Project Title: Climate Monitoring and Data Management for the Pacific Island Inventory and Monitoring Network

Task Agreement Number: P16AC01566
Cooperative Agreement Number: P11AC8R001
Project Funding Source: National Park Service, Great Basin Cooperative Ecosystem Studies Unit
Cooperative Agreement Partners: (1) U.S. Department of the Interior, National Park Service; (2) Nevada System of Higher Education, Desert Research Institute
Period of Performance: 8/29/2016 – 8/15/2021
Document Title: Final Report
Date: 11/22/21
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Photo: Pola Island Trail, National Park of American Samoa. Photo credit: D. Simeral

Executive Summary

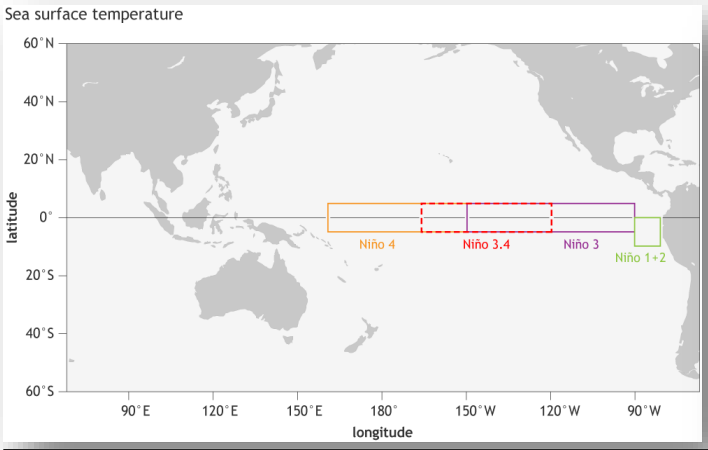
The Desert Research Institute (DRI) and the National Park Service (NPS) Pacific Island Inventory and Monitoring (I&M) Network have worked collaboratively for nearly a decade to maintain a network of eight long-term climate monitoring stations within NPS Units across the Hawaiian Islands and U.S. Affiliated Pacific Islands. This document is a continuation of that partnership and represents the final report for the most recent project award period spanning from 8/29/2016 through 8/15/2021. The purpose of the climate monitoring network is to provide high-quality, baseline climate data necessary to draw insights not only into the long-term climatic patterns and more recent trends, but also to provide critical spatial coverage and data necessary to gain insights on the sharp gradients which are an important driver in ecological and biological processes within NPS Units in the Pacific Islands. The two entities have worked in partnership since the inception of the network and initial station deployment from 2012 through 2014. Responsibilities for the day-to-day operations and maintenance of the network have been conducted collaboratively between the NPS and DRI, while data management activities and web-based data access and tools have been the responsibility of DRI.

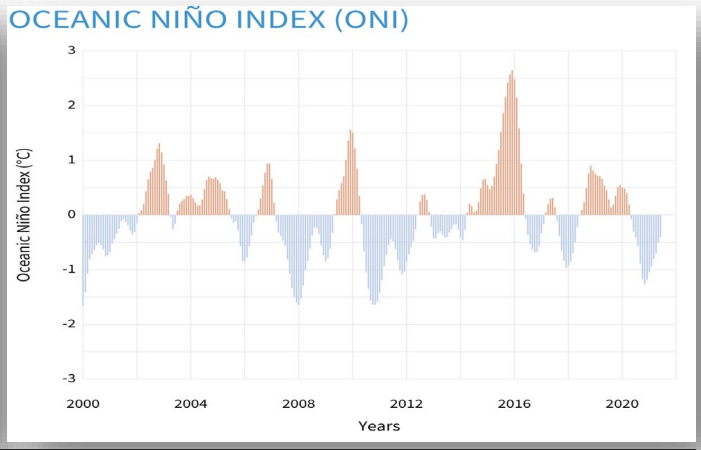
The intent of this report is to provide an overview of the station-based climate data from the network, and to produce a synopsis of other supplementary climate information that could be used as a reference for resource staff. NPS and DRI have agreed upon this scope of reporting as the most appropriate to deliver relevant, concise, and clearly summarized information to interested stakeholders. The additional climate information includes summaries of important climate components of the region including ENSO, tropical cyclones, and drought. Supplementary data was also provided on climate trends from key reference monitoring stations in the Hawaiian Islands as well as information on the new climate normals that were recently updated by the National Oceanic & Atmospheric Administration's National Centers for Environmental Information (NCEI) to reflect with latest 30-year normals period (1991-2020). Finally, station data from the network was utilized to verify gridded climate data from the Hawaii Rainfall Atlas.



Photo: The leeward Kohala Mountains on Hawai'i Island are an example of the sharp climate gradients present in Hawai'i and the USAPI. The summit at Puʻukiʻiʻāina receives over 3,900 mm of precipitation annually, while Kawaihae, the site of an I&M/DRI climate station on the Kohala coast only 8 miles away, receives less than 250 mm annually. Photo credit: D. Simeral

Climate Overview – *ENSO & Tropical Cyclones*

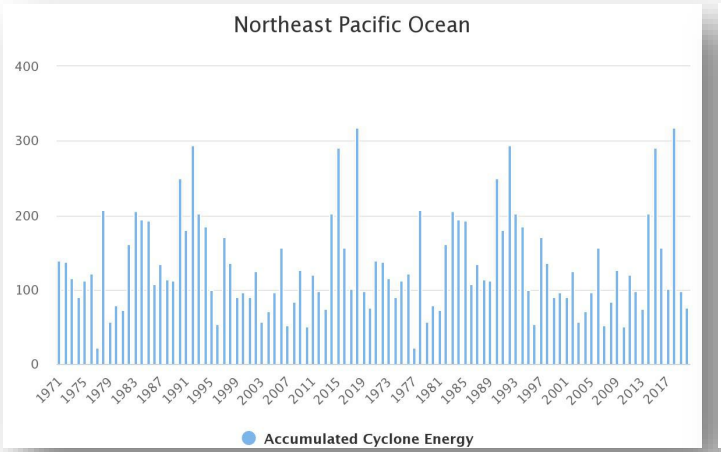


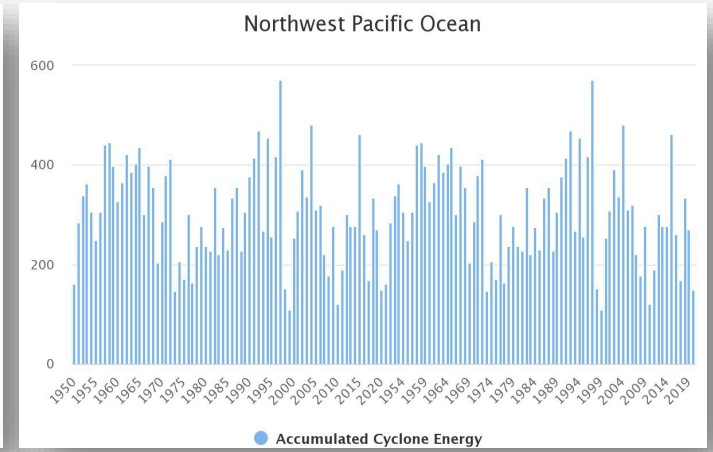


Areas used for monitoring sea surface temperatures in the tropical Pacific (left). Time series plot of Oceanic Niño Index (3-month average SST anomaly in Niño 3.4) displaying SST anomalies (blue=La Niña; red=El Niño) from 2000-2021 (right). Note: warm events (El Niño) at or above +0.5ºC anomaly and cold events (La Niña) at or below -0.5ºC anomaly.
Source: NOAA NCEI. https://www.climate.gov/news-features/understanding-climate/climate-variability-oceanic-ni%C3%B1o-index

During the 2016-2021 period, the following **ENSO conditions** were present across the central and eastern equatorial Pacific Ocean: 2015-16 El Niño (very strong); 2016-17 La Niña (weak); 2017-18 La Niña (weak); 2018-19 El Niño (weak); 2019-20 Neutral; 2020-21 La Niña (moderate); and 2021-22 La Niña (moderate) (https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php).

