ANNUAL REPORT

For the

KEAHOLE POINT RESEARCH CAMPUS METEOROLOGICAL STATION

Covering the Monitoring Year:

January 1, 2019 – December 31, 2019

Historical Data Plots:

November 1, 2012 – December 31, 2019

Prepared by:

Keith Olson

NELHA Chief Science Officer

Hawaii Ocean Science and Technology Park

Administered by:

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MET STATION ANNUAL REPORT (2019) v3.docx

EXECUTIVE SUMMARY

The Hawaiian Ocean Science and Technology (HOST) park's clients utilize the real time meteorological data for aquaculture management decisions, meteorological analytics models, and the development of smart models in energy generation and storage systems. The Keahole Point Research Campus Meteorological Station was initially deployed at HOST Park's Research Campus on November 1, 2012. The United States Department of Energy through the National Renewable Energy Laboratory provided the source funding for the meteorological station's tower and instrumentation. Raw data and data plots are available in real time through the National Renewable Energy Laboratory's Measurement and Instrumentation Data Center [http://www.nrel.gov/midc/] or within this and previous annual meteorological reports found on the NELHA web site [http://nelha.hawaii.gov/resources/library/].

This report highlights the annual meteorological data set collected at Keahole Point from January 1, 2019 to December 31, 2019 (monitoring year). The report also includes the historical meteorological data trends starting from November 1, 2012 at Keahole Point. The monitoring year was relatively uneventful with no notable weather events, severe weather storms or hurricanes. Details of recent weather events, severe weather storms and hurricanes can be found in Section 6, Hurricanes and Tropical Storms, starting on page 37. The remainder of the meteorological data found in this report chronicles the seasonal cycle during the monitoring year and the historical data set recorded since November 1, 2012.

The monitoring year's mean yearly temperature was 26.65°C (79.97°F) with a maximum-recorded temperature of 34.6˚C (94.2˚F) on September 13, 2019 and a minimum-recorded temperature of 16.7˚C (62.0˚F) on February 13, 2019. The mean historical annual temperature since November 1, 2012 was 26.16°C (79.09°F). The annual accumulated precipitation record during the monitoring year was 447.25 mm (17.6 in.), with 29% of the precipitation occurring during the month of April and 13% occurring during the month of February. The mean historical annual accumulated precipitation since November 1, 2012 was 334.9 mm (13.19 in.). Historically, the wettest months are typically February through April and driest months are June and July. The mean relative humidity for the monitoring year was 64.6%, with a maximum-recorded relative humidity of 92.5% in April, and a minimum-recorded relative humidity of 35.3% in January. The mean historical annual relative humidity since November 1, 2012 was 66.3%. Wind speed throughout the period was consistent at a yearly mean of 2.53 m/s (5.66 mph) with a standard deviation of 1.35 m/s (3.02 mph). The mean historical annual wind speed since November 1, 2012 was 2.48 m/s (5.56 mph). Wind direction at Keahole Point exhibits a typical land-sea directional profile and has two general bearings averaging at 221.3° from the north in the daytime hours (8 am – 8 pm) and 124.1° from the north during the nighttime hours. Barometric pressure

at Keahole Point recorded a mean yearly value of 1014.2 mBar (29.95 in. of Hg) with a range of 1006.3 to 1020.8 mBar (29.72 to 30.14 in. of Hg).

The yearly total global horizontal solar irradiance recorded at the Keahole Point Research Campus Meteorological Station was 2211 kW-hr/m^2. This is comparable with Tucson, Arizona at 2138 kW-hr/m^2, and Las Vegas, Nevada at 2047 kW-hr/m^2. It is surprising to see Keahole Point receiving as much total yearly global horizontal irradiance (at 6.06 kW-hr/m^2 mean daily) as the desert southwestern United States. The difference between Tucson, Arizona was -12.1 days and for Las Vegas, Nevada it was -27.2 days of total irradiance during the monitoring year to Keahole Point, Hawaii. Keahole Point has been noted as having the highest solar insolation in the Coastal United States. This is mostly due to the proximity to the equator and dry conditions. When reviewing the yearly data plots, Keahole Point's proximity to the equator results in greater solar irradiance during the winter months and a generally flatter, or consistent solar exposure throughout the year *(Figure 16. - 19.)*. Additional regional comparisons can be found in Section 7 of this report.

In 2019, the HOST park meteorological station has continued to confirm minimal natural variability at Keahole Point, Hawaii in temperature, relative humidity, barometric pressure, wind speed and direction, and precipitation through the monitoring year. The meteorological station has also recorded a notable total global horizontal solar irradiance similar to the desert southwestern United States and episodic wind conditions and precipitation accumulation during the tropical storm and hurricane season.

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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:	January 1, 2017 to December 31, 2017

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 section 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 lightning rod mounted 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 data logger's ground and continues to the towers grounding system.[(1)] On August 21, 2018, just as Hurricane Lane was approaching the Hawaiian Islands as a category 5 Hurricane, NELHA permanently installed guy wires to the meteorological station tower. On February 5, 2019 the base of the tower's metal brackets, and anchor bolts were replaced with stainless steel hardware.

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 are connected to the CS I/O port (Campbell Scientific, Inc. Model CR1000KD). The data logger can 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 a Campbell Scientific, Inc., model # 083E-1-35 (serial # N11762) temperature and relative humidity sensors on November 1, 2012. The sensor was replaced with a newly purchased and calibrated sensor (serial # N11767) on April 7, 2015. On February 9, 2017, the recalibrated original sensor (serial # N11762) replaced the sensor installed on April 7, 2015. The calibration was performed by Met One Instruments in Grants Pass, Oregon on January 13, 2017. On February 5, 2019, the recalibrated secondary sensor (serial # N11767) replaced the primary sensor installed on February 9, 2017. The calibration was performed by Met One Instruments in Grants Pass, Oregon on November 5, 2018. The relative humidity and temperature sensor are extremely accurate microprocessor controlled units. The relative humidity sensor responds to the full range from 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]

The temperature sensor is connected to differential channel 3 (H red, G black & green) and excitation voltage channel VX2 (white 23100Ω ±0.1 resistor). The internal Array table designator is 9, with a 16-bit Floating Point Modbus Address 40017 for instantaneous measurements. For 1 minute average temperature data, the internal table designator is 24, with a 16-bit Floating Point Modbus Address 40047. The relative humidity sensor is connected to differential channel 4 (H yellow) with an internal Array table designator 10, and a 16-bit Floating Point Modbus Address 40019 for instantaneous measurements. 1 minute average relative humidity data is in the internal Array table designator 25, with a 16-bit Floating Point Modbus Address 40049.

3.3.2. BAROMETRIC PRESSURE

The Keahole Point Research Campus Meteorological Station deployed a Campbell Scientific, Inc., model # 092 (serial # N11882) barometric pressure sensor on November 1, 2012. The sensor was replaced with a newly purchased and calibrated sensor (serial # T10674) on April 7, 2015. On February 9, 2017, the recently recalibrated original sensor (serial # N11882) replaced the sensor installed on April 7, 2015. The calibration was performed by Met One Instruments in Grants Pass, Oregon on January 13, 2017. On February 5, 2019, the recalibrated secondary sensor (serial # T10674) replaced the primary sensor installed on February 9, 2017. The calibration was performed by Met One Instruments in Grants Pass, Oregon on November 5, 2018. 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 the communications services to the data logger. 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]

The barometric sensor is connected to differential channel 8 (L white, G black & green) with an internal table designator 12, and a 16-bit Floating Point Modbus Address 40023 for instantaneous measurements. 1 minute average temperature data is located in the internal table under designator #27, with a 16-bit Floating Point Modbus Address 40053.

3.3.3. WIND MONITOR

The Keahole Point Research Campus Meteorological Station deployed a R.M. Young Company, marine model # 05106 (serial # WM121997) wind monitor-MA on November 1, 2012. The sensor was replaced with a newly purchased and calibrated sensor (serial # WM140238) on April 7, 2015. On February 9, 2017, the recently recalibrated original sensor (serial # WM121997) replaced the sensor installed on April 7, 2015. The calibration was performed by R.M. Young Company in Traverse City, Michigan on December 22, 2016. On

February 5, 2019, the recalibrated secondary sensor (serial # WM140238) replaced the primary sensor installed on February 9, 2017. The calibration was performed by R.M. Young Company in Traverse City, Michigan on October 31, 2018. The wind monitor was designed for a marine environment to measure horizontal wind speed and direction. 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.

The propeller rotation measures wind speed. The measured rotation produces an AC sine wave signal with frequency proportional to wind speed. This AC signal is induced in a stationary coil by a 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]

The wind direction sensor is connected to differential channel 1 (L green, G black) and excitation voltage channel VX1 (white, G blue). The internal Array table designator is 8, and the 16-bit Floating Point Modbus Address is 40015 for instantaneous measurements. For 1 minute average temperature data, the internal table designator is 21, and the 16-bit Floating Point Modbus Address 40041. The relative wind speed sensor is connected to pulse input channel P1 (red) with an internal table designator 7, and a 16-bit Floating Point Modbus Address 40013 for instantaneous measurements. 1 minute average wind speed data is located in the internal array table designator 20, with a 16-bit Floating Point Modbus Address 40039.

3.3.4. PRECIPITATION

The Keahole Point Research Campus Meteorological Station deployed a Met One Instruments, Inc., model # 370C (serial # N11206) 8” tipping bucket rain gauge on November 1, 2012. The sensor was replaced with a newly purchased and calibrated sensor (serial # T11827) on April 7, 2015. On February 9, 2017, the recently recalibrated original sensor (serial # N11206) replaced the sensor installed on April 7, 2015. The calibration was performed by Met One Instruments in Grants Pass, Oregon on January 13, 2017. On February 5, 2019, the recalibrated secondary sensor (serial # T11827) replaced the primary sensor installed on February 9, 2017. The calibration was performed by Met One Instruments in Grants Pass, Oregon on November 5, 2018. 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]

The precipitation sensor is connected to pulse input channel P2 (red, G black). The internal Array table designator is 14, and the 16-bit Floating Point Modbus Address is 40027 for instantaneous totalized measurement. For total rain data, the internal table designator is 29, and the 16-bit Floating Point Modbus Address 40057.
T me

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 Hale Iako 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, photosynthetically active radiation and ultraviolet light. Most of the sensors are mounted on an aluminum tower at approximately 2 - 3 meters in elevation from grade except for the ground mounted precipitation sensor and the wind speed and direction sensor at 10 meters elevation from grade. The data is collected by a Campbell Scientific CR1000 data logger at a 1 second sample rate with reporting capabilities of one-minute averages. The meteorological data is transmitted from the CR1000 to the NELHA internal SCADA system in real time and to NREL's Measurement and Instrumentation Data Center (MIDC) at five minute intervals. The data is readily available for public review at the MIDC web portal. A dashboard display *(Figure 2.)* of all measured meteorological parameters are graphically presented at a five minute 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 be downloaded in ASCII format as one-minute, hourly, and daily mean data *(Figure 3.).*

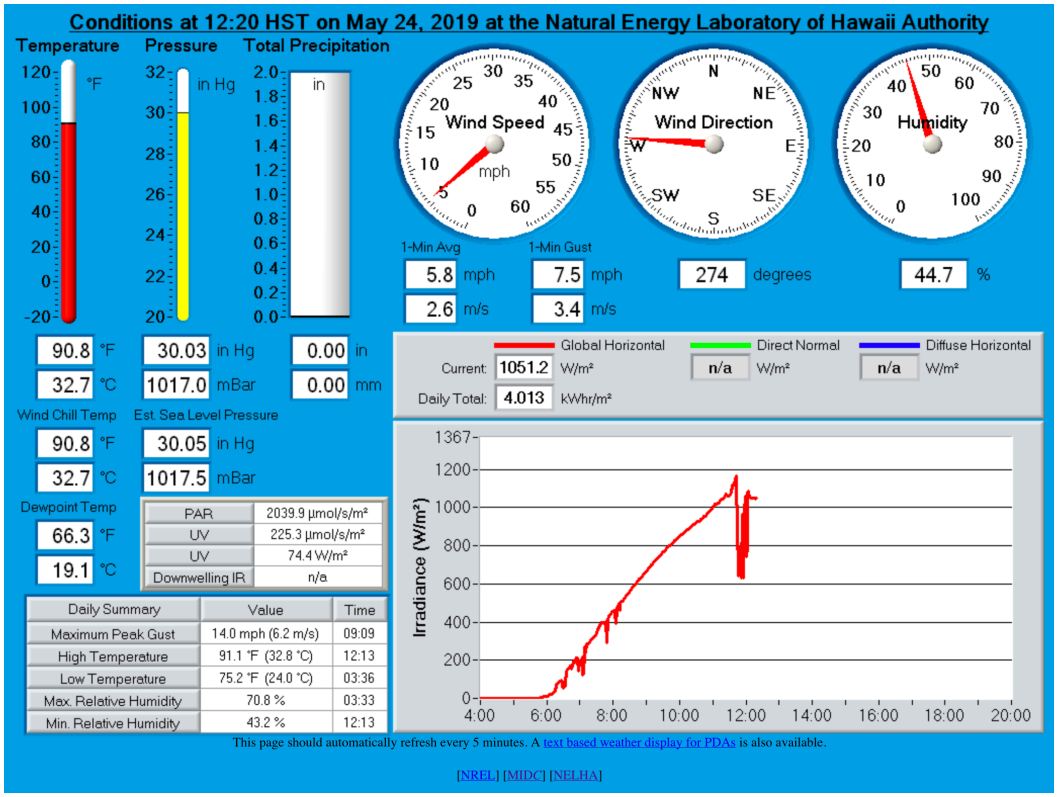


Figure 2. *Dashboard View from NREL's MIDC web portal*

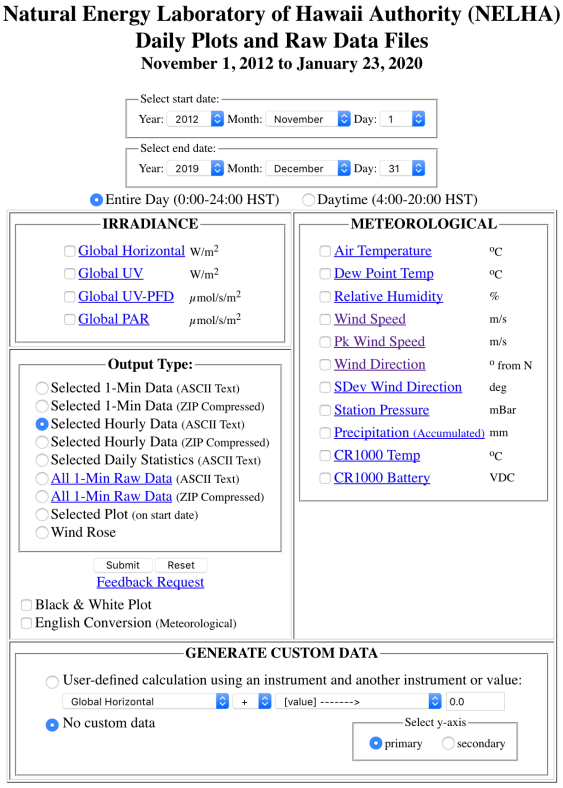


Figure 3. *User Selected Daily Plots and Raw Data Files*

5. RESULTS

5.1. AIR TEMPERATURE

Monthly mean air temperature recorded in 2019 followed a narrow seasonal cycle. Mean hourly air temperatures ranged from a low in February of 16.7˚C (62.0˚F) to a high in September of 34.6˚C (94.2˚F). The daily mean air temperature shows very little variation throughout the year with a range from 21.2 to 29.8˚C (70.1 to 85.7˚F). The yearly mean temperature during this period was 26.65˚C (79.97˚F).

Mean Monthly Max/Min Hourly	Jan. 2019	Feb. 2019	Mar. 2019	Apr. 2019	May 2019	Jun. 2019	Jul. 2019	Aug. 2019	Sep. 2019	Oct. 2019	Nov. 2019	Dec. 2019
Mean Temperature (˚C)	24.2	***23.5***	24.3	26.1	27.0	28.1	28.6	28.8	***28.8***	27.7	27.1	25.6
Max Temperature (˚C)	30.3	32.7	31.2	31.7	33.0	34.0	34.2	34.5	**34.6**	33.8	33.5	31.2
Min Temperature (˚C)	18.7	***16.7***	18.3	20.4	18.8	22.1	23.1	24.1	23.2	22.4	21.6	20.2
Mean Temperature (˚F)	75.5	***74.4***	75.7	79.0	80.6	82.5	83.4	83.8	***83.8***	81.9	80.7	78.0
Max Temperature (˚F)	86.6	90.8	88.1	89.1	91.5	93.1	93.6	94.2	**94.2**	92.8	92.3	88.2
Min Temperature (˚F)	65.7	***62.0***	65.0	68.7	65.8	71.8	73.7	75.4	73.8	72.3	70.9	68.3

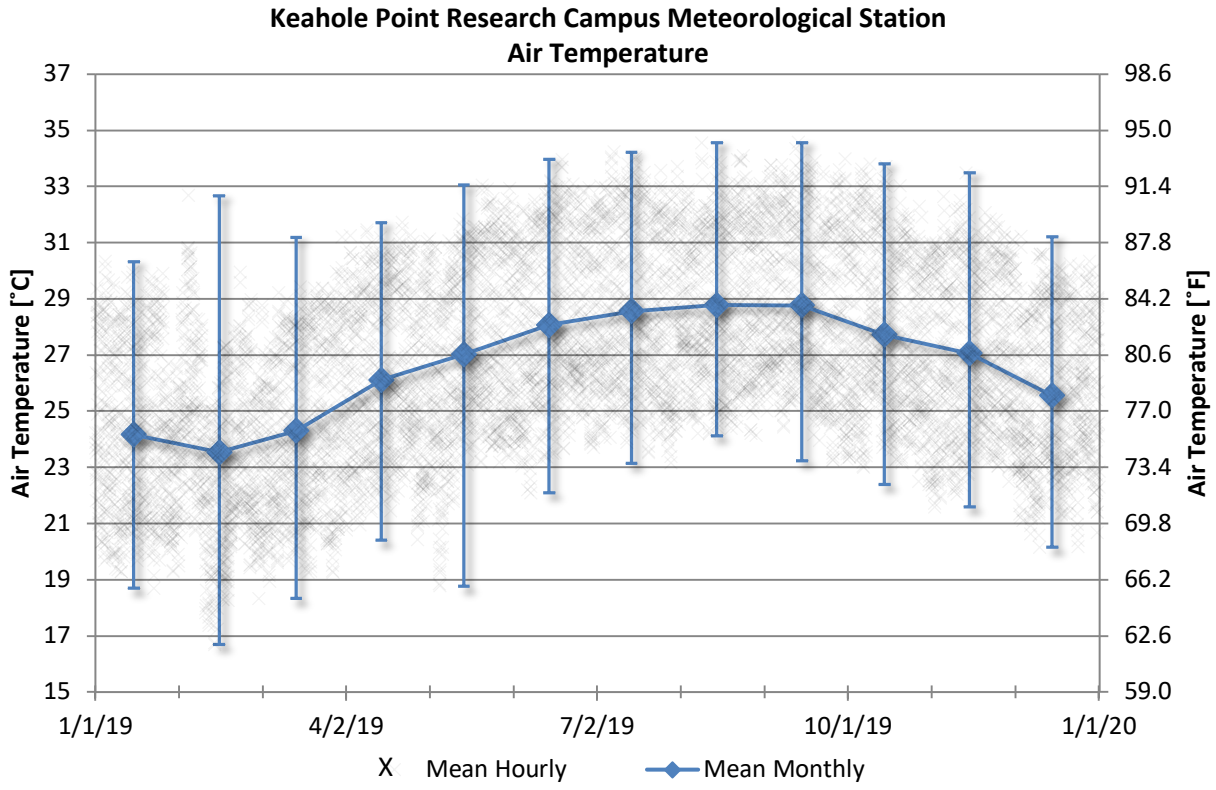


Figure 4a. *Monthly air temperature result table and scatter plot*

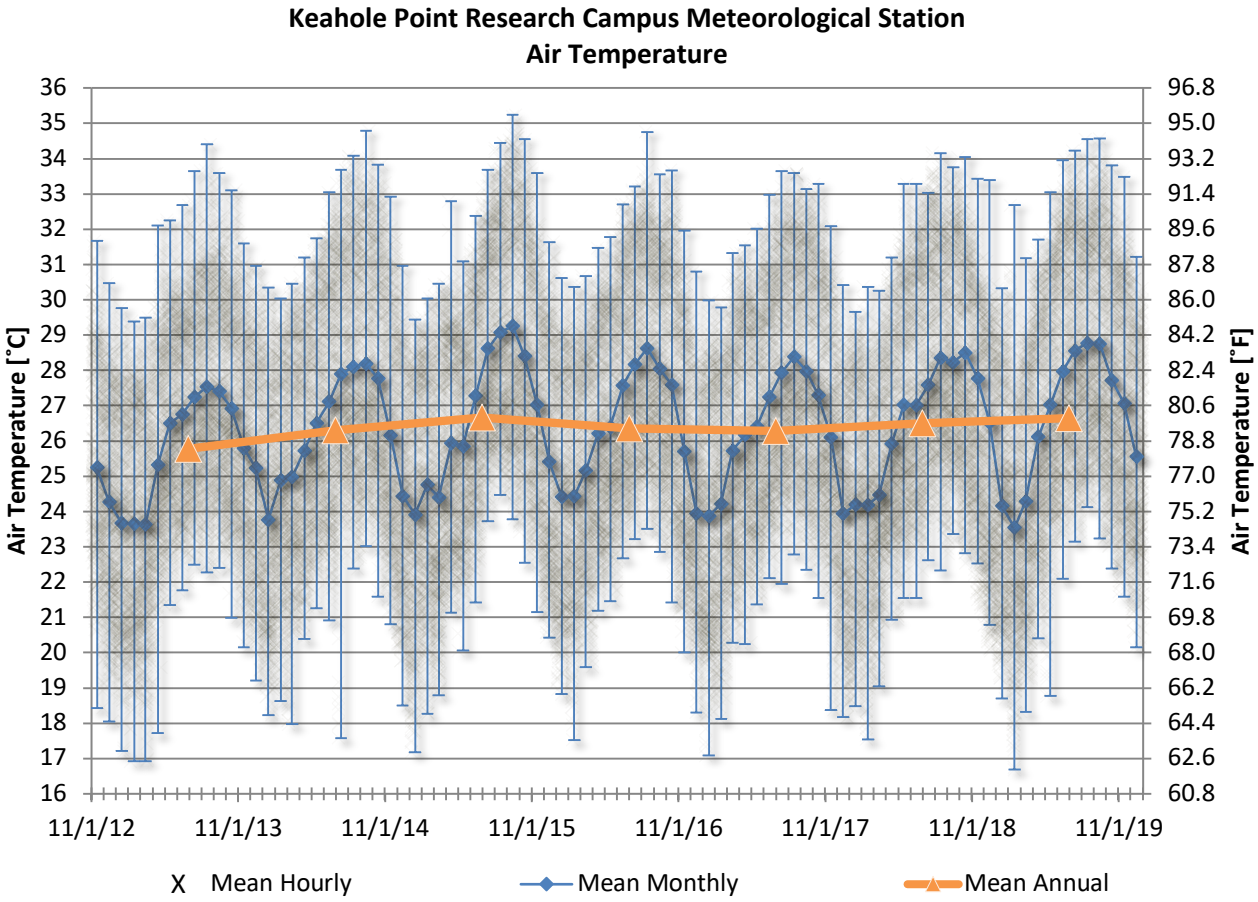


Figure 4b. *Historical air temperature scatter plot*

	Mean Monthly Air Temperature (˚C)												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
2012											25.25	24.26	24.72
2013	23.66	23.65	23.63	25.32	26.50	26.75	27.24	27.54	27.42	26.92	25.79	25.24	**25.78**
2014	23.77	24.88	24.98	25.72	26.50	27.11	27.89	28.10	28.19	27.77	26.16	24.43	26.30
2015	23.92	24.76	24.40	25.94	25.85	27.29	28.62	29.08	**29.25**	28.40	27.02	25.41	**26.67**
2016	24.42	24.43	25.17	26.21	26.39	27.58	28.16	28.62	28.05	27.59	25.70	23.94	26.36
2017	23.87	24.22	25.73	26.17	26.41	27.25	27.94	28.38	27.97	27.29	26.11	23.94	26.28
2018	24.19	24.19	24.46	25.93	27.03	27.01	27.58	28.36	28.23	28.50	27.78	26.51	26.50
2019	24.16	**23.54**	24.29	26.11	27.02	27.97	28.55	28.77	28.76	27.72	27.06	25.55	26.65
Mean	**24.00**	**24.24**	**24.66**	**25.91**	**26.53**	**27.28**	**28.00**	**28.41**	**28.27**	**27.74**	**26.36**	**24.91**	**26.16**

