Small Scale Irradiance Measuring Device

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Team 20

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Document

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1.0 Problem Statement

1.1 Introduction

The small-scale solar irradiance project aims to implement a device which may accurately model the irregularities of solar irradiance on COBar Ranch outside of Flagstaff, AZ. The Institute for Sustainable Energy Solutions (ISES) at Northern Arizona University is working to evaluate the reliability of the solar resource on a square mile of land outside of Flagstaff, AZ. The current evaluation method uses a large land area and many data collection devices to determine the variation of irradiance. The project intent is to streamline data collection while minimizing cost, land area usage, and system setup time.

1.2 Needs Identification

The current system is inefficient with its use of land, man hours, and produces poor data. The irradiance measuring system is large, semi-permanent, difficult to maintain, and costly. Due to the large area of the current site, a large amount of time is required to set up the numerous pyranometers in the system and to retrieve the data. In addition to creating an inconvenience for both the operators and land owners, the increased maintenance time creates unnecessary expenses. In summary, the current system is inefficient with its use of land, man hours, and produces poor data.

1.3 Project Goal

The project goal is to design a relatively small, portable solar irradiance measuring system that can accurately quantify variance in solar irradiance over a larger area that can be used to help determine the viability of installing a solar PV plant.

1.4 Objectives

The following points outline the pertinent objectives required to achieve this goal.

- Scales down site - Required surface area for data collection is minimized.
- Location - Each of the sensor locations needs to be known for representative data.
- Simple set up/operation - Minimal set up time and error propagation.
- Longevity – Must operate in an outside environment for the duration of the study.
- Transportable - Must be deployed easily to the test site.
- Inexpensive - Must be cost effective.

1.5 Constraints

The constraints are identified as follows:

- The data collected must correlate with the larger site.
- The surface area must not exceed that of a 100 foot diameter circle.
- The system must store data safely.
- The system must be properly set up in 16 man hours.
- The system must function autonomously between data collection visits.
- The sensors must take synchronized readings.
- The system must be inexpensive.
- The system must be able to withstand local environmental conditions for approximately 14 months.

2.0 System Design

2.1 Overview

The system utilizes one Campbell Scientific CR-1000 Data Acquisition Center (DAQ) connected to 5 Licor LI-200 Pyranometers set up in an 80 foot diameter circle. This singular data acquisition center allows data to be collected at a consistent frequency and stored in a consistent format eliminating local sensor time drift. Four of the five sensors are mounted on tripods that are located at a 40 foot radius from the DAQ in the cardinal directions, while the fifth is on the central tripod.

This layout is shown in Figure 1 below. An operational manual that further outlines the system set-up and operations is presented in Appendix A.

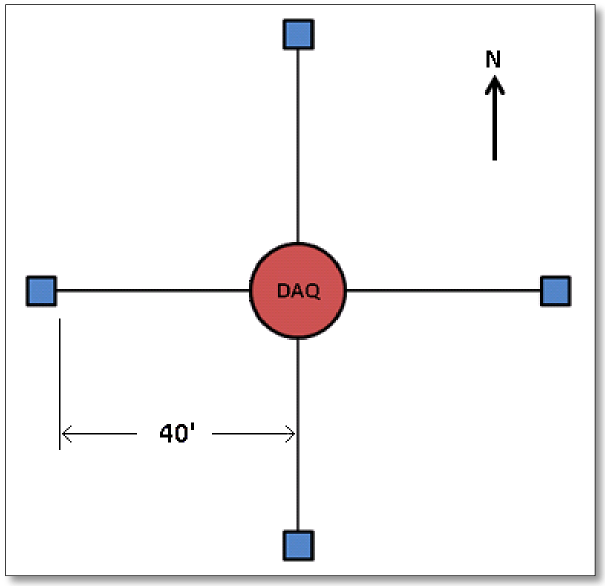

Figure 1: Diagram of Site

2.2 Pyranometers

Li-Cor Li-200 Pyranometers were chosen to measure the irradiance due to their low-cost, simple design, and reliability. The Li-Cor LI200 Pyranometers produce a voltage as a linear function of beam irradiance.

2.2.1 Pyranometer Connections:

The system uses a single ended voltage measurement where shunt resistors are connected between a common ground. Measuring the current across a known resistance allows the datalogger to determine the voltage output. The shunt resistor connection is shown in Figure 2 below.

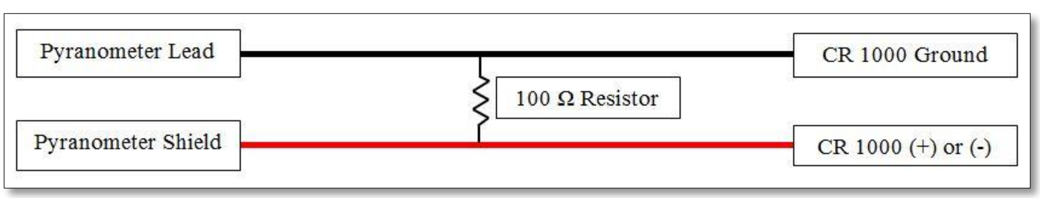

Figure 2: Pyranometer wiring diagram

2.2.2 Pyranometer Calibration

Pyranometers must be recalibrated every two years and it is possible to recalibrate them by calculating a coefficient between the measured value and the actual value of irradiance as established by a factory new sensor. Figure 3 shows the calibration setup of the pyranometers.

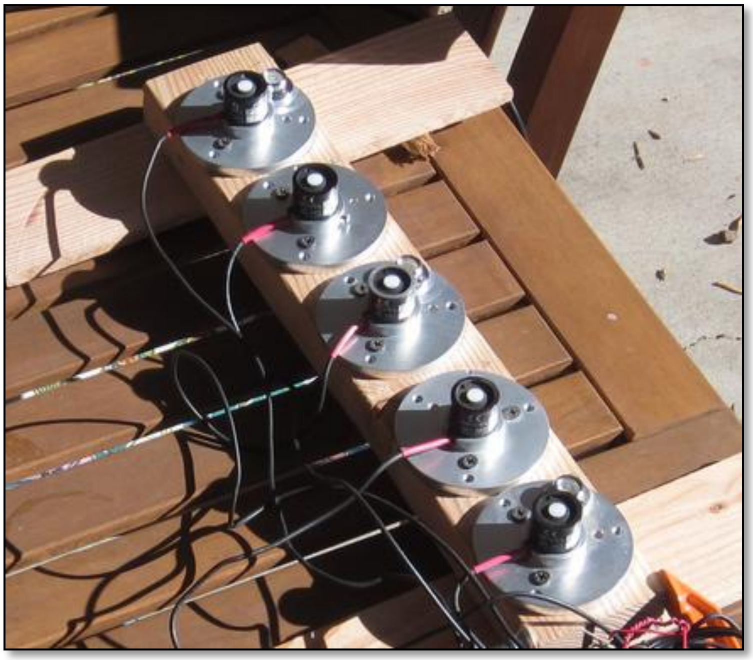

Figure 3: Pyranometer calibration setup

2.3 Pyranometer Mount

The mounting system for each Pyranometer consists of two main components: the leveling plate and the tripod mount, both shown in Figure 4.

