ANNUAL REPORT

For the

KEAHOLE POINT RESEARCH CAMPUS METEOROLOGICAL STATION

Covering the period:

November 1, 2012 through October 31, 2013

Prepared by:

Keith Olson
NELHA Water Quality Laboratory Manager

Hawaii Ocean Science and Technology Park
Administered by:
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MET STATION ANNUAL REPORT (2013) v16.docx

EXCUTIVE SUMMARY

The Keahole Point Research Campus Meteorological Station was fully deployed on November 1, 2012 at the Hawaii Ocean Science and Technology Park's Natural Energy Laboratory of Hawaii Authority Research Campus. The funding for the meteorological station was provided by the United States Department of Energy through the National Renewable Energy Laboratory. Raw Data and data plots are available through the National Renewable Energy Laboratory's Measurement and Instrumentation Data Center [http://www.nrel.gov/midc/].

This report highlights the annual meteorological data set collected this year at Keahole Point. The meteorological station observed one notable weather event on July 29, 2013, tropical storm Flossie. The remainder of the meteorological data observed from November 1, 2012 to October 31, 2013 (monitoring year), chronicles the seasonal cycle.

The mean yearly temperature for the monitoring year was 25.70°C (78.25°F) with a maximum-recorded temperature of 34.4°C (93.9°F) in August, 2013 and a minimum-recorded temperature of 16.92°C (62.45°F) in February, 2013. The annual accumulated precipitation record in this period was 139.4 mm (5.49 in.) with most of the precipitation occurring during the months of January (34%), May (10%), March (14%) and October (15%). The mean relative humidity for this period was 66.6% with a maximum-recorded relative humidity of 96.5% and a minimum-recorded relative humidity of 34.3%. Wind speed throughout the period was constant at a yearly mean of 2.4 m/s (5.41 mph). The exception was on July 29, 2013 where tropical storm Flossie registered a peak wind speed of 15.1 m/s (33.8 mph). Wind direction at Keahole Point exhibits a typical land-sea directional profile and has two distinct bearings averaging at 139° from the North in the A.M. hours and 271° from the North during the P.M. hours. Barometric pressure at Keahole Point recorded a mean yearly value of 1014 mBar (29.96 in. of Hg) with a range of 997 to 1021 mBar (29.44 to 30.14 in. of Hg).

The yearly total global horizontal solar irradiance recorded at the Keahole Point Research Campus Meteorological Station was 2135 kW-hr/m^2. This is equivalent with Tucson, Arizona at 2146 kW-hr/m^2, and Las Vegas, Nevada at 2053 kW-hr/m^2. It is important to note that Keahole Point receives as much total yearly global horizontal irradiance (at 5.8 kW-hr/m^2 mean daily) as the desert southwestern United States. The difference between Keahole Point and Tucson, Arizona was -1.8 days total irradiance for the monitoring year and for Las Vegas, Nevada it was +14.2 days total irradiance during the monitoring year. Keahole Point has been noted as having the highest solar insolation in the Coastal United States Region. This is anecdotally confirmed with yearly measurements of 1875.0 kW-hr/m^2 at Kalaeloa Oahu, Hawaii and 1865.1 kW-hr/m^2 at Loyola Marymount University, Los Angeles, California. Additional regional comparisons can be found in Section 5 of this report.

The meteorological station has confirmed minimal changes in temperature, relative humidity, barometric pressure, wind speed and direction, and precipitation through the monitoring year. It has also recorded a notable total global horizontal solar irradiance similar to the desert southwestern United States and elevated wind conditions of Tropical Storm Flossie.

Contents

1. INTRODUCTION

The Keahole Point Research Campus Meteorological Station is located at the Hawaii Ocean Science and Technology Park (HOST) administered by the Natural Energy Laboratory of Hawaii Authority (NELHA). The Keahole Point Research Campus Meteorological Station has continuously recorded meteorological conditions since November 1, 2012. The meteorological station has enhanced the overall understanding of weather conditions at the facility and is used by many of the research and development organizations, commercial business and government agencies located at the HOST facility. The meteorological station is a significant addition to the facility, which permits NELHA to continue to perform its mission as a test bed for the development of clean energy and ocean-related research.

2. GLOSSARY

2.1. ACRONYMS

HOST	Hawaii Ocean Science and Technology Park
NELHA	Natural Energy Laboratory of Hawaii Authority
NOAA	National Oceanic and Atmospheric Administration
NREL	National Renewable Energy Laboratory

2.2. DEFINITIONS

Mean yearly:	Yearly mean calculated from mean hourly data
Mean daily:	Daily mean calculated from mean hourly data
Mean hourly:	Hourly mean calculated from mean minute data
Maximum monthly:	Monthly maximum result from mean hourly data
Minimum monthly:	Monthly minimum result from mean hourly data
Maximum yearly:	Yearly maximum result from mean hourly data
Minimum yearly:	Yearly minimum result from mean hourly data
Monitoring year:	November 1, 2012 to October 31, 2013

2.3. UNITS

˚C	Degree Celsius - unit of temperature
˚F	Degree Fahrenheit - unit of temperature
mBar	Millibar – unit of pressure – 1000 mbar equals atmospheric pressure at sea level
in. of Hg	Inches of mercury – unit of pressure – 29.92 in of Hg equals 1000 mbar
m/s	meters per second – unit of velocity
mph	miles per hour – unit of velocity
°	Degree – unit of direction – ° from the North
mm	Millimeter – unit of length
in.	Inch – unit of length
kW-hr/m^2	Kilowatt-hour per square meter – unit of solar irradiation
mmol-hr/s/m^2	Millimole-hour per second per square meter – unit of photons

3. INSTRUMENTS, SENSORS AND EQUIPMENT

3.1. TOWER

The Keahole Point Research Campus Meteorological Station tower (Met One Instruments, Inc., Model 970895) is 10 meters (32.8 feet) in height and constructed from aluminum wall tubes and bent bars in three sections. The base sections is 45.7 cm (18 in.) width, middle section is tapered down to 35.6 cm (14 in.), while the top section is tapered down to 27.9 cm (11 in.). The base of the meteorological tower is anchored into a concrete slab. The tower can tip in the northeastern direction for maintenance and hurricane force winds. The towers grounding system (Met One Instruments, Inc., Model 5284) consists of a top mounted lightning rod at the top of the tower, #2 copper cable, and grounding rod at the base of the tower. In addition, #14 copper cable is connected to the grounding system to the data logger's ground.(1)

3.2. DATA LOGGER

The Keahole Point Research Campus Meteorological Station uses a Campbell Scientific, Inc. CR1000 data logger. The data logger system includes network interface module (Campbell Scientific, Inc. Model NL130), and AC surge protection module (Campbell Scientific, Inc. Model MCG-415). The data logger is powered by 120V AC connection. In addition, a keyboard and display and connected to the CS I/O port (Campbell Scientific, Inc. Model CR1000KD). The data logger has the ability to be Modbus configured and programming can be performed using Campbell Scientific, Inc. LoggerNet Data logger Support Software. The data logger has eight differential inputs for measuring voltages up to ±5V, switched unregulated 12 volts (off-on) under program control, switch voltage excitation for precision programmable voltage within ±2.5V range for bridge measurements, eight digital channels for frequency measurements, pulse counting, digital control and triggering and two pulse inputs channels to count pulses, switch closer, or low level A/C signals.(2)

3.3. METEOROLOGICAL SENSORS

3.3.1. AIR TEMPERATURE AND RELATIVE HUMIDITY

The Keahole Point Research Campus Meteorological Station deployed on November 1, 2012, a Campbell Scientific, Inc., model # 083E-1-35 (serial # N11762) temperature and relative humidity sensor. The sensors were last calibrated on September 17, 2012. These sensors are extremely accurate microprocessor controlled relative humidity and temperature sensor. The relative humidity sensor responds to the full range of 0 to 100% humidity. Response is linear with negligible hysteresis or temperature dependence. The temperature sensor is a three-element composite thermistor type with linear response over a range of -50 to +50˚C (-58 to 122 ˚F). The sensor is mounted in a naturally aspirated solar radiation shield (Met One Instruments, Inc., Model 5980). The shield has concentric aluminum plates to reflect solar energy, which reduces direct, and terrestrial radiation.(3)(4)(5)

3.3.2. BAROMETRIC PRESSURE

The Keahole Point Research Campus Meteorological Station deployed on November 1, 2012, a Campbell Scientific, Inc., model # 092 (serial # N11882) barometric pressure sensor. The sensor was last calibrated on September 20, 2012. The barometric pressure sensor is designed to measure ambient atmospheric pressures and provides a serial digital output from the sensor module. Pressure is measured using a board mounted digital pressure sensor. An on board CPU scales pressure measurement and performs communications. The sensor has a measurement range of 600 – 1100 mbar (17.72 – 32.48 in Hg) at a 0.1 mbar (0.003 Hg) resolution, accuracy of ±0.35 mbar at 25˚C and a long-term stability of ±1 mbar in 12 months.(6)(7)

3.3.3. WIND MONITOR

The Keahole Point Research Campus Meteorological Station deployed on November 1, 2012, a R.M. Young Company, marine model # 05106 (serial # N11489) wind monitor-MA. The sensors on the wind monitor were last calibrated on October 24, 2012. The wind monitor measures horizontal wind speed and direction, and was designed for a marine environment. The wind monitor is mounted on a horizontal arm at a 10 m (32.8 ft.) height from ground level where it records wind conditions at Keahole Point.

Wind speed is measured by the propeller rotation. The propeller rotation produces an AC sine wave signal with frequency proportional to wind speed. This AC signal is induced in a stationary coil by six pole magnet mounted on the propeller shaft. Three complete sine wave cycles are produced for each propeller revolution. The wind speed sensor has a measurement range of 0 – 100 m/s (0 – 224 mph) with a threshold sensitivity of 1.1 m/s (2.4 mph).

