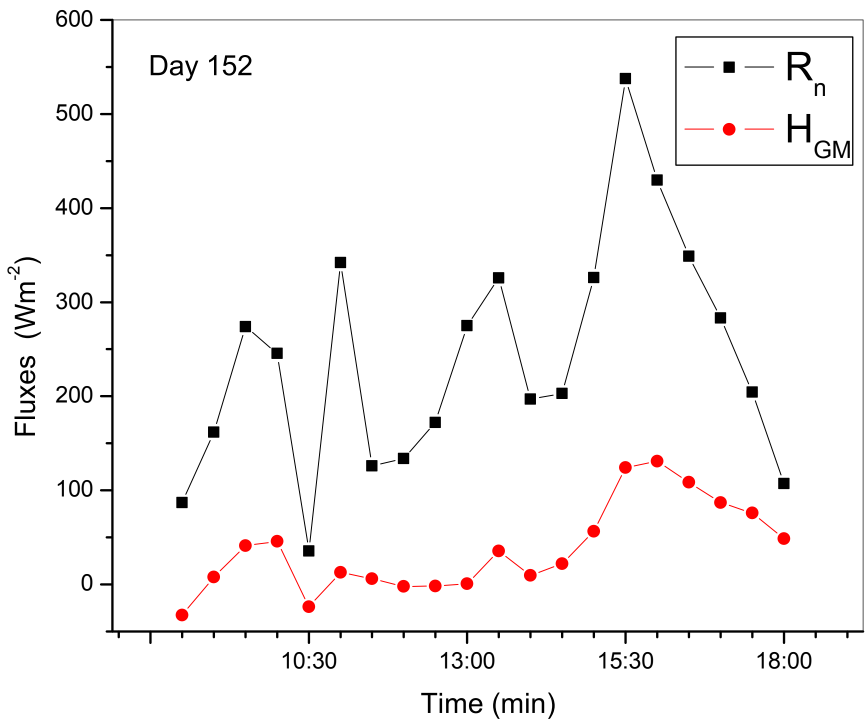


Fig. 1. Daytime variation of ground heat flux and net radiation for 1st June, 2013 (DOY 152)

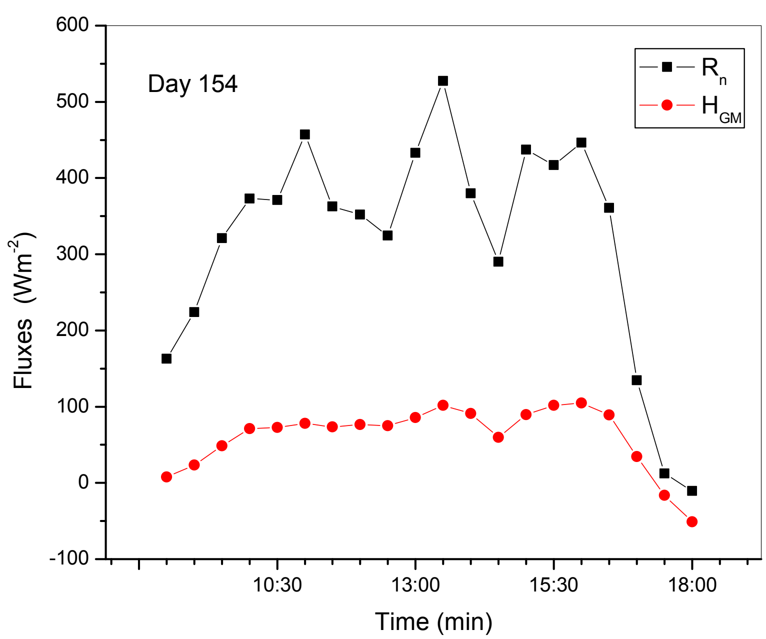


Fig. 2. Daytime variation of ground heat flux and net radiation for 3rd June, 2013 (DOY 154)

The net radiation values observed in Fig. 2 were found to be considerably lower than the period average due to the extensive cloud cover on the 3rd of June, 2013 (see Appendix I). The maximum net radiation value, 527.29 Wm^{-2} was measured at about 1330 hrs, decrease to -10.75 Wm^{-2} at 1800 hrs due to the cloudy condition at that particular time. The dips noticed in the net radiation values plotted in Fig. 2 in the daytime can be attributable to the drifting convective clouds thereby blocking out the incoming solar radiation intermittently. This is a common feature for the tropical humid areas Jegede, [15]. The cloud amount contributed to lowering the magnitude of the net radiation. The influence of clouds on the net radiation has been investigated by Ramanathan et al., (1989) and Harrison et al., (1990), they reported that cloud reduce the solar radiation by 48 Wm^{-2}.

