Small Scale Irradiance Measuring Device

By

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Team 20

Project Proposal

Document

Submitted towards partial fulfillment of the requirements for

Mechanical Engineering Design – Fall 2012

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1 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) and Dr. Tom Acker at NAU are working with Next Era Energy to evaluate the reliability of the solar resource on a square mile of area outside of Flagstaff, AZ in order to determine the viability of a large-scale energy generation project at COBar Ranch. The current evaluation method uses a large land area and many data collection devices to determine the reliability of irradiance. The project intent is to streamline data collection while minimizing cost, land area usage, and system assembly time.

1.2 Background Research

Next Era Energy is one of America's top 10 producers of power. Next Era is North America's largest owner and operator of wind and solar electricity generating assets. Working with ISES, Next Era is determining the viability of installing a photovoltaic power plant in northern Arizona.

The Institute for Sustainable Energy Solutions is associated with the College of Engineering, Forestry, and Natural Sciences (CEFNS) at NAU and aims to provide society with broadly educated energy experts to promote renewable energy resources.

1.3 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 operate and maintain, and costly. Due to the large area of the current site, much time is required to set up the numerous pyranometers in the system and collect their data. This is an inconvenience for both the operators and land owners, as well as creates unnecessary expense. Our purpose is to design a more efficient system with respect to these issues. Presumably, we will be able to design a smaller scaled system which will collect data even more precisely. While striving to achieve our goal of designing a relatively small, portable solar irradiance measuring system that can accurately quantify variance in solar irradiance over a larger area, we generated various unique designs.

Need Statement:

The current system is inefficient with its use of land, man hours, and produces poor data.

1.4 Project Goal

Goal:

Design a relatively small, portable solar irradiance measuring system that can accurately quantify variance in solar irradiance over a larger area that can help determine the viability of installing a solar PV plant.

1.5 Objectives

Objectives:

- The following list describes the pertinent objectives as seen in **Table 1** 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.
- Easy set up/operation- minimal set up time and error propagation.
- Longevity- the device needs to operate in an outside environment for the duration of the study.
- Transportable- the device should be deployed easily to the study site.
- Inexpensive- device should be cost effective.

Table 1 Basis of measurement for objectives

Objectives	Basis for Measurement	Units
Scales Down Site	Surface Area	Ft^2
Location of Sensor	GPS	Lat./Long.
Easy Set-up/Operation	Set Up Time	Hours
Longevity	Durability	Months
Transportable	Packed Volume	Ft^3
Transportable	Weight	lbf
Inexpensive	Cost	$

1.6 Constraints

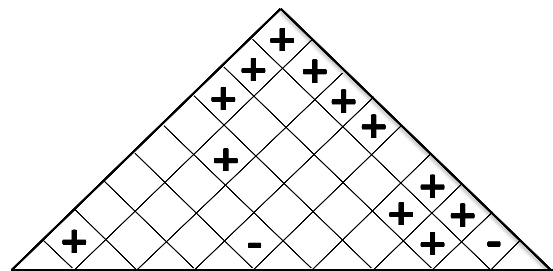
Constraints:

Appendix A shows how the customer's requirements relate to the constraints in the list below.

- Does the data collected correlate with the larger site?
- The surface area must not exceed that of a 100 ft diameter circle.
- Does the system store data safely?
- The system must be properly set up in 16 man hours.
- Does the system autonomously function between data collection visits?
- Does the system measure an accurate location for each sensor?
- Are the sensors taking readings in synchronization?
- Is the system inexpensive?
- The system must be able to withstand 'typical' environment conditions for approximately 14 months.

1.7 Quality Function Deployment

The customer requirements and engineering requirements can be seen in **Figure 1**, the Quality Function Deployment (QFD). In addition, the QFD includes the house of quality comparing the relationships between the engineering requirements. This is useful in determining the most important qualities of the device. These qualities were then given higher weights in the decision matrix for concept selection.



Customer Requirments	Surface area	Set-Up Time	GPS Location	Data Storage	Frequency	Longevity	Packed Sized	Weight	Cost
	Engineering Requirements								
Scales Down Current Site	X						X		
Useable Data Collection			X	X	X				
Store Data Safely				X		X			X
Easy to Set Up		X						X	X
GPS Location for Each Sensor			X	X					
Stand Alone Functioning				X		X			X
Time Stamped Data				X	X				
Inexpensive	X								X
Units	ft^2	hours	ft	days eq.	Hz	months	ft^3	Lb	$
Engineering Targets	~7800	16	±1	30	1	14	30	50	5000

Figure 1 Quality Function Deployment

2 Concept Generation and Selection

2.1 Concept Evaluation Methodology

Individual concepts must be evaluated before progressing through the design process. Providing criteria which either directly support the objectives or are the objectives themselves is the basis for our concept evaluation. Each of the criteria seen in **Table 2** represents a component that is instrumental to achieving our project goal and our determination of its importance represents the weight for that criteria. A few definitions of the criteria are:

- Technical adaptability- the ability of the system to accommodate additional pyranometers, varying their location, and the ease with which this can be accomplished.
- Environmental adaptability- the capability of the system to be assembled and operate as designed on ground surfaces which are uneven and whose soil composition varies from loose sand to dense rock.
- Wildlife- the ability of the system to remain unchanged when in the presence of large animals such as cows.

The criteria are rated on a scale of one to ten for each concept with the scoring system seen in **Table 3**. The score received is multiplied by the weight for each criterion to determine the concept's final score for each individual criterion. The final scores are then summed to achieve a total score, which provides a basis to rank concepts. All conceptual designs are available for review in Appendix D.

Table 2 Weighted Criteria for Concept Analysis.

Criteria	Weight
Technical Adaptability	5%
Setup 30%	
Time Required	7.5%
Tools Required	5%
Ease of Assembly	7.5%
Number of Pieces	2.5%
Environmental Adaptability	7.5%
Durability 15%	
Weather	7.5%
Wildlife	7.5%
Portability 10%	
Packed Size	5%
Weight	5%
Cost 40%	
Initial	24%
Setup	8%
Recurring	8%

Table 3 Performance Levels for Concept Analysis

Performance Level	Score
Perfect	10
Excellent	9
Very Good	8
Good	7
Satisfactory	6
Adequate	5
Tolerable	4
Poor	3
Very Poor	2
Inadequate	1

2.2 Concepts

Tripod

The tripod concept uses simple tripods with telescoping legs and brackets on the feet to support individual pyranometers in addition to a wireless transfer device. The telescoping legs allow the assembly to be set up level on nearly any reasonable gradient. 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. A small solar panel would power a wireless data transfer device so that site data may be stored and collected on a single, centrally located data acquisition center.

The tripod concept would be a good solution to the problem because it would be simple to physically add or remove pyranometers, and can set up quickly and easily on nearly any site. Furthermore, the tripod concept would not be a good solution to the problem because it is very expensive and has unique and difficult hardware and software integration issues. Some of these issues include:

- Reliable power is required for each transmission station to ensure data acquisition center receives proper data.
- Enough open channels of wireless transfer for the number of pyranometers is required.
- Accurate time keeping across an array of pyranometers is required.

These were the main benefits and drawbacks to this concept, though many more were considered during its evaluation. The final evaluation can be seen in **Table 4** below.

Table 4 Tripod Concept Analysis

Criteria	Weight	Raw Score	Final Score
Technical Adaptability	5%	8	0.4
Setup 30%			
Time Required	7.5%	6	0.45
Tools Required	5%	5	0.25
Ease of Assembly	7.5%	7	0.525
Number of Pieces	2.5%	8	0.2
Environmental Adaptability	7.5%	8	0.6
Durability 15%			
Weather	7.5%	6	0.45
Wildlife	7.5%	6	0.45
Portability 10%			
Packed Size	5%	7	0.35
Weight	5%	8	0.4
Cost 40%			
Initial	24%	4	0.96
Setup	8%	6	0.48
Recurring	8%	6	0.48
	Total:	85	5.995

Umbrella

The Umbrella design is similar to a typical umbrella in that a collar slides up and down a main pole to raise and lower the arms. This collar is held by a pin that is placed by the operator. The sensors are located at the end of the telescoping arms. These arms are similar to a quick release bike post; lifting a lever will allow the arm to be extended to the desired length and locked in place. The data will be collected by one data acquisition system powered by a photovoltaic panel located on the main shaft. The entire array could be mounted on a tripod that will possibly be weighted or staked into the ground. If the ground conditions permit, the pole could be driven into the earth to provide a secure base.

The Umbrella design allows for reproducible sensor array setups despite ground conditions. Unfortunately, this design has limited sensor array options in both positioning and number of sensors. The telescoping arms have a bound on the maximum length. For instance, a 50ft telescoping arm is impractical. To add more sensors, the entire system would have to be redesigned to account for more arms. **Table 5** displays the exact weight for each component that has been a factor in this design.

Table 5 Umbrella Concept Analysis

Criteria	Weight	Raw Score	Final Score
Technical Adaptability	5%	5	.25
Setup 30%			
Time Required	7.5%	5	.375
Tools Required	5%	7	.35
Ease of Assembly	7.5%	6	.45
Number of Pieces	2.5%	7	.175
Environmental Adaptability	7.5%	9	.675
Durability 15%			
Weather	7.5%	5	.375
Wildlife	7.5%	7	.525
Portability 10%			
Packed Size	5%	6	.3
Weight	5%	6	.3
Cost 40%			
Initial	24%	5	1.2
Setup	8%	6	.48
Recurring	8%	8	.68
	Total:	82	6.095

Sky Net

The Sky Net design consists of two poles supported by a tension system and a net with mounted sensors. The design works by using a triangulated tension system to position and hold each pole vertically, and to provide tension to steady the net. The two poles will be separated by 25 feet. Each pole will be approximately eight feet tall. This height will allow the system to minimize interactions with ground animals like cows that can be found on a site like CObar Ranch. The tensioning system will be anchored with large spikes, or expansion bolts placed in rock depending on the specific attributes of the ground. The tensioning system will be a basic pulley system of adequate reduction, as determined in our engineering analysis.