Wind direction is measured by vane position. The vane position is transmitted by a 10K ohm conductive plastic potentiometer, which requires a regulated excitation voltage. With a constant voltage applied to the potentiometer, the output signal is analog voltage directly proportional to azimuth angle. The wind direction sensor has a 360˚ mechanical, 355˚ electrical (5˚ open) range and a threshold sensitivity of 1.1 m/s (2.4 mph) at 10˚ displacement.(8)

3.3.4. PRECIPITATION

The Keahole Point Research Campus Meteorological Station deployed on November 1, 2012, a Met One Instruments, Inc., model # 370C (serial # N11206) 8" tipping bucket rain gauge. The sensor was last calibrated on September 20, 2012. The rain gauge tipping bucket was designed to measure rainfall on a continuous basis, as water does not collect in the sensor. The internal bucket fills with 0.25 mm (0.01 in) to send a switch closure pulse to the data logger for counting. The sensor accuracy is ±1% at 25.4 to 76.2 mm per hour at 21.1˚C (±1% at 1 to 3 inches per hour at 70˚F).(9)

3.3.5. GLOBAL HORIZONTAL IRRADIANCE

The Keahole Point Research Campus Meteorological Station deployed on November 1, 2012, a Kipp & Zonen model # CMP-11 (serial # 126933) ISO secondary-standard pyranometer that monitors solar radiation for the full solar spectrum range. The sensor was last calibrated on March 22, 2012. The CMP11 measures solar radiation with a blackened thermopile protected by two glass domes. Its flat spectral sensitivity, from 285 to 2800 nm, with a desiccant-filled drying cartridge prevents dew from forming on the inner sides of the CMP11's domes and a 15 cm (5.9 in.) sun shield to reduce senor temperature. The CMP-11 produces a millivolt signal that is measured directly by the CR1000 data logger. The CMP-11 has a sensitivity of 7 to 14µV/W/m^2 and a temperature sensitivity of <1% from -10˚ to 40˚C (14˚ to 104˚F).[10][11]

3.3.6. PHOTOSYNTHETICALLY ACTIVE RADIATION

The Keahole Point Research Campus Meteorological Station deployed on April 23, 2013, a LI-COR model # LI-190 (serial # Q99293) LI-COR Terrestrial Radiation Sensor that monitors photosynthetically active radiation (PAR) in the 400 to 700 nm waveband. The sensor was last calibrated on April 3, 2013. The LI-190 PAR sensor was designed to measure on plane surface. The silicon photodiode is enhanced to respond in the visible wavelengths and approximates the photosynthetic response of plants. The LI-COR 190 has a sensitivity of 5 µA per 1000 µmoles s^{-1} m^{-2}, stability of < ±2% change over a 1 year period, and an operating temperature of -40˚ to 65˚C (-40˚ to 219˚F).[12][13]

4. METHODS

4.1. STUDY SITE

NELHA adhered to the *Guidance for Instrument Siting Based on EPA Requirements, Quality Assurance Handbook for Air Pollution Measurement Systems Volume IV – Meteorological Measurements* for the site location evaluation for Keahole Point Research Campus Meteorological Station with relevant input and approval from NREL Staff. The meteorological station is currently located at the end of Makako Bay Drive inside the NELHA Research Campus, 34 meters SE from the administration building. The GPS location datum is latitude 19°43'41.42"N and longitude 156° 3'31.69"W at an elevation of 4m (13 ft.).

Figure 1. *Keahole Point Meteorological Station Site is inside the NELHA Research Campus on the Big Island of Hawaii*

4.2. DATA COLLECTION

The Keahole Point Research Campus Meteorological Station collects data from sensors recording air temperature, relative humidity, wind speed, peak wind speed, wind direction, barometric pressure, precipitation, global horizontal irradiance, and photosynthetically active radiation. All the sensors are mounted on an aluminum tower at approximately 10 meters in height with the exception of the ground mounted precipitation sensor. The data is collected by a Campbell Scientific CR1000 data logger at a 1 second sample rate with reporting capabilities of one-minute averages. Data is transferred hourly from the CR1000 to NREL's Measurement and Instrumentation Data Center (MIDC) and graphically displayed from the MIDC web portal. A dashboard display of all measured meteorological parameters are graphically presented at a one-hour data frequency. In addition, a solar calendar, wind rose plot, and user-selected parameters in daily time series can be graphically plotted at http://www.nrel.gov/midc/nelha/. All data can also be downloaded in ASCII format as one-minute, hourly, and daily statistical data.

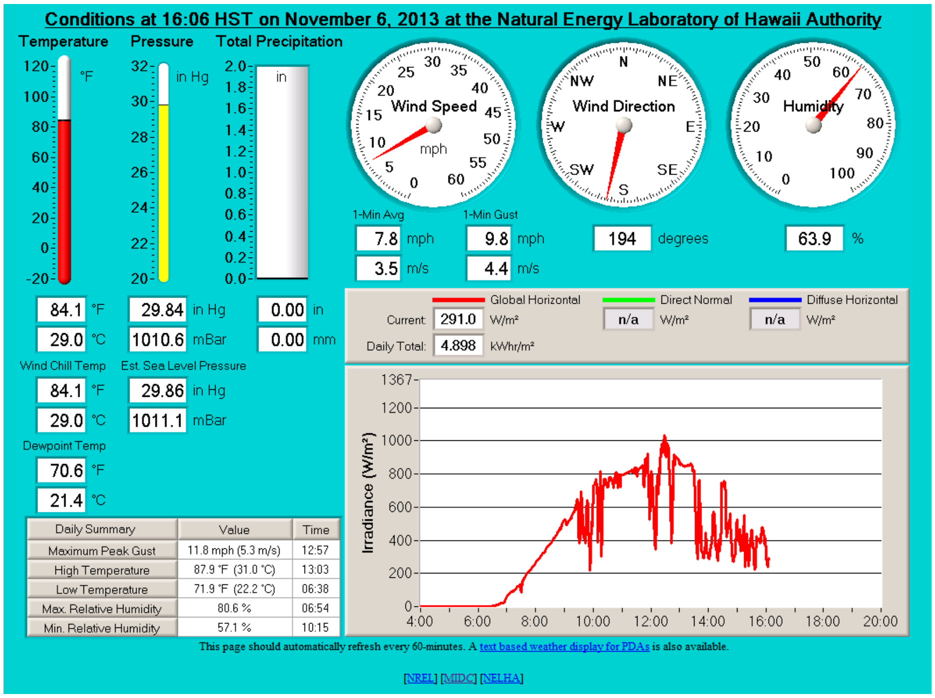


Figure 2. *Dashboard View from NREL's MIDC web portal*

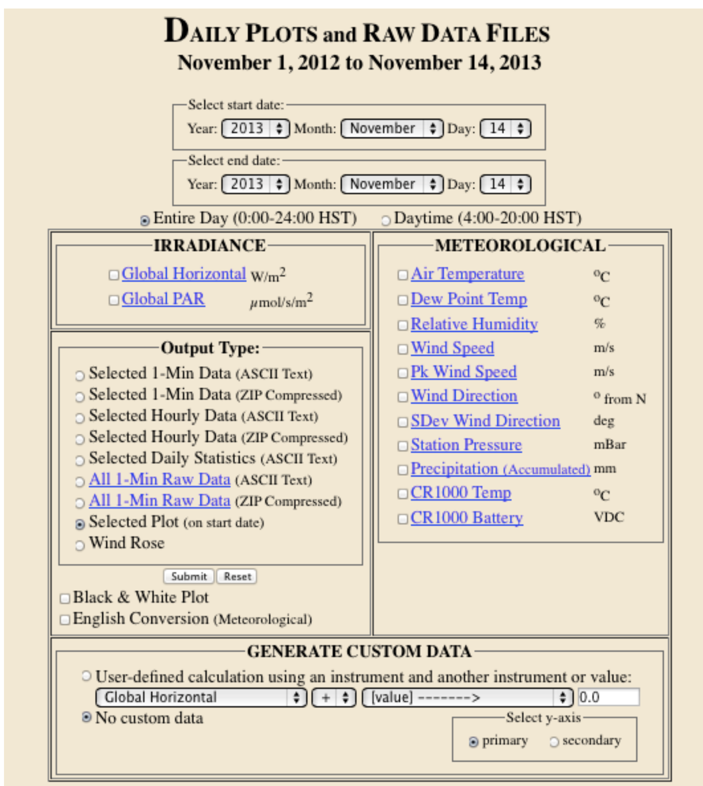


Figure 3. *User Selected Daily Plots and Raw Data Files*

5. RESULTS

5.1. AIR TEMPERATURE

Monthly mean air temperature (˚C) recorded for November 2012 to October 2013 followed a narrow seasonal cycle. Mean hourly air temperatures ranged from a low in February of 16.9˚C (62.5˚F) to a high in August of 34.4˚C (93.9˚F). The daily mean air temperature shows very little variation throughout the year with a range from 22.0 to 28.6˚C (71.6 to 83.5˚F). The yearly mean temperature during this period was 25.7˚C (78.3˚F).

Monthly	Nov. 2012	Dec. 2012	Jan. 2013	Feb. 2013	Mar. 2013	Apr. 2013	May 2013	Jun. 2013	Jul. 2013	Aug. 2013	Sep. 2013	Oct. 2013
Mean Temperature (˚C)	25.2	24.3	23.7	23.7	23.6	25.3	26.5	26.7	27.2	27.5	27.4	26.9
Max Temperature (˚C)	31.7	30.5	29.8	29.4	29.5	32.1	32.3	32.7	33.7	34.4	33.6	33.1
Min Temperature (˚C)	18.4	18.1	17.2	16.9	16.9	17.7	21.4	21.8	22.5	22.3	22.4	21.0
Mean Temperature (˚F)	77.4	75.7	74.6	74.6	74.5	77.6	79.7	80.1	81.0	81.6	81.3	80.5
Max Temperature (˚F)	89.0	86.8	85.6	84.9	85.1	89.8	90.1	90.8	92.6	93.9	92.5	91.6
Min Temperature (˚F)	65.2	64.5	63.0	62.4	62.5	63.9	70.4	71.2	72.5	72.1	72.3	69.8

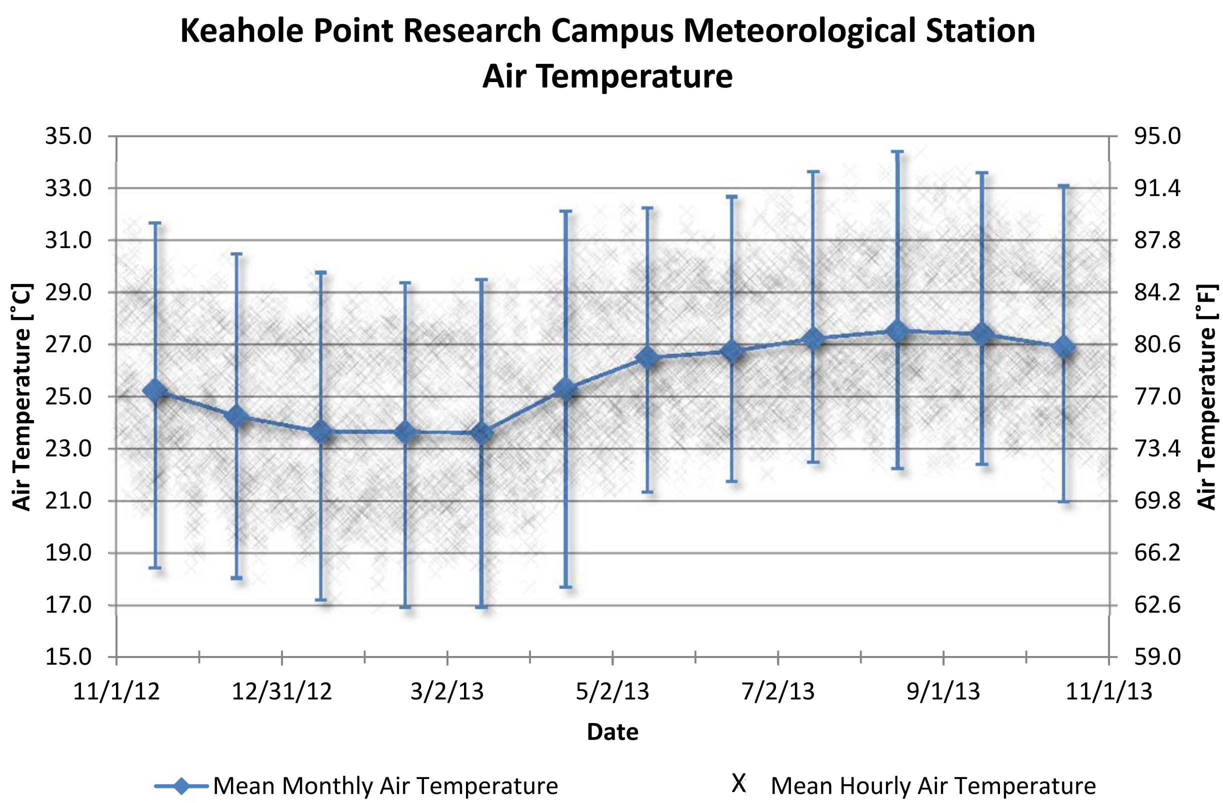


Figure 4. *Monthly air temperature result table and scatter plot.*

5.2. RELATIVE HUMIDITY

Monthly mean relative humidity recorded during the period of November 2012 to October 2013 was consistent through the seasonal cycle. Variations in mean hourly relative humidity showed a significant range from 34.3 to 96.5%. Yearly mean relative humidity during this period was 66.6%.

