ANNUAL REPORT

For the

KEAHOLE POINT RESEARCH CAMPUS METEOROLOGICAL STATION

Covering the Monitoring Year:

January 1, 2020 through December 31, 2020

Historical Data Plots:

November 1, 2012 - April 30, 2021

Prepared by:

Keith Olson

NELHA Water Quality Laboratory Manager

Hawaii Ocean Science and Technology Park

Administered by:

Natural Energy Laboratory of Hawaii Authority

June 2021

MET STATION ANNUAL REPORT (2020) v3.docx

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EXECUTIVE SUMMARY

Clients at the Hawaiian Ocean Science and Technology (HOST) park and researchers from around the world utilize the real time meteorological data from the Keahole Point Research Campus Meteorological Station for aquaculture management decisions, meteorological analytics models, and the development of artificial intelligence algorithms for renewable energy generation and storage systems. The Keahole Point Research Campus Meteorological Station was initially installed 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. The Natural Energy Laboratory of Hawaii Authority (NELHA) provides funding for the maintenance and calibration of the meteorological station's tower, logger, and instruments. 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 in the resource library on the NELHA website [http://nelha.hawaii.gov/resources/library/].

This report highlights the annual meteorological data set collected at Keahole Point from January 1, 2020, to December 31, 2020 (monitoring year). The report also includes the historical meteorological data trends at Keahole Point starting from November 1, 2012, to April 30, 2021. 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 43. 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 26.06°C (78.91°F) with a maximum-recorded temperature of 33.2˚C (91.8˚F) on October 24, 2020, and a minimum-recorded temperature of 17.7˚C (63.9˚F) on February 11, 2020. The mean historical annual temperature since November 1, 2012, was 26.2°C (79.2°F). The annual accumulated precipitation recorded during the monitoring year was 310.5 mm (12.2 in.), with 21% of the precipitation occurring during the month of March and 13% occurring during the month of May. The mean historical annual accumulated precipitation since November 1, 2012, was 331.9 mm (13.07 in.). Historically, the wettest months are typically February and March, and driest months are June, July, and September. The mean relative humidity for the monitoring year was 64.9%, with a maximum-recorded relative humidity of 92.7% in June, and a minimum-recorded relative humidity of 34.9% in February. The mean historical annual relative humidity since November 1, 2012, was 66.0%. Wind speed throughout the period was consistent at a yearly mean of 2.40 m/s (5.36 mph) with a standard deviation of 1.11 m/s (2.48 mph). The mean historical annual

wind speed since November 1, 2012, was 2.50 m/s (5.59 mph). Wind direction at Keahole Point exhibits a typical land-sea directional profile and has two general bearings averaging at 218.9° from the north in the daytime hours (8 am – 8 pm) and 121.1° from the north during the nighttime hours. Barometric pressure at Keahole Point recorded a mean yearly value of 1015.4 mBar (29.98 in. of Hg) with a range of 1005.9 to 1021.2 mBar (29.70 to 30.16 in. of Hg).

The yearly total global horizontal solar irradiance recorded at the Keahole Point Research Campus Meteorological Station was 2136 kW-hr/m^2. This is comparable with Tucson, Arizona at 2143 kW-hr/m^2, and Las Vegas, Nevada at 2128 kW-hr/m^2. It is surprising to see Keahole Point receiving as much total yearly global horizontal irradiance (at 5.84 kW-hr/m^2 mean daily) as the desert southwestern United States. The difference between Tucson, Arizona was -1.20 days and for Las Vegas, Nevada it was 1.28 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 due to the proximity to the equator and dry conditions at Keahole Point. 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 2020, 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.

Table of Content

1. INTRODUCTION 1
2. GLOSSARY 2
2.1. ACRONYMS 2
2.2. DEFINITIONS 2
2.3. UNITS 2
3. INSTRUMENTS, SENSORS AND EQUIPMENT 3
3.1. TOWER 3
3.2. DATA LOGGER 3
3.3. METEOROLOGICAL SENSORS 3
3.3.1. AIR TEMPERATURE AND RELATIVE HUMIDITY 3
3.3.2. BAROMETRIC PRESSURE 4
3.3.3. WIND MONITOR 5
3.3.4. PRECIPITATION 6
3.3.5. GLOBAL HORIZONTAL IRRADIANCE 6
3.3.6. PHOTOSYNTHETICALLY ACTIVE RADIATION 7
3.3.7. ULTRAVIOLET LIGHT 8
4. METHODS 8
4.1. STUDY SITE 8
4.2. DATA COLLECTION 9
5. RESULTS 12
5.1. AIR TEMPERATURE 12
5.2. RELATIVE HUMIDITY 15
5.3. DEW POINT 17
5.4. BAROMETRIC PRESSSURE 20
5.5. WIND SPEED 23
5.6. PEAK WIND SPEED 26
5.7. WIND DIRECTION 29
5.8. ACCUMULATED PRECIPATATION 30
5.9. GLOBAL HORIZONTAL IRRADIANCE 34
5.10. PHOTOSYNTHETICALLY ACTIVE RADIATION 38
5.11. ULTRAVIOLET LIGHT 42
6. HURRICANES AND TROPICAL STORMS 45
7. REGIONAL COMPARITIVE CHART 51
8. ACKNOWLEDGEMENT 59
9. REFERENCES 60

APPENDIX .... A
A. FUNDING AND PROCUREMENT .... A
1. SCOPE OF WORK .... A
2. TIMELINE AND SPECIFICATIONS .... A

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 HOST Park, which enhances NELHA's ability to continue to perform its mission as a test bed for the development of clean energy and ocean-related blue technologies.

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
MIDC	NREL's Measurement and Instrument Data Center

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, 2020, to December 31, 2020

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 a 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 Campbell Scientific, Inc., model # 083E-1-35 temperature and relative humidity sensors on the Keahole Point Research Campus Meteorological Station (see Service Period and Calibration Table. 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]

Campbell Scientific, Inc., Air Temperature and Relative Humidity Sensor Service Period and Calibration			
Service Period	Model	Serial #	Calibration Date
Nov. 1, 2012 – Apr. 7, 2015	083E-1-35	N11762	New: Sep. 14, 2012
Apr. 7, 2015 – Feb. 9, 2017	083E-1-35	N11767	New: Sep. 14, 2012
Feb. 9, 2017 – Feb. 5, 2019	083E-1-35	N11762	Met One Instruments: Jan. 13, 2017
Feb. 5, 2019 – Apr. 16, 2021	083E-1-35	N11767	Met One Instruments: Nov. 5, 2018
Apr. 16, 2021 - Present	083E-1-35	N11762	Met One Instruments: Jan. 13, 2021

Figure 3.3.1. *Campbell Scientific, Inc., Air Temperature and Relative Humidity Sensor Service Period and Calibration*

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 one 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. One 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 Campbell Scientific, Inc., model # 092 barometric pressure sensor on the Keahole Point Research Campus Meteorological Station. 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)

Campbell Scientific, Inc., Barometric Pressure Sensor Service Period and Calibration			
Service Period	Model	Serial #	Calibration Date
Nov. 1, 2012 – Apr. 7, 2015	092	N11882	New: Sep. 20, 2012
Apr. 7, 2015 – Feb. 9, 2017	092	T10674	New: Jan. 16, 2015
Feb. 9, 2017 – Feb. 5, 2019	092	N11882	Met One Instruments: Jan. 13, 2017
Feb. 5, 2019 – Apr. 16, 2021	092	T10674	Met One Instruments: Nov. 5, 2018
Apr. 16, 2021 - Present	092	N11882	Met One Instruments: Jan. 13, 2021

Figure 3.3.2. *Campbell Scientific, Inc., Barometric Pressure Sensor Service Period and Calibration*

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. One 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 wind monitor-MA on the Keahole Point Research Campus Meteorological Station. 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.

R.M. Young Company, Wind Monitor Service Period and Calibration			
Service Period	Model	Serial #	Calibration Date
Nov. 1, 2012 – Apr. 7, 2015	05106	WM121997	New: Sep. 26, 2012
Apr. 7, 2015 – Feb. 9, 2017	05106	WM140238	New: Mar. 18, 2015
Feb. 9, 2017 – Feb. 5, 2019	05106	WM121997	R.M Young Company: Dec. 22, 2016
Feb. 5, 2019 – Apr. 16, 2021	05106	WM140238	R.M Young Company: Oct. 31, 2018
Apr. 16, 2021 - Present	05106	WM121997	R.M Young Company: Jan. 19, 2021

Figure 3.3.3. *R.M. Young Company, Wind Monitor Service Period and Calibration*

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 one 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. One 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 the Keahole Point Research Campus Meteorological Station. 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)

Met One Instruments, Inc., Rain Gauge Service Period and Calibration			
Service Period	Model	Serial #	Calibration Date
Nov. 1, 2012 – Apr. 7, 2015	370C	N11206	New: Sep. 20, 2012
Apr. 7, 2015 – Feb. 9, 2017	370C	T11827	New: Feb. 10, 2015
Feb. 9, 2017 – Feb. 5, 2019	370C	N11206	Met One Instruments: Jan. 13, 2017
Feb. 5, 2019 – Apr. 16, 2021	370C	T11827	Met One Instruments: Nov. 5, 2018
April 16, 2021 - Present	370C	N11206	Met One Instruments: Jan. 13, 2021

Figure 3.3.4. *Met One Instruments, Inc.,* *Rain Gauge Service Period and Calibration*

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.

3.3.5. GLOBAL HORIZONTAL IRRADIANCE

The Keahole Point Research Campus Meteorological Station deployed a Kipp & Zonen model # CMP-11 (serial # 126933) ISO secondary-standard pyranometer that monitors solar radiation for the full solar spectrum range on November 1, 2012. The sensor was replaced with a newly purchased and calibrated CMP 10 sensor (serial # 140710) on April 7, 2015. On February 9, 2017, the recently recalibrated original sensor (serial # 126933) replaced the sensor installed on April 23, 2015. The calibration was performed by Kipp & Zonen in Delft, The Netherlands on January 6, 2017. On February 5, 2019, the recalibrated secondary CMP 10 sensor (serial # 140710) replaced the primary sensor installed on February 9, 2017. The calibration was performed by OTT HydroMet Corp. in Sterling, Virginia on November 14, 2018. On April 16, 2021, the recalibrated original CMP 11 sensor (serial # 126933) replaced the secondary sensor installed on February 5, 2019. The calibration was performed by OTT HydroMet Corp. in Sterling, Virginia on January 21, 2021. The main difference between the CMP11 and CMP10 is the CMP10 has a sealed sensor, while the CMP11 is not and requires periodic desiccant changes. The CMP11 and CMP10 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 and CMP10's domes and a 15 cm (5.9 in.) sun shield to reduce senor temperature. The CMP11 and CMP10 produces a millivolt signal that is measured directly by the CR1000 data logger. The CMP11 and CMP10 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]

Kipp & Zonen, Global Horizontal Irradiance Service Period and Calibration			
Service Period	Model	Serial #	Calibration Date
Nov. 1, 2012 – Apr. 7, 2015	CMP-11	126933	New: Mar. 22, 2012
Apr. 7, 2015 – Feb. 9, 2017	CMP 10	140710	New: Apr. 30, 2014
Feb. 9, 2017 – Feb. 5, 2019	CMP-11	126933	Kipp & Zonen: Jan. 6, 2017
Feb. 5, 2019 – Apr. 16, 2021	CMP 10	140710	OTT HydroMet Corp: Nov. 14, 2018
April 16, 2021 - Present	CMP-11	126933	OTT HydroMet Corp: Feb. 5, 2021

Figure 3.3.5. *Kipp & Zonen, Global Horizontal Irradiance Service Period and Calibration*

The global horizontal irradiance sensor is connected to differential channel 5 (H red, L blue, G black). The internal Array table designator is 13, and the 16-bit Floating Point Modbus Address is 40025 for instantaneous measurements. For one minute average data, the internal table designator is 28, and the 16-bit Floating Point Modbus Address 40055.

3.3.6. PHOTOSYNTHETICALLY ACTIVE RADIATION

The Keahole Point Research Campus Meteorological Station deployed a LI-COR model # LI-190 Terrestrial Radiation Sensor that monitors photosynthetically active radiation (PAR) in the 400 to 700 nm waveband on April 23, 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 149˚F).[12][13]

LI-COR, Photosynthetically Active Radiation Service Period and Calibration			
Service Period	Model	Serial #	Calibration Date
Apr. 23, 2013 – Apr. 7, 2015	LI-190	Q99293	New: Apr. 3, 2013
Apr. 7, 2015 – Feb. 9, 2017	LI-190	Q52979	New: Dec. 22, 2014
Feb. 9, 2017 – Feb. 5, 2019	LI-190	Q99293	LI-COR: Dec. 21, 2016
Feb. 5, 2019 – Apr. 16, 2021	LI-190/R	Q108322	New: Nov. 14, 2018
April 16, 2021 - Present	LI-190	Q99293	LI-COR: Jan. 8, 2021

Figure 3.3.6. *LI-COR, Photosynthetically Active Radiation Service Period and Calibration*

The PAR sensor is connected to differential channel 2 (H black, L red, G green to L). The internal Array table designator is 17, and the 16-bit Floating Point Modbus Address is 40033 for instantaneous measurements. For one minute average data, the internal table designator is 32, and the 16-bit Floating Point Modbus Address 40063.

3.3.7. ULTRAVIOLET LIGHT

The Keahole Point Research Campus Meteorological Station deployed an Apogee Instruments ultraviolet radiation sensor model SU-100 that monitors electromagnetic spectrum from 250 to 400 nm waveband on the Keahole Point Research Campus Meteorological Station. On June 6, 2020, there was a sharp drop in UV radiation, and it is believed that the senor failed. Unfortunately, the failure was not noticed until December 2020. The original SU-100 (serial # SU-100_2380) was submitted to Apogee for calibration and was determined to be outside of the specifications. Apogee no longer manufactures the SU-100. The sensor was not designed to withstand the harsh conditions of an outside marine environment. Apogee developed the SU-200 to replace the SU-100. The SU-200 was designed specifically for the outdoor UV measurements. Unlike the SU-100 sensor, the SU-200 can only measure in UV A (300 to 400nm) spectrum. The Apogee ultraviolet sensor was designed to measure on plane surface. The photodiode and signal processing circuitry are designed to detect UV radiation in photon flux units (µmoles s^{-1} m^{-2}) and energy flux units (W m^{-2}). The Keahole Point Meteorological Station will be collecting both output expressions. The calibration factors for the Apogee SU-100 are 5.0 µmoles s^{-1} m^{-2} per mV and 1.65 W m^{-2} per mV. The Apogee SU-100 has a sensitivity of 0.20 mV per 1 µmoles s^{-1} m^{-2}, 0.61 mV per 1 W m^{-2}, stability of < ±3% change over a 1-year period, and an operating temperature of -40˚C to 70˚C (-40˚F to 158˚F).[14] The calibration factors for the Apogee SU-200 are 32.7 µmoles s^{-1} m^{-2} per mV and 10 W m^{-2} per mV. The Apogee SU-200 has a sensitivity of 0.03 mV per 1 µmoles s^{-1} m^{-2}, 0.1 mV per 1 W m^{-2}, stability of < ±10% change over a 1-year period, and an operating temperature of -30˚C to 85˚C (-22˚F to 185˚F).[14]

Apogee Instruments, Ultraviolet Radiation Sensor Service Period and Calibration			
Service Period	Model	Serial #	Calibration Date
Apr. 4, 2017 – Jun. 13, 2019	SU-100	2380	New: Dec. 21, 2016
Jun. 13, 2019 – Apr. 16, 2021	SU-100	2553	New: Nov. 14, 2018
April 16, 2021 - Present	SU-200	1109	LI-COR: Jan. 8, 2021

Figure 3.3.7. *LI-COR, Photosynthetically Active Radiation Service Period and Calibration*

The SU-100 and the SU-200 sensors are connected to differential channel 6 (H red, L black, G shield). The internal Array table designator is 18 for photon flux units (19 for energy flux units), and the 16-bit Floating Point Modbus Address is 40035 (40037 for energy flux units) for instantaneous measurements. For one minute average data, the internal table designator is 33 for flux units (34 for energy flux units), and the 16-bit Floating Point Modbus Address 40065 (40067 for energy flux units).

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 4.1. *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 at grade, 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 4.2.a)* 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/. Most data can be downloaded in ASCII format as one-minute, hourly, and daily mean data *(Figure 4.2.b).*

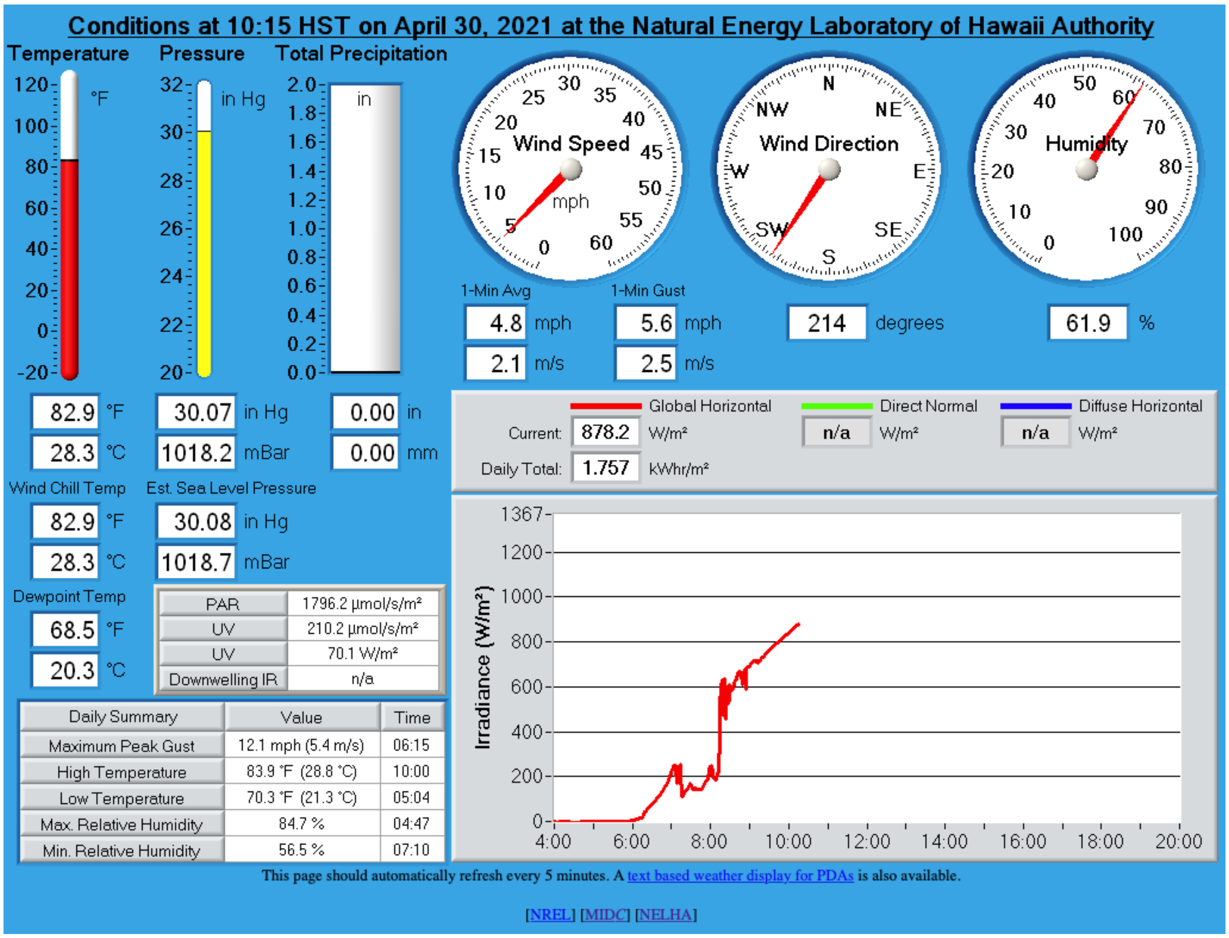
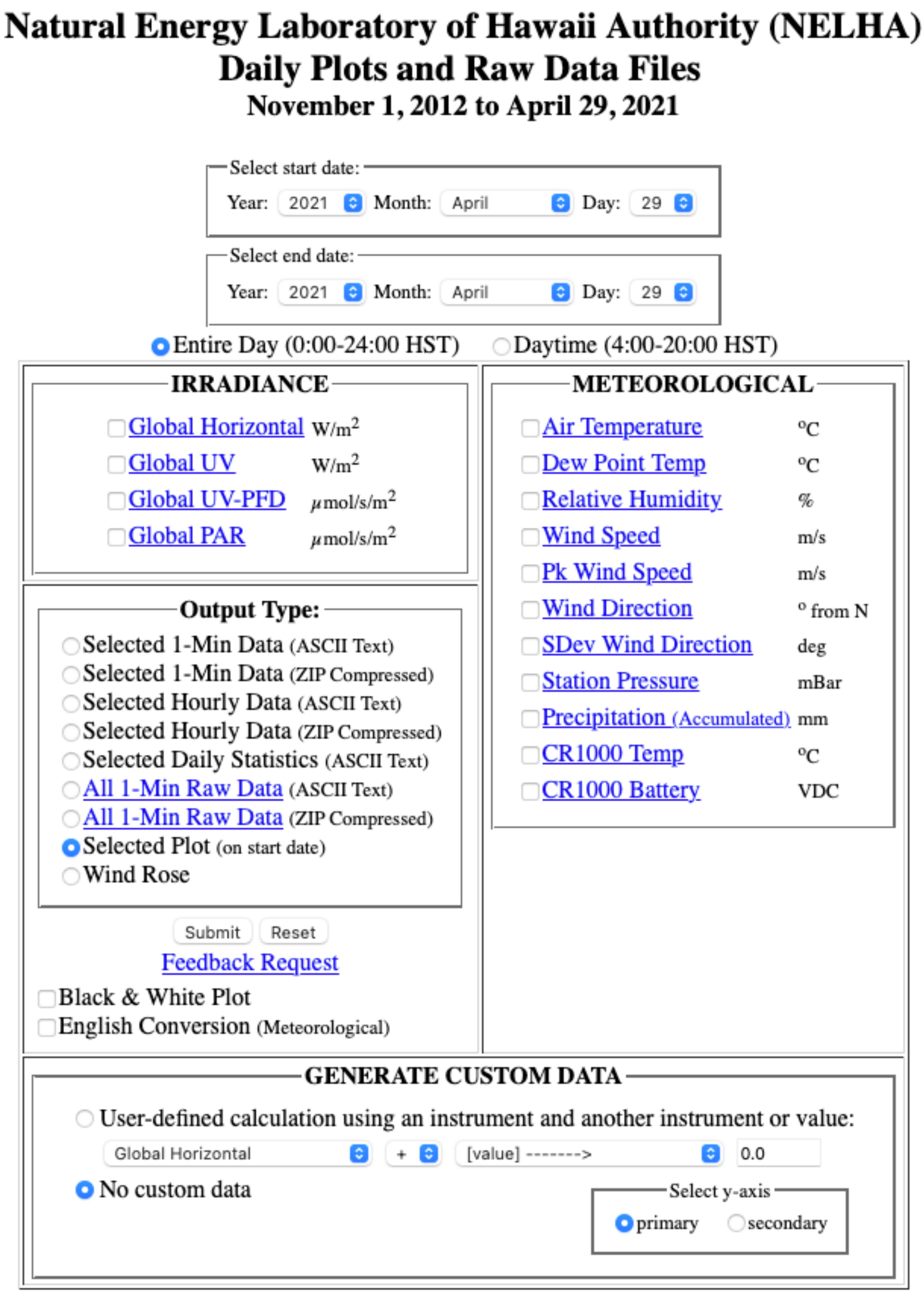


Figure 4.2.a. *Dashboard View from NREL's MIDC web portal*



Natural Energy Laboratory of Hawaii Authority (NELHA)
Daily Plots and Raw Data Files
November 1, 2012 to April 29, 2021

Select start date:
Year: 2021 Month: April Day: 29

Select end date:
Year: 2021 Month: April Day: 29

Entire Day (0:00-24:00 HST) Daytime (4:00-20:00 HST)

IRRADIANCE

Global Horizontal	W/m^2
Global UV	W/m^2
Global UV-PFD	μmol/s/m^2
Global PAR	μmol/s/m^2

METEOROLOGICAL

Air Temperature	°C
Dew Point Temp	°C
Relative Humidity	%
Wind Speed	m/s
Pk Wind Speed	m/s
Wind Direction	° from N
SDev Wind Direction	deg
Station Pressure	mBar
Precipitation (Accumulated)	mm
CR1000 Temp	°C
CR1000 Battery	VDC

Output Type:

- Selected 1-Min Data (ASCII Text)
- Selected 1-Min Data (ZIP Compressed)
- Selected Hourly Data (ASCII Text)
- Selected Hourly Data (ZIP Compressed)
- Selected Daily Statistics (ASCII Text)
- All 1-Min Raw Data (ASCII Text)
- All 1-Min Raw Data (ZIP Compressed)
- Selected Plot (on start date)
- Wind Rose

Submit Reset

Feedback Request

Black & White Plot
English Conversion (Meteorological)

GENERATE CUSTOM DATA

User-defined calculation using an instrument and another instrument or value:
Global Horizontal + [value] -------> 0.0

No custom data

Select y-axis
primary secondary

Figure 4.2.b. *User Selected Daily Plots and Raw Data Files*

5. RESULTS

5.1. AIR TEMPERATURE

Monthly mean air temperature recorded in 2020 followed a narrow seasonal cycle. Mean hourly air temperatures ranged from a low in February of 17.7˚C (63.9˚F) to a high in August of 33.1˚C (91.6˚F). The daily mean air temperature shows very little variation throughout the year with a range from 22.1 to 28.6˚C (71.9 to 83.5˚F). The yearly mean temperature during this period was 26.06˚C (78.91˚F).

