



Annual Weather/Climate Data Summary 2010

Pacific Island Network

Natural Resource Data Series NPS/PACN/NRDS—2012/273



ON THE COVER

Sunset at American Memorial Park (AMME), Saipan, Commonwealth of the Northern Mariana Islands.
Photograph courtesy of National Park Service staff.

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April 2012

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado publishes a range of reports that address natural resource topics of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

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All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

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Please cite this publication as:

Casey, T. L. C. 2012. Annual weather/climate data summary 2010: Pacific Island Network. Natural Resource Data Series NPS/PACN/NRDS—2012/273. National Park Service, Fort Collins, Colorado.

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Acknowledgments

Many thanks to all park staff and cooperators who help maintain weather stations and report data. Data for this report were made available by the Western Regional Climate Center; in addition, data published by the National Climatic Data Center (NCDC) and the Drought Monitor is presented. Karin Schlappa contributed a great deal to the original report, from which this 2010 report was expanded, especially with her R statistical scripts for most of the weather stations analysis. Thanks also to Kelly Kozar who added significant scrutiny to corrections needed on some of the tables in near final form.

ACRONYMS

AAFB	Anderson Air Force Base
ALKA	Ala Kahakai National Historical Trail
AMME	American Memorial Park
CESU	Cooperative Ecosystems Studies Unit
CNMI	Commonwealth of the Northern Mariana Islands
COOP	Cooperative Observer Program
CPC	Climate Prediction Center
CPHC	Central Pacific Hurricane Center
CRN	Climate Reference Network
CWOP	Citizen Weather Observer Program
DRI	Desert Research Institute
ENSO	El Nino Southern Oscillation
ESCAP/WMO	Economic and Social Commission for Asia and the Pacific/World Meteorological Organization
GOES	Geostationary Operational Environmental Satellite
GPMN	Gaseous Pollutant Monitoring Network
HALEnet	Haleakala Climate Network
HAVO	Hawaii Volcanoes National Park
hPa	HectoPascal
IQR	Interquartile Range
KAHO	Kaloko Honokohau National Historical Park
KALA	Kalaupapa National Historical Park
MS	Microsoft
MTSAT	Multifunctional Transport Satellite
NAS	Naval Air Station
NCA	National Coastal Assessment
NCDC	National Climatic Data Center
NEPA	National Environmental Policy Act
NOAA	National Oceanographic and Atmospheric Administration
NPHQ	National Park Headquarters
NPS	National Park Service
NPSA	National Park of American Samoa
NRCS	Natural Resources Conservation Service
NRPM	Natural Resources Publications Management
NWS	National Weather Service
PACN	Pacific Island Network
PDO	Pacific Decadal Oscillation
PEAC	Pacific ENSO Application Climate Center
PUHE	Puukohola Heiau National Historical Site
PUHO	Puu Honua O Honaunau National Historical Park
RAWS	Remote Automated Weather Stations
SST	Sea Surface Temperature
TC	Tropical Cyclone
USAPI	U.S. Affiliated Pacific Islands

ACRONYMS (continued)

USGS	United States Geological Survey
VALR	World War II Valor in the Pacific National Monument
WRCC	Western Regional Climate Center
WSMO	Weather Service Meteorological Office
WSO	Weather Service Office

Introduction

Weather/climate monitoring is one of several long-term vital sign monitoring efforts of the Pacific Island Network (PACN). Climate and weather information affects virtually all of the measured vital signs. Climate and weather affect benthic marine communities: warmer ocean temperatures can affect coral growth and permutations can affect whole reef ecosystems. Climate/weather variations affect how invasive species fare and what happens in a focal terrestrial plant community. Precipitation directly affects groundwater dynamics, fresh water animal communities, and water quality. Land and sea birds are affected by the changes in seasons: rain and temperature signal insect breeding and abundance, which often precipitate breeding in many birds (Hogan 2010).

One of the primary goals of climate and weather monitoring is to determine the status and trend of weather patterns and long term climate regimes, so managers can effectively make informed decisions about the conditions of each national park. Similarly, monitoring of weather and climate may provide early warning of abnormal conditions.

Annual reports summarize data for a previous year and provide information from as many weather stations as possible, regardless of station record length. Five-year trend reports focus on system patterns with data analyzed from stations with a long record periods and high observation frequencies. More in-depth data verification is possible and analysis can be statistically robust.

Climate is generally mild on equatorial Pacific islands. Weather patterns in the national parks are largely controlled by island geomorphology and the surrounding Pacific Ocean. The ocean temperatures vary only about six degrees throughout the year, from lows near 73° or 74° in March to 80° in August. Because there are no near continents, weather systems are moderated by the ocean.

Seasons are less defined on Pacific islands. Two seasons prevail in Hawaii, summer (April through October) and winter, (November through March). Dry and wet seasons somewhat correlate with summer and winter, respectively. The wet season (winter) in American Samoa is from October through April and from July through November in the Marianas (Saipan and Guam).

Interestingly, in Hawaii, the coldest months are not December and January as they are in the continental United States, but January and February. Cold winds come from the Arctic but the lower temperatures arrive one to two months later due to the lag in the Pacific Ocean's temperature (PEAC 2011).

The hottest months are also set back, rather than the traditional continental high temperatures in June (7 states), July (34 states) and August (10 states) (NOAA 2011). Hawaii has the hottest days varying from July to August and September (PEAC 2011). See **bold** portions in maximum temperature analysis in all Hawaiian national park tables.

PACN national parks are located in the Hawaiian Islands, in the Commonwealth of the Northern Mariana Islands: on Guam and Saipan and in American Samoa and include the following park units (Table 1; Figure 1).

Table 1. National parks in the Pacific Island Network (PACN).

National Park	Island	Total size in acres (marine portion)	Terrestrial Elevation Range ft
War in the Pacific National Historical Park (WAPA)	Guam	1,980 (990)	0 to 1,043
American Memorial Park (AMME)	Saipan	143 (0)	0 to 9
National Park of American Samoa (NPSA)	Tutuila, Ofu-Olosega, Tau	14,616 (5,261)	0 to 3,169
World War II Valor in the Pacific National Monument (VALR)	Oahu	17 (5)	0 to 75
Kalaupapa National Historical Park (KALA)	Molokai	11,251 (2061)	0 to 4,222
Haleakala National Park (HALE)	Maui	29,032 (0)	0 to 10,022
Ala Kahakai National Historic Trail (ALKA)	Hawaii	TBD	0 to 400
Puukohola Heiau National Historic Site (PUHE)	Hawaii	86 (7)	0 to 170
Kaloko-Honokohau National Historical Park (KAHO)	Hawaii	1,188 (536)	0 to 79
Puuhonua o Honaunau National Historical Park (PUHO)	Hawaii	571 (0)	0 to 899
Hawaii Volcanoes National Park (HAVO)	Hawaii	333,817 (0)	0 to 13,678

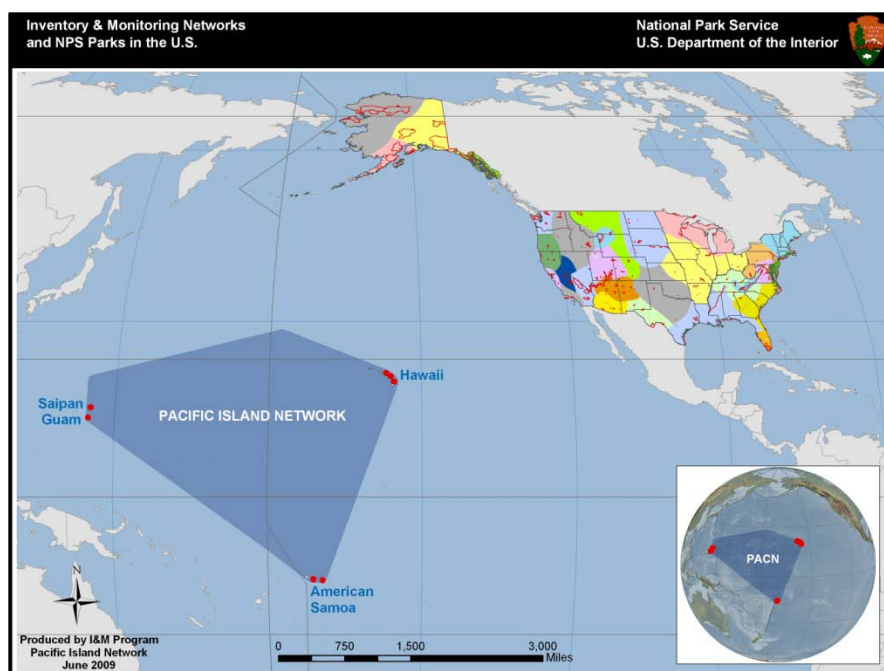


Figure 1. Map showing the extent of the Pacific Island Network; red dots indicate national park units.

Atmospheric Phenomena

Climate and weather across the Pacific are affected by many atmospheric phenomena. Most of the following information was summarized from a variety of sources. Specifically, these phenomena and their sources include: the Hadley Cell, (NASA 2009, Windrim 2004), the Walker Circulation (Weier 2003, NOAA 2007), ENSO (El Niño/La Niña Southern Oscillation) (PEAC 2011, Chu 2004, Chu and Wang 1997, Ropelewski and Halpert 1987, Lander and Guard 2003, and Lander 2004), Kelvin Waves (NASA Science 2005, NOAA 2006), the Madden-Julian Oscillation (NOAA 2006, United Press International 2010, Madden and Julian 1994), tropical cyclones/hurricanes (Angove and Falvey, 2011) and to a lesser degree the Pacific Decadal Oscillation (PDO) (Hane 2006, JISAO 2000).

The Hadley Cell

The Hadley Cell circulation pattern (Figures 2 & 3) accounts for thermal movement of air latitudinally from the Equator to the Tropic of Cancer and Tropic of Capricorn at 23° 26' north and south latitude. Solar radiation is the largest cause of atmospheric circulation on Earth. As the air at the Equator heats, the warm air rises and moves up to about 17 kilometers (11 miles/58,080 feet) high, at the tropopause (Figure 4). The air then moves northward and descends at roughly 30° north and south, depending on the season. After descending, it moves towards the Equator near the surface. With the addition of the Coriolis Effect, caused by the rotation of the Earth on its axis, the trade winds are born. Coriolis action on the winds aloft creates the jet stream. The whole system also moves north and south with the seasons, as far as 23.5° north and south latitudes.

The Intertropical Convergence Zone, (ITCZ) is where the north and south trade winds converge at the ocean surface near the Equator. This band of merging air masses creates a band of thunderstorms across the Earth's surface (Figure 5).