Monthly	Nov. 2012	Dec. 2012	Jan. 2013	Feb. 2013	Mar. 2013	Apr. 2013	May 2013	Jun. 2013	Jul. 2013	Aug. 2013	Sep. 2013	Oct. 2013
Mean RH (%)	66.6	69.5	68.6	65.1	67.4	66.4	68.2	64.3	66.7	64.7	63.8	67.9
Max RH (%)	91.1	89.4	96.5	87.5	92.7	92.8	87.1	83.3	89.9	81.5	86.8	90.0
Min RH (%)	43.1	46.3	34.3	42.7	45.1	40.3	43.8	41.7	42.2	46.0	41.7	46.8

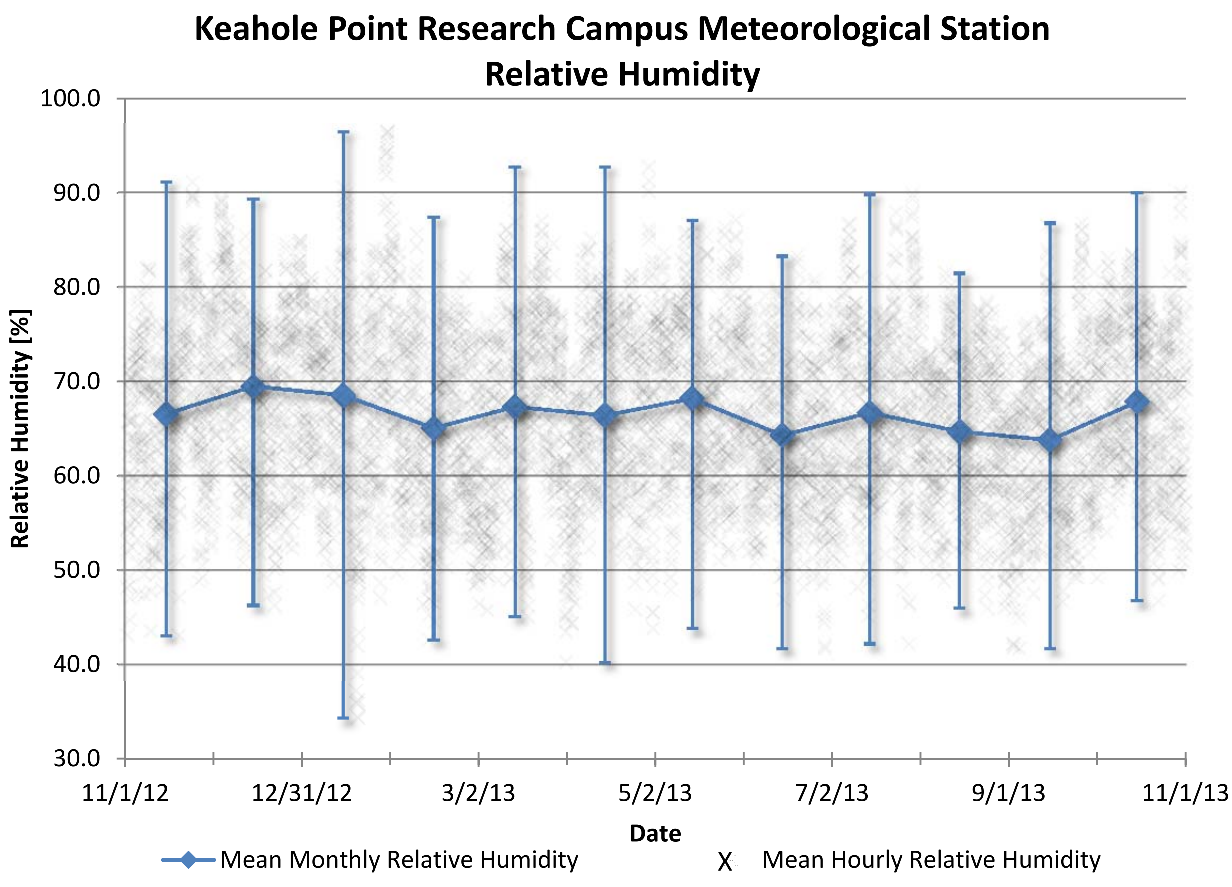


Figure 5. *Monthly relative humidity result table and scatter plot.*

5.3. BAROMETRIC PRESSSURE

Monthly mean barometric pressure recorded during the period of November 2012 to October 2013 was consistent through the seasonal cycle with slightly elevated recorded results in the month of February. A one-time minimum mean hourly recording was made on December 11, 2012 at 997 mBar (29.44 in. of Hg). Daily variation in mean hourly barometric pressure ranged from 997 to 1021 mBar (29.44 to 30.14 in. of Hg). The yearly mean barometric pressure during this period was 1014.7 mBar (29.96 in. of Hg)

Monthly	Nov. 2012	Dec. 2012	Jan. 2013	Feb. 2013	Mar. 2013	Apr. 2013	May 2013	Jun. 2013	Jul. 2013	Aug. 2013	Sep. 2013	Oct. 2013
Mean Barometric Pressure (mBar)	1015	1015	1014	1017	1015	1016	1015	1015	1014	1014	1014	1013
Max Barometric Pressure (mBar)	1018	1019	1019	1021	1020	1020	1019	1018	1018	1017	1018	1018
Min Barometric Pressure (mBar)	1010	997	1009	1014	1011	1011	1011	1012	1010	1010	1010	1010
Mean Barometric Pressure (in. of Hg)	29.97	29.97	29.95	30.03	29.98	29.99	29.98	29.97	29.94	29.94	29.94	29.93
Max Barometric Pressure (in. of Hg)	30.07	30.08	30.08	30.14	30.12	30.13	30.08	30.06	30.07	30.03	30.06	30.05
Min Barometric Pressure (in. of Hg)	29.81	29.44	29.80	29.94	29.86	29.85	29.86	29.88	29.81	29.83	29.82	29.81

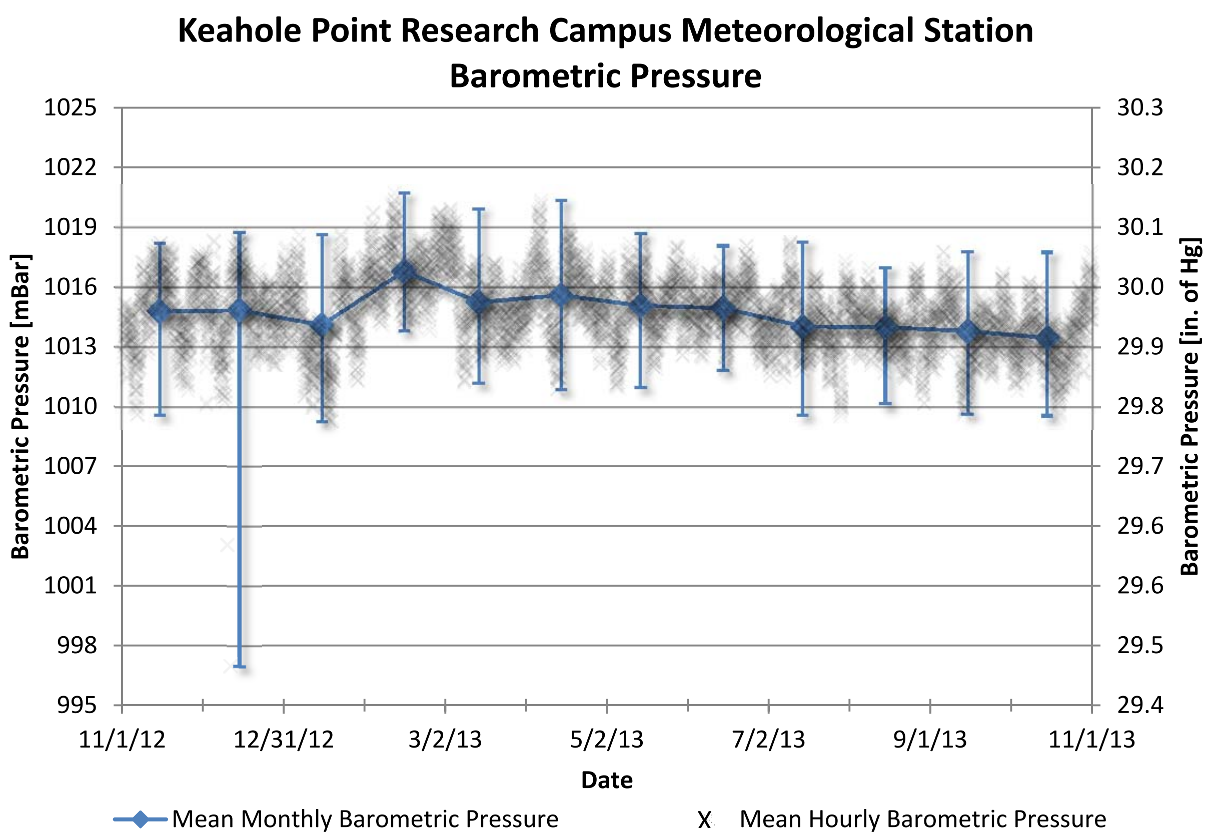


Figure 6. *Monthly barometric pressure result table and scatter plot.*

5.4. WIND SPEED

Monthly mean wind speed recorded during the period of November 2012 to October 2013 was consistent through the seasonal cycle with a mean yearly wind speed of 2.4 m/s (5.41 mph). A one-time maximum mean hourly recording was made on July 29, 2013 at 12.6 m/s (28.2 mph) during tropical storm Flossie. Daily variation in mean hourly wind speed ranged from 0.18 to 12.6 m/s (0.4 to 28.2 mph).