Mean Monthly Max/Min Hourly	Jan. 2020	Feb. 2020	Mar. 2020	Apr. 2020	May 2020	Jun. 2020	Jul. 2020	Aug. 2020	Sep. 2020	Oct. 2020	Nov. 2020	Dec. 2020
Mean Temperature (˚C)	24.6	***24.0***	24.4	25.7	26.1	26.7	27.2	***27.6***	27.4	27.3	26.2	25.4
Max Temperature (˚C)	30.0	30.2	30.6	31.9	32.1	32.0	32.3	***33.1***	32.8	33.2	32.3	31.6
Min Temperature (˚C)	18.8	***17.7***	19.0	20.4	21.1	22.4	21.5	22.9	22.0	21.9	20.0	19.9
Mean Temperature (˚F)	76.4	***75.2***	75.9	78.3	79.0	80.1	80.9	***81.7***	81.3	81.2	79.1	77.7
Max Temperature (˚F)	86.0	86.3	87.0	89.3	89.7	89.6	90.2	***91.6***	91.1	91.8	90.2	88.9
Min Temperature (˚F)	65.8	***63.9***	66.3	68.7	70.1	72.3	70.7	73.2	71.6	71.5	67.9	67.8

Figure 5.1.a. *Monthly air temperature result table.*

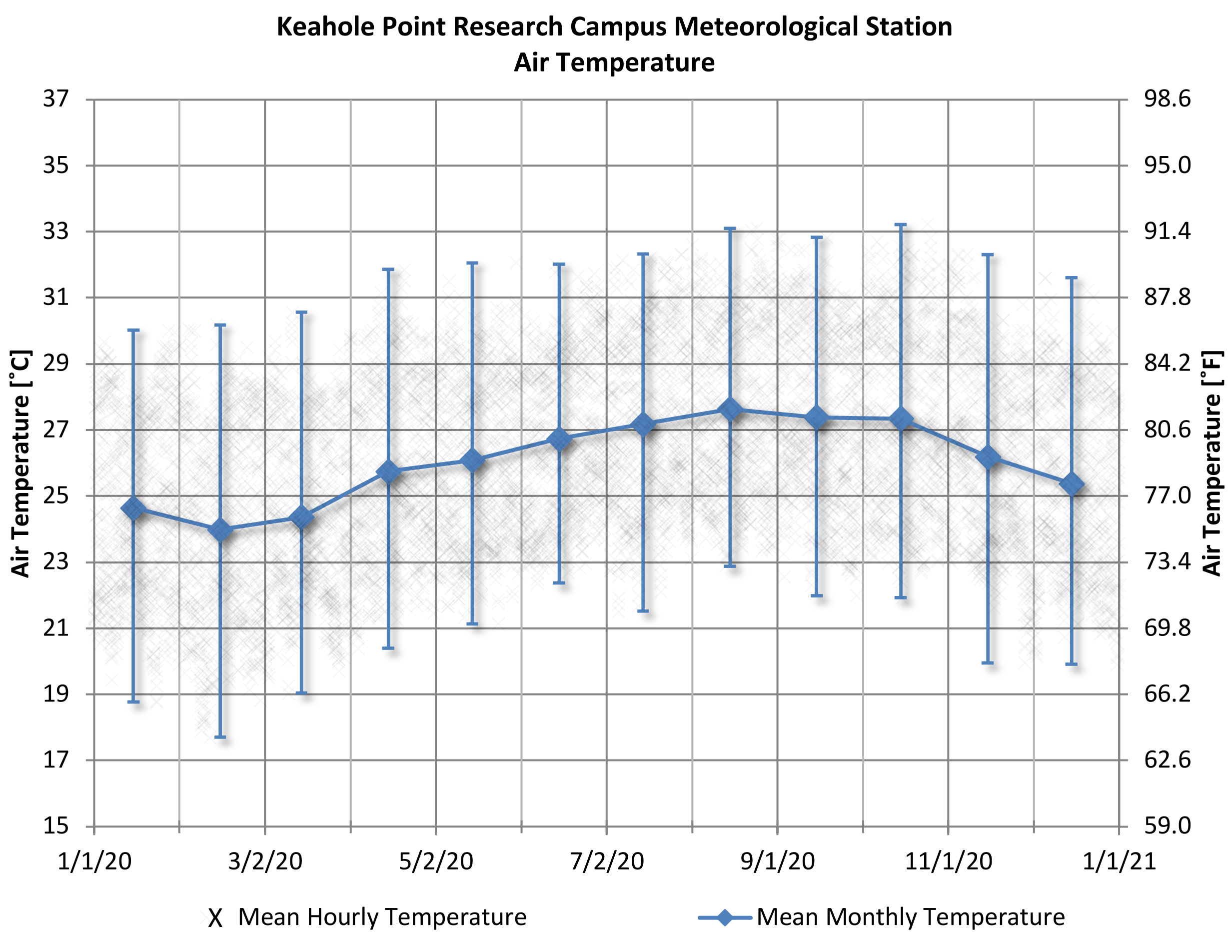


Figure 5.1.b. *Monthly air temperature scatter plot*

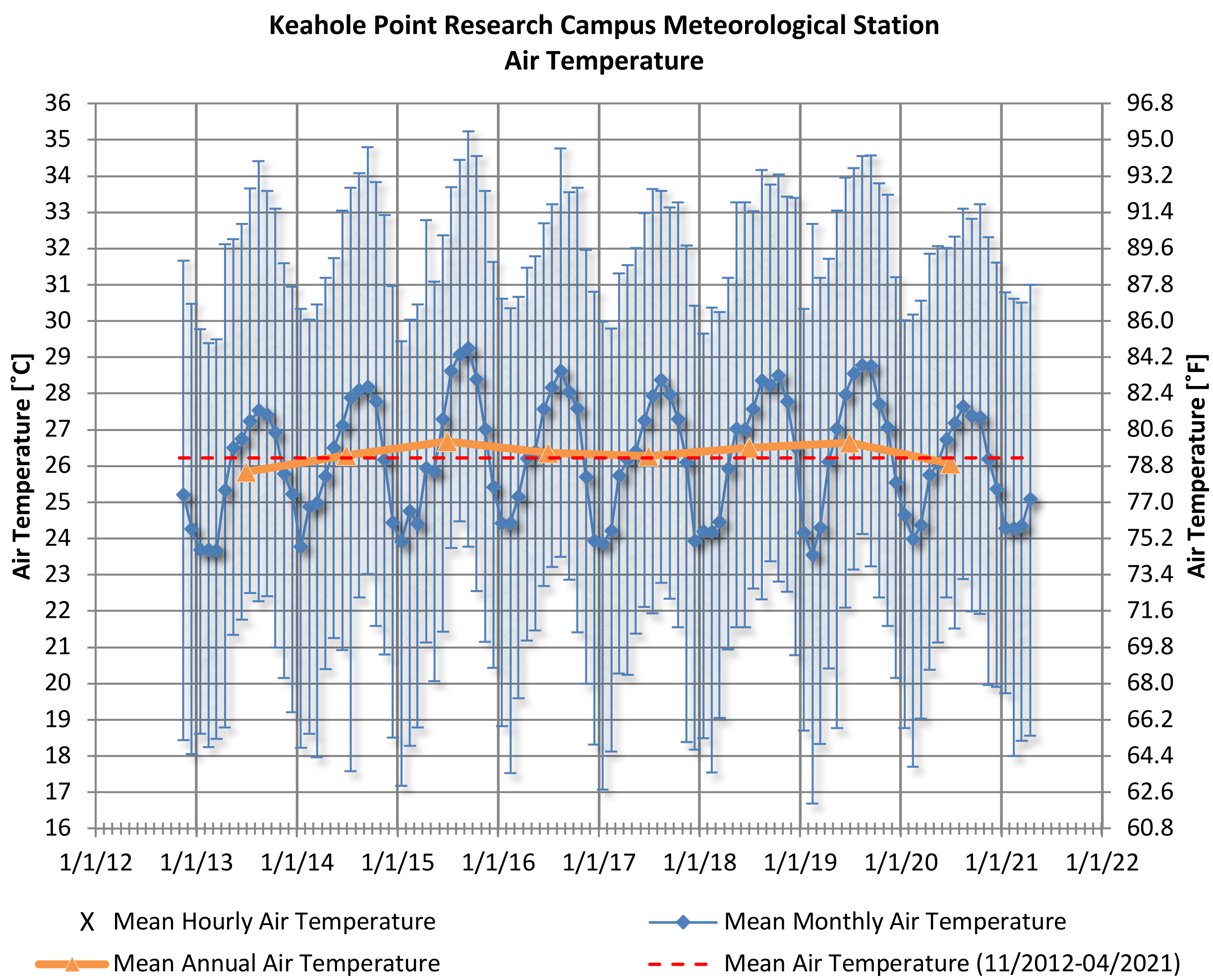


Figure 5.1.c. *Historical air temperature scatter plot*

	Mean Monthly Air Temperature (˚C)												
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
2012											25.25	24.26	-
2013	23.69	23.69	23.68	25.33	26.51	26.75	27.24	27.54	27.42	26.92	25.79	25.24	***25.84***
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
2020	24.64	23.99	24.37	25.75	26.09	26.73	27.18	27.63	27.39	27.34	26.19	25.37	26.06
2021	24.29	24.28	24.35	25.09									-
Mean	***24.10***	**24.21**	**24.60**	**25.80**	**26.47**	**27.21**	**27.90**	***28.31***	**28.16**	**27.69**	**26.34**	**24.96**	**26.22**

Figure 5.1.d. *Historical mean monthly air temperature table (˚C)*

	Mean Monthly Air Temperature (˚F)												
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
2012											77.44	75.67	-
2013	74.65	74.64	74.62	77.60	79.71	80.14	81.03	81.56	81.35	80.46	78.42	77.42	***78.51***
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
2020	76.35	75.18	75.86	78.35	78.96	80.12	80.92	81.74	81.29	81.22	79.14	77.67	78.91
2021	75.71	75.70	75.83	77.16									-
Mean	***75.38***	**75.58**	**76.27**	**78.45**	**79.65**	**80.98**	**82.21**	***82.96***	**82.68**	**81.85**	**79.41**	**76.93**	**79.20**

Figure 5.1.e. *Historical mean monthly air temperature table (˚F)*

5.2. RELATIVE HUMIDITY

Monthly mean relative humidity recorded in 2020 showed a consistent trend through the seasonal cycle. Annual variations in mean hourly relative humidity showed a range from 34.9 to 92.7%. Yearly mean relative humidity during this period was 65.9%.

Mean Monthly Max/Min Hourly	Jan. 2020	Feb. 2020	Mar. 2020	Apr. 2020	May 2020	Jun. 2020	Jul. 2020	Aug. 2020	Sep. 2020	Oct. 2020	Nov. 2020	Dec. 2020
Mean RH (%)	66.1	***63.5***	***68.8***	64.9	66.2	67.6	67.1	64.6	63.2	65.5	67.8	65.9
Max RH (%)	90.5	87.9	91.4	87.7	91.9	***92.7***	90.2	90.2	85.7	83.8	88.6	87.6
Min RH (%)	41.8	***34.9***	39.9	37.4	39.4	42.8	43.1	40.2	41.8	43.5	43.1	40.9

Figure 5.2.a. *Monthly relative humidity result table*

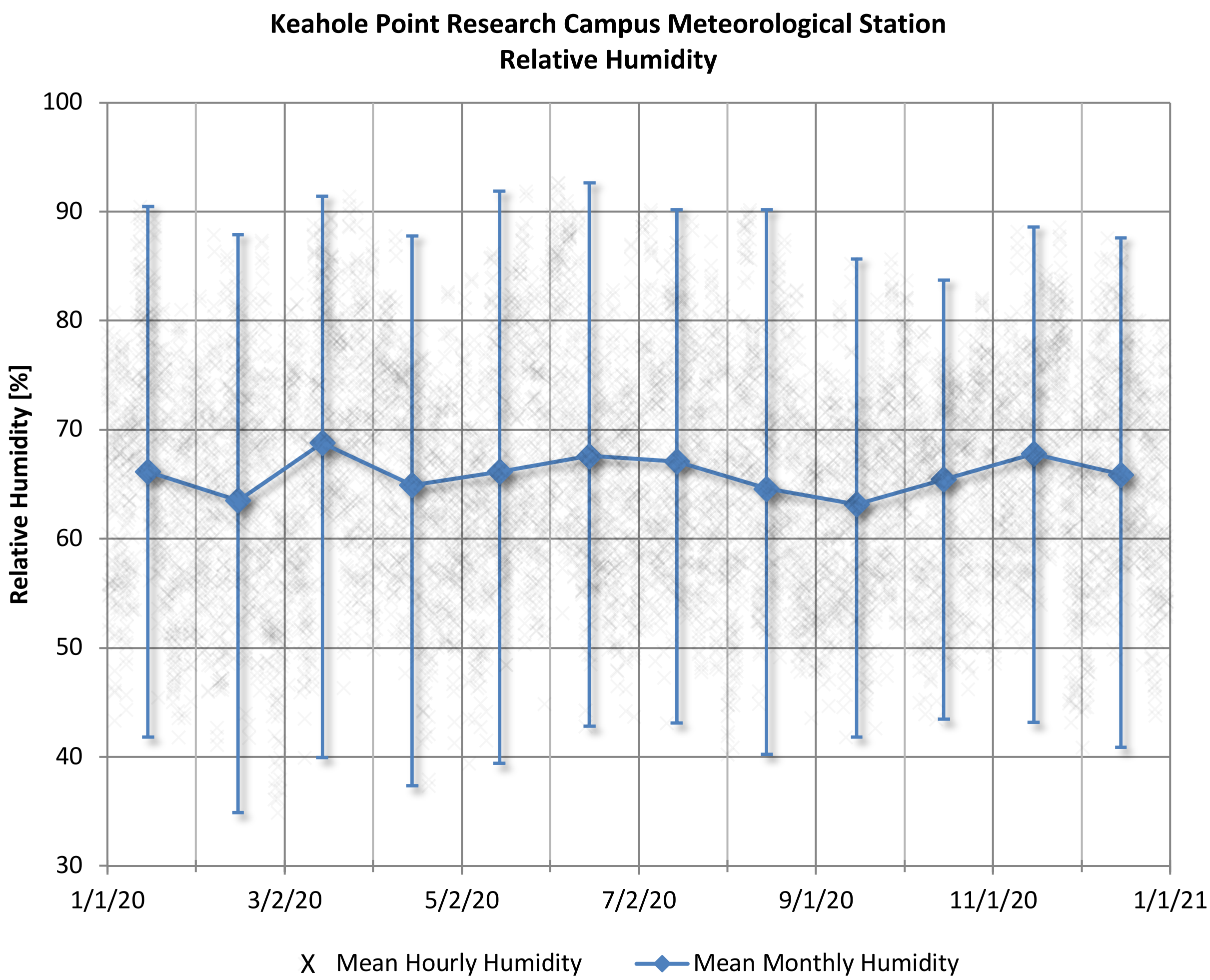


Figure 5.2.b. *Monthly relative humidity scatter plot*

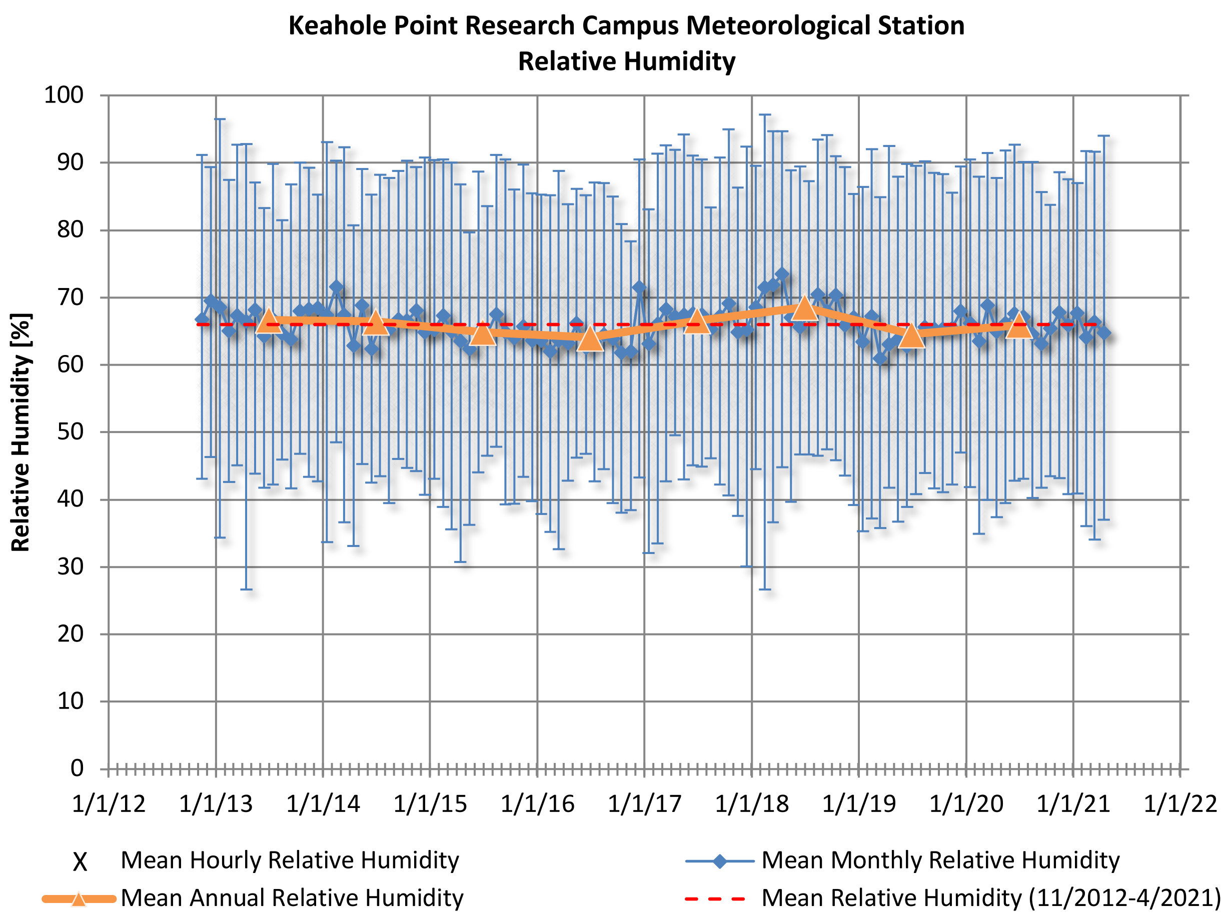


Figure 5.2.c. *Historical relative humidity scatter plot*

	Mean Monthly Relative Humidity (%)												
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
2012											66.8	69.5	-
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	**66.68**
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	**66.47**
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	**64.87**
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	***64.07***
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	**66.59**
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	***68.61***
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	**64.56**
2020	66.1	63.5	68.8	64.9	66.2	67.6	67.1	64.6	63.2	65.5	67.8	65.9	**65.93**
2021	67.7	64.1	66.4	64.7									-
Mean	**65.98**	**66.51**	**66.63**	**65.50**	**66.25**	***64.72***	**65.86**	**66.00**	**65.39**	**66.33**	**66.10**	***67.12***	**65.99**

Figure 5.2.d. *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, 2020, to December 31, 2020. Annual variations in mean hourly dew point temperatures showed a range from 9.4˚C (48.9˚F) to 23.5˚C (74.3˚F). Yearly mean dew point temperature during this period was 19.0˚C (66.2˚F)

Mean Monthly Max/Min Hourly	Jan. 2020	Feb. 2020	Mar. 2020	Apr. 2020	May 2020	Jun. 2020	Jul. 2020	Aug. 2020	Sep. 2020	Oct. 2020	Nov. 2020	Dec. 2020
Mean Dew Point (˚C)	17.7	***16.4***	18.1	18.5	19.1	20.0	***20.4***	20.2	19.6	20.2	19.6	18.4
Max Dew Point (˚C)	21.3	21.5	21.6	21.1	21.7	22.5	23.5	23.4	22.9	23.2	23.1	21.5
Min Dew Point (˚C)	12.1	***9.4***	10.0	12.5	13.5	13.5	15.1	14.4	13.7	16.8	10.8	11.8
Mean Dew Point (˚F)	63.9	***61.5***	64.5	65.2	66.4	68.1	***68.7***	68.3	67.3	68.3	67.3	65.1
Max Dew Point (˚F)	70.4	70.8	70.9	70.0	71.0	72.5	***74.3***	74.2	73.3	73.7	73.6	70.8
Min Dew Point (˚F)	53.7	***48.9***	50.0	54.6	56.4	56.4	59.2	57.9	56.7	62.2	51.5	53.2