The Ferrell Cell (Figure 4) operates in the 30-60° latitudes; the circulation pattern is roughly the opposite of the Hadley Cell, although there are marked differences due to the westerlies which are subject to passing weather systems and high and low pressure cells. It is not a closed system like the Hadley Cell and the Polar Cell. The Polar Cell circulates from 60° north and south towards both poles (Figures 3 and 4).

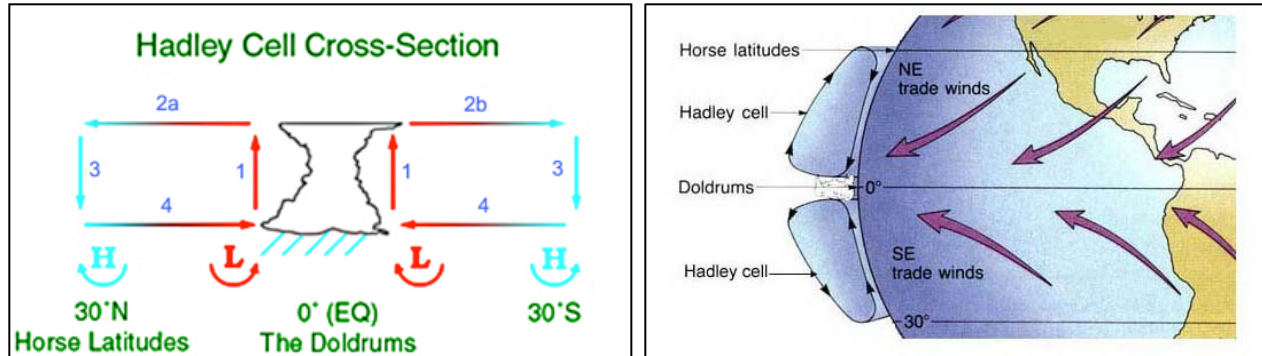


Figure 2. Hadley Cell Cross-Section and location of Hadley cell between the Tropic of Cancer and the Tropic of Capricorn (23° 26' north and south latitudes (Windrim 2004)).

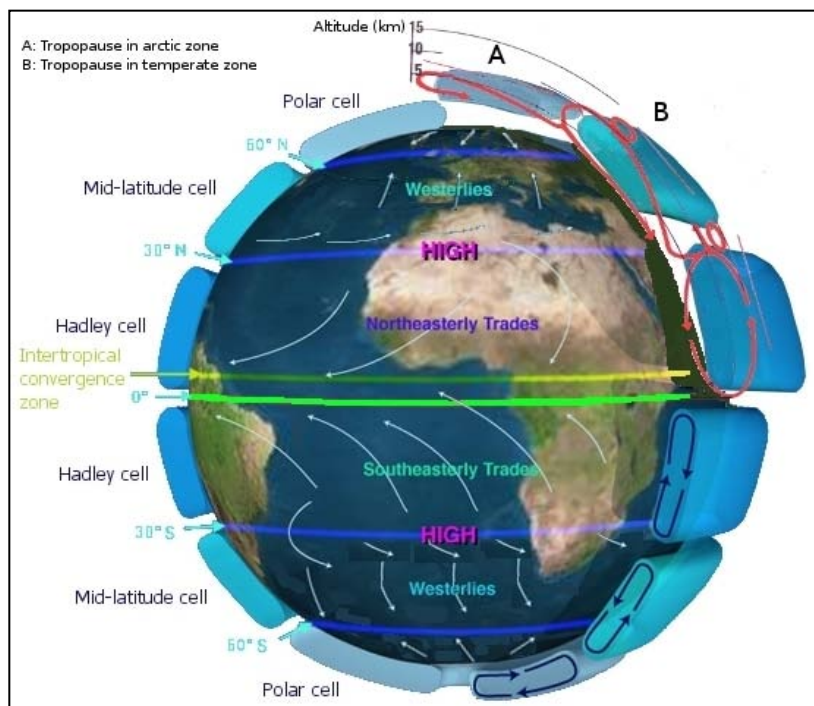


Figure 3. Illustration of the Earth's thermal circulation patterns (highly stylized) with the Coriolis Effect considered (NASA 2009).

The Hadley, Ferrel and Polar Cells are mainly latitudinal systems. There is also a longitudinal component to the Earth's circulation system. These patterns are largely due to the difference in the solar absorption and dissipation between water (oceans) and land. Oceans have a larger heat capacity and absorb and release more heat than land, but the temperatures are less extreme than land. Land temperatures have a much higher difference between day and night. This creates an

imbalance that affects longitudinal weather and climate patterns. This atmospheric phenomenon is what causes sea breezes in the morning. The cooler air from the ocean (sea breeze) comes in as the warmer air above the land rises as it is heated during the day. At night, the land temperatures cool faster than the ocean and cool winds go out to sea (land breeze) (Appendix A).

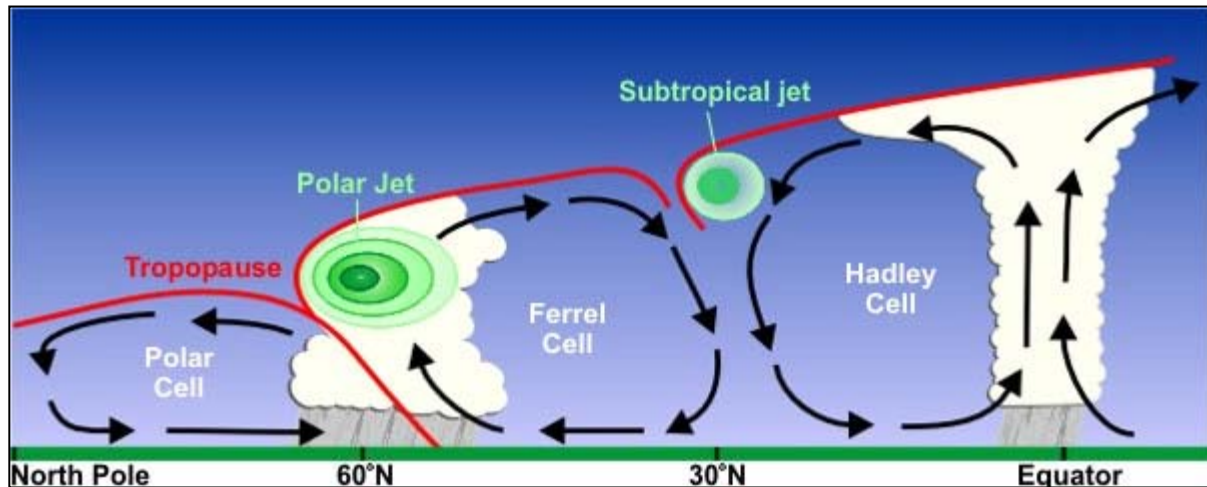


Figure 4. A cross-section of the Earth's atmosphere showing the tropopause, the boundary between the troposphere and the stratosphere (NOAA 2008).

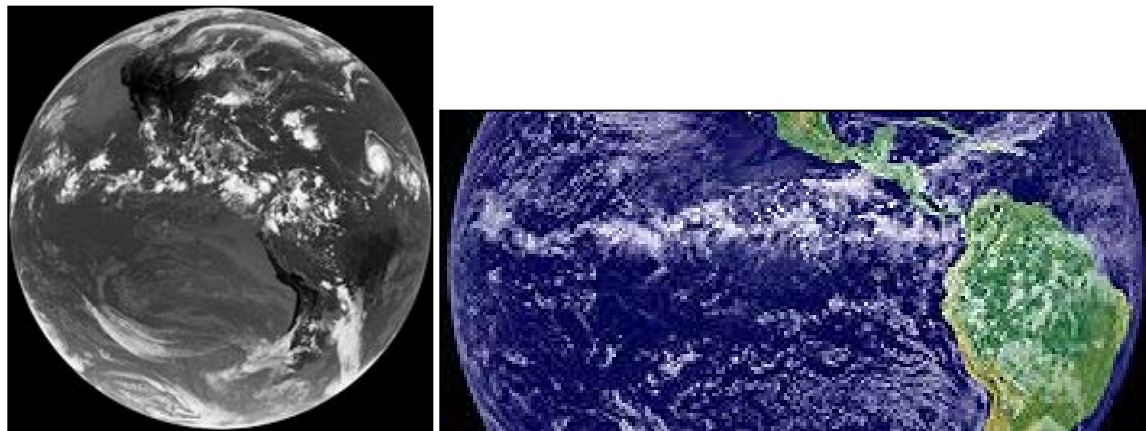


Figure 5. Satellite imagery of the Intertropical Convergence Zone, where the north and south trade winds converge, creating a band of thunderstorms, near the equator (NOAA-NASA GOES project 2011).

Walker Circulation

The Pacific Ocean cell generates weather patterns by differences in temperature from the east to the west Pacific. This tremendous system is called the Walker Circulation (Figures 6 and 7), and also influences weather patterns in the Atlantic and Indian oceans. This conceptual system of circulation is across the Equatorial Pacific and in the troposphere. It is caused by differences in the heat distribution between ocean and land (NOAA 2007).

The Walker circulation transports air east and west along both sides of the equator. Air currents rise high above the warm pool over the far western Pacific and the Indian oceans and then flow east towards the coasts of the Americas. The air currents then descend and travel west, skimming the surface of the Pacific and help create the trade winds (Weier 2003).

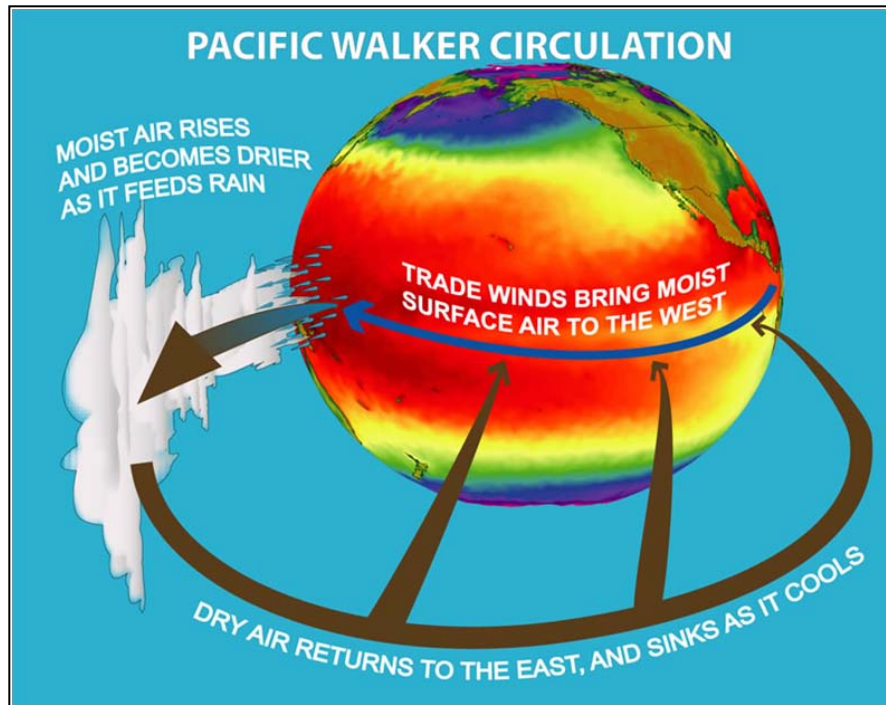


Figure 6. The Walker Circulation pattern across the Pacific Ocean (NOAA Geophysical Fluid Dynamics Laboratory 2001).