Monthly	Nov. 2012	Dec. 2012	Jan. 2013	Feb. 2013	Mar. 2013	Apr. 2013	May 2013	Jun. 2013	Jul. 2013	Aug. 2013	Sep. 2013	Oct. 2013
Mean Wind Speed (m/s)	2.2	2.2	2.3	2.4	2.6	2.4	2.5	2.4	2.6	2.5	2.6	2.2
Max. Wind Speed (m/s)	7.1	7.4	8.0	6.3	9.1	6.3	6.3	7.5	12.6	7.0	6.9	5.8
Min. Wind Speed (m/s)	0.3	0.2	0.2	0.2	0.3	0.3	0.2	0.3	0.2	0.4	0.2	0.3
Mean Wind Speed (mph)	5.0	4.9	5.2	5.3	5.9	5.4	5.6	5.5	5.9	5.6	5.8	5.0
Max. Wind Speed (mph)	15.9	16.6	17.8	14.1	20.5	14.0	14.1	16.8	28.2	15.8	15.3	12.9
Min. Wind Speed (mph)	0.7	0.4	0.5	0.4	0.7	0.6	0.5	0.7	0.5	0.9	0.4	0.7

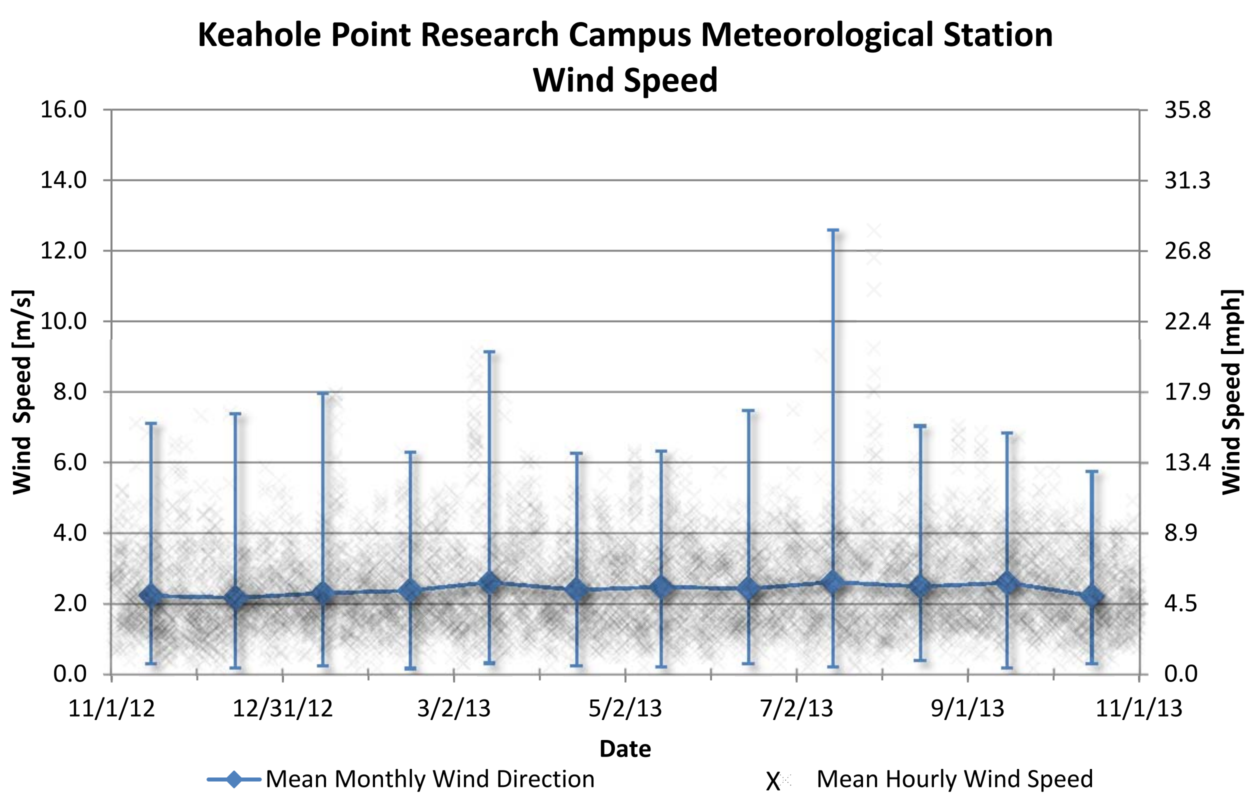


Figure 7. *Monthly wind speed result table and scatter plot*

5.5. PEAK WIND SPEED

Monthly peak wind speed recorded during the period of November 2012 to October 2013 was consistent through the seasonal cycle with a mean yearly peak wind speed of 3.1 m/s (7.00 mph). A peak hourly wind speed recording was made on July 29, 2013 at 15.1 m/s (33.8 mph) during tropical storm Flossie. Daily variation in hourly peak wind speed ranged from 0.24 to 15.1 m/s (0.54 to 33.84 mph).

Monthly	Nov. 2012	Dec. 2012	Jan. 2013	Feb. 2013	Mar. 2013	Apr. 2013	May 2013	Jun. 2013	Jul. 2013	Aug. 2013	Sep. 2013	Oct. 2013
Mean Peak Wind Speed (m/s)	2.9	2.8	3.0	3.1	3.4	3.2	3.2	3.1	3.4	3.2	3.3	2.9
Max. Peak Wind Speed (m/s)	9.5	9.9	10.9	8.5	11.0	7.8	7.6	9.7	15.1	9.8	9.0	6.8
Min. Peak Wind Speed (m/s)	0.5	0.3	0.3	0.4	0.5	0.4	0.4	0.4	0.3	0.5	0.2	0.4
Mean Peak Wind Speed (mph)	6.5	6.2	6.7	6.8	7.7	7.1	7.2	7.0	7.6	7.3	7.5	6.5
Max. Peak Wind Speed (mph)	21.3	22.1	24.4	19.0	24.5	17.4	17.0	21.6	33.8	21.9	20.2	15.2
Min. Peak Wind Speed (mph)	1.1	0.7	0.7	0.9	1.0	0.9	0.9	0.9	0.7	1.2	0.5	1.0

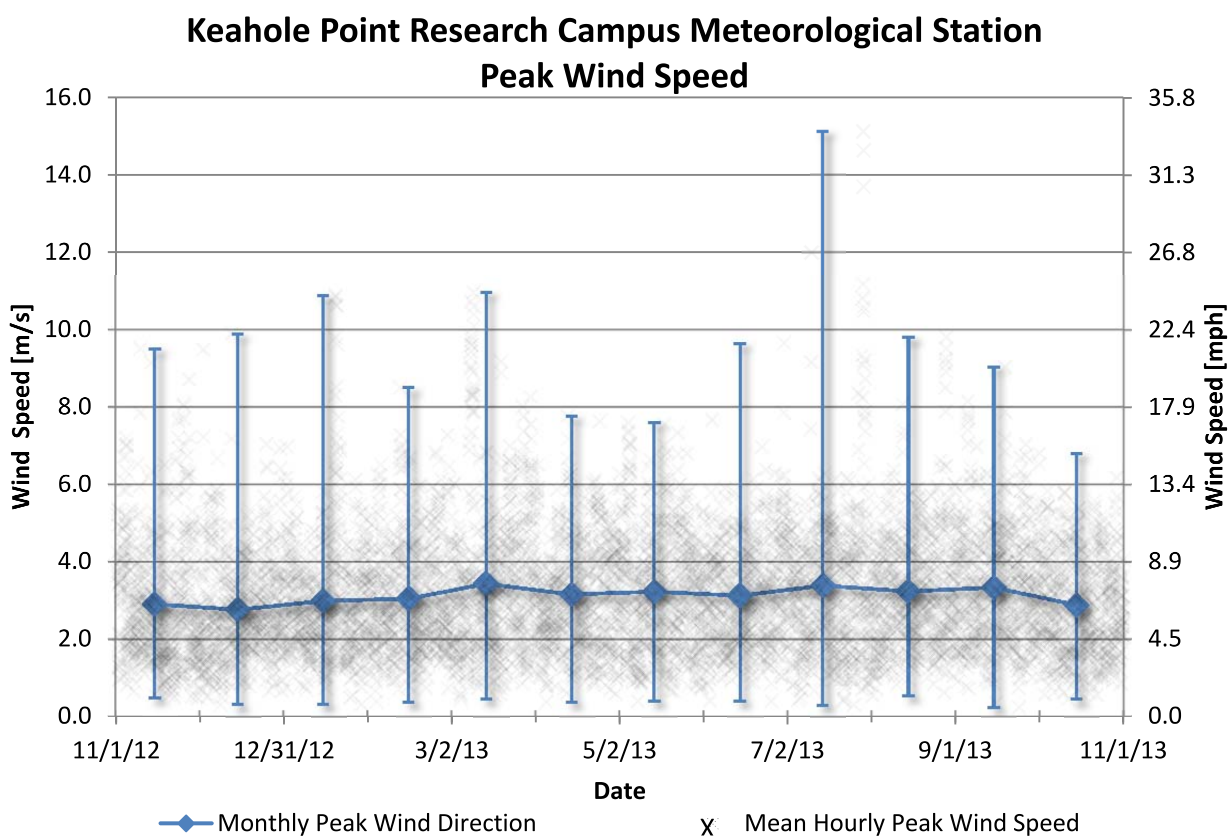


Figure 8. *Monthly peak wind speed result table and scatter plot*

5.6. WIND DIRECTION

Monthly wind direction recorded during the period of November 2012 to October 2013 was consistent through the daily cycle with a mean yearly wind direction of 174˚ from the North. Wind direction at Keahole Point exhibits a typical land-sea directional profile and has two distinct bearings averaging at 139° from the North in the A.M. hours and 271° from the North during the P.M. hours.

Monthly	Nov. 2012	Dec. 2012	Jan. 2013	Feb. 2013	Mar. 2013	Apr. 2013	May 2013	Jun. 2013	Jul. 2013	Aug. 2013	Sep. 2013	Oct. 2013
Mean Wind Direction (° from North)	151.4	169.8	172.9	142.9	186.3	202.4	183.8	170.6	180.2	180.3	167.9	175.2
A.M. Wind Direction (° from North)	116.8	126.7	129.1	113.0	138.1	167.0	155.1	143.9	153.6	147.9	144.9	133.0
P.M. Wind Direction (° from North)	274.5	286.9	297.1	247.4	301.4	290.2	261.2	254.6	256.2	258.5	251.6	277.8