Tropical cyclone (TC) activity was **above normal** (based on 1991-2020 climatology – Accumulated Ace Index [ACE] = 132.7), in the **Northeast Pacific Basin** (east of 180º) during 2016 and 2018 with an ACE Index of 156.2 and 317.1, respectively. Conversely, **below normal** TC activity in the basin was observed in 2017 (100.7), 2019 (97.5), and in 2020 (76.5). In the **Northwest Pacific Basin** (west of 180º), **above normal** TC activity (based on 1991-2020 climatology – ACE Index = 299.5) was observed during 2018 with an ACE Index of 334.7 while **below normal** levels were observed in 2016 (261.9), 2017 (169.4), 2019 (269.4), and 2020 (148.5), according to the Colorado State University, Department of Atmospheric Science Tropical Meteorology Project (http://tropical.atmos.colostate.edu/Realtime/).

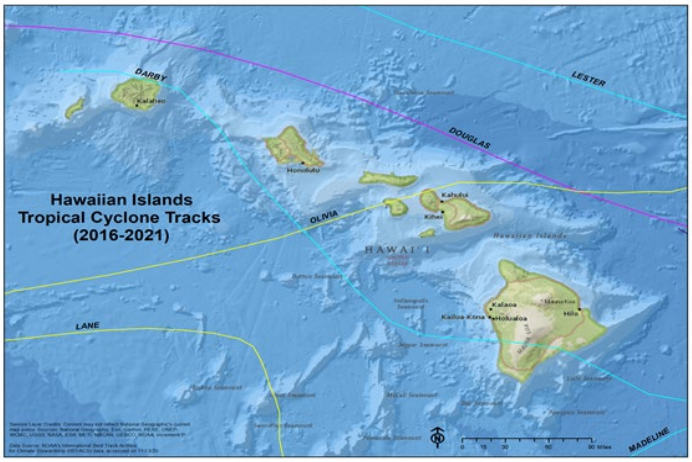


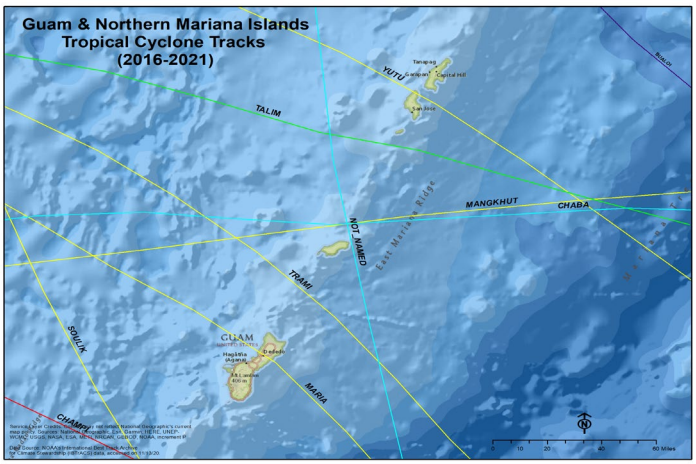


Time-series graphs illustrating annual Accumulated Ace Index (ACE) values for the Northeast Pacific (left) and Northwest Pacific sectors.
Data Source: Colorado State University, Dept. of Atmospheric Science.
http://tropical.atmos.colostate.edu/Realtime/index.php?arch&loc=northwestpacific
http://tropical.atmos.colostate.edu/Realtime/index.php?arch&loc=northeastpacific

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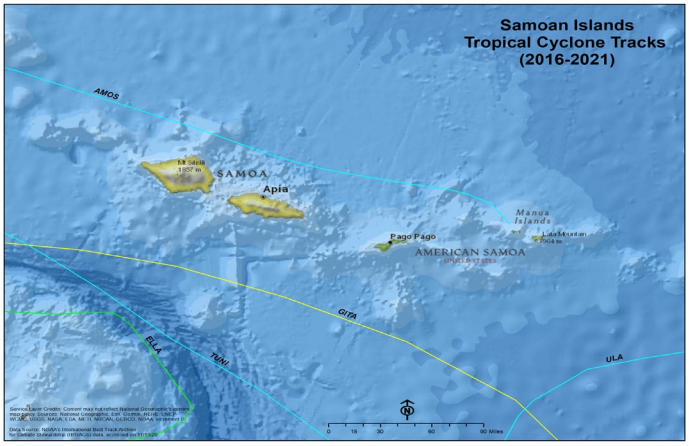
Climate Overview – *Tropical Cyclones (2016–2021)*

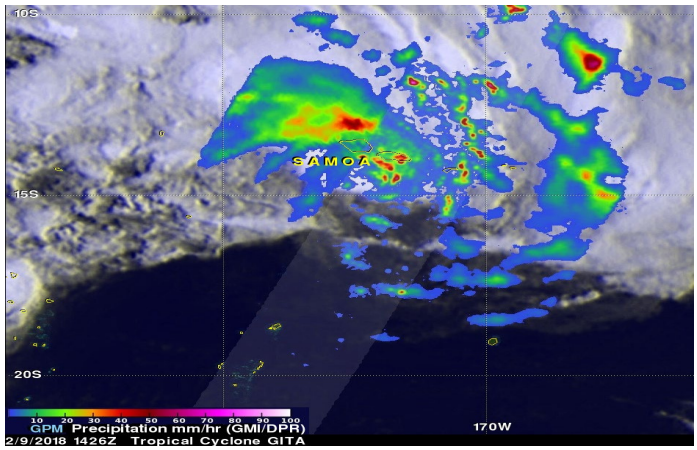




Maps of significant tropical cyclone storm tracks (2016-2021) impacting the Hawaiian Islands (left) and the Northern Mariana Islands and Guam (right).
Data Source: NOAA NCEI. https://www.ncdc.noaa.gov/ibtracs/index.php?name=ib-v4-access. Map credit: D. Simeral

Tropical cyclone (TC) activity impacting the Hawaiian Islands (above left) during the 2016-2021 period was highlighted by TC Darby that made landfall (only the fifth landfalling cyclone in Hawaii since records began in 1949) on Hawaii Island during July 2016 followed by Hurricane Lester which tracked north of the island chain during September 2016. In September 2018, Tropical Storm Olivia (former Hurricane Olivia) made landfall on Maui and Lanai marking the first TC to make landfall on those islands and causing severe flooding and wind damage. In July 2020, Hurricane Douglas passed within 40 miles of Maui, Oahu, and Kauai as a Category 1 hurricane. Hurricane Douglas became the closest passing TC in Oahu's history. In the Northwest Pacific, noteworthy TC activity included an active season during 2017-18 with Tropical Storm Maria making landfall during July 2018 in Guam as well as Typhoon Yutu making landfall in the Northern Mariana Islands causing catastrophic damage on Tinian and Saipan in October 2018. In the Southwest Pacific, notable TCs included TC Amos (April 2016) that veered just to the north (within ~40 miles of Tutuila, American Samoa) of the Samoan Islands causing flooding and impacts to infrastructure. In February 2018, TC Gita passed to the south of the Samoan Islands causing severe flooding and damage to homes and infrastructure. Since 1990, only five severe TCs have affected the island chain (https://www.sciencedirect.com/science/article/pii/S2225603219300128).





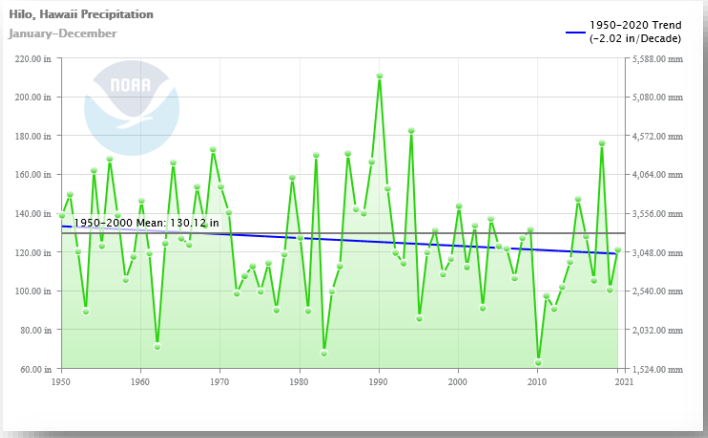
Map of significant tropical cyclone storm tracks (2016-2021 period) impacting the Samoan Islands (left) and satellite image of precipitation intensity from the NASA Global Precipitation Measurement's (GPM) Microwave Imager and Dual-Frequency Precipitation Radar of TC Gita passing over the Samoan Islands on February 9, 2018 (right).
Data Source: https://gpm.nasa.gov/extreme-weather/gpm-examines-tropical-cyclone-gita-over-samoa)