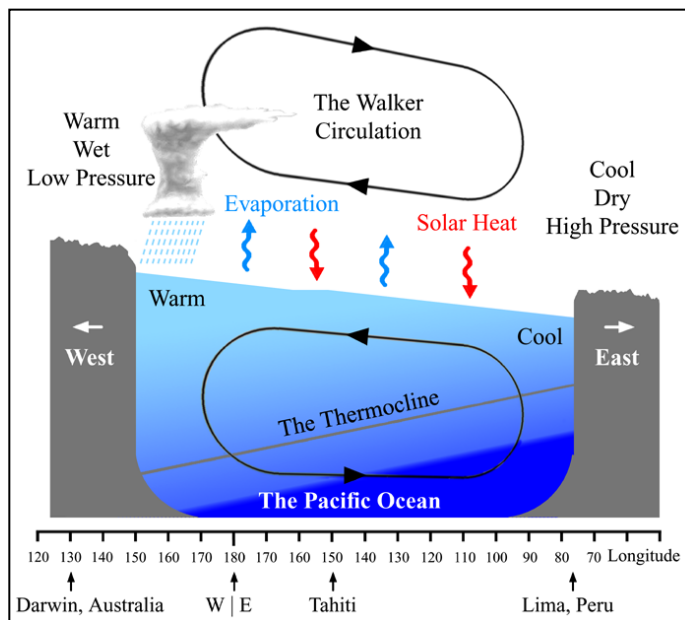


Figure 7. Schematic diagram of the quasi-equilibrium and La Niña phase of the southern oscillation (DAR 2005).

The Walker circulation is seen at the surface as easterly trade winds which move water and air warmed by the sun towards the west. The western side of the equatorial Pacific is characterized by warm, wet low pressure weather as the collected moisture is dumped in the form of typhoons and thunderstorms. The ocean is some 60 cm higher in the western Pacific as the result of this motion. The water and air are returned to the east. Both are now much cooler, and the air is much drier. An El Niño episode is characterized by a breakdown of this water and air cycle, resulting in relatively warm water and moist air in the eastern Pacific (DAR 2005).

El Niño/La Niña Southern Oscillation (ENSO)

Another atmospheric phenomenon that affects weather and climate in the PACN is the El Niño/La Niña Southern Oscillation (ENSO). ENSO is responsible for the cyclical weather patterns in the Pacific. El Niño and La Niña are measured by the temperature of the ocean, the sea surface temperature (SST) compared to a normal temperature across the central and eastern Pacific. It is an apparently periodic function across the Pacific Ocean that follows an approximate two to seven year pattern. Within this cycle are often seven to nine month cycles called “conditions”. When the cycles occur longer than this they are called “episodes” (PEAC 2011).

El Niño is responsible for serious environmental perturbations, particularly in the eastern Pacific. When warm water comes in contact with the Humboldt Current, the deep cold water upwelling on the South American coast, the differences in temperature cause huge fish movements, up and down the thermocline and geographically. If the event lasts a long time, the economic health of the coastal communities in South America is affected.

La Niña is the cold phase of ENSO, seemingly but not exactly the opposite of El Niño, where colder SST occur in the eastern Pacific then migrate west (Figures 7 and 8). The intense rains move to the west, causing dry conditions to the east. The start of La Niña is often an increase in the strength of the trade winds. This increases the abundance of tropical cyclones in the western Pacific, although the opposite happened in 2010. With the shift of winds towards the west, the rise in the sea level can be as much as 60 cm, or 25 inches in the western Pacific (PEAC-NOAA 2011).

This sea level rise is associated with warmer water at the ocean’s surface. Wherever this warm water moves across the Pacific, sea levels are higher

During normal and La Niña conditions, much of this water is concentrated in the western tropical Pacific, where it is essentially "piled up" by easterly winds pushing sun-warmed ocean waters in from as far away as South America. This maintains a comparatively thick layer of warm water called the "warm pool" in the Western Pacific, also causing sea levels there to be slightly higher than in the east (PEAC, 1997). Also during La Niña, the increased flow of cold deep water to the surface (Humboldt or Peru Current) acts to lower the sea level in the eastern Pacific (PEAC-NOAA 2011).

During an El Niño, sea level in the eastern Pacific is well above average, The thermal expansion of the warming water measurably raises the sea level in this region; this change in sea level can be measured by satellite sensors.

In the Commonwealth of the Northern Mariana Islands, on Saipan (AMME) and Guam (WAPA) very dry conditions prevail in the year following an El Niño (Ropelewski and Halpert 1987, Lander and Guard 2003, Lander 2004).

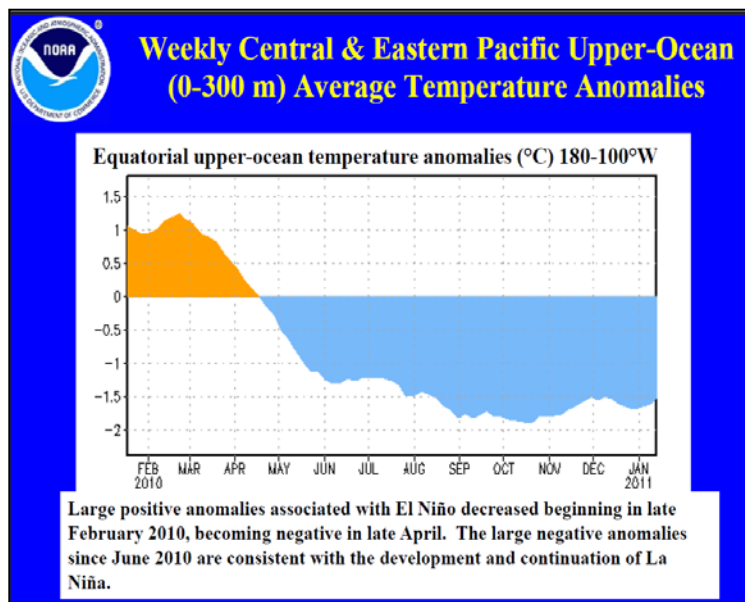


Figure 8. La Niña began in mid April 2010 (NOAA 2011).

In American Samoa (NPSA) rainfall increases during all seasons of an El Niño year; in the following year rainfall is also increased, but to a lesser extent in all seasons except during summer when it is slightly decreased (PEAC 2011).

In Hawaii (HAVO, KAHO, PUHO, PUHE, ALKA, HALE, VALR, KALA), tropical cyclone activity in the Pacific Ocean is also affected by ENSO (Chu 2004). For example, tropical cyclones occurred near Hawaii during El Niño years with fewer storms during La Niña years (Chu and Wang 1997).

The second half of the ENSO phenomenon is the Southern Oscillation which is the measured difference in the atmospheric pressure between Darwin, Australia and Tahiti. During El Niño, the air pressure is higher over northern Australia and less in Tahiti and the central Pacific. It is the opposite during La Niña.

Kelvin Waves

When the Southern Oscillation occurs, relatively warm subsurface waves of water a few centimeters high and hundreds of kilometers wide called Kelvin waves (NASA Science 2005) (Figure 9) start to move across the Pacific from west to east. This warmth takes the cloud masses with it, lessening the chance of rain in the west and increasing the chance of rain in the east.

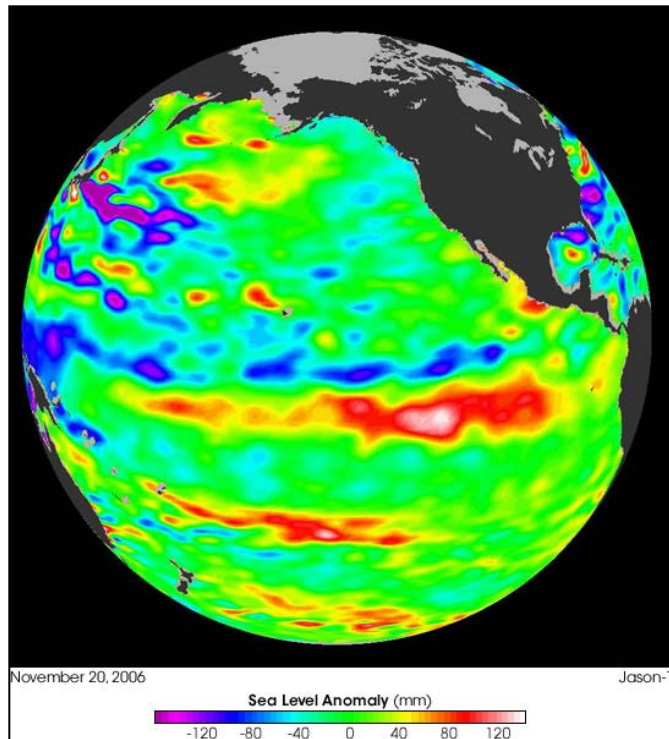


Figure 9. During ENSO, this pulse of returning warm water (red), causing higher sea levels at the Equator, is called a Kelvin wave (NOAA 2006).

Madden-Julian Oscillation

The Madden-Julian Oscillation (MJO) is a 30-60 day wave of enhanced, then suppressed, rainfall or atmospheric moisture. One half of the oscillation is wet and the other dry: The MJO moves across the Pacific from west to east in that period of time (Madden and Julian 1994). It is a coupling of atmospheric circulation and tropical deep ocean convection (upwelling), and often is characterized by irregular cloud formations that bring large amounts of rainfall across the Pacific. A phase of this oscillation has been dubbed “the Pineapple Express” for large amounts of rain-enhanced clouds that form over the Hawaiian Islands and continue eastward to North America dumping large amounts of precipitation on the west coast (NOAA 2006).