	Mean Monthly Air Temperature (˚F)												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
2012											77.44	75.67	76.50
2013	74.60	74.58	74.54	77.57	79.71	80.14	81.03	81.56	81.35	80.46	78.42	77.42	**78.40**
2014	74.79	76.78	76.96	78.30	79.71	80.80	82.21	82.59	82.74	81.99	79.10	75.98	79.34
2015	75.05	76.56	75.92	78.70	78.53	81.12	83.52	84.34	**84.65**	83.11	80.63	77.74	**80.01**
2016	75.96	75.97	77.30	79.18	79.51	81.64	82.69	83.52	82.49	81.66	78.25	75.08	79.45
2017	74.96	75.59	78.31	79.10	79.53	81.06	82.28	83.08	82.35	81.13	78.99	75.09	79.31
2018	75.55	75.53	76.03	78.67	80.65	80.63	81.64	83.04	82.81	83.30	82.00	79.72	79.71
2019	75.49	**74.37**	75.73	79.00	80.64	82.35	83.40	83.79	83.77	81.89	80.70	77.99	79.97
Mean	**75.20**	**75.63**	**76.40**	**78.64**	**79.75**	**81.11**	**82.40**	**83.13**	**82.88**	**81.94**	**79.44**	**76.84**	**79.09**

Figure 4c. *Historical mean monthly air temperature table (˚C & ˚F)*

5.2. RELATIVE HUMIDITY

Monthly mean relative humidity recorded in 2019 showed a consistent trend through the seasonal cycle. Annual variations in mean hourly relative humidity showed a range from 35.3 to 92.5%. Yearly mean relative humidity during this period was 64.6%.

Mean Monthly Max/Min Hourly	Jan. 2019	Feb. 2019	Mar. 2019	Apr. 2019	May 2019	Jun. 2019	Jul. 2019	Aug. 2019	Sep. 2019	Oct. 2019	Nov. 2019	Dec. 2019
Mean RH (%)	63.5	67.2	***61.0***	63.0	63.5	62.8	64.3	65.6	65.3	65.3	65.5	***68.0***
Max RH (%)	86.5	92.0	84.9	***92.5***	87.9	89.9	89.5	90.2	88.6	88.4	85.6	89.5
Min RH (%)	***35.3***	37.2	35.8	41.8	36.7	38.9	40.8	44.0	41.7	41.1	42.2	47.0

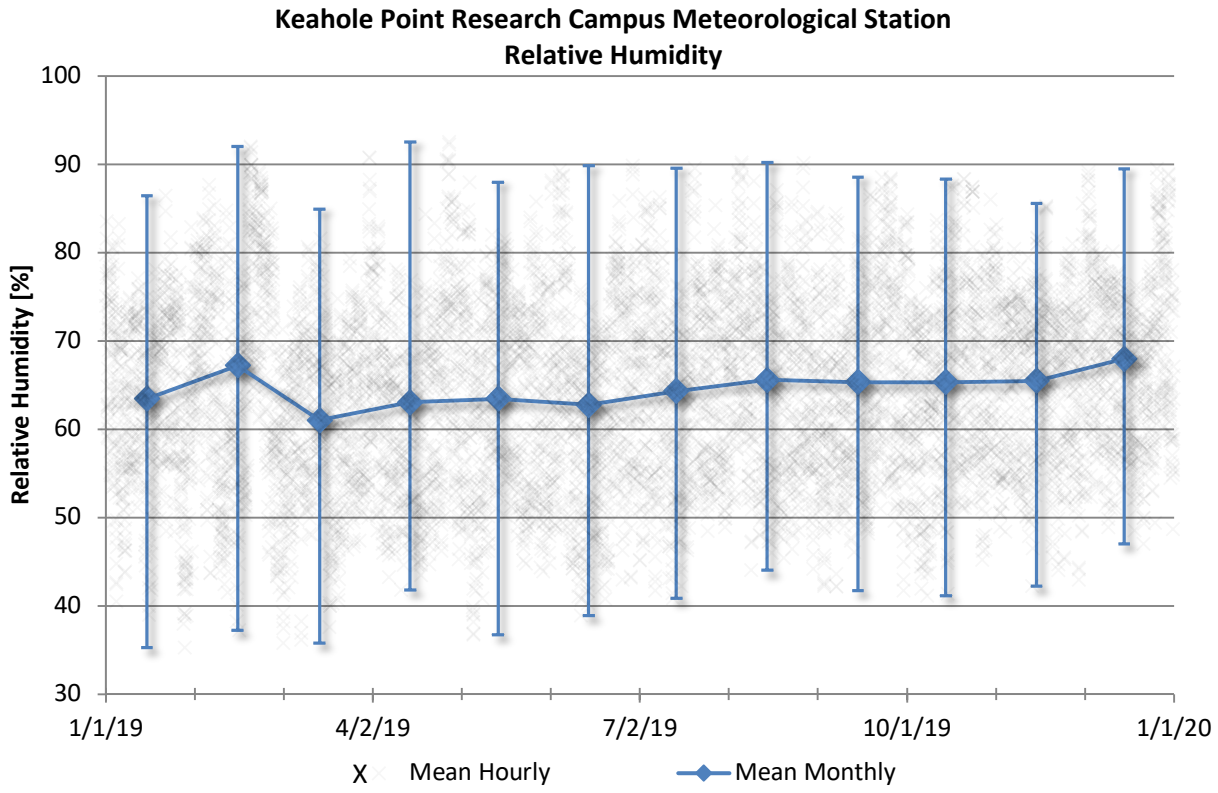


Figure 5a. *Monthly relative humidity result table and scatter plot*

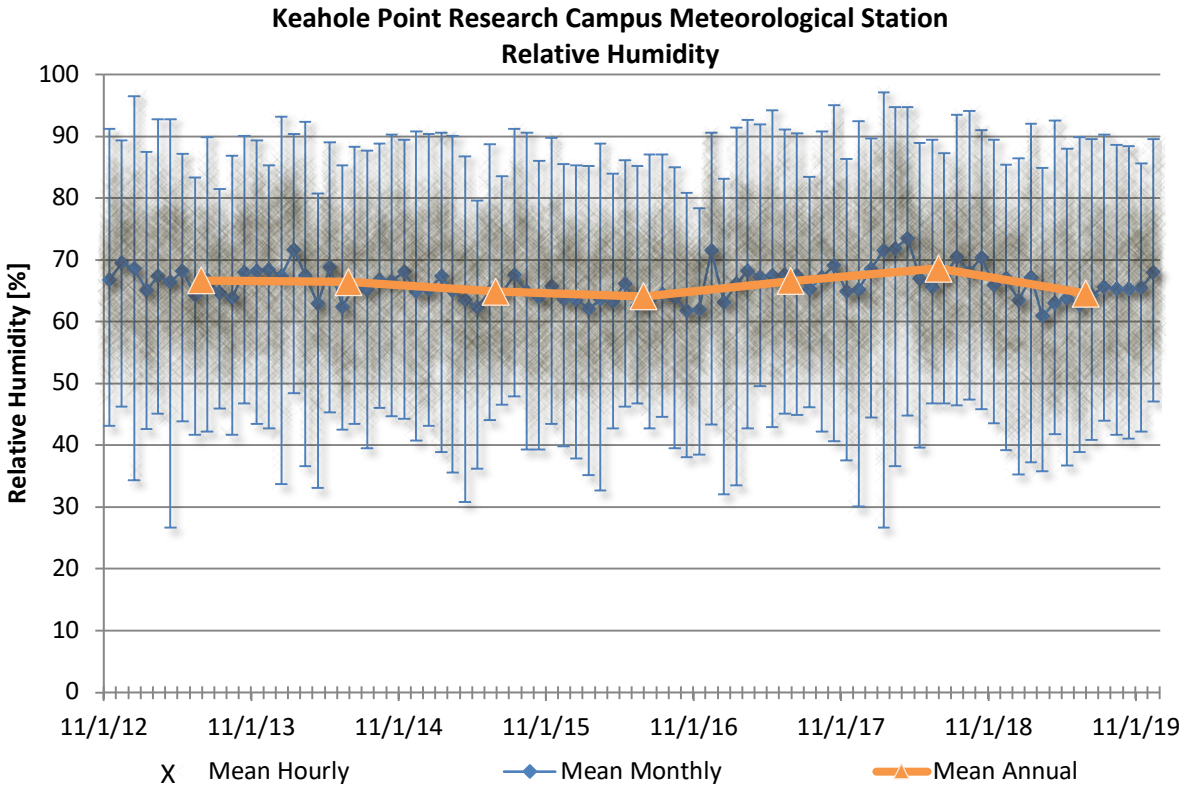


Figure 5b. *Historical relative humidity scatter plot*

	Mean Monthly Relative Humidity (%)												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
2012											66.8	69.5	**68.2**
2013	68.6	65.1	67.4	66.4	68.2	64.3	66.7	64.7	63.8	68.0	68.2	68.4	**66.7**
2014	67.4	71.6	67.5	62.9	68.8	62.4	65.9	65.2	66.8	66.5	68.1	64.9	**66.4**
2015	65.2	67.3	65.0	63.5	62.3	64.8	64.6	67.6	64.9	64.0	65.7	63.6	**64.9**
2016	63.6	62.1	63.6	63.2	66.2	62.6	63.5	64.5	63.9	61.8	62.0	71.5	***64.1***
2017	63.1	66.1	68.2	67.2	67.4	67.6	67.4	65.3	67.2	69.1	64.9	65.2	**66.6**
2018	68.5	71.5	71.9	***73.5***	67.0	65.6	67.4	70.5	68.0	70.4	65.9	67.0	***68.6***
2019	63.5	67.2	***61.0***	63.1	63.8	62.8	64.3	65.6	65.3	65.3	65.5	68.0	**64.6**
Mean	**65.7**	***67.3***	**66.4**	**65.7**	**66.3**	***64.3***	**65.7**	**66.2**	**65.7**	**66.5**	**65.9**	**67.3**	**66.3**

Figure 5c. *Historical monthly mean relative humidity table*

5.3. DEW POINT

Monthly mean dew point temperatures are reflected in the table below for the period of January 1, 2019 to December 31, 2019. Annual variations in mean hourly dew point temperatures showed a range from 6.0˚C (42.7˚F) to 26.7˚C (80.0˚F). Yearly mean dew point temperature during this period was 19.2˚C (66.6˚F)

Mean Monthly Max/Min Hourly	Jan. 2019	Feb. 2019	Mar. 2019	Apr. 2019	May 2019	Jun. 2019	Jul. 2019	Aug. 2019	Sep. 2019	Oct. 2019	Nov. 2019	Dec. 2019
Mean Dew Point (˚C)	16.6	16.9	*16.1*	18.3	19.3	20.1	20.9	***21.5***	21.4	20.4	19.9	19.1
Max Dew Point (˚C)	20.9	***26.7***	21.6	21.0	22.2	23.4	23.7	24.2	24.1	24.4	22.5	22.8
Min Dew Point (˚C)	*6.0*	7.0	10.9	12.1	11.0	14.7	15.3	16.0	15.3	14.5	14.3	15.7
Mean Dew Point (˚F)	61.9	62.3	*61.0*	64.9	66.7	68.1	69.7	***70.7***	70.5	68.7	67.8	66.3
Max Dew Point (˚F)	69.6	***80.0***	70.8	69.8	72.0	74.2	74.6	75.5	75.4	76.0	72.4	73.0
Min Dew Point (˚F)	*42.7*	44.7	51.5	53.8	51.8	58.4	59.5	60.9	59.5	58.1	57.7	60.3

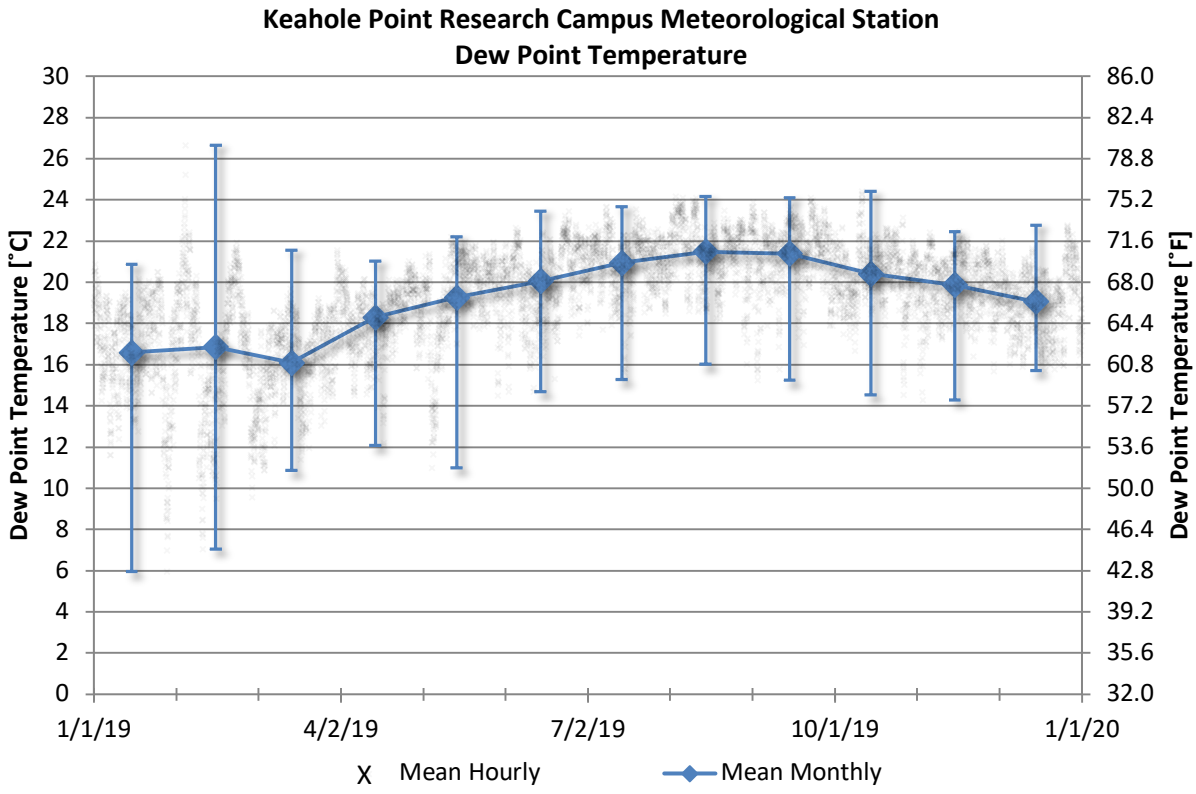


Figure 6a. *Monthly dew point temperature result table and scatter plot*

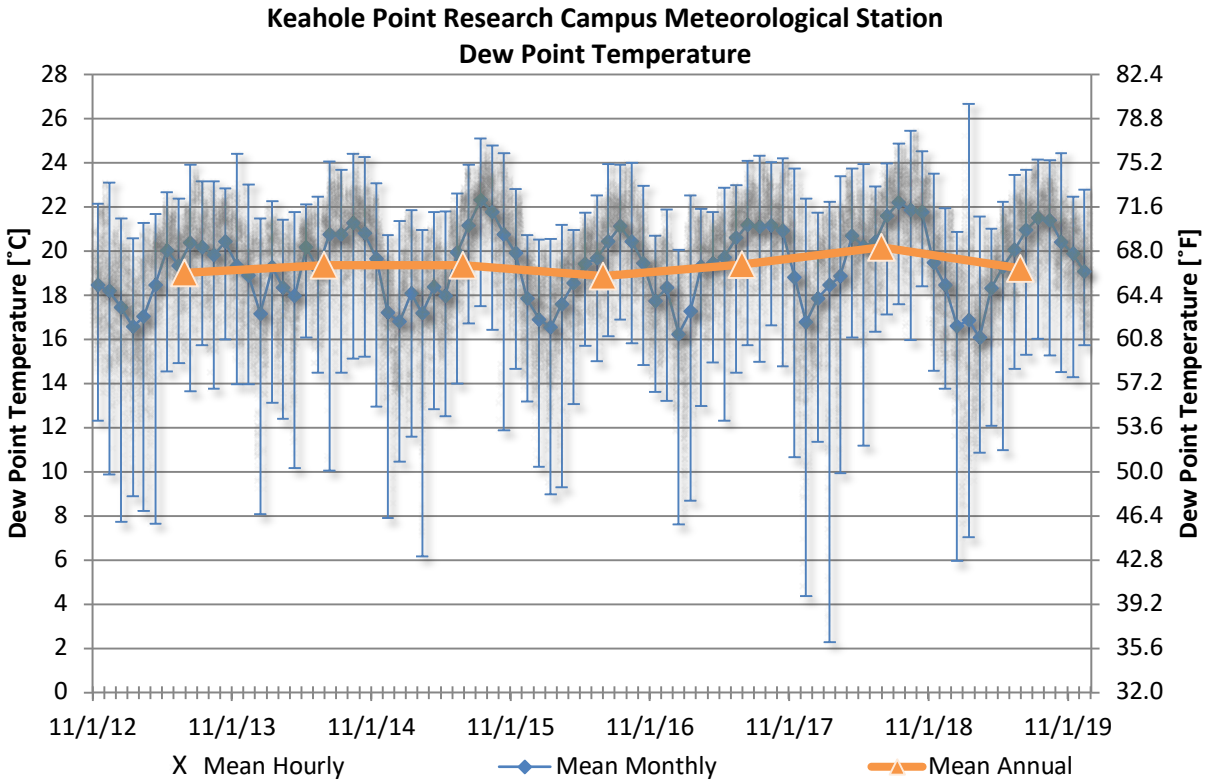


Figure 6b. *Historical dew point temperature scatter plot*

	Mean Monthly Dew Point Temperature (˚C)												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
2012											18.4	18.2	**18.3**
2013	17.4	16.6	17.0	18.5	20.0	19.3	20.4	20.2	19.8	20.4	19.3	18.9	**19.0**
2014	17.2	19.3	18.3	18.0	20.2	19.2	20.8	20.8	21.3	20.8	19.6	17.2	**19.4**
2015	16.8	18.1	17.2	18.4	18.0	19.9	21.2	***22.3***	21.8	20.8	19.9	17.8	**19.3**
2016	16.9	16.5	17.6	18.6	19.4	19.7	20.4	21.1	20.4	19.4	17.7	18.3	***18.9***
2017	16.2	17.3	19.3	19.5	19.7	20.6	21.2	21.1	21.2	20.9	18.8	16.8	**19.4**
2018	17.9	18.5	18.9	20.7	20.2	20.4	21.6	22.2	21.9	21.8	19.5	18.4	***20.2***
2019	16.6	16.9	***16.1***	18.3	19.3	20.1	20.9	21.5	21.4	20.4	19.9	19.1	**19.2**
Mean	***17.0***	**17.6**	**17.8**	**18.8**	**19.5**	**19.9**	**20.9**	***21.3***	**21.1**	**20.6**	**19.2**	**18.1**	**19.2**

	Mean Monthly Dew Point Temperature (˚F)												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
2012											65.2	64.7	**64.9**
2013	63.4	61.8	62.7	65.2	68.1	66.8	68.7	68.3	67.7	68.8	66.8	66.0	**66.2**
2014	62.9	66.7	65.0	64.3	68.3	66.5	69.4	69.4	70.3	69.4	67.3	63.0	**66.9**
2015	62.3	64.6	62.9	65.1	64.4	67.9	70.1	***72.2***	71.2	69.4	67.8	64.1	**66.8**
2016	62.4	61.8	63.7	65.4	67.0	67.4	68.8	70.0	68.8	67.0	63.9	65.0	***66.0***
2017	61.2	63.1	66.7	67.0	67.5	69.1	70.1	70.0	70.1	69.7	65.9	62.2	**66.9**
2018	64.2	65.2	65.9	69.2	68.4	68.8	70.8	72.0	71.4	71.2	67.1	65.2	***68.3***
2019	61.9	62.4	***60.9***	64.9	66.7	68.1	69.7	70.7	70.5	68.7	67.8	66.3	**66.6**
Mean	***62.6***	**63.6**	**64.0**	**65.9**	**67.2**	**67.8**	**69.7**	***70.4***	**70.0**	**69.2**	**66.5**	**64.6**	**66.6**

Figure 6c. *Historical mean monthly dew point temperature table (˚C & ˚F)*

5.4. BAROMETRIC PRESSSURE

Monthly mean barometric pressure recorded during the period of January 2019 to December 2019 was consistent through the seasonal cycle with slightly elevated recorded results in the month of March and April. A one-time minimum mean hourly recording was made on February 10, 2019 at 1006.3 mBar (29.72 in. of Hg). Annual variation in mean hourly barometric pressure ranged from 1006.3 to 1020.8 mBar (29.72 to 30.14 in. of Hg). The yearly mean barometric pressure during this period was 1014.2 mBar (29.95 in. of Hg).