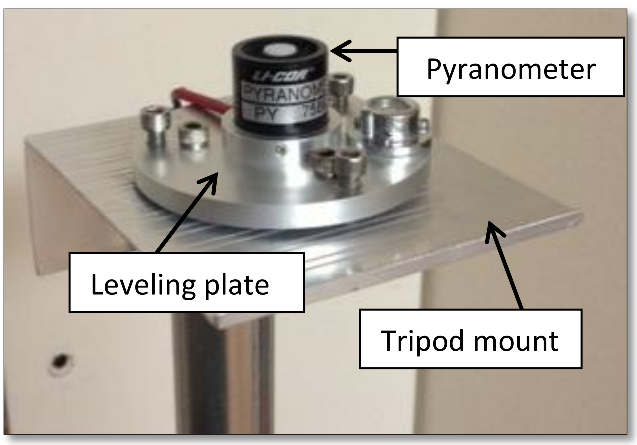

Figure 4: Fully Assembled Mounting System

2.3.1 Leveling Plate

The leveling plate is machined from a block of 6061 Aluminum. The plate includes two sets of bolt holes, a bubble level, and a collar for the pyranometer to be attached as seen in Figure 5. The raised perimeter for the pyranometer includes a set screw to secure the device and a recess to give the wire an unobstructed path to the datalogger. The inner bolt holes are for bolts that firmly secure the LI-2003S to the base plate and are smooth bore. The outer bolt holes are threaded to allow the leveling screws to be adjusted before tightening the inner bolts.

Figure 5: Close-up view of the LI-2003S leveling plate

2.3.2 Support Platform

The support platform is made of common components and materials so any repairs, modifications, or supplementations could be made by field teams setting up the system or collecting data. An extruded aluminum segment with an L-shaped cross-section was chosen for its corrosion resistance and manufacturability. The platform was cut from a large piece of stock into four inch lengths and care was taken to remove the rough edges to prevent user injury.

2.4 Data Acquisition Center (DAQ)

A Campbell Scientific CR-1000 Data Acquisition Center, shown in Figure 6, reads the analog voltage produced by the pyranometers. The voltage is measured by reference to a grounded cable and is transmitted to an NL-115 Compact Flash Module. The NL-115 stores data on a removable flash card allowing for easier data transfer, as well as increasing the amount of data storage. The CR1000 is programmed to store data in a format that is easily read by MATLAB to ease in data processing. This data will then be analyzed with the algorithms discussed below in Data analysis.

Figure 6: Data Acquisition Center

2.5 Tripod

The individual pyranometers are mounted on tripods during data collection. Brackets on the feet provide a way to anchor the tripod to the earth by using heavy duty stakes in sand and soil, or bolt anchors in compact rock. The tripod can be seen in Figure 7. The tripods make it easier to physically add or remove pyranometers to the system, as well as simplify set-up of the site.

Figure 7: Tripod with pyranometer mounted

2.6 Bill of Materials

The final design will consist of the components found in the Bill of Materials in Table 1 below.

Table 1: Bill of Materials

	Quantity	Approximate Cost
Campbell Scientific CR1000	1	$ 1,795.00
LI-COR LI 200 Sensors	5	$ 1,128.00
T Posts - 8ft	4	$ 21.00
Tripod	1	$ 71.17
Conduit	200ft	$ 76.36
Misc. Hardware		
Aluminum Sheet	1 (4 ½ x 1 ¾)	$13.12
Nuts and Bolts	7	$43.02
USB Cable	6feet	$41.58
Total		**$3,189.25**

3.0 Engineering Analysis

3.1 Natural Variance of Irradiance

To begin an analysis of the data (one second irradiance data from six pyranometers between 10:00am and 2:00pm for September 22, 2012) provided from the Next Era site, irradiance was plotted versus time for each of the pyranometers. The configuration of the pyranometers can be seen in Figure 8, and the plot of irradiance versus time can be seen in Figure 8.