In 2010, a Pineapple Express (Figure 10) system ravaged much of California from December 17 through December 22, bringing with it as much as two feet of rain to the San Gabriel Mountains and over five feet of snow in the Sierra Nevada. Although the entire state was affected, the Southern California counties of San Bernardino, Orange, San Diego, and Los Angeles bore the brunt of the system of storms as coastal and hillside areas were impacted by mudslides and major flooding (United Press International 2010).

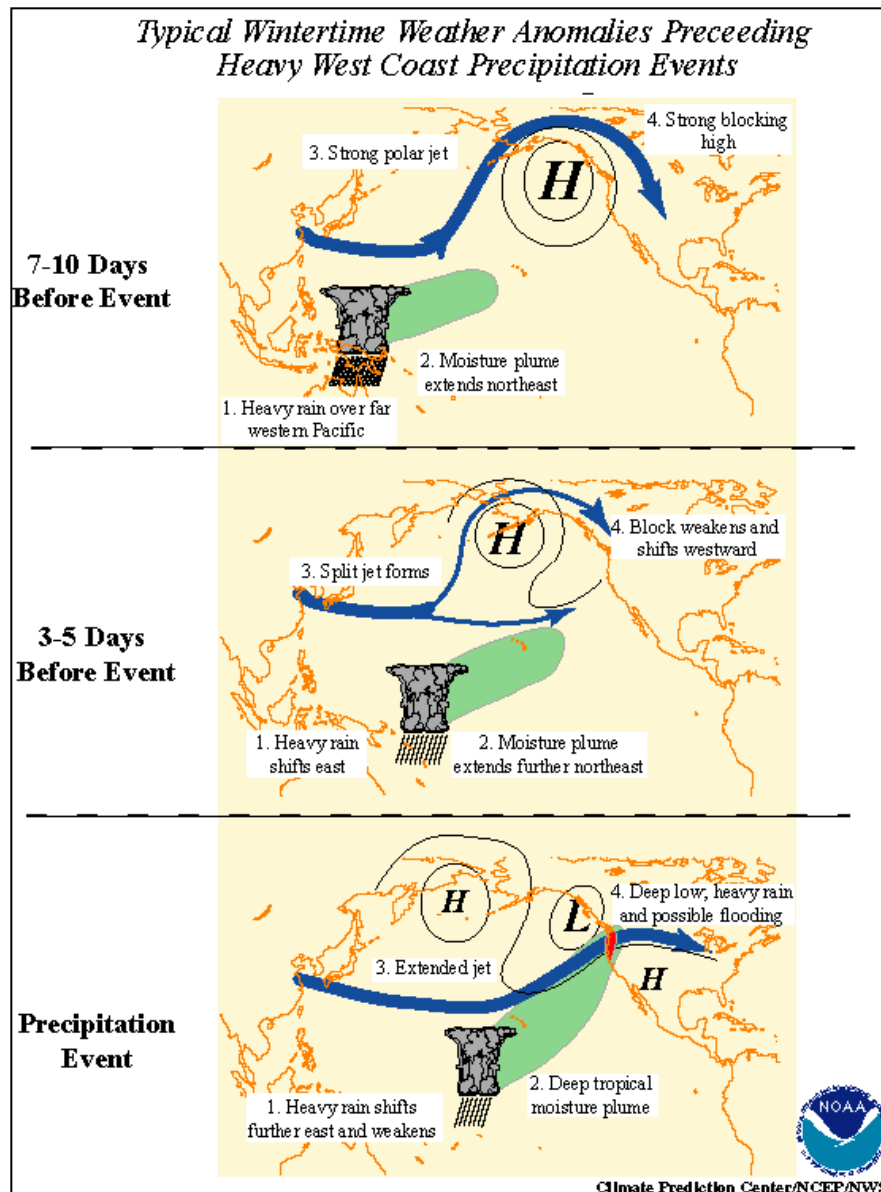


Figure 10. The Pineapple Express is an effect of the Madden-Julian Oscillation (NOAA 2006).

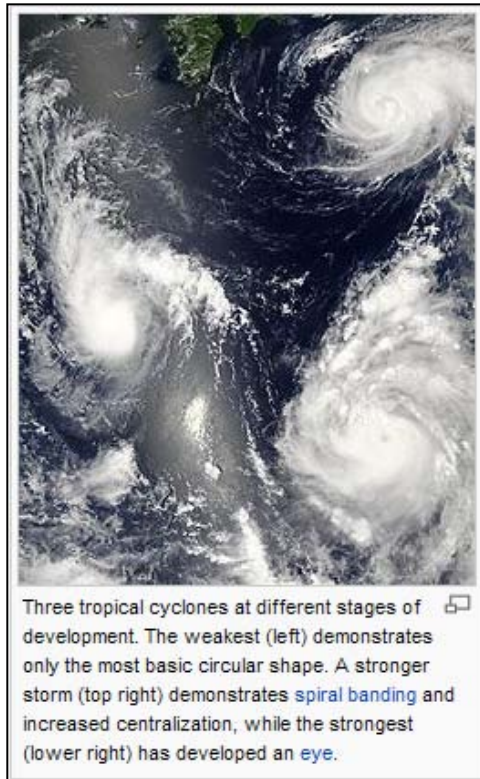


Figure 11. Three different tropical cyclones at various stages of development (NASA 2006).

Tropical Cyclones

Tropical cyclones are known as tropical depressions, tropical storms, cyclones, typhoons, cyclonic storms or hurricanes depending on location and strength. A tropical depression has winds less than 38 mph. A tropical storm is when the winds are between 38 mph and 74 mph. Above 74 mph, a storm in the NE Pacific or Atlantic is called a hurricane. Figure 11 illustrates three tropical cyclones in various stages of development at one time in the Pacific. In the NW Pacific it is called a typhoon. In the southern hemisphere or Indian Ocean they are called cyclones. Figure 12 is a diagrammatic cross-section of the structure of a “typical” tropical cyclone. Figure 13 illustrates all the hurricanes and typhoons in the world from 1985-2005. It is very interesting to note the lack of storms in the south eastern Pacific and southern Atlantic.

The tropical cyclone season in Hawaii starts in June, normally lasting through November. In American Samoa, the season begins in November, extending through April. In the western Pacific, which includes Guam and Saipan, these storms are more frequent and often more intense than in the rest of the Pacific (Figures 19 and 20). While the majority of typhoons occur between June and November they may occur year-round.

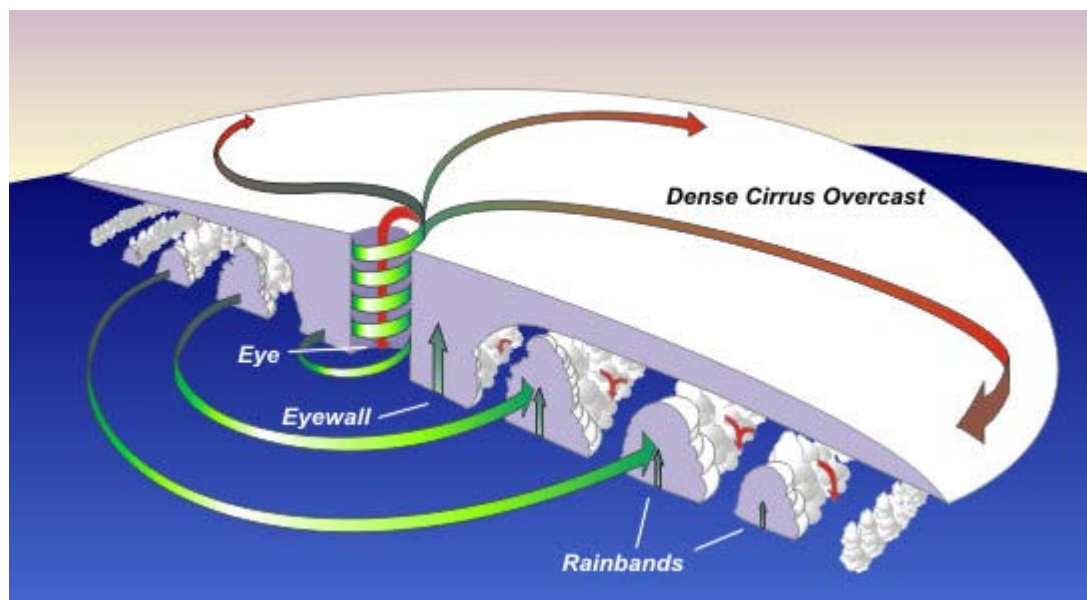


Figure 12. Structure of a tropical cyclone (NOAA 2010).

Tropical cyclones are areas of low atmospheric pressure (depression), which intensify over the open ocean. Water vapor from a warm sea evaporates (condenses) and rises towards the troposphere. Condensation leads to higher wind speeds, as a tiny fraction of the released energy is converted into mechanical energy; the faster winds and lower pressure associated with them in turn cause increased surface evaporation and thus even more condensation (NOAA 2010). This cycle is a positive feedback loop and while ocean temperatures remain conducive to condensation, the cyclone will continue on guided by the high and low pressure systems, wind shears, and Coriolis force. Generally, when a cyclone hits land, the condensation cycle stops and the storm dissipates.

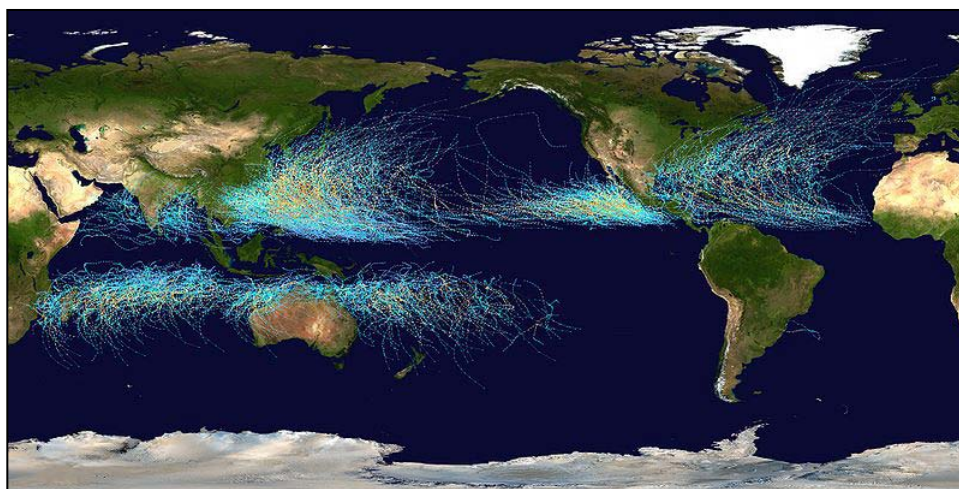


Figure 13. Map of the cumulative tracks of all tropical cyclones during the 1985–2005 time period. The Pacific Ocean west of the International Date Line sees more tropical cyclones than any other basin, while there is almost no activity in the Atlantic Ocean south of the Equator (Nilfanion 2006).