Figure 5.3.a. *Monthly dew point temperature result table*

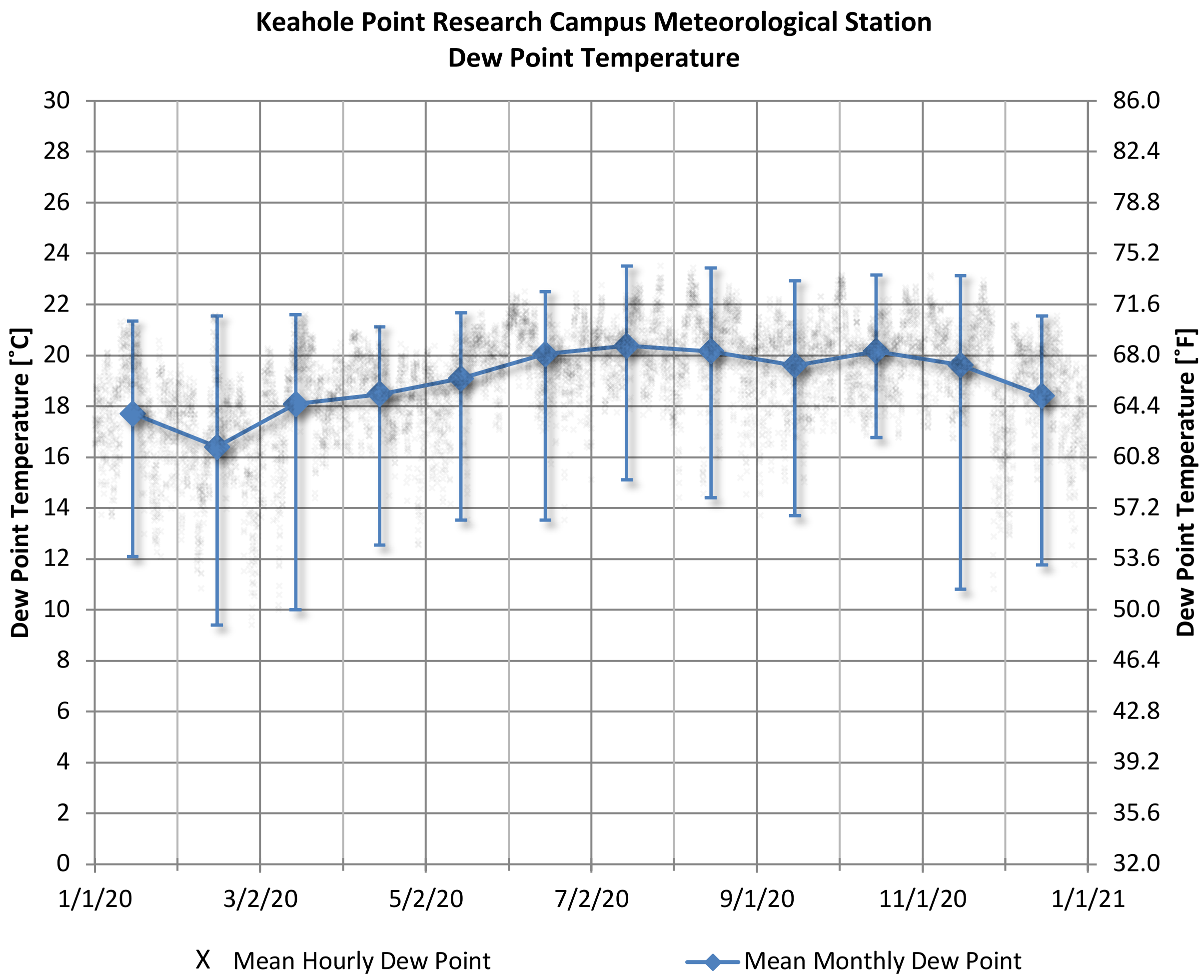


Figure 5.3.b. *Monthly dew point temperature scatter plot*

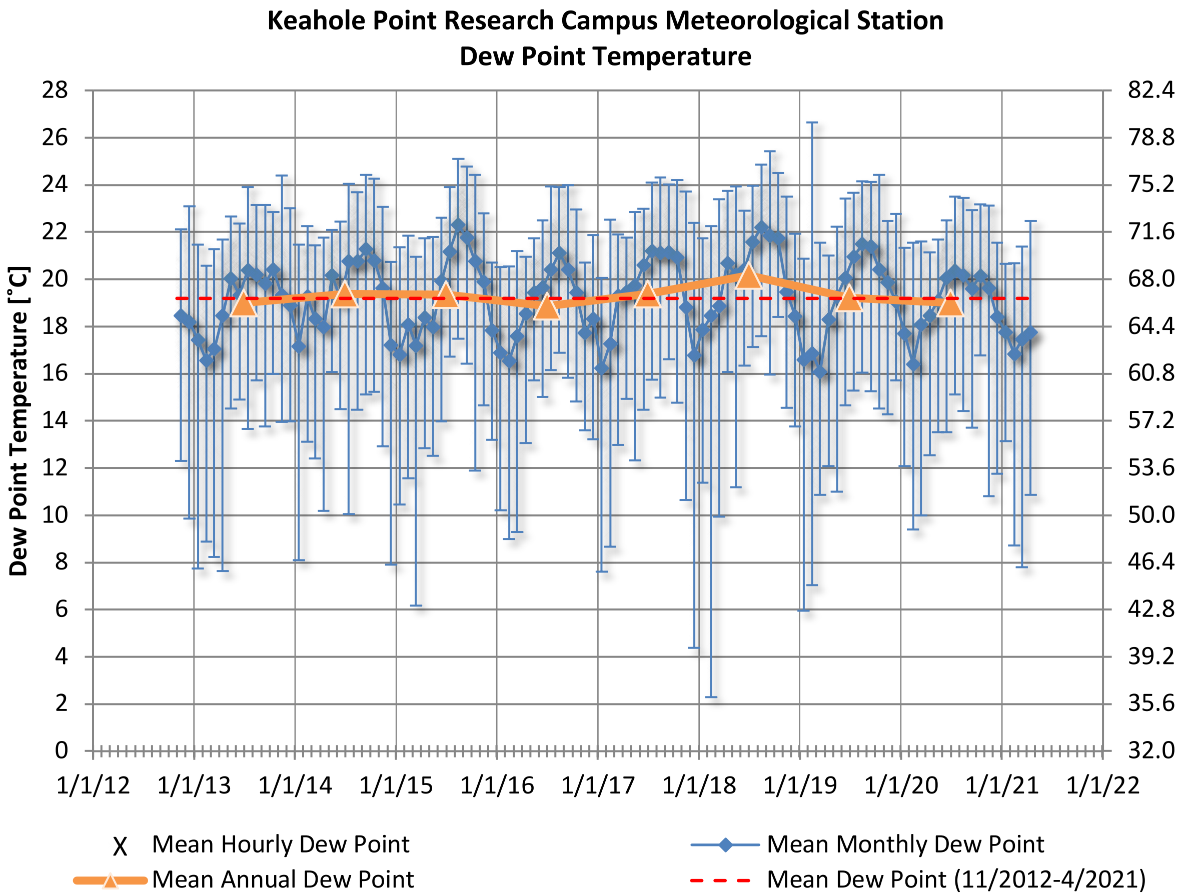


Figure 5.3.c. *Historical dew point temperature scatter plot*

	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	-
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	**19.01**
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	**19.37**
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	**19.34**
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	***18.86***
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	**19.39**
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	***20.16***
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	**19.21**
2020	17.7	16.4	18.1	18.5	19.1	20.0	20.4	20.2	19.6	20.2	19.6	18.4	**19.01**
2021	17.8	16.8	17.5	17.8									-
Mean	***17.16***	**17.37**	**17.77**	**18.67**	**19.49**	**19.90**	**20.85**	***21.17***	**20.91**	**20.58**	**19.20**	**18.13**	**19.20**

Figure 5.3.d. *Historical mean monthly dew point temperature tables (˚C)*

	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	-
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	**66.22**
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	**66.87**
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	**66.82**
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	***65.95***
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	**66.90**
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	***68.29***
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	**66.57**
2020	63.9	61.5	64.5	65.2	66.4	68.1	68.7	68.3	67.3	68.3	67.3	65.1	**66.22**
2021	64.0	62.3	63.4	64.0									-
Mean	***62.89***	**63.26**	**63.98**	**65.61**	**67.07**	**67.83**	**69.53**	***70.10***	**69.64**	**69.05**	**66.57**	**64.63**	**66.56**

Figure 5.3.e. *Historical mean monthly dew point temperature tables (˚F)*

5.4. BAROMETRIC PRESSSURE

Monthly mean barometric pressure recorded during the period of January 1, 2020, to December 31, 2020, 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, 2020, at 1005.9 mBar (29.70 in. of Hg). Annual variation in mean hourly barometric pressure ranged from 1005.9 to 1021.2 mBar (29.70 to 30.16 in. of Hg). The yearly mean barometric pressure during this period was 1015.4 mBar (29.98 in. of Hg).

Mean Monthly Max/Min Hourly	Jan. 2020	Feb. 2020	Mar. 2020	Apr. 2020	May 2020	Jun. 2020	Jul. 2020	Aug. 2020	Sep. 2020	Oct. 2020	Nov. 2020	Dec. 2020
Mean Barometric Pressure (mBar)	1015.8	1014.8	1016.4	1016.2	***1017.0***	1015.9	1014.7	***1014.5***	1014.7	1013.1	1015.6	1015.9
Max Barometric Pressure (mBar)	***1021.2***	1020.8	***1021.2***	1020.6	1021.2	1019.6	1017.1	1017.5	1018.1	1016.6	1019.3	1020.4
Min Barometric Pressure (mBar)	1009.0	***1005.9***	1011.7	1010.7	1013.8	1012.8	1011.5	1011.7	1009.8	1009.6	1011.9	1010.9
Mean Barometric Pressure (in. of Hg)	30.00	29.97	30.01	30.01	***30.03***	30.00	29.96	***29.96***	29.96	29.92	29.99	30.00
Max Barometric Pressure (in. of Hg)	***30.16***	30.14	***30.16***	30.14	30.15	30.11	30.04	30.05	30.06	30.02	30.10	30.13
Min Barometric Pressure (in. of Hg)	29.80	***29.70***	29.88	29.84	29.94	29.91	29.87	29.88	29.82	29.81	29.88	29.85

Figure 5.4.a. *Monthly barometric pressure result table*

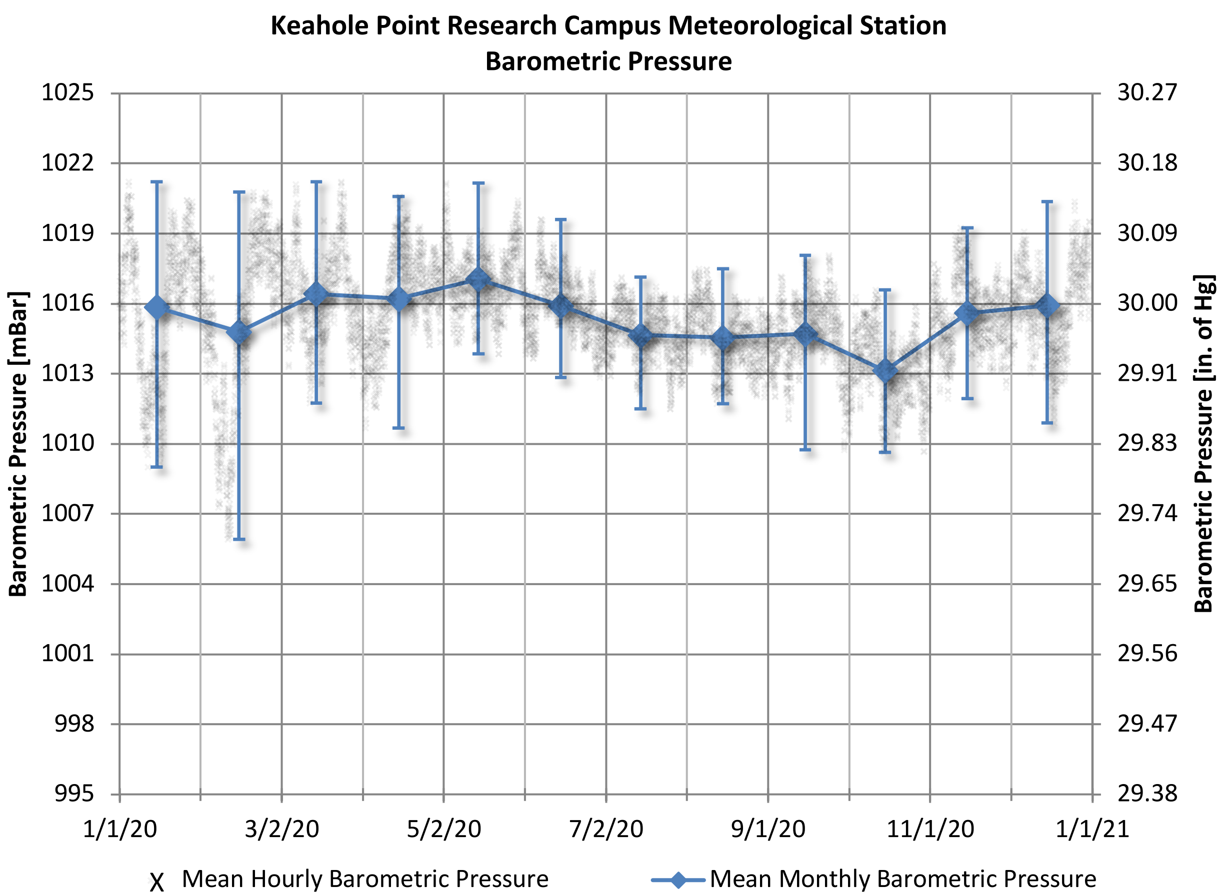


Figure 5.4.b. *Monthly barometric pressure scatter plot*

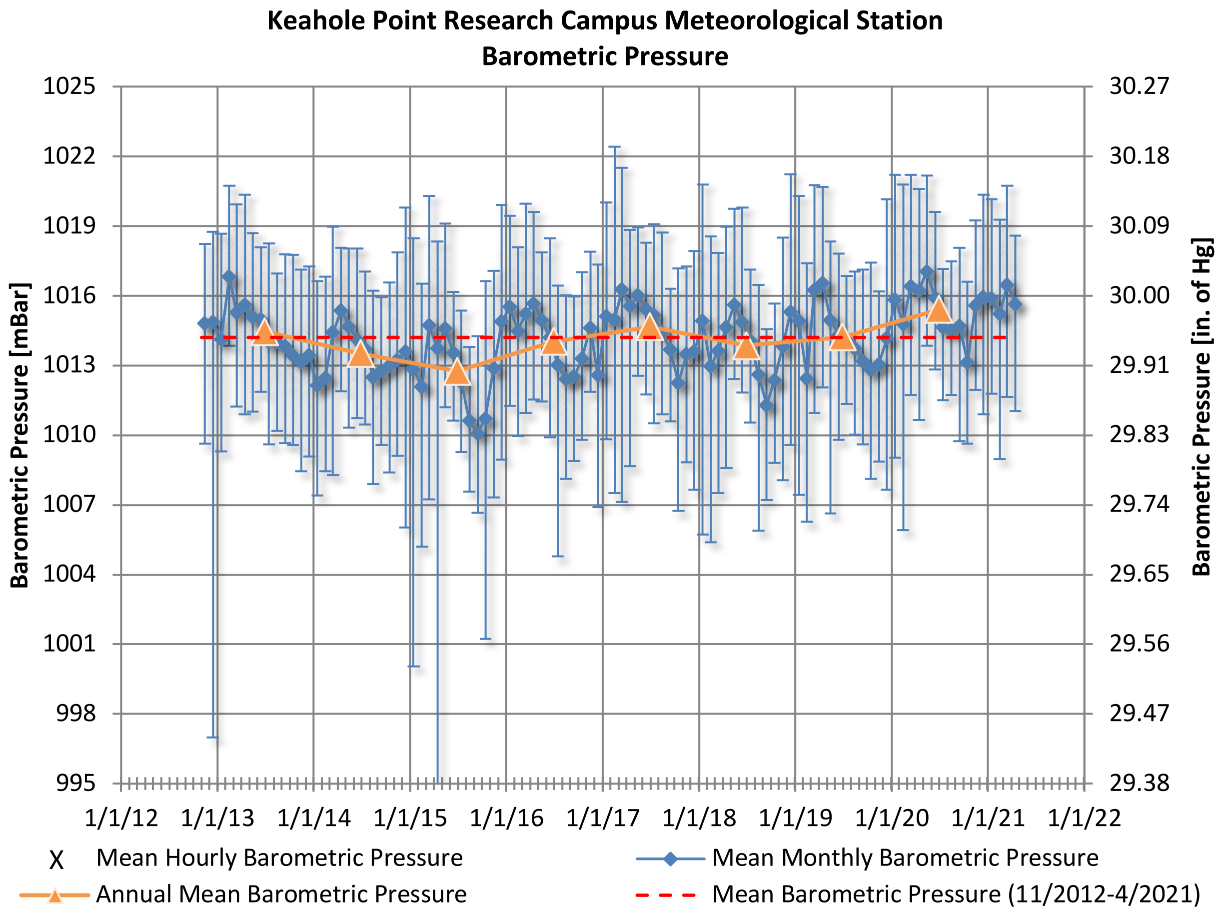


Figure 5.4.c. *Historical barometric pressure scatter plot*

	Mean Monthly Barometric Pressure (mBar)												
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
2012											1014.8	1014.9	-
2013	1014.1	1016.8	1015.3	1015.6	1015.1	1015.0	1014.1	1014.0	1013.8	1013.4	1013.1	1013.4	**1014.5**
2014	1012.1	1012.5	1014.4	1015.4	1014.7	1014.1	1013.7	1012.5	1012.8	1013.0	1013.2	1013.6	**1013.5**
2015	1012.8	1012.1	1014.7	1013.7	1014.6	1013.5	1012.3	1010.6	***1010.1***	1010.7	1012.9	1014.9	***1012.8***
2016	1015.5	1014.5	1015.2	1015.7	1014.9	1014.2	1013.0	1012.4	1012.5	1013.3	1014.6	1012.6	**1014.0**
2017	1015.1	1015.0	1016.3	1015.6	1016.0	1015.4	1015.2	1014.4	1013.7	1012.3	1013.5	1013.6	**1014.7**
2018	1014.9	1013.0	1013.6	1014.7	1015.6	1014.9	1014.1	1012.6	1011.3	1012.4	1013.8	1015.3	**1013.8**
2019	1014.9	1012.4	1016.2	1016.5	1015.0	1014.3	1014.1	1013.7	1013.2	1012.8	1013.1	1014.2	**1014.2**
2020	1015.8	1014.8	1016.4	1016.2	***1017.0***	1015.9	1014.7	1014.5	1014.7	1013.1	1015.6	1015.9	***1015.4***
2021	1015.9	1015.2	1016.5	1015.7									-
Mean	**1014.6**	**1014.0**	**1015.4**	***1015.4***	**1015.4**	**1014.7**	**1013.9**	**1013.1**	**1012.8**	1012.6	**1013.9**	**1014.3**	**1014.2**

Figure 5.4.d. *Historical mean monthly Barometric Pressure tables (mBar)*

	Mean Monthly Barometric Pressure (in. of Hg)												
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
2012											29.97	29.97	-
2013	29.95	30.03	29.98	29.99	29.98	29.97	29.94	29.94	29.94	29.93	29.92	29.93	**29.96**
2014	29.89	29.90	29.96	29.98	29.96	29.95	29.93	29.90	29.91	29.91	29.92	29.93	**29.93**
2015	29.91	29.89	29.96	29.94	29.96	29.93	29.89	29.84	***29.83***	29.85	29.91	29.97	***29.91***
2016	29.99	29.96	29.98	29.99	29.97	29.95	29.91	29.90	29.90	29.92	29.96	29.90	**29.94**
2017	29.98	29.97	30.01	29.99	30.00	29.99	29.98	29.96	29.93	29.89	29.93	29.93	**29.96**
2018	29.97	29.91	29.93	29.96	29.99	29.97	29.95	29.90	29.86	29.90	29.94	29.98	**29.94**
2019	29.97	29.90	30.01	30.02	29.97	29.95	29.95	29.94	29.92	29.91	29.92	29.95	**29.95**
2020	30.00	29.97	30.01	30.01	***30.03***	30.00	29.96	29.96	29.96	29.92	29.99	30.00	***29.98***
2021	30.00	29.98	30.02	29.99									-
Mean	**29.96**	**29.94**	**29.98**	***29.99***	**29.98**	**29.96**	**29.94**	**29.92**	**29.91**	***29.90***	**29.94**	**29.95**	**29.95**

Figure 5.4.e. *Historical mean monthly Barometric Pressure tables (in. of Hg)*

5.5. WIND SPEED

Monthly mean wind speed recordings in 2020 was relatively consistent through the seasonal cycle with a mean yearly wind speed of 2.40 m/s (5.36 mph). A maximum mean hourly wind speed was recorded on January 17, 2020, at 9.3 m/s (20.9 mph). Annual variation in mean hourly wind speed ranged from 0.09 to 9.3 m/s (0.21 to 20.9 mph).

Mean Monthly Max/Min Hourly	Jan. 2020	Feb. 2020	Mar. 2020	Apr. 2020	May 2020	Jun. 2020	Jul. 2020	Aug. 2020	Sep. 2020	Oct. 2020	Nov. 2020	Dec. 2020
Mean Wind Speed (m/s)	2.4	***2.6***	2.4	2.2	2.6	2.4	2.6	2.5	2.5	***2.1***	2.2	2.2
Max. Wind Speed (m/s)	***9.3***	9.3	7.7	7.2	6.9	5.7	6.5	5.4	7.7	5.5	7.9	8.5
Min. Wind Speed (m/s)	0.2	0.4	0.2	0.2	0.1	0.1	0.3	0.2	***0.1***	0.2	0.3	0.4
Mean Wind Speed (mph)	5.3	***5.9***	5.4	5.0	5.7	5.5	5.8	5.7	5.6	***4.6***	5.0	4.9
Max. Wind Speed (mph)	***20.9***	20.8	17.2	16.1	15.4	12.7	14.5	12.0	17.2	12.3	17.8	19.0
Min. Wind Speed (mph)	0.5	0.9	0.5	0.4	0.3	0.2	0.6	0.4	***0.3***	0.5	0.6	0.8

Figure 5.5.a. *Monthly wind speed result table*

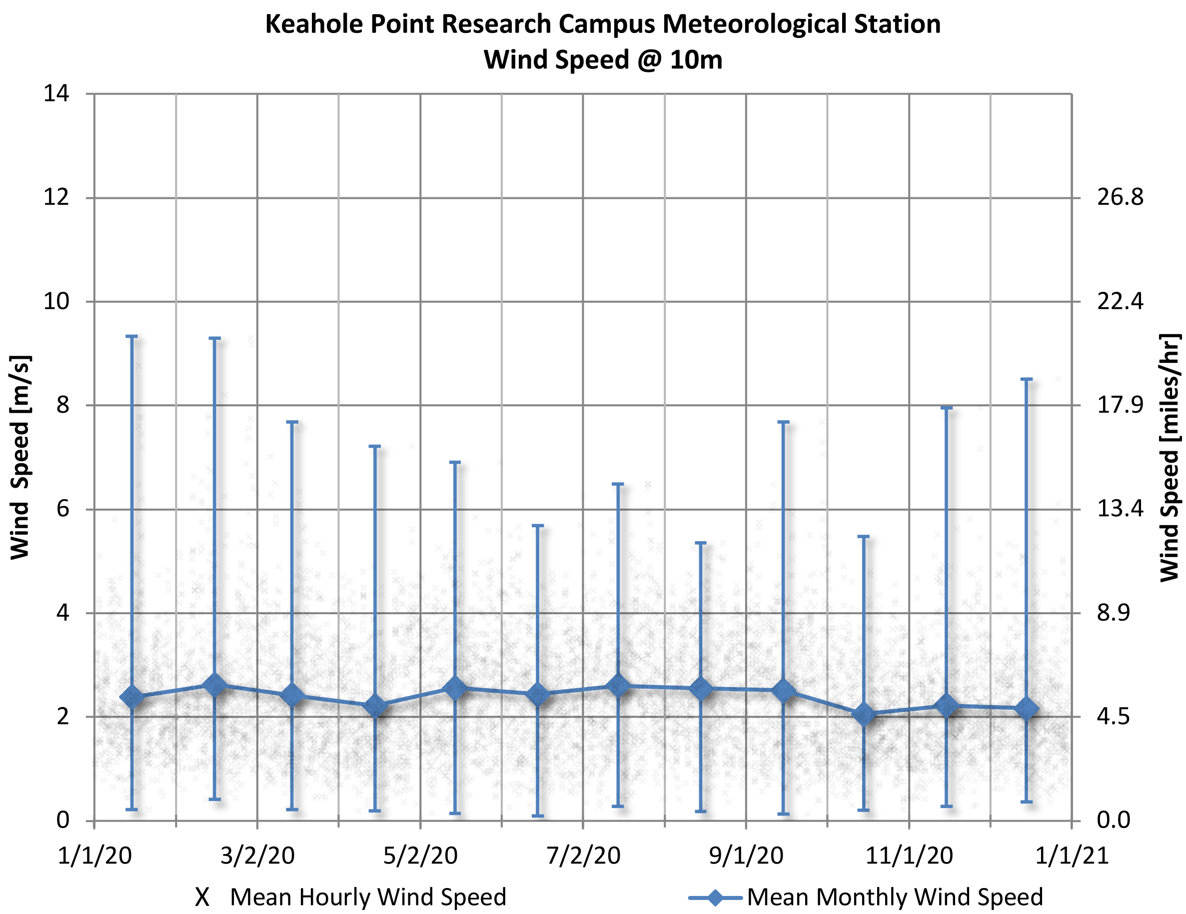


Figure 5.5.b. *Monthly wind speed scatter plot*

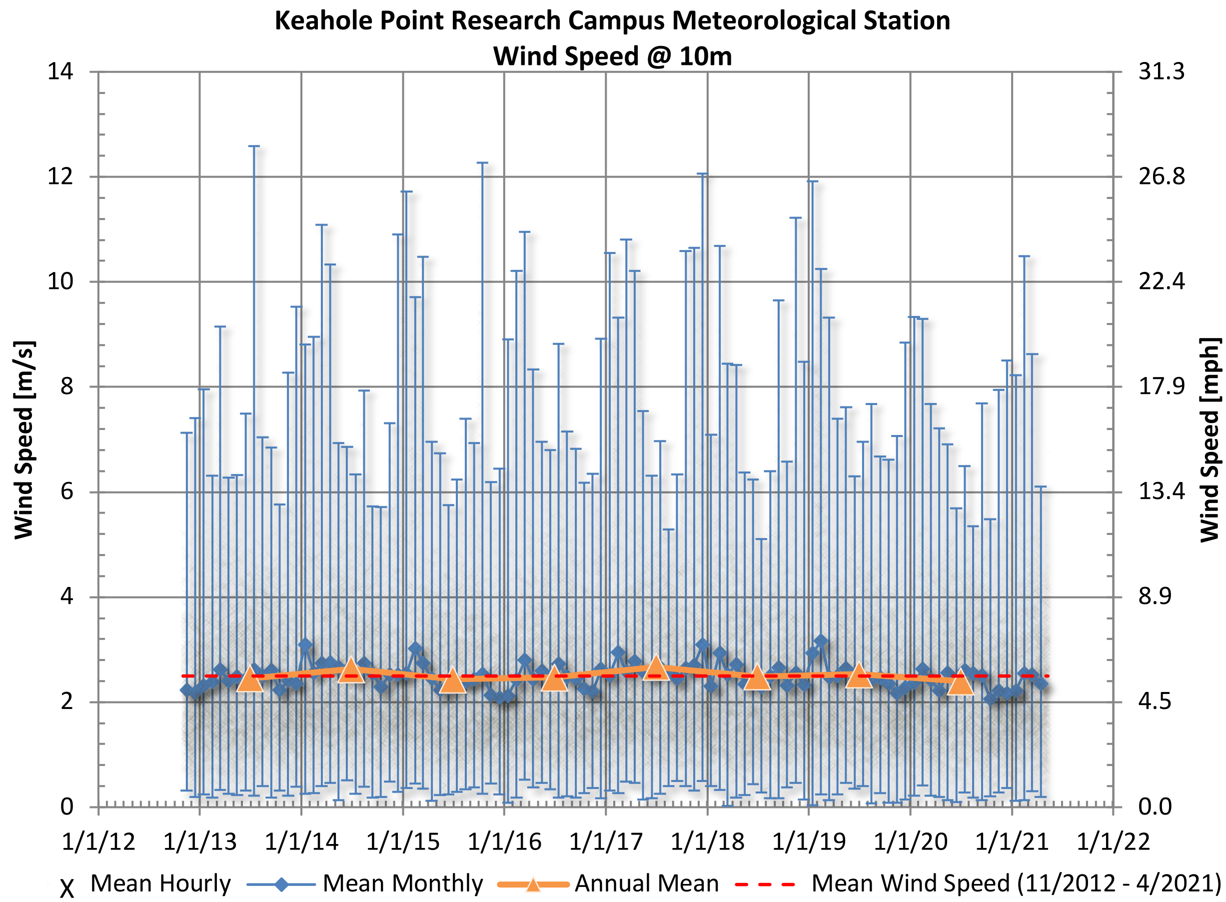


Figure 5.5.c. *Historical wind speed scatter plot*

	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	2.27	**2.53**
2020	2.38	2.63	2.42	2.22	2.56	2.44	2.61	2.55	2.51	***2.06***	2.22	2.17	***2.40***
2021	2.22	2.55	2.53	2.35									
Mean	**2.49**	***2.74***	**2.60**	**2.51**	**2.51**	**2.47**	**2.53**	**2.52**	**2.51**	***2.33***	**2.35**	**2.35**	**2.50**

Figure 5.5.d. *Historical mean monthly wind speed at 10m tables (m/s)*

	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	5.08	**5.66**
2020	5.32	5.87	5.41	4.96	5.73	5.45	5.83	5.70	5.61	***4.61***	4.97	4.85	***5.36***
2021	4.96	5.71	5.65	5.26									
Mean	**5.57**	***6.12***	**5.83**	**5.62**	**5.62**	**5.52**	**5.66**	**5.64**	**5.62**	***5.22***	**5.26**	**5.26**	**5.59**

Figure 5.5.e. *Historical mean monthly wind speed at 10m tables (mph)*

5.6. PEAK WIND SPEED

Monthly peak wind speed recorded during 2020 was consistent through the seasonal cycle with a mean yearly peak wind speed of 3.1 m/s (6.97 mph). A mean peak hourly wind speed was recorded on February 28, 2020, at 12.34 m/s (27.6 mph). A mean peak one minute wind speed of 16.14 m/s (36.13 mph) was recorded on December 26 at 8:01 pm. Annual variation in one minute peak wind speed ranged from 0.00 to 16.14 m/s (0.00 to 36.13 mph).