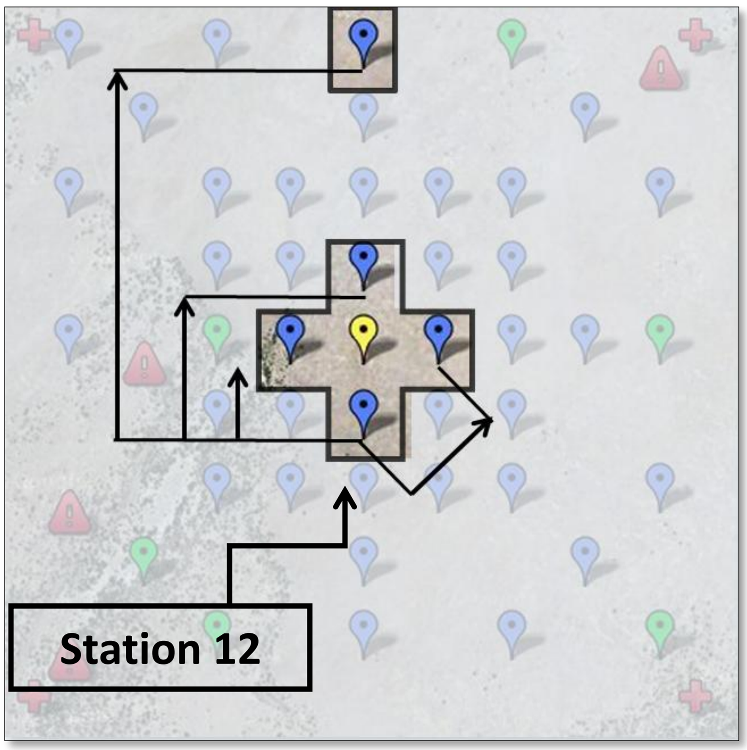

Figure 8: Configuration of Sensor from which Data was Received

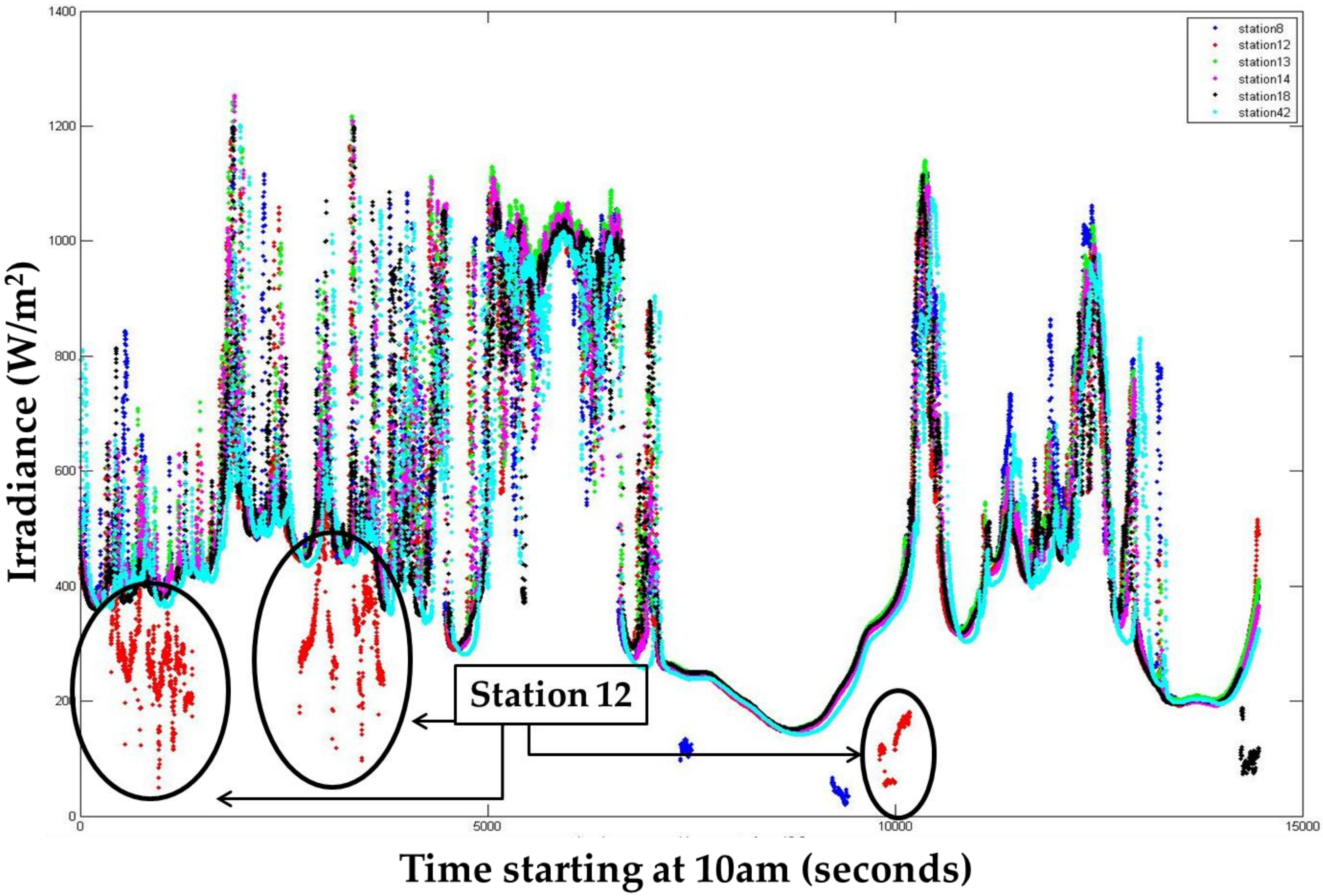

Figure 9: Irradiance versus Time for all Sensors

In looking at the plot in Figure 9, it was noted that all of the sensors are showing the same trend in irradiance observed. The one station that exhibits a significant amount of outlying points is Station 12. This is significant because when looking at the positioning of Station 12 in Figure 4, data was not received for stations South, East, or West of Station 12 so it cannot be determined with 100% certainty if Station 12 was seeing localized cloud cover, or if Station 12 was malfunctioning and recording bad data.

To try to determine if Station 12 was malfunctioning during the time period of the data set, the maximum and minimum change in irradiance between each data point was found for Station 12 and compared to the maximum and minimum change in irradiance for the other stations from which data was received. These maximum and minimum values can be viewed in Table 2.

Table 2: Changes in Irradiance

Station	Maximum Change in Irradiance (W/m^2)	Minimum Change in Irradiance (W/m^2)
8	99	-107
12	333	-336
13	100	-123
14	101	-143
18	99	-107
42	99	-107

Viewing the changes in irradiance, it was observed that Station 12 had significantly greater changes than any other station. Based on the trends seen at the other stations, it is thought that Station 12 was malfunctioning.

The next step that was completed in the data analysis was to calculate the Natural Variance in Irradiation (NVI) for the data set. NVI is a tool that compares the change in irradiance to the average irradiance seen at a point over a time set and is calculated using equation 1.

$$NVI = \frac{\sigma_{\Delta G}}{\bar{G}} \quad (1)$$

NVI was calculated for each station over the course of the 4 hour period, over an average at each hour, and over an average every 10 minutes which can be seen in Table 3, Figure 9, and Figure 10 respectively, noting that the bold lines in Figures 6 and 7 are the average NVI for all station.

Table 3: NVI Over the Four Hour Period

Station	NVI
8	0.02369
12	0.03642
13	0.02054
14	0.02093
18	0.02174
42	0.02213
Average	0.02424