Mean Monthly Max/Min Hourly	Jan. 2019	Feb. 2019	Mar. 2019	Apr. 2019	May 2019	Jun. 2019	Jul. 2019	Aug. 2019	Sep. 2019	Oct. 2019	Nov. 2019	Dec. 2019
Mean Barometric Pressure (mBar)	1014.9	***1012.4***	1016.2	***1016.5***	1015.0	1014.3	1014.1	1013.7	1013.2	1012.8	1013.1	1014.2
Max Barometric Pressure (mBar)	1020.3	1017.4	***1020.8***	1020.7	1018.3	1017.8	1016.9	1017.0	1017.1	1017.4	1016.2	1020.1
Min Barometric Pressure (mBar)	1007.4	***1006.3***	1010.9	1012.1	1006.6	1009.8	1011.3	1010.0	1009.6	1008.1	1008.9	1007.6
Mean Barometric Pressure (in. of Hg)	29.97	***29.90***	30.01	***30.02***	29.97	29.95	29.95	29.94	29.92	29.91	29.92	29.95
Max Barometric Pressure (in. of Hg)	30.13	30.04	***30.14***	30.14	30.07	30.06	30.03	30.03	30.04	30.04	30.01	30.12
Min Barometric Pressure (in. of Hg)	29.75	***29.72***	29.85	29.89	29.73	29.82	29.87	29.83	29.81	29.77	29.79	29.76

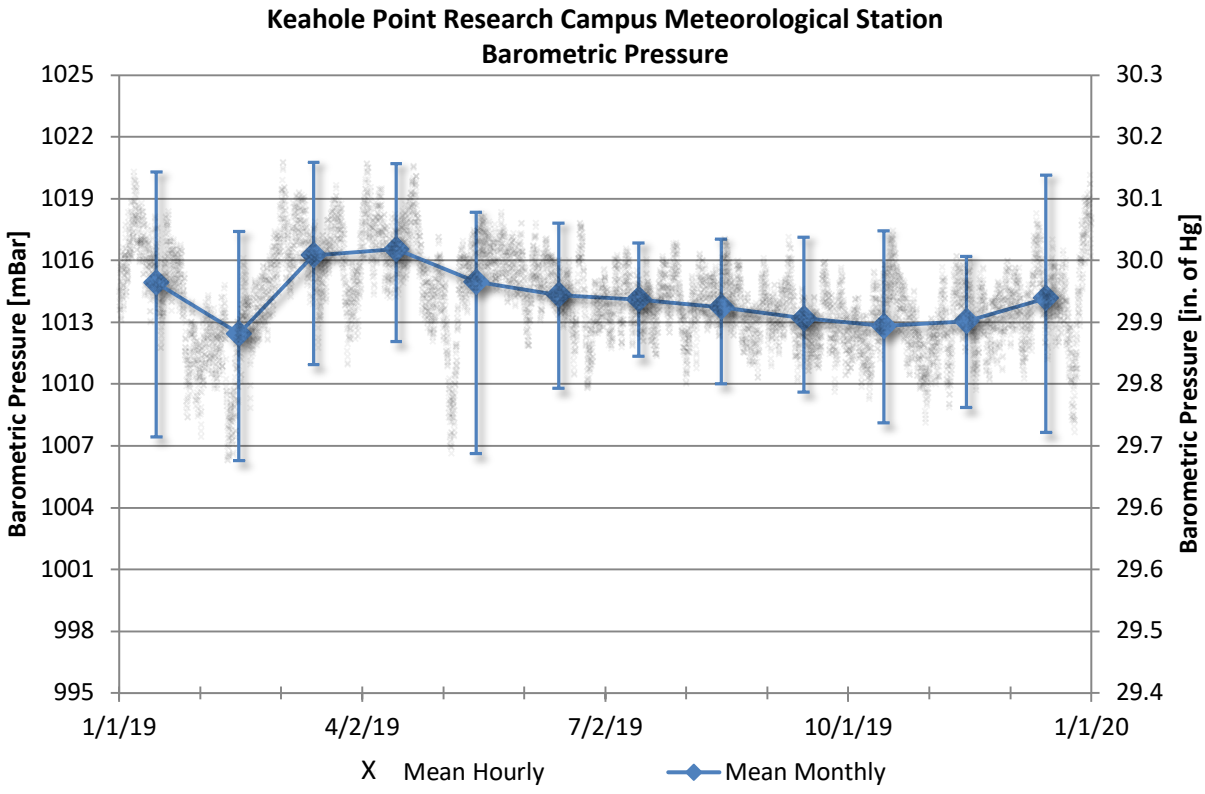


Figure 7a. *Monthly barometric pressure result table and scatter plot*

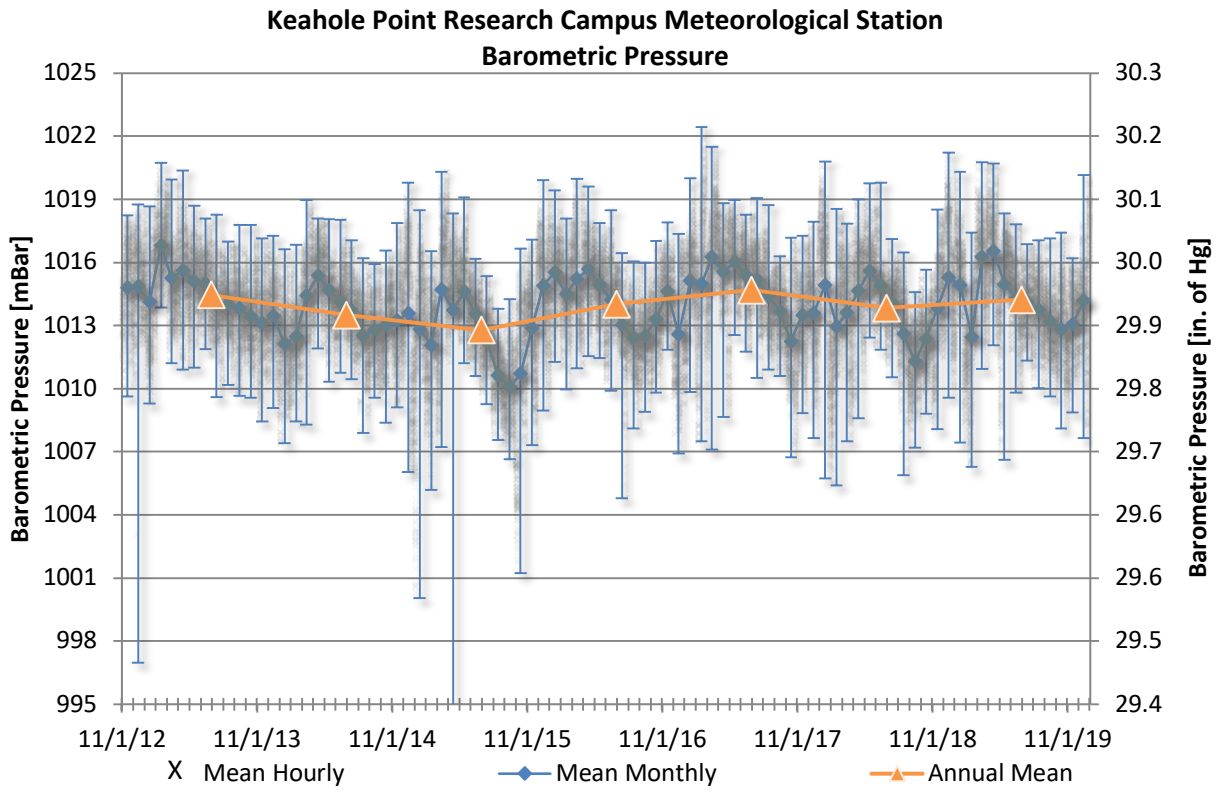


Figure 7b. *Historical barometric pressure scatter plot*

5.5. WIND SPEED

Monthly mean wind speed recordings in 2019 was relatively consistent through the seasonal cycle with a mean yearly wind speed of 2.53 m/s (5.66 mph). A maximum mean hourly wind speed was recorded on January 28, 2019 at 11.91 m/s (26.64 mph). Annual variation in mean hourly wind speed ranged from 0.03 to 11.91 m/s (0.07 to 26.64 mph).

Mean Monthly Max/Min Hourly	Jan. 2019	Feb. 2019	Mar. 2019	Apr. 2019	May 2019	Jun. 2019	Jul. 2019	Aug. 2019	Sep. 2019	Oct. 2019	Nov. 2019	Dec. 2019
Mean Wind Speed (m/s)	2.9	***3.2***	2.5	2.5	2.6	2.5	2.5	2.4	2.5	2.4	***2.2***	2.3
Max. Wind Speed (m/s)	***11.9***	10.2	9.3	7.4	7.6	6.3	7.0	7.7	6.7	6.6	7.1	8.8
Min. Wind Speed (m/s)	***0.0***	0.2	0.1	0.2	0.5	0.3	0.4	0.1	0.3	0.1	0.1	0.1
Mean Wind Speed (mph)	6.6	***7.1***	5.5	5.6	5.9	5.7	5.5	5.4	5.5	5.3	***4.9***	5.1
Max. Wind Speed (mph)	***26.6***	22.9	20.9	16.6	17.0	14.1	15.6	17.2	14.9	14.8	15.8	19.8
Min. Wind Speed (mph)	***0.1***	0.6	0.3	0.5	1.0	0.8	0.9	0.2	0.6	0.2	0.2	0.3

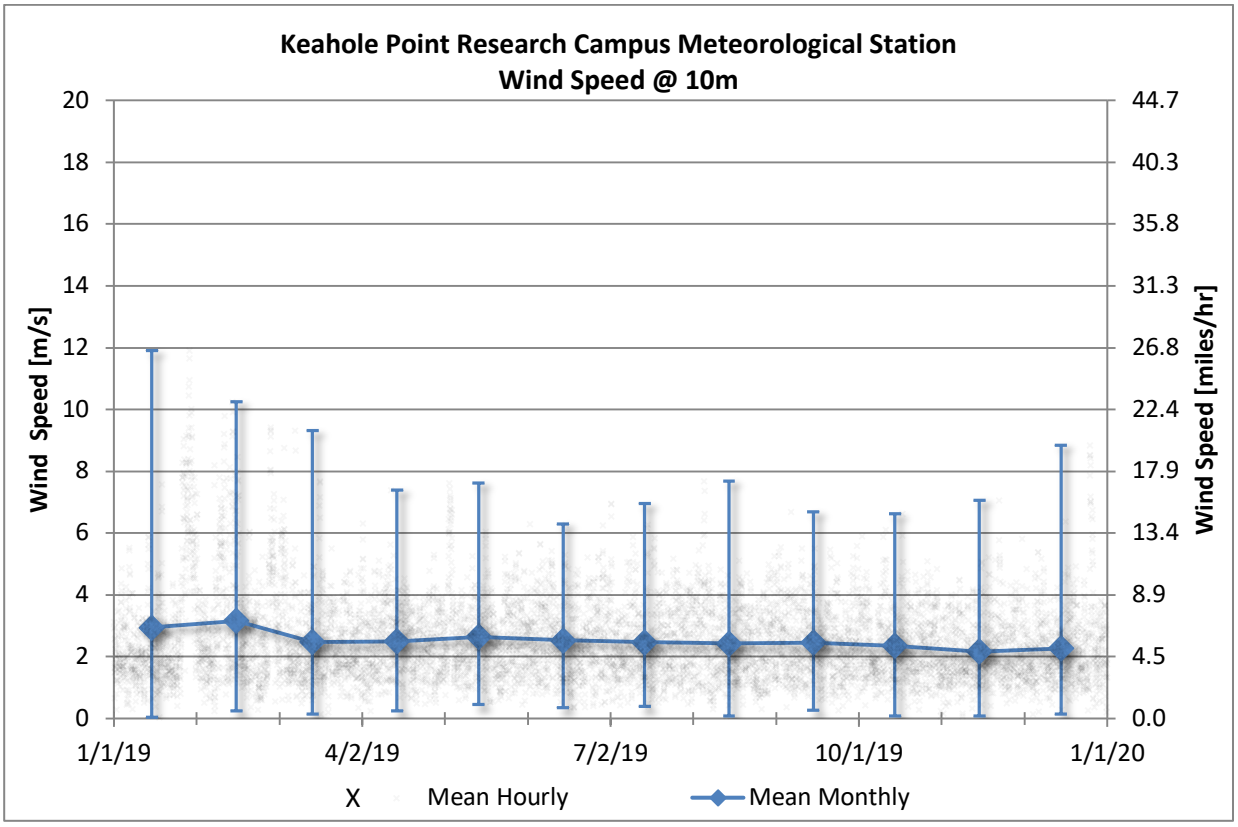


Figure 8a. *Monthly wind speed result table and scatter plot*

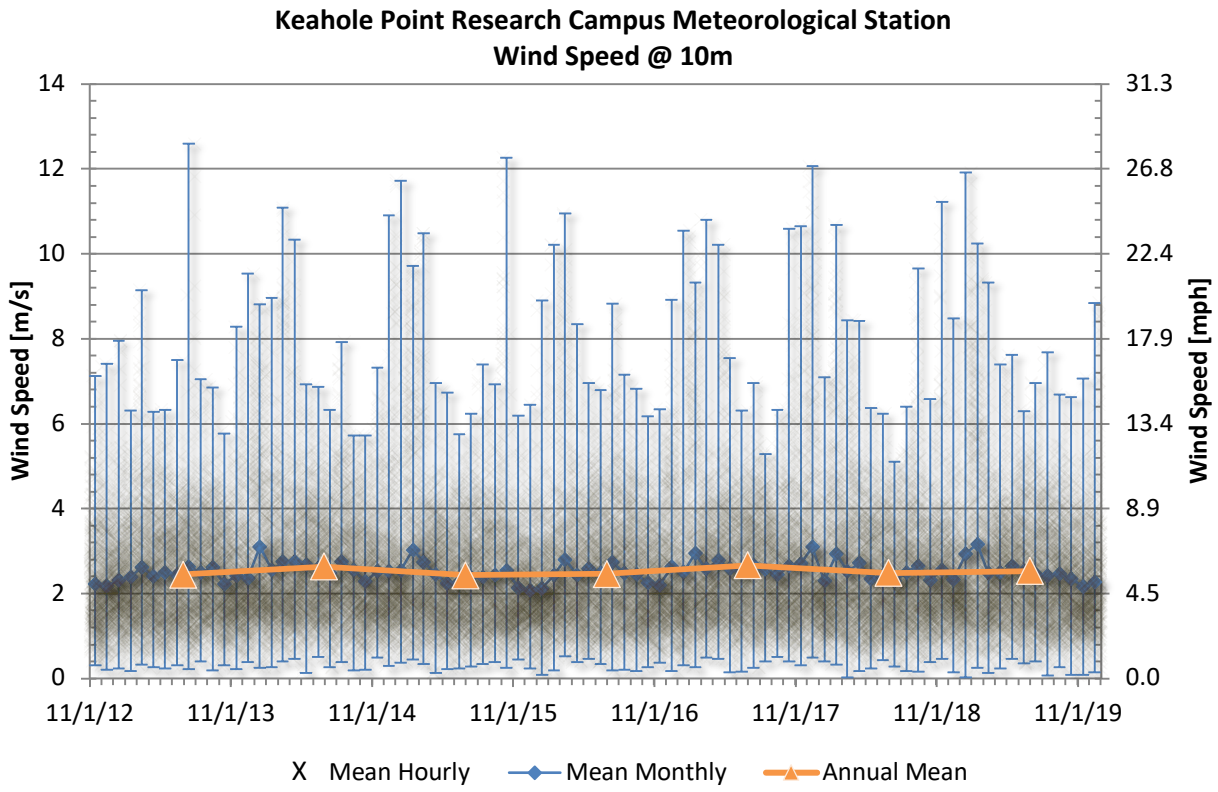


Figure 8b. *Historical wind speed scatter plot*

	Mean Monthly Wind Speed at 10m (m/s)												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Year**
2012											2.23	2.18	**2.21**
2013	2.32	2.39	2.62	2.40	2.49	2.44	2.62	2.50	2.61	2.23	2.42	2.42	**2.45**
2014	3.10	2.55	2.75	2.76	2.67	2.61	2.48	2.75	2.55	2.28	2.52	2.52	**2.64**
2015	2.54	3.02	2.74	2.45	2.23	2.28	2.38	2.39	2.44	2.54	2.14	2.14	***2.43***
2016	***2.13***	2.43	2.80	2.43	2.59	2.49	2.73	2.48	2.45	2.26	2.20	2.20	**2.46**
2017	2.51	2.95	2.58	2.78	2.59	2.53	2.66	2.57	2.44	2.65	2.70	2.70	***2.66***
2018	2.30	2.93	2.53	2.72	2.34	2.42	2.30	2.50	2.65	2.31	2.56	2.56	**2.49**
2019	2.94	***3.17***	2.48	2.50	2.64	2.53	2.47	2.42	2.46	2.35	2.17	2.17	**2.53**
Mean	**2.55**	***2.78***	**2.64**	**2.58**	**2.51**	**2.47**	**2.52**	**2.52**	**2.51**	**2.37**	***2.37***	**2.36**	**2.48**

	Mean Monthly Wind Speed at 10m (mph)												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Year**
2012											4.99	4.88	**4.95**
2013	5.18	5.34	5.86	5.37	5.57	5.45	5.87	5.59	5.84	4.98	5.41	5.41	**5.47**
2014	6.93	5.71	6.14	6.17	5.98	5.84	5.55	6.14	5.71	5.11	5.65	5.65	**5.90**
2015	5.69	6.76	6.13	5.49	4.99	5.09	5.33	5.34	5.45	5.67	4.78	4.78	***5.44***
2016	***4.76***	5.43	6.26	5.44	5.79	5.56	6.11	5.55	5.47	5.05	4.92	4.92	**5.51**
2017	5.61	6.59	5.78	6.21	5.79	5.65	5.95	5.75	5.47	5.92	6.04	6.04	***5.96***
2018	5.14	6.56	5.65	6.08	5.23	5.42	5.13	5.60	5.94	5.17	5.73	5.73	**5.56**
2019	6.58	***7.08***	5.55	5.59	5.91	5.66	5.51	5.42	5.50	5.26	4.85	4.85	**5.66**
Mean	**5.70**	***6.21***	**5.91**	**5.76**	**5.61**	**5.53**	**5.64**	**5.63**	**5.62**	**5.31**	***5.30***	**5.28**	**5.56**

Figure 8c. *Historical mean monthly wind speed at 10m table (m/s & mph)*

5.6. PEAK WIND SPEED

Monthly peak wind speed recorded during 2019 was consistent through the seasonal cycle with a mean yearly peak wind speed of 3.3 m/s (7.39 mph). A mean peak hourly wind speed was recorded on January 28, 2019 at 15.2 m/s (33.9 mph). A mean peak one minute wind speed of 19.0 m/s (42.46 mph) was recorded on January 28 at 5:28pm. Annual variation in one minute peak wind speed ranged from 0.00 to 19.0 m/s (0.00 to 42.46 mph).