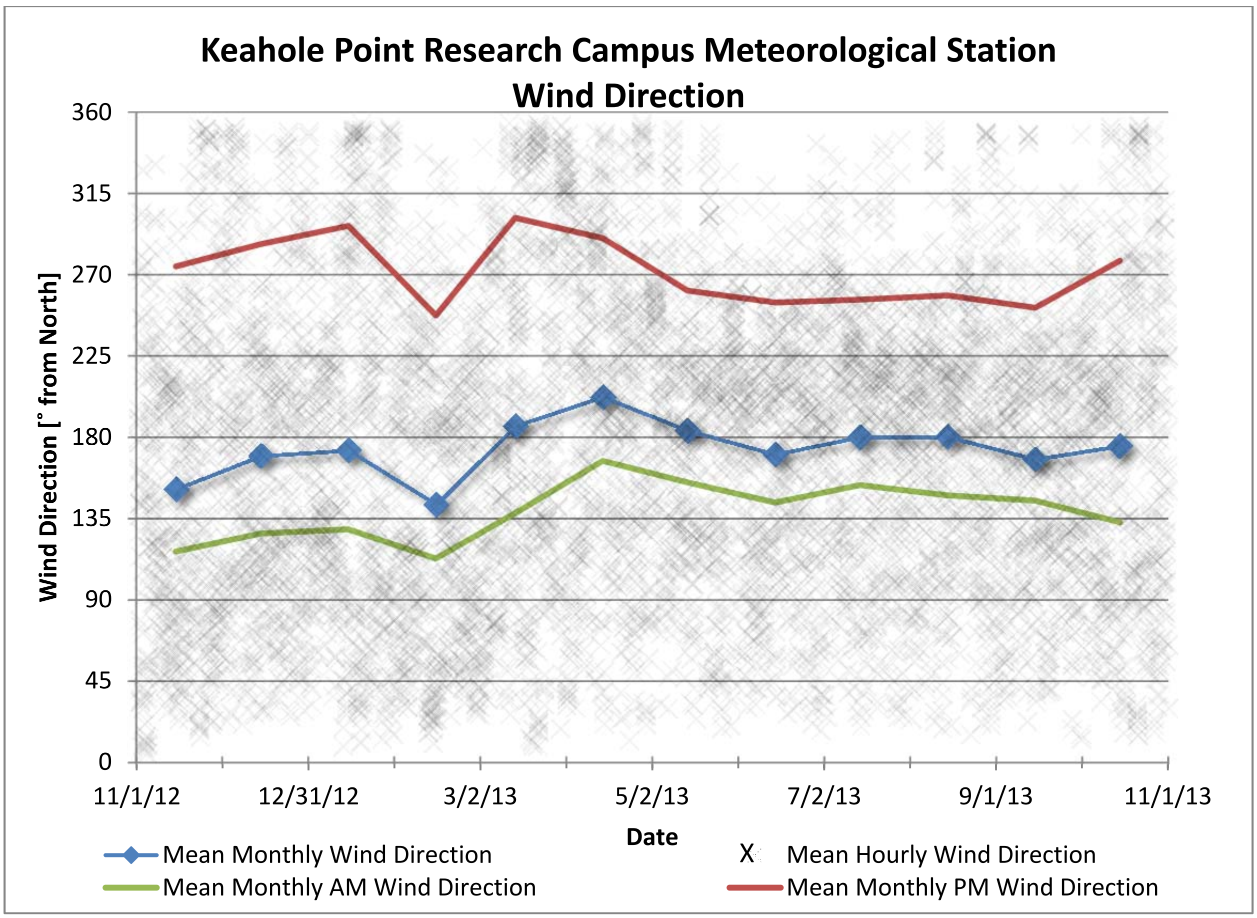
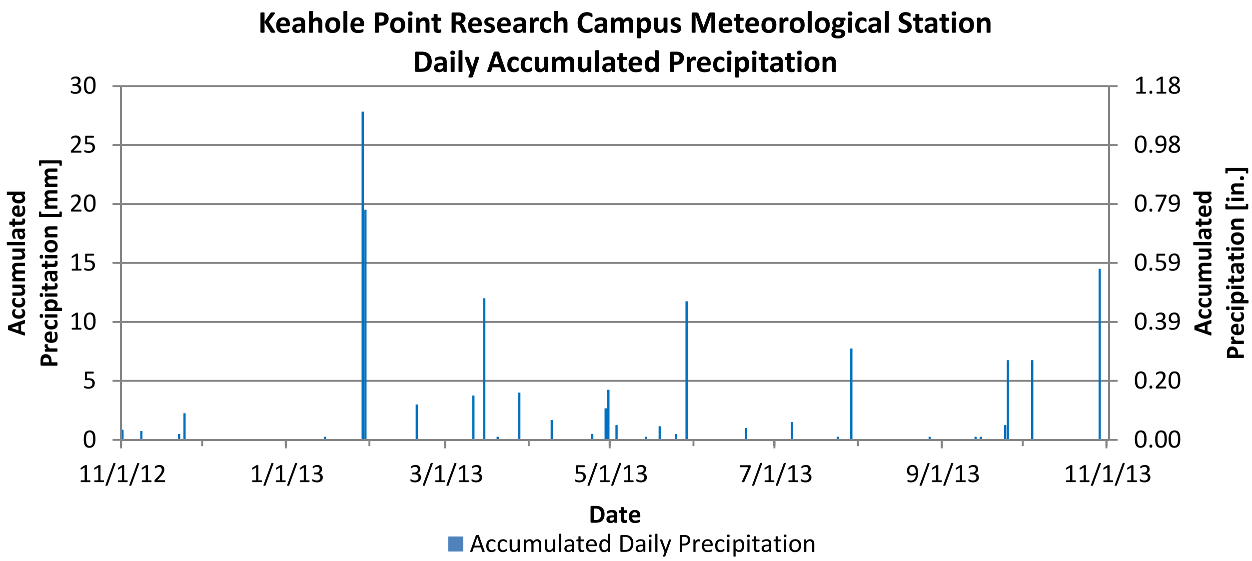


Figure 9. *Monthly wind direction result table and scatter plot*

5.7. ACCUMULATED PRECIPATATION

Yearly accumulated precipitation recorded during the period of November 2012 to October 2013 was 139 mm (5.49 in.). A daily maximum recording was made on January 29, 2013 at 27.83 mm (1.1 in.). During tropical storm Flossie on July 29, 2013 the recorded accumulated precipitation was 7.75 mm (0.35 in.).

Monthly	Nov. 2012	Dec. 2012	Jan. 2013	Feb. 2013	Mar. 2013	Apr. 2013	May 2013	Jun. 2013	Jul. 2013	Aug. 2013	Sep. 2013	Oct. 2013
Accumulated Precipitation (mm)	4.4	0.0	47.6	3.0	20.0	9.1	14.9	1.0	9.5	0.3	8.5	21.3
Accumulated Precipitation (in.)	0.17	0.00	1.87	0.12	0.79	0.36	0.59	0.04	0.37	0.01	0.33	0.84



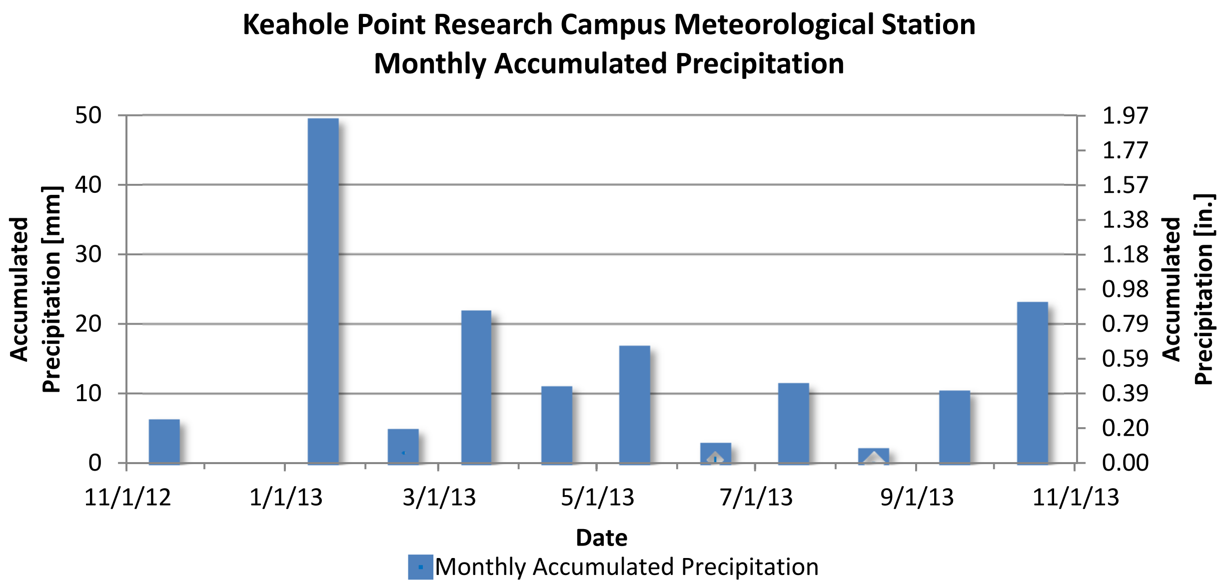
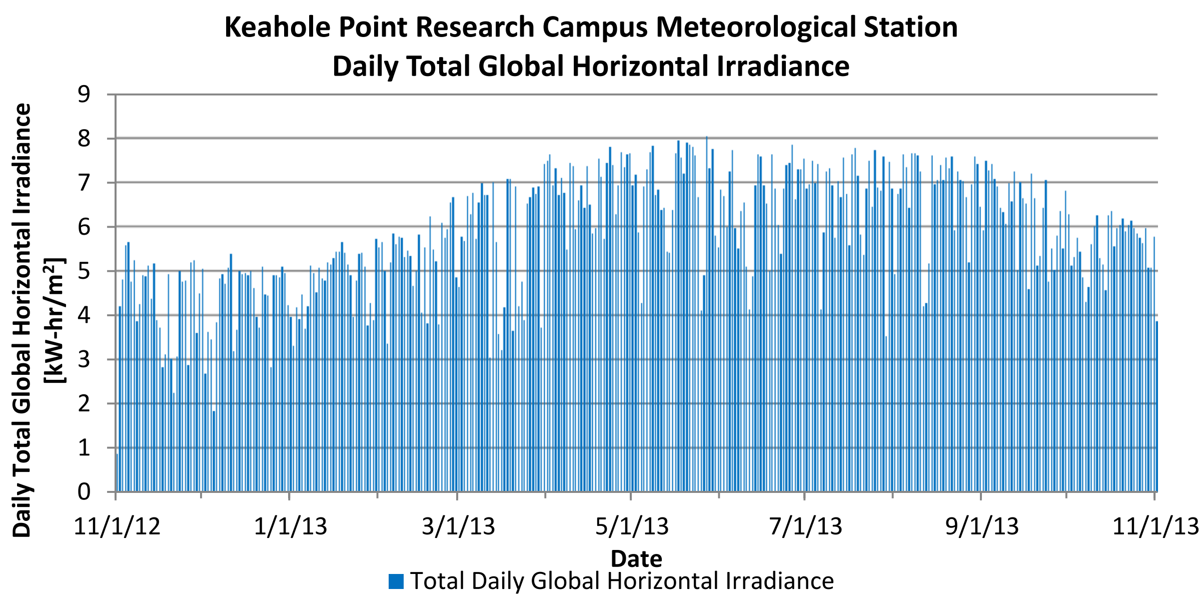


Figure 10. *Monthly accumulated precipitation table and daily and monthly bar charts*

5.8. GLOBAL HORIZONTAL IRRADIANCE

Yearly total global horizontal irradiance recorded during the period of November 2012 to October 2013 was 2139 kW-hr/m^2. A monthly total maximum global horizontal irradiance recording was made in August, 2013at 210 kW-hr/m^2. A monthly total minimum global horizontal irradiance recording was made in November 2012 at 127 kW-hr/m^2.