This system is complex and will require a large amount of time to setup, and will be affected largely by weather. Regardless of the tension achieved in the system, the net will still move with the wind. Although the setup system will be large, the portability of the system is very high. All of the components such as the support poles, steaks, net, and the rest of the needed hardware and tools can easily be loaded into the bed of a full size pick-up truck. The aspects were evaluated and can be found in **Table 6**.

Table 6 Sky Net Concept Analysis

Criteria	Weight	Raw Score	Final Score
Technical Adaptability	5%	4	.2
Setup 30%			
Time Required	7.5%	4	.3
Tools Required	5%	6	.3
Ease of Assembly	7.5%	5	.375
Number of Pieces	2.5%	8	.2
Environmental Adaptability	7.5%	6	.45
Durability 15%			
Weather	7.5%	5	.375
Wildlife	7.5%	6	.45
Portability 10%			
Packed Size	5%	8	.4
Weight	5%	8	.4
Cost 40%			
Initial	24%	7	1.26
Setup	8%	5	.4
Recurring	8%	8	.64
	Total:	80	6.17

Bucket Post

The bucket post idea consists of a five gallon bucket filled with cement. A sleeve fitting for a t-Post will be placed in the cement. This allows for insertion and removal of an approximately five foot tall t-Post. A pyranometer will be attached to the top of the t-Post to measure solar irradiance. This design concept will allow for a singular data acquisition unit for multiple sensors, or having a data acquisition device for each sensor.

This design has several attributes that gave it high scores in the decision matrix. These attributes include simple set up with few pieces, and low initial cost. This design also has some negative attributes that gave it low scores in the decision matrix. These aspects include the weight and size of the design in addition to poor environmental adaptability. The full decision matrix is shown in **Table 7** below.

Table 7 Bucket Post Concept Analysis

Criteria	Weight	Raw Score	Final Score
Technical Adaptability	5%	8	.4
Setup 30%			
Time Required	7.5%	4	.3
Tools Required	5%	8	.4
Ease of Assembly	7.5%	7	.525
Number of Pieces	2.5%	9	.225
Environmental Adaptability	7.5%	3	.225
Durability 15%			
Weather	7.5%	8	.6
Wildlife	7.5%	5	.375
Portability 10%			
Packed Size	5%	3	.15
Weight	5%	2	.1
Cost 40%			
Initial	24%	8	1.92
Setup	8%	6	.48
Recurring	8%	6	.48
	Total:	77	6.18

2.3 Concept Selection

For the concepts analyzed, the bucket post concept had the highest total score, though all four total scores were very similar. **Table 8** below presents the final scores for each design.

Table 8 Concept total score comparison

Concept	Tripod	Umbrella	Sky Net	Bucket Post
Total Weighted Score	5.995	6.095	6.17	6.18

3 Engineering Analysis

3.1 Natural Variance of Irradiance

To begin an analysis of the data (one second irradiance data from 6 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 2** and the plot of irradiance versus time can be seen in **Figure 3.**

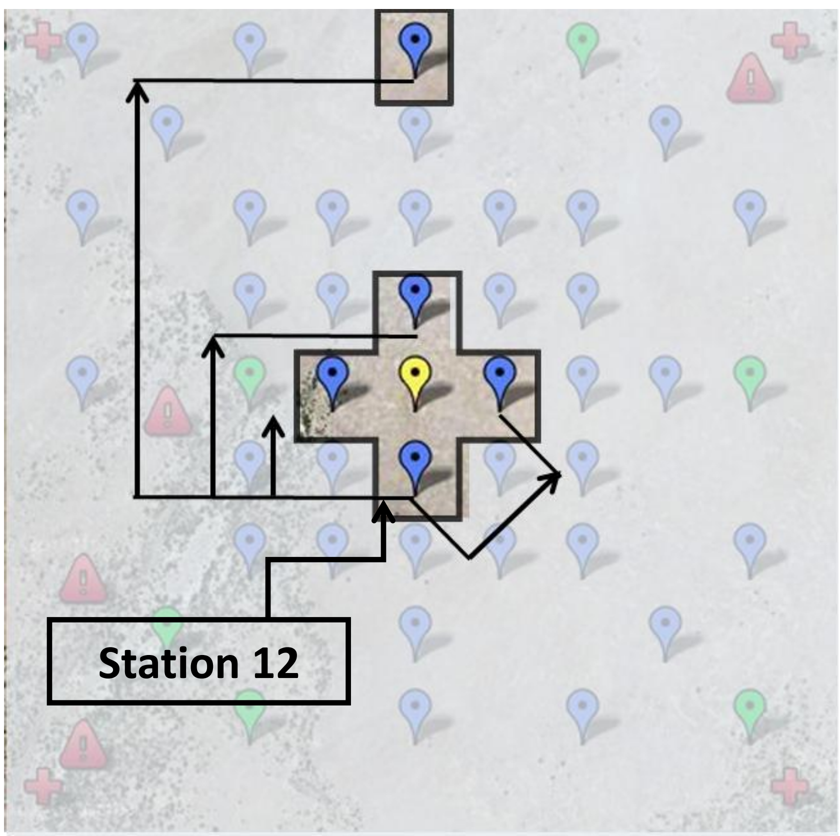


Figure 2 Configuration of sensor from which data was received.

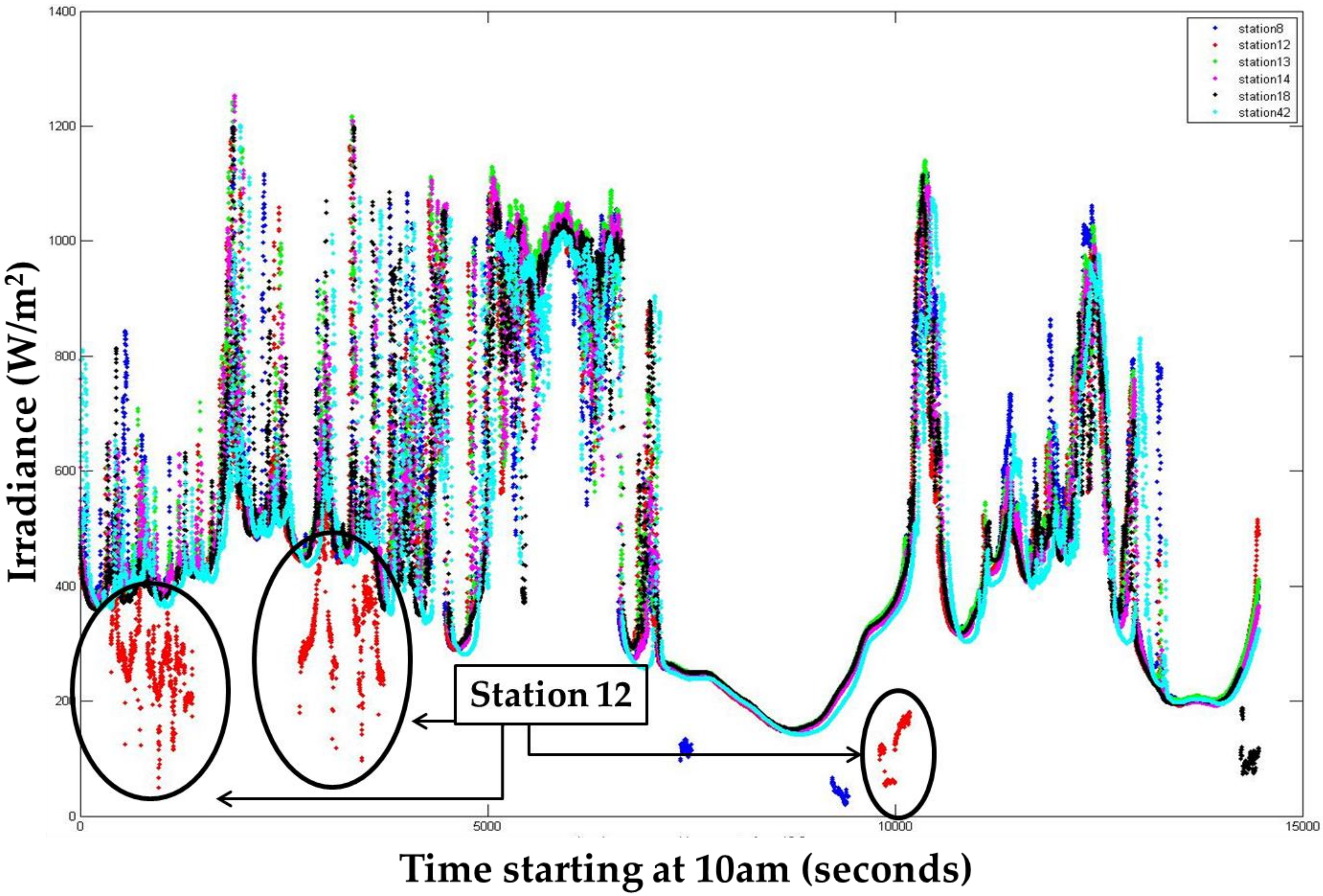


Figure 3 Irradiance versus time for all sensors.

In looking at the plot in **Figure 3**, 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 2**, 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 received 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 9**.

Table 9 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; however, more data and input from technical advisors are required before it can be said that Station 12 was in fact malfunctioning.

The next step that was completed in the data analysis was to calculate the Natural Variance in Irradiation (NVI) for the data sight. 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**.

$$NVI = \frac{\sigma_{\Delta G}}{\overline{G}} \qquad \textbf{eqn. 1}$$

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 10**, **Figure 4**, and **Figure 5** respectively, noting that the bold lines in **Figures 4** and **5** are the average NVI for all station.