Mean Monthly Max/Min Minute	Jan. 2019	Feb. 2019	Mar. 2019	Apr. 2019	May 2019	Jun. 2019	Jul. 2019	Aug. 2019	Sep. 2019	Oct. 2019	Nov. 2019	Dec. 2019
Mean Peak Wind Speed (m/s)	3.8	***4.2***	3.3	3.3	3.4	3.3	3.2	3.1	3.3	3.0	***2.8***	2.9
Max. Peak Wind Speed (m/s)	***19.0***	18.1	16.3	13.1	11.5	11.0	12.0	10.6	14.3	12.1	12.0	14.5
Min. Peak Wind Speed (m/s)	0.78	***0.00***	1.14	***0.00***	1.41	1.14	1.31	0.85	1.14	1.18	0.75	1.18
Mean Peak Wind Speed (mph)	8.58	***9.41***	7.29	7.30	7.69	7.43	7.18	7.04	7.27	6.80	***6.30***	6.55
Max. Peak Wind Speed (mph)	***42.46***	40.40	36.40	29.24	25.72	24.70	26.82	23.67	31.94	27.04	26.75	32.44
Min. Peak Wind Speed (mph)	1.75	***0.00***	2.56	***0.00***	3.14	2.56	2.92	1.90	2.56	2.63	1.68	2.63

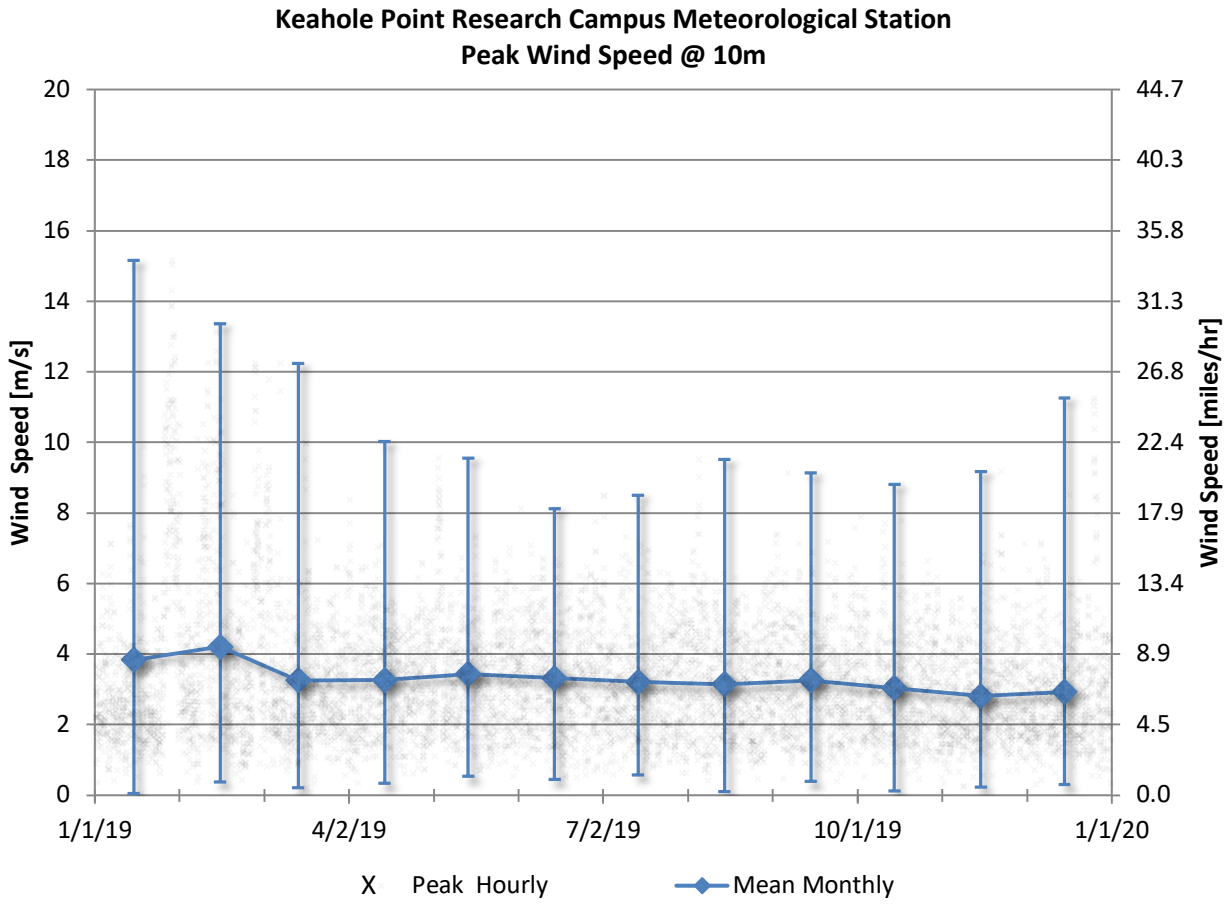


Figure 9a. *Monthly peak wind speed result table and scatter plot*

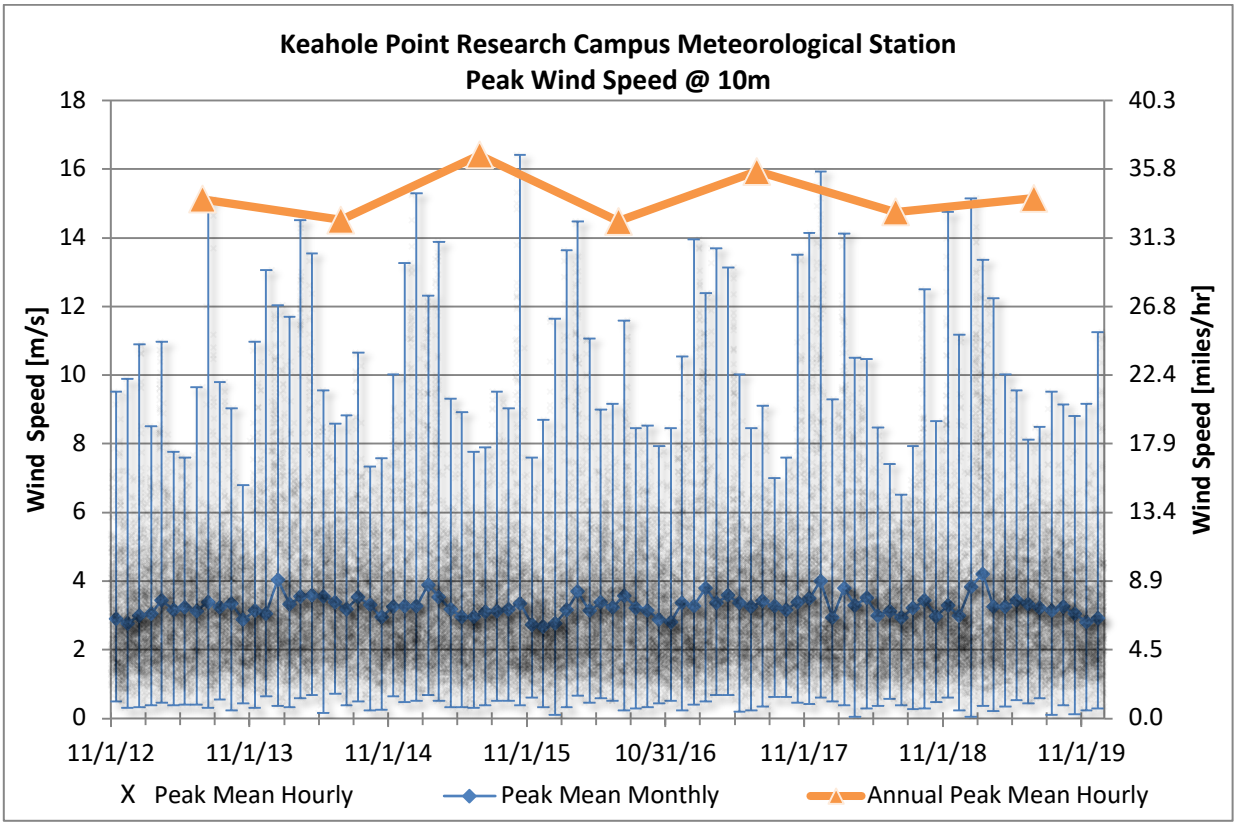


Figure 9b. *Historical monthly peak wind speed scatter plot*

	Monthly Peak Mean Hourly Wind Speed at 10m (m/s)												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Year**
2012											9.51	9.90	**9.90**
2013	10.89	8.51	10.97	7.77	7.61	9.66	15.13	9.81	9.03	6.80	10.98	10.98	**15.13**
2014	12.03	11.70	14.51	13.54	9.56	8.58	8.83	10.65	7.33	7.59	10.03	10.03	**14.51**
2015	15.30	12.31	13.88	9.31	8.92	7.77	7.89	9.51	9.03	***16.41***	7.61	7.61	***16.41***
2016	11.64	13.63	14.48	11.07	9.00	9.16	11.59	8.46	8.53	7.92	8.45	8.45	**14.48**
2017	13.96	12.38	13.70	13.14	10.02	8.45	9.10	7.01	7.59	13.50	14.15	14.15	**15.93**
2018	9.30	14.13	10.51	10.46	8.47	7.40	***6.52***	7.94	12.49	8.65	14.75	14.75	**14.75**
2019	15.16	13.36	12.25	10.03	9.56	8.12	8.50	9.52	9.14	8.82	9.17	9.17	**15.16**
Mean	***12.61***	**12.29**	**12.90**	**10.76**	**9.02**	***8.45***	**9.65**	**8.98**	**9.02**	**9.96**	**10.58**	**10.63**	**14.53**

	Monthly Peak Mean Hourly Wind Speed at 10m (mph)												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Year**
2012											21.27	22.14	**22.14**
2013	24.37	19.03	24.54	17.37	17.01	21.60	33.84	21.94	20.21	15.22	24.56	24.56	**33.84**
2014	26.92	26.17	32.47	30.28	21.38	19.20	19.75	23.83	16.39	16.98	22.43	22.43	**32.47**
2015	34.21	27.55	31.05	20.82	19.95	17.37	17.65	21.28	20.20	***36.71***	17.01	17.01	***36.71***
2016	26.03	30.49	32.40	24.77	20.13	20.49	25.92	18.91	19.08	17.73	18.91	18.91	**32.40**
2017	31.22	27.69	30.65	29.40	22.42	18.91	20.36	15.67	16.99	30.20	31.65	31.65	**35.64**
2018	20.80	31.60	23.52	23.40	18.95	16.56	***14.58***	17.76	27.94	19.36	32.99	32.99	**32.99**
2019	33.90	29.88	27.40	22.44	21.38	18.16	19.02	21.29	20.45	19.73	20.51	20.51	**33.90**
Mean	***28.21***	**27.49**	**28.86**	**24.07**	**20.17**	***18.90***	**21.59**	**20.10**	**20.18**	**22.27**	**23.67**	**23.78**	**32.51**

Figure 9c. *Historical monthly peak wind speed at 10m table (m/s & mph)*

5.7. WIND DIRECTION

Wind direction recorded during 2019 was consistent with historical measurements through the daily cycle. The mean yearly wind direction is 172.9˚ from the north. Wind direction at Keahole Point exhibits a typical land-sea directional profile and has two distinct bearings averaging at 221.3° from the north in the daytime hours (8 am – 8 pm) and 124.1° from the north during the nighttime hours (8 pm – 8 am).

Monthly	Jan. 2019	Feb. 2019	Mar. 2019	Apr. 2019	May 2019	Jun. 2019	Jul. 2019	Aug. 2019	Sep. 2019	Oct. 2019	Nov. 2019	Dec. 2019
Mean Wind Direction (° from north)	161.0	174.1	166.9	174.9	188.6	189.3	177.2	181.6	175.0	162.8	169.0	154.6
Day Wind Direction (° from north)	98.8	112.3	112.1	132.2	147.7	148.6	137.0	143.5	137.1	122.4	125.9	109.3
Night Wind Direction (° from north)	222.9	236.8	220.9	218.2	229.4	230.1	217.4	219.6	212.8	203.5	212.2	199.6

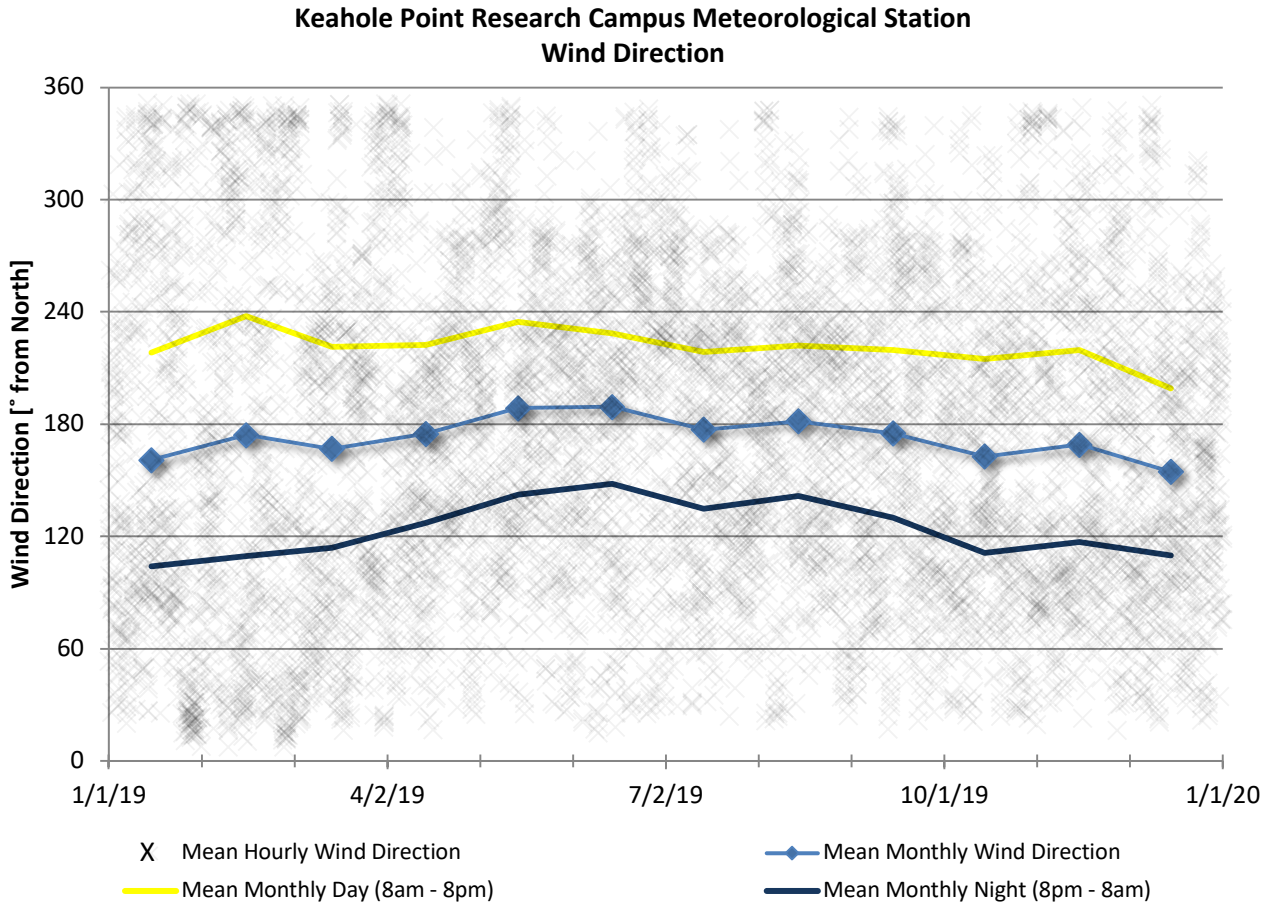


Figure 10. *Monthly wind direction results table and scatter plot*

5.8. ACCUMULATED PRECIPATATION

Yearly accumulated precipitation recorded during 2019 was 447.25 mm (17.6 in.). Seven precipitation events were greater than 12.7 mm (> 0.5 in.) and accounted for 49% of the accumulated precipitation for the year. Four precipitation events recorded a daily accumulation that was greater than 25.4 mm (> 1 in.) and accounted for 36% of the accumulated precipitation for the year. Between April 26 - 28, 2019, 28% of the annual precipitation was recorded, accumulating 124.0 mm (4.88 in.) during the three day period.

Monthly	Jan. 2019	Feb. 2019	Mar. 2019	Apr. 2019	May 2019	Jun. 2019	Jul. 2019	Aug. 2019	Sep. 2019	Oct. 2019	Nov. 2019	Dec. 2019
Accumulated Precipitation (mm)	1.3	58.0	21.8	130.8	29.3	43.8	27.3	48.8	26.8	24.0	3.0	32.8
Accumulated Precipitation (in.)	0.0	2.3	0.9	5.1	1.2	1.7	1.1	1.9	1.1	0.9	0.1	1.3
%	0%	13%	5%	29%	7%	10%	6%	11%	6%	5%	1%	7%

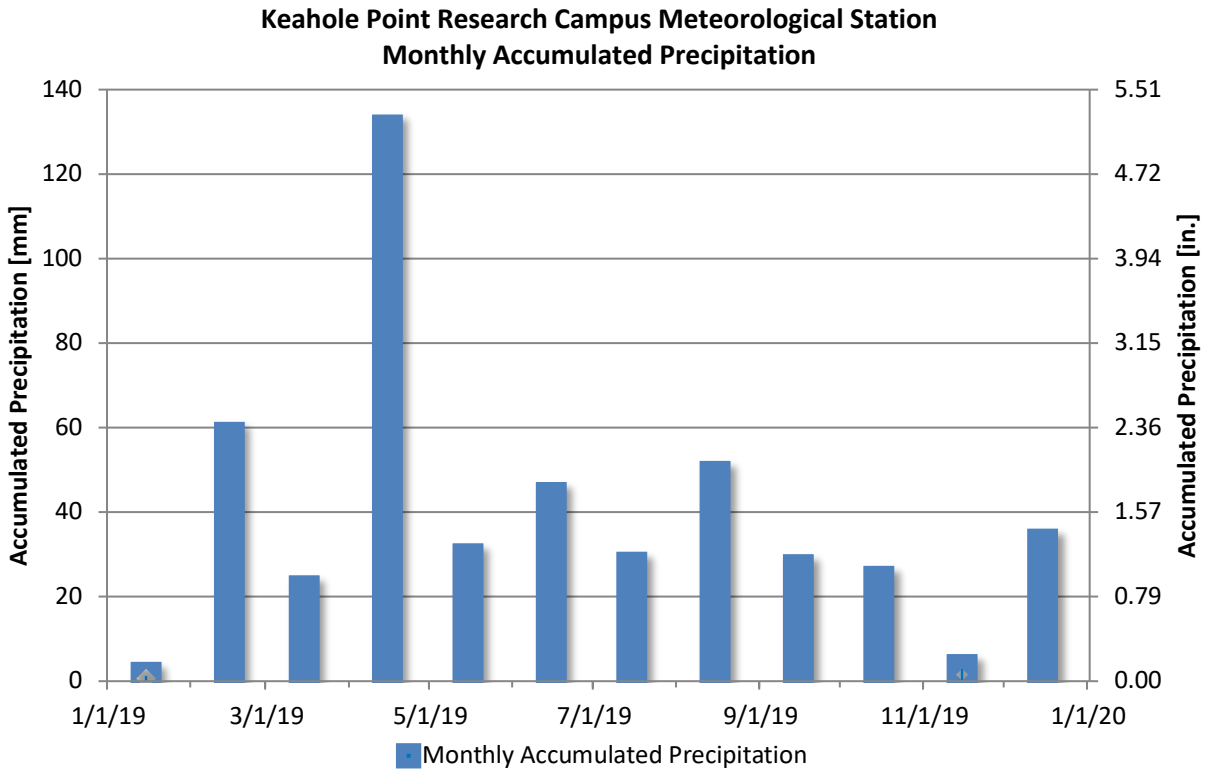


Figure 11a. *Monthly accumulated precipitation table and bar chart*

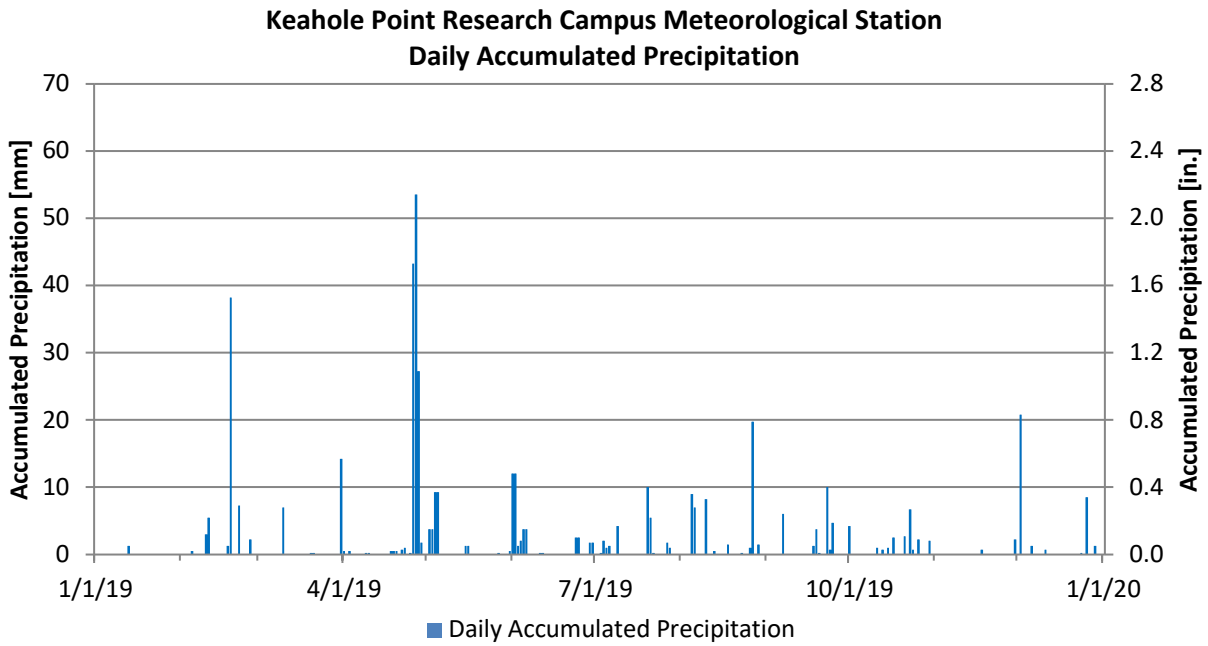


Figure 11b. *Daily accumulated precipitation bar chart*

	Total Monthly Precipitation [mm]												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Year**
2012											4.4	***0.0***	**4.4**
2013	47.6	3.0	20.0	9.1	14.9	1.0	9.5	0.3	8.5	21.3	36.3	7.5	***178.8***
2014	93.1	41.8	96.1	***0.0***	23.0	2.5	5.5	10.7	32.5	38.7	37.1	25.0	**405.9**
2015	41.0	35.8	31.3	33.5	0.3	36.0	1.8	65.3	45.5	4.0	6.0	2.0	**302.3**
2016	3.8	9.5	45.5	2.3	20.8	7.5	9.0	34.3	11.5	1.8	***0.0***	***137.8***	**283.5**
2017	***0.0***	38.5	18.5	33.0	72.8	17.3	26.8	3.3	48.5	74.0	4.5	20.3	**357.3**
2018	2.0	129.8	39.0	22.5	2.5	3.0	18.5	37.5	42.3	30.5	41.8	0.3	**369.5**
2019	1.3	58.0	21.8	130.8	29.3	43.8	27.3	48.8	26.8	24.0	3.0	32.8	***447.3***
Mean	**27.0**	***45.2***	**38.9**	**33.0**	**23.3**	**15.9**	***14.0***	**28.6**	**30.8**	**27.7**	**18.4**	**32.2**	**334.9**

	Total Monthly Precipitation [in.]												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Year**
2012											0.17	***0.00***	**0.17**
2013	1.87	0.12	0.79	0.36	0.59	0.04	0.37	0.01	0.33	0.84	1.43	0.30	***7.04***
2014	3.67	1.64	3.78	***0.00***	0.90	0.10	0.22	0.42	1.28	1.52	1.46	0.98	**15.98**
2015	1.61	1.41	1.23	1.32	0.01	1.42	0.07	2.57	1.79	0.16	0.24	0.08	**11.90**
2016	0.15	0.37	1.79	0.09	0.82	0.30	0.35	1.35	0.45	0.07	***0.00***	***5.42***	**11.16**
2017	***0.00***	1.52	0.73	1.30	2.86	0.68	1.05	0.13	1.91	2.91	0.18	0.80	**14.06**
2018	0.08	5.11	1.54	0.89	0.10	0.12	0.73	1.48	1.66	1.20	1.64	0.01	**14.55**
2019	0.05	2.28	0.86	5.15	1.15	1.72	1.07	1.92	1.05	0.94	0.12	1.29	***17.61***
Mean	**1.06**	***1.78***	**1.53**	**1.30**	**0.92**	**0.62**	**0.55**	**1.12**	**1.21**	**1.09**	**0.72**	**1.27**	**13.19**

Figure 11c. *Historical total monthly precipitation table (mm & in.)*

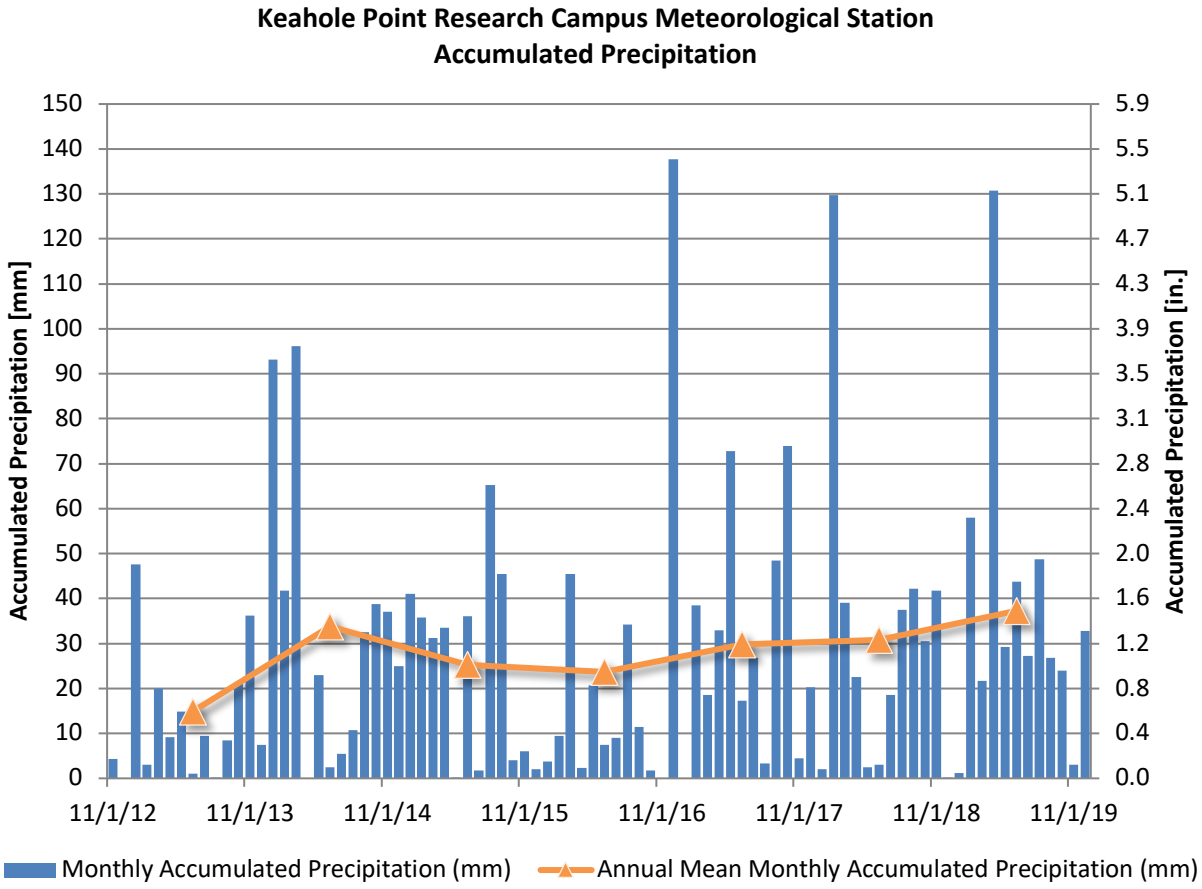


Figure 11d. *Monthly accumulated precipitation bar chart 11/1/2012 – 12/31/2019*

Keahole Point has received a mean annual rainfall of 334.9 mm (13.2 in.) and a mean monthly rainfall of 27.9 mm (1.10 in.) since January 1, 2013.