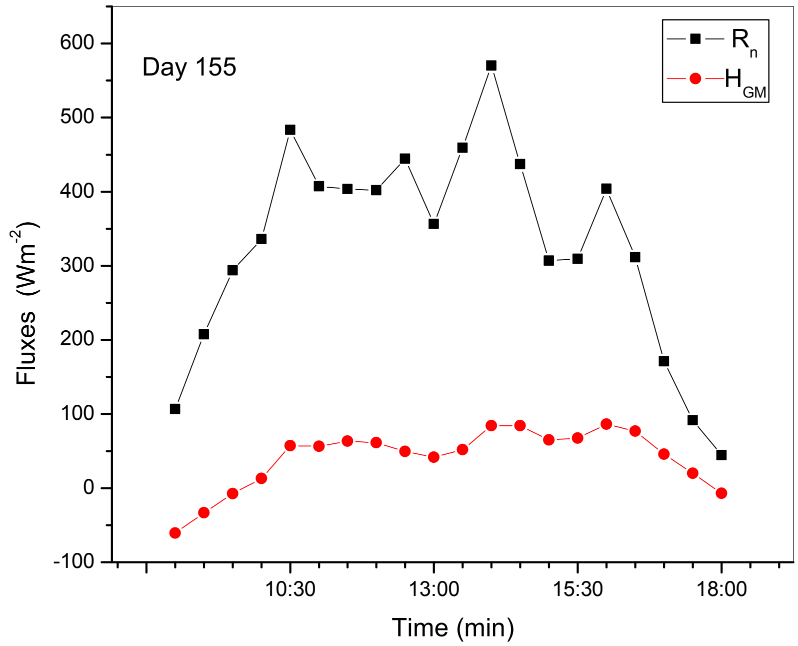


Fig. 3. Daytime variation of ground heat flux and net radiation for 4th June, 2013 (DOY 155)

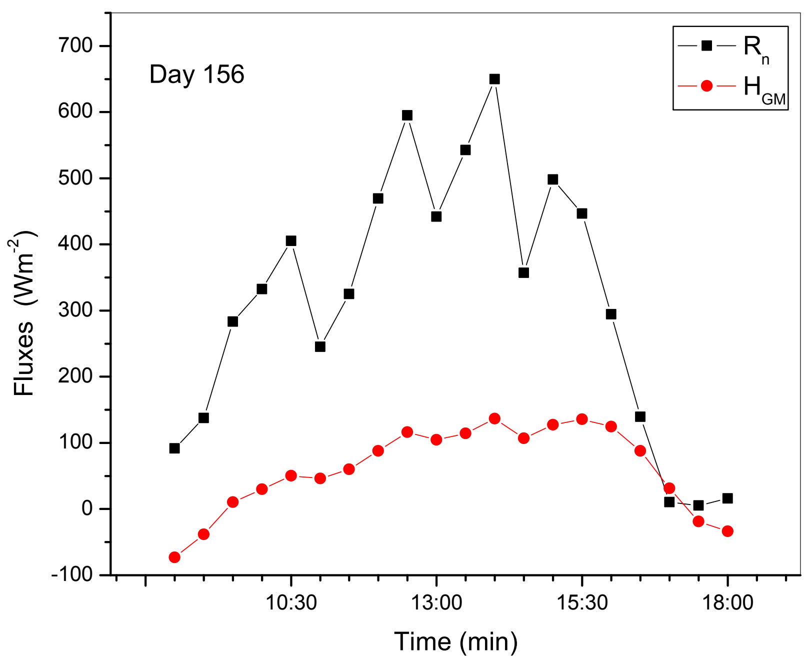


Fig. 4. Daytime variation of ground heat flux and net radiation for 5th June, 2013 (DOY 156)