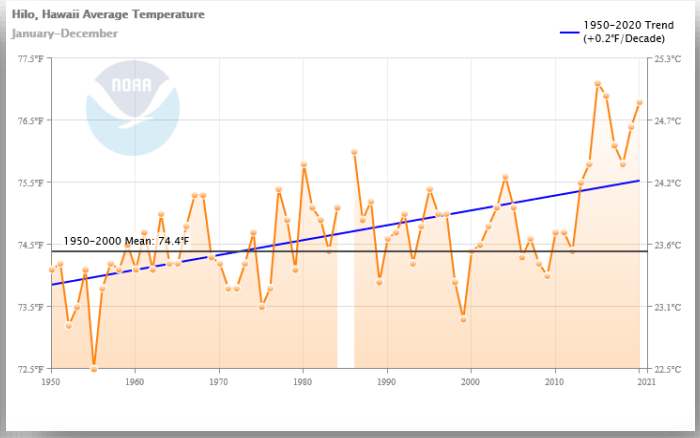
David Simeral (david.simeral@dri.edu)
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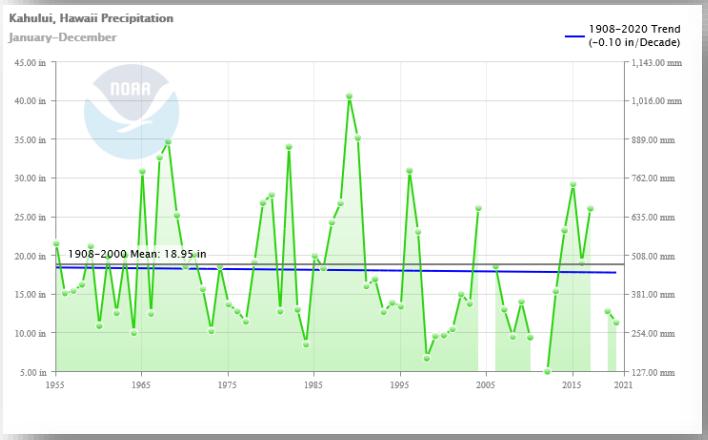
Climate Overview – *Climate Trends*

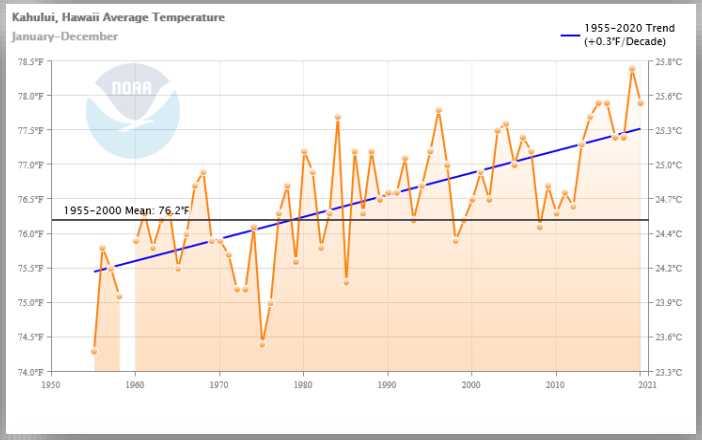


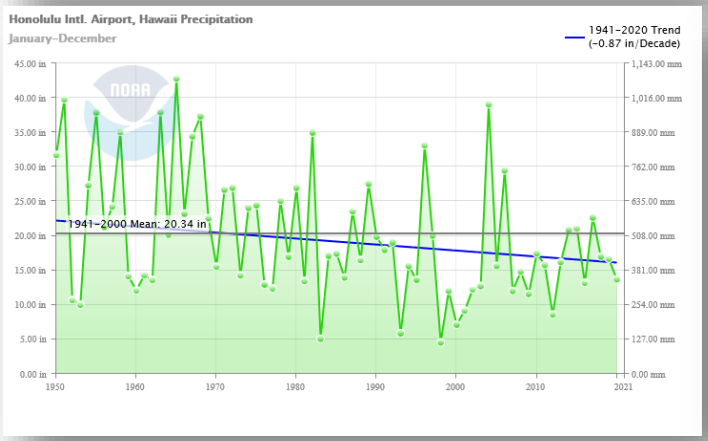


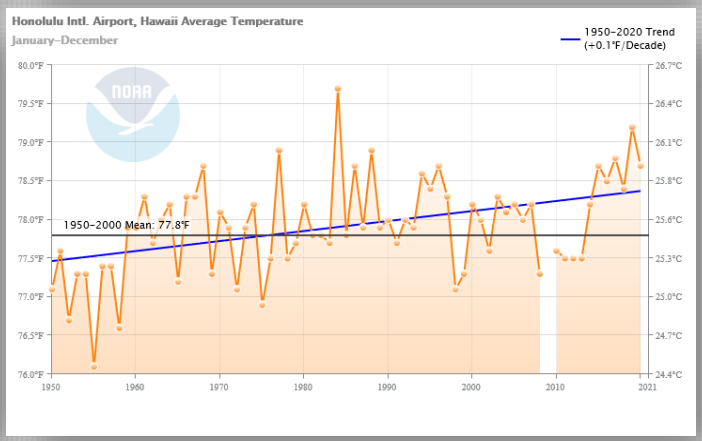












Time series plots of annual (calendar year) precipitation and average temperature observations and trends for Hilo (Hawaii Island), Kahului (Maui), and Honolulu (Oahu) from 1950-2020.

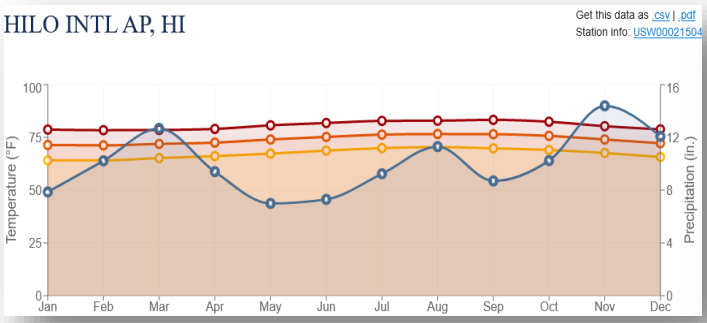
Data Source: https://www.ncdc.noaa.gov/cag/city/time-series

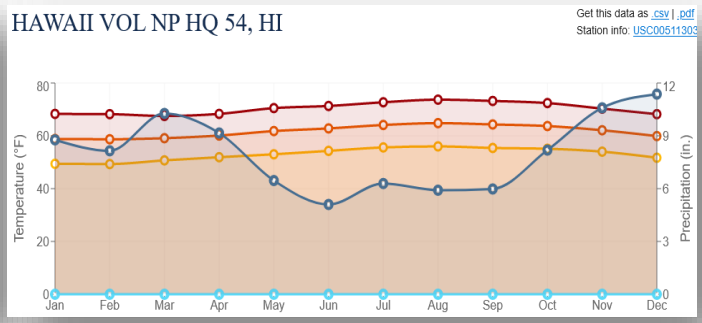
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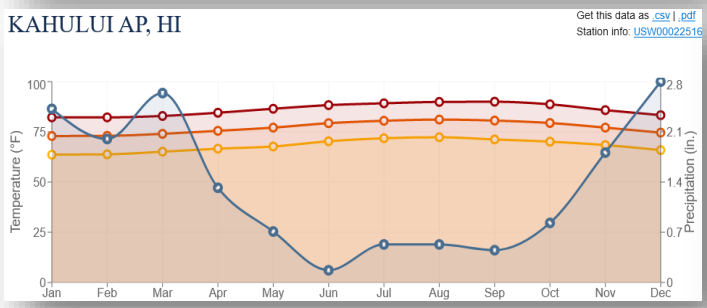
Climate Overview – *Climate Normals (1991-2020)*