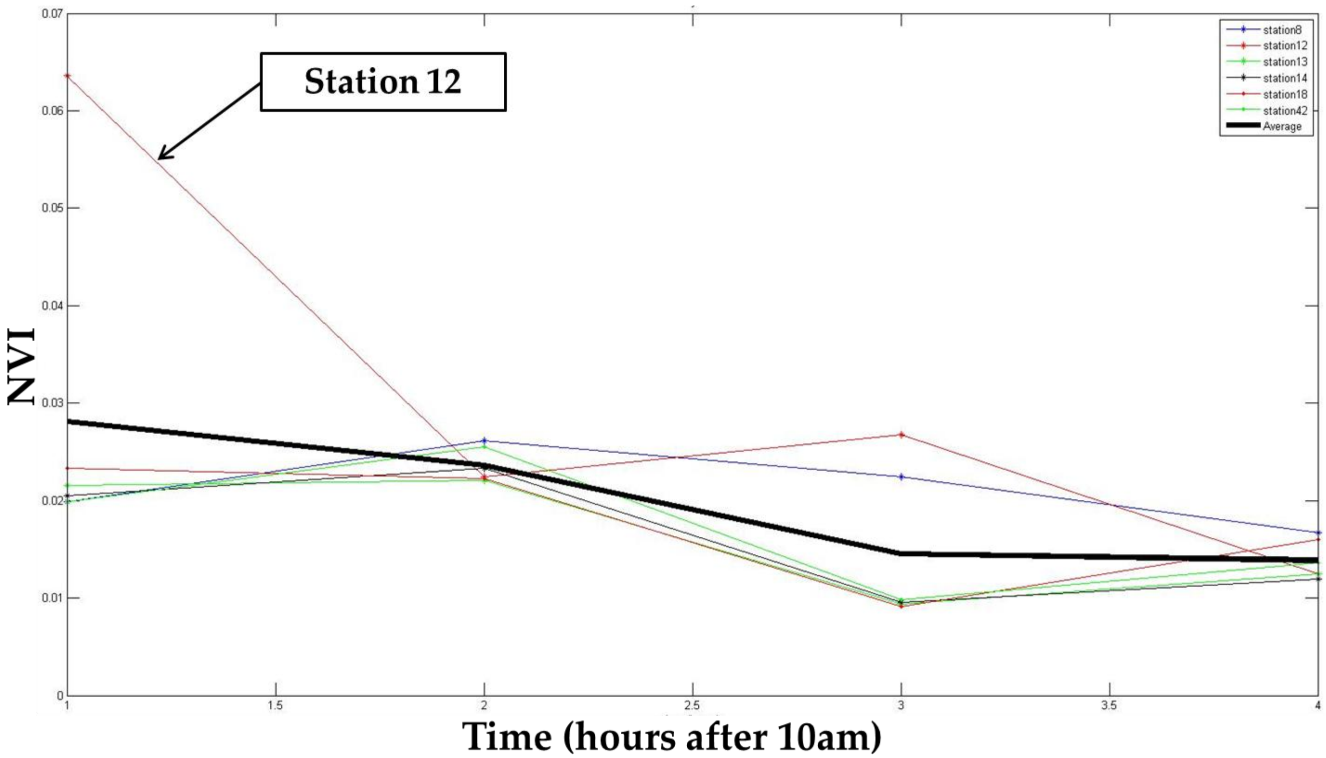

Figure 9: Hourly NVI

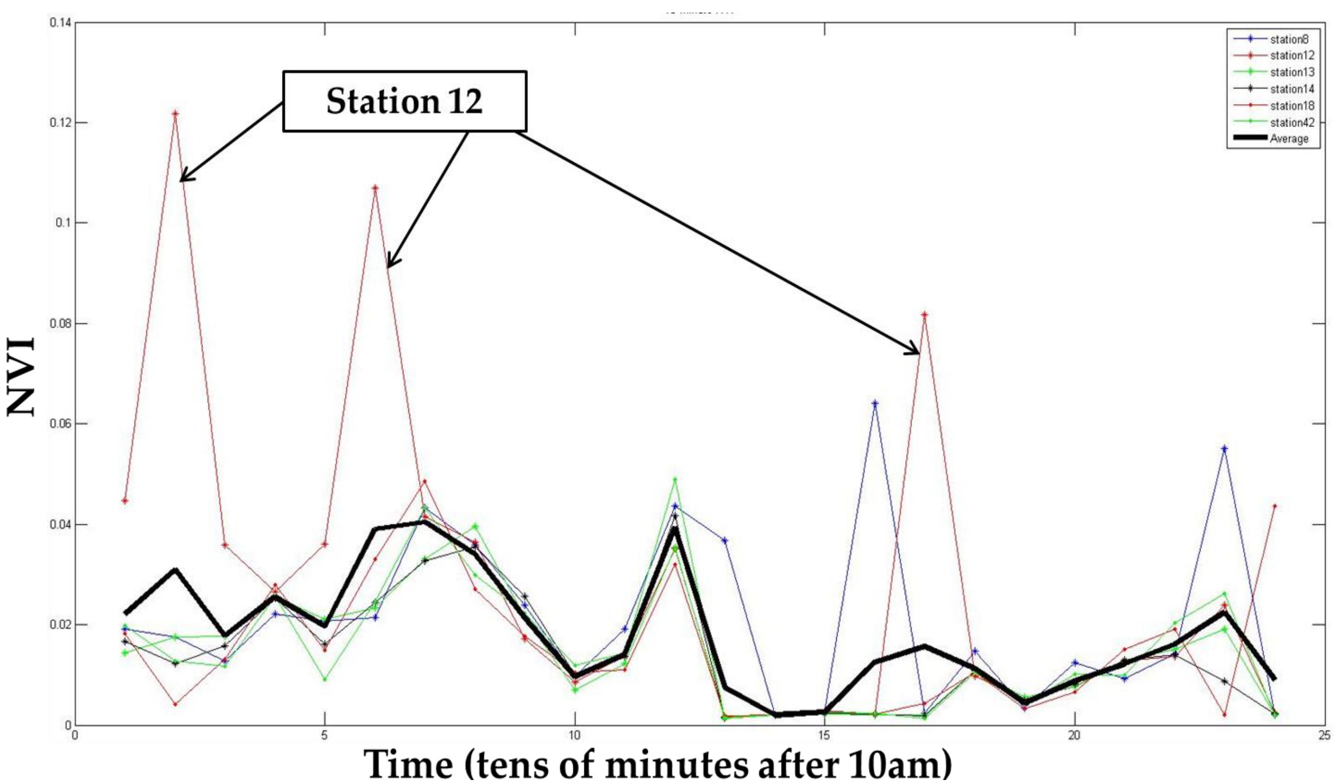

Figure 9**:** 10 Minute NVI

3.2 Calculating Needed Sample Rate

To calculate the needed sample rate for pyranometers placed 40 feet apart, one second data from Stations 17, 18, and 22 was used. The Matlab Correlation function (corr2) was used to relate data from Stations 18 and 22 to Station 17. This correlation was run through iterations, each iteration removing one data point from the end of the Station 17 data set and one data point from the beginning of both the Station 18 and 22 data sets. Removing these data points allowed for looking at the relationship between Stations 17, 18, and 22 through time while keeping the lengths of the data set. The iteration that provided the highest correlation value was assumed to be the average amount of time in seconds that it took for Stations 18 and 22 to see the same irradiance values that Station 17 saw. Since changes in irradiance values are caused by cloud movement, this method is used to track the movement of the clouds.