Mean Monthly Max/Min Minute	Jan. 2020	Feb. 2020	Mar. 2020	Apr. 2020	May 2020	Jun. 2020	Jul. 2020	Aug. 2020	Sep. 2020	Oct. 2020	Nov. 2020	Dec. 2020
Mean Peak Wind Speed (m/s)	3.07	***3.47***	3.17	2.95	3.33	3.16	3.34	3.28	3.23	***2.71***	2.86	2.80
Max. Peak Wind Speed (m/s)	12.1	***12.3***	10.8	9.68	8.45	7.54	8.72	6.97	10.1	6.96	10.9	11.5
Min. Peak Wind Speed (m/s)	0.36	0.74	0.32	0.25	0.24	***0.18***	0.45	0.28	0.23	0.40	0.41	0.59
Mean Peak Wind Speed (mph)	6.88	***7.76***	7.09	6.60	7.46	7.07	7.47	7.33	7.22	***6.06***	6.40	6.27
Max. Peak Wind Speed (mph)	27.1	***27.6***	24.2	21.7	18.9	16.9	19.5	15.6	22.5	15.6	24.3	25.7
Min. Peak Wind Speed (mph)	0.81	1.65	0.71	0.57	0.54	***0.40***	1.00	0.63	0.51	0.90	0.93	1.32

Figure 5.6.a. *Monthly peak wind speed result table*

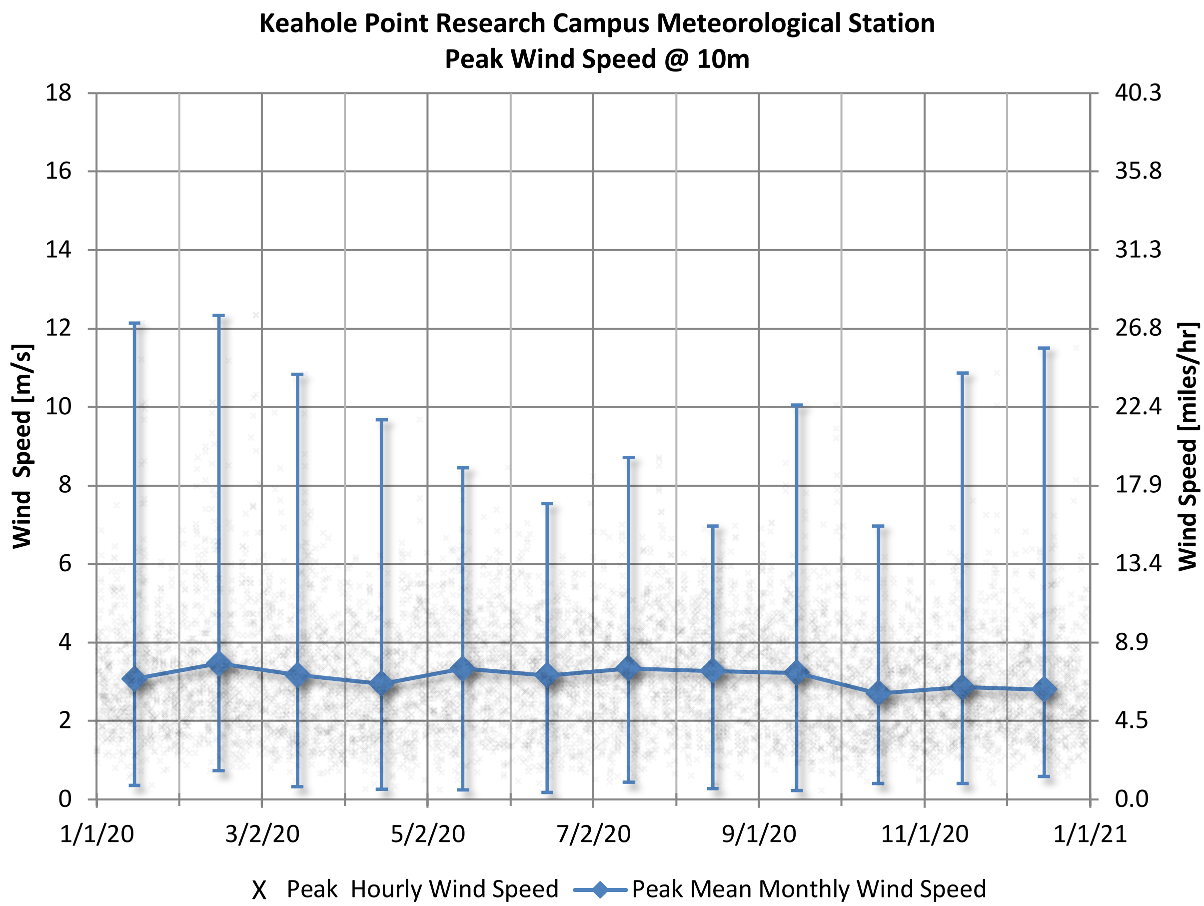


Figure 5.6.b. *Monthly peak wind speed scatter plot*

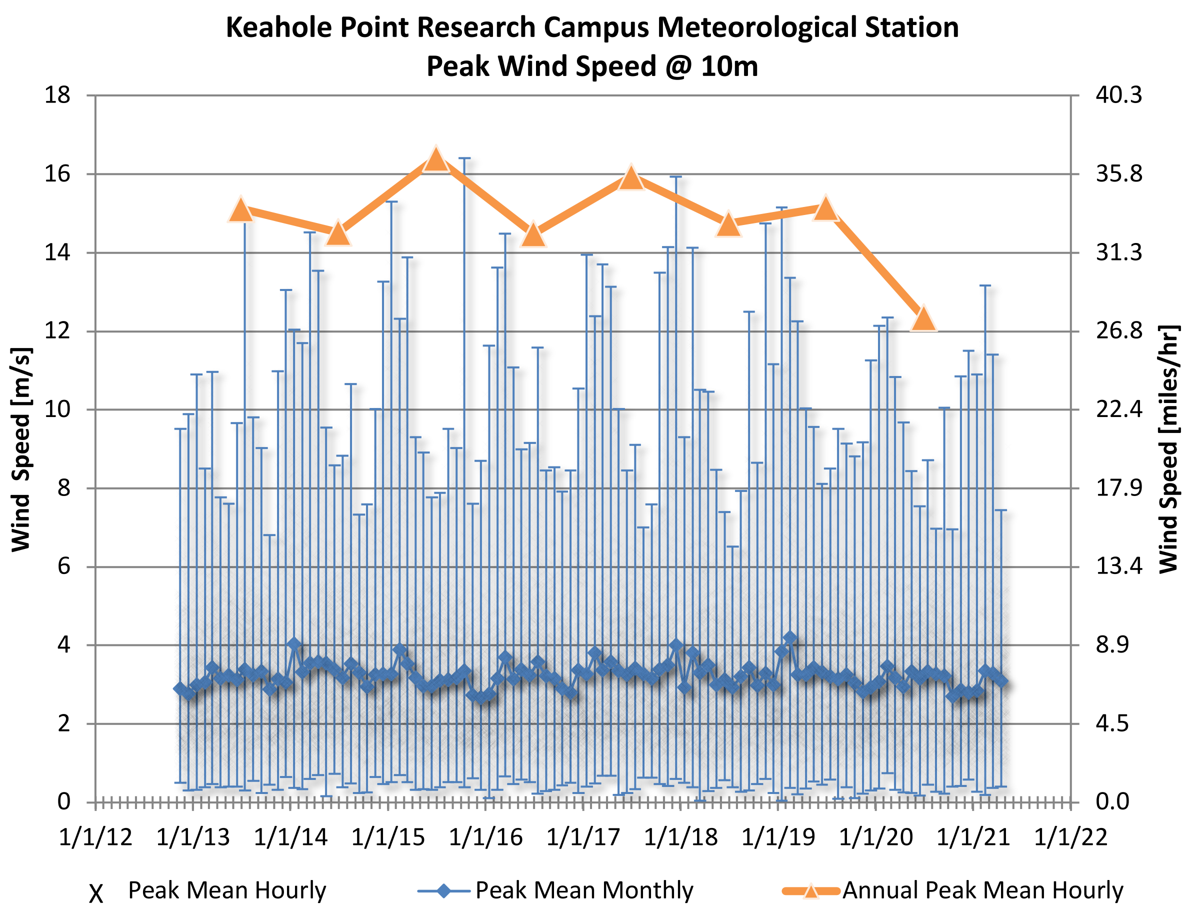


Figure 5.6.c. *Historical monthly peak wind speed scatter plot*

	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	-
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	11.26	**15.16**
2020	12.13	12.34	10.83	9.68	8.45	7.54	8.72	6.97	10.05	6.96	10.86	11.50	***12.34***
2021	10.90	13.17	11.40	7.44									-
Mean	**12.37**	**12.39**	***12.50***	**10.27**	**8.95**	**8.34**	**9.53**	***8.73***	**9.15**	**9.58**	**10.61**	**10.96**	**14.56**

Figure 5.6.d. *Historical monthly peak wind speed at 10m tables (m/s)*

	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	-
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	25.18	**33.90**
2020	27.14	27.61	24.22	21.66	18.90	16.87	19.50	15.58	22.49	15.57	24.29	25.72	***27.61***
2021	24.39	29.47	25.50	16.64									-
Mean	**27.67**	**27.72**	***27.97***	**22.98**	**20.01**	**18.65**	**21.33**	***19.53***	**20.47**	**21.44**	**23.74**	**24.51**	**31.97**

Figure 5.6.e. *Historical monthly peak wind speed at 10m tables (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 169.9˚ from the north. Wind direction at Keahole Point exhibits a typical land-sea directional profile and has two distinct bearings averaging at 218.9° from the north in the daytime hours (8 am – 8 pm) and 121.1° from the north during the nighttime hours (8 pm – 8 am).

Monthly	Jan. 2020	Feb. 2020	Mar. 2020	Apr. 2020	May 2020	Jun. 2020	Jul. 2020	Aug. 2020	Sep. 2020	Oct. 2020	Nov. 2020	Dec. 2020
Mean Wind Direction (° from north)	159.5	164.4	166.2	188.4	174.1	177.1	167.3	168.0	167.8	186.4	159.5	160.4
Day Wind Direction (° from north)	214.5	224.0	221.1	246.8	211.6	213.9	205.8	207.5	212.9	249.9	206.2	212.8
Night Wind Direction (° from north)	104.3	106.0	111.2	130.5	136.9	140.4	128.5	128.5	122.8	122.9	112.6	107.9

Figure 5.7.a. *Monthly wind direction results table*

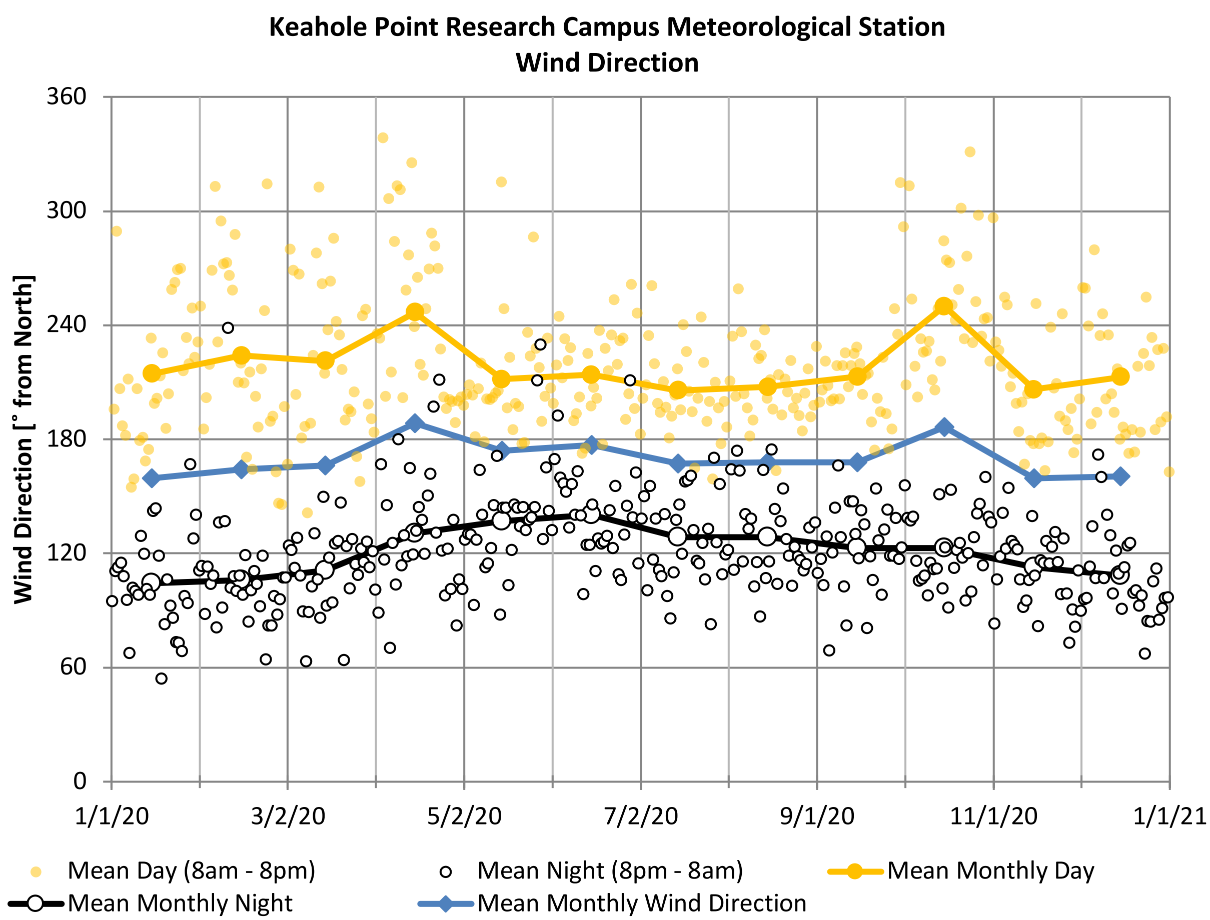


Figure 5.7.b. *Monthly wind direction scatter plot*

5.8. ACCUMULATED PRECIPATATION

Yearly accumulated precipitation recorded during 2020 was 310.5 mm (12.2 in.). Eight precipitation events were greater than 12.7 mm (> 0.5 in.) and accounted for 46% of the accumulated precipitation for the year. One precipitation event on May 22, 2020, recorded a daily accumulation that was greater than 25.4 mm (> 1 in.) and accounted for 9% of the accumulated precipitation for the year.

Monthly	Jan. 2020	Feb. 2020	Mar. 2020	Apr. 2020	May 2020	Jun. 2020	Jul. 2020	Aug. 2020	Sep. 2020	Oct. 2020	Nov. 2020	Dec. 2020
Accumulated Precipitation (mm)	33.8	34.8	65.5	5.0	41.8	33.5	25.5	18.8	27.3	0.8	11.5	12.5
Accumulated Precipitation (in.)	1.3	1.4	2.6	0.2	1.6	1.3	1.0	0.7	1.1	0.0	0.5	0.5
%	11%	11%	21%	2%	13%	11%	8%	6%	9%	0%	4%	4%

Figure 5.8.a. *Monthly accumulated precipitation table*

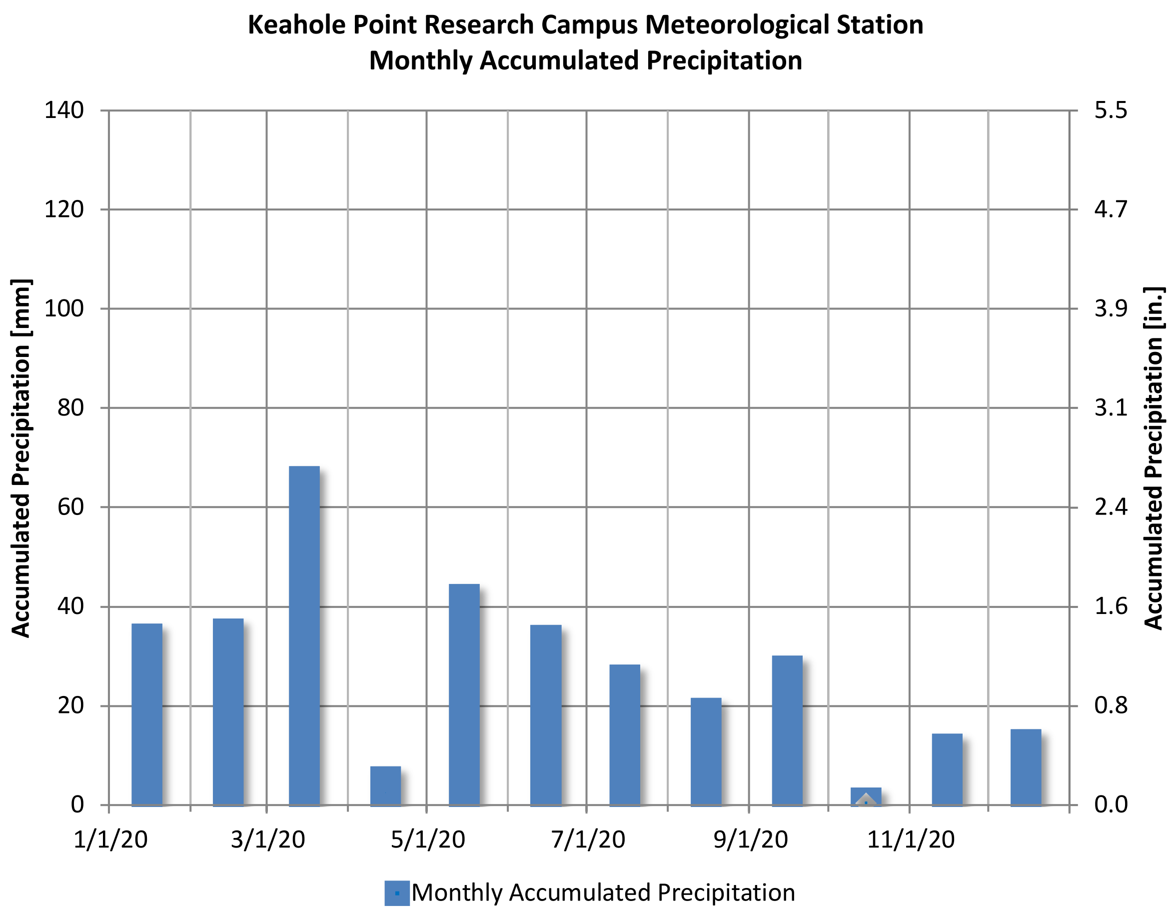


Figure 5.8.b. *Monthly accumulated precipitation bar chart*

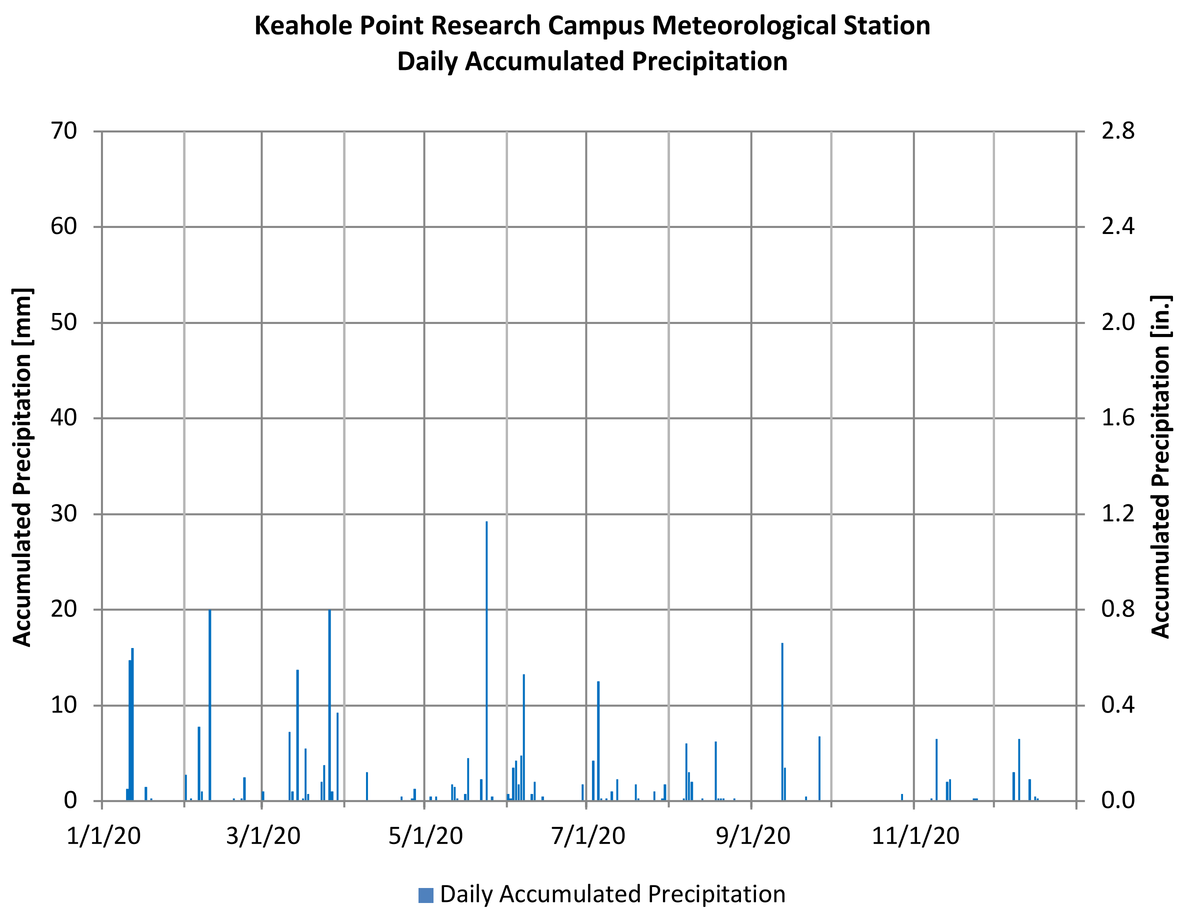


Figure 5.8.c. *Daily accumulated precipitation bar chart*

	Total Monthly Precipitation [mm]												
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
2012											4.4	***0.0***	**-**
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**
2020	33.8	34.8	65.5	5.0	41.8	33.5	25.5	18.8	27.3	0.8	11.5	12.5	**310.5**
2021	48.5	42.5	89.0	29.3									-
Mean	**30.1**	**43.7**	***47.4***	**29.5**	**25.6**	**18.1**	***15.5***	**27.3**	**30.3**	**24.4**	**17.5**	**29.8**	**318.2**

Figure 5.8.d. *Historical total monthly precipitation tables (mm)*

	Total Monthly Precipitation [in.]												
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
2012											0.17	***0.00***	-
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***
2020	1.33	1.37	2.58	0.20	1.64	1.32	1.00	0.74	1.07	0.03	0.45	0.49	**12.22**
2021	1.91	1.67	3.50	1.15									-
Mean	**1.19**	**1.72**	***1.87***	**1.16**	**1.01**	**0.71**	***0.61***	**1.08**	**1.19**	**0.96**	**0.69**	**1.17**	**12.53**

Figure 5.8.e. *Historical total monthly precipitation tables (in.)*

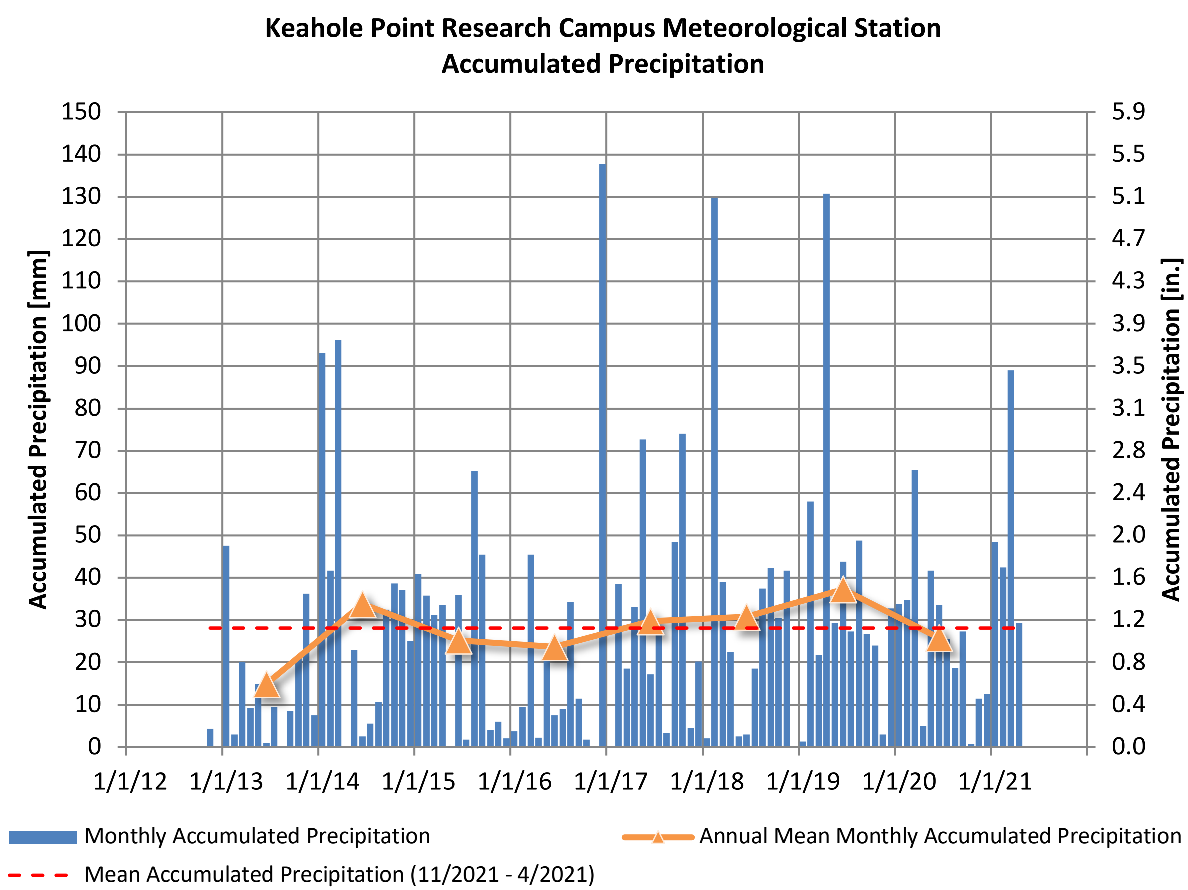


Figure 5.8.f. *Historical monthly accumulated precipitation bar chart*

Keahole Point has received a mean annual rainfall of 337.5 mm (13.3 in.) and a mean monthly rainfall of 28.1 mm (1.11 in.) since November 1, 2012.