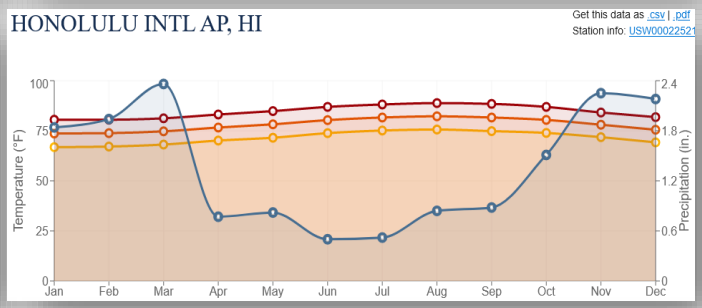


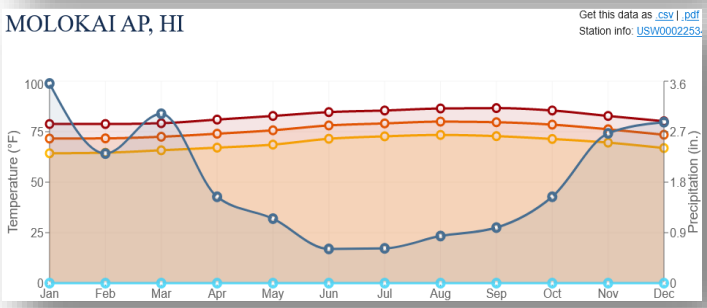


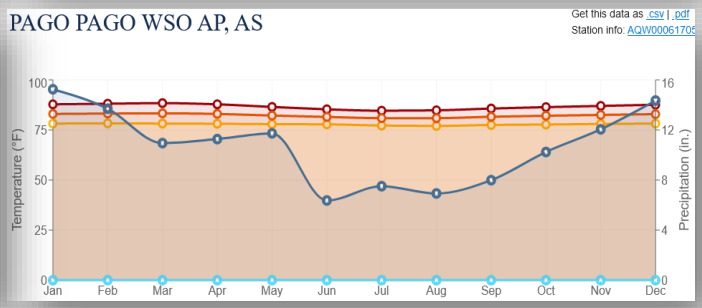


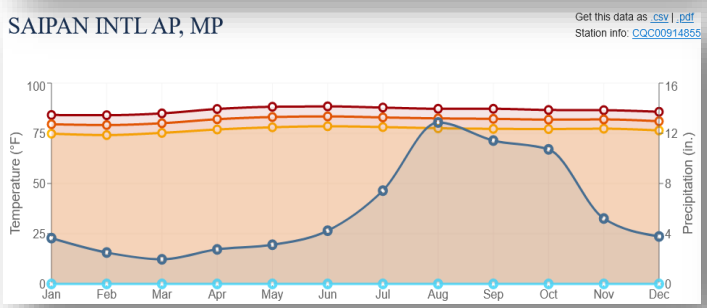


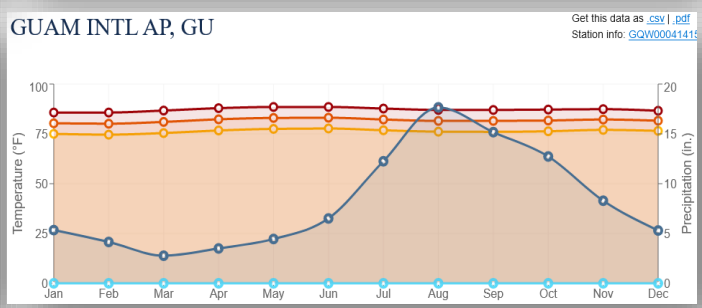










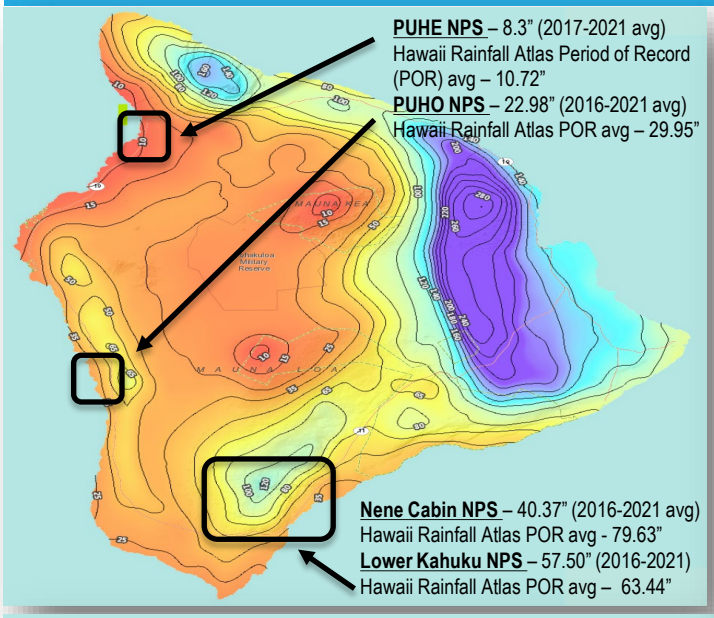


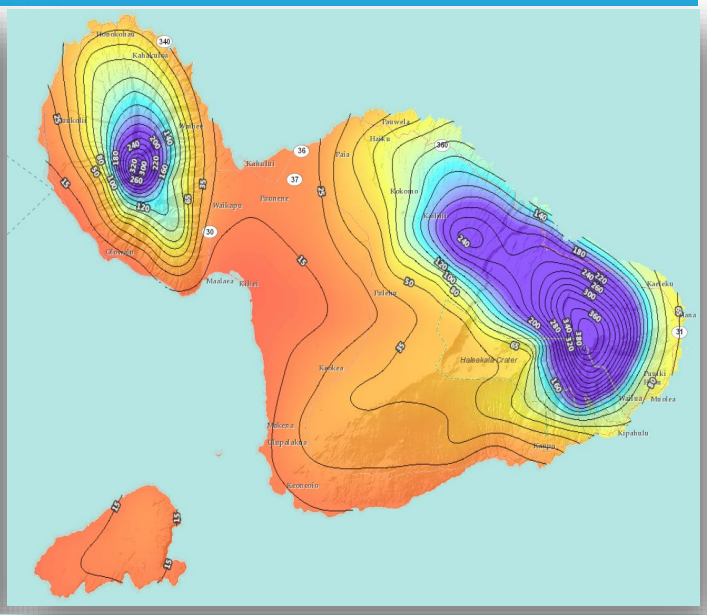
Monthly climate normals (1991-2020) for precipitation and average temperature for Hilo AP, Hawaii Volcanoes NP HQ, Kahului AP, Honolulu AP, Molokai AP, Pago Pago AP, Saipan AP, and Guam AP.

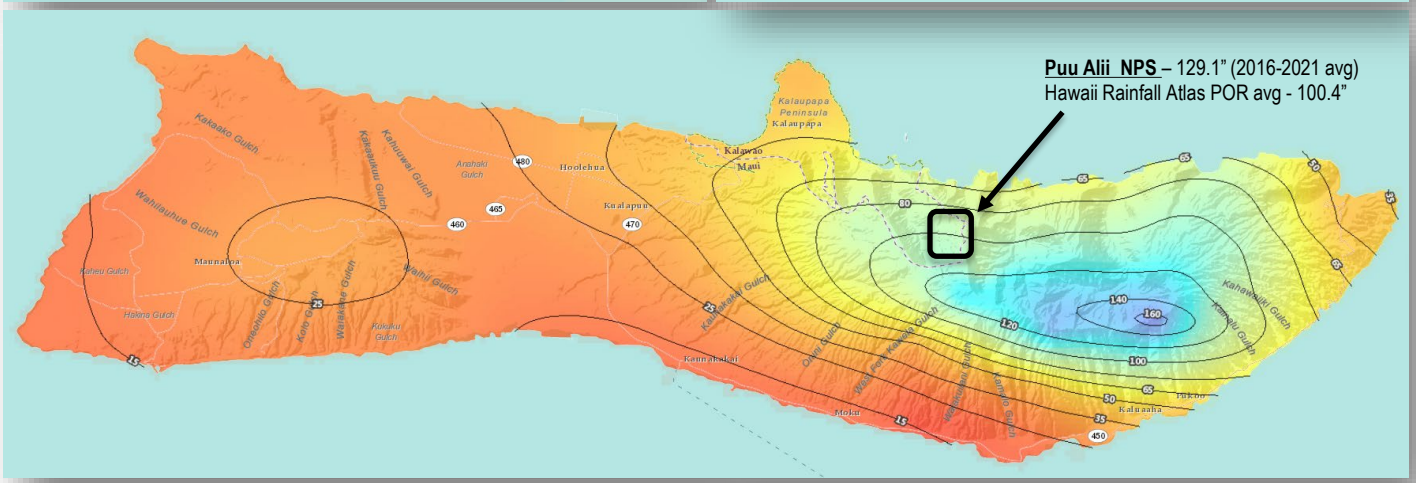
Data Source: https://www.ncei.noaa.gov/products/land-based-station/us-climate-normals