Monthly	Nov. 2012	Dec. 2012	Jan. 2013	Feb. 2013	Mar. 2013	Apr. 2013	May 2013	Jun. 2013	Jul. 2013	Aug. 2013	Sep. 2013	Oct. 2013
Global Horizontal Irradiance (kW-hr/m^2)	126.7	135.4	147.3	149.5	177.9	208.7	209.5	198.1	208.3	210.2	195.6	171.9



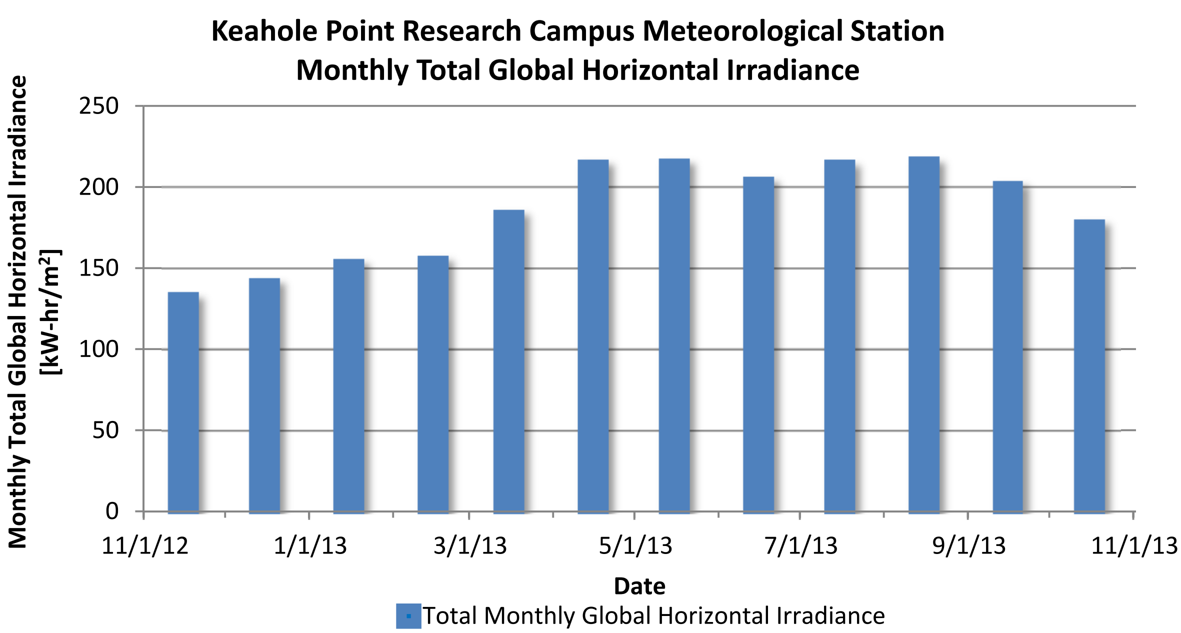
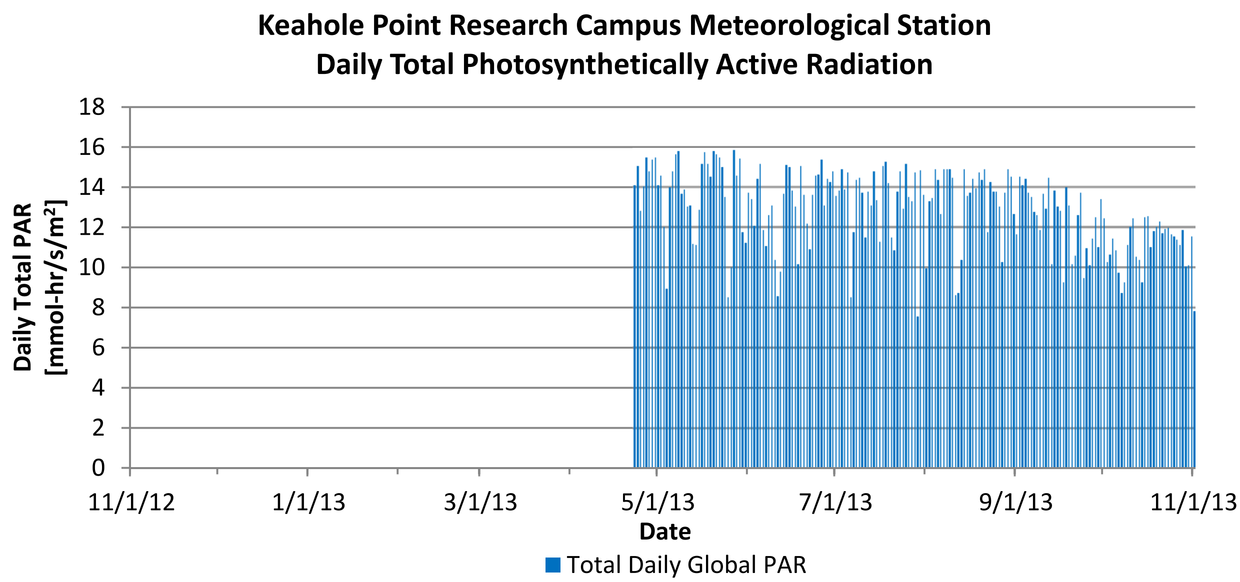


Figure 11. *Monthly total global horizontal irradiance table and daily and monthly bar charts*

5.9. PHOTOSYNTHETICALLY ACTIVE RADIATION

Photosynthetically active radiation (PAR) was recorded from April 2013 to October 2013. During this period a monthly total maximum was recorded in May 2013 of 422 mmol-hr/s/m^2. A monthly total minimum of 341 mmol-hr/s/m^2 was recorded in October 2013. The PAR sensor records a similar solar profile as the global horizontal sensor (285 – 2800nm) but measures light in the visible light spectrum (400 – 700nm) where photosynthetic plants readily absorb the Suns energy.

Monthly	Nov. 2012	Dec. 2012	Jan. 2013	Feb. 2013	Mar. 2013	Apr. 2013	May 2013	Jun. 2013	Jul. 2013	Aug. 2013	Sep. 2013	Oct. 2013
Photosynthetically Active Radiation (mmol-hr/s/m^2)							422.7	394.0	413.1	413.4	385.4	341.9



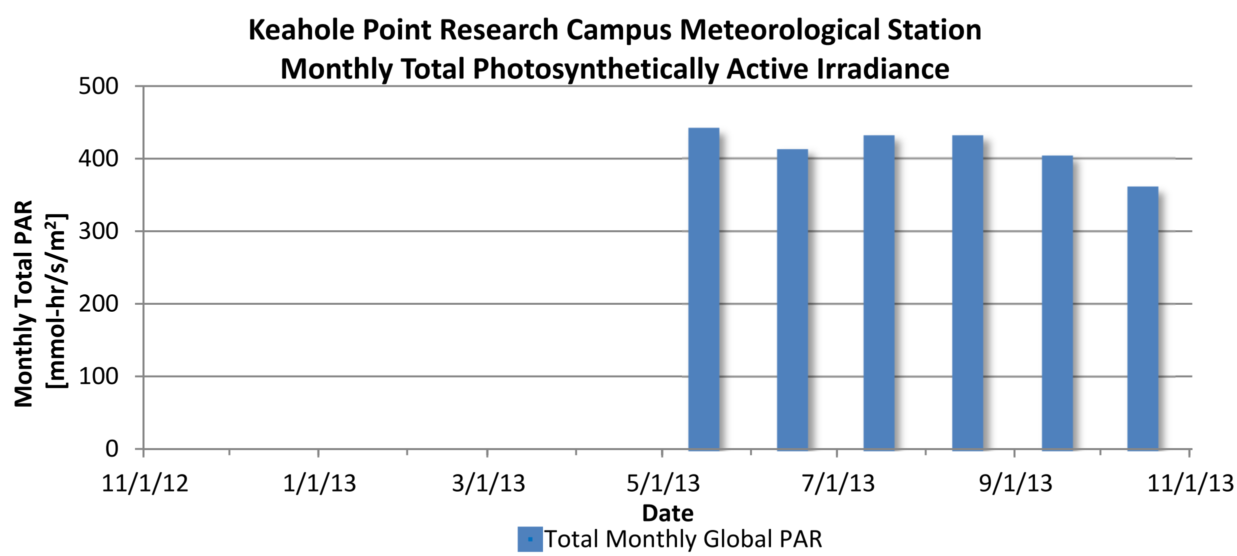


Figure 12. *Monthly PAR table and daily and monthly bar charts*

6. TROPICAL STORM FLOSSIE

Tropical Storm Flossie started as a broad area of low pressure south-southwest of Acapulco, Mexico on July 21, 2013. By July 22, 2013, showers and thunderstorm activity become defined as the system tracked west-northwestward. With favorable environmental conditions, the system began to organize into a tropical depression by July 24th. The tropical depression continued to organize and maintained a general west-northwest direction when it was upgraded to a Tropical Storm Flossie on July 25th. A mid-level eye developed on July 27th with estimated peak winds of 30.6 m/s (70 mph). Cooler waters, drier air, and increased wind shear caused Tropical Storm Flossie to weaken as it approached the Hawaiian Islands. The storm passed the northern shore of the Big Island of Hawaii on July 29th and eventually weakened to a tropical depression on July 30 just offshore of the northeast coast of Maui.

The Keahole Point Research Campus Meteorological Station recorded a peak wind speed of 15.1 m/s (33.8 mph) at approximately 180° from the north on July 29, 2013, between 4 p.m. and 5 p.m. The accumulated rain for July 29, 2013 was 7.75mm (0.35 in.). 5.69 mm (0.22 in.) of the daily accumulated precipitation occurred between 5 p.m. and 7 p.m. July 29th was mostly cloudy, confirmed by the unusually low daily global horizontal recording of 3.53 kW-hr/m^2 (daily average at Keahole Point Research Campus is 5.84 kW-hr/m^2) and photosynthetically active radiation recording of 7.58 μmol/s/m^2 (daily average at Keahole Point Research Campus is 12.89 μmol/s/m^2). After the storm, only wind related damage to sun screens and tarps was observed at the HOST facility.