Mean Monthly 11/2012 – 4/2021	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**Jun.**	**Jul.**	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**
Mean Accumulated Precipitation (mm)	30.1	43.7	47.4	29.5	25.6	18.1	15.5	27.3	30.3	24.4	17.5	29.8
Mean Accumulated Precipitation (in.)	1.19	1.72	1.87	1.16	1.01	0.71	0.61	1.08	1.19	0.96	0.69	1.17
%	8.9%	12.9%	14.0%	8.7%	7.6%	5.3%	4.6%	8.1%	8.9%	7.2%	5.2%	8.8%

Figure 5.8.g. *Historical monthly mean accumulated precipitation table*

Annual Precipitation	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Accumulated Precipitation (mm)	178.8	405.9	302.2	283.5	357.3	369.5	447.3	310.5
Accumulated Precipitation (in.)	7.04	15.97	11.90	11.16	14.06	14.55	17.61	12.22

Figure 5.8.h. *Historical annual accumulated precipitation table*

5.9. GLOBAL HORIZONTAL IRRADIANCE

Yearly total global horizontal irradiance recorded during 2020 measured 2136 kW-hr/m^2. A monthly total maximum global horizontal irradiance was recorded in May 2020 at 209.2 kW-hr/m^2. A monthly total minimum global horizontal irradiance was recorded in November 2020 at 128.6 kW-hr/m^2. The mean daily total global horizontal irradiance in 2020 was 5.85 kW-hr/m^2.

Global Horizontal Irradiance	Jan. 2020	Feb. 2020	Mar. 2020	Apr. 2020	May 2020	Jun. 2020	Jul. 2020	Aug. 2020	Sep. 2020	Oct. 2020	Nov. 2020	Dec. 2020
Monthly Total (kW-hr/m^2)	140.2	156.1	166.8	199.6	***209.2***	200.4	204.6	209.1	199.3	177.3	***128.6***	145.0
Mean Daily Total (kW-hr/m^2)	5.52	6.15	6.57	7.86	***8.24***	7.89	8.05	8.23	7.85	6.98	***5.06***	5.71

Figure 5.9.a. *Monthly total global horizontal irradiance table*

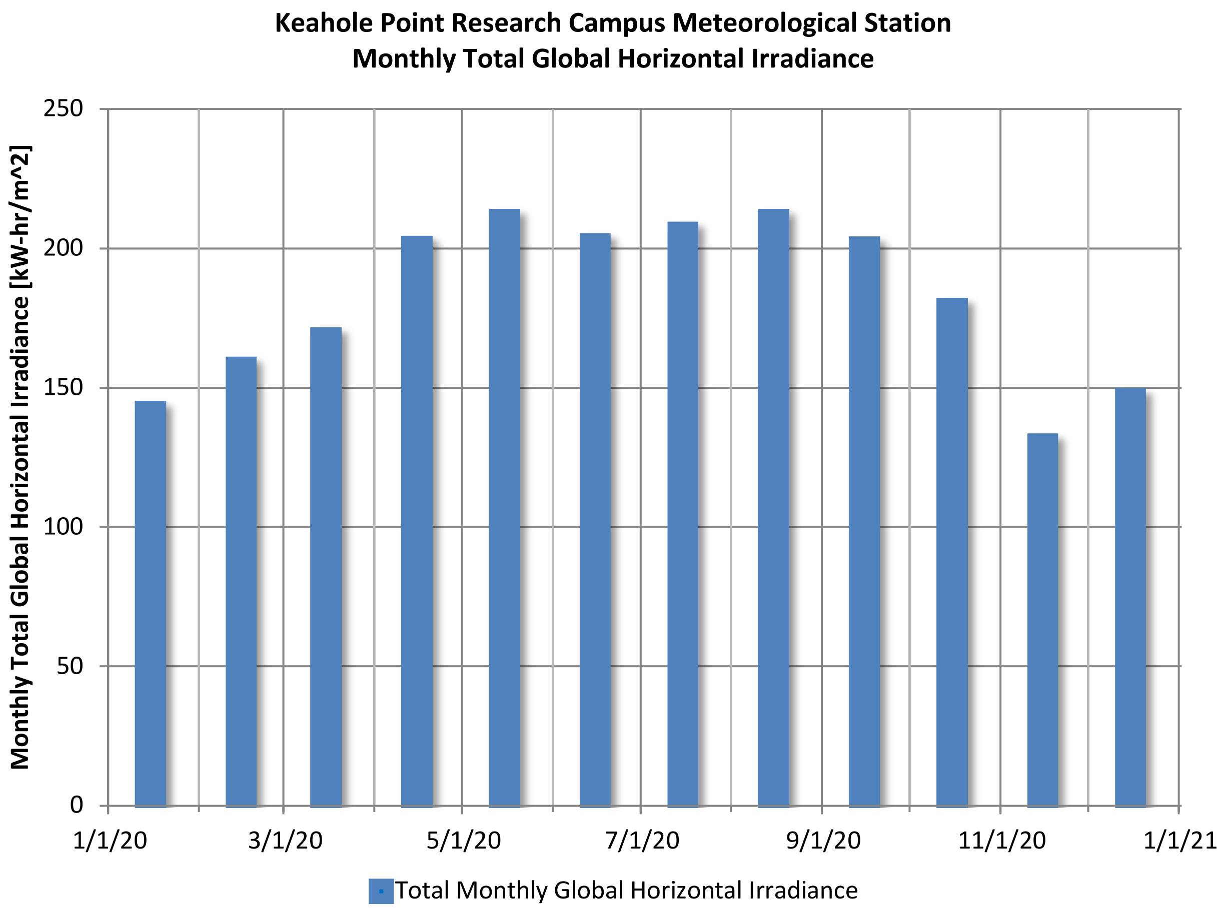


Figure 5.9.b. *Monthly total global horizontal irradiance monthly bar chart*

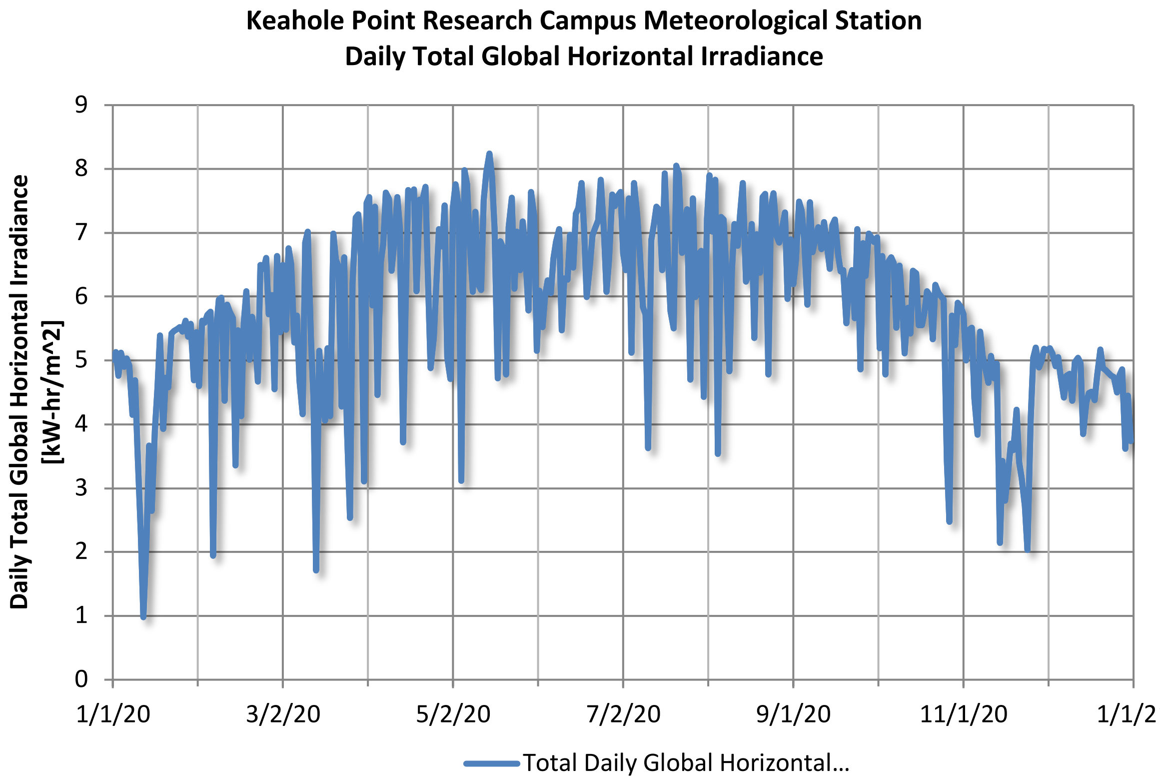


Figure 5.9.c. *Annual total global horizontal irradiance line chart*

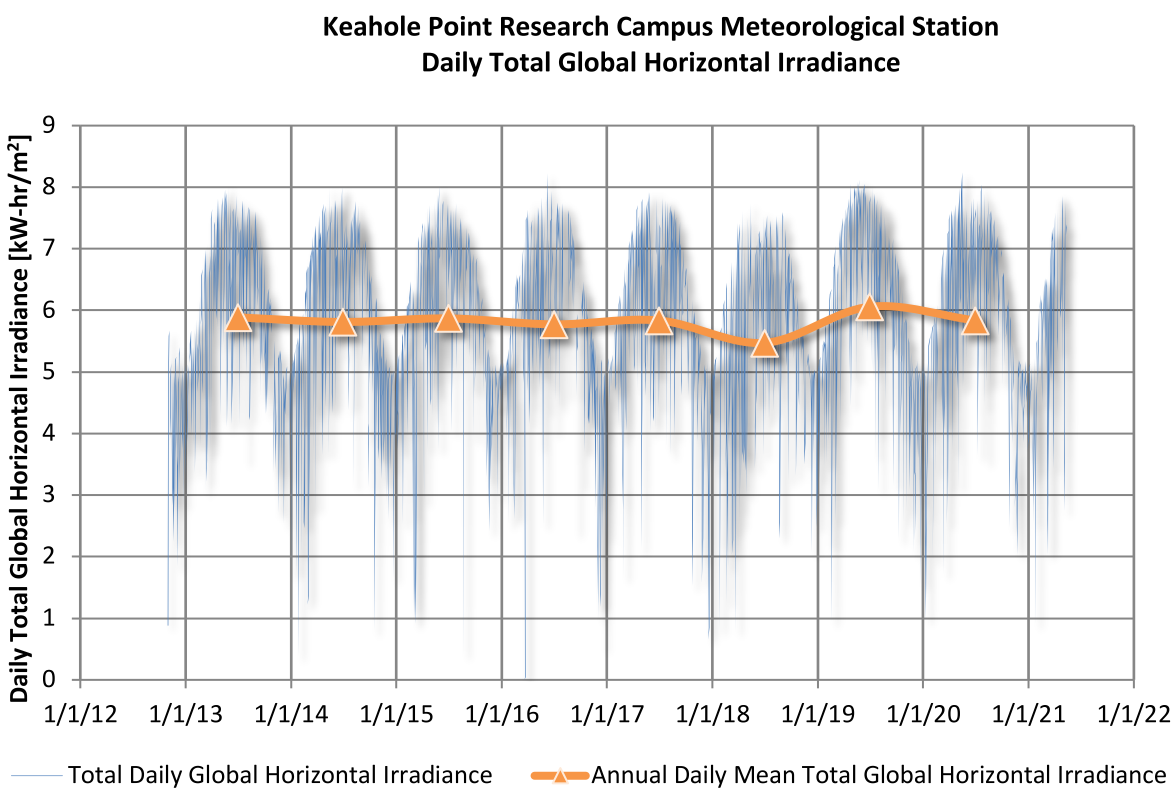


Figure 5.9.d. *Historical daily total global horizontal irradiance line chart*

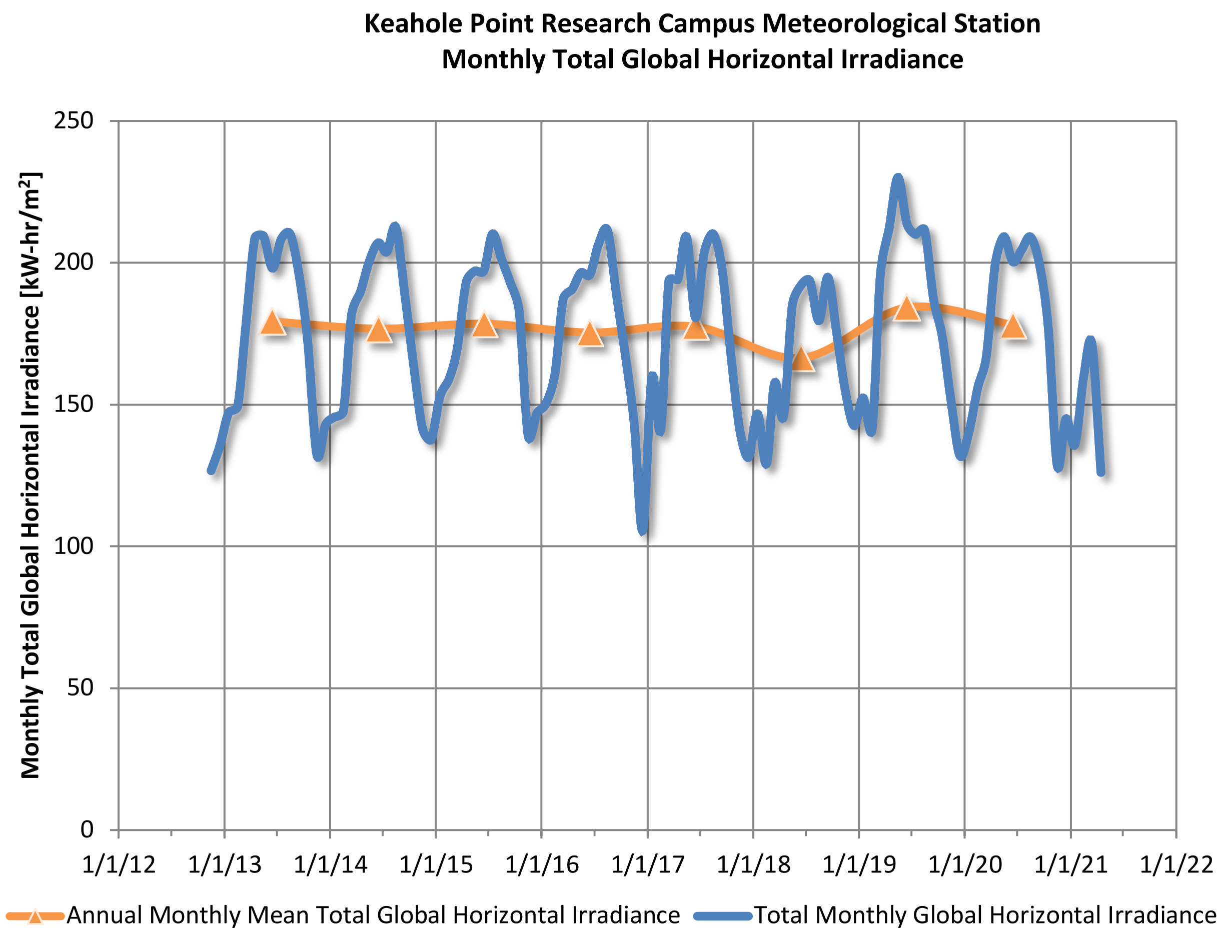


Figure 5.9.e. *Historical monthly total global horizontal irradiance line chart*

	Mean Daily Global Horizontal Irradiance [kW-hr/m^2]												
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
2012											4.2	4.4	-
2013	4.8	5.3	5.7	7.0	6.8	6.6	6.7	6.8	6.5	5.5	4.4	4.6	**5.9**
2014	4.7	5.3	5.9	6.3	6.5	6.9	6.6	6.9	6.3	5.3	4.7	4.4	**5.8**
2015	4.9	5.7	5.5	6.4	6.4	6.6	6.8	6.5	6.4	5.9	4.6	4.7	**5.9**
2016	4.8	5.5	6.0	6.4	6.3	6.5	6.7	6.8	6.3	5.4	4.8	***3.4***	**5.8**
2017	5.1	5.0	6.2	6.5	6.7	6.0	6.6	6.8	6.6	5.4	4.7	4.2	**5.8**
2018	4.7	4.6	5.1	4.9	6.0	6.4	6.2	5.8	6.5	5.7	5.1	4.6	***5.5***
2019	4.9	5.1	6.3	7.1	***7.4***	7.1	6.8	6.8	6.2	5.6	5.0	4.3	***6.1***
2020	4.5	5.4	5.4	6.7	6.7	6.7	6.6	6.7	6.6	5.7	4.3	4.7	**5.8**
2021	4.4	5.7	5.7	4.2									-
Mean	**4.8**	**5.3**	**5.8**	**6.1**	**6.6**	**6.6**	**6.6**	**6.6**	**6.4**	**5.6**	**4.7**	**4.4**	**5.8**

Figure 5.9.f. *Historical monthly mean daily global horizontal irradiance tables (kW-hr/m^2)*

	Mean Monthly Total Global Horizontal Irradiance [kW-hr/m^2]												
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
2012											126.7	135.4	**-**
2013	147.3	149.5	177.9	208.7	209.5	198.1	208.3	210.2	195.6	171.9	132.5	142.9	**179.4**
2014	145.6	147.8	181.7	189.8	200.4	207.0	203.9	212.5	188.9	164.3	141.6	137.7	**176.8**
2015	153.0	159.1	169.7	193.1	197.1	197.2	210.2	201.3	192.8	182.9	139.0	146.9	**178.5**
2016	150.3	160.6	187.1	190.6	196.5	195.8	206.6	211.4	188.8	167.9	143.6	***105.7***	**175.4**
2017	159.3	141.3	193.7	194.2	209.1	180.7	203.6	210.2	197.7	167.8	141.0	131.5	**177.5**
2018	146.7	129.2	157.6	145.9	184.9	192.2	193.6	179.6	194.9	175.6	154.4	142.6	***166.4***
2019	152.3	141.4	195.4	212.4	***230.1***	213.8	210.0	211.6	187.3	174.0	150.9	132.0	***184.3***
2020	140.2	156.1	166.8	199.6	209.2	200.4	204.6	209.1	199.3	177.3	128.6	145.0	**178.0**
2021	136.0	160.2	171.4	126.1									**-**
Mean	**147.9**	**149.5**	**177.9**	**184.5**	**204.6**	**198.2**	**205.1**	***205.7***	**193.2**	**172.7**	**139.8**	***135.5***	**177.0**

Figure 5.9.g. *Historical total monthly global horizontal irradiance tables (kW-hr/m^2)*

5.10. PHOTOSYNTHETICALLY ACTIVE RADIATION

Photosynthetically active radiation (PAR) recorded annual total daily mean for 2020 of 11.45 mmol-hr/s/m^2. During this period a monthly total daily mean maximum was recorded in May 2020 of 15.81 mmol-hr/s/m^2. A monthly mean total daily minimum of 2.18 mmol-hr/s/m^2 was recorded in January 2020. 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. 2020	Feb. 2020	Mar. 2020	Apr. 2020	May 2020	Jun. 2020	Jul. 2020	Aug. 2020	Sep. 2020	Oct. 2020	Nov. 2020	Dec. 2020
Total Monthly	270.1	308.2	328.8	388.8	407.9	389.7	397.9	405.5	385.6	348.2	258.1	290.0
Monthly Mean Total Daily	8.71	10.63	10.61	12.96	13.16	12.99	12.84	13.08	12.85	11.23	8.60	9.36