Table 10 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

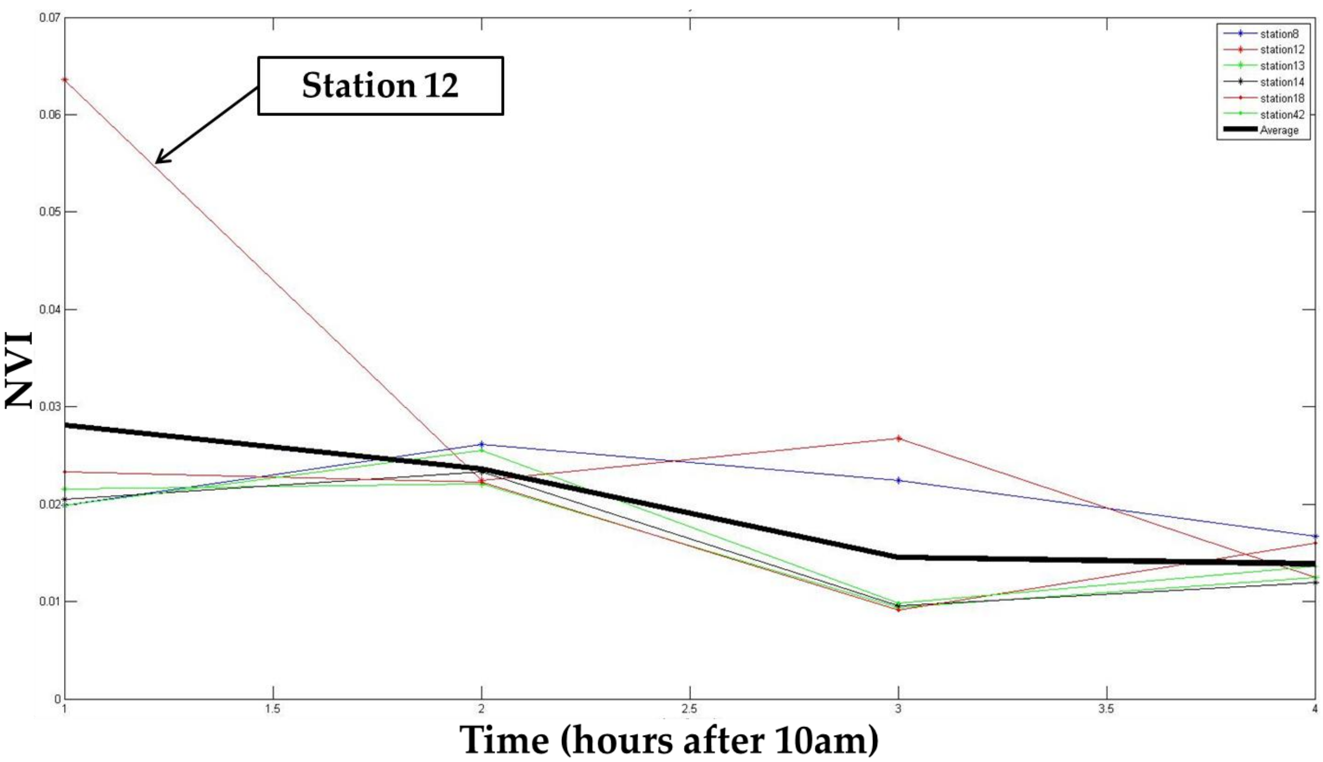


Figure 4 Hourly NVI

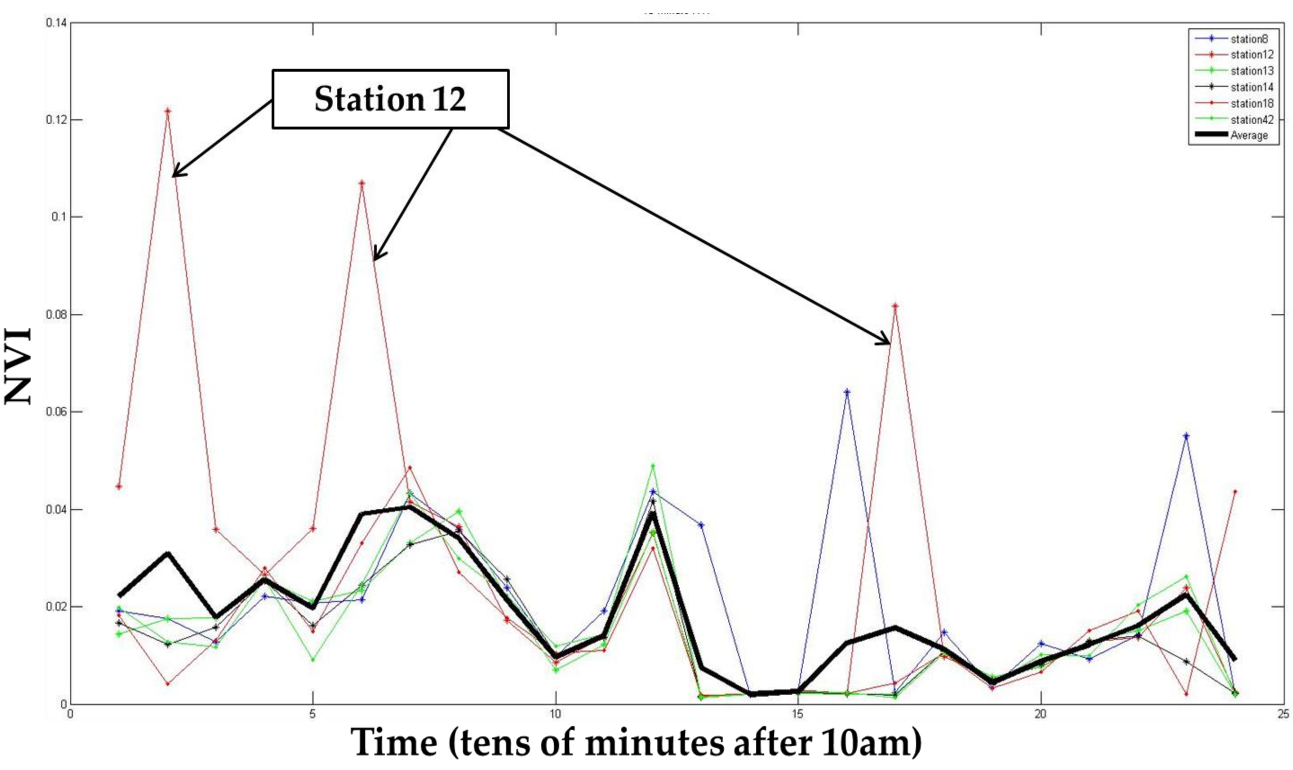


Figure 5 10 Minute NVI

3.2 Calculating Needed Sample Rate

To calculate the needed sample rate for pyranometers placed 40 feet apart, one second data from Stations 13, 14, and 18 was used. The MatLab Correlation function (corr2) was used to relate data from Stations 14 and 18 to Station 13. This correlation was ran through iterations, each iteration removing one data point from the end of the Station 13 data set and one data point from the beginning of both the Station 14 and 18 data sets. Removing these data points allowed for looking at the relationship between Stations 13, 14, and 18 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 14 and 18 to see the same irradiance values that Station 13 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 18 to Station 13 and Station 14 to Station 13 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 12.2 m/s. This value was applied to a Rayleigh distribution. The probability density function can be seen in **Figures 6** and **7** respectively.

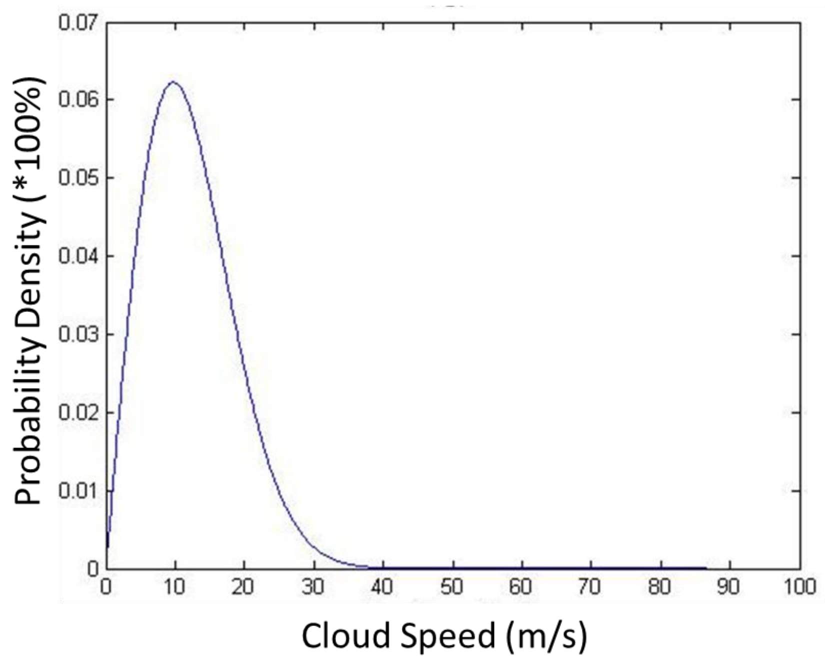


Figure 6 Probability Density Function

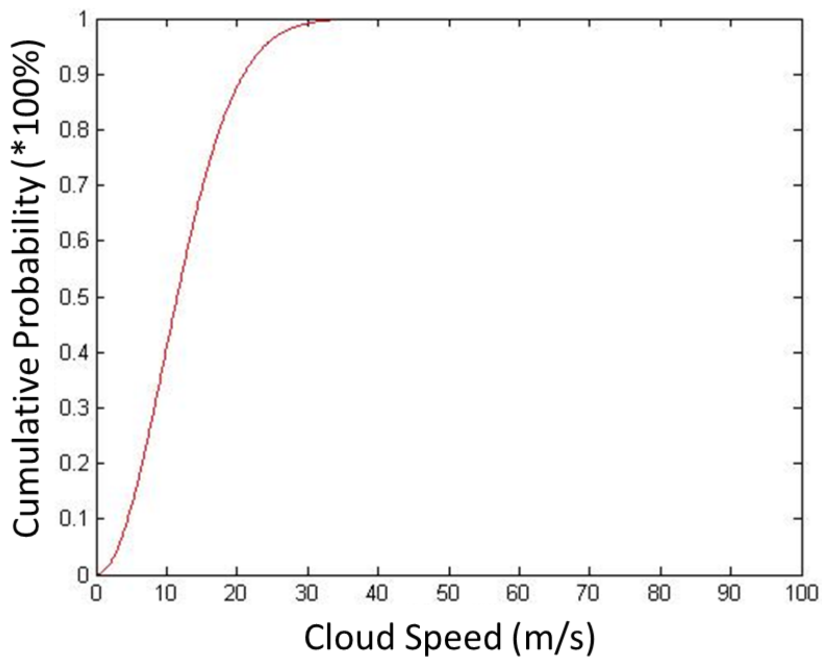


Figure 7 Cumulative Density Function

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 20 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 20 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 in **Figure 8** and **Table 11**.