Knowing the distance between the stations and the time it took for a cloud to move between stations, x and y components of cloud velocity were found by comparing Station 22 to Station 17 and Station 18 to Station 17 respectively. Knowing an x and y component allowed for finding the actual cloud velocity vector. The magnitude of this vector was then assumed to be the average magnitude of cloud vectors.

This average cloud speed was found to be about 25.5 m/s. A Weibull distribution was applied to the data set and a cumulative density function was found which can be seen in Figure 11.

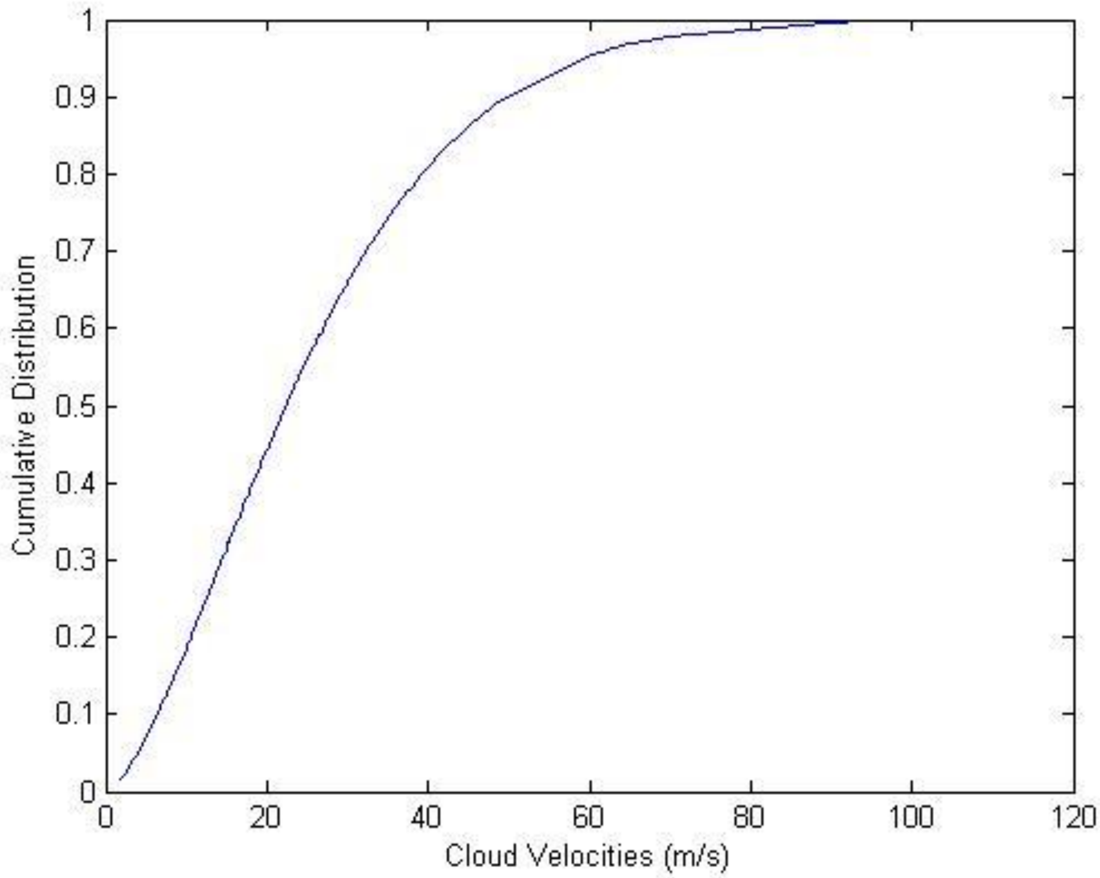

Figure 11: Cumulative Density Function

Using the cumulative probability density function, probability values were selected to see what velocity values could be seen, for example selecting a probability of 90% would see cloud speeds of about 60 m/s and less. So to see 90% of all cloud movement, the new site would have to be able to capture clouds that are moving up to 60 m/s. Using the known spacing of the pyranometers for the new site (40 feet), the amount of time it would take for a cloud to travel that distance at a given speed was found. The sampling rate (in Hz) at which would be needed to see that particular cloud movement is one over the time found. A summary of the sample rate needed for a given percent of velocities to be captured can be viewed Table 4.

Table 4: Required sampling rates

Velocities Seen (%)	Sample Rate Needed (Hz)
80	3.21
85	3.58
90	4.08
95	4.86
100	Infinity

3.3 Small Site Cloud Velocity

Using a 4 Hz sampling rate, data was collected at the COBar site with the center stations located at the same locations. A similar analysis was done on the smaller sites data to determine the cloud velocities shown in Figure 12.

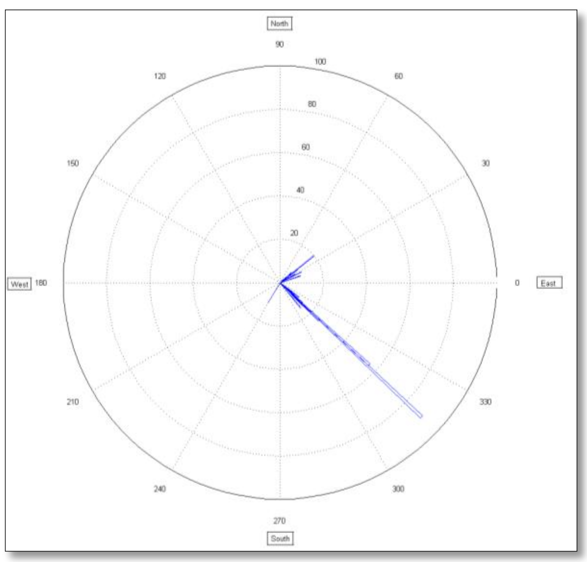

Figure 12: Number and direction of cloud vectors from small site.

At the time of the writing this report, it was not possible to accurately compare the data from the small site to the large site. Similar time series have been obtained from both the small site and the large site; however the data set from the large site is missing data points.

The missing data points prevent an accurate comparison between the sites to be completed. Figure 13 illustrates the missing data points from the large site's data set.