Figure 5.10.a. *Total monthly and monthly mean total daily PAR table*

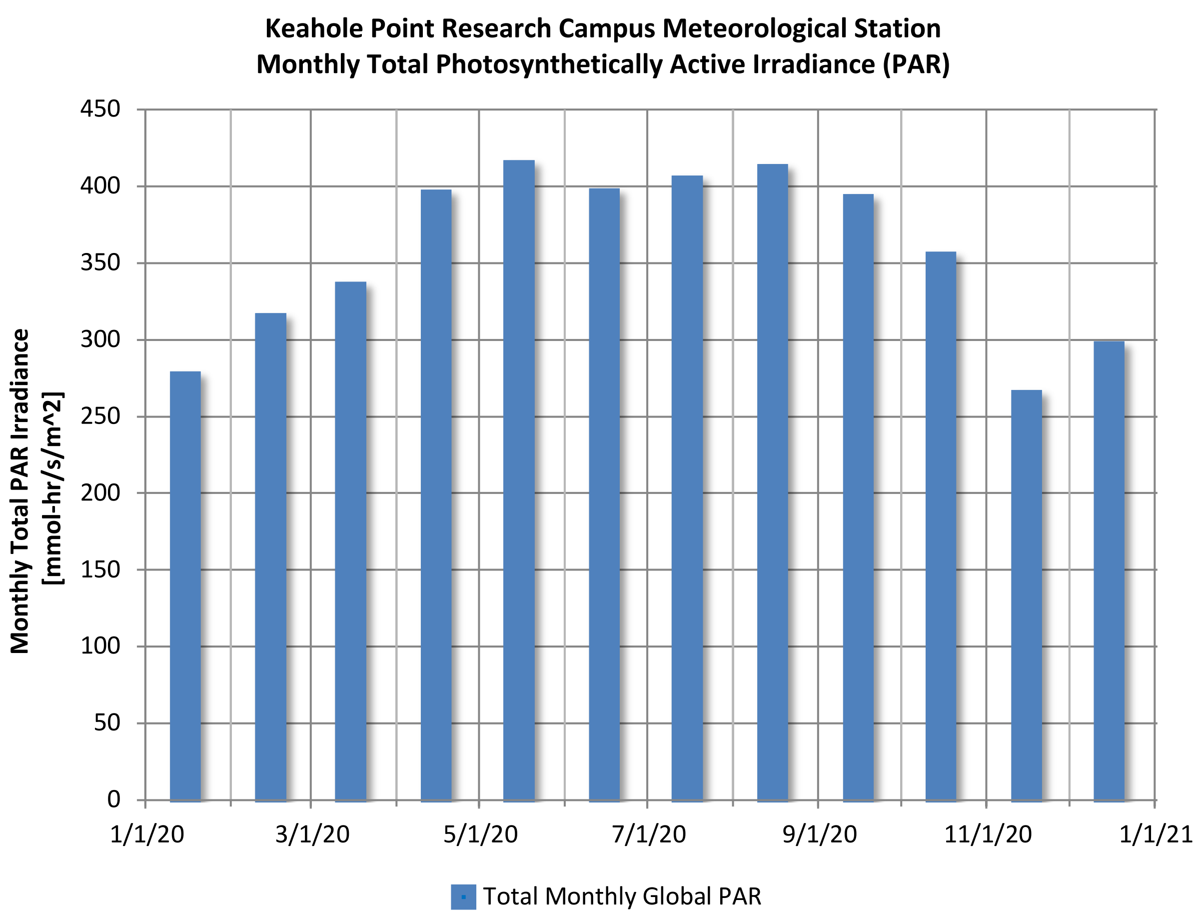


Figure 5.10.b. *Monthly total PAR bar chart*

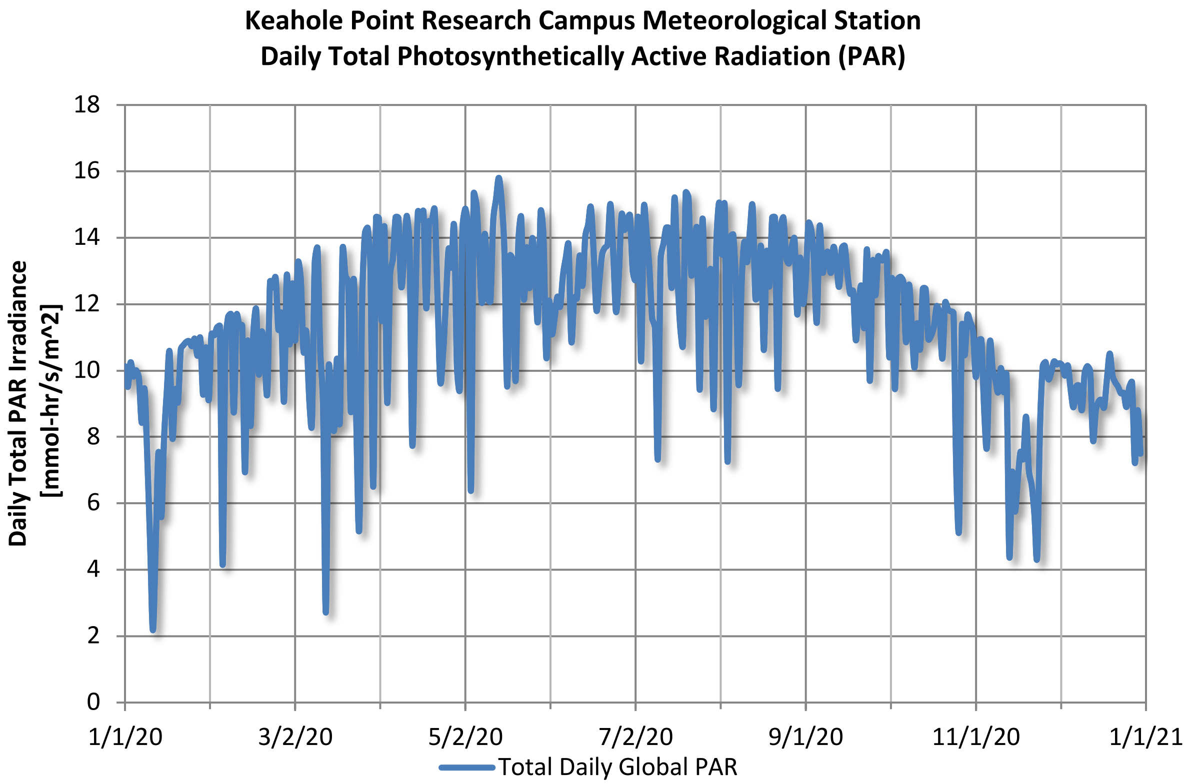


Figure 5.10.c. *Daily PAR line charts*

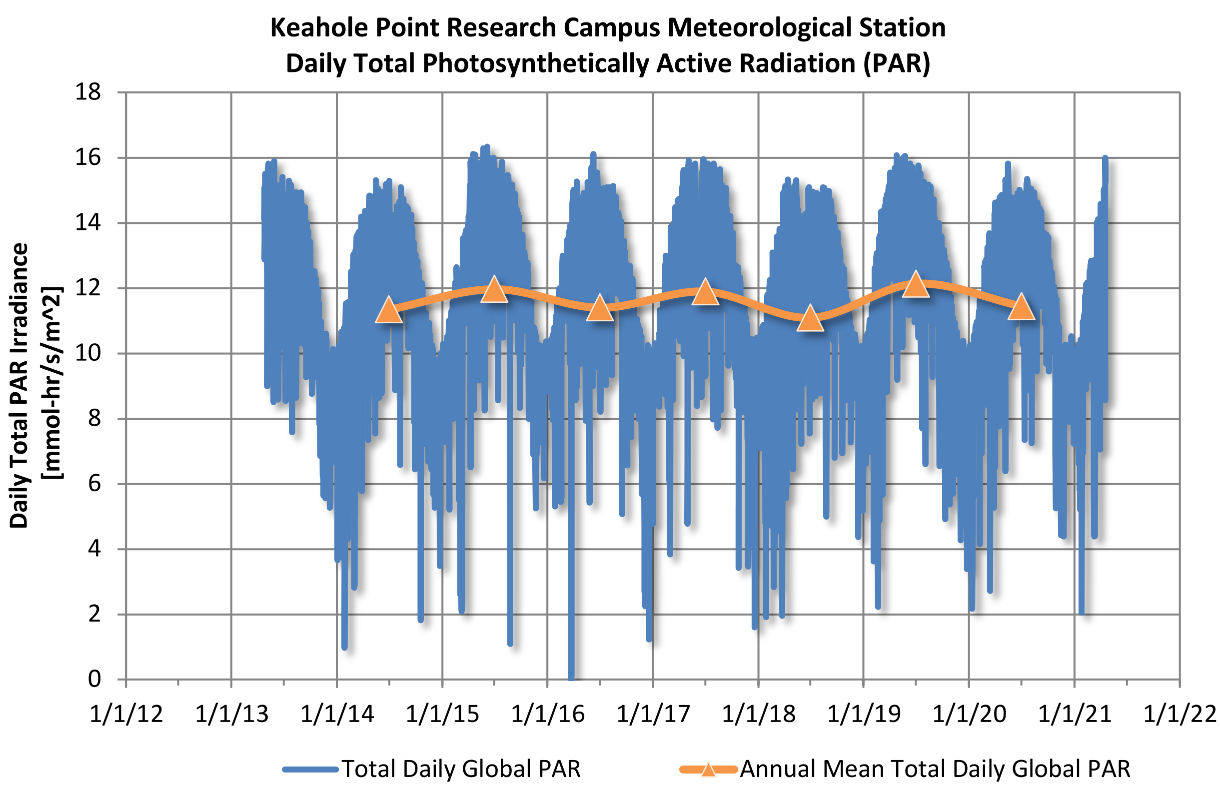


Figure 5.10.d. *Historical daily PAR line charts*

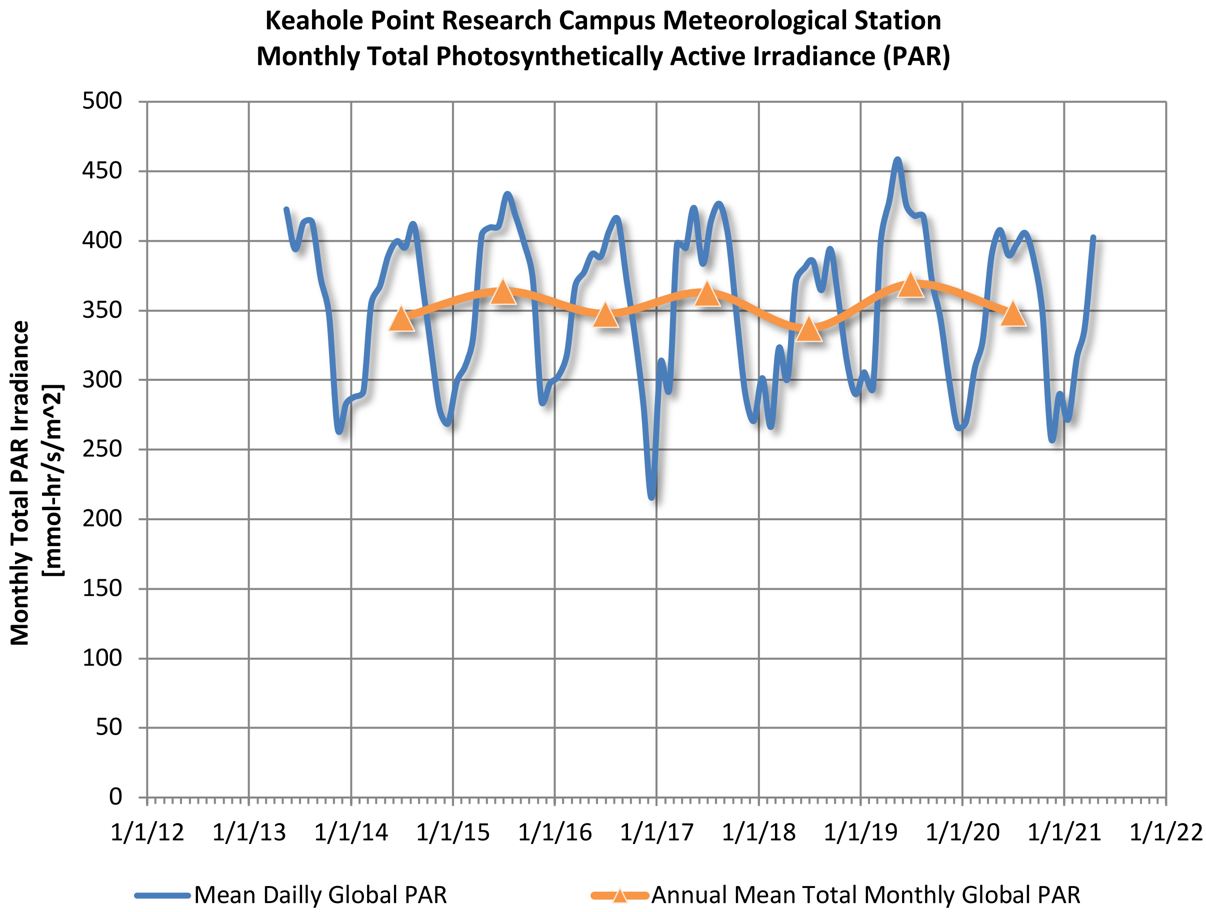


Figure 5.10.e. *Historical monthly PAR line chart*

	Mean Daily Total PAR Irradiance [mmol-hr/s/m^2]												
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
2013					13.63	13.13	13.33	13.34	12.43	11.18	8.83	9.13	-
2014	9.29	10.42	11.44	12.25	12.56	13.33	12.76	13.28	12.29	10.42	9.30	8.67	**11.34**
2015	9.62	11.08	10.66	13.47	13.22	13.69	13.99	13.47	13.26	12.02	9.49	9.60	**11.97**
2016	9.77	11.01	11.86	12.57	12.60	12.96	13.14	13.40	12.42	10.72	9.39	6.96	**11.40**
2017	10.08	10.47	12.83	13.16	13.67	12.79	13.37	13.76	13.42	11.14	9.66	8.73	**11.89**
2018	9.72	9.52	10.42	10.04	11.96	12.69	12.44	11.76	13.14	11.52	10.41	9.35	***11.09***
2019	9.86	10.50	12.87	14.29	14.80	14.19	13.48	13.47	12.37	11.11	10.01	8.59	**12.13**
2020	8.71	10.63	10.61	12.96	13.16	12.99	12.84	13.08	12.85	11.23	8.60	9.36	**11.44**
2021	8.77	11.28	10.88	13.42									-
Mean	**9.58**	**10.52**	**11.53**	**12.68**	**13.20**	***13.22***	**13.17**	**13.19**	**12.77**	**11.17**	**9.46**	*8.80*	**11.61**

Figure 5.10.f. *Historical monthly mean daily total PAR table (mmol-hr/s/m^2)*

	Mean Monthly Total PAR Irradiance [mmol-hr/s/m^2]												
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
2013					422.7	394.0	413.1	413.4	372.9	346.6	264.8	283.0	**-**
2014	288.0	291.9	354.8	367.4	389.3	399.8	395.4	411.6	368.6	323.1	279.0	268.8	**344.8**
2015	298.1	310.1	330.4	404.1	409.7	410.8	433.7	417.6	397.7	372.8	284.8	297.5	**363.9**
2016	302.9	319.2	367.5	377.2	390.7	388.8	407.3	415.3	372.5	332.3	281.7	215.7	**347.6**
2017	312.6	293.1	397.8	394.8	423.7	383.6	414.4	426.5	402.5	345.5	289.8	270.6	**362.9**
2018	301.4	266.5	323.0	301.1	370.7	380.6	385.5	364.6	394.3	357.0	312.3	289.8	***337.2***
2019	305.6	294.0	398.8	428.8	458.7	425.6	418.0	417.6	371.0	344.4	300.4	266.3	***369.1***
2020	270.1	308.2	328.8	388.8	407.9	389.7	397.9	405.5	385.6	348.2	258.1	290.0	**348.2**
2021	271.9	315.8	337.3	402.5									**-**
Mean	**297.0**	**297.6**	**357.3**	**380.3**	***409.2***	**396.6**	**408.2**	**409.0**	**383.1**	**346.2**	**283.9**	**272.7**	**353.4**

Figure 5.10.g. *Historical total monthly PAR table (mmol-hr/s/m^2)*

5.11. ULTRAVIOLET LIGHT

Ultraviolet Light (UV) sensor was installed on April 4, 2018. A maximum daily total measurement of 105.9 W/m^2 (320.8 $\mu mol/s/m^2$) was recorded on May 12, 2020. During the period, a monthly total maximum was recorded in May 2020 at 15.1 $kW\text{-}hr/m^2$ (45.9 $mmol\text{-}hr/s/m^2$). A monthly total minimum of 4.2 W/m^2 (12.7 $mmol\text{-}hr/s/m^2$) was recorded in November 2020. The data from mid-June 2020 to April 16, 2021, may be compromised due to a failing Apogee SU-100 Sensor.

Monthly Total Ultraviolet Light	Jan. 2020	Feb. 2020	Mar. 2020	Apr. 2020	May 2020	Jun. 2020	Jul. 2020	Aug. 2020	Sep. 2020	Oct. 2020	Nov. 2020	Dec. 2020
($kW\text{-}hr/m^2$)	9.6	11.1	12.5	14.6	***15.1***	9.0	6.6	6.4	6.2	5.5	***4.2***	4.5
($mmol\text{-}hr/s/m^2$)	28.9	33.7	37.8	44.1	***45.9***	27.3	20.1	19.5	18.7	16.7	***12.7***	13.5