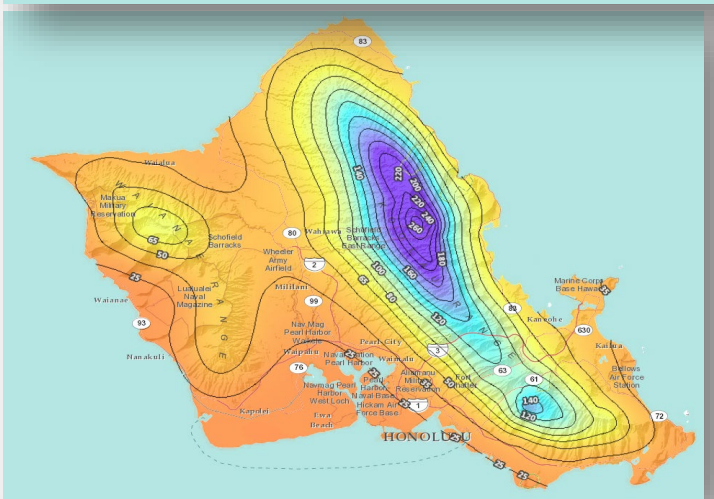
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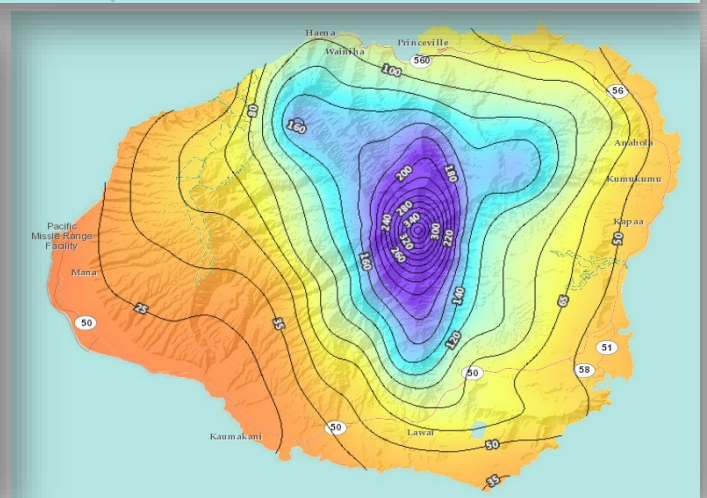
Climate Overview – *Annual Precipitation (Hawaii Rainfall Atlas vs NPS Observations)*









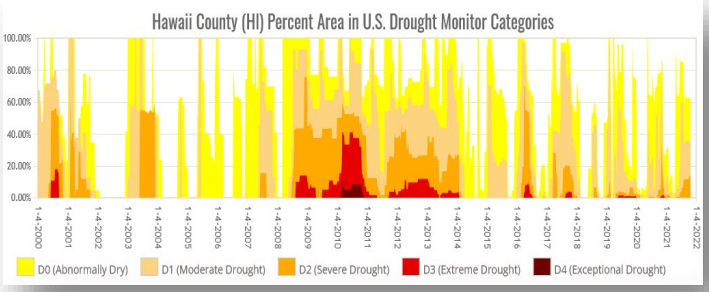


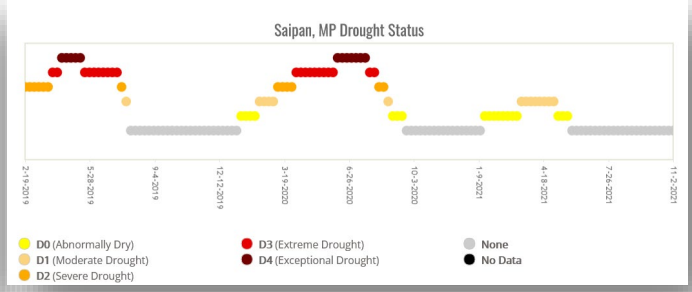
Maps of annual rainfall estimates for Hawaii Island, Maui, Molokai, Oahu, and Kauai from the Rainfall Atlas of Hawaii in comparison to observed average rainfall (2016-2021) from NPS PACN climate monitoring stations.

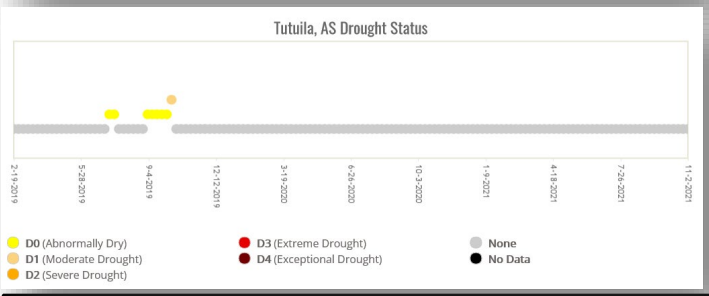
Data Source: Frazier, A. G., and Giambelluca, T. W. (2017), Spatial trend analysis of Hawaiian rainfall from 1920 to 2012. Int. J. Climatol., 37(5), 2522–2531. doi: 10.1002/joc.4862

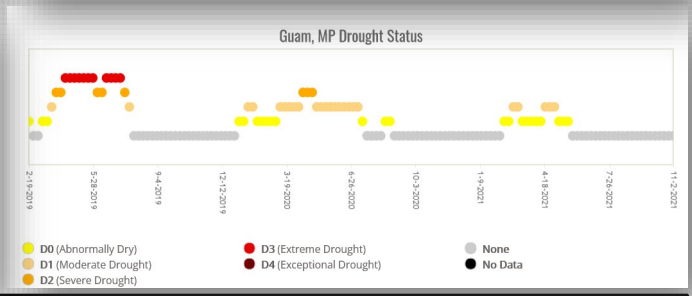
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Climate Overview – *Drought*









Time-series graphs depicting drought intensity on Hawaii Island from 2000-2021 (upper left), Tutuila, American Samoa (lower left), Saipan (upper right), and Guam (lower right) for 2019-2021. Note: Official drought monitoring (by the U.S. Drought Monitor) for the U.S. Affiliated Pacific Islands began in 2019.

Data Source: U.S. Drought Monitor (USDM). https://droughtmonitor.unl.edu/DmData/TimeSeries.aspx;

In the Hawaiian Islands, drought conditions were observed throughout much of 2016-2021 with periods of Severe (D2) to Extreme (D3) drought observed in Hawaii and Maui counties during 2016, 2017, 2019, and 2020. In 2020 to 2021, areas of Extreme (D3) to Exceptional (D4) drought were observed in Maui County with significant drought-related impacts reported including poor vegetation health, and cattle and deer mortality. In the U.S. Affiliated Pacific Islands (USAPI), Severe (D2) to Extreme (D3) drought were observed in Guam during April-July 2019 with Moderate (D1) drought re-developing during March-June 2020 and again in March-May 2021. In Saipan, more severe drought conditions were observed during the 2019-2021 with periods of Extreme (D3) to Exceptional (D4) drought observed during April-July 2019 and similarly during the contemporaneous period in 2020. In American Samoa, drought-free conditions were observed throughout most of the 2019-2021 period except for a brief period of Moderate (D1) drought observed during October 2018, according to the USDM.





Drought-impacted landscape in South Maui during June 2021 (left).
Wildfire activity on Capitol Hill, Saipan (Northern Mariana Islands) on January 21, 2021 (right).