Pacific Decadal Oscillation (PDO)

The Pacific Decadal Oscillation (PDO) takes place in 20-30 year cycles. It is a sum of several atmospheric and oceanic processes and mechanisms such as the ENSO teleconnections, an atmospheric bridge (Alexander et al 2002), the SST reemergence (Deser et al. 2003), stochastic atmospheric forcing (Alexander and Penland 1996), advective resonance (Saravanan and McWilliams 1998) and the north Pacific oceanic gyre circulation (Jin 1997). The PDO is a cycle of warm and cold SST across the Pacific, north of 20°, just at the Hawaiian Island latitude (Figure 14).

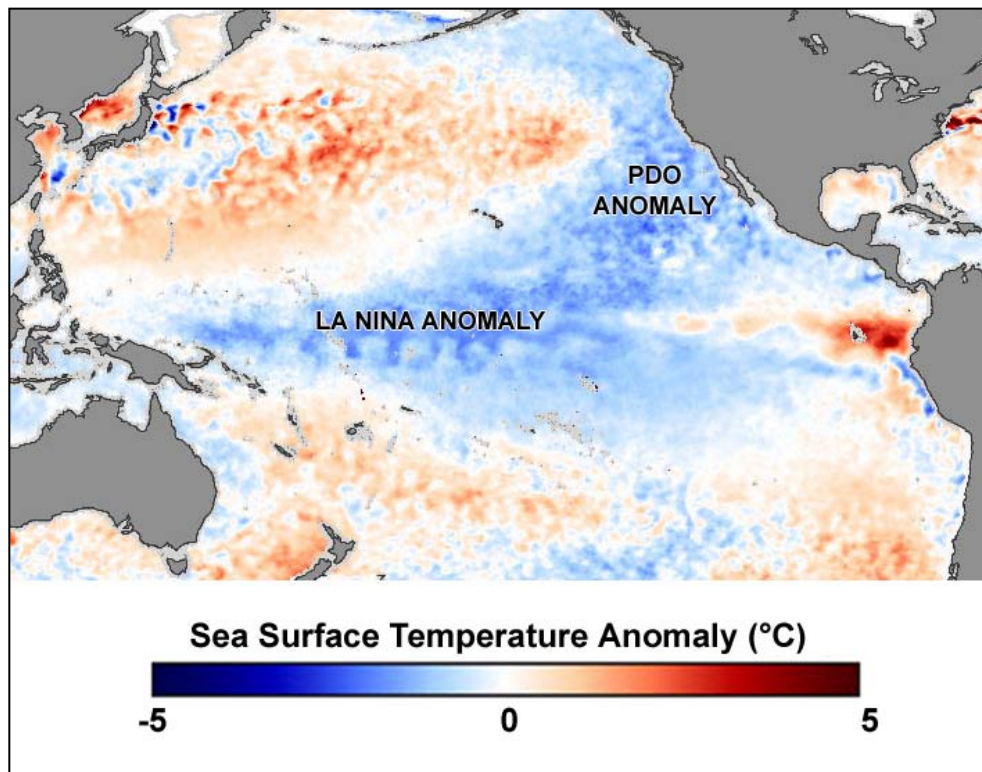


Figure 14. Pacific Decadal Oscillation (PDO) with La Niña. (NASA 2008).

PDO has a long cycle and was first discovered by Steven Hare, a fisheries scientist at the University of Washington (Hare 1996). The cycle has occurred twice in the last century; the cool phase from 1890–1924 and 1947-1976. The warm phase dominated from 1925-1946 and 1977 through the mid 1990's. These phases (Figure 15) have been directly related to marine productivity and probably affect Hawaii's marine systems as well (JISAO 2000).

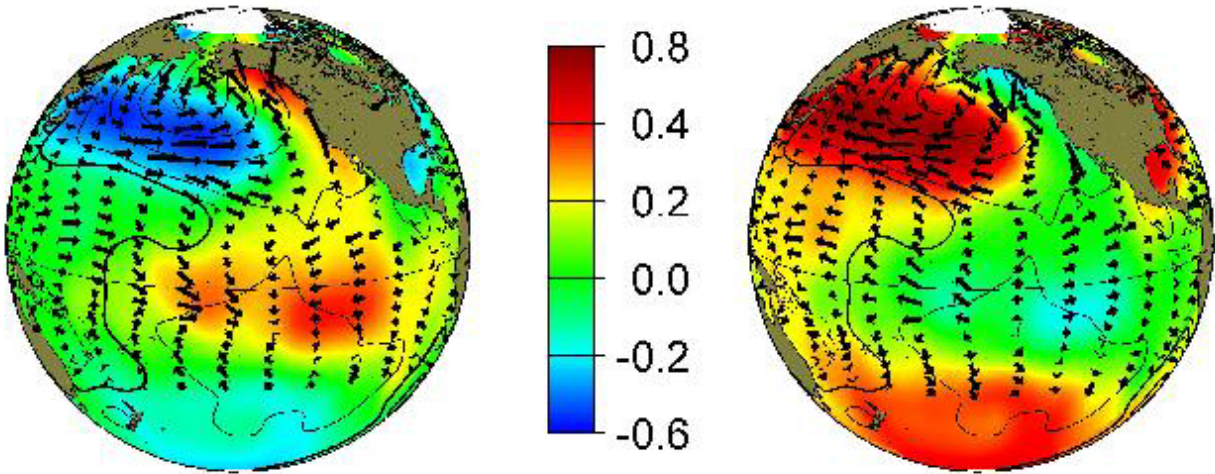


Figure 15. Cool phase (left) and warm phase (right) of the Pacific Decadal Oscillation (JISAO 2000).

Methods

Detailed methods of data collection for weather observations in the PACN are described in the PACN Weather/Climate Monitoring Protocol (Schlappa et al. 2011). In short, the PACN's weather monitoring efforts primarily rely on weather observations obtained from two national weather monitoring networks, the National Weather Service Cooperative Observer Program (COOP) and the Remote Automated Weather Station program (RAWS).

Observations for COOP weather stations are taken by park personnel, volunteers or contractors to provide meteorological data required to define the climate of the United States and to help measure long-term climate changes. Most COOP stations in the PACN are read manually. They measure 24-hour precipitation totals and most stations measure daily maximum and minimum temperatures.

RAWS provide weather data that assists land management agencies with a variety of projects such as monitoring air quality, rating fire danger, and providing information for research applications. Hourly averages of meteorological variables are downloaded via the Geostationary Operational Environmental Satellite (GOES). Measured variables vary from station to station, but typically include temperature, precipitation, wind, humidity, solar radiation, barometric pressure, fuel temperature, and fuel moisture.

The stations used in the data collection and analyses were as follows:

- AMME (American Memorial Park, Saipan): Capitol Hill COOP.
- WAPA (War in the Pacific National Historical Park, Guam): Agat COOP, Guam NAS COOP.
- NPSA (National Park of American Samoa): Pago Pago COOP.
- HAVO (Hawaii Volcanoes National Park, Hawaii): Hawaii Vol NP HQ 54 COOP, Mauna Loa Slope Obs 39 COOP, Kealakomo RAWS, Keaumo RAWS, Pali2 RAWS.
- KAHO (Kaloko-Honokōhau National Historical Park, Hawaii): Kaloko-Honokohau RAWS, Honokohau Harbor 68.14 COOP.
- PUHO (Puuhonua O Honaunau National Historical Park, Hawaii): Puuhonuaohonaunau 27.4 COOP.
- PUHE (Puukohola Heiau National Historical Park, Hawaii): Puukohola Heiau 98.1 COOP.
- KALA (Kalaupapa National Historical Park, Molokai): Kalaupapa 583 COOP, Makapulapai RAWS.
- HALE (Haleakala National Park, Maui): HaleakalaRS338 COOP, Oheo 258.6 COOP, KaupoGap RAWS.

Weather data for RAWS and NWS COOP stations were acquired from Western Regional Climate Center (WRCC) and incorporated into a MS Access database that stores data for all stations included in PACN weather/climate monitoring. The acquired weather data consist of daily values, i.e., hourly RAWS data had already been summarized by WRCC.

All of the 2010 data was downloaded directly from the COOP or RAWS sites managed by WRCC. The WRCC also performs a preliminary data validation process. Data were translated into Excel spreadsheets and then downloaded into the PACN database. Data were imported into R (version 2.10.0) (Gentleman, R and R. Ihaka 1997) for data analysis and graphing.

Boxplot analysis and illustrations

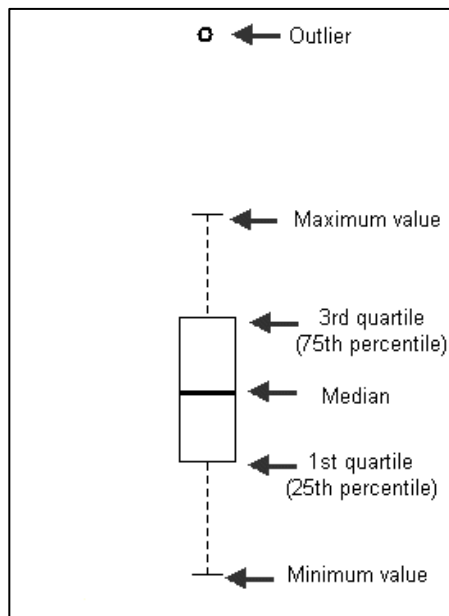


Figure 16. Anatomy of a boxplot.

Boxplots are used extensively to place data from 2010 in context with the long-term variability for each station. Boxplots in R are constructed based on the original definition of a boxplot by (Tukey 1977). However, since in some publications different definitions are used, the features of a generic boxplot produced in R are illustrated above (Figure 16).

To understand boxplots the term “quartile” needs to be understood. Quartiles are dividing lines that separate a dataset into four equal parts: 25% (one quarter) of the data points are below the 1st quartile, 25% are between the 1st and 2nd quartile (2nd quartile = median), 25% of the data lie between the 2nd and 3rd quartile, and another 25% lie above the 3rd quartile.