Figure 5.11.a. *Total monthly ultraviolet light table*

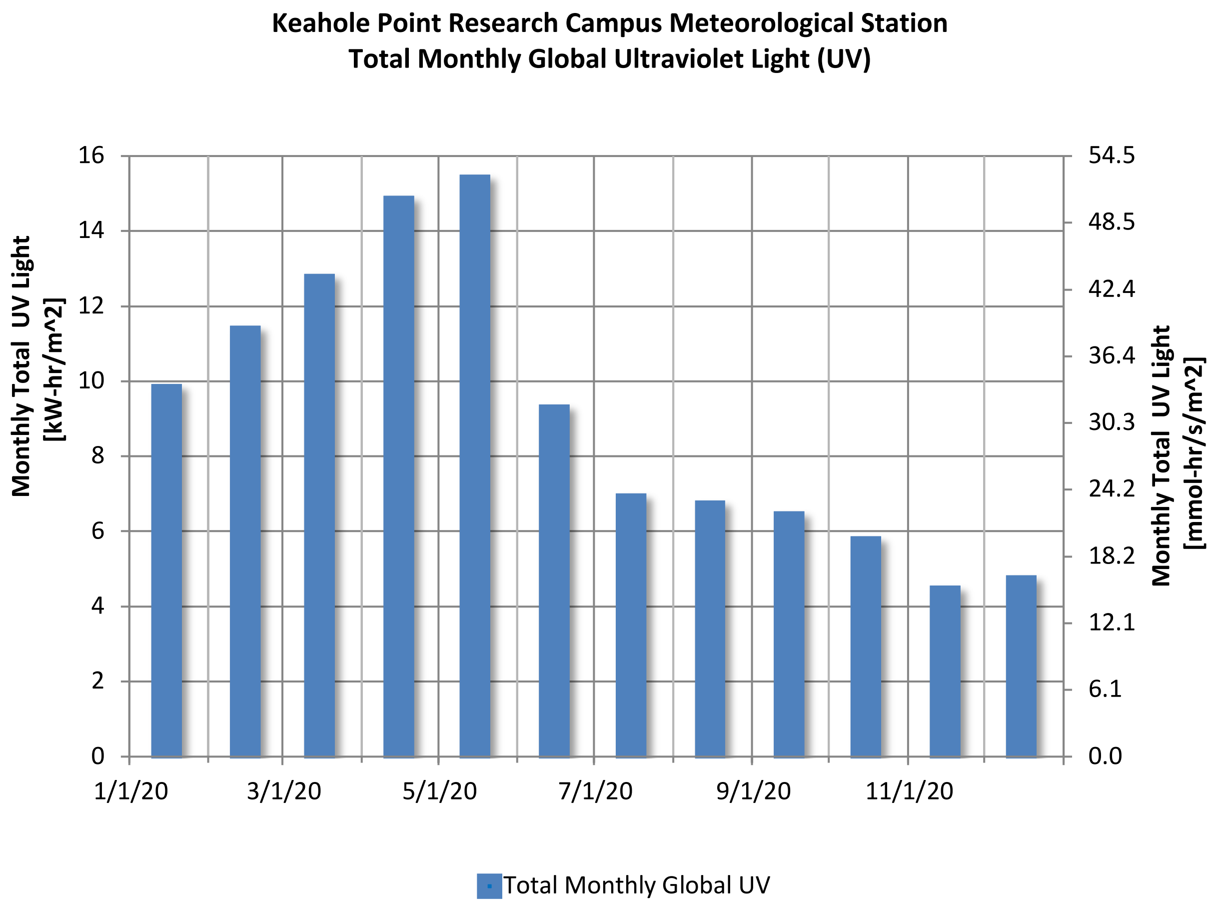


Figure 5.11.b. *Total monthly ultraviolet light bar chart*

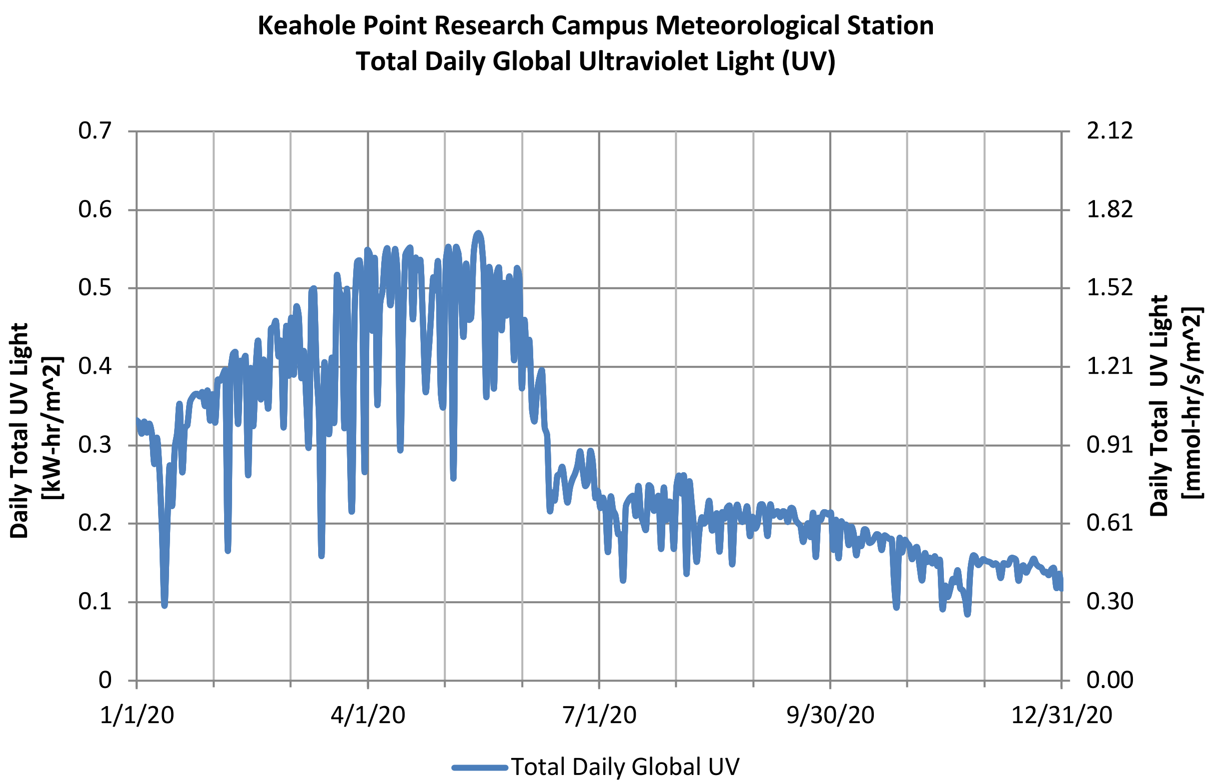


Figure 5.11.c. *Daily ultraviolet light bar chart*

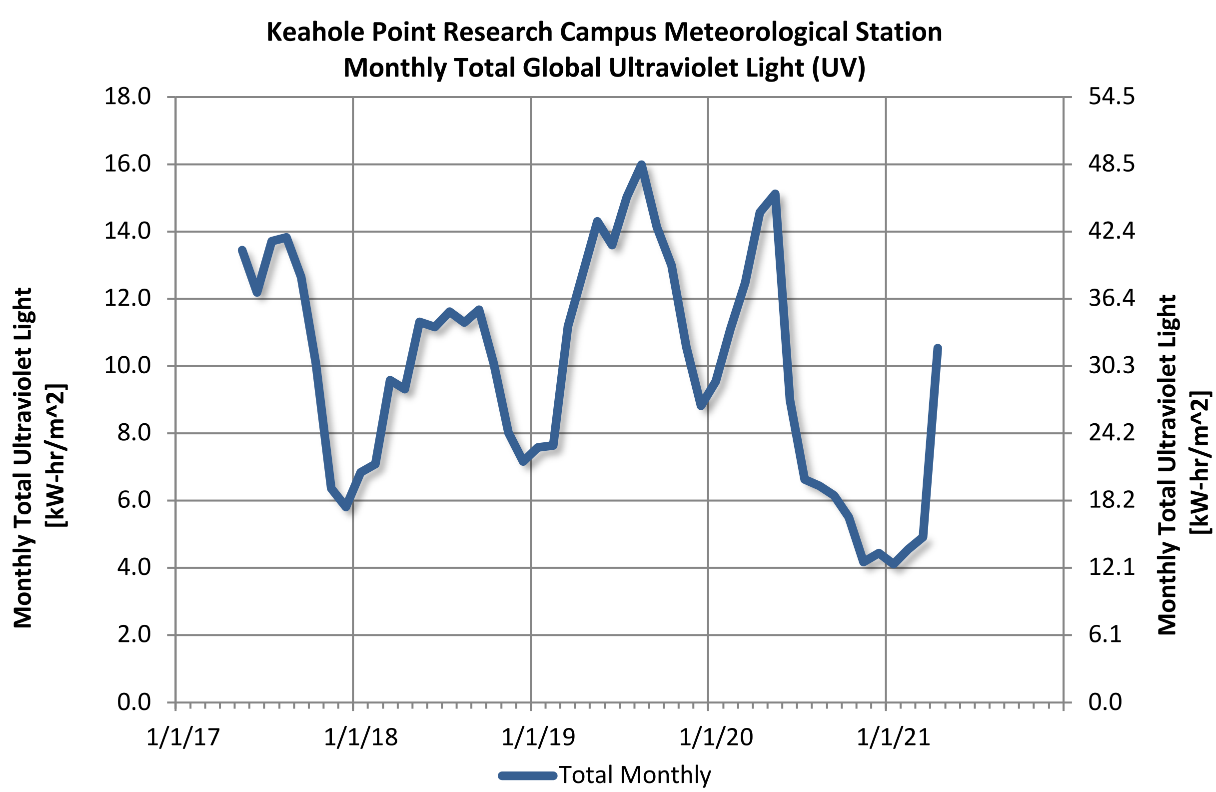


Figure 5.11.d. *Historical total monthly ultraviolet light line charts*

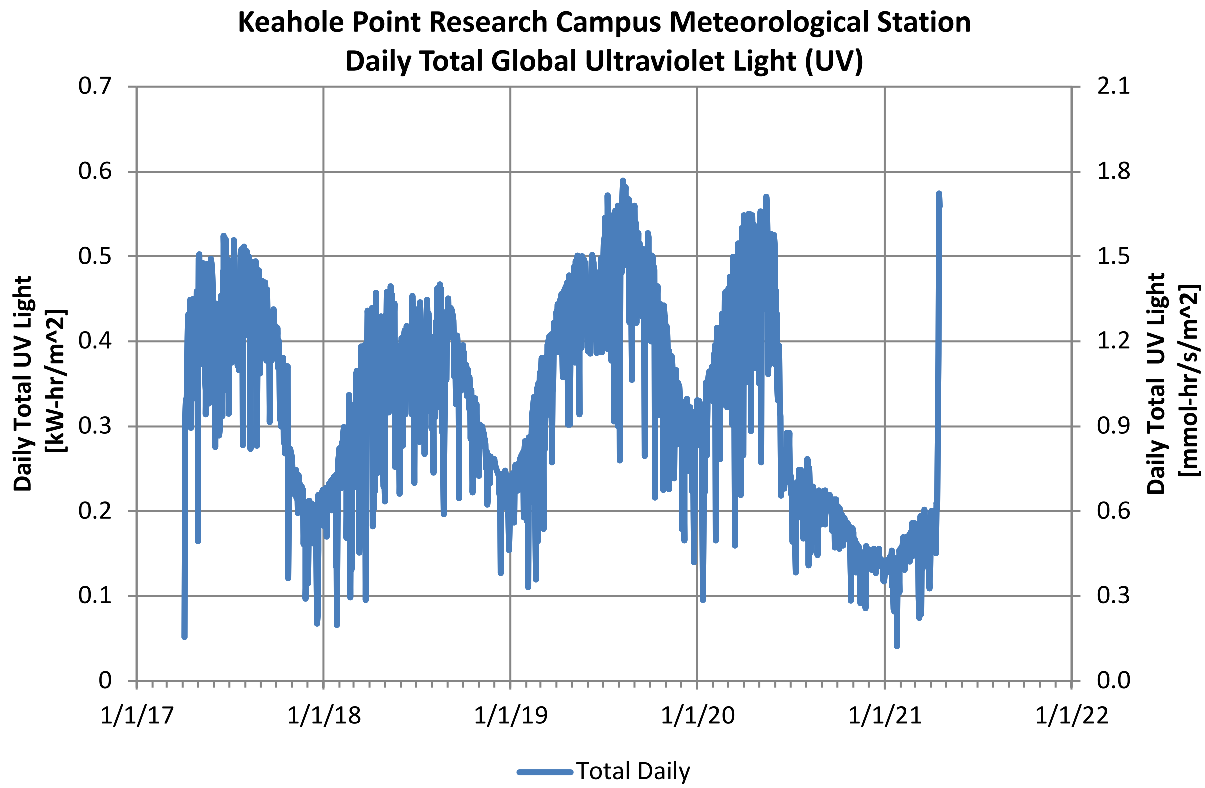


Figure 5.11.e. *Historical total daily ultraviolet light line charts*

6. HURRICANES AND TROPICAL STORMS

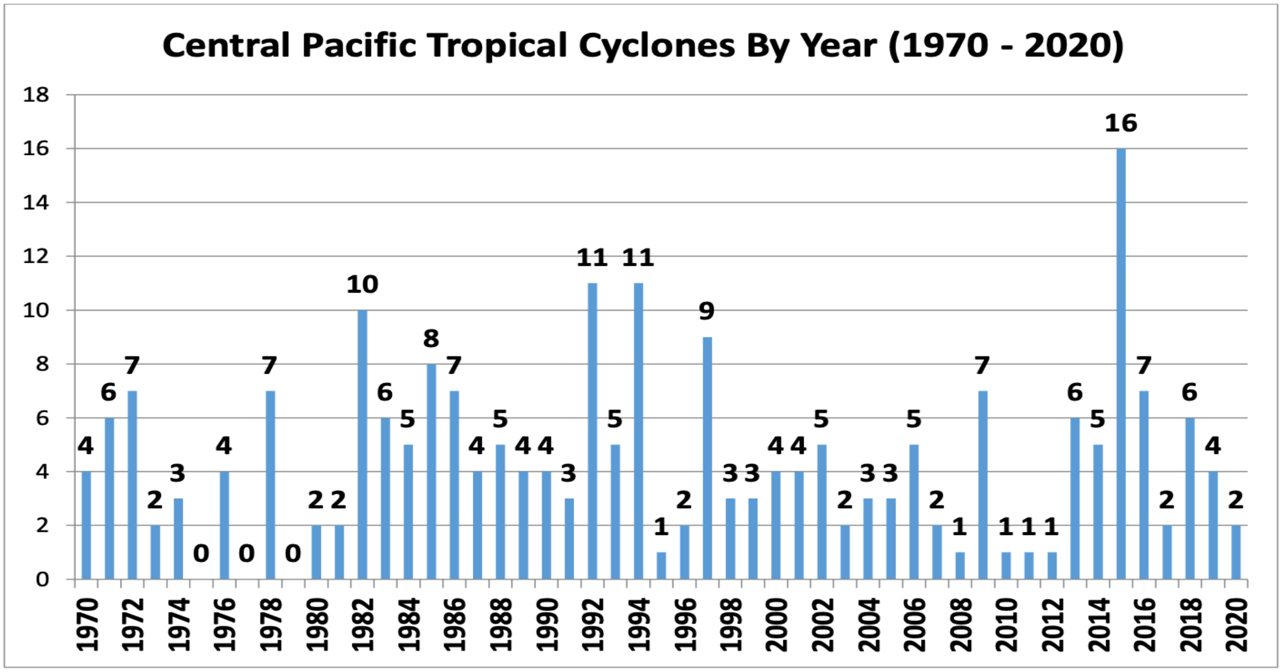


Figure 6.a. *Annual Comparison of Tropical Cyclones by Year*(18)

2020: Two tropical cyclones were recorded in the Central Pacific region in 2020. Tropical Depression Boris approached the Hawaiian Islands from the East on June 25 and weakened to a remnant low southeast of the island by June 28. Hurricane Douglas entered the Basin on July 24 as a category 4 hurricane. Hurricane Douglas weakened to a tropical storm from July 25 – July 28. Hurricane Douglas passed the Hawaiian Islands on the north side. The islands experienced heavy rains over a portion of the state with no significant wind damage. (18)

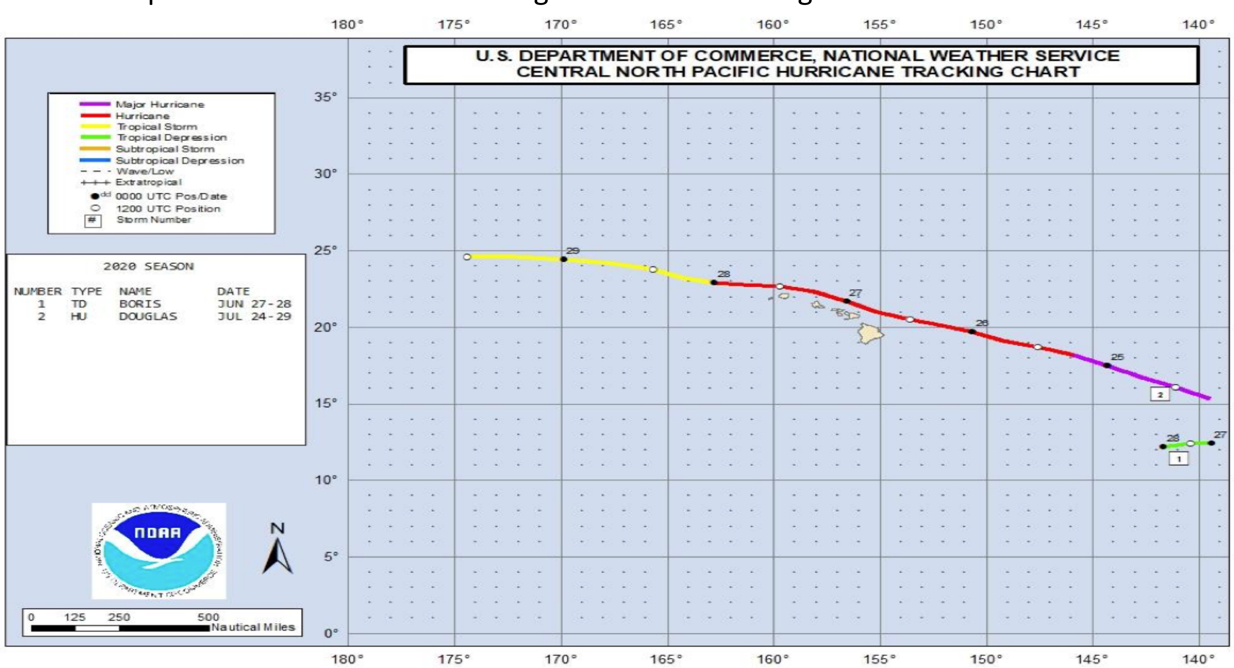


Figure 6.b. *NOAA Central North Pacific Hurricane Center 2020 Hurricane Tracking Chart*(18)

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 at NELHA**		**Peak Wind Speed at NELHA**	
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 6.c. *2019 hurricane wind speed table*

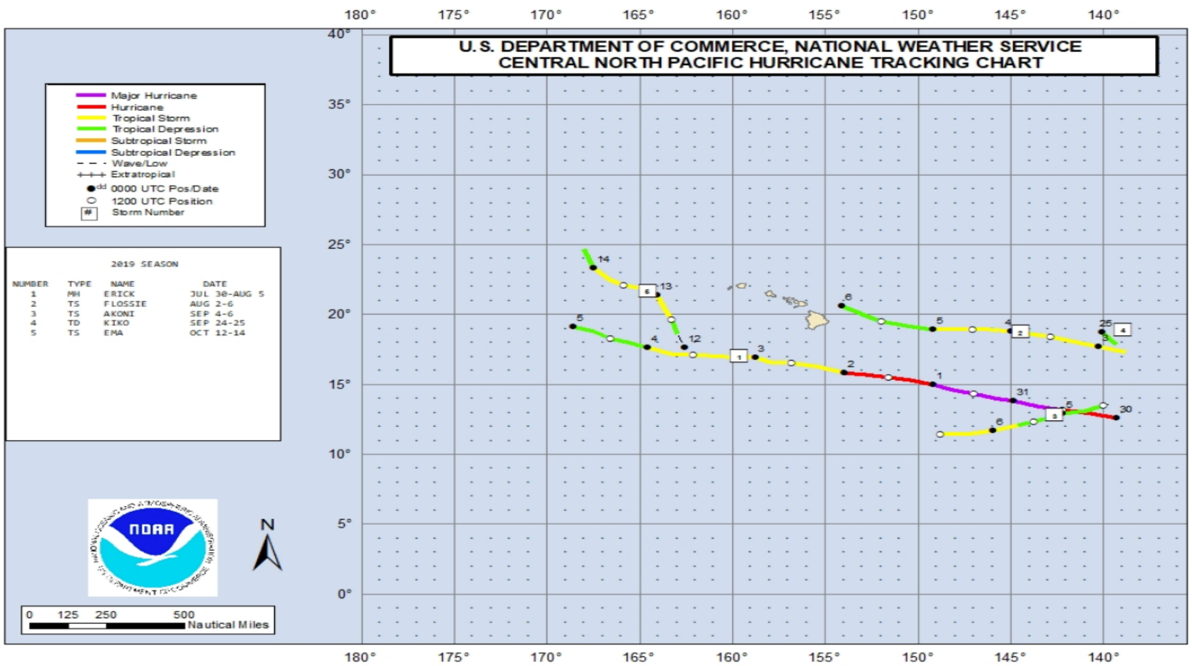


Figure 6.d. *NOAA Central North Pacific Hurricane Center 2019 Hurricane Tracking Chart*[17]

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 at NELHA**		**Peak Wind Speed at NELHA**	
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

Figure 6.e. *2018 hurricane wind speed table*

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 at NELHA		Peak Wind Speed at NELHA	
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	-	-	-	-	-

Figure 6.f. *2017 hurricane wind speed table*

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 at NELHA		Peak Wind Speed at NELHA	
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 6.g. *2016 hurricane wind speed table*

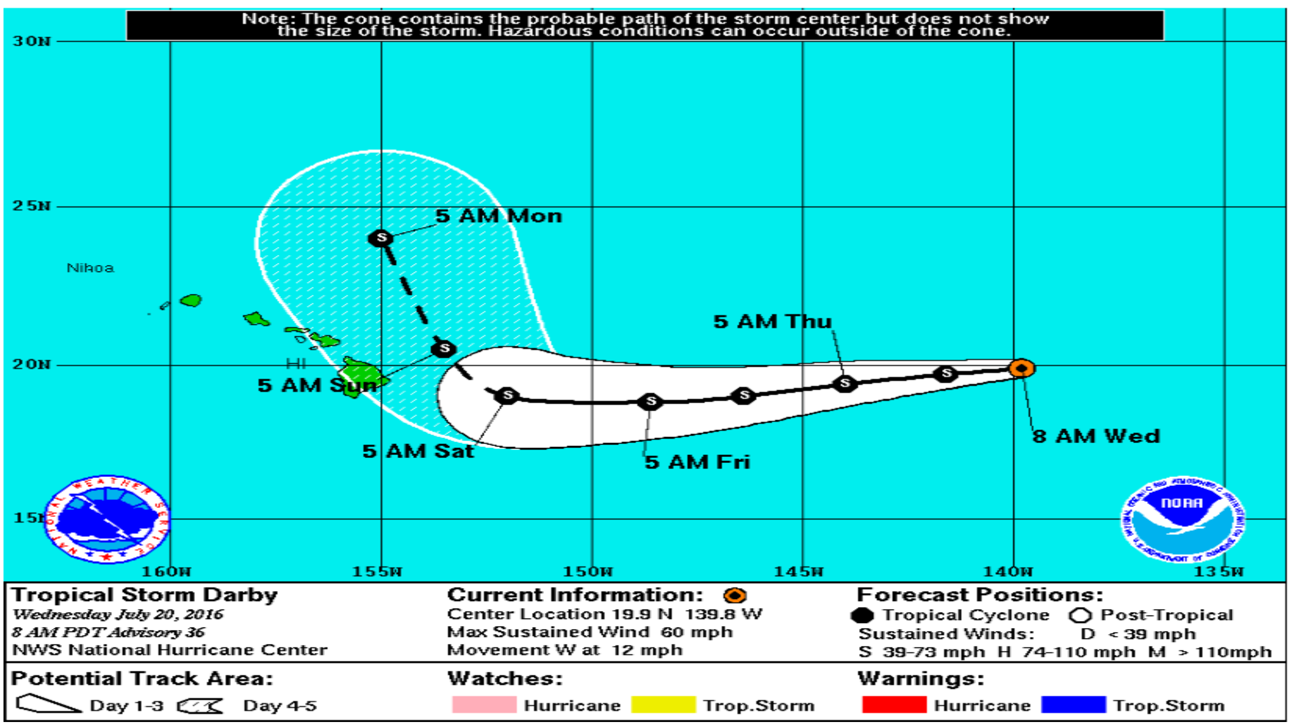


Figure 6.h. *NOAA Central Pacific Hurricane Center 5-day track of Tropical Storm Darby*

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 at NELHA		Peak Wind Speed at NELHA	
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 6.i. *2015 hurricane wind speed table*

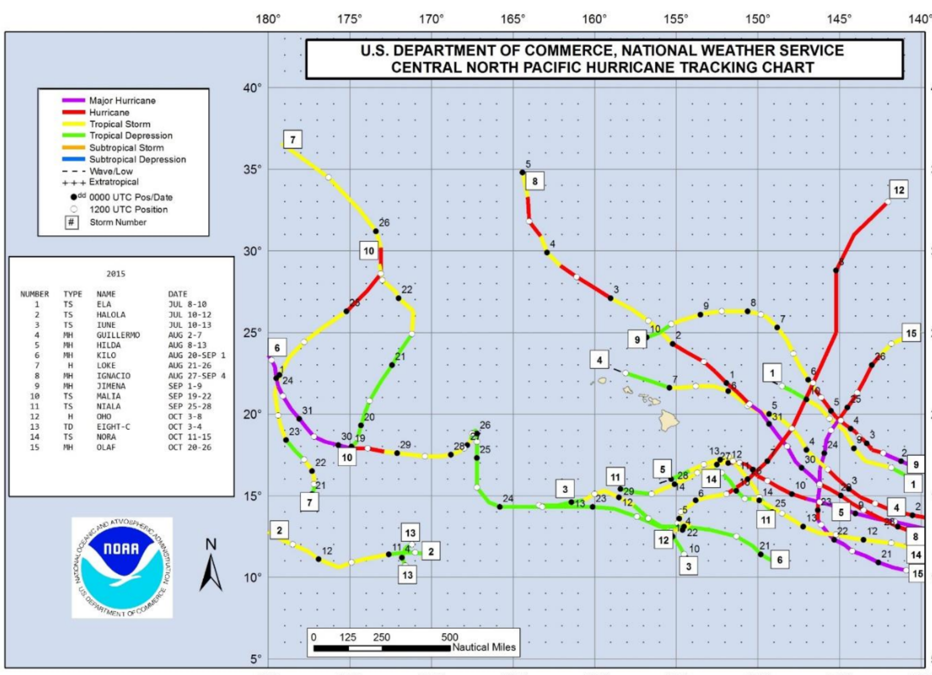


Figure 6.j. *NOAA Central North Pacific Hurricane Center 2015 Hurricane Tracking Chart*[15]

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.

Hurricane/Tropical Storm	Date	Time	Mean Wind Speed at NELHA		Peak Wind Speed at NELHA	
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 6.k. *2014 hurricane wind speed table*

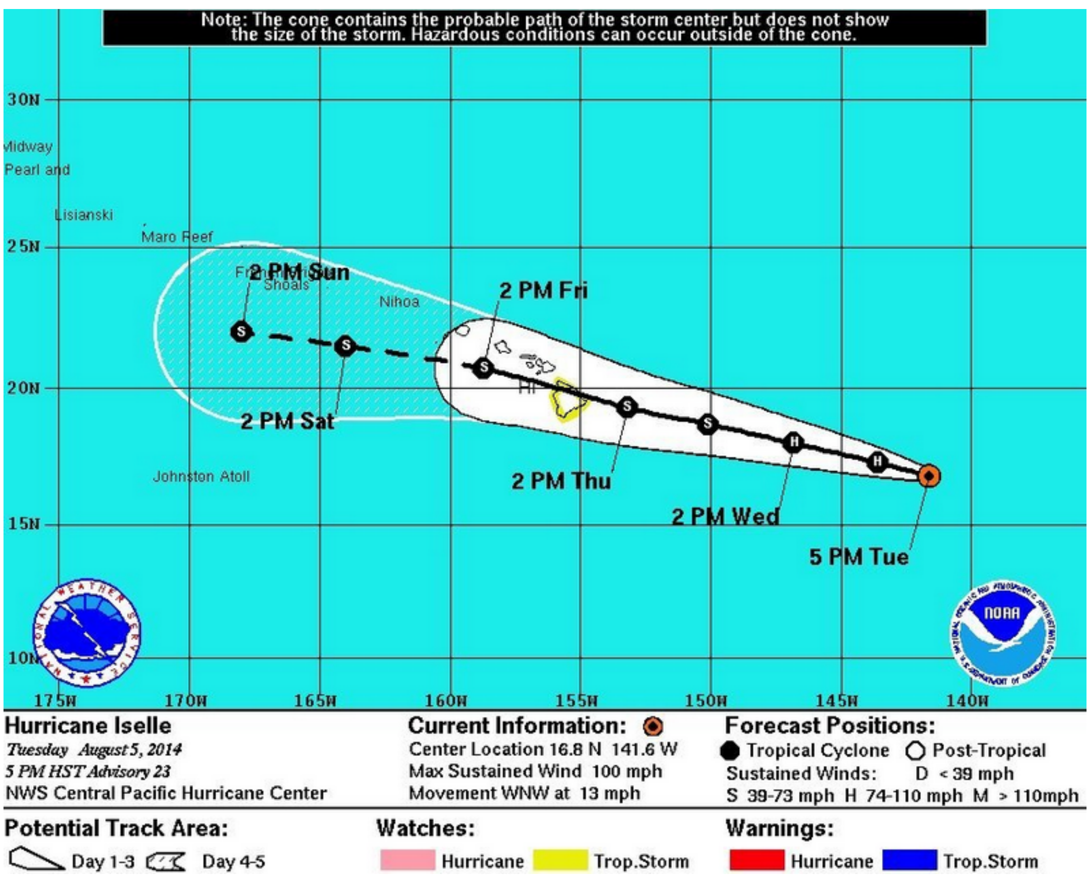


Figure 6.l. *NOAA Central Pacific Hurricane Center 5-day track of Hurricane Iselle*

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.

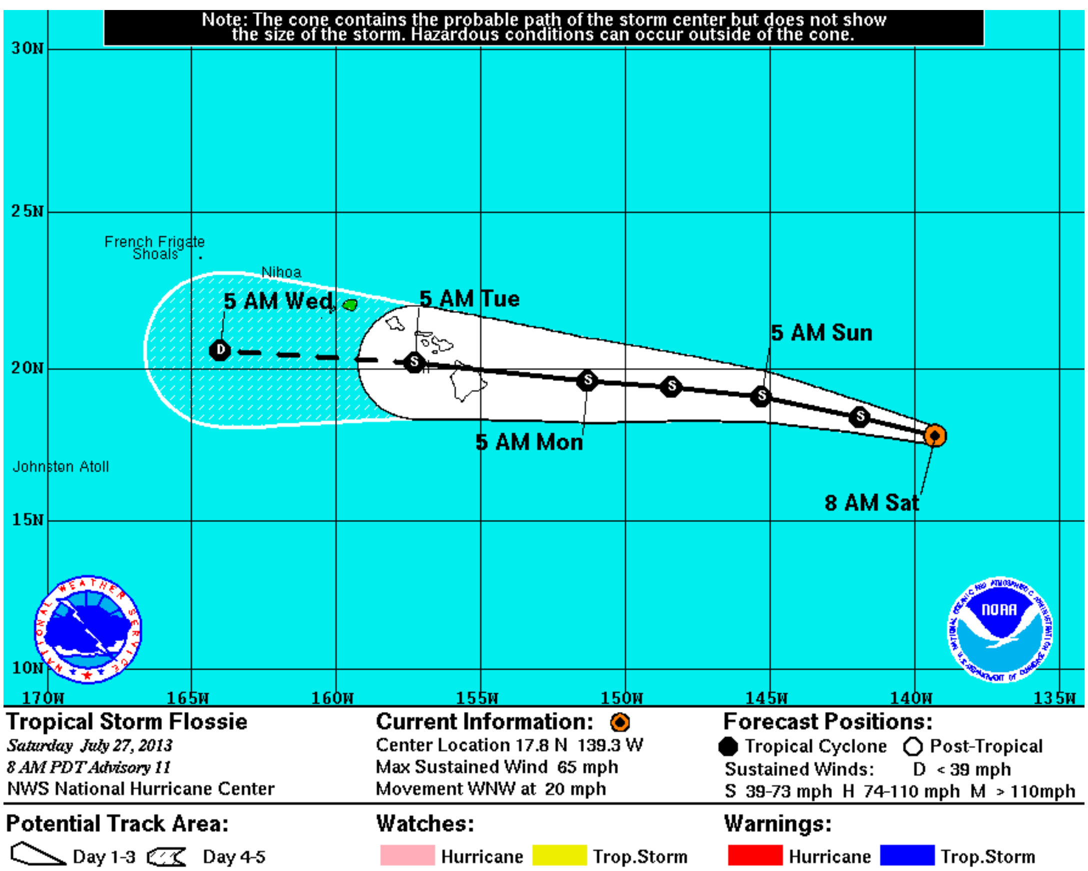


Figure 6.m. *NOAA Central Pacific Hurricane Center 5-day track of Tropical Storm Flossie*

7. REGIONAL COMPARITIVE CHART

The regional comparative data was assembled from NREL's MIDc website. NREL's MIDc has hosted solar and meteorological data since 1997. The approximately thirty-three meteorological stations found on the MIDc website use similar instrumentation and data collection sampling rates as the Keahole Point Research Campus Meteorological Station. The Regional Meteorological Data Comparison Chart *(Figure 7.)* 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, and Southwestern 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.

Figure 7.a. 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 narrower profiles in the summer months in comparison to the Southwest United States.

Figure 7.b. Shows a comparison of global horizontal irradiance profile of weekly totals through the monitoring year.

Figure 7.c. Shows a comparison of global horizontal irradiance profile of a winter day on December 23, 2020. In the winter, Keahole Point, Hawaii has a higher intensity (amplitude) and longer day (wider) which yields a favorable irradiance profile.

Figure 7.d. Shows a comparison of global horizontal irradiance profile of a summer day on July 4, 2020. In the summer, Keahole Point, Hawaii has a similar intensity (amplitude) to University of Nevada, Las Vegas and University of Arizona, Tucson. Keahole Point also has a shorter day which yields a slightly less favorable (narrower) irradiance profile in the summer.