Mean Monthly 1/2013 – 12/2019	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Mean Accumulated Precipitation (mm)	27.0	45.2	38.9	33.0	23.3	15.9	14.0	28.6	30.8	27.7	18.4	32.2
Mean Accumulated Precipitation (in.)	1.06	1.78	1.53	1.30	0.92	0.62	0.55	1.12	1.21	1.09	0.72	1.27
%	8.0%	13.5%	11.6%	9.9%	7.0%	4.7%	4.2%	8.5%	9.2%	8.3%	5.5%	9.6%

Annual Precipitation	2013	2014	2015	2016	2017	2018	2019
Accumulated Precipitation (mm)	178.8	405.9	302.2	283.5	357.3	369.5	447.3
Accumulated Precipitation (in.)	7.04	15.97	11.90	11.16	14.06	14.55	17.61

Figure 11e. *Annual accumulated precipitation table 1/1/2013 – 12/31/2019*

5.9. GLOBAL HORIZONTAL IRRADIANCE

Yearly total global horizontal irradiance recorded during 2019 measured 2211 kW-hr/m^2. A monthly total maximum global horizontal irradiance was recorded in August 2019 at 211.6 kW-hr/m^2. A monthly total minimum global horizontal irradiance was recorded in December 2019 at 132.0 kW-hr/m^2. The mean daily total global horizontal irradiance in 2019 was 6.06 kW-hr/m^2.

Global Horizontal Irradiance	Jan. 2019	Feb. 2019	Mar. 2019	Apr. 2019	May 2019	Jun. 2019	Jul. 2019	Aug. 2019	Sep. 2019	Oct. 2019	Nov. 2019	Dec. 2019
Monthly Total (kW-hr/m^2)	152.3	141.4	195.4	212.4	230.1	213.8	210.0	211.6	187.3	174.0	150.9	132.0
Mean Daily Total (kW-hr/m^2)	4.91	5.05	6.30	7.08	7.42	7.13	6.78	6.83	6.24	5.61	5.03	4.26

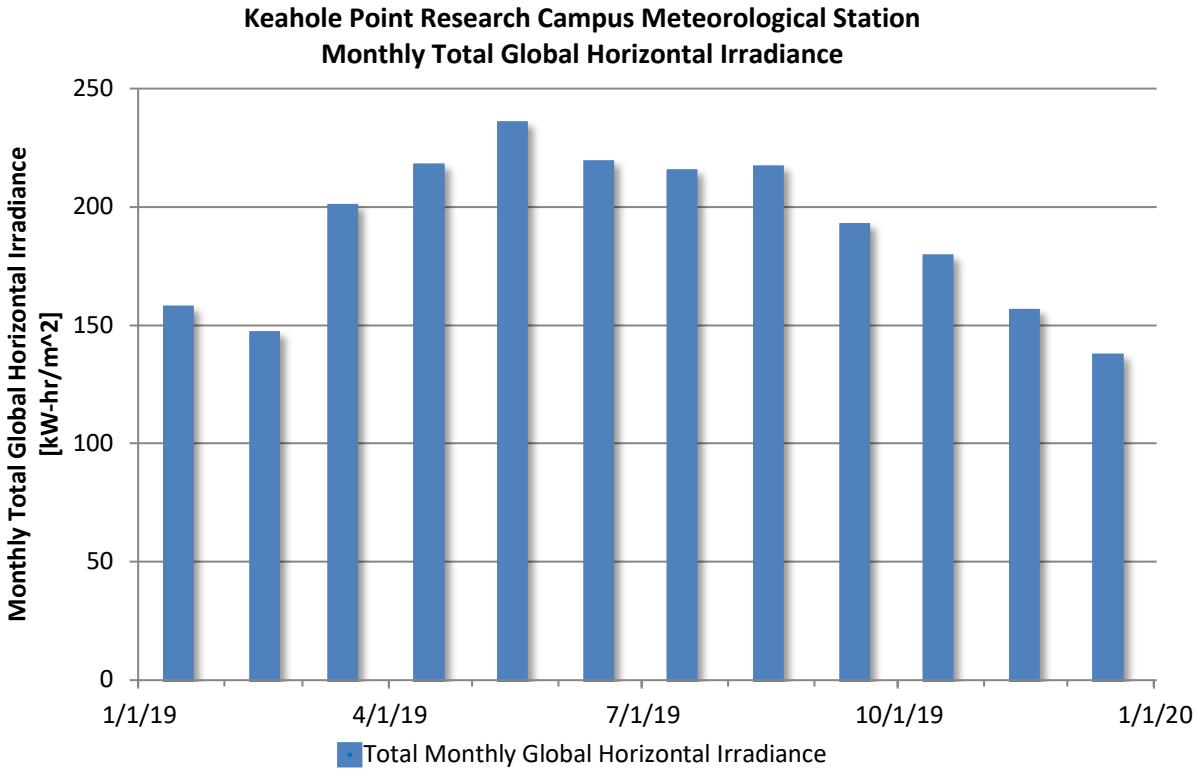
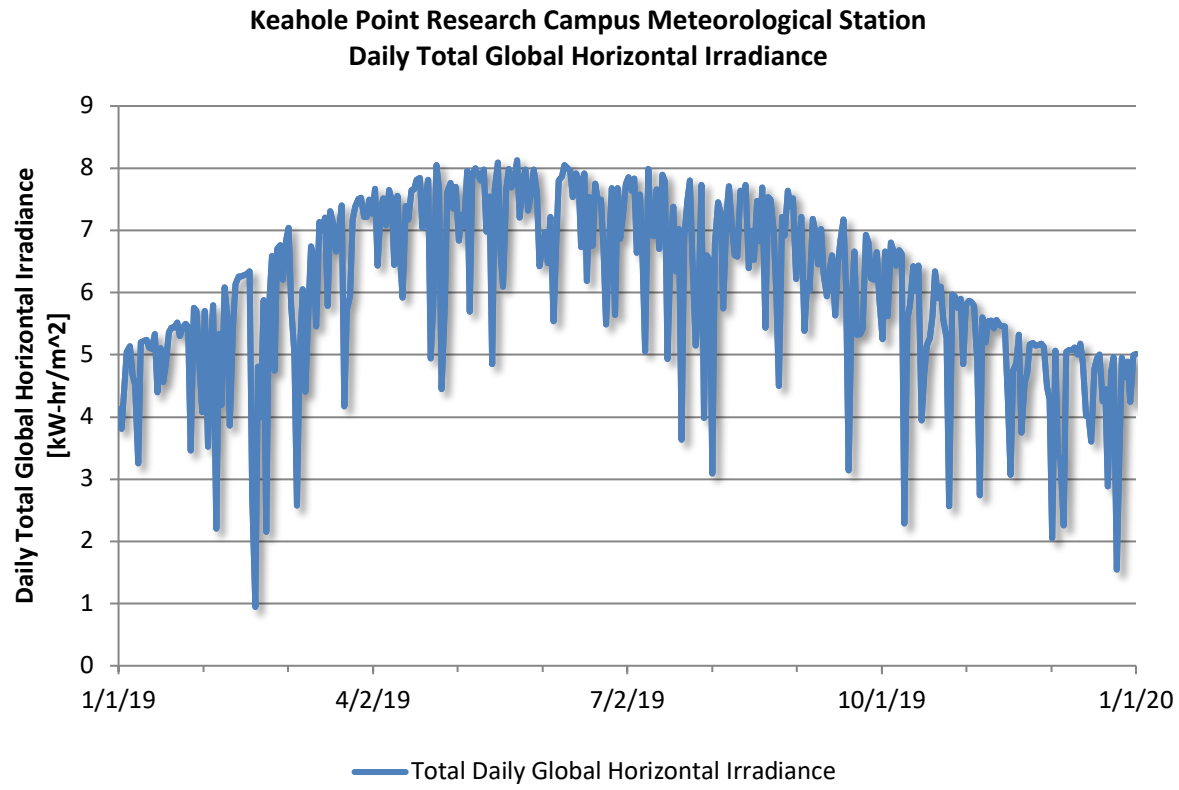


Figure 12a. *Monthly total global horizontal irradiance table and monthly bar chart*



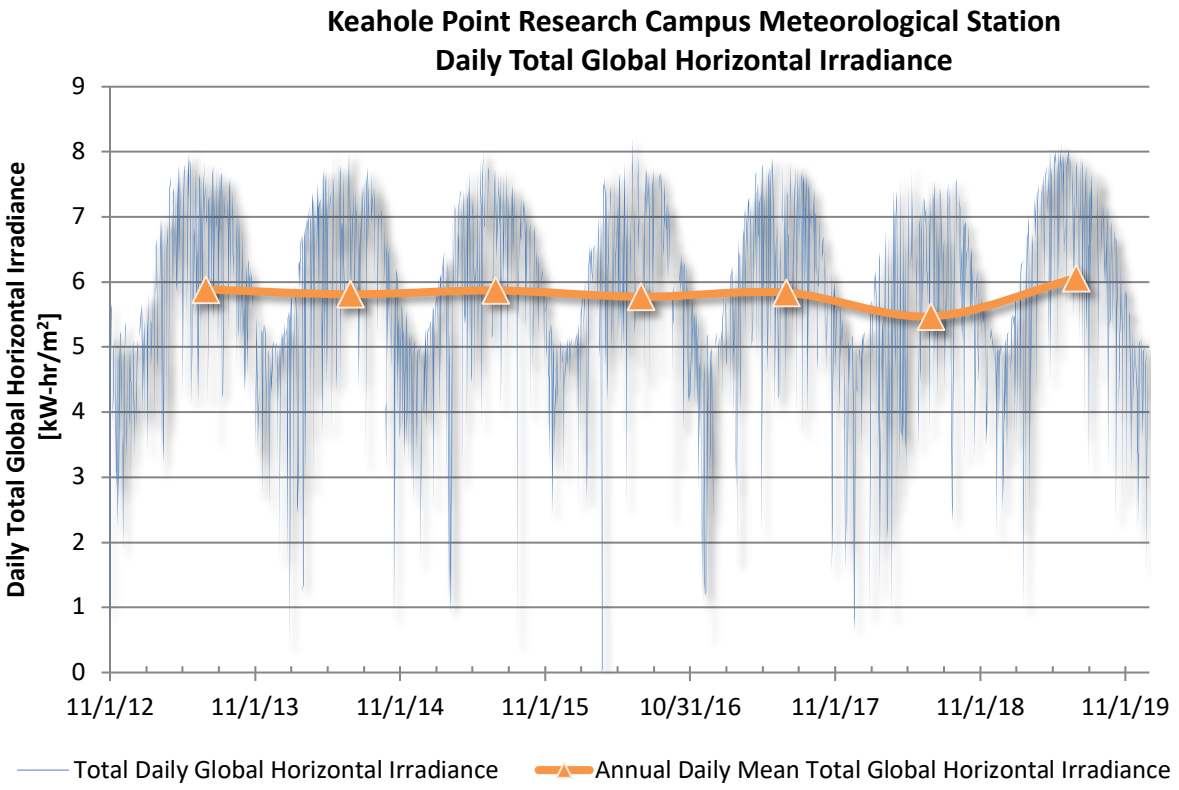


Figure 12b. *Annual and historical daily total global horizontal irradiance line chart*

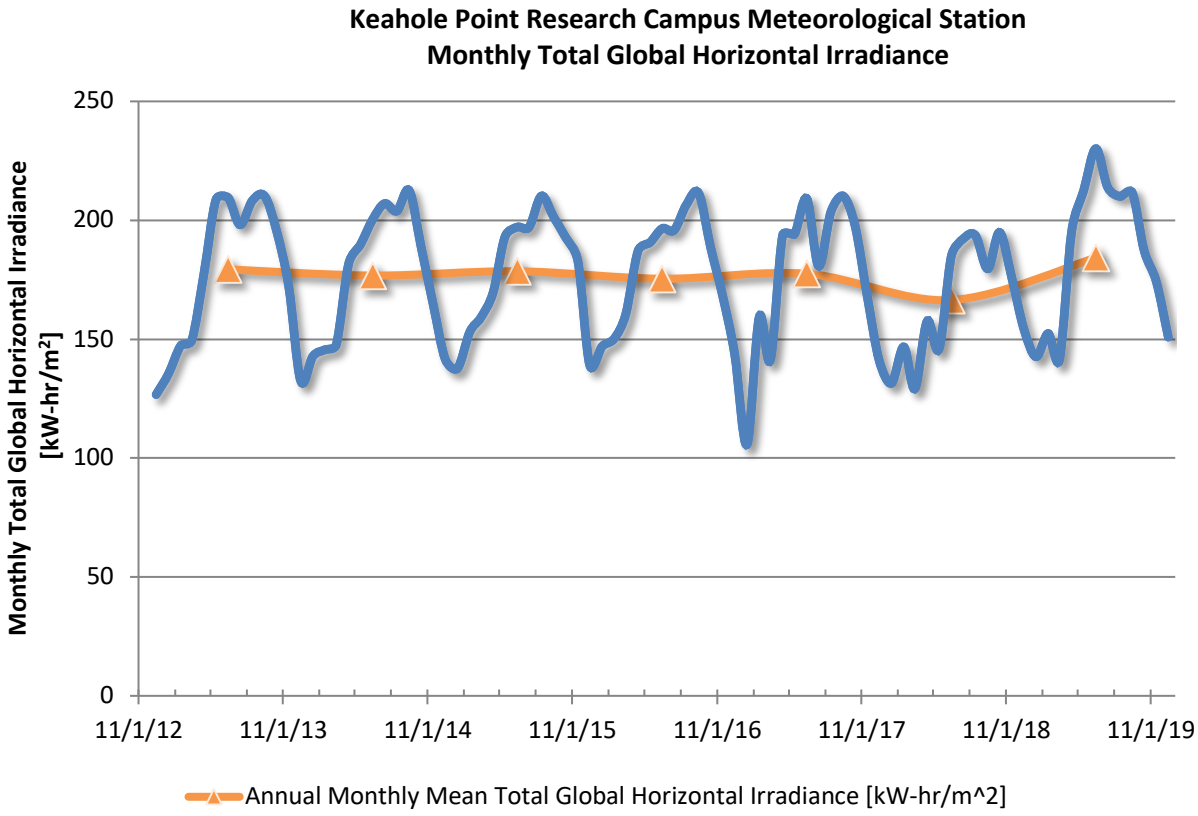


Figure 12c. *Historical monthly total global horizontal irradiance line chart*

5.10. PHOTOSYNTHETICALLY ACTIVE RADIATION

Photosynthetically active radiation (PAR) recorded annual total daily mean for 2019 of 12.13 mmol-hr/s/m^2. During this period a monthly total daily mean maximum was recorded in May 2019 of 12.9 mmol-hr/s/m^2. A monthly mean total daily minimum of 8.6 mmol-hr/s/m^2 was recorded in December 2019. The PAR sensor records a similar solar profile as the global horizontal sensor (285 – 2800nm) but measures photons in the visible light spectrum (400 – 700nm) where photosynthetic plants readily absorb the sun's energy.

Photosynthetically Active Radiation (mmol-hr/s/m^2)	Jan. 2019	Feb. 2019	Mar. 2019	Apr. 2019	May 2019	Jun. 2019	Jul. 2019	Aug. 2019	Sep. 2019	Oct. 2019	Nov. 2019	Dec. 2019
Total Monthly	305.6	294.0	398.8	428.8	458.7	425.6	418.0	417.6	371.0	344.4	300.4	266.3
Monthly Mean Total Daily	9.9	10.5	12.9	14.3	14.8	14.2	13.5	13.5	12.5	11.1	10.0	8.6

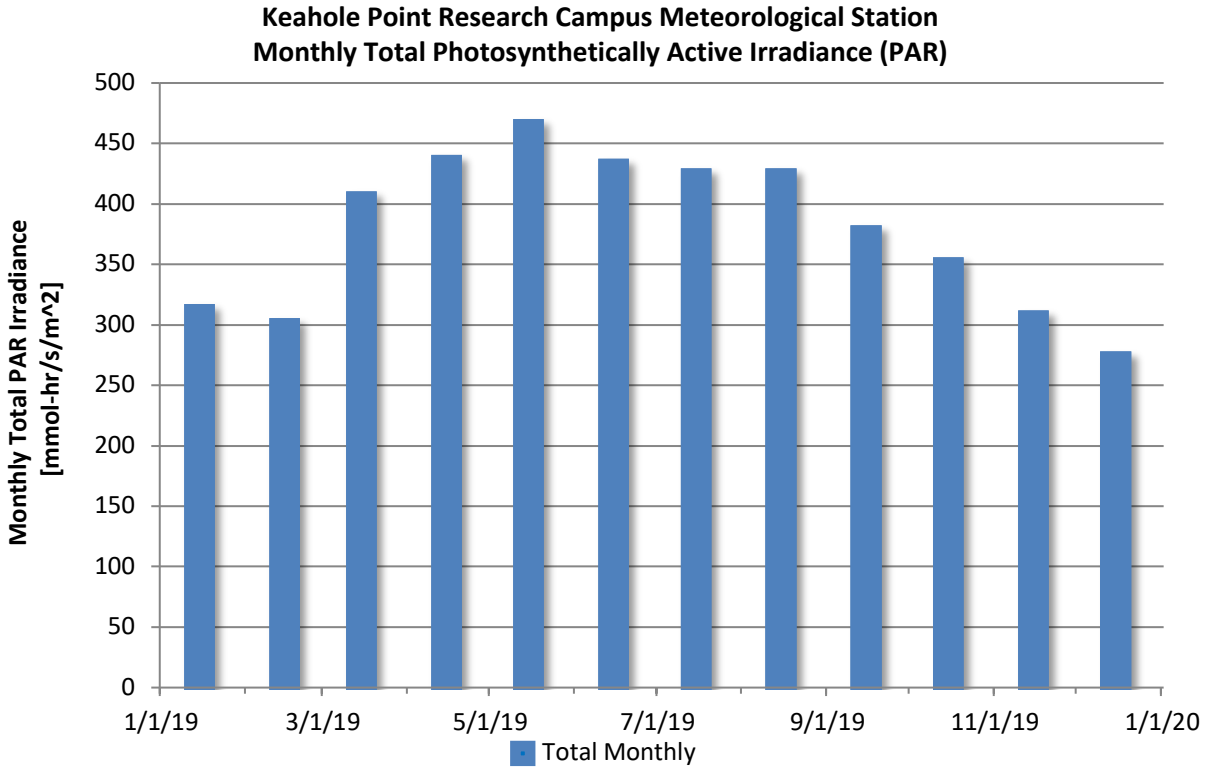
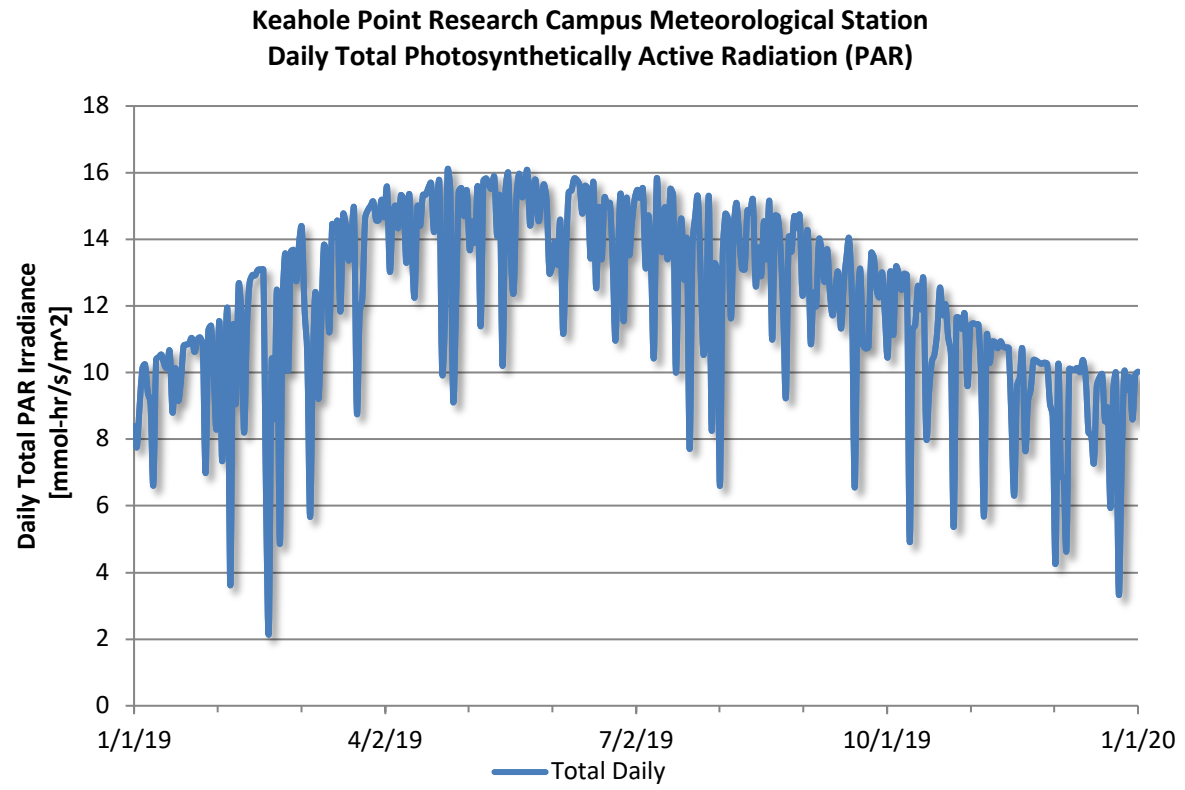