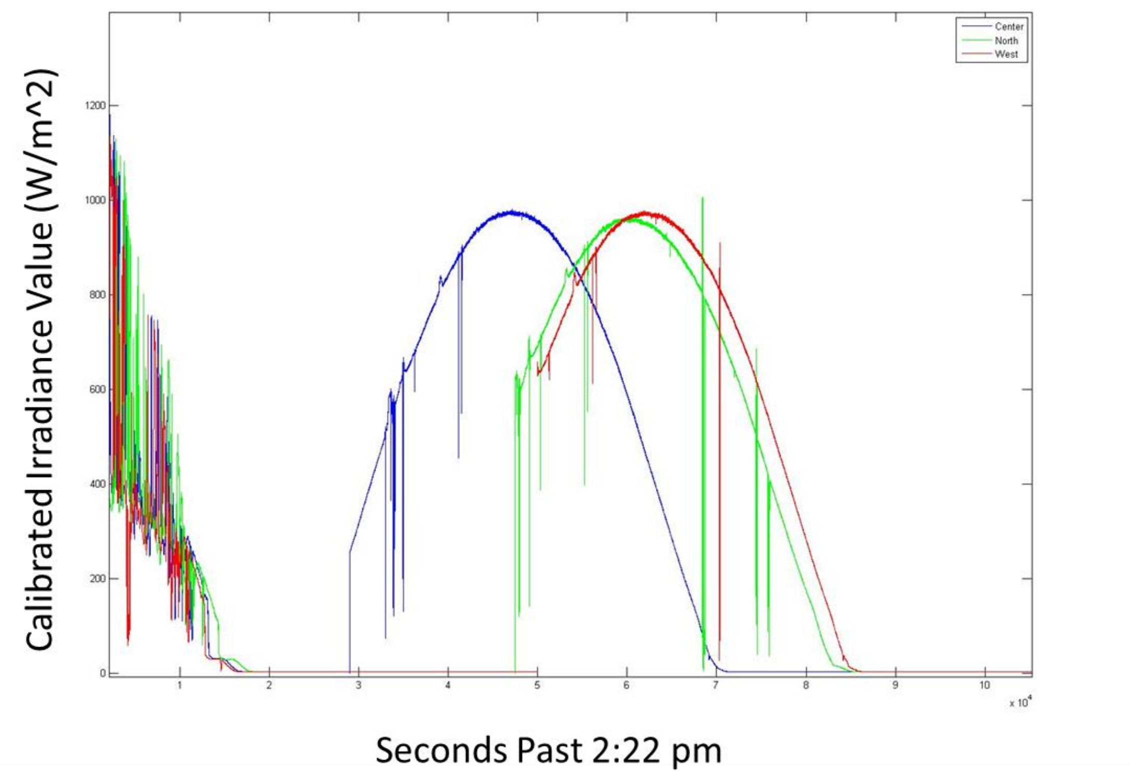

Figure 13: Missing data from large site.

An attempt to line the data set from the large site to the small site was completed so a rough comparison could be made between the two sites. Figure 14 shows the data sets from the two sites. It is a concern that the data from the larger site does not line up properly with the data from the small site.

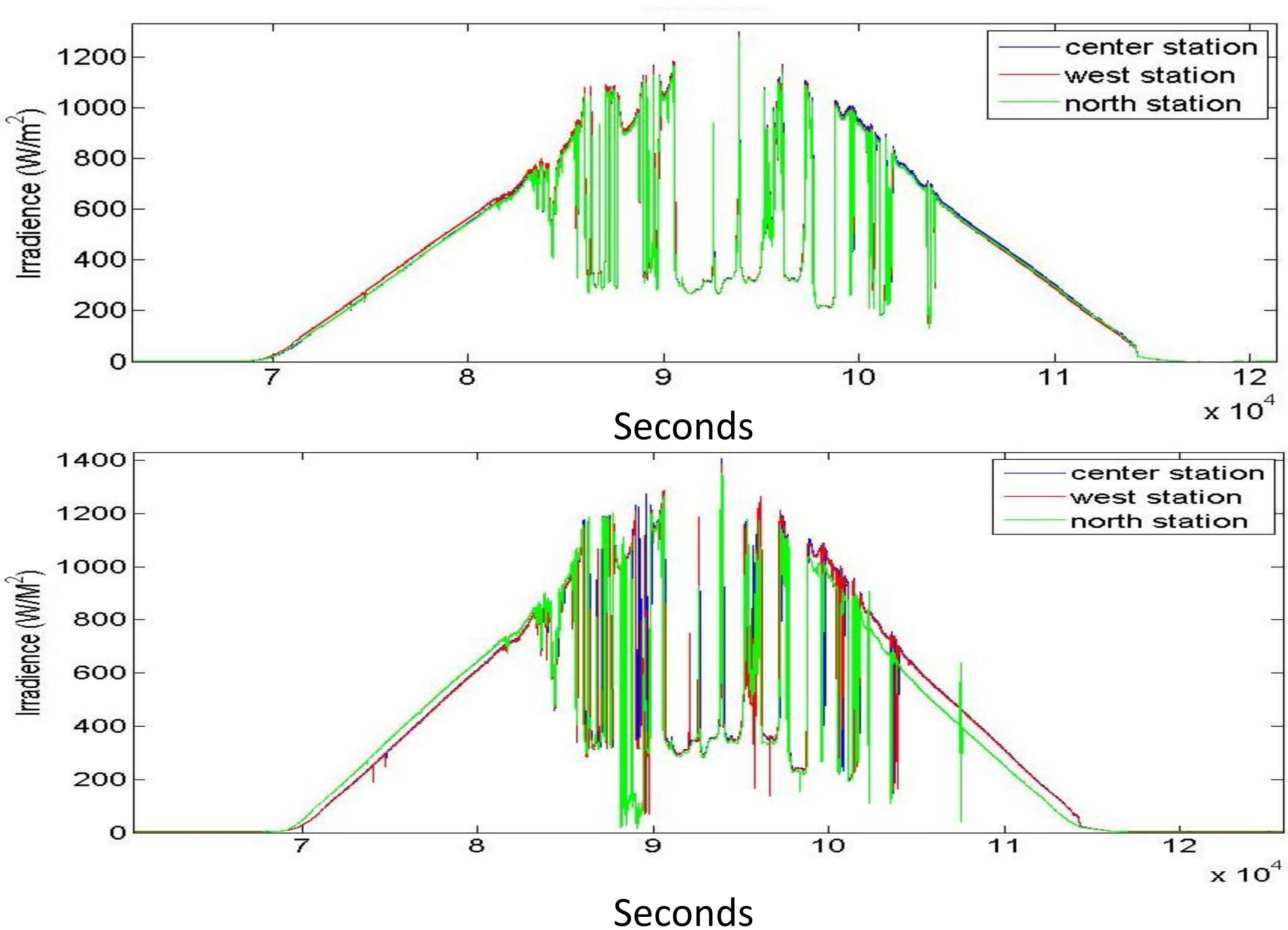

Figure 14: The top graph shows data from the small site, the lower graph shows data from the large site

Ten minute NVI values were also calculated between the two sites. NVI values can be seen in Figure 15. Small site values are seen on the left and large site values are on the right. One trend that can be seen in Figure 15 is that both graphs show similar trends, although the magnitudes are significantly different.