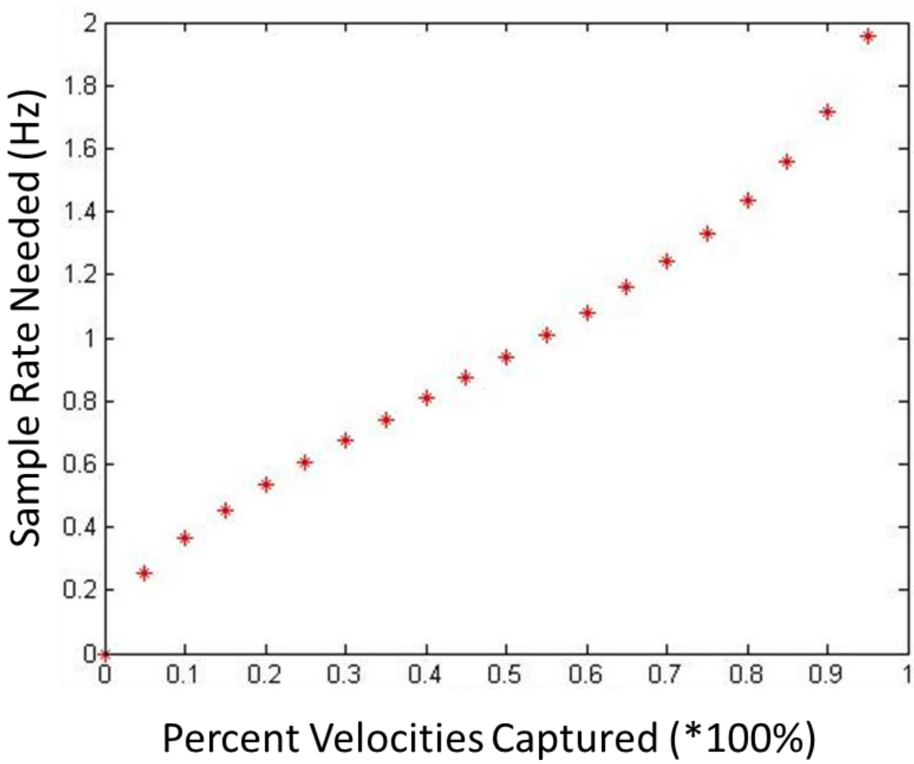


Figure 8 Sample Rate Needed

Table 11 Sample rate needed

Velocities Seen (%)	Sample Rate Needed (Hz)
70	1.24
75	1.33
80	1.43
85	1.56
90	1.71
95	1.96
100	Infinity

3.3 Continuation of Analysis

This analysis will be refined before the needed sample rate can be determined. There is much uncertainty associated with the data sets that were used. The data that was used only encompasses a short four hour period and there is much time drift associated with Station 13 (about 7 seconds is gained per day). This analysis will be completed running a month's worth of data for three new stations with the same configuration as Stations 13, 14, and 18, but with smaller and more consistent drift.

4 Final Design

4.1 Physical Components

The final design will consist of the components found in the Bill of Materials below, **Table 12**

Table 12 Bill of Materials

	Quantity	Approximate Cost
Campbell Scientific CR800	1	$ 1,395.00
LI-COR LI 200 Sensors	5	$ 1,128
T Posts - 8ft	4	$ 21.00
Tripod	1	$ 80.00
Conduit	200ft	$ 70.00
Misc. Hardware	-	$ 50.00

4.2 Physical Setup

The physical setup of the components includes 4 posts with a LI-COR 200 mounted axially on the top, see **Figure 9**. The Tripod will be used to support the Campbell Scientific CR800 and one LI-COR LI200. The system will be set up in the orientation found in **Figure 10.** Sensors will be connected to the Data Acquisition Center using simple 12 gage wires run through a flexible metal conduit.

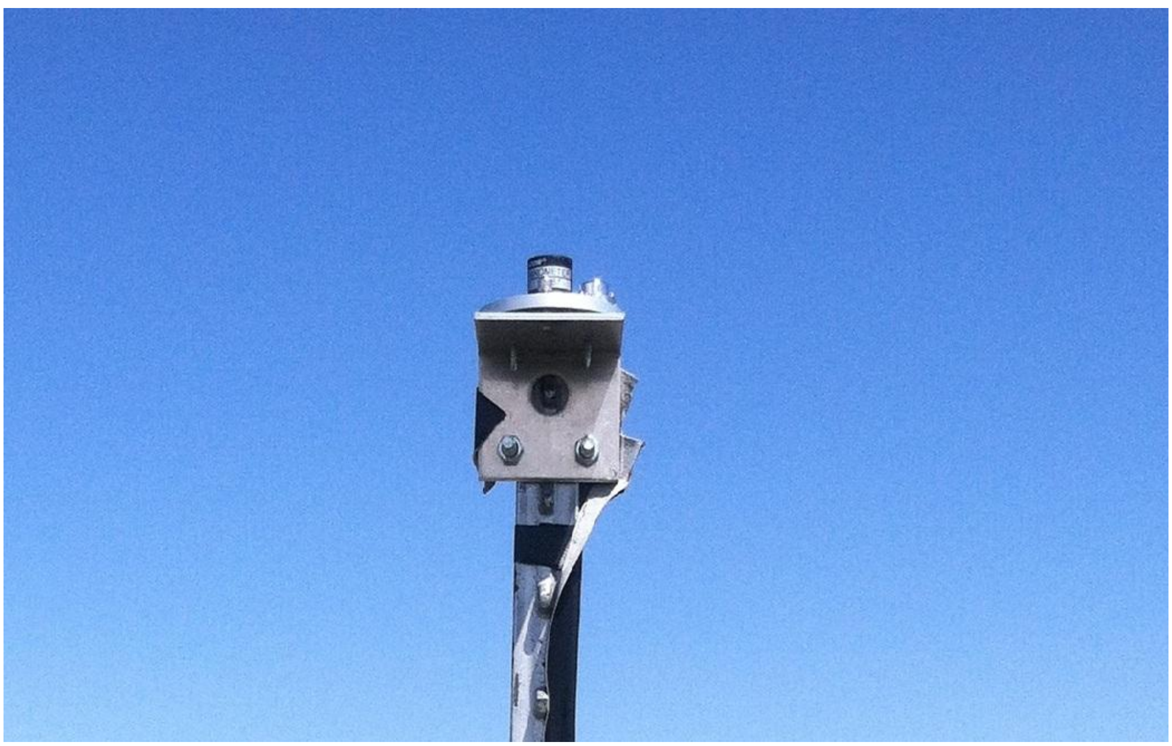


Figure 9 with picture of LI-COR on top of the post

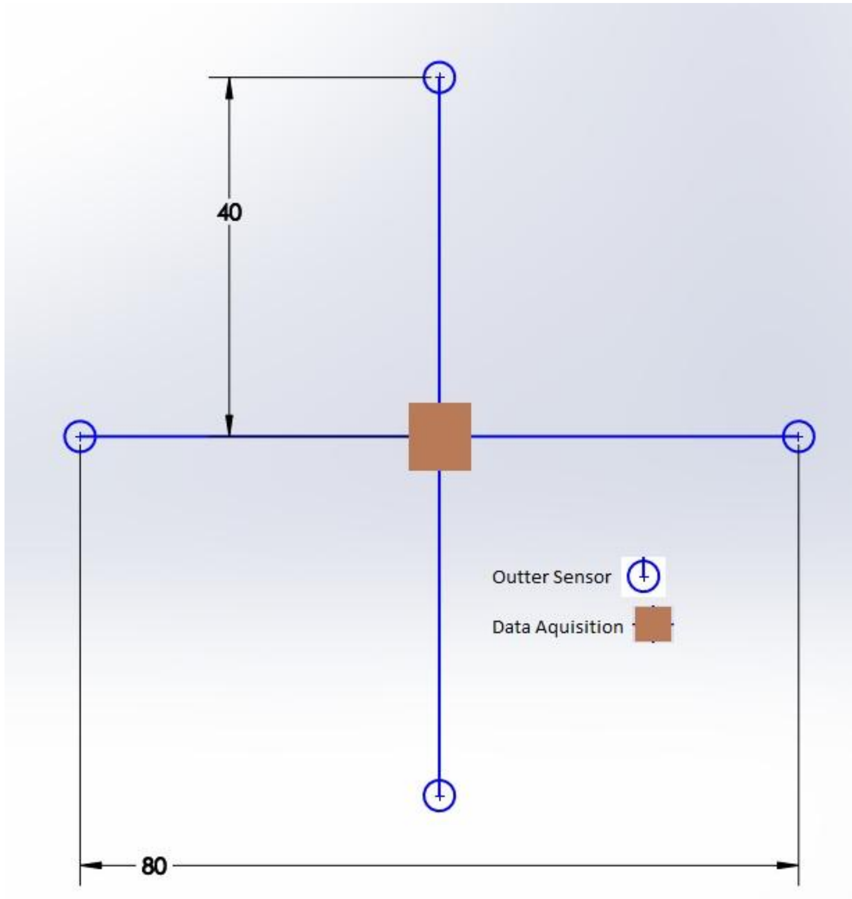


Figure 10 setup showing area

4.3 Data and Analysis

The Campbell Scientific CR800 will be programmed to store data in a format that will be readable by MATLAB. The benefit of having this singular data acquisition center is that the data will be collected at a consistent frequency and in a consistent format. This data will then be analyzed with the algorithm discussed in section 3.