Fig. 3 shows the ground heat flux and net radiation on 4th June, 2013. The ground heat flux value of -60.65 Wm^{-2} was observed at about 0830 hrs and an increase in the value continued until about 1030 hrs when it its value is about +57.11 Wm^{-2} due to the incoming solar radiation from the sun (see Appendix I). The maximum ground heat flux of 86.44 Wm^{-2} occurred at about 1600 hrs, which is slightly below 16% of net radiation and decrease steadily to about -7.08 Wm^{-2} around 1800 hrs due to cloud cover at that particular period.

The maximum value of net radiation measured was 569.97 Wm^{-2} at about 1400 hrs and it fell to 91.55 Wm^{-2} around 1730 hrs due little insolation (see Appendix I).

On 5th June, 2013 (DOY 156; Fig. 4), the daytime variation of ground heat flux of -72.87 Wm^{-2} was observed at about 0830 hrs which represented the lowest value for the entire period considered, and a gradual rise was observed until about 1030 hrs. Around 1400 hrs, a value of 136.86 Wm^{-2} was observed which represented the maximum value for the entire period considered while the maximum value of net radiation observed in Fig. 4 was 649.65 Wm^{-2} at 1400 hrs. This value is lower by about 61 Wm^{-2} when compared with the value reported by Bashiru [16], this is due to the differences in the type of surface used.

4. CONCLUSION

Continuous measurements of soil heat flux, soil temperature, surface temperature and net radiation at an experimental site (7.50°N, 4.52°E) located at the Obafemi Awolowo University Sport Complex; Ile-Ife, Nigeria, was carried out between 31st May and June 14th, 2013. Using the direct measurement technique, these datasets were used to investigate the daytime characteristic variation of the ground heat flux and net radiation.

The results showed that the measured ground heat flux, H_{GM} during the daytime increases until 1400 hrs with maximum value of about 136.86 Wm^{-2} and minimum value of about -72.87 Wm^{-2} at 0830 hrs (DOY 156). The measured net radiation, R_n value of 649.65 Wm^{-2} observed at 1400 hrs (DOY 156), represented the maximum value for the entire period of the study. -10.75 Wm^{-2} value observed at1800 hrs (DOY 154), represented the minimum value for the entire period of the study due to the cloudy condition of the sky which reduces the amount of incoming solar radiation reaching the earth surface.

ACKNOWLEDGEMENT

The Authors are grateful to the leader, Professor O.O. Jegede and members of Atmospheric Research Group, Department of Physics, Obafemi Awolowo University, Ile-Ife, Nigeria for making available the equipment used for this research.

The authors acknowledged Professor O.O. Jegede for providing the equipment used for this work.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Davies JA. Net radiation studies in the Schefferville area. Arctic. 1963;16:41-46.
2. Idso SB, Aase JK, Jackson RD. Net radiation-soil heat flux relations as influences by soil water content variations, Boundary-Layer Meteorol. 1975;9:113-122.
3. Foken T. Micrometeorology. Springer-Verlag Berlin Heidelberg. 2008;11.
4. Oke TR, Spronken SRA, Jauregui E, Grimmond CSB. The energy balance of central Mexico City during the dry season. Atmos Environ. 1999;33:3919–3930.
5. Jauregui E, Moreno MC, Tejeda A. The energy balance of central Barcelona, Fourth Symposium on the Urban Environment, Am. Meteor. Soc, Norfolk. 2002;9.6-3 S.
6. Hatfield JL, Perrier A, Jackson RD. Estimation of evapotranspiration at one time-of-day using remotely sensed surface temperatures. Agric. Water Manage. 1984;7:341-350.
7. Foken T, Göckede M, Mauder M, Mahrt L, Amiro B, Munger W. Handbook of micrometeorology: A guide for surface flux measurements. Kluwer, Dordrecht, NL. 2004;181–208.
8. Halldin S. Radiation measurements in integrated terrestrial experiments. Vegetation, water, humans and the