Figure 7.e. 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 65.9% yearly mean throughout the monitoring year.

Figure 7.f. 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 26.06˚C (78.91˚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
Period	MM/DD/YY	1/01/20 - 12/31/20	1/01/20 - 12/31/20	1/01/20 - 12/31/20	1/01/20 - 12/31/20	1/01/20 - 12/31/20
GPS	Latitude	19.73° N	36.06° N	32.23° N	26.49° N	40.88° N
	Longitude	156.06° W	115.08° W	110.96° W	98.17° W	124.08° W
Elevation	m	4	615	786	45.4	36
	ft.	13	2018	2579	149	118
Mean Yearly Temperature	˚C	26.06	22.59	23.48		
	˚F	78.91	72.67	74.27		
Max Yearly Temperature	˚C	34.34	46.06	44.62		
	˚F	93.81	114.91	112.32		
Min Yearly Temperature	˚C	17.52	0.71	-1.08		
	˚F	63.54	33.28	30.06		
Yearly Total Global Solar Irradiance	$kW\text{-}hr/m^2$	2136.14	2128.64	2143.13	1461.69	1498.72
Mean Daily Total Global Solar Irradiance	$kW\text{-}hr/m^2$	5.84	5.82	5.86	5.30	4.09
Mean Yearly Relative Humidity	%	65.9		26.8		
Max Yearly Relative Humidity		93.0		93.4		
Min Yearly Relative Humidity		29.5		2.9		
Mean Yearly Barometric Pressure	mBar	1015		926		
	in. of Hg	29.98		27.34		
Mean Yearly Wind Speed	m/s	2.40	2.07	2.64		
	mph	5.36	4.62	5.90		
Yearly Accumulated Precipitation	mm	310.5				
	in.	12.2				

*** University of Texas Pan America Global Solar Irradiance instrumentation was not recording measurements from October 3, 2020 – December 31, 2020.**

Figure 7. *Regional Meteorological Comparison Chart*

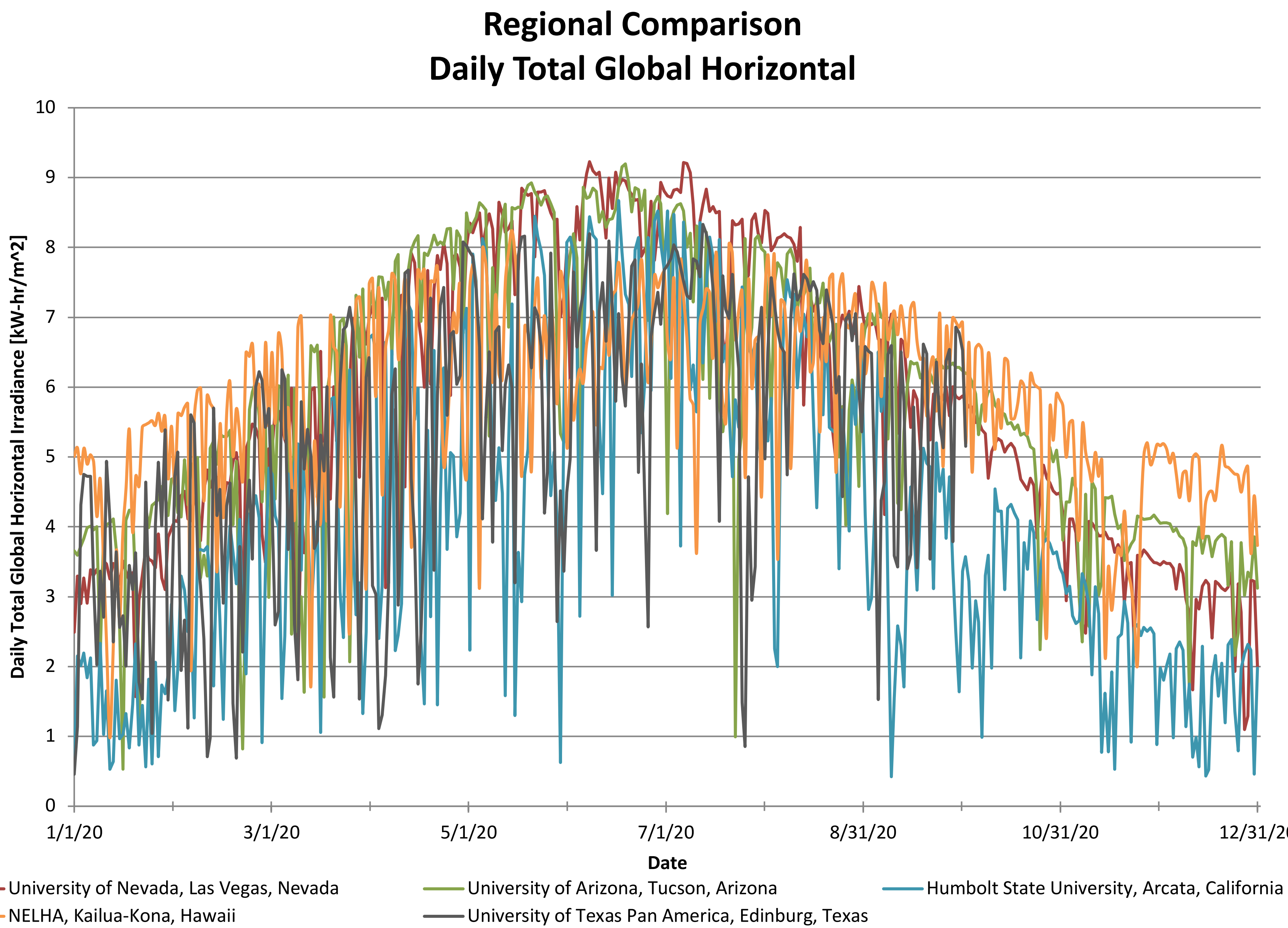


Figure 7.a. *Regional comparison of daily total global horizontal irradiance profiles*

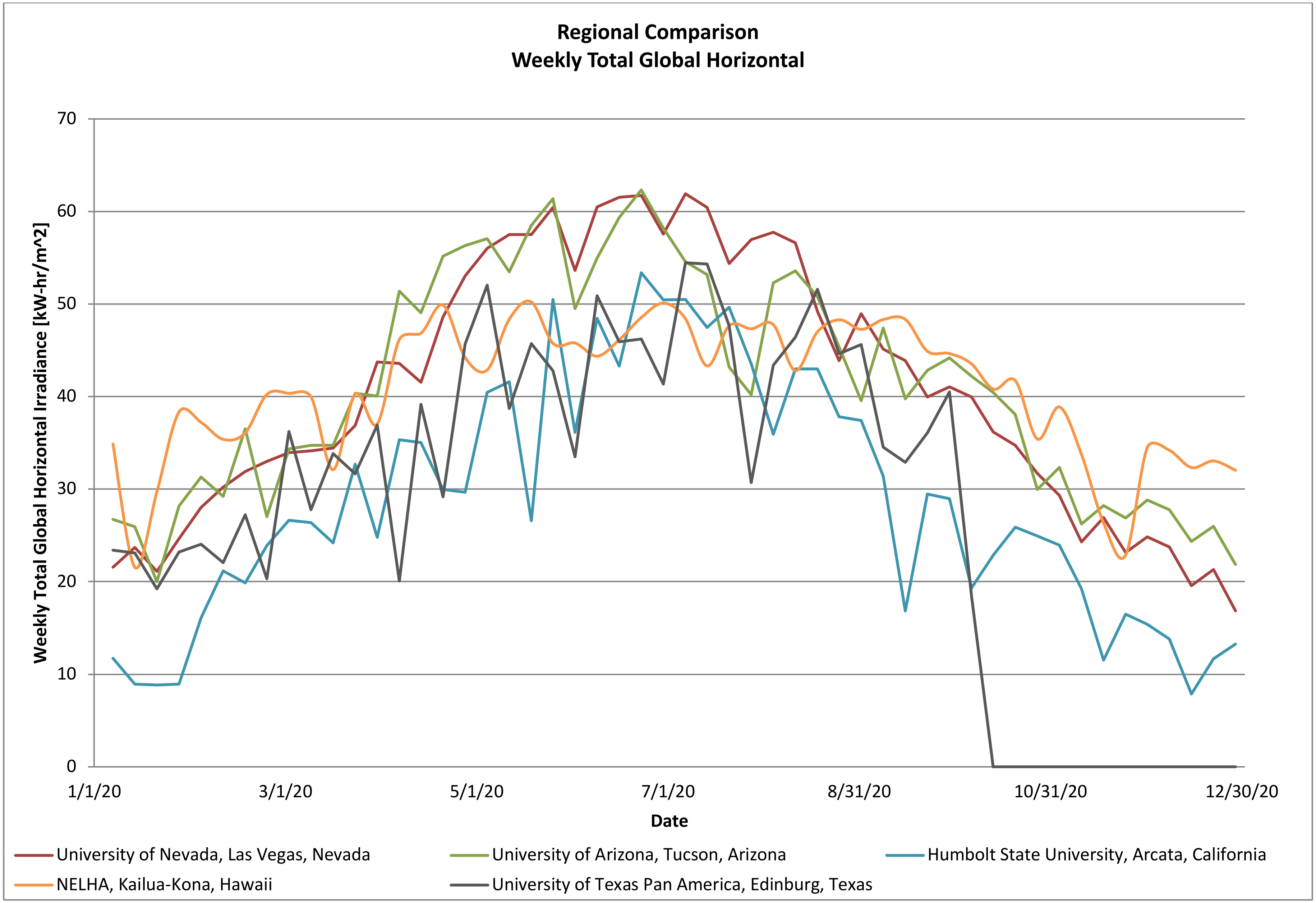


Figure 7.b. *Regional comparison of weekly total global horizontal irradiance profiles*

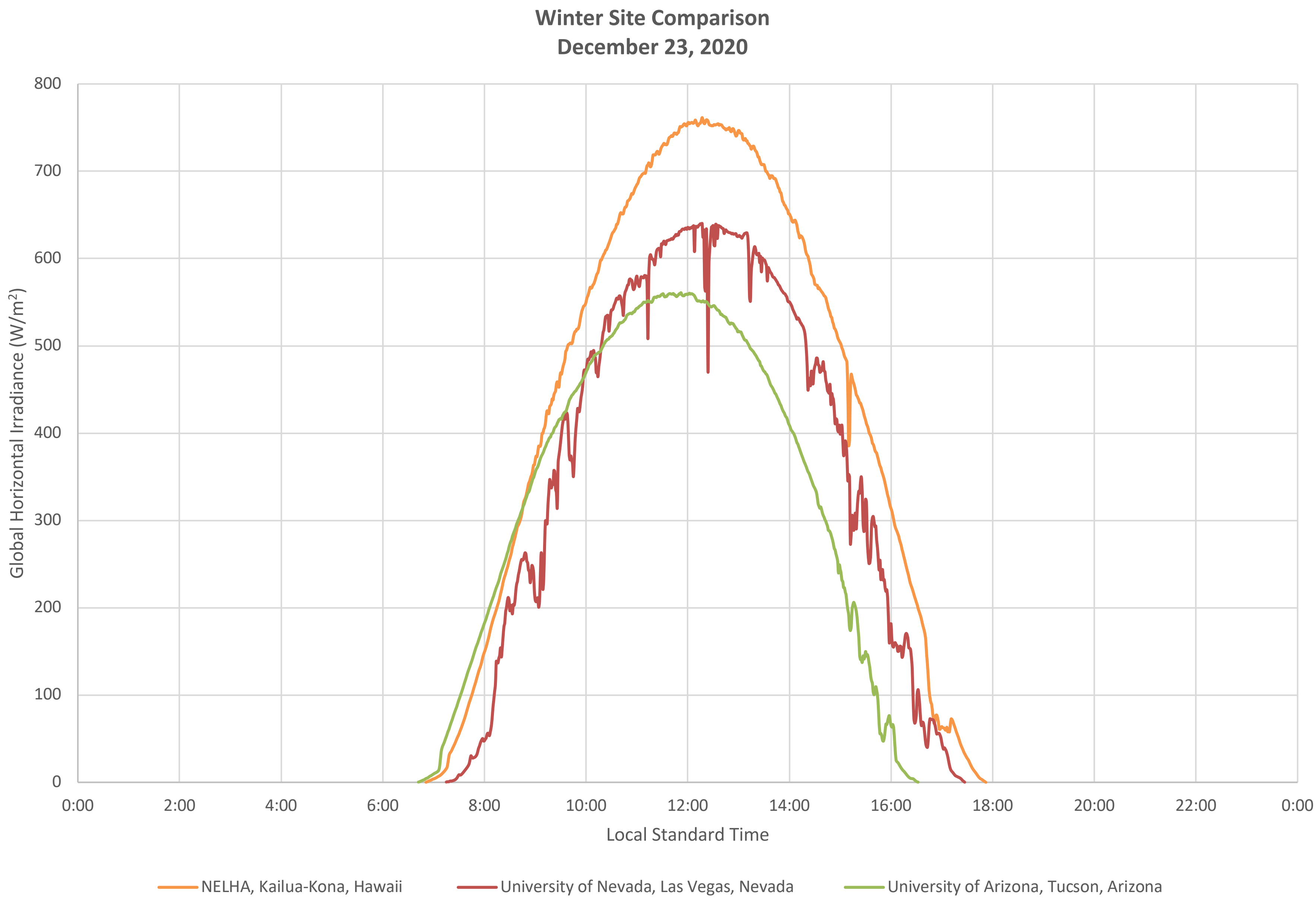


Figure 7.c. *Winter comparison of global horizontal irradiance profiles*

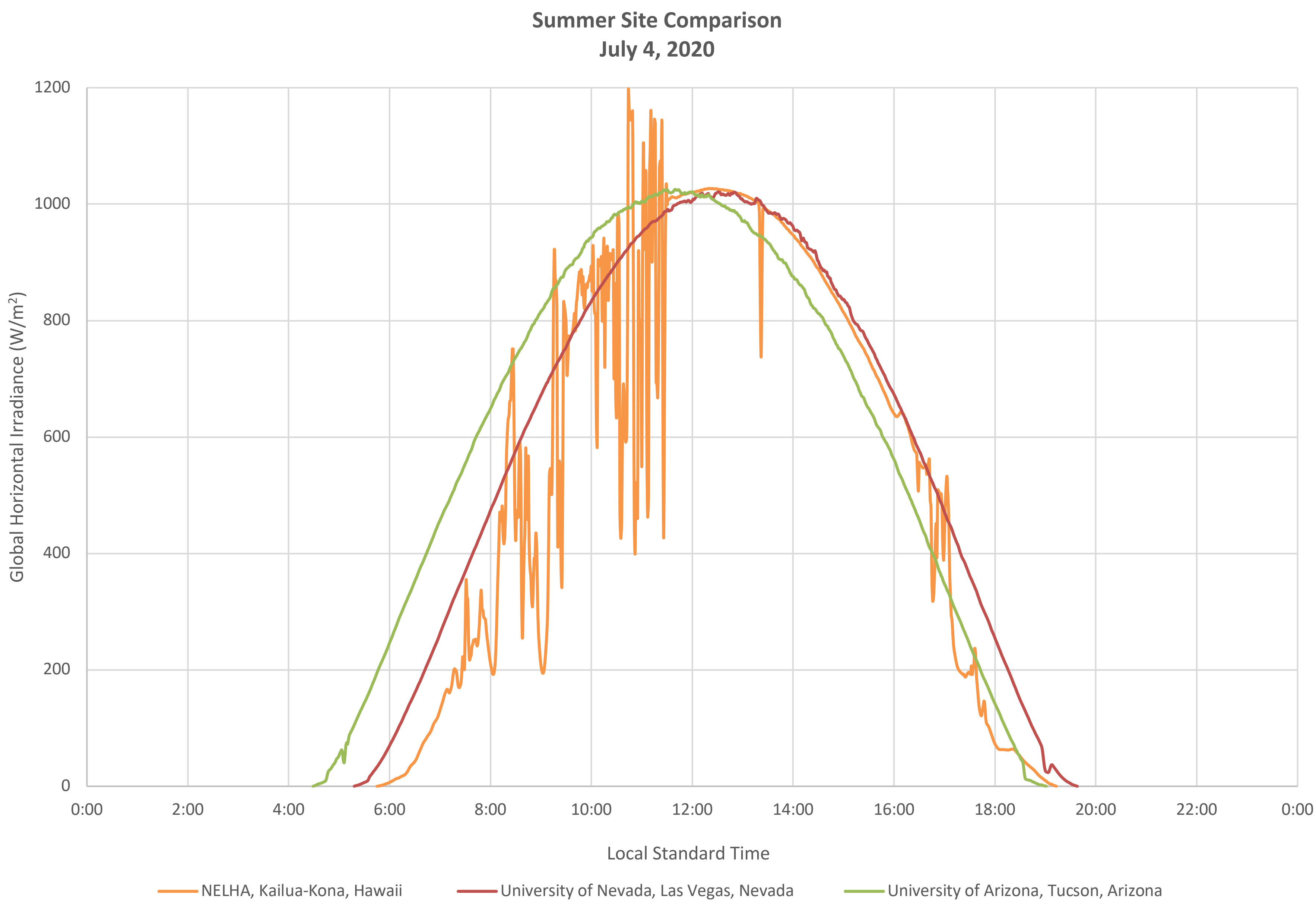


Figure 7.d. *Summer comparison of global horizontal irradiance profiles*

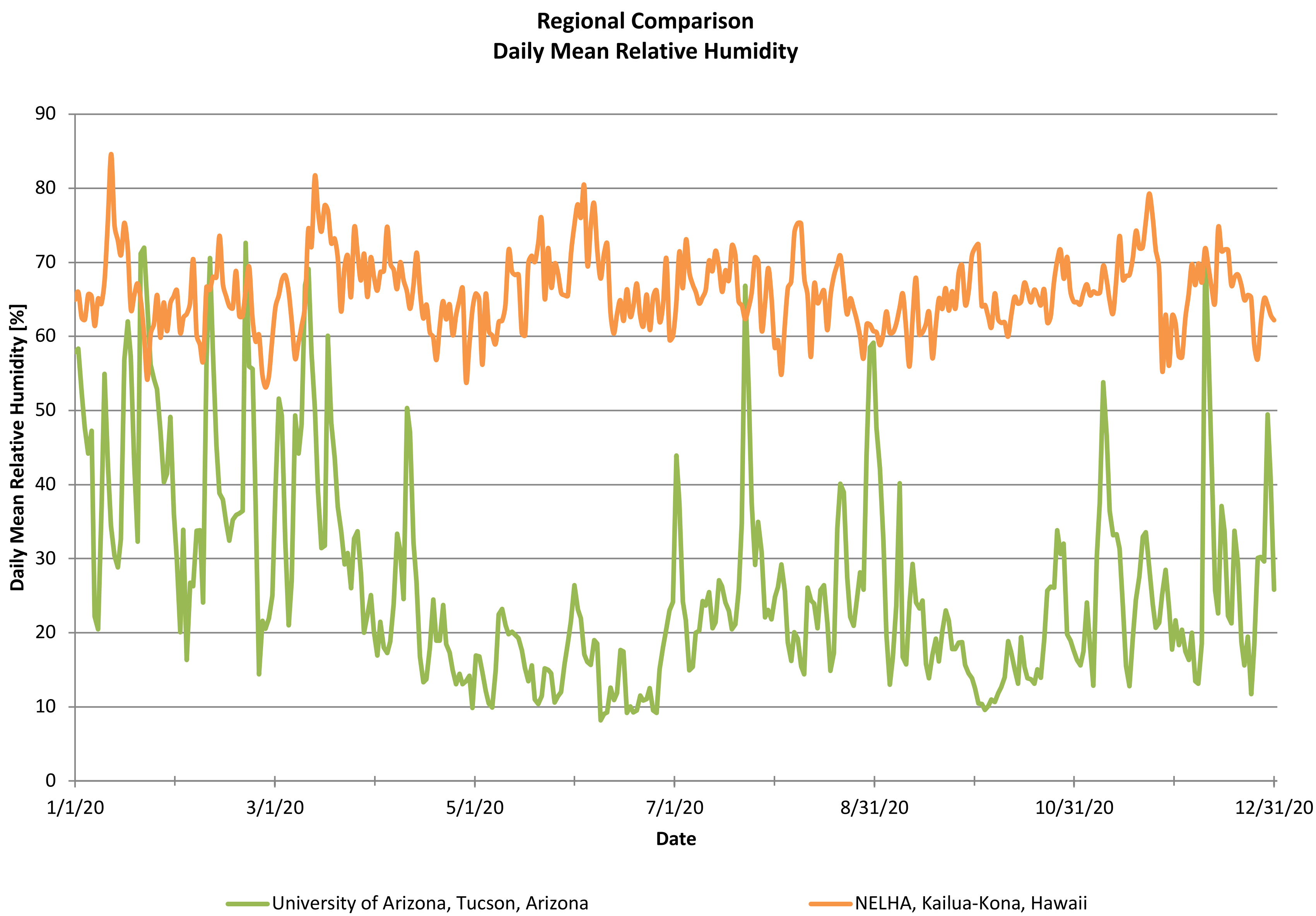


Figure 7.e. *Regional comparison of daily relative humidity profiles*

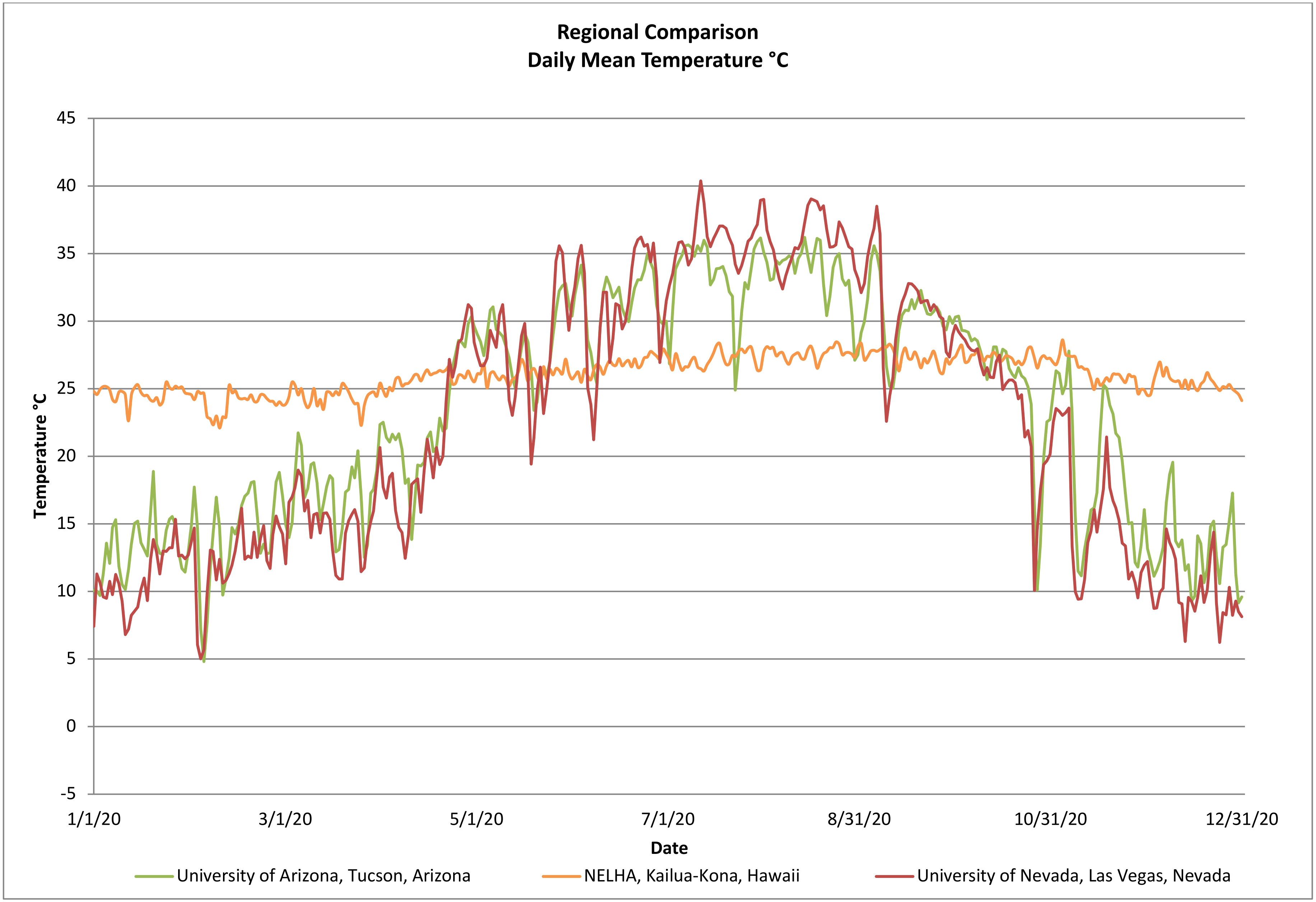


Figure 7.f. *Regional comparison of daily temperature profiles*

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. On April 16, 2021, an Apogee SU-200 UV A sensor replaced the failing and discontinued Apogee SU-100 total ultra-violet sensor