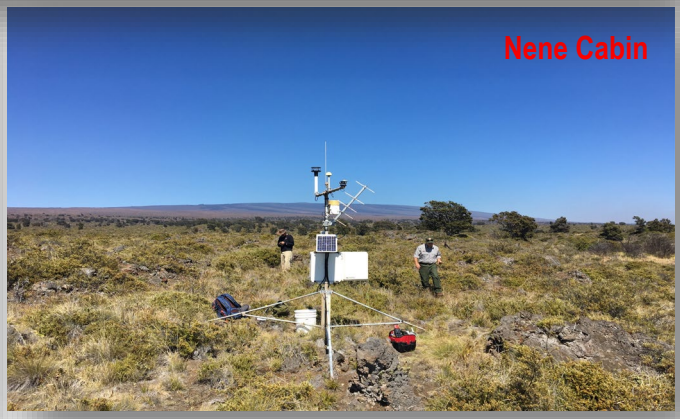
Data Source: https://www.drought.gov/reports

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NPS PACN Climate Monitoring Stations – *Hawaii Island*











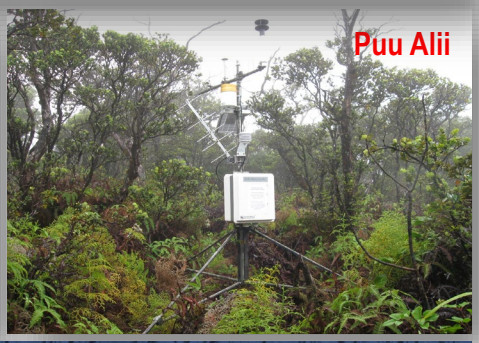
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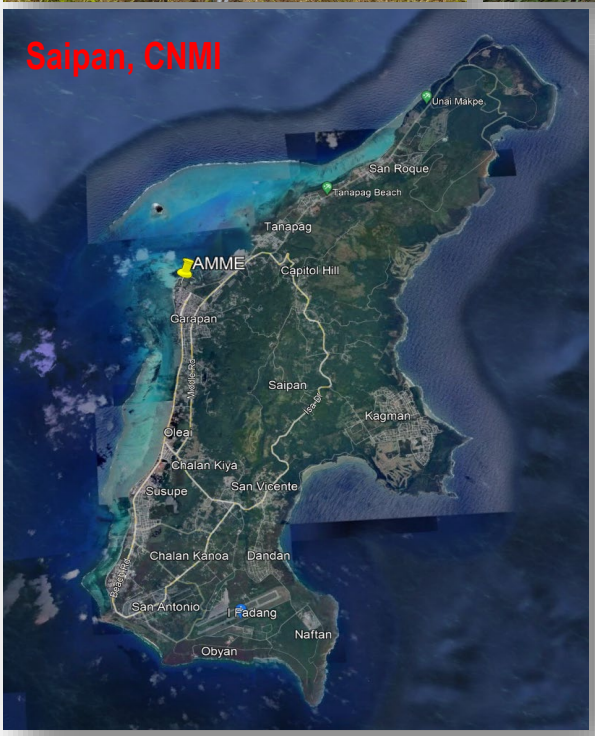
NPS PACN Climate Monitoring Stations –*American Samoa, Saipan, Molokai*











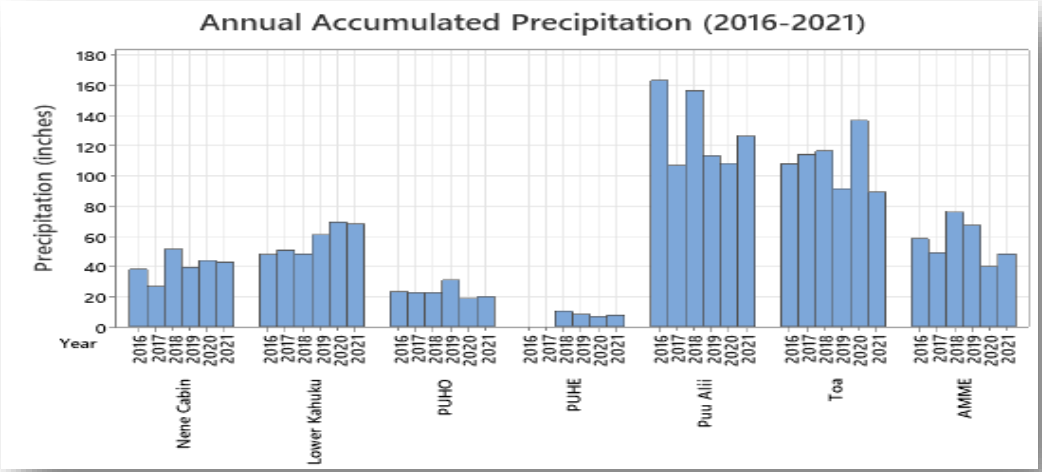




NPS PACN weather station photos. Top row (left to right): Siufaga Ridge (American Samoa) Toa Ridge (American Samoa), and Puu Alii (Molokai). Bottom: AMME (Saipan, Northern Mariana Islands).

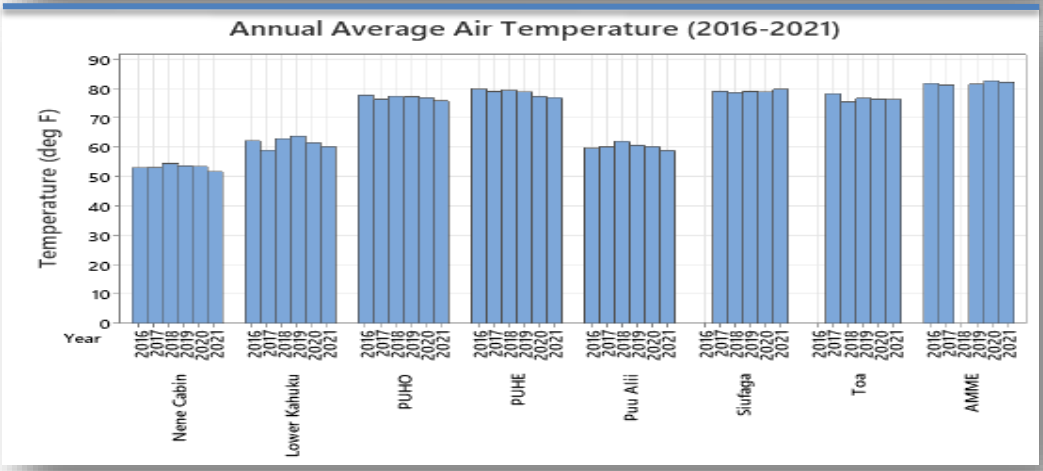
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Climate Overview – *NPS PACN Station Descriptive Statistics*



Statistics

Variable	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Nene Cabin	6	0	40.37	3.34	8.19	26.65	35.23	41.03	45.85	51.43
Lower Kahuku	6	0	57.50	4.05	9.92	47.80	48.10	55.75	68.42	69.40
PUHO	6	0	22.98	1.74	4.26	18.52	19.71	22.63	25.05	30.87
PUHE	4	2	8.300	0.788	1.577	6.800	7.025	7.950	9.925	10.500
Puu Alii	6	0	129.1	10.1	24.9	106.8	108.0	119.8	158.1	163.2
Siufaga	6	0	131.80	8.56	20.96	112.70	113.37	125.00	154.97	161.80
Toa	6	0	109.37	7.16	17.53	89.30	91.02	111.10	121.53	136.60
AMME	6	0	56.43	5.45	13.36	39.90	46.13	53.70	69.41	75.83



Statistics

Variable	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Nene Cabin	6	0	53.073	0.384	0.940	51.520	52.503	53.090	53.752	54.360
Lower Kahuku	6	0	61.483	0.719	1.761	58.900	59.800	61.700	63.025	63.700
PUHO	6	0	76.715	0.297	0.728	75.560	76.040	76.885	77.295	77.550
PUHE	6	0	78.323	0.456	1.117	76.800	77.025	78.690	79.215	79.560
Puu Alii	6	0	60.157	0.433	1.061	58.770	59.325	60.105	60.873	61.930
Siufaga	5	1	78.860	0.175	0.391	78.500	78.550	78.800	79.200	79.500
Toa	5	1	76.418	0.464	1.038	75.300	75.650	76.200	77.295	78.100
AMME	5	1	81.644	0.262	0.585	80.940	81.130	81.580	82.190	82.480

Descriptive statistics of annual (2016-2021) accumulated precipitation (top) and annual average air temperature from NPS PACN monitoring network. Notes: (1) data is preliminary; (2) data does not include Nov. and Dec. 2021.