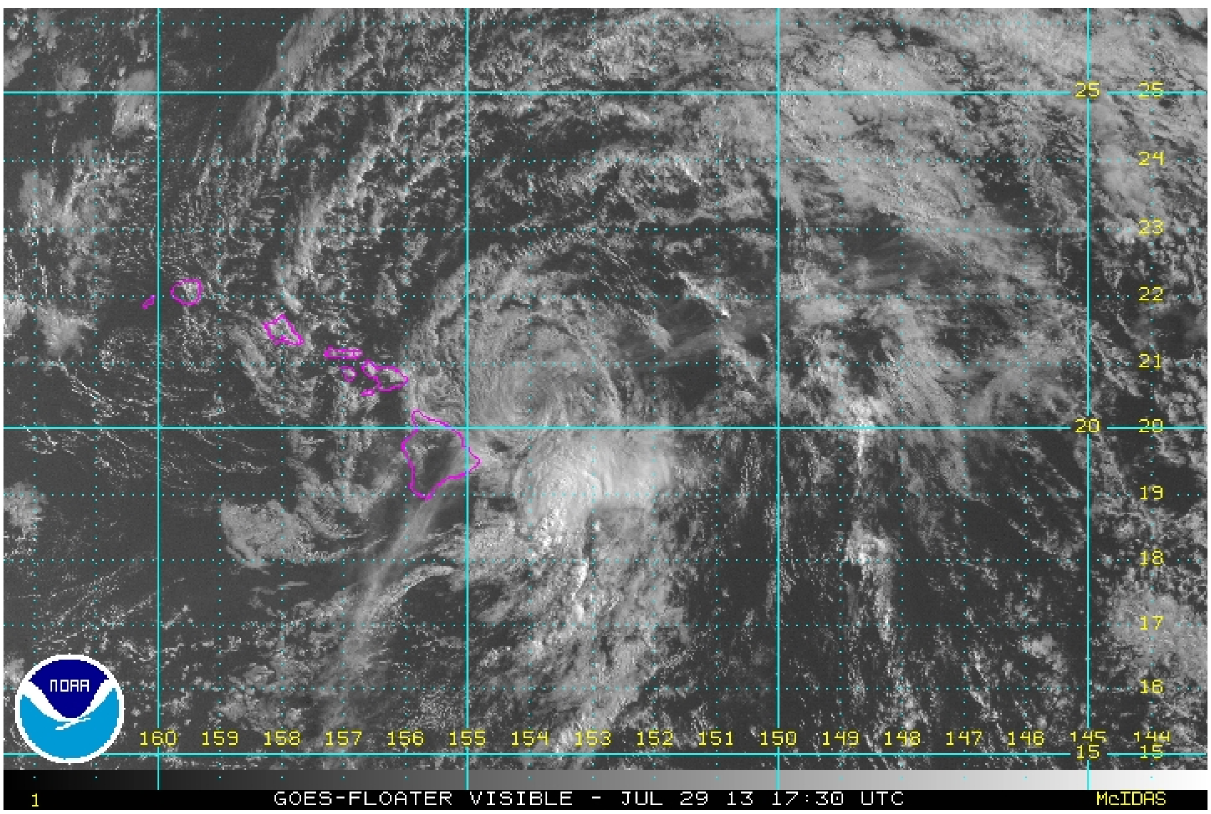


Figure 13. *NOAA GEOS–Floater Satellite imagery of Tropical Storm Flossie*

7. REGIONAL COMPARITIVE CHART

The regional comparative data in **Figure 14** was assembled from NREL's MIDc web site. NREL's MIDc has hosted solar and meteorological data since 1997. The approximately thirty one meteorological stations found on the MIDc web site use similar instrumentation and data collection sampling rates as the Keahole Point Research Campus Meteorological Station. The data table in **Figure 14** represents mean, maximum and minimum yearly data calculated from daily mean data.

The weather stations were selected based on similar instruments deployed to measure solar and meteorological conditions, and to illustrate a comparison of Keahole Point Research Campus to other regions in the United States. The regions selected were coastal Hawaii, Southwestern United States, Coastal California, and Eastern United States. Coastal Hawaii was represented by meteorological stations at Keahole Point Research Campus on the Big Island of Hawaii and the Solar Resources & Meteorological Assessment, Kalaeloa Oahu, Hawaii. The Solar Resources & Meteorological Assessment data is only available from March 16, 2010 to November 1, 2011. The comparison table will relate the November 1, 2010 to October 31 2011 data from the Solar Resources & Meteorological Assessment with the remainder of the regional site data collected between November 1, 2012 and October 31, 2013. The Southwestern United States was represented by a meteorological station at University of Nevada at Las Vegas and the University of Arizona, Tucson Arizona. Coastal California was represented by Loyola Marymount University, Los Angeles, California. The Eastern United States was represented by a meteorological station at Oak Ridge National Laboratory.

Figure 15 shows a line plot of global horizontal irradiance data profiles of weekly totals through the monitoring year. Keahole Point Research Campus solar irradiance is very consistent data throughout the monitoring year and indicates favorable profiles in the winter months and slightly lower profiles in the summer months in comparison to the Southwest United States.

Figure 16 shows a line plot of relative humidity data profiles of daily means through the monitoring year. Keahole Point Research Campus relative humidity profiles indicate little variation from the 67% yearly mean throughout the monitoring year.

Figure 17 shows a line plot of temperature profiles of daily means through the monitoring year. Keahole Point Research Campus temperature profile indicates little variation from the 25.7˚C (78.3˚F) yearly mean throughout the monitoring year.

Regional Meteorological Data Comparison Chart

Meteorological Measurement	Units	NELHA Kailua-Kona, Big Island, Hawaii	Solar Resources & Met. Assessment Kalaeloa Oahu, Hawaii	University of Nevada Las Vegas, Nevada	University of Arizona Tucson, Arizona	Loyola Marymount University Los Angeles, California	Oak Ridge National Laboratory Oak Ridge, Tennessee
Period	MM/DD/YY	11/01/12-10/31/13	11/01/10-10/31/11	11/01/12-10/31/13	11/01/12-10/31/13	11/01/12-10/31/13	11/01/12-10/31/13
GPS	Latitude	19.73° N	21.31° N	36.06° N	32.23° N	33.96° N	35.93° N
	Longitude	156.06° W	158.08° W	115.08° W	110.96° W	118.42° W	84.31° W
Elevation	m	4	11	615	786	27	245
	ft.	13	36	2018	2579	89	804
Mean Yearly Temperature	°C	25.70	24.30	21.88	22.42	16.85	14.837
	°F	78.25	75.73	71.39	72.36	62.33	58.707
Max Yearly Temperature	°C	34.40	32.51	47.37	44.25	32.91	36.910
	°F	93.93	90.52	117.27	111.65	91.24	98.438
Min Yearly Temperature	°C	16.92	13.54	-3.65	-5.93	3.68	-7.922
	°F	62.45	56.37	25.43	21.33	38.62	17.740
Yearly Total Global Solar Irradiance	kW-hr/m^2	2135.2	1875.0	2052.9	2145.7	1865.1	1376.5
Mean Daily Total Global Solar Irradiance	kW-hr/m^2	5.84	5.14	5.62	5.88	5.11	3.77
Mean Yearly Relative Humidity	%	66.6	71.0		29.4	76.8	77.8
Max Yearly Relative Humidity		96.5	98.5		94.9	100.0	98.6
Min Yearly Relative Humidity		34.3	30.0		2.2	7.2	20.7
Mean Yearly Barometric Pressure	mBar	1014.72	1015.43		925.59		1003.44
	in. of Hg	29.96	29.99		27.33		29.63
Mean Yearly Wind Speed	m/s	2.42	2.40	2.00	2.61	1.74	0.80
	mph	5.41	5.36	4.48	5.85	3.89	1.79
Yearly Accumulated Precipitation	mm	139.42				148.61	1463.26
	in.	5.49				5.85	57.61

Figure 14. Regional Meteorological Comparison Chart

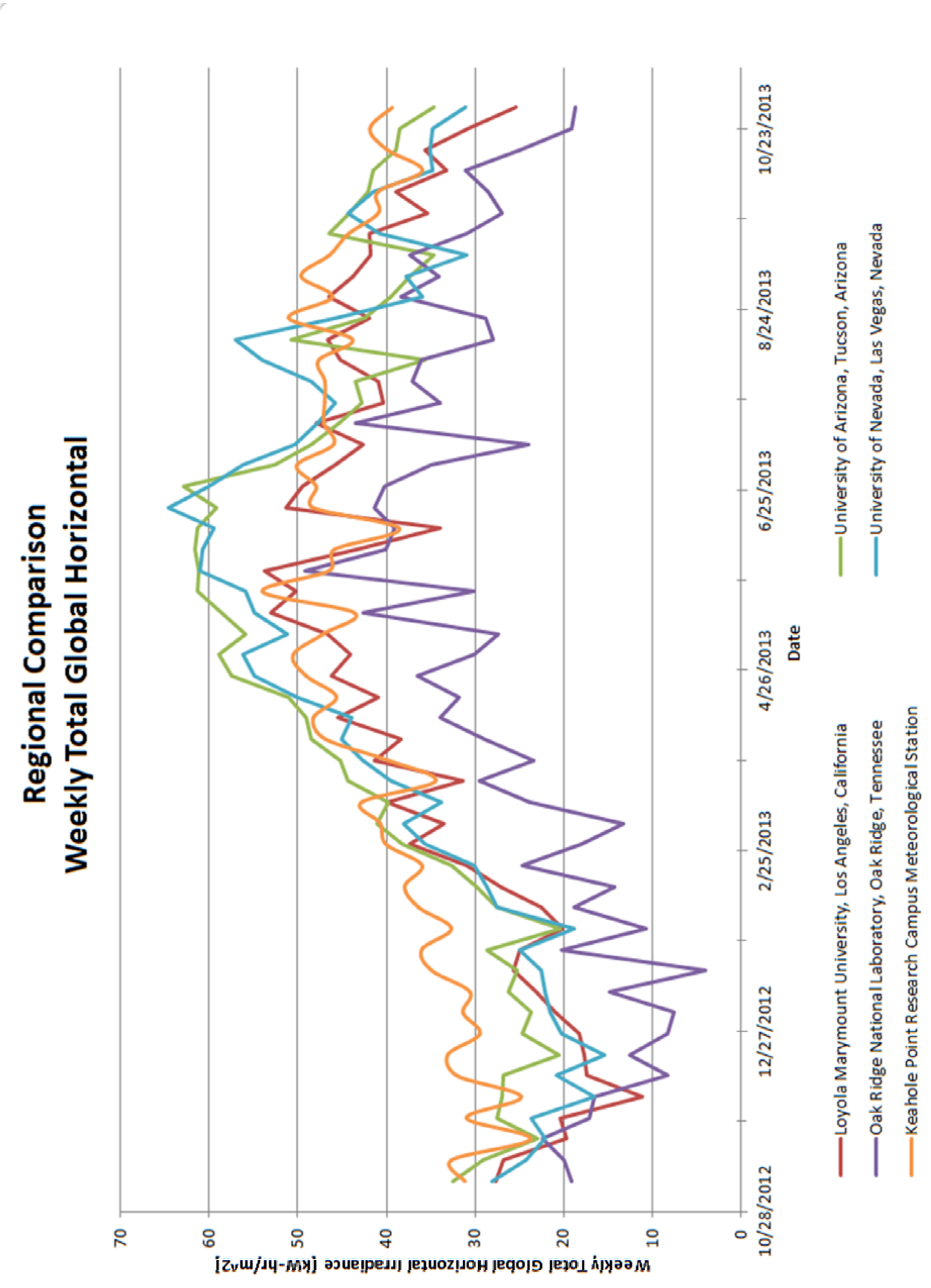


Figure 15. Regional comparison of weekly total global horizontal irradiance profiles