Figure 13a. *Monthly PAR table and bar chart*



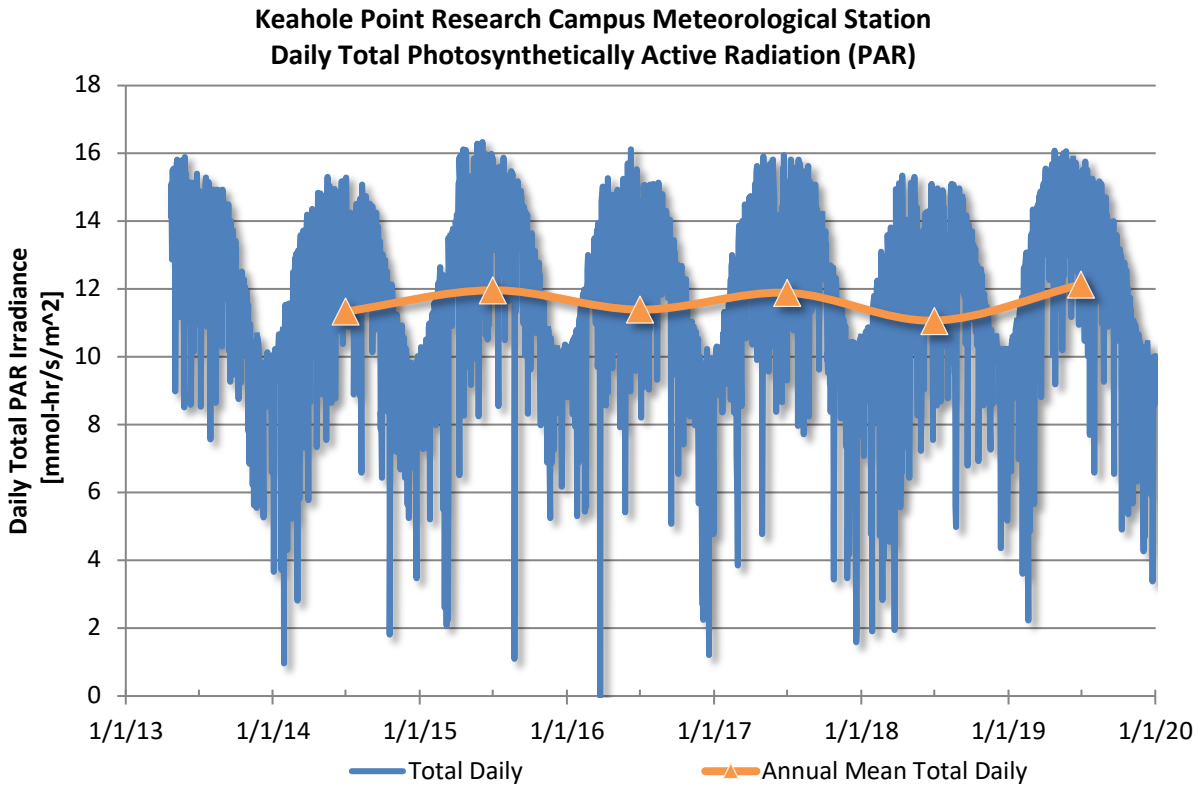


Figure 13b. *Daily annual and historical PAR line charts*

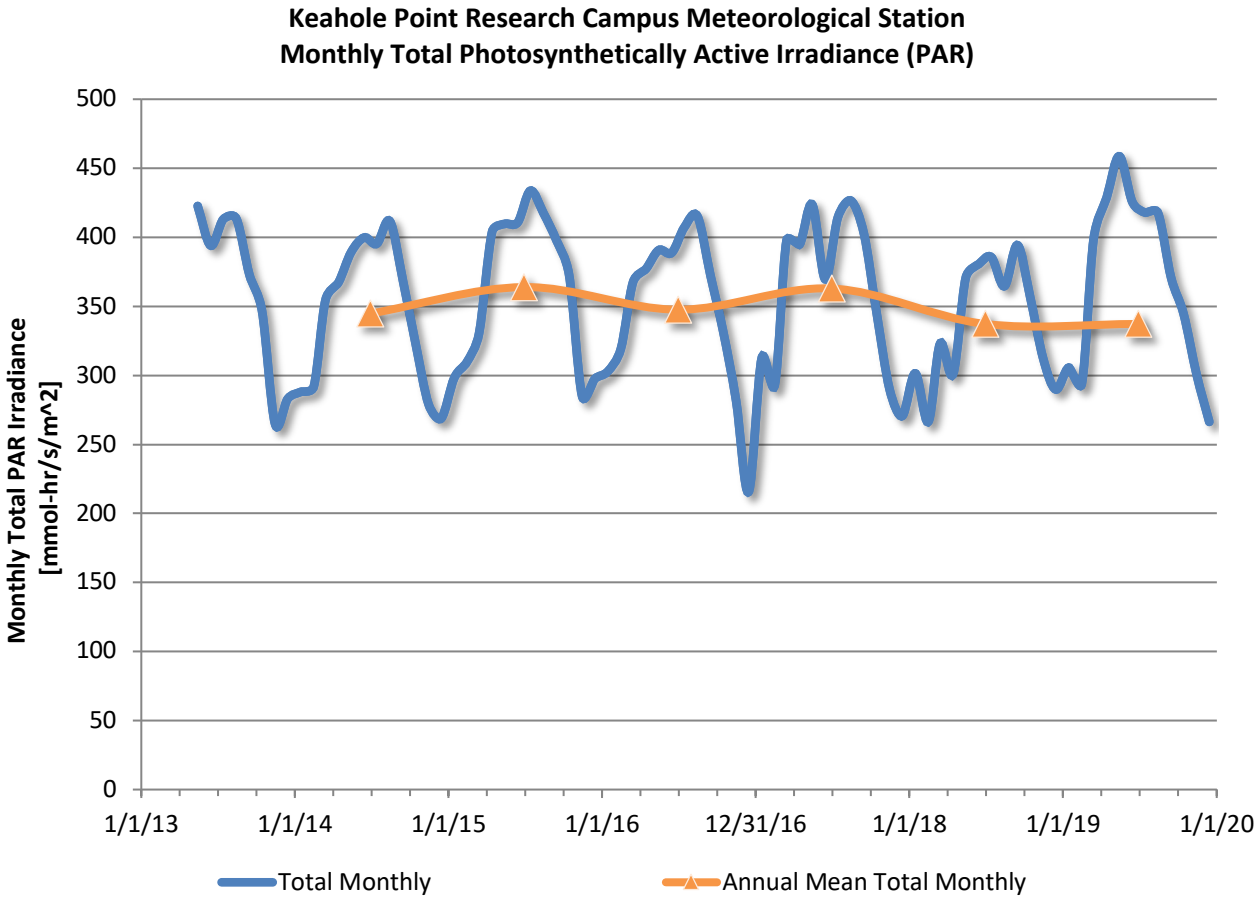


Figure 13c. *Daily and monthly bar charts for the period between 11/1/2012 – 11/30/2018*

5.11. ULTRAVIOLET LIGHT

Ultraviolet Light (UV) sensor was installed on April 4, 2018. A mean measurement of 10.9 W/m^2 (33.1 mmol-hr/s/m^2) was recorded from April 4, 2018 to December 31, 2018. During this period a monthly total maximum was recorded in August 2018 of 13.7 W/m^2 (41.9 mmol-hr/s/m^2). A monthly total minimum of 5.8 W/m^2 (17.6 mmol-hr/s/m^2) was recorded in December 2018.

Monthly Total Ultraviolet Light	Jan. 2019	Feb. 2019	Mar. 2019	Apr. 2019	May 2019	Jun. 2019	Jul. 2019	Aug. 2019	Sep. 2019	Oct. 2019	Nov. 2019	Dec. 2019
(kW-hr/m^2)	7.6	7.6	11.2	12.7	14.3	13.6	15.0	16.0	14.1	13.0	10.6	8.8
(mmol-hr/s/m^2)	23.0	23.2	33.9	38.6	43.3	41.2	45.5	48.5	42.8	39.3	32.0	26.7

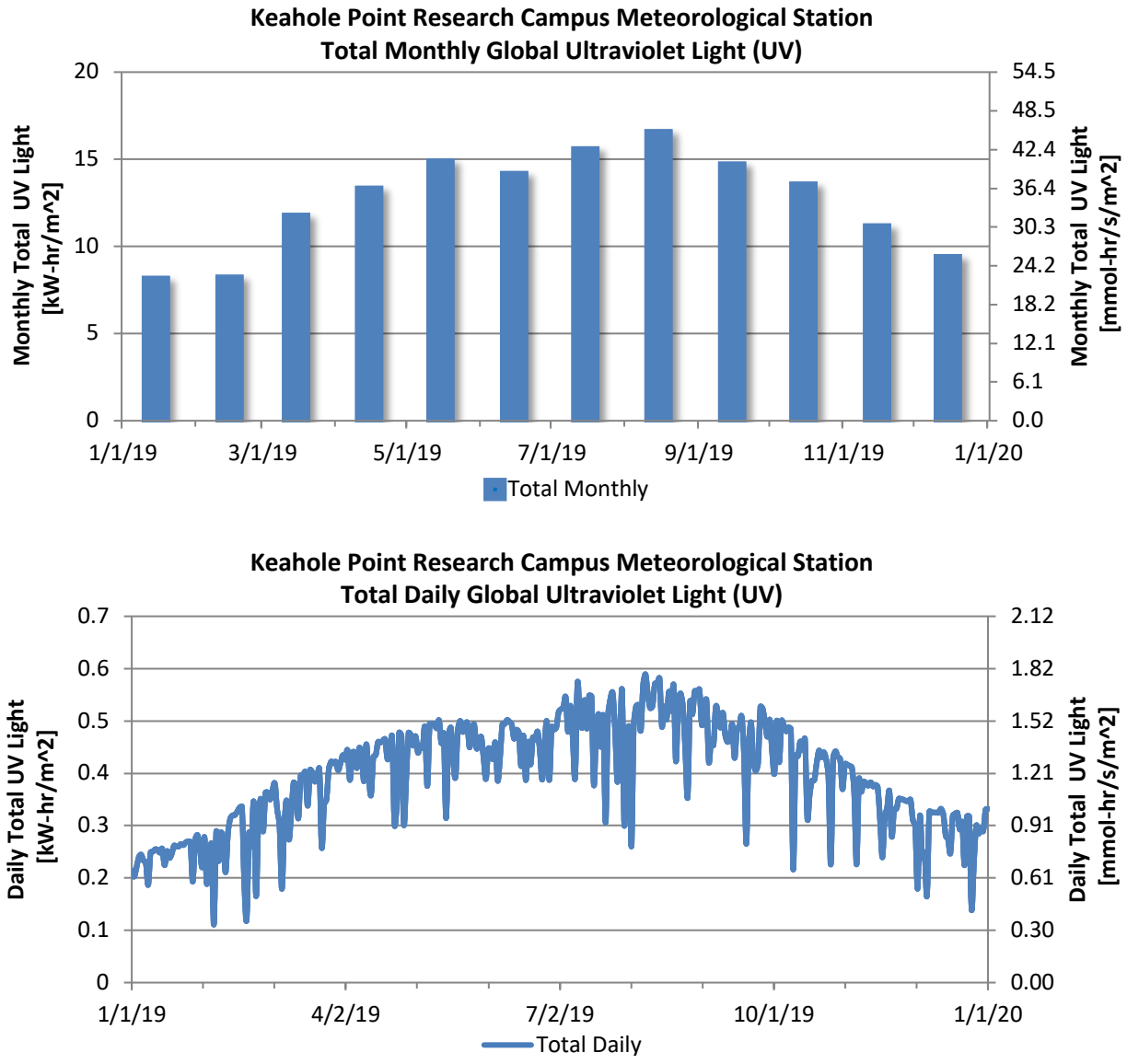


Figure 14a. *Monthly UV table, and monthly and daily charts*

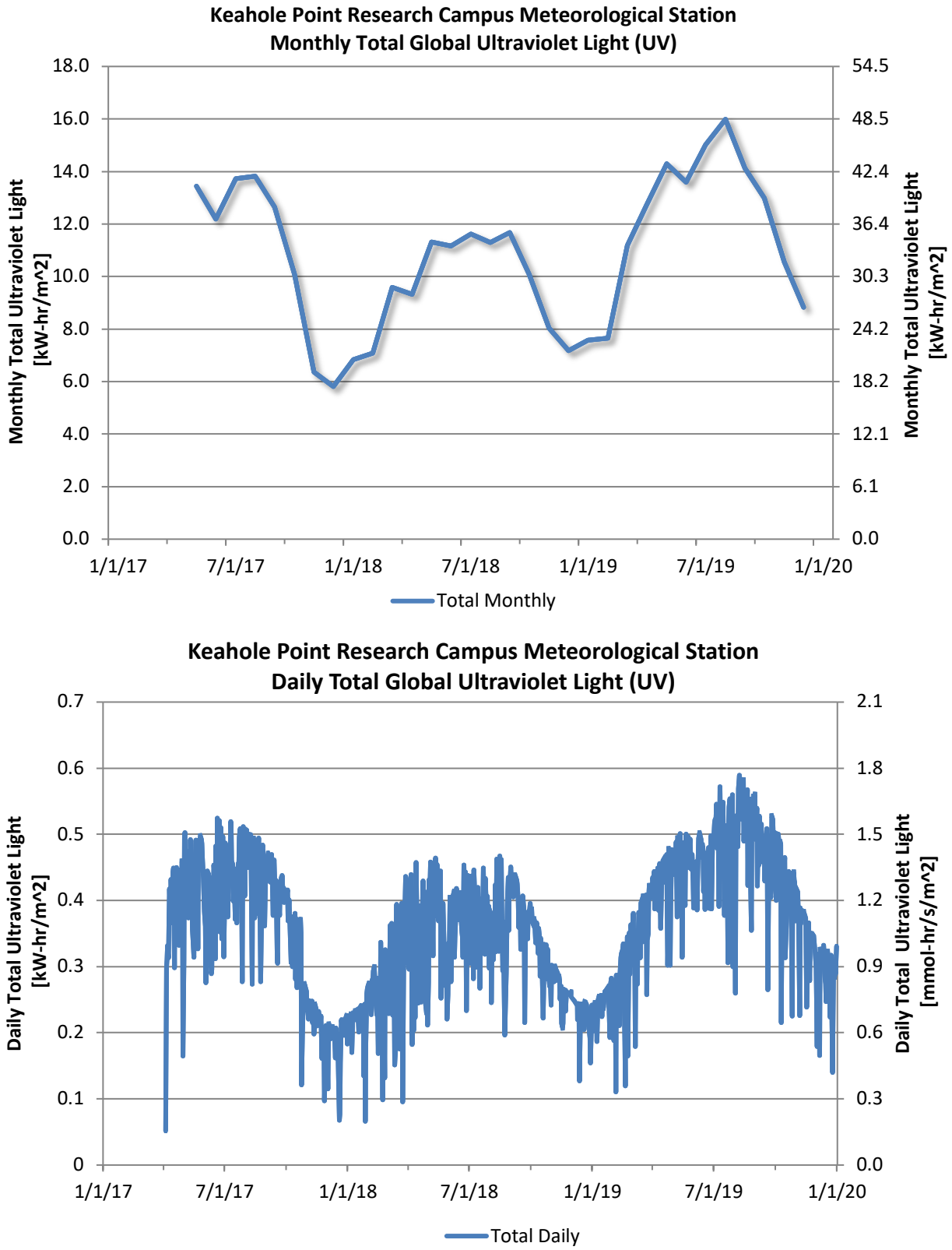


Figure 14b. *Historical total monthly and total daily Ultraviolet Light line charts*

6. HURRICANES AND TROPICAL STORMS

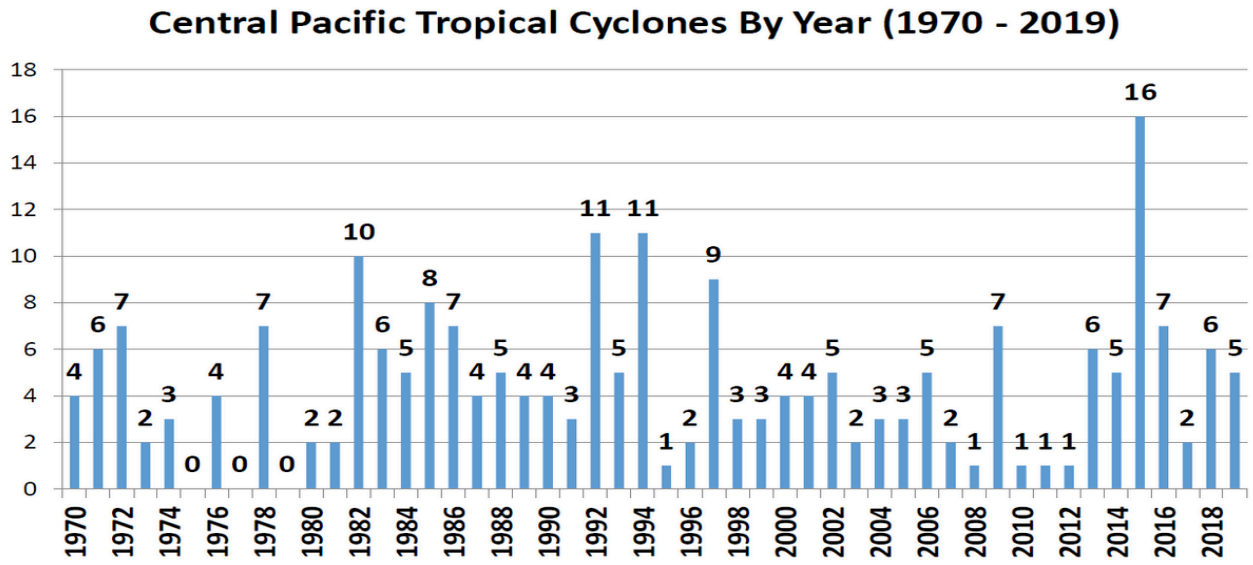


Figure 15a. *Annual Comparison of Tropical Cyclones by Year*[17]

2019: Hurricane Erick was the first tropical cyclone of the season in the Central Pacific, moving into the basin from the east on July 30. Erick rapidly intensified to a major hurricane (category 4 on the Saffir-Simpson Hurricane Wind Scale) later that day, then steadily weakened as it passed far south of the main Hawaiian Islands. Tropical Storm Flossie entered the basin on August 3 and approached Hawaii from the east, eventually dissipating before reaching the islands.[17]

Hurricane/Tropical Storm	Date	Time	Mean Wind Speed		Peak Wind Speed	
Hurricane Erick	8/3/19	12:00	6.0 m/s	13.4 mph	8.2 m/s	18.3 mph
Hurricane Flossie	8/5/19	11:00	-	-	-	-

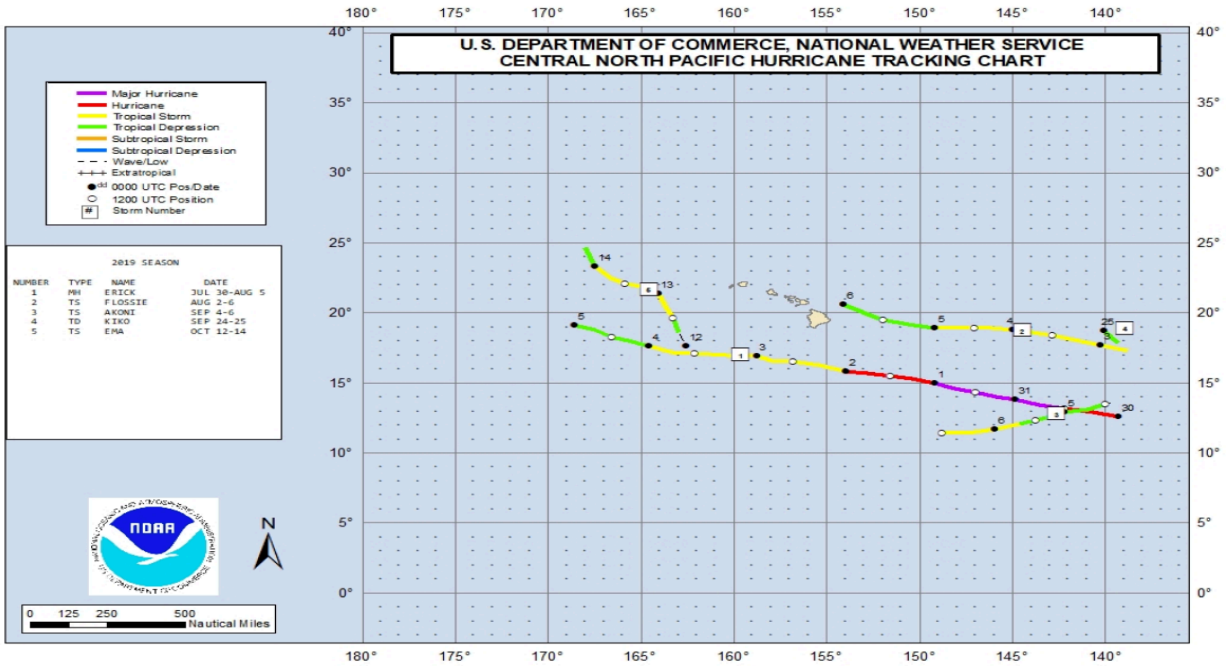


Figure 15b. *NOAA Central North Pacific Hurricane Center 2019 Hurricane Tracking Chart*[17]

2018: Three hurricanes threatened Hawaii Island in 2018. All of the 2018 hurricanes and tropical storms had minimal or no impact to Hawaii Island.