Boxplots generally display at least five important pieces of information about a set of data: (1) the median (2nd quartile) of the data is represented by the line in the center of the rectangular box; (2) the lower end of the rectangle represents the 1st quartile; (3) the upper end of the rectangle is the 3rd quartile; (4) the lower whisker extends to the minimum value; and (5) the upper whisker extends to the maximum value. In addition, most boxplots show outliers of the dataset.

The rectangle defines the distance between the 1st and 3rd quartile, called the interquartile range (IQR). The minimum value of the dataset is defined as the minimum point within a distance of 1.5 IQR from the 1st quartile. The maximum value is a point within a 1.5 IQR from the 3rd quartile. Data points beyond either limit are considered outliers.

Boxplots in all weather and climate reports are based on long-term datasets for temperature, precipitation, and relative humidity. Data points for 2010 are overlaid on the graphics to place the current year's data into the context of long-term variability.

Wind rose graphs

Wind graphics (Figures 37, 38, 42, 46 and 51), [see also Appendix A] are generated using the online data analysis tools for individual RAWS set up by WRCC and the Desert Research Institute (DRI). These graphs show the wind directions and strengths. Annual graphs are shown (Figures above) as well as some specific monthly graphs in Appendix A. Directional wind shifts from land to ocean and vice versa is an interesting phenomenon that has been recorded and graphed in the morning and afternoon wind details shown in Appendix A. Some of these graphs show the effect of onshore and offshore winds extremely well, especially Kaloko-Honokohau, the station at a lower elevation, Kaupo Gap also shows this daily wind switch and is at higher elevation, but is geographically situated at the top of a sloping gap between two steep valley walls.

Period of record for data at stations

The period of record varies for individual stations and is noted in each graph. A threshold of 85% valid daily records is used for calculating monthly means or totals. So if more than 15% of daily data is missing for any given month, the data is considered insufficient for the calculation of a monthly mean or total. Because of this, the long-term data record may be shorter than the period of record (found online in the metadata for each station).

For months with insufficient data, we do not necessarily substitute data from nearby stations since often there are no nearby stations available. For comparison of the two Kaloko stations at very similar elevations, it was done this year (Table 8). Often, for precipitation, even nearby stations do not provide representative data, given the steep, elevation-driven precipitation gradients on many of the islands.

Annually downloaded tabular data provides comparisons of the 2010 values with climate normals for the 1971-2000 time period published by the National Climatic Data Center (NCDC) (NOAA 2002), if available.

A climate normal is defined as the arithmetic average of a climatological element such as temperature or precipitation for a 30 year time period (Guttman 1989). NCDC computes climate normals for only some of the COOP stations and no RAWS stations in the U.S. So we compare 2010 data for stations without climate normals to the long-term mean of that station's record.

Ideally, data for the 30-year period should not have missing values or inconsistencies such as changes in station location, instrumentation, time of observation and such that leads to dissimilar data. In reality, since normal random factors often result in missing values or changes to instrumentation, records for some stations are adjusted using statistical methods to equalize the data prior to calculation of averages. In addition the NCDC makes corrections to the datasets to

adjust for the time of observation. The most current time period for published climate normals by NCDC is 1971 to 2000.

Weather station locations are determined by 1) type of station, i.e.: COOP or RAWS, and 2) vital sign research interests.

Manually downloaded COOP stations are located mainly based on ease of access, then site suitability. RAWS stations sites are generally determined by wildfire threat. Our new station locations have been determined by the need for weather data to support other vital sign monitoring as well as other park specific needs (Davey et al. 2006).

Satellite downloaded RAWS stations are often located in the backcountry. Several parks (AMME, WAPA, and NPSA) do not yet have weather stations located within park boundaries. Instead, data from nearby COOP stations is analyzed. Station locations are in Appendix C.

Nine more Campbell Scientific, Inc. (CSI) weather stations will be added in 2012, two in HAVO, two in KALA, two in NPSA, one at PUHO, to replace the WeatherHawk instrumentation, one at AMME, and one at PUHE. An additional RAWS station may be added at WAPA. These stations will be automated and will mostly use the GOES satellite. The new stations will be RAWS stations.

Station names in this report appear exactly as they do in the NCDC and WRCC databases. For this reason, the spelling may be unusual (as in Puuhonuaohonaunau).

Results

General ENSO conditions and tropical cyclone activity for the year are described first. Then data for stations in the western North Pacific (AMME, WAPA) and the South Pacific (NPSA) are presented, followed by results for stations in national parks in the Hawaiian Islands. Finally, an overview of drought conditions in Hawaii is presented.

El Niño/La Niña Conditions

El Niño/La Niña conditions are here summarized based on information obtained from the Pacific ENSO Update (PEAC 2011) and the ENSO diagnostic discussions of the Climate Prediction Center (CPC 2011).

2009 ended with strong El Niño conditions which persisted through the beginning of 2010. A special bulletin was put out by CPC to emphasize probably drier conditions than usual especially across the western Pacific. Neutral conditions began to be observed in April 2010 and lasted through June, when La Niña conditions began to be noted. The rest of 2010 continued to be moderate to strong La Niña conditions.

In the Hawaiian Islands, the recently completed October 2009 through April 2010 wet season, or "Hooilo", ranks as the driest in the past thirty years, and one of the driest in the past 55 years (PEAC 2010).

The tropical cyclone activity in both western and eastern North Pacific basins was at an all time low. "It is also the lowest my forecast has ever issued on this date in all the 52 years of data"- Paul Stanko (senior forecaster, Guam WFO) on 10 October 2010 (PEAC 2010). Hawaii had only one hurricane/cyclone to deal with, in December of 2010, Hurricane Omeka which formed west of the islands but had no appreciable effect in Hawaii. It was a rare phenomenon, starting in sub-tropical waters.

If not referenced otherwise, information about tropical cyclones tracks, storm intensities, and effects was obtained from the Joint Typhoon Warning Center and the Central Pacific Hurricane Center websites. As in the previous two years, 2010 had below normal tropical cyclone activity (19 compared to a normal of 31) in the western North Pacific (Angove and Falvey 2011). At the beginning of the year tropical cyclone activity in the western North Pacific was still displaced westward and northward as is typical for La Niña conditions (PEAC 2009). As conditions transitioned to El Niño displacement shifted far eastward as is typical during El Niño years (Chu 2004).

Tropical Cyclone Activity

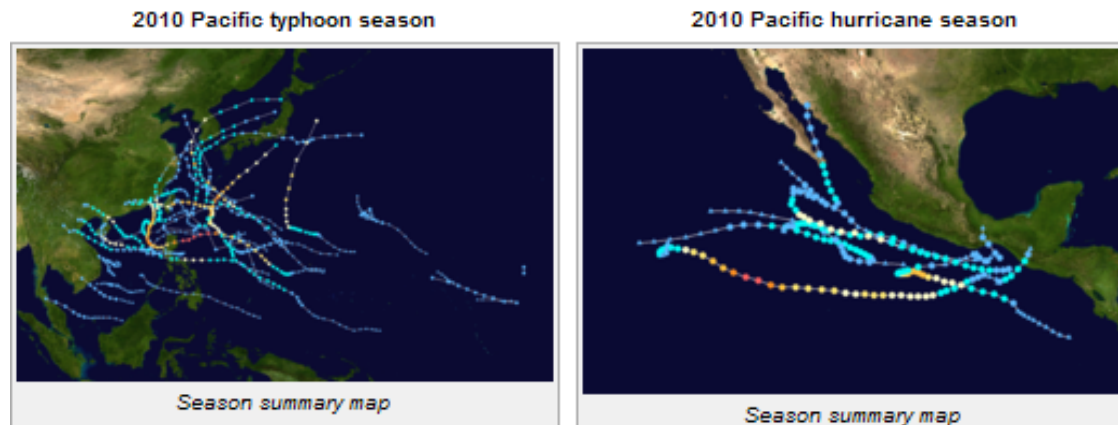


Figure 17. Western Pacific typhoon and Eastern Pacific hurricane tracts, (Edkins 2010).

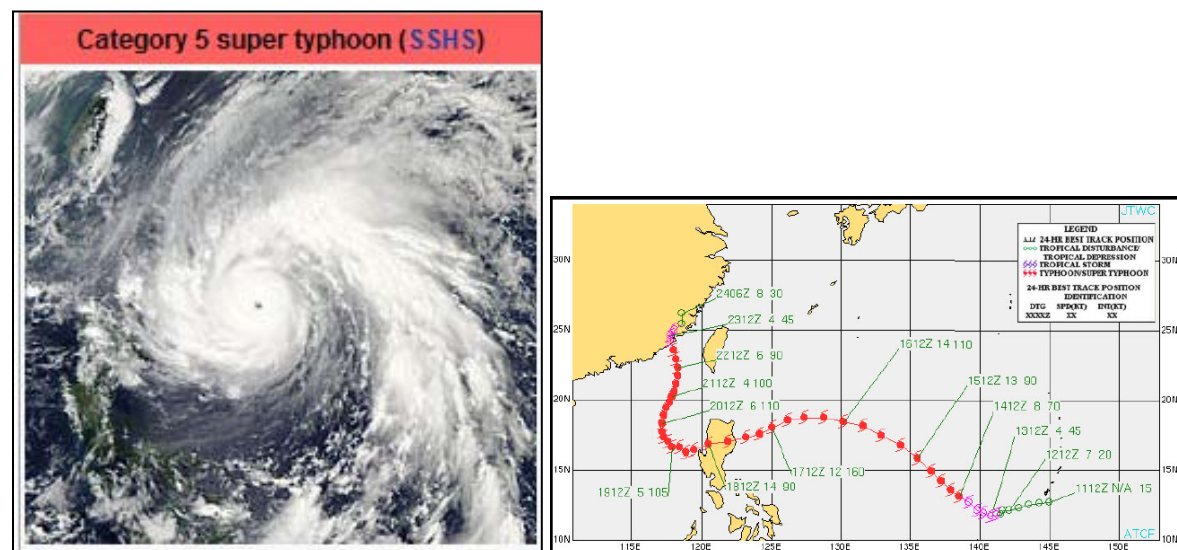


Figure 18. Super Typhoon Megi (15W), 12 to 23 October, (NASA 2010a) and the path of Megi across the northern Pacific (Angove and Falvey 2011).