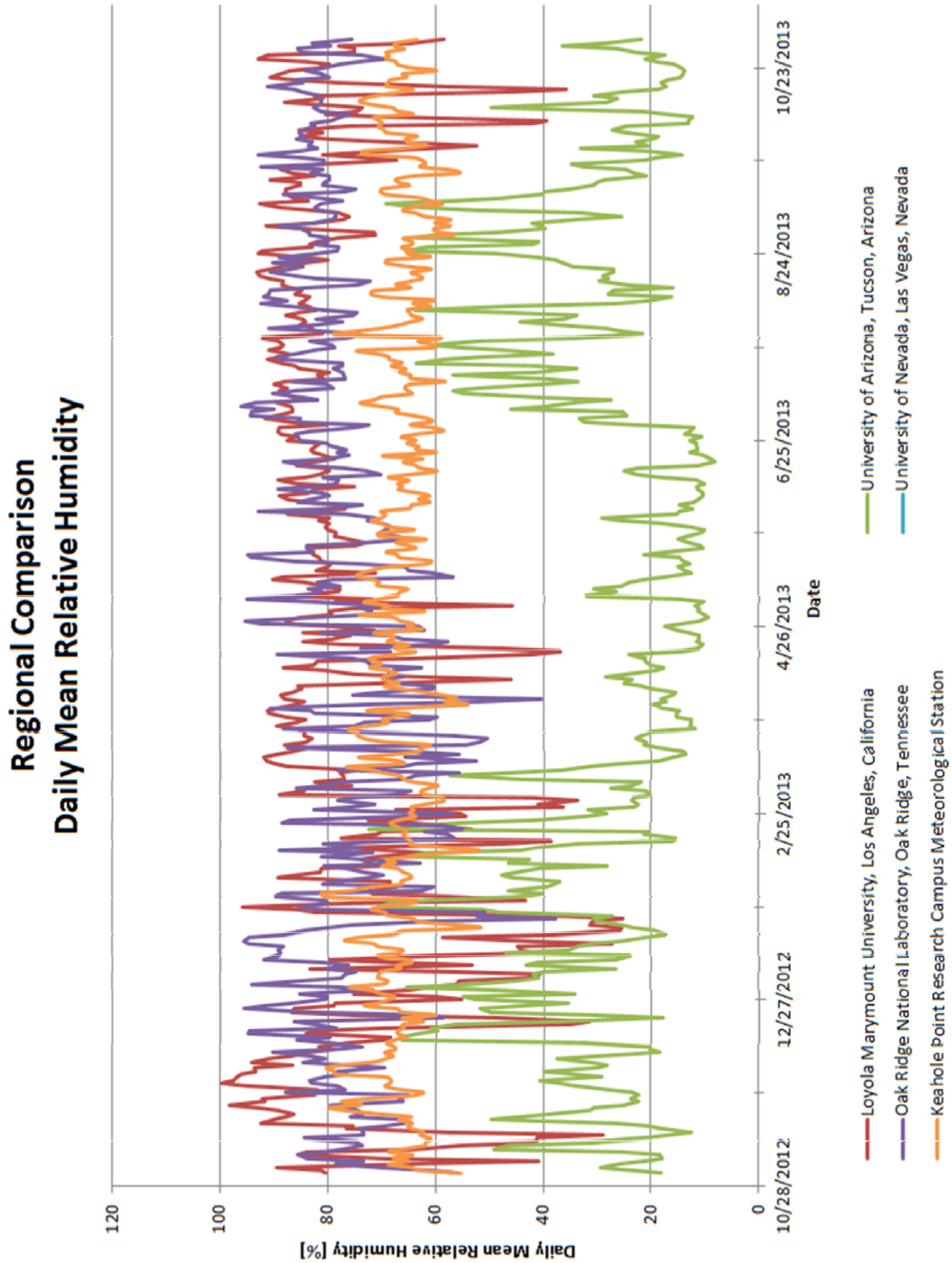


Figure 16. Regional comparison of daily relative humidity profiles

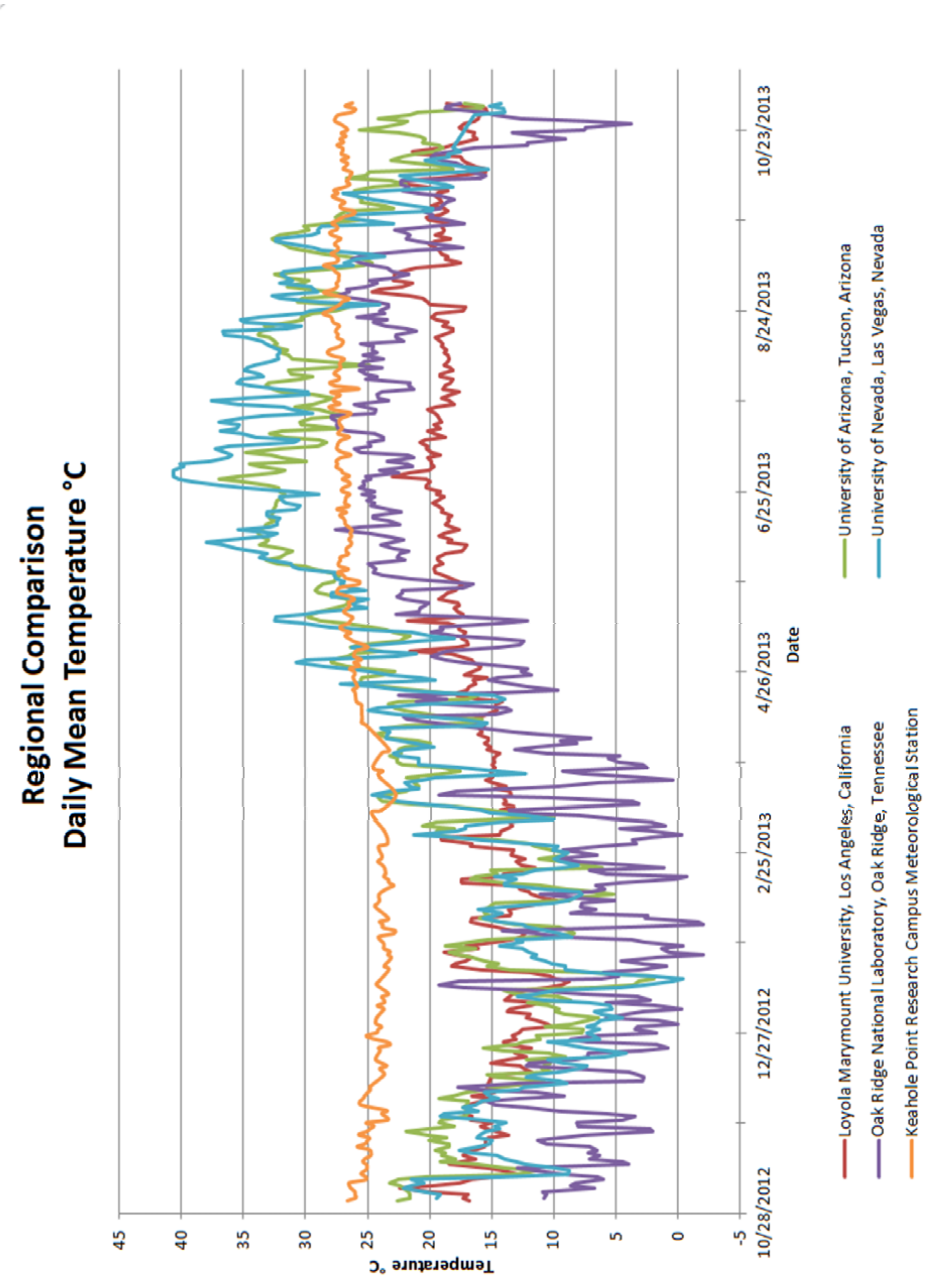


Figure 17. Regional comparison of daily temperature profiles

8. ACKNOWLEDGEMENT

The author would like to acknowledge the staff members at the Natural Energy Laboratory of Hawaii Authority for all their efforts to successfully procure, build, and record meteorological data at the Keahole Point Research Campus. A special thanks goes to Tom Pierce, NELHA Utility Electrician, for his efforts in the assembly of the meteorological station on October 30 and 31, 2012 and his dedication to regularly clean the optical housings for the global horizontal sensor, PAR sensor, and logging temperature and precipitation data for NOAA. In addition, acknowledgement goes to Laurence Sombardier, NELHA Chief Marketing Officer, for her efforts in writing, and managing the NREL contract.

NELHA would like to acknowledge Byron Kay, Algae Specialist, Big Island Abalone Corporation for spear-heading the addition of a PAR sensor to the Keahole Point Research Campus Meteorological Station. A big thank you also goes to Big Island Abalone Corporation for providing a recently calibrated Li-COR LI-190 PAR sensor to be placed on the meteorological station and openly sharing the collected data.

NELHA would also like to acknowledge the support and advice received from the staff at NREL. This includes valuable insights Peter Gotseff provided for equipment and instrument specifications, site location, and general meteorological enquiries by NELHA staff. In addition, NELHA would also like to recognize Afshin Andreas for his help in setting up the data logger's communications and providing the graphical data display at NREL's Measurement and Instrumentation Data Center web portal. A special thanks needs to be mentioned for the vision of NREL's Dr. Bill Kramer and NELHA Executive Director, Greg Barbour. Without their determination, this project would not have seen fruition.

Finally, NELHA would like to acknowledge Lee Fausak, Research Manager, National Defense Center of Excellence for Research in Ocean Sciences for providing the initial scoping of the grant proposal and specifications for the meteorological station.

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APPENDIX

A. FUNDING AND PROCUREMENT

1. SCOPE OF WORK

The meteorological station was funded through the US Department of Energy under prime contract number DE-AC36-08GO28308 through the National Renewable Energy Laboratory (NREL) in partnership with Natural Energy Laboratory of Hawaii Authority (NELHA) under sub contract number NAT-2-22050-01. NELHA completed the scope of work in **Task 3** under sub contract number NAT-2-22050-01 on December 17, 2012:

<u>Acquire and Install Equipment for Monitoring, Collecting, and Reporting Data Related to Solar Resources and Meteorological Conditions at NELHA</u>.

I. Determining the specifications of a meteorological station guided by NREL's measurement requirements.
II. Procuring a meteorological station by following the State of Hawaii's small purchase procurement policies.
III. Installing the meteorological station under the guidance of NREL and EPA's *Quality Assurance Handbook for Air Pollution Measurement Systems Volume IV – Meteorological Measurements.*
IV. Providing real-time and historical data access to the public.

2. TIMELINE AND SPECIFICATIONS

The timeline of events for the completion of task 3 occurred as follows:

I. The specification for the meteorological station was assembled by May 29, 2012 and request for bids using the State of Hawaii's small purchase procurement procedures followed shortly thereafter.

II. The specifications included the following meteorological sensors and related mounting equipment, cable assemblies, tower, and data logger.

   i. Marine wind direction and speed monitor and cable assembly manufactured by R.M. Young Company, Model #05106.
   ii. Temperature and humidity sensor, radiation shield, and cable assemble sourced by Met One Instruments, Inc., Model # 083E-1-35.

   iii. Barometric pressure sensor, 800 – 1100 MB, and cable assembly sourced by Met One Instruments, Inc., Model # 092.

   iv. First class global horizontal solar radiation sensor and cable assemble manufactured by Kipp & Zonn, Model CMP-11.

v. Rain gauge tipping bucket, pole mounting base, and cable assembly sourced by Met One Instruments, Inc., Model # 370C.

vi. Data logger CR-1000 with external keyboard and display, NL120 Network interface module with Modbus protocols, AC surge protection module MCG-415 manufactured by Campbell Scientific, Inc.

vii. Self-supporting 10 meter aluminum tower, lightning rod and grounding system, and mounting clamps and bars manufactured by Universal Towers.

III. Met One Instruments, Inc. was the vendor awarded the small purchase agreement on September 27, 2012.

IV. NELHA received delivery of the meteorological station tower on October 18, 2012 and erected it on October 25, 2012. The meteorological instrument arrived at the NELHA facility on October 29, 2012. The meteorological station was assembled over one and half days on October 30 and 31, 2012.

V. A data stream to NREL was established on December 13, 2012 and measurements have been available to the public at http://www.nrel.gov/midc/nelha/ from December 17, 2012.

VI. A LI-COR LI-190 quantum sensor measures photosynthetically active radiation (PAR) in the 400 to 700 nm waveband was installed on April 23, 2013. The Sensor was donated by Big Island Abalone Corporation.