Hurricane/Tropical Storm	Date	Time	Mean Wind Speed		Peak Wind Speed	
Hurricane Hector	8/8/18	16:00	5.3 m/s	11.9 mph	6.70 m/s	15.0 mph
Hurricane Lane	8/24/18	8:00	9.0 m/s	20.1 mph	11.0 m/s	24.6 mph
Hurricane Norman	9/6/18	5:00	-	-	-	-
Tropical Storm Olivia	9/11/18	13:00	11 m/s	24.6 mph	13 m/s	29.0 mph

2017: With only 2 storms that threatened the islands, and both dissipating before they approached the land, 2017 was a below average hurricane and tropical storm season. The Central Pacific basin average averages around four to five tropical cyclones during an average year.[16]

Hurricane/Tropical Storm	Date	Time	Mean Wind Speed		Peak Wind Speed	
Tropical Storm Fernanda	7/23/17	17:00	6.96 m/s	15.5 mph	9.10 m/s	20.4 mph
Tropical Depression Greg	7/26/17	-	-	-	-	-

2016: Although 8 hurricanes potentially threatened the Hawaiian Islands, most weakened and/or plotted a trajectory away from Hawaii. 2016 was a relatively uneventful hurricane year in comparison to 2014 and 2015. Below is a list of the significant storms in 2016:

Hurricane/Tropical Storm	Date	Time	Mean Wind Speed		Peak Wind Speed	
Tropical Storm Celia	7/17/16	16:00	6.46 m/s	14.5 mph	8.94 m/s	20.0 mph
Tropical Storm Darby	7/24/16	7:00	8.82 m/s	19.7 mph	11.6 m/s	25.9 mph
Tropical Depression Ivette	8/11/16	11:00	4.41 m/s	9.85 mph	5.56 m/s	12.4 mph
Tropical Depression Madeline	8/31/16	11:00	5..27 m/s	11.79 mph	6.75 m/s	15.1 mph
Tropical Depression Lester	9/3/16	16:00	6.825 m/s	15.27 mph	8.47 m/s	19.0 mph
Tropical Depression Ulika	10/3/16	13:00	3.57 m/s	7.98 mph	4.46 m/s	9.98 mph

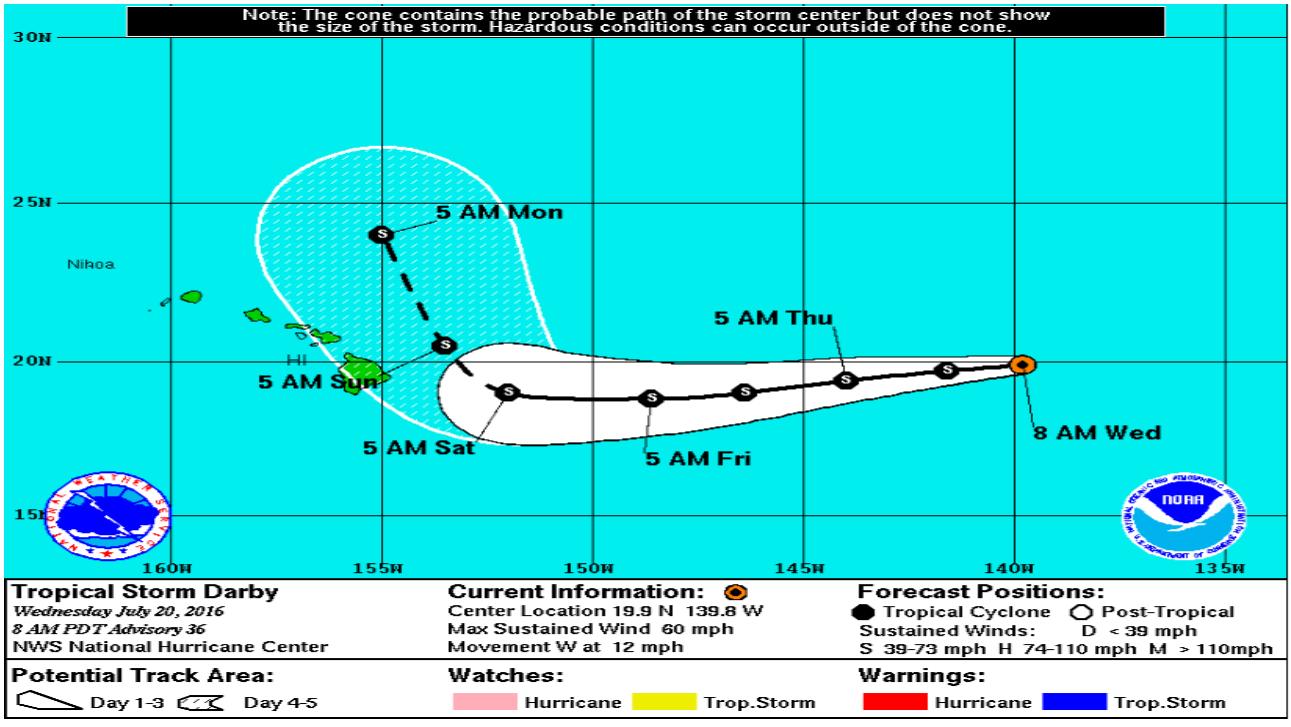


Figure 15c. *NOAA Central Pacific Hurricane Center 5-day track of Tropical Storm Darby*

2015: Like 2014, 2015 was another eventful year for Hurricanes and Tropical Storms. This above average activity has been attributed to the strong 2014 – 2018 El Niño. Fortunately, little to no damage was recorded during these two hurricane seasons on the west side of the Big Island. The 2015 hurricane season started out with Hurricane Guillermo on August 2 – 6. Soon after, Hurricane Hilda tracked just south of the Hawaiian Islands from August 12 – 14. On August 20, Tropical Storm Kilo develop south of the Hawaiian Islands and its remnants triggered a large rain event in West Hawaii on August 23 - 24. Hurricane Ignacio passed north of the Hawaiian Island chain causing minimal impact from August 29 to September 1. Hurricane Jimena passed north of the Hawaiian Island chain as it weakened from a category 4 hurricane to a tropical storm from August 31 to September 5. Hurricane Oho passed the southern part of the big island heading in a northeasterly direction from October 3 to October 8. The final hurricane for the season was Olaf. Hurricane Olaf, a category 4 hurricane was heading northwest towards the Big Island when it weakened from a passing trough and changed directions to the north on October 22.

The Keahole Point Research Campus Meteorological Station recorded a mean and peak wind speed for the following Hurricanes and Tropical Storms:

Hurricane/Tropical Storm	Date	Time	Mean Wind Speed		Peak Wind Speed	
Hurricane Guillermo	8/3/15	12:00	7.38 m/s	16.5 mph	9.5 m/s	21.2 mph
Tropical Storm Kilo	8/23/15	19:00	6.23 m/s	13.9 mph	8.24 m/s	18.43 mph
Hurricane Ignacio	8/31/15	16:00	6.70 m/s	15.0 mph	9.20 m/s	20.58 mph
Hurricane Oho	10/6/15	15:00	12.26 m/s	27.4 mph	16.41 m/s	36.71 mph

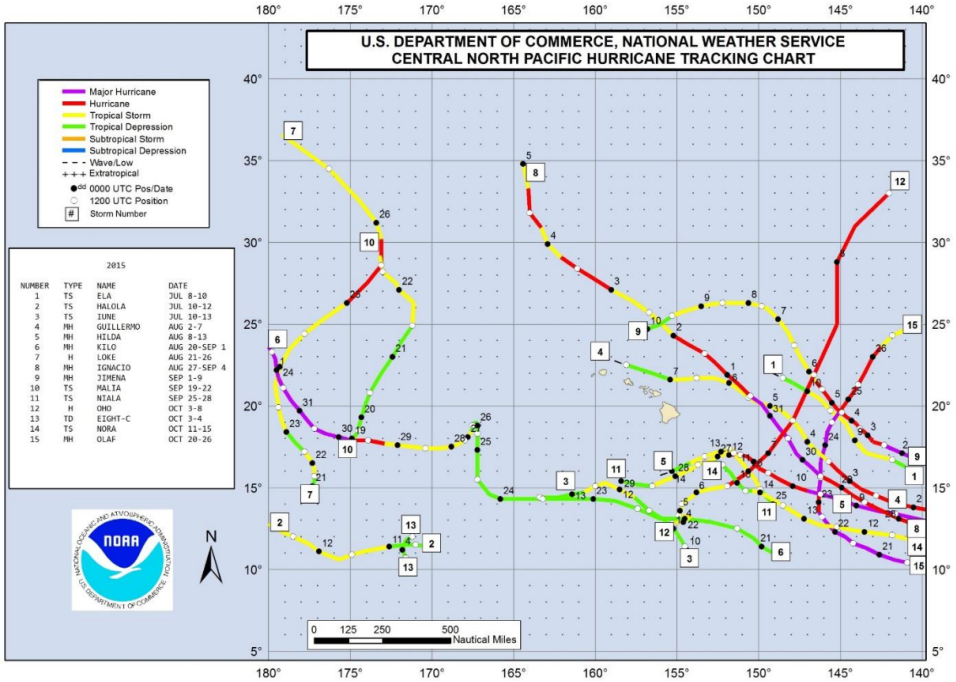


Figure 15d. *NOAA Central North Pacific Hurricane Center 2015 Hurricane Tracking Chart*[15]

2014: Hurricanes and Tropical Storms were very active in 2014. Fortunately, in most cases, little to no damage was recorded on the west side of the big island. The season started out with Tropical Storm Wali on July 20 – 21. Soon after, Hurricane Genevieve tracked just south of the Hawaiian Islands from July 30 – August 2. On August 7, Hurricane Iselle, a category 4 hurricane and the strongest tropical cyclone to make land fall on the Big Island in recorded history arrived. Iselle did weaken by the mountainous terrain of the Big Island and manifested as a collection of smaller vortices in the south-east region of the Big Island. The storm caused approximately $80 million in damages. Hurricane Julio followed behind Iselle a few days later and luckily Julio tracked north of the Hawaiian Islands from August 8 – 10. The season ended with Hurricane Ana, which degraded as it approached just south of the Hawaiian Islands to Tropical Storm Ana. The storm mostly affected the west side of the Hawaiian Islands with strong winds from October 17 - 19.

The Keahole Point Research Campus Meteorological Station peak wind speed:

Hurricane/Tropical Storm	Date	Time	Mean Wind Speed		Peak Wind Speed	
Tropical Storm Wali	7/20/14	13:00	6.33 m/s	14.2 mph	8.83 m/s	19.7 mph
Hurricane Genevieve	7/30/14	19:00	5.31 m/s	11.9 mph	6.88 m/s	15.4 mph
Hurricane Iselle	8/7/14	12:00	7.49 m/s	16.8 mph	10.65 m/s	23.8 mph
Hurricane Julio	8/11/14	19:00	5.08 m/s	11.4 mph	6.38 m/s	14.3 mph
Hurricane Ana	10/18/14	15:00	5.26 m/s	11.8 mph	7.06 m/s	15.8 mph

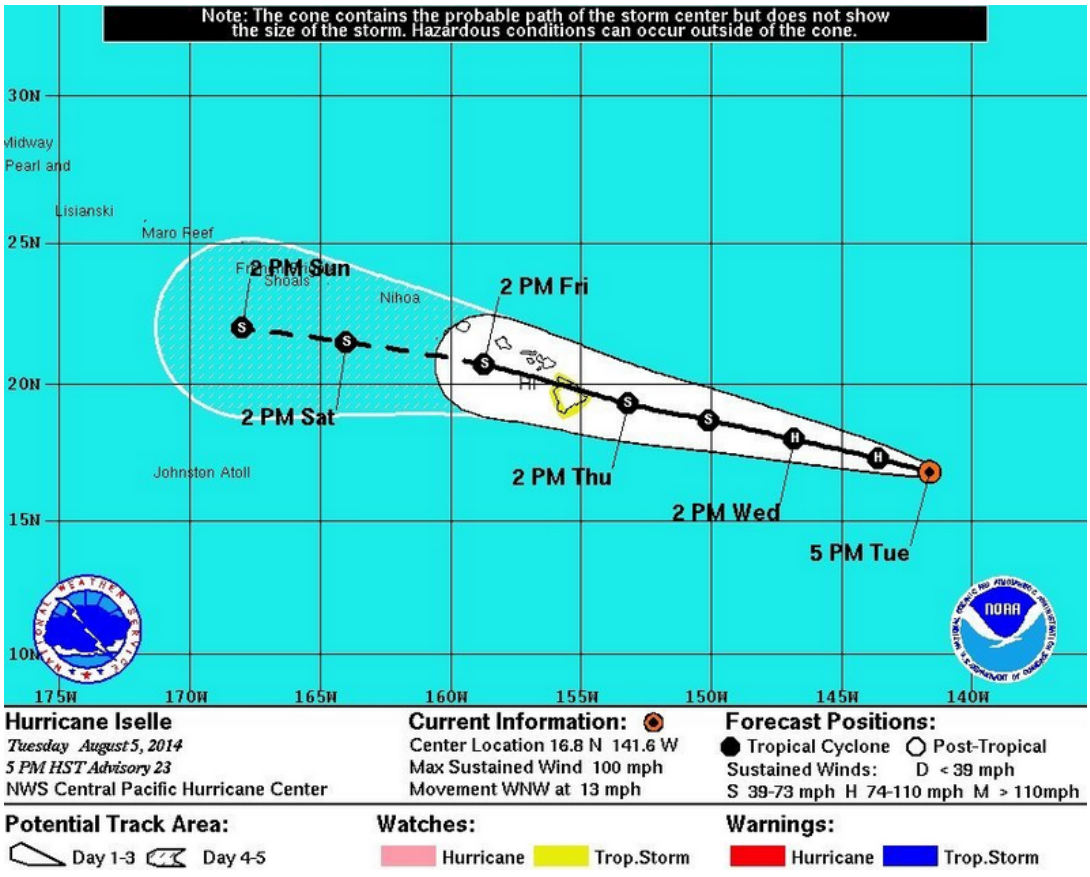


Figure 15e. *NOAA Central Pacific Hurricane Center 5-day track of Hurricane Iselle*

2013: 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.). With 5.69 mm (0.22 in.) of the daily accumulated precipitation occurring 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.

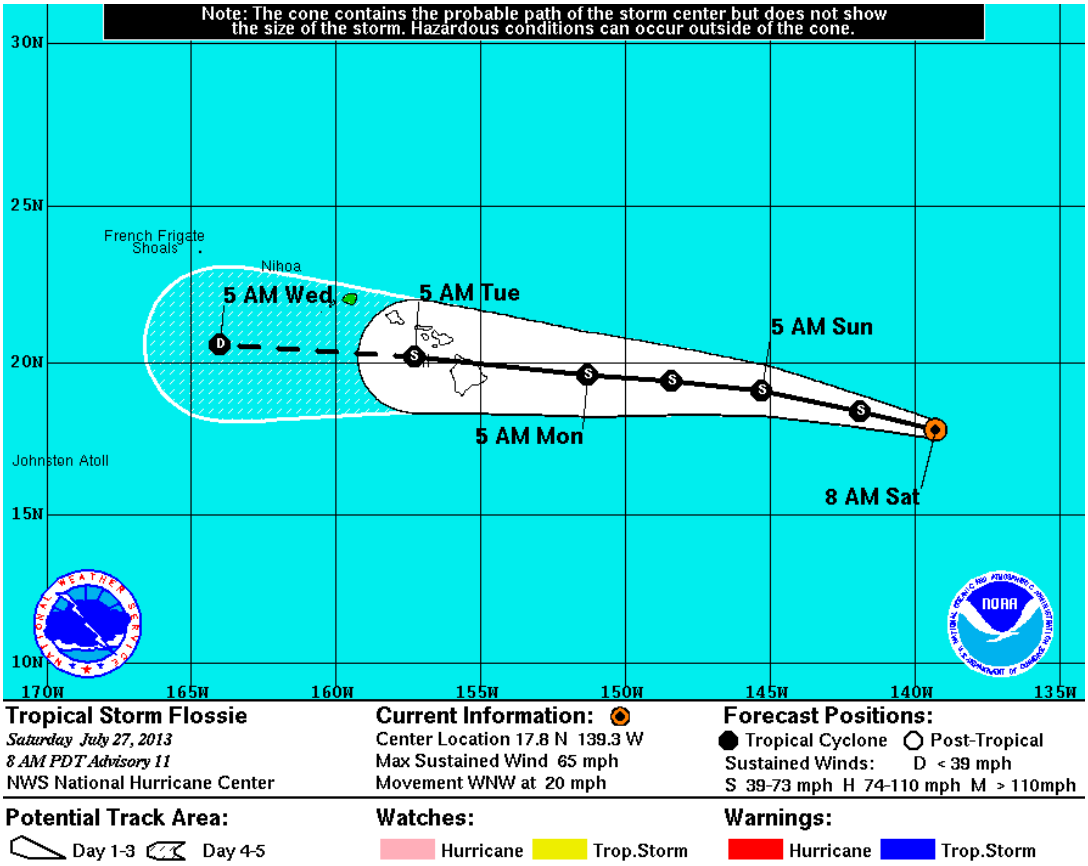


Figure 15f. *NOAA Central Pacific Hurricane Center 5-day track of Tropical Storm Flossie*

7. REGIONAL COMPARITIVE CHART

The regional comparative data was assembled from NREL's MIDc web site. NREL's MIDc has hosted solar and meteorological data since 1997. The approximately thirty-three 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 Regional Meteorological Data Comparison Chart *(Figure 16.)* represents mean, maximum and minimum yearly measurements computed 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, Northern Coastal California, Southwestern United States and Eastern United States. Coastal Hawaii was represented by meteorological stations at Keahole Point Research Campus. Coastal northern California by Humbolt State University. The Southwestern United States was represented by a meteorological station at University of Nevada at Las Vegas, University of Texas Pan America, and the University of Arizona, Tucson Arizona. The Eastern United States was represented by a meteorological station at Oak Ridge National Laboratory.

Figure 16a. Shows a line plot of global horizontal irradiance data profiles of daily totals through the monitoring year. Keahole Point Research Campus solar irradiance is consistent 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 16b. Shows a comparison of global horizontal irradiance profile of weekly totals through the monitoring year.

Figure 16c. Shows a comparison of global horizontal irradiance profile of a winter day on December 19, 2019. In the winter, Keahole Point, Hawaii has a higher intensity and longer day which yields a favorable irradiance profile.

Figure 16d. Shows a comparison of global horizontal irradiance profile of a summer day on June 21, 2019. In the summer, Keahole Point, Hawaii has a similar intensity to University of Nevada, Las Vegas but slightly lower intensity to University of Arizona, Tucson. Keahole Point also has a shorter day which yields a slightly less favorable irradiance profile in the summer.

Figure 16e. 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 64.6% yearly mean throughout the monitoring year.