climate. A new perspective on an interactive system. Springer, Berlin, Heidelberg. 2004;167–171.
9. Mauder M, Foken T. Documentation and instruction manual of the eddy covariance software package TK2. Arbeitsergebnisse 26. Universität Bayreuth, Abt. Mikrometeorologie. 2004;44.
10. Kohsiek W, Liebethal C, Vogt R, Oncley SP, Bernhofer C, Foken T. The energy balance experiment EBEX-2000. Part III: Radiometer comparison. Boundary-Layer Meteorology and some alternative. Agron. J. 2006;98:1005–1014.
11. Kimball BA, Jackson RD. Soil heat flux. Modification of the aerial environment of plants. Am. Soc. Agric. Eng., Michigan. 1979;211–229.
12. Fuchs M. Heat flux. methods of soil analysis, Part 1: Physical and Mineralogical Methods. Am. Soc. Agro. (ASA) and Soil Sci. Soc. Am. (SSSA), Madison, WI. 1987;957–968.
13. Stull RB. An Introduction to boundary layer meteorology. Kluwer Academic Pub. 1988;666.
14. Jegede OO, Ogolo EO, Aregbesola TO. Estimating net radiation using routine meteorological data at a tropical location In Nigeria. International Journal of Sustainable Energy. 2006;25(2):107-115.
15. Jegede OO. Observations of daytime surface energy balance in cloudy tropical conditions at Ile-Ife, Nigeria. MAUSAM. 2002;3:359-366.
16. Bashiru MI. An investigation of mass, momentum and energy fluxes at the NIMEX site in Ile-Ife, Nigeria. Unpublished Masters Degree thesis, Obafemi Awolowo University, Ile-Ife; 2012.

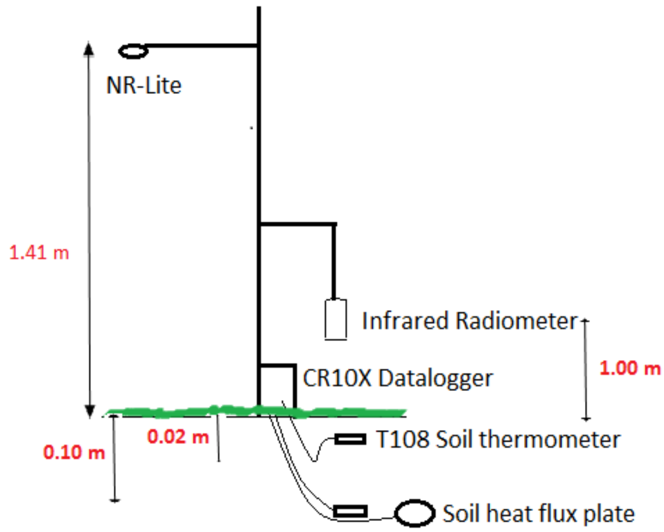
APPENDIX I

SYNOPTIC OBSERVATION OF SOME SELECTED DAYS AT THE SITE DURING 31st MAY TO 14th JUNE, 2013

Date	Time	Weather Remarks
01-06-2013	7hr	Cloudy, No isolation
	9hr	Cloudy, No isolation
	12hr	Rainy, Partly Cloudy, No insolation
	15hr	Partly Cloudy, Dry Air
	18hr	Partly Cloudy, Dry Air
03-06-2013	7hr	Cloudy, No insolation
	9hr	Clear Skies, High insolation
	12hr	Partly Cloudy, Little insolation
	15hr	Partly Cloudy, Little insolation
	18hr	Cloudy, No insolation
04-06-2013	7hrs	No rain, Partly Cloudy, no insolation
	9hrs	No rain, Partly Cloudy, sun is dimly visible
	12hrs	No rain, Partly Cloudy, sun is dimly visible
	15hrs	No rain, Cloudy, Little insolation
	18hrs	No rain, Partly Cloudy, Little insolation
05-06-2013	7hrs	No rain, Cloudy, no insolation
	9hrs	No rain, Partly Cloudy, sun is dimly visible
	12hrs	No rain, Partly Cloudy, Little insolation
	15hrs	No rain, Cloudy, high insolation
	18hrs	No rain, Cloudy, No insolation

APPENDIX II

SCHEMATIC DIAGRAM OF THE SENSORS USED IN THIS RESEARCH



Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/62814