5 Future Tasks

Beginning promptly at the start of the spring semester one of the primary concerns will be finding and establishing a temporary site, preferably closer to Flagstaff than the COBar Ranch location to allow little time to be wasted on data retrieval. Another will be initially programming the DAC to communicate with the pyranometers in a desirable fashion.

Immediately after locating a suitable site the bucket post apparatus will be assembled including the power source for the central tripod location. After initial setup, there will be an initial data collection period that will last approximately 2-3 days. This will allow ample data to be analyzed so changes may be made to either the temporary site or the programming of the DAC. This process, not including the initial setup will be iterated until satisfactory data can be collected. When the team is satisfied with the short-term data, the device will be moved to a location on the COBar to begin a longer-term data collection period. If there is enough time, after the iterative phase of the project, a month long data collection period will begin. This will allow the program to be tested on a large data set with our own data that has been verified for accuracy.

6 Project Plan

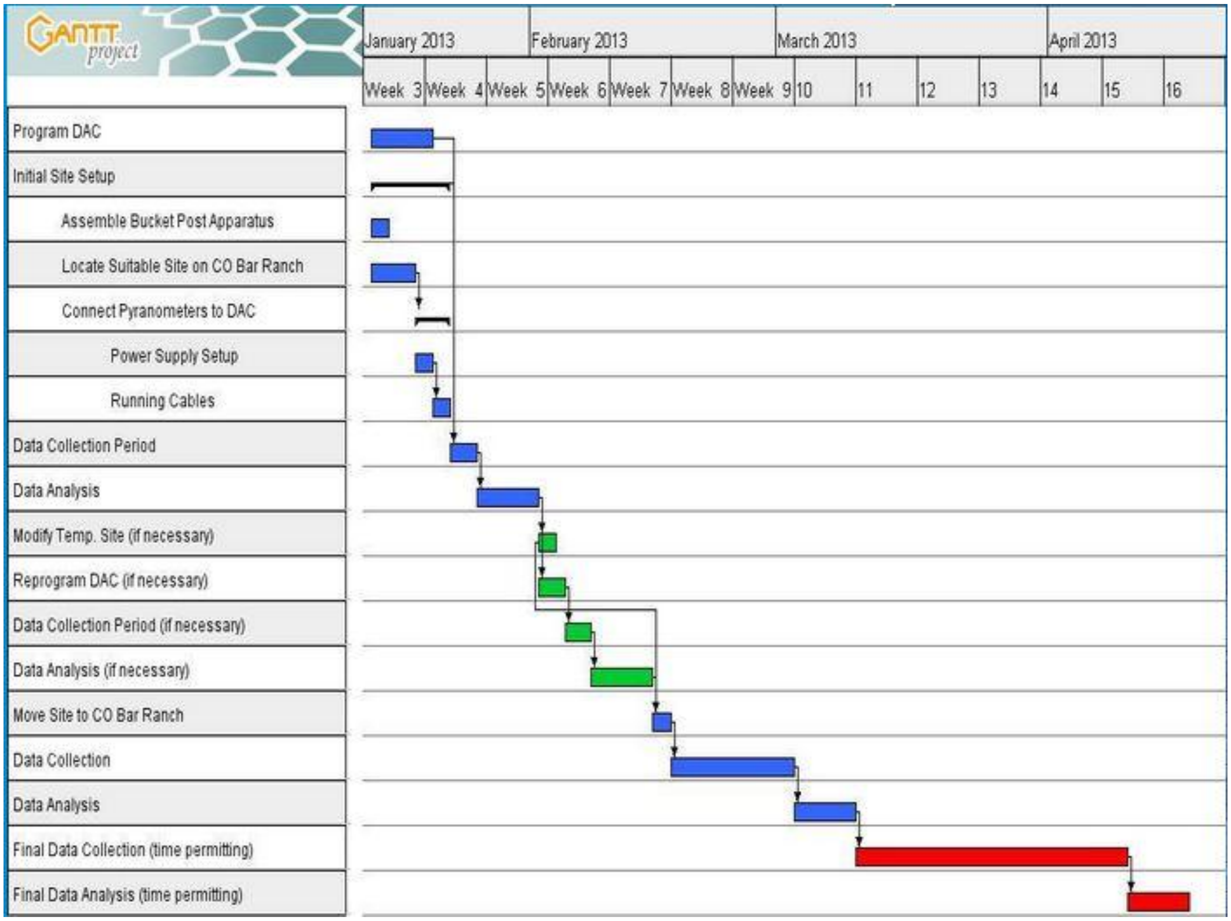
The overall approach to accomplishing tasks was to divide up the broader tasks and have team members work individually. The Concept Generation and Selection phase of the project is a prime example of this method as each team member had a concept to develop by themselves. After a predetermined time had passed, we would compile our parts into one document or presentation and assign one or two team members to format and submit. As the semester progressed it was realized that a large part of the project was research oriented, so the goal of the project shifted more towards programming. It was decided that, for purposes of efficiency, one team member would be in charge of programming code to analyze the initial data supplied by Dr. Thomas Acker. The final tasks for this semester will be accomplished before the start of the spring semester by establishing a budget with Next Era through the CEFNS administration. Materials required to set up a test site will be procured over winter break. Please see Appendix A for the project time line.

7 Conclusion

Team 20 will implement a relatively small, portable solar irradiance measuring system that can accurately quantify variance in solar irradiance over a larger area. The reason for this is to determine the viability of a solar PV power plant at COBar Ranch. The objectives and constraints seen in sections 1.5 and 1.6 will be met for the project by using the centralized tripod concept seen in section 2.2. The finalized design, in brief, will consist of a single tripod with the DAC, PV panel, and pyranometer in the middle of four equally spaced pyranometers on t-posts. These pyranometers will be hardwired to the DAC with their wires contained in flexible conduit for protection. Ultimately, the physical design is merely the channel by which data can be collected to determine the viability of using a small site to determine the irradiance variation on the larger site. With the design finalized the future tasks, seen in section 5, can now be pursued.

8 Appendices

Appendix A: Timeline



Appendix B: Tables

Table 1 Basis of measurement for objectives

Objectives	Basis for Measurement	Units
Scales Down Site	Surface Area	Ft^2
Location of Sensor	GPS	Lat./Long.
Easy Set-up/Operation	Set Up Time	Hours
Longevity	Durability	Months
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Table 4 Tripod Concept Analysis

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Table 5 Umbrella Concept Analysis

Criteria	Weight	Raw Score	Final Score
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Tools Required	5%	7	.35
Ease of Assembly	7.5%	6	.45
Number of Pieces	2.5%	7	.175
Environmental Adaptability	7.5%	9	.675
Durability 15%			
Weather	7.5%	5	.375
Wildlife	7.5%	7	.525
Portability 10%			
Packed Size	5%	6	.3
Weight	5%	6	.3
Cost 40%			
Initial	24%	5	1.2
Setup	8%	6	.48
Recurring	8%	8	.68
	Total:	82	6.095

Table 6 Sky Net Concept Analysis

Criteria	Weight	Raw Score	Final Score
Technical Adaptability	5%	4	.2
Setup 30%			
Time Required	7.5%	4	.3
Tools Required	5%	6	.3
Ease of Assembly	7.5%	5	.375
Number of Pieces	2.5%	8	.2
Environmental Adaptability	7.5%	6	.45
Durability 15%			
Weather	7.5%	5	.375
Wildlife	7.5%	6	.45
Portability 10%			
Packed Size	5%	8	.4
Weight	5%	8	.4
Cost 40%			
Initial	24%	7	1.26
Setup	8%	5	.4
Recurring	8%	8	.64
	Total:	80	6.17

Table 7 Bucket Post Concept Analysis

Criteria	Weight	Raw Score	Final Score
Technical Adaptability	5%	8	.4
Setup 30%			
Time Required	7.5%	4	.3
Tools Required	5%	8	.4
Ease of Assembly	7.5%	7	.525
Number of Pieces	2.5%	9	.225
Environmental Adaptability	7.5%	3	.225
Durability 15%			
Weather	7.5%	8	.6
Wildlife	7.5%	5	.375
Portability 10%			
Packed Size	5%	3	.15
Weight	5%	2	.1
Cost 40%			
Initial	24%	8	1.92
Setup	8%	6	.48
Recurring	8%	6	.48
	Total:	77	6.18

Table 8 Concept total score comparison

Concept	Tripod	Umbrella	Sky Net	Bucket Post
Total Weighted Score	5.995	6.095	6.17	6.18

Table 9 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

Table 10 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

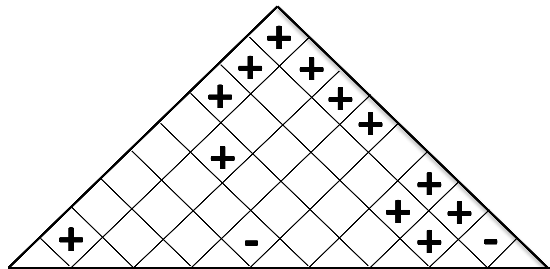
Table 11 Sample rate needed

Velocities Seen (%)	Sample Rate Needed (Hz)
70	1.24
75	1.33
80	1.43
85	1.56
90	1.71
95	1.96
100	Infinity

Table 12 Bill of Materials

	Quantity	Approximate Cost
Campbell Scientific CR800	1	$ 1,395.00
LI-COR LI 200 Sensors	5	$ 1,128
Posts - 8ft	4	$ 21.00
Tripod	1	$ 80.00
Conduit	200ft	$ 70.00
Misc. Hardware	-	$ 50.00