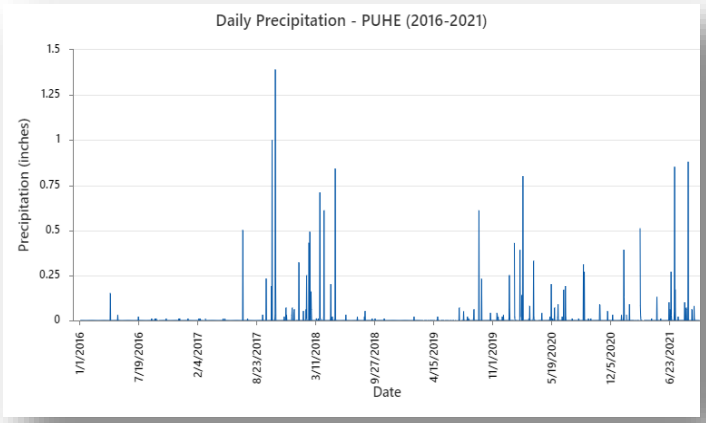
Data Source: Western Regional Climate Center. https://wrcc.dri.edu/NPS.html; https://nps-pacn.dri.edu/acuity/map/show?map=2

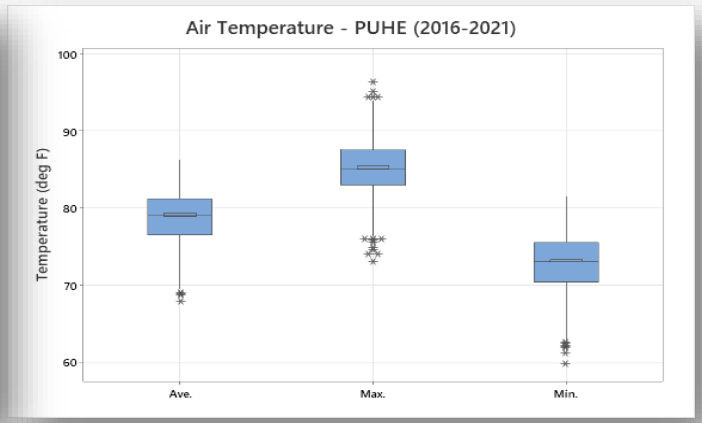
David Simeral (david.simeral@dri.edu)
https://wrcc.dri.edu/

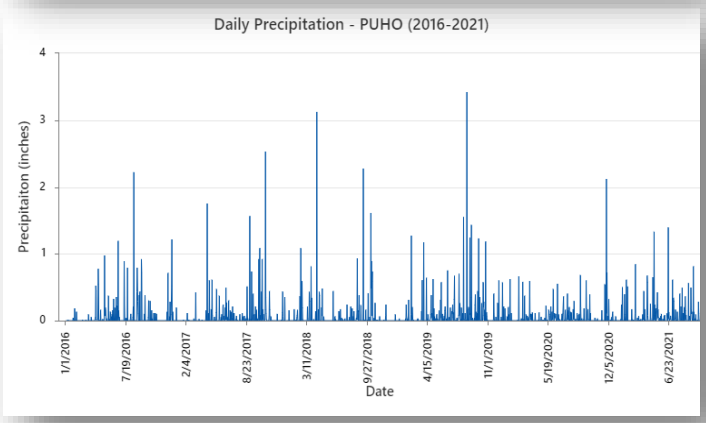
Climate Overview – *NPS PACN Station Data (preliminary)*

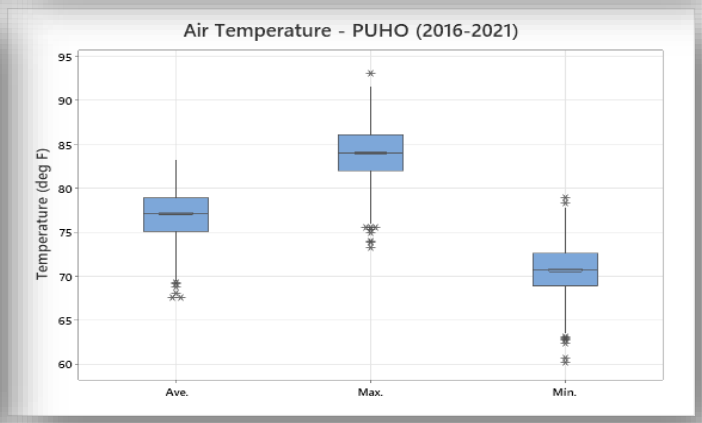


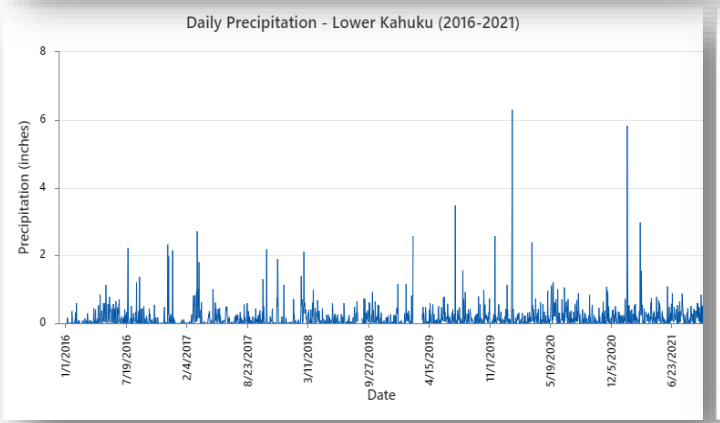


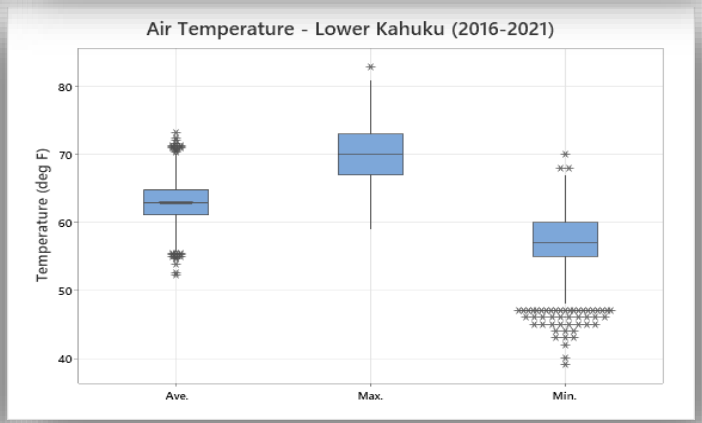












Time series plots of daily precipitation (2016-2021) and boxplots of average temperature data from the NPS PACN observational stations.

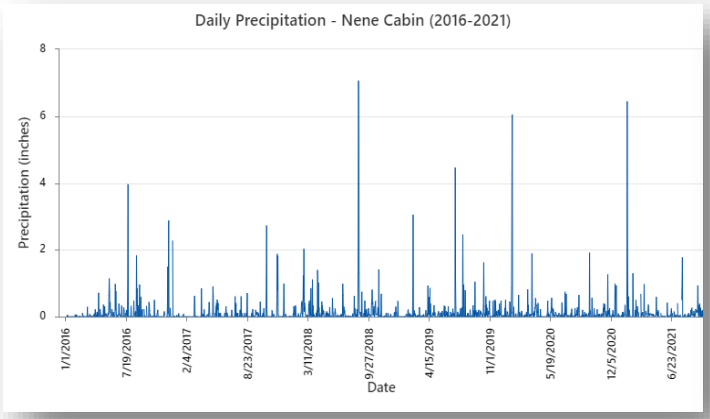
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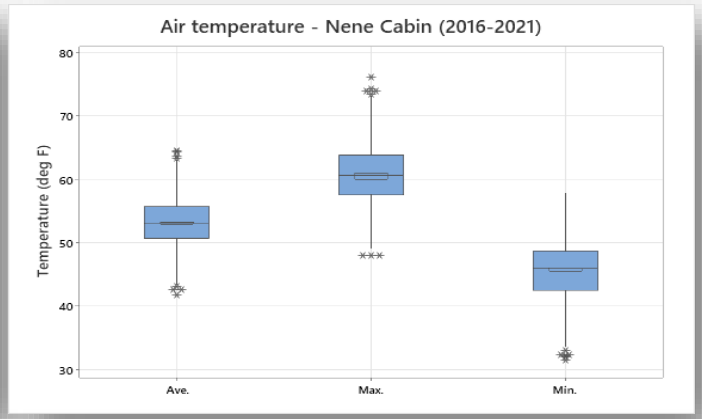
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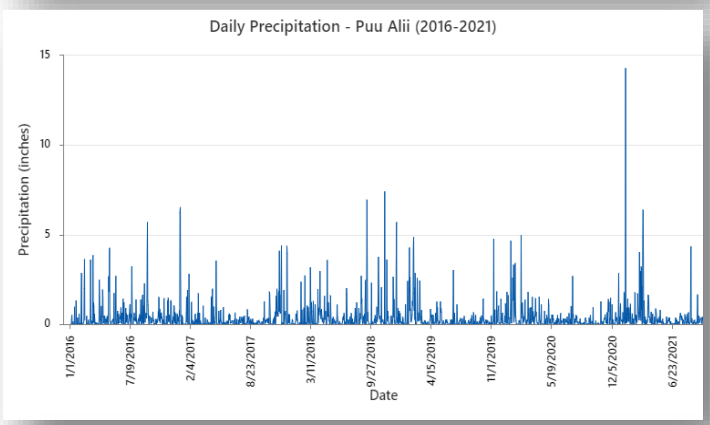
Climate Overview – *NPS PACN Station Data (preliminary)*