The first tropical cyclone (TC) in the western North Pacific region formed in mid-January. The most significant typhoon of the season was Super Typhoon Megi (Korean for “catfish”). This tropical cyclone coalesced as a tropical disturbance which started 51 miles southeast of Guam and moved northwestward gathering strength as a tropical cyclone midway to the Philippines where it caused extensive damage and 19 lives were lost. Its maximum sustained winds were 150 mph, with gusts estimated to 220 mph (Angove and Falvey 2011). Unusually, it remained strong across land but began to dissipate across the South China Sea, but caused the loss of more than 530 homes in southern China and millions of dollars in damages (Xinhua 2010)

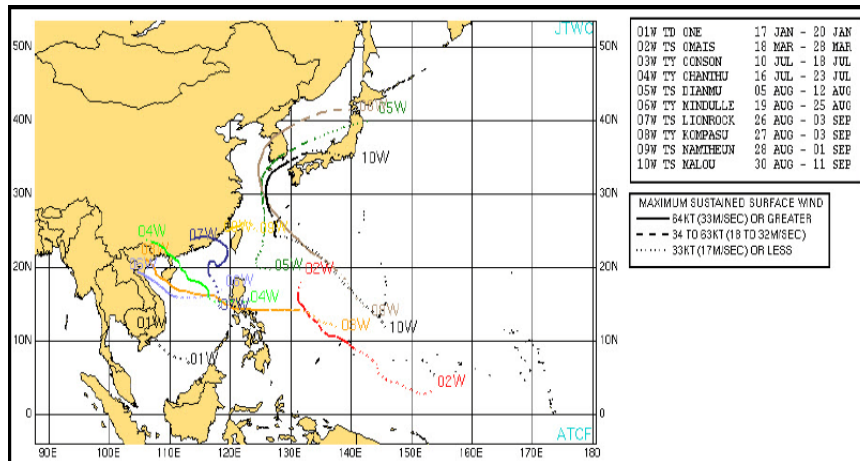


Figure 19. Western North Pacific Cyclone activity #1–10. Saipan is at 15N and Guam is at 13N, both are near 145E (Angove and Falvey 2011)

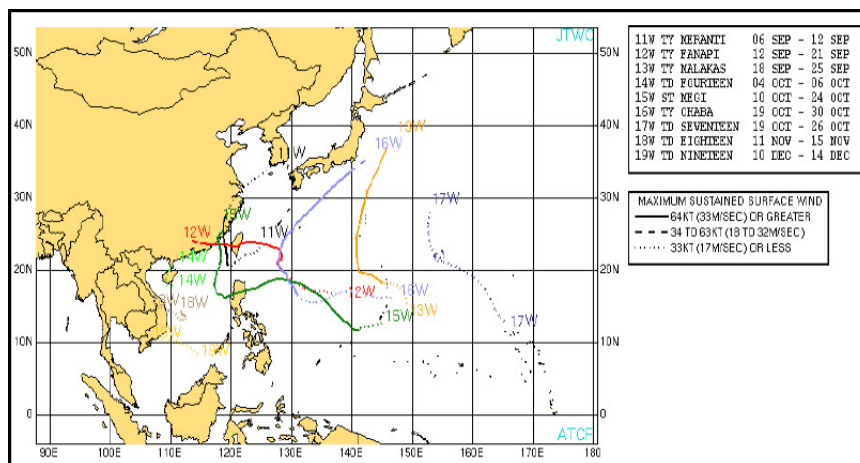


Figure 20. Western North Pacific Cyclone Activity, Tropical Cyclones #11–19. Megi was number 15. (Angove and Falvey 2011).

Figures 19 and 20 show the 19 storms that were generated in the western Pacific. Note how many started between 140 – 150E and 10 – 20N, near Guam and Saipan (Figure 22). Only Typhoon Rene (Figures 23 and 24) was significant in its path, giving much needed rain to the area in February. March in Guam and Saipan was exceedingly dry.

Around Hawaii, all storms with the exception of Omeka, passed far from the Hawaiian Islands. Most were very distant and decreased to tropical depressions as they neared Hawaiian waters. The first storm of the 2010 season, Agatha, formed during the last part of May near the coast of Guatemala. Early June saw a significant number of storms (four) developing. Two became Hurricanes Celia and Darby. No named storms came in July, an unprecedented anomaly since 1966. Tropical Storm Omeka (Figure 21) was the latest forming eastern tropical storm since reliable records began in 1949. The storm crossed the dateline on December 20 (PEAC 2011).

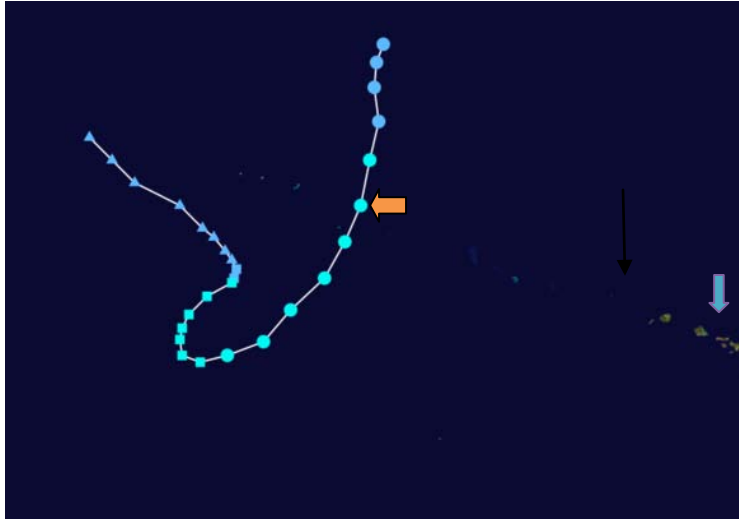


Figure 21. The path of Tropical Storm Omeka. On December 21, 2010 the eye crossed Lisianski Island (orange arrow) in the northwestern Hawaiian chain. Hawaii is located below the blue arrow (Edkins 2010).

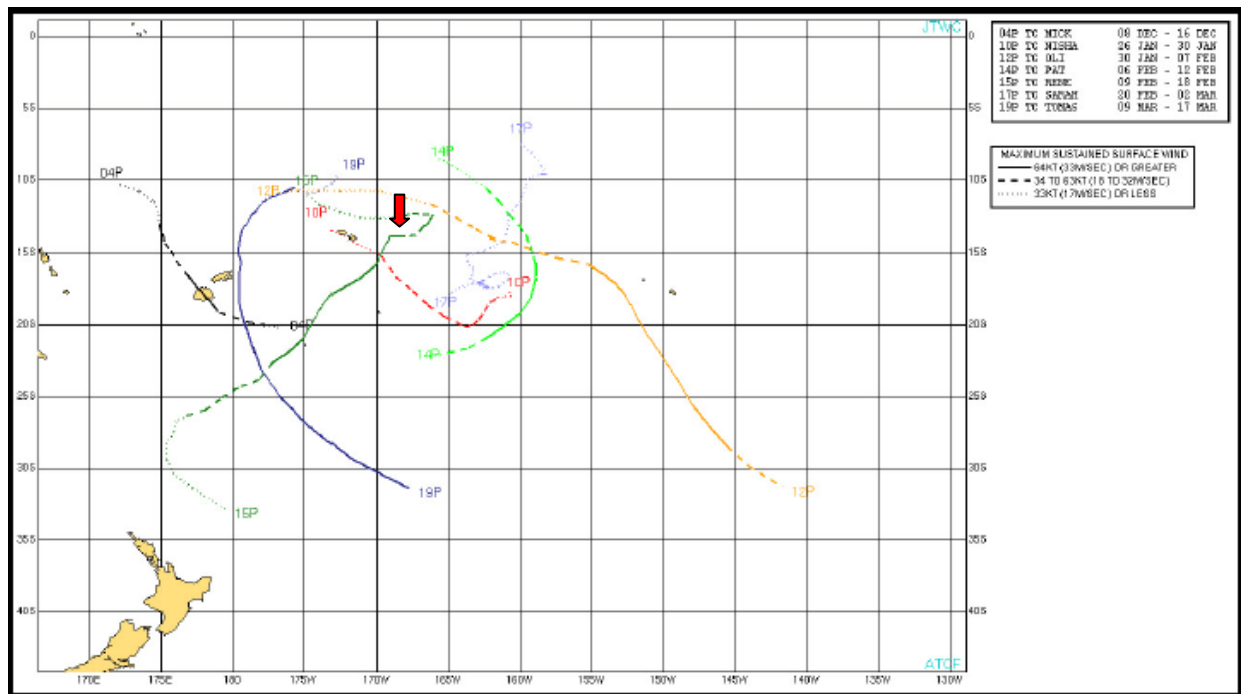


Figure 22. South Pacific Tropical Cyclones. American Samoa is at approximately 13S- 171W indicated by the red arrow (Angove and Falvey 2011).

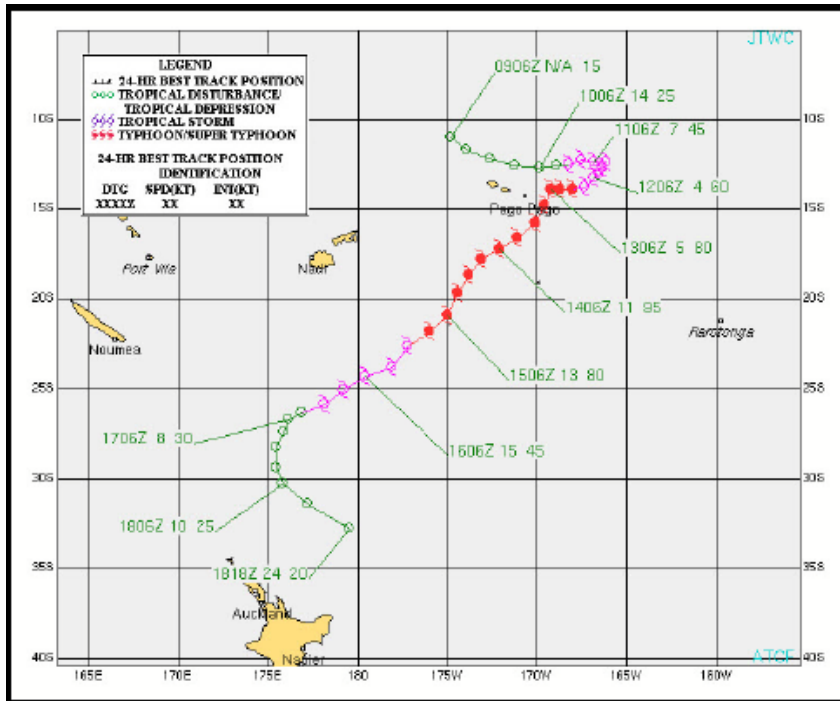


Figure 23. Tropical cyclone Rene, Feb. 9–16, 2010, hit the Manua islands of Samoa on the 12th, and the eye came near Pago Pago in American Samoa with winds as high as 90 mph (Angove and Falvey 2011).