Appendix C: Figures



Customer Requirments	Surface area	Set-Up Time	GPS Location	Data Storage	Frequency	Longevity	Packed Sized	Weight	Cost
	Engineering Requirements								
Scales Down Current Site	X						X		
Useable Data Collection			X	X	X				
Store Data Safely				X		X			X
Easy to Set Up		X						X	X
GPS Location for Each Sensor			X	X					
Stand Alone Functioning				X		X			X
Time Stamped Data				X	X				
Inexpensive	X								X
Units	ft^2	hours	ft	days eq.	Hz	months	ft^3	Lb	$
Engineering Targets	~7800	16	±1	30	1	14	30	50	5000

Figure 1 Quality Function Deployment

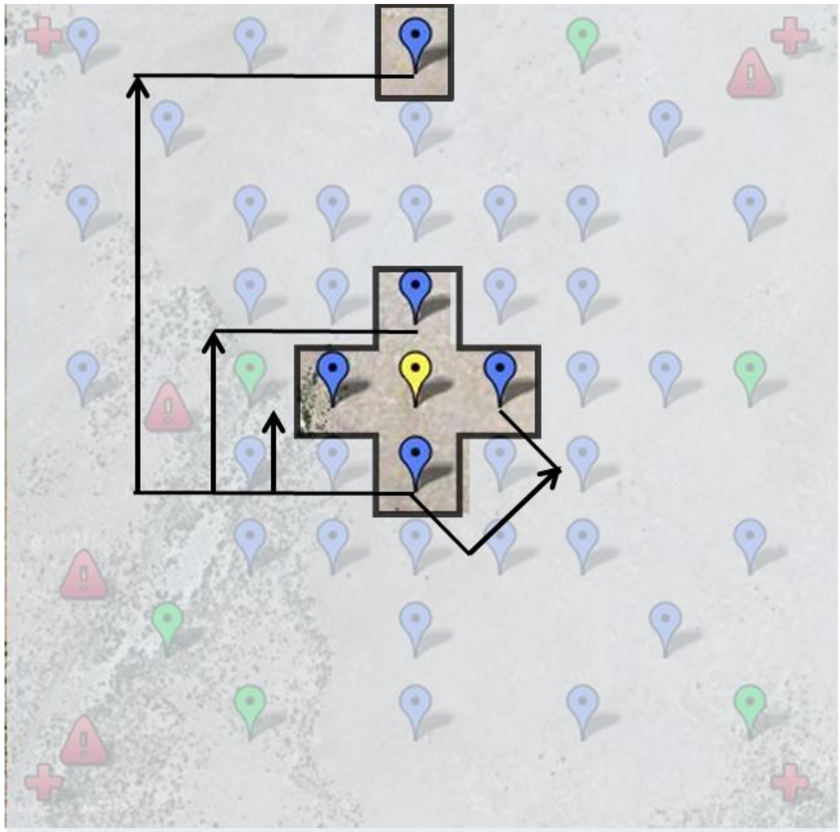


Figure 2 Configuration of sensor from which data was received.