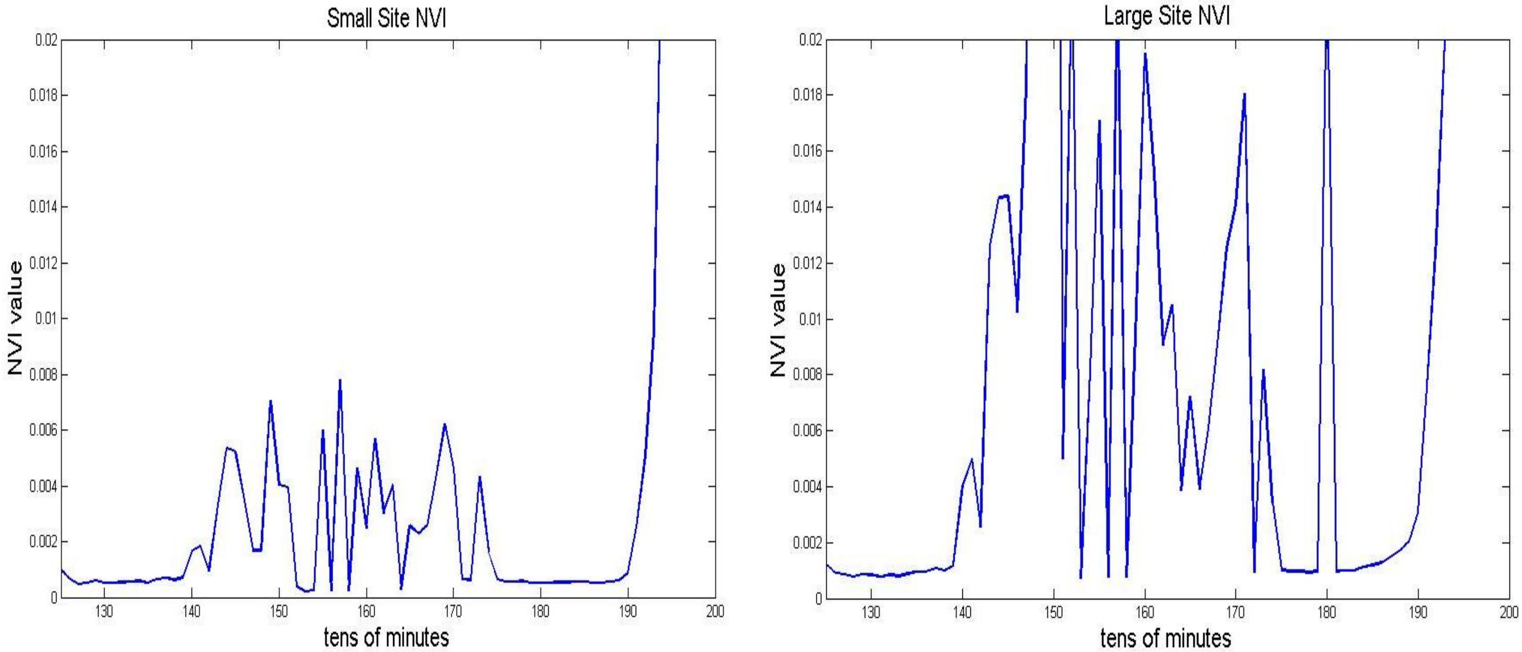

Figure 15: Comparison of NVI between small and large site.

Cloud velocities from the large site were also calculated and can be seen in Figure 16. Comparing Figure 16 with Figure 12, it is seen that the two plots do not show similar trends. It is a concern of the team's that the large site has the majority of its vectors point solely in the East, North, and West directions.

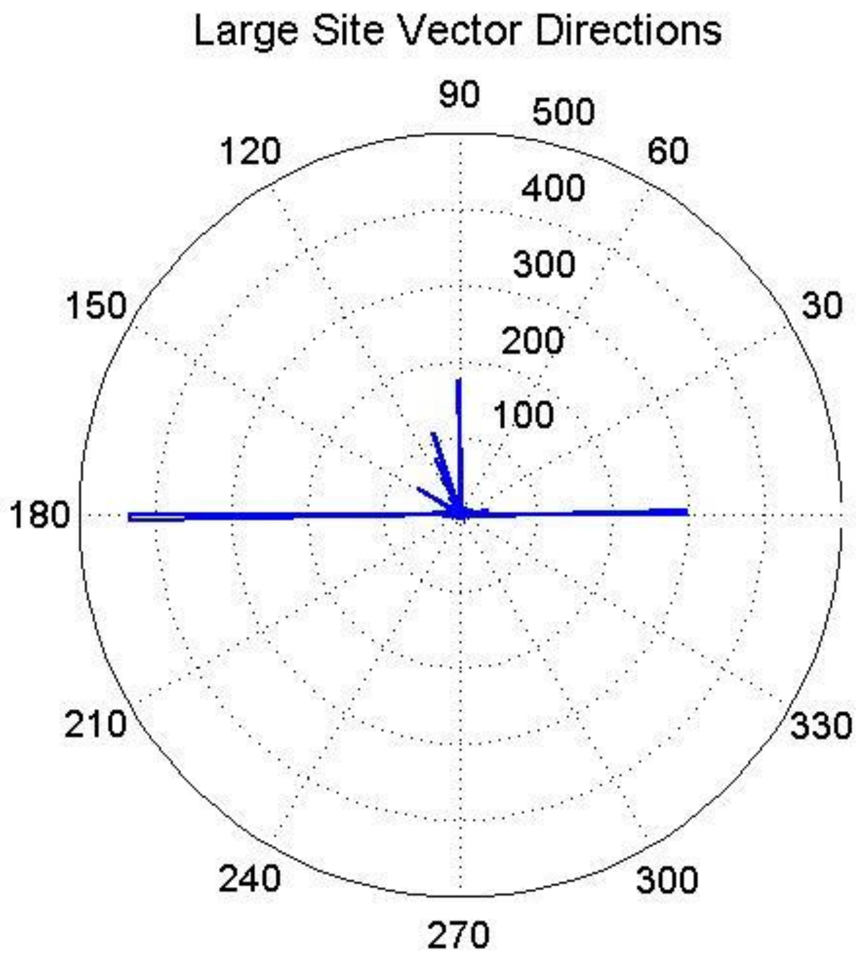

Figure 16: Number and direction of cloud vectors from large site.