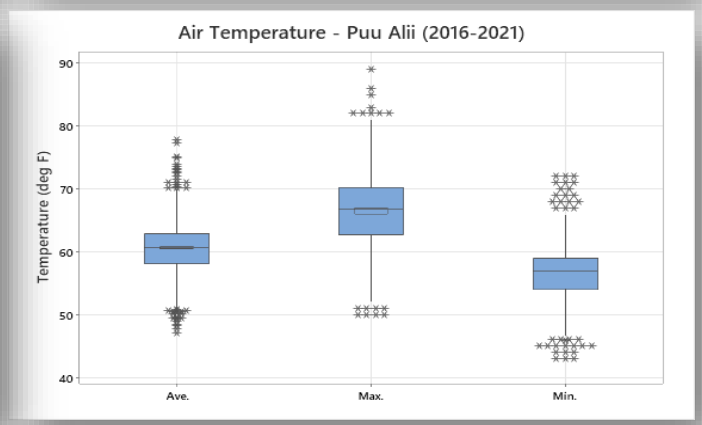


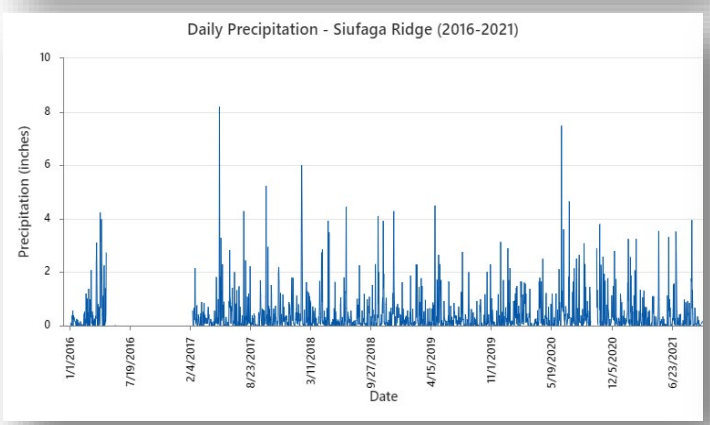


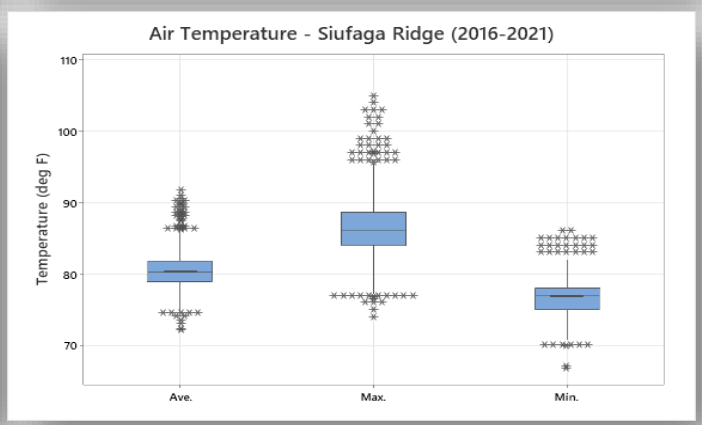












Time series plots of daily precipitation (2016-2021) and boxplots of average temperature data from the NPS PACN observational stations.

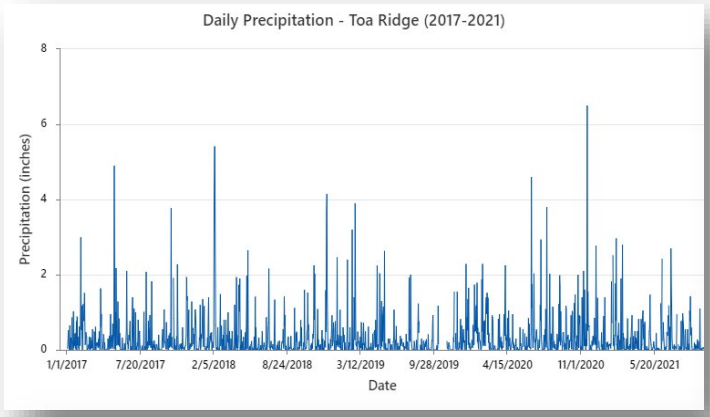
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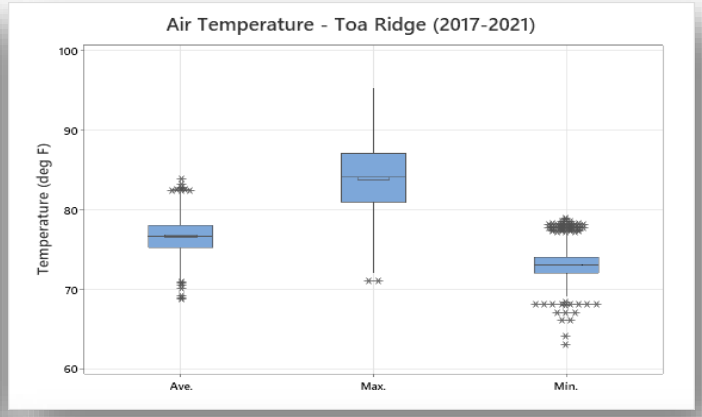
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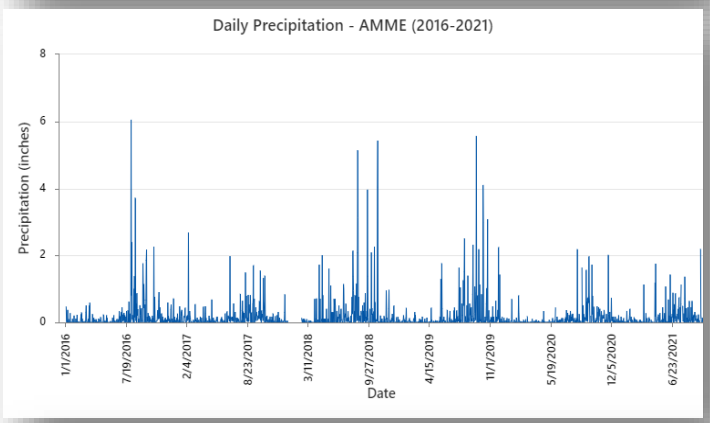
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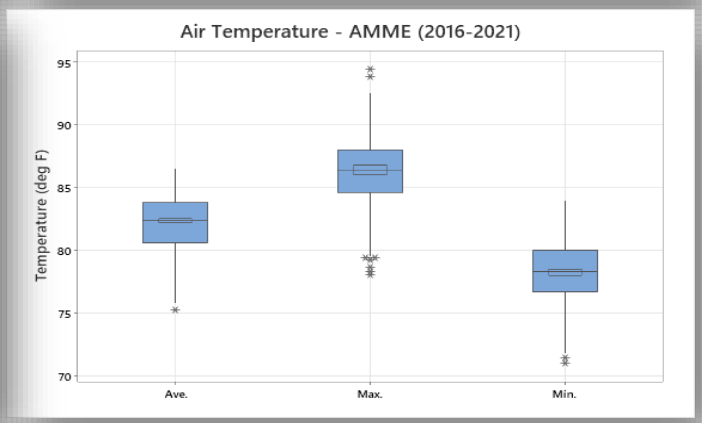
















Time series plots of daily precipitation (2016-2021) and boxplots of average temperature data from the NPS PACN climate monitoring stations. Fieldwork photos from Puu Alli (Kalaupapa NHP) in 2021 (left) and Toa Ridge in the National Park of American Samoa in 2019 (right).

Data Source: https://wrcc.dri.edu/NPS.html; https://nps-pacn.dri.edu/acuity/map/show?map=2

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