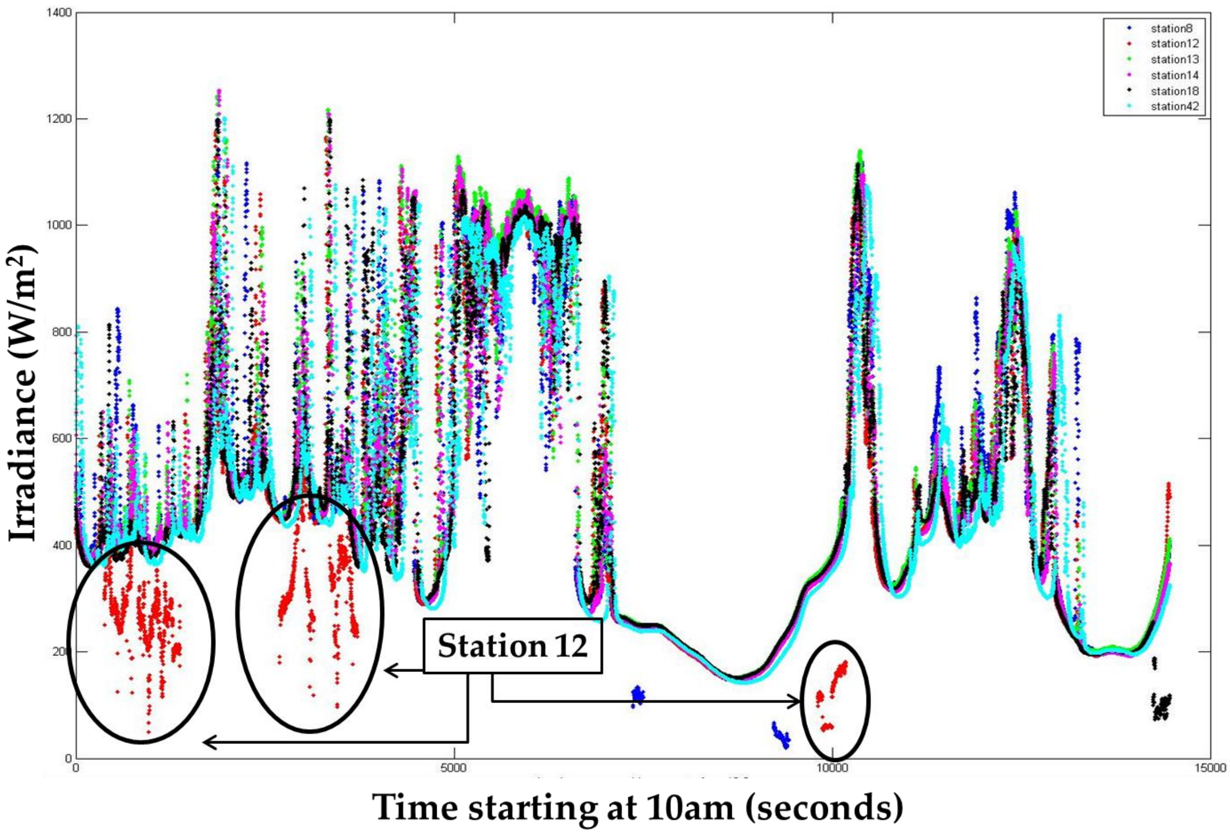


Figure 3 Irradiance versus time for all sensors

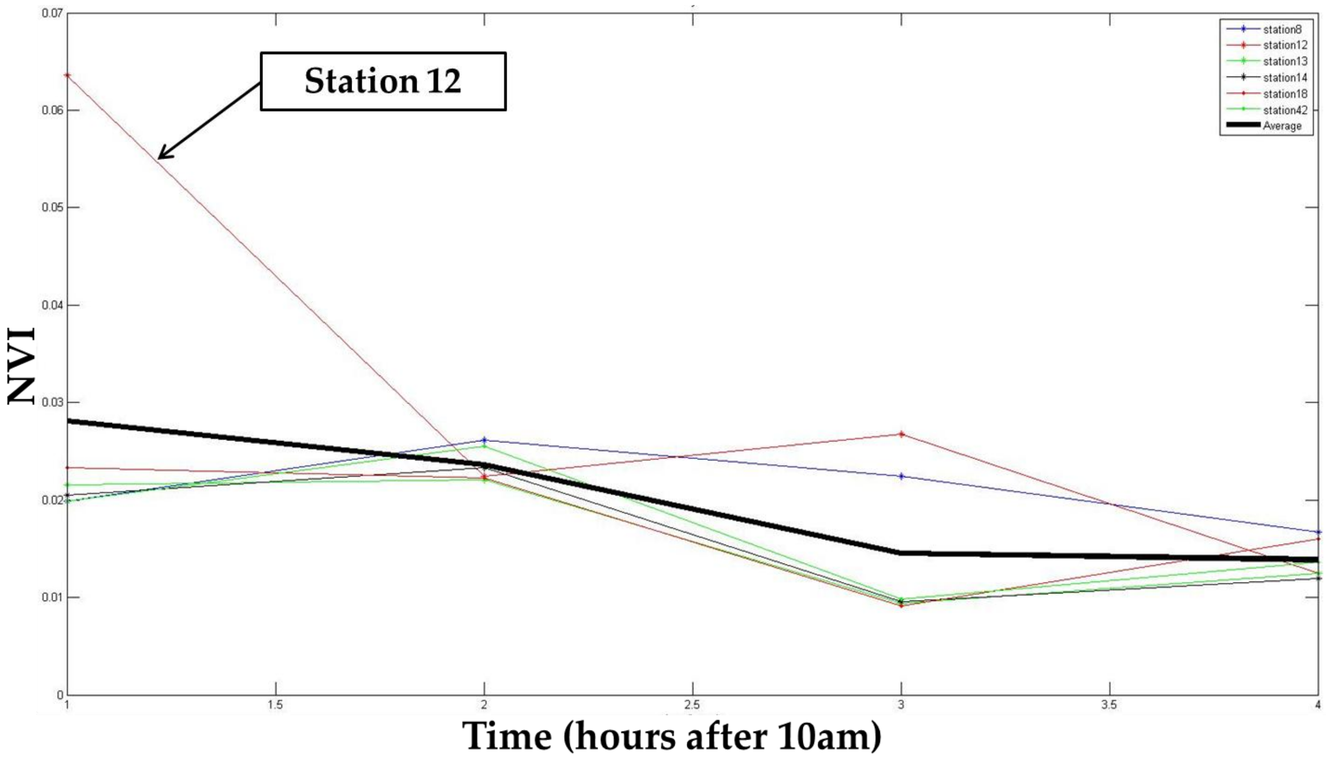


Figure 4 Hourly NVI

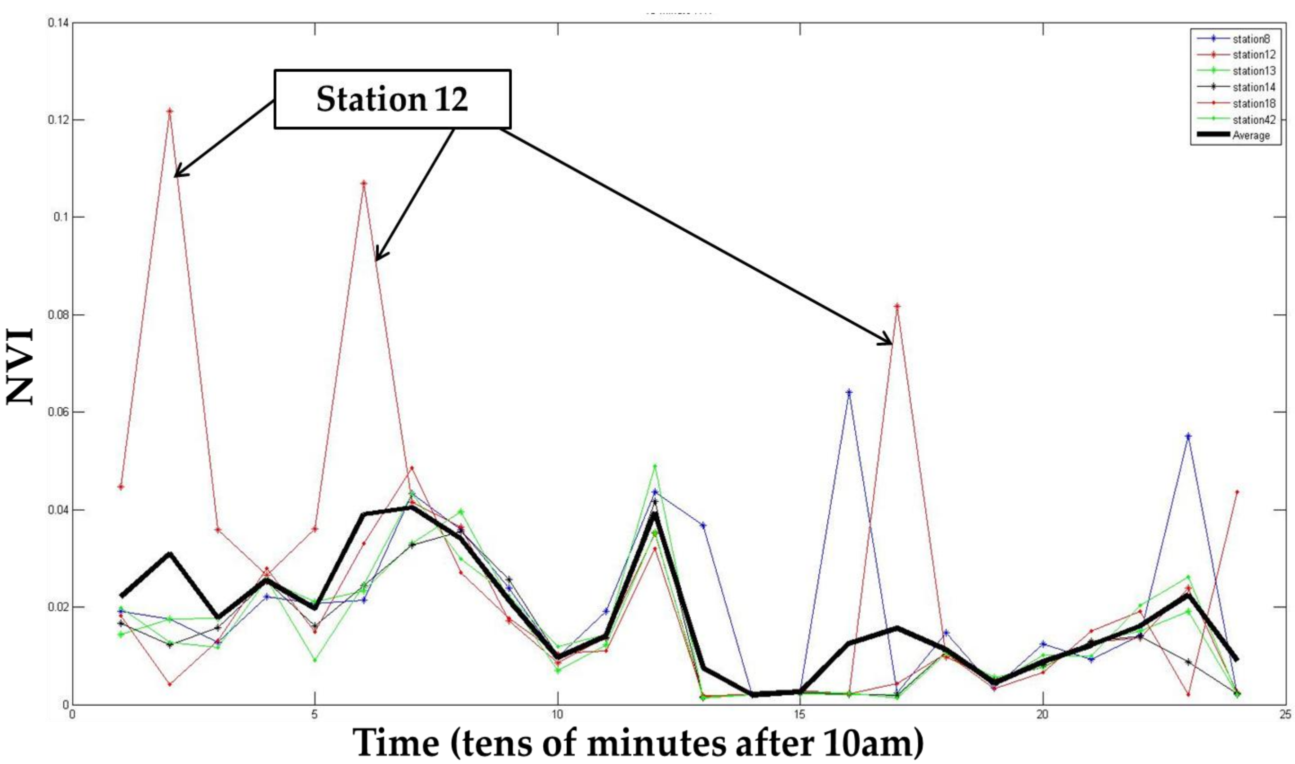


Figure 5 10 Minute NVI

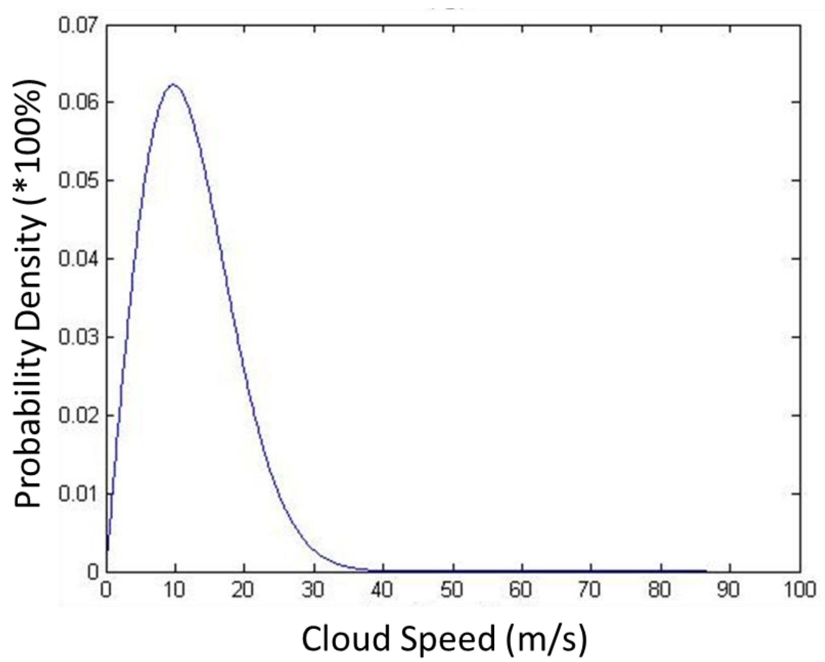


Figure 6 Probability Density Function

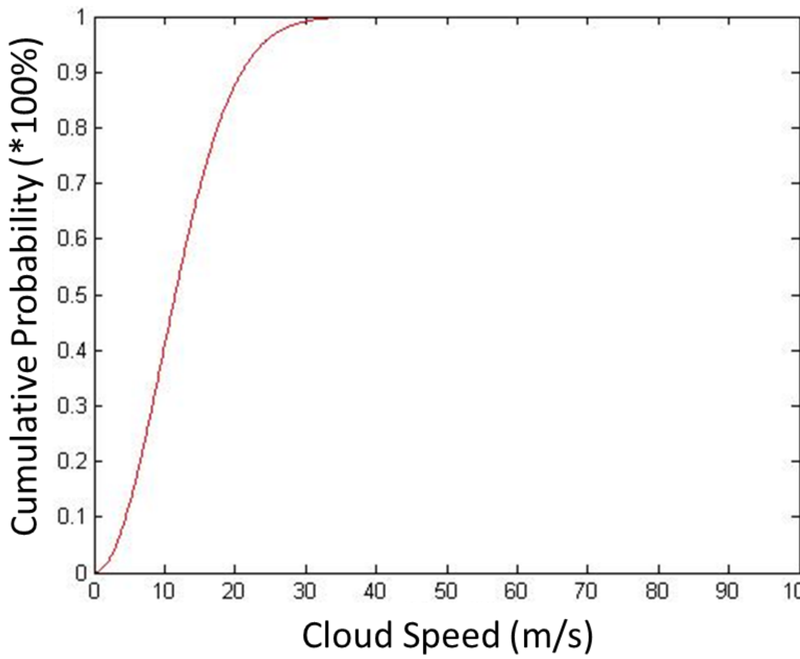


Figure 7 Cumulative Density Function

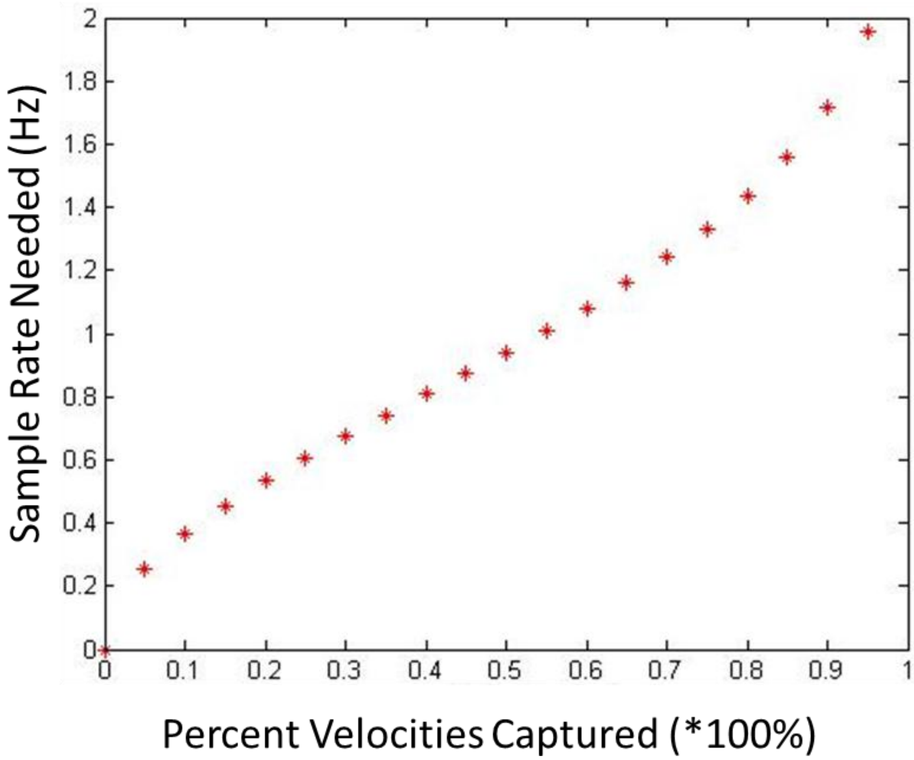


Figure 8 Sample Rate Needed

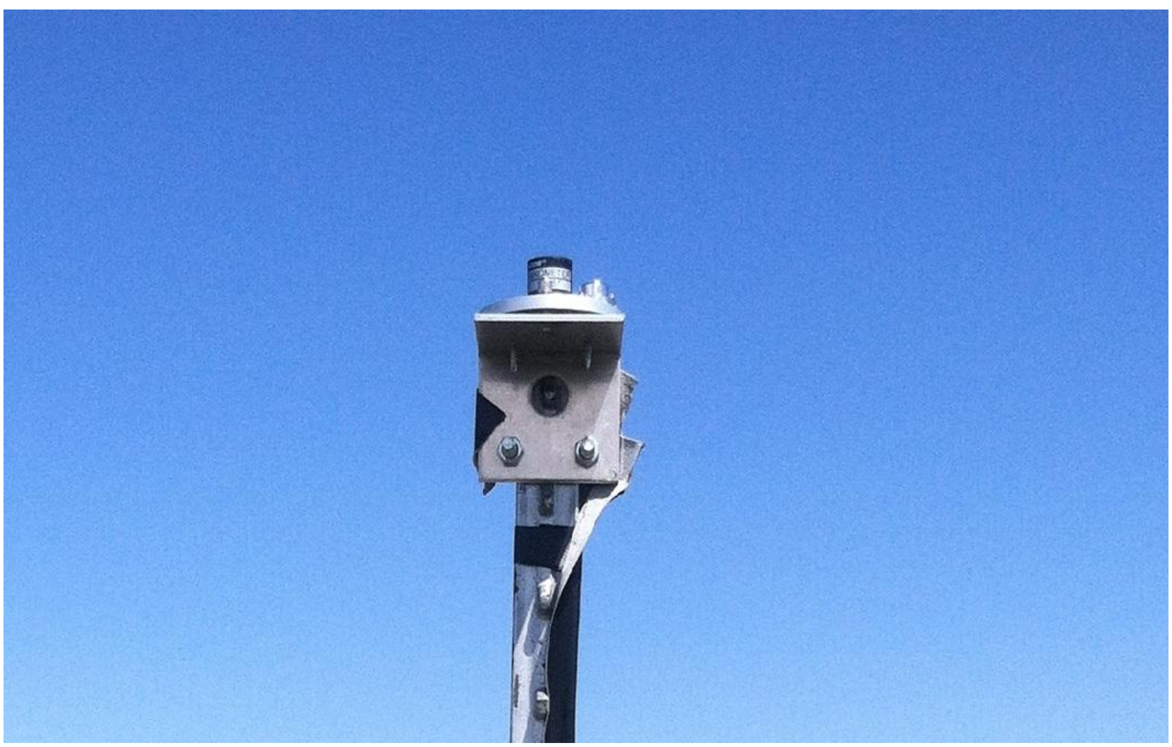


Figure 9 with picture of LI-COR on top of the post

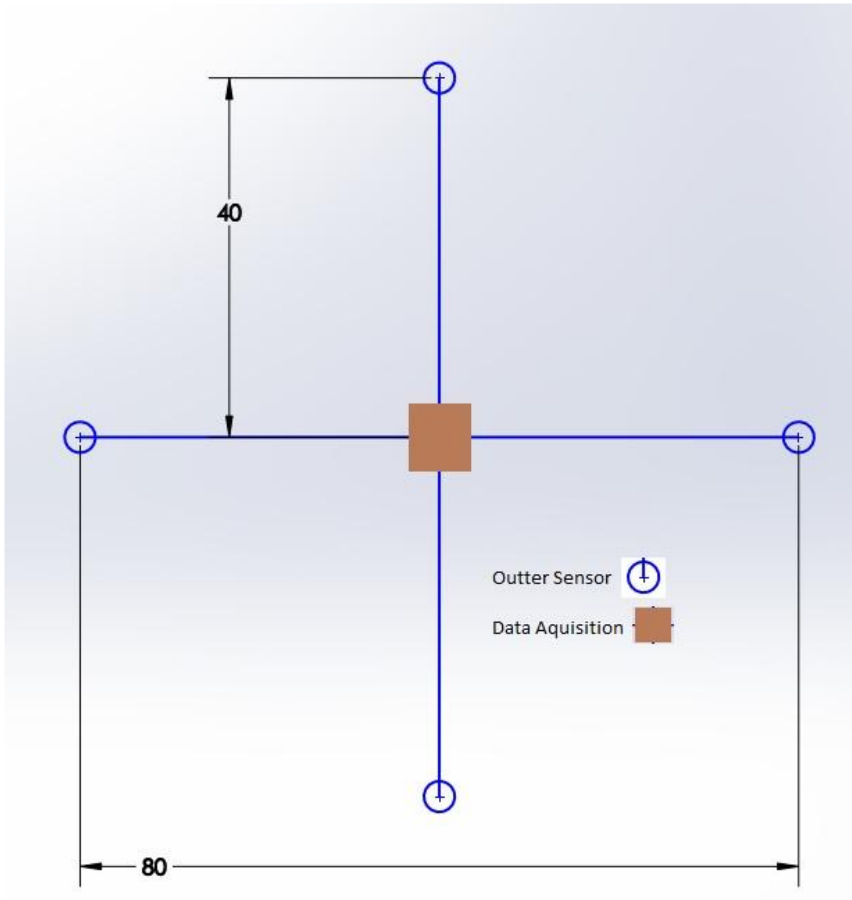
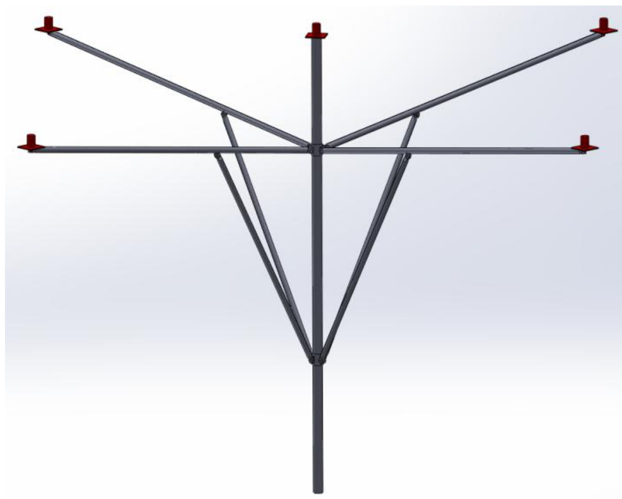


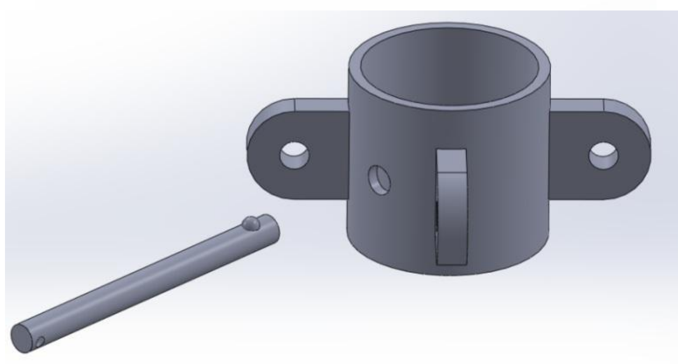
Figure 10 setup showing area

Appendix D: Design Diagrams