Figure 16f. 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 26.65˚C (79.97˚F) yearly mean throughout the monitoring year

Regional Meteorological Data Comparison Chart

Meteorological Measurement	Units	NELHA Kailua-Kona, Big Island, Hawaii	University of Nevada Las Vegas, Nevada	University of Arizona Tucson, Arizona	University of Texas Pan American	Humbolt State University	Oak Ridge National Laboratory Oak Ridge, Tennessee
Period	MM/DD/YY	1/01/19 - 12/31/19	1/01/19 - 12/31/19	1/01/19 - 12/31/19	1/01/19 - 12/31/19	1/01/19 - 12/31/19	1/01/15 - 11/20/19**
GPS	Latitude	19.73° N	36.06° N	32.23° N	26.49° N	40.88° N	35.93° N
	Longitude	156.06° W	115.08° W	110.96° W	98.17° W	124.08° W	84.31° W
Elevation	m	4	615	786	45.4	36	245
	ft.	13	2018	2579	149	118	804
Mean Yearly Temperature	˚C	26.65	21.16	22.13			23.30
	˚F	79.97	70.08	71.83			73.94
Max Yearly Temperature	˚C	35.25	43.99	43.46			43.46
	˚F	95.45	111.18	110.23			110.23
Min Yearly Temperature	˚C	16.52	-0.30	-0.37			-0.37
	˚F	61.74	31.45	31.34			31.34
Yearly Total Global Solar Irradiance	kW-hr/m^2	2211.3	2046.8	2137.9	1241.6 *	1459.4	1250.1
Mean Daily Total Global Solar Irradiance	kW-hr/m^2	6.06	5.61	5.86	4.53 *	4.00	3.97
Mean Yearly Relative Humidity	%	64.6		34.0			76.5
Max Yearly Relative Humidity		93.3		96.4			96.9
Min Yearly Relative Humidity		32.4		3.8			19.8
Mean Yearly Barometric Pressure	mBar	1014		925			998
	in. of Hg	29.95		27.33			29.47
Mean Yearly Wind Speed	m/s	2.53	2.27	2.62			0.79
	mph	5.66	5.09	5.87			1.76
Yearly Accumulated Precipitation	mm	447.25					
	in.	17.61					

*** University of Texas Pan America Global Solar Irradiance instrumentation not recording measurements from April 22 – July 8, 2019.**

**** Oak Ridge National Laboratory stopped recording meteorological data on November 20, 2019.**

Figure 16. *Regional Meteorological Comparison Chart*

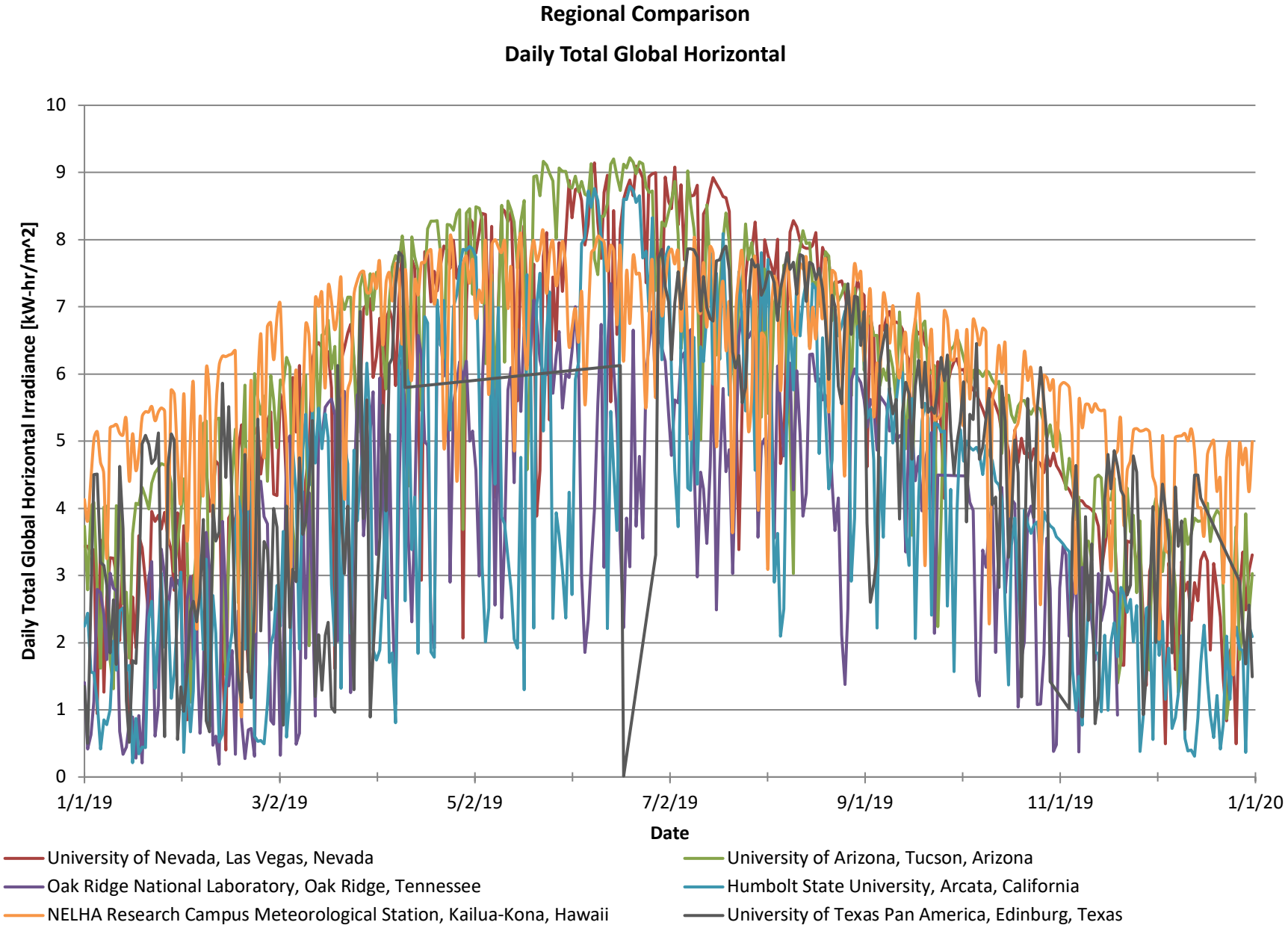


Figure 16a. *Regional comparison of daily total global horizontal irradiance profiles*

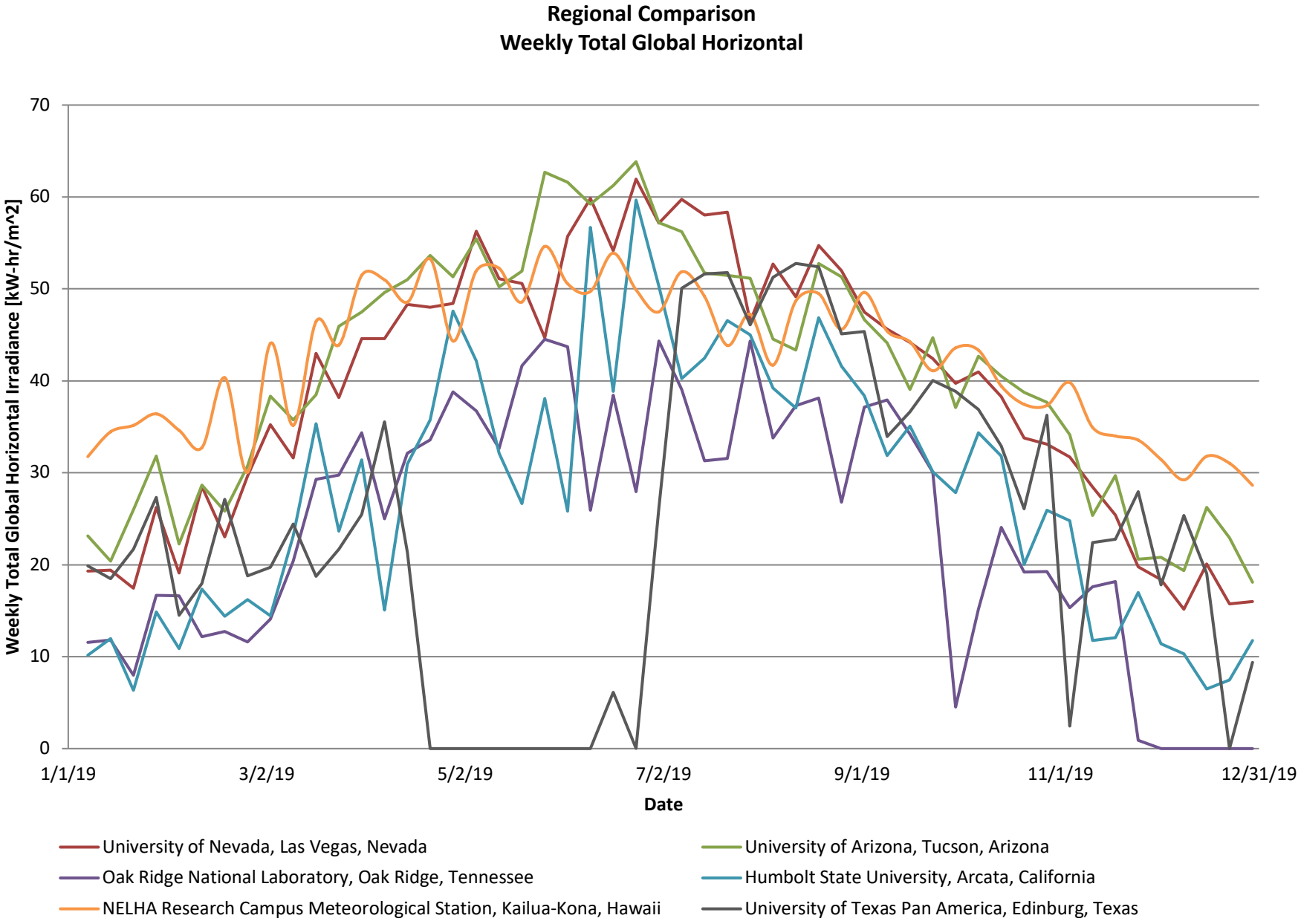


Figure 16b. *Regional comparison of weekly total global horizontal irradiance profiles*

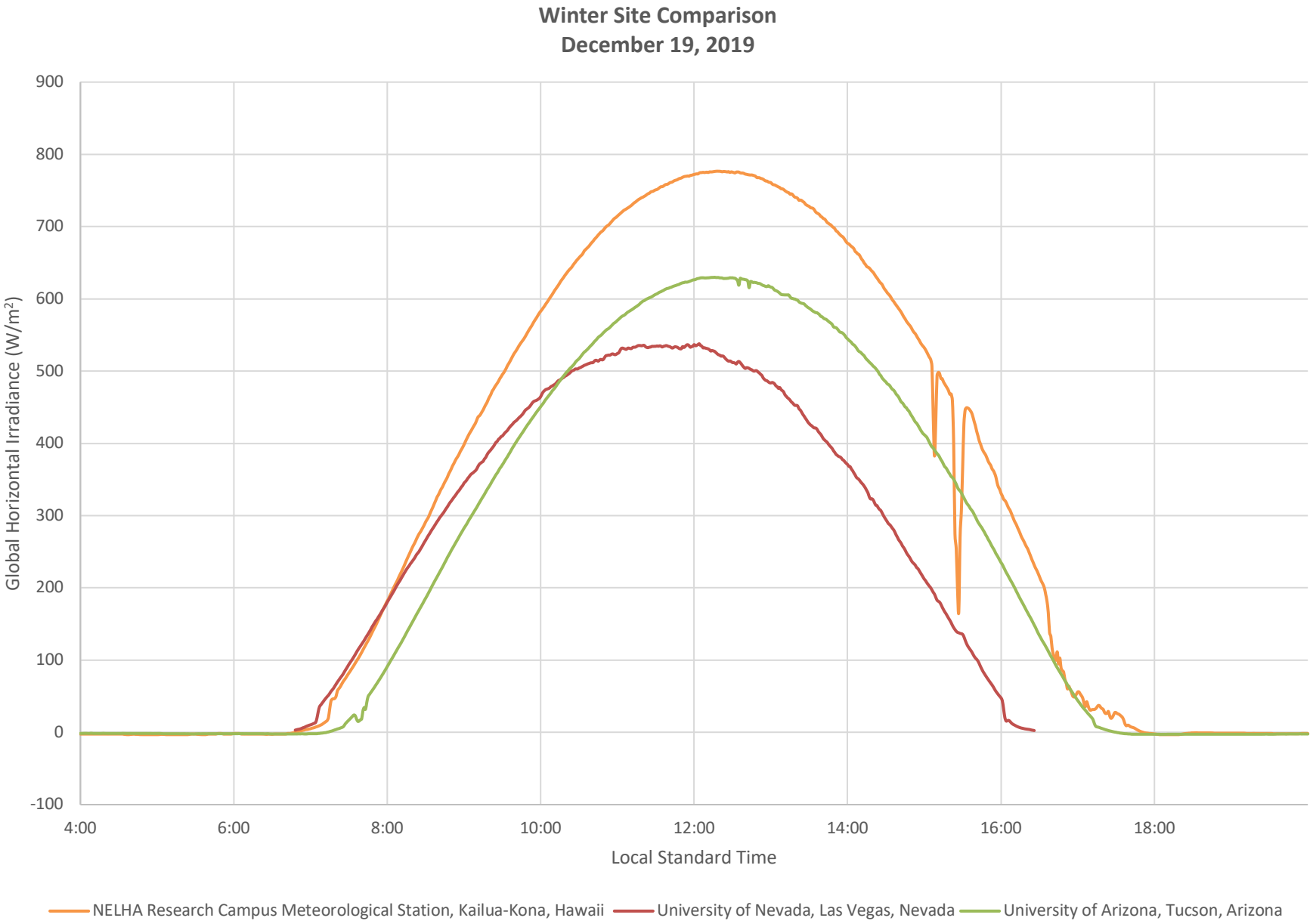


Figure 16c. *Winter comparison of global horizontal irradiance profiles*

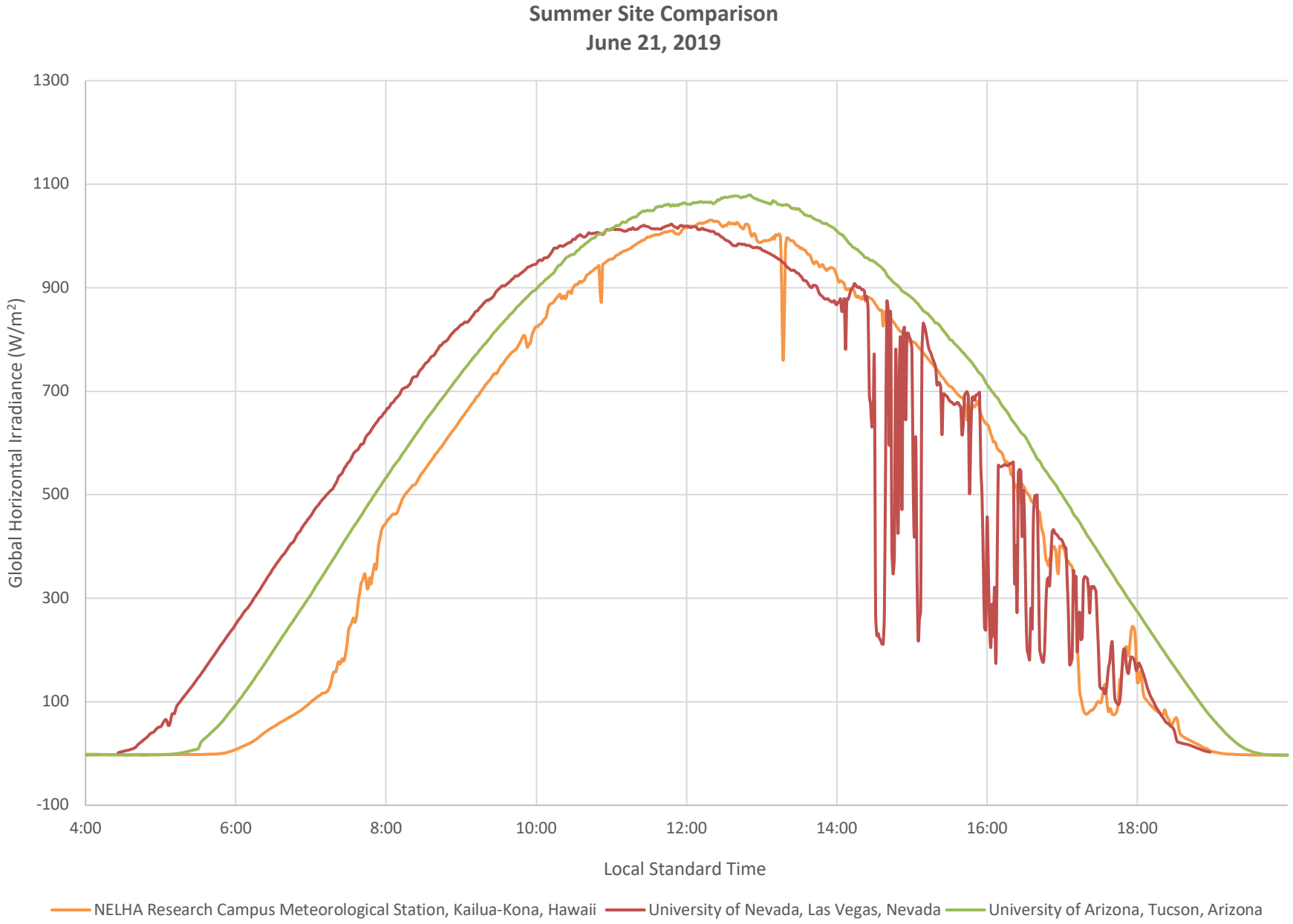


Figure 16d. *Summer comparison of global horizontal irradiance profiles*

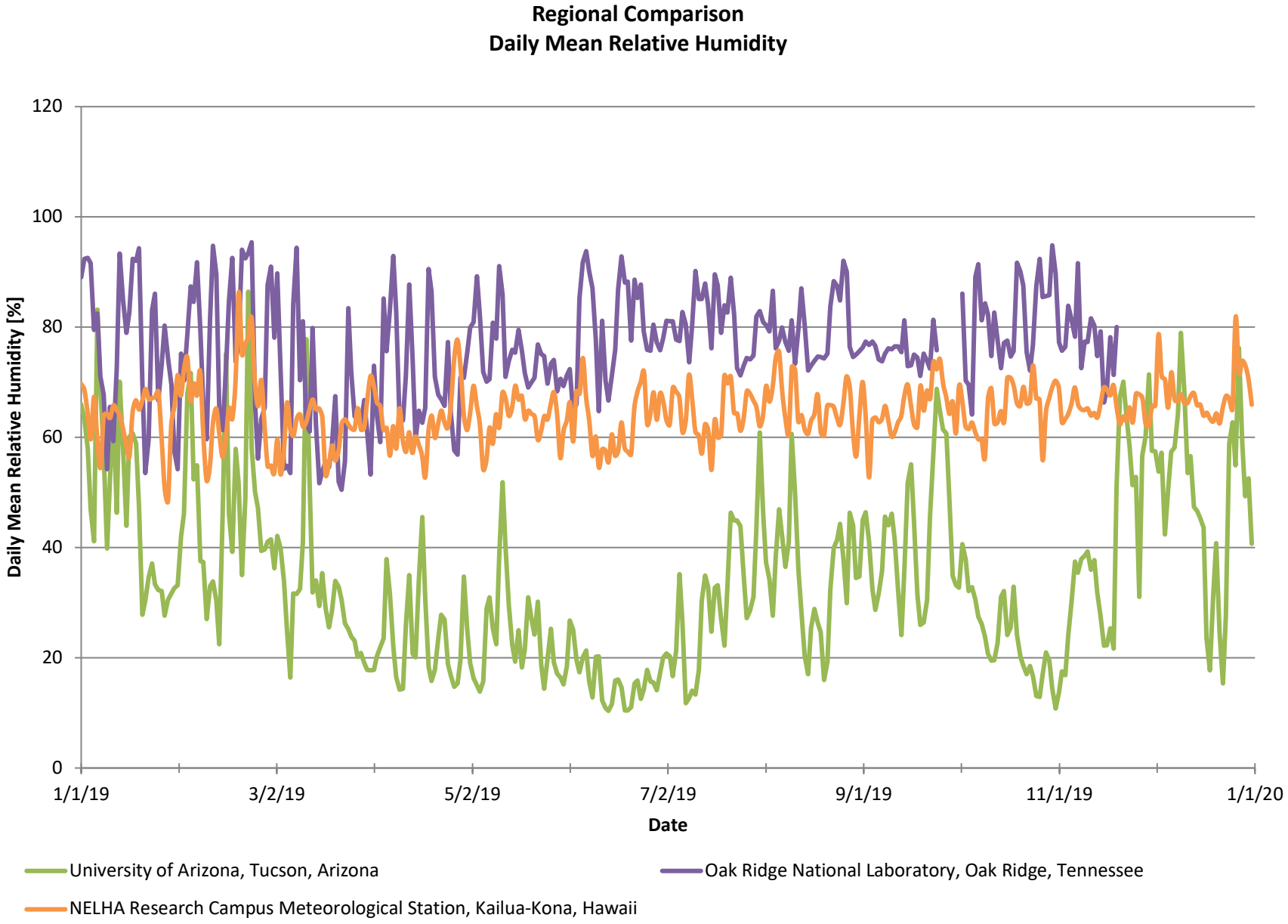


Figure 16e. *Regional comparison of daily relative humidity profiles*

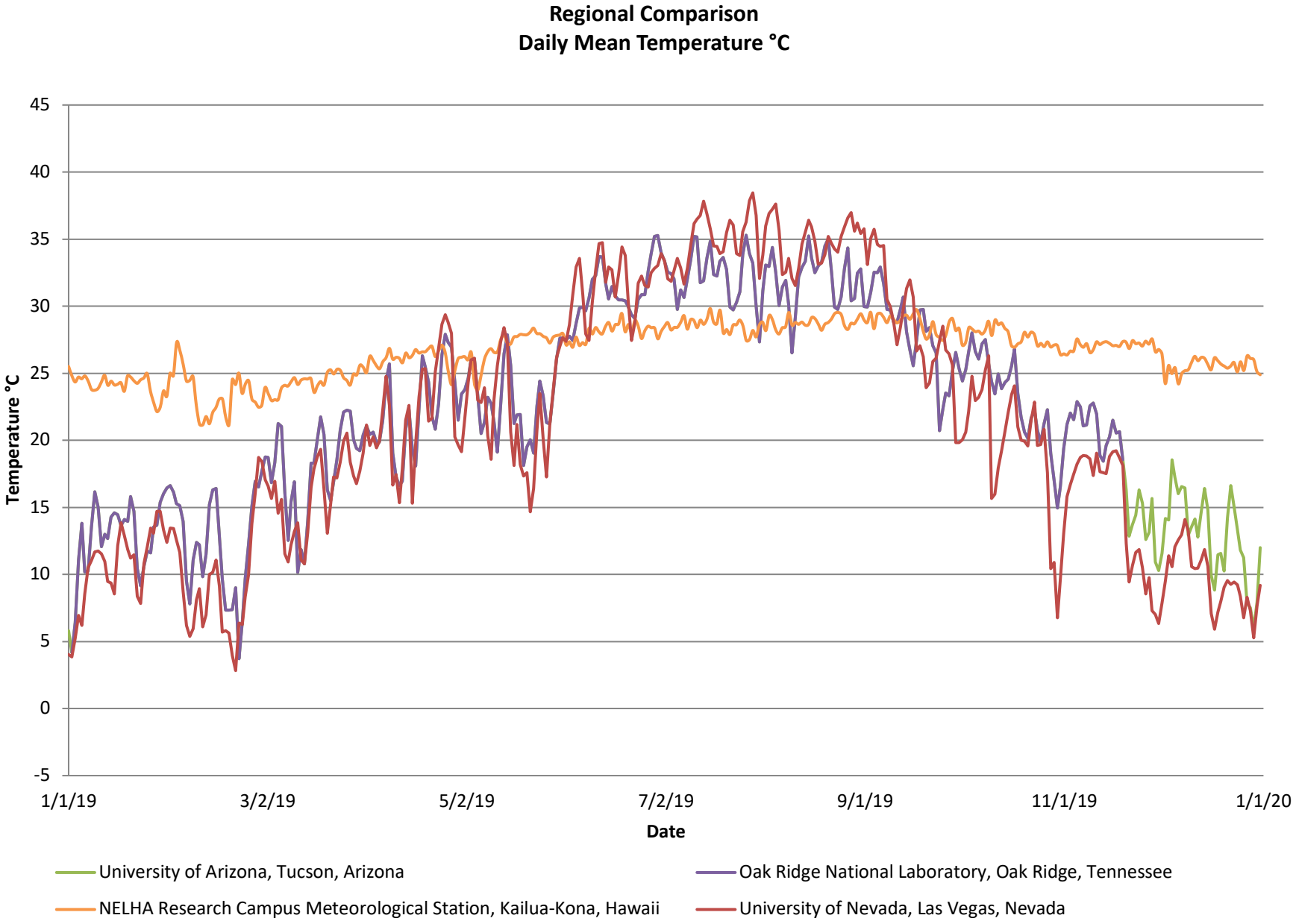


Figure 16f. *Regional comparison of daily temperature profiles*

8. ACKNOWLEDGEMENT

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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:

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

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 & Zonen, 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. Big Island Abalone Corporation donated the Sensor.

VII. An Apogee SU-100 total ultra-violet sensor measuring UV in the 250 to 400 nm waveband was installed on April 4, 2018. Cyanotech Corporation donated the sensor.