4.0 Conclusion

With a system satisfying the goal requirements, the client now has valid data to compare with the existing site. With a quality set of data; the magnitudes, directions, and quantity of cloud vectors can be compared between the large and small site. In addition, NVI values from the large site can be compared on ten-minute to one-day intervals collected from the new site.

5.0 Appendices

Appendix A:

Small Scale Solar Irradiance Measuring Device

Set-Up and Operations manual

NORTHERN ARIZONA UNIVERSITY

College of Engineering, Forestry & Natural Sciences

Contents

Hardware

- Campbell Scientific CR-1000 Data acquisition system with CF card reader (DAQ)
- CF card (512 MB minimum)
- Weather proof Box for CR-1000
- 5-Tripods
- 5-Calibrated Licor LI-200 Pyronometers on leveling plates w/ 50ft of cable
- 5-Mount plates
- 4-50ft sections of conduit

Required Tools

- Socket Set
- Phillips head screw driver
- Compass
- 50ft measuring tape
- Computer with LoggerNet program installed
- 20+ Zip ties

Pre-Deployment Set-up*

Programing

a. Plug 9-pin to USB serial cable into the CR-1000 and connect to computer.
b. Choose “Setup” under the “Main” tab and create a new data logger if one has not been setup yet.
c. Open LoggerNet program.
d. Choose “Short Cut” under the “Programming” tab and specify data logger.
e. Specify sampling rate.
f. Choose single ended voltage measurement in generic sensors.
g. Fill Table 1 with sensor records and any other desired samples. Delete Table 2.
h. Download the program to CR-1000

Sensor Mounts

a. Put the outer bolts through the mounting plate and tighten down. Be sure to leave the bolt loose enough to allow leveling with the inside bolts
b. Inspect the cable ends for damage and wear: Replace if necessary.

Sensor Calibration

a. Calibration values must be recalculated every two years, but preferably every year.
b. Gather data logger measurements and known irradiance values for those times.
c. Divide the known irradiance by the voltage output to get the new coefficient.

*For detailed information on each component, please refer to their manuals:

Licor Li-200x—http://www.campbellsci.com/li200x-l

LoggerNet—http://www.campbellsci.com/loggernet

CR-1000—http://www.campbellsci.com/cr1000

NL-115— http://www.campbellsci.com/nl115

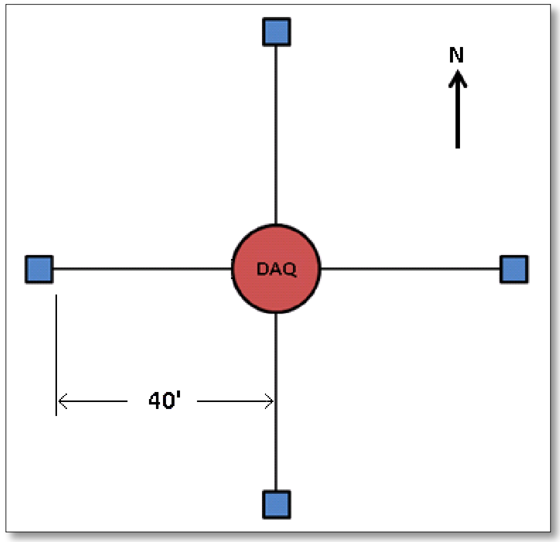

Figure 3: Diagram of site setup

Site Set up

Center Station Set-Up

a. Lay two paver stones down for each foot
b. Attach tripod feet to paver using bolts
c. Insert tripod legs into feet and tighten Allen keys

Sensor Set-up

a. Tripod
    i. Measure 40 ft. in North Direction
    ii. Set-up tripod, “eyeball plumb”
    iii. Weight tripod as shown
b. Sensor
    i. Inspect the sensor labeled *North*'s mount plate to ensure it is securely attached. Note: The thru-bolts should have a little play in them to allow for leveling with the inner-bolts
    ii. Place sensor at the north tripod, laying the conduit on the ground back to the center station
    iii. Attach each sensor to Tripod using the U-bolt as shown.
    iv. Attach conduit connectors to junction box at the bottom of the Data Acquisition System as shown. Ensuring that the wires reach the inputs.
    v. Attach sensor wires to respective input using figure as a reference.
    vi. Zip tie the conduit to the tripod as shown below to ensure it does not shift during testing.
c. Repeat steps a and b for the East, West, and South Directions

d. Center sensor attaches to the top of the center tripod using the same method outlined in step b

Data Acquisition Set up

a. Once all sensors are plugged into their appropriate inputs, connect the power cable into the CR-1000 power port
b. Red Indication light should be blinking every 15 seconds

Check Sensors

a. Plug the 9-pin serial cable into the 9-pin serial port on the CR-1000 and plug the USB end into the computer
b. Open LoggerNet program
c. Check input data from all sensors to ensure precise readings
d. If there are no issues, unplug computer from CR-1000

CF Card Use

Installation

a. To install a NL-115 Compact Flash Module, remove rubber cap on the CR 1000 data logger peripheral port.
b. Push, but don't force the NL-115 port onto the data logger port and tighten screw in the center of the NL-115.
c. Unplug the CR-1000 from any power source before continuing.
d. Open CF port on right side of the NL-115 and install a CF card.
e. Close port and tighten screw.
f. Reconnect power and ensure the "Status" light is blinking red. (Orange indicates card error, green indicates the card may be removed)

Card Removal

a. Check to ensure the "Status" light is still blinking red.
b. Press "Initiate Removal" and ensure the "Status" light turns green.
c. Unscrew far right screw, open port, and remove CF card.

Data Extraction

a. Insert CF card to card reader and connect to computer.
b. Open LoggerNet program.
c. Choose "Card Convert" under the "Data" tab.
d. Select the card reader as the input and specify the desired output.
e. Select "Start Conversion'.
f. Once the file is converted, delete the contents of the CF card and follow installation steps to return the card to the CF module.

6.0 References

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