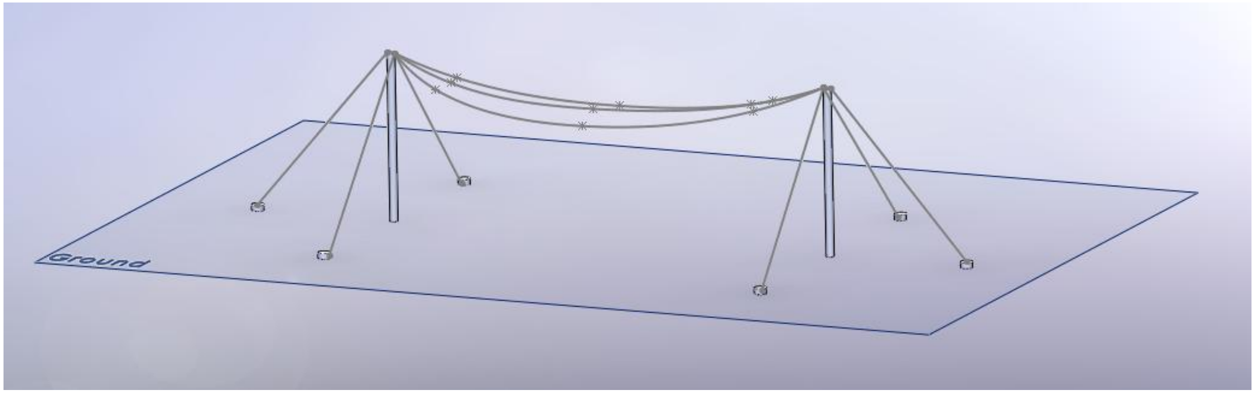
Tripod

Umbrella

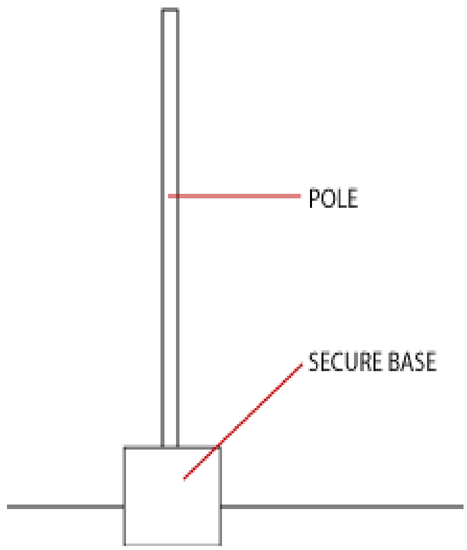




Sky Net



Bucket Post



9 References

1) http://www.homedepot.com/h_d1/N-5yc1v/R-100000208/h_d2/ProductDisplay?catalogId=10053&langId=-1&keyword=t+post&storeId=10051#.UMJn0IMgDGI

2) http://www.homedepot.com/Electrical-Electrical-Boxes-Conduit-Fittings-Conduit/h_d1/N-5yc1vZbohl/R-100010697/h_d2/ProductDisplay?catalogId=10053&langId=-1&storeId=10051#.UMJoQoMgDGI

3) https://www.google.com/shopping/product/5884791281810610335?q=flexible%20conduit&hl=en&bav=on.2,or.r_gc.r_pw.r_qf.&bpcl=39650382&biw=1600&bih=1139&sa=X&ei=WmfCUKb8BI3oiQLpwIGoDg&ved=0CHsQ8wIwAQ

4) http://www.licor.com/env/products/light/pyranometers/index.html

5) http://www.campbellsci.com/cr850