Figure 24. Tropical cyclone Rene, acquired on Feb. 12, 2010 by (NASA 2010b).

Table 2. Total typhoon statistics for 2010 for the western Pacific. (Modified from Angove and Falvey 2011).

2010 typhoon data in the Western Pacific	
First storm formed:	January 16, 2010
Last storm dissipated:	December 20, 2010
Strongest storm:	Megi – 885 hPa (mbar), 145 mph (10 minute sustained)
Tropical depressions:	32
Total storms:	14 official, 2 unofficial (record low)
Typhoons:	7 official, 1 unofficial (record low)
Super typhoons:	1 unofficial
Total fatalities:	398
Total damage:	\$2.3063billion (2010 USD)

Parks in the Western North Pacific and the South Pacific

Table 3 and Figures 25–28 present precipitation and temperature data for COOP stations near WAPA on Guam, AMME on Saipan, and NPSA on Tutuila. No wind data were available for these stations, though it will be possible to obtain these in future years with the new Campbell Scientific weathers stations being installed early in 2012.

Note that the Agat station on Guam is a rain gauge only (Figure 25). Total rainfall in 2010 was only 30% of the 30 year average (average) at this location. No rain fell in August, September and October, with very little rain falling in February and November. Guam NAS (Table 3, Figure 26) averaged 85% of its 30 year average for 2010. May was the driest month of the year with only 15% of average precipitation; all other months were between 29% and 172% of the 30 year average.

On Saipan, Capitol Hill (Table 3, Figure 27) had an annual rainfall below the long-term mean (69%) from 22–97% of the norm. Capitol Hill data shows temperatures were below the long-term mean for the first half of the year, and were mostly below the maximum temperatures all year long.

In American Samoa, Pago Pago (Table 3, Figure 28) had an annual rainfall total 9% above the 30 year average with most of the high rainfall months scattered across the year. January had twice the 30 year average, February was higher than usual and July, September and October brought more than usual rainfall. Minimum temperatures were higher than prior records as were maximum temperatures. This is typical of La Niña conditions.

Appendix B shows graphs with monthly rainfall and temperature maximums and minimums for all these locations.

Table 3. Comparison of precipitation and temperature data from 2010 with long-term records for stations on Guam, Saipan, and Tutuila, Samoa. Comparisons are made with 1971-2000 normals for Agat and Pago Pago WSO AP COOP stations. For Capitol Hill, data are compared to the long-term means (period of record indicated, not including the last year) since normals are not available. Guam NAS has long term data from 1950.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Agat (1979-2009) COOP Park: near WAPA, Guam Elev. 10 ft. (3 m)													
Precipitation (in)													
1971-2000 normal	4.30	3.23	3.13	3.77	4.58	6.35	11.48	15.06	11.87	11.58	9.07	6.49	91.18
2010 totals	3.82	0.18	2.60	2.76	0.68	3.83	7.64	0.00	0.00	0.00	0.61	5.53	27.65
% Normal	89%	6%	83%	73%	15%	60%	67%	0%	0%	0%	7%	85%	30%
Guam NAS (1950-2009) COOP Park: near WAPA, Guam Elev. 254 ft. (77m)													
Precipitation (in)													
Long-term mean	4.42	3.64	2.56	3.33	5.01	6.44	10.51	14.52	13.55	12.14	8.51	5.68	90.34
2010 total	4.69	1.06	4.40	2.16	0.74	5.33	12.09	12.18	12.15	13.54	4.38	4.09	76.81
%long-term mean	106%	29%	172%	65%	15%	83%	115%	84%	90%	112%	51%	72%	85%
Min. temp. (°F)													
Long-term mean	75.0	74.6	75.0	76.2	76.9	77.1	76.5	76.1	76.1	76.4	76.5	76.1	76.1
2010 means	75.2	74.7	76.3	77.2	79.0	78.9	77.7	76.5	75.8	77.2	78.4	77.4	77.0
Difference	0.2	-0.1	1.3	1.0	2.1	1.8	1.2	0.4	-0.3	0.8	1.9	1.3	1.0
Max. temp. (°F)													
Long-term mean	85.1	85.3	86.1	87.1	87.4	87.7	87.2	86.8	86.8	87.2	86.7	85.9	86.6
2010 means	85.8	86.4	86.3	87.3	89.3	89.8	87.4	86.5	86.1	87.5	88.5	87.8	87.4
Difference	0.7	1.1	0.2	0.2	1.8	2.1	0.2	-0.3	-0.7	0.3	1.8	1.9	0.8
Capitol Hill (1995-2009) COOP Park: near AMME, Saipan Elev. 827 ft. (252 m)													
Precipitation (in)													
Long-term mean	3.83	4.20	3.15	3.82	3.64	5.24	9.91	12.97	11.35	10.74	7.92	6.27	83.05
2010 totals	0.00	0.94	2.90	2.29	1.01	4.94	9.44	7.01	10.61	7.68	5.78	4.06	56.66
% Long-term	NA	22%	94%	57%	27%	96%	97%	56%	93%	73%	70%	67%	69%
Min. temp. (°F)													
Long-term mean	73.4	72.9	73.4	74.1	75.3	75.6	75.2	75.1	74.8	75.0	75.2	74.4	74.5
2010 means	NA	72.5	72.4	73.1	75.3	74.5	74.8	76.2	65.4	73.6	70.8	71.9	72.8 ¹
Difference	NA	-0.4	-1.0	-1.0	0.0	-1.1	-0.4	1.1	-9.4	-1.4	-4.4	-2.5	1.7
Max. temp. (°F)													
Long-term mean	81.3	80.8	82.0	83.5	84.7	85.0	84.3	83.9	83.5	84.0	83.4	82.5	83.2
2010 means	NA	82.0	81.5	82.6	85.3	85.3	83.7	85.5	74.3	82.9	82.8	81.8	82.5 ¹
Difference	NA	1.2	-0.5	-0.9	0.6	0.3	-0.5	-1.5	-9.2	-1.1	-0.6	-0.7	0.7

¹ Average temperature of the 11 months for which data were collected.

Table 3. Comparison of precipitation and temperature data from 2010 with long-term records for stations on Guam, Saipan, and Tutuila, Samoa (continued).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Pago Pago WSO AP (1957-2010) COOP Park: near NPSA, Samoa Elev. 12 ft. (3.7 m)													
Precipitation (in)													
1971-2000 normal	14.02	12.14	11.15	11.16	10.43	5.94	5.76	6.43	7.36	10.03	11.16	13.38	118.96
2010 totals	28.31	15.83	4.99	10.33	6.61	5.05	8.30	4.32	9.68	15.33	9.15	12.34	130.24
% Normal	202%	130%	45%	93%	63%	85%	144%	67%	132%	153%	82%	92%	109%
Min. temp. (°F)													
1971-2000 normal	76.1	76.3	76.6	76.3	76.2	76.1	75.5	75.5	75.8	76.2	76.5	76.4	76.1
2010 means	80.4	79.8	80.1	78.3	78.5	77.6	77.4	76.5	76.6	77.0	76.1	76.8	78.0
Difference	4.3	3.5	3.5	2.0	1.7	0.5	2.1	1.0	0.8	0.8	-0.4	0.4	1.9
Max. temp. (°F)													
1971-2000 normal	86.8	87.2	87.3	86.9	85.6	84.5	83.8	84.0	84.8	85.2	85.8	86.9	85.7
2010 means	89.5	88.0	90.3	87.6	86.8	85.3	84.7	84.3	85.1	85.9	85.8	86.8	86.7
Difference	2.7	0.8	3.0	0.7	0.8	0.8	0.9	-0.3	0.3	0.7	0.0	0.1	1.0

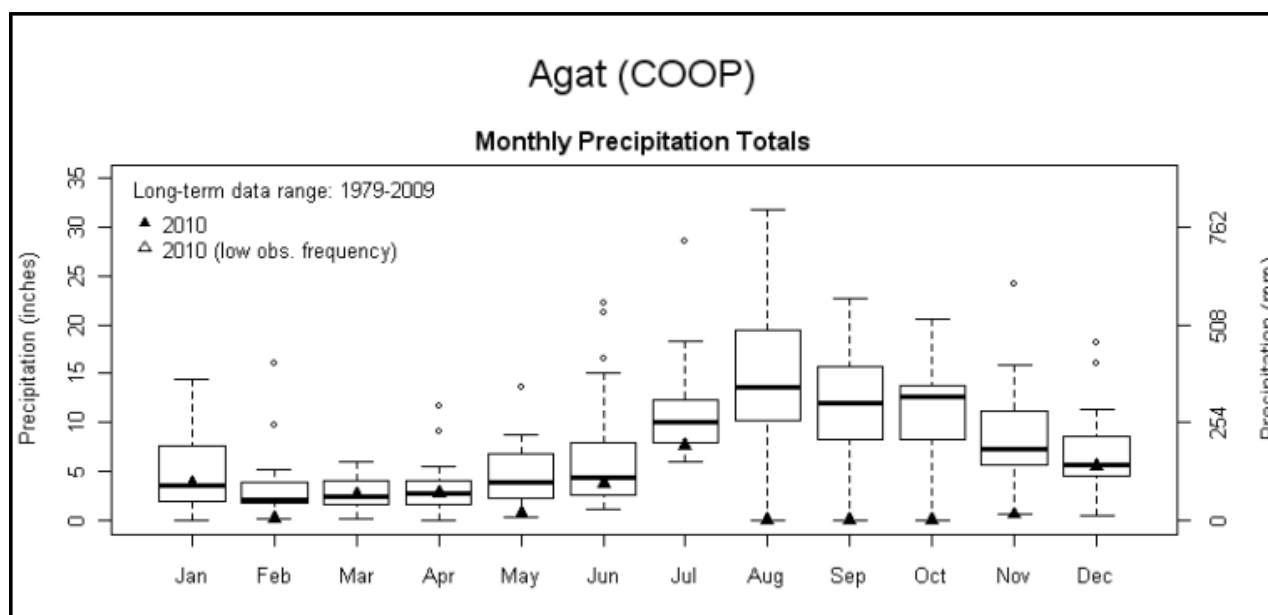


Figure 25. Boxplot of monthly precipitation data for Agat (COOP) Guam. To facilitate a better scale the boxplot does not show one outlier at 45 inches for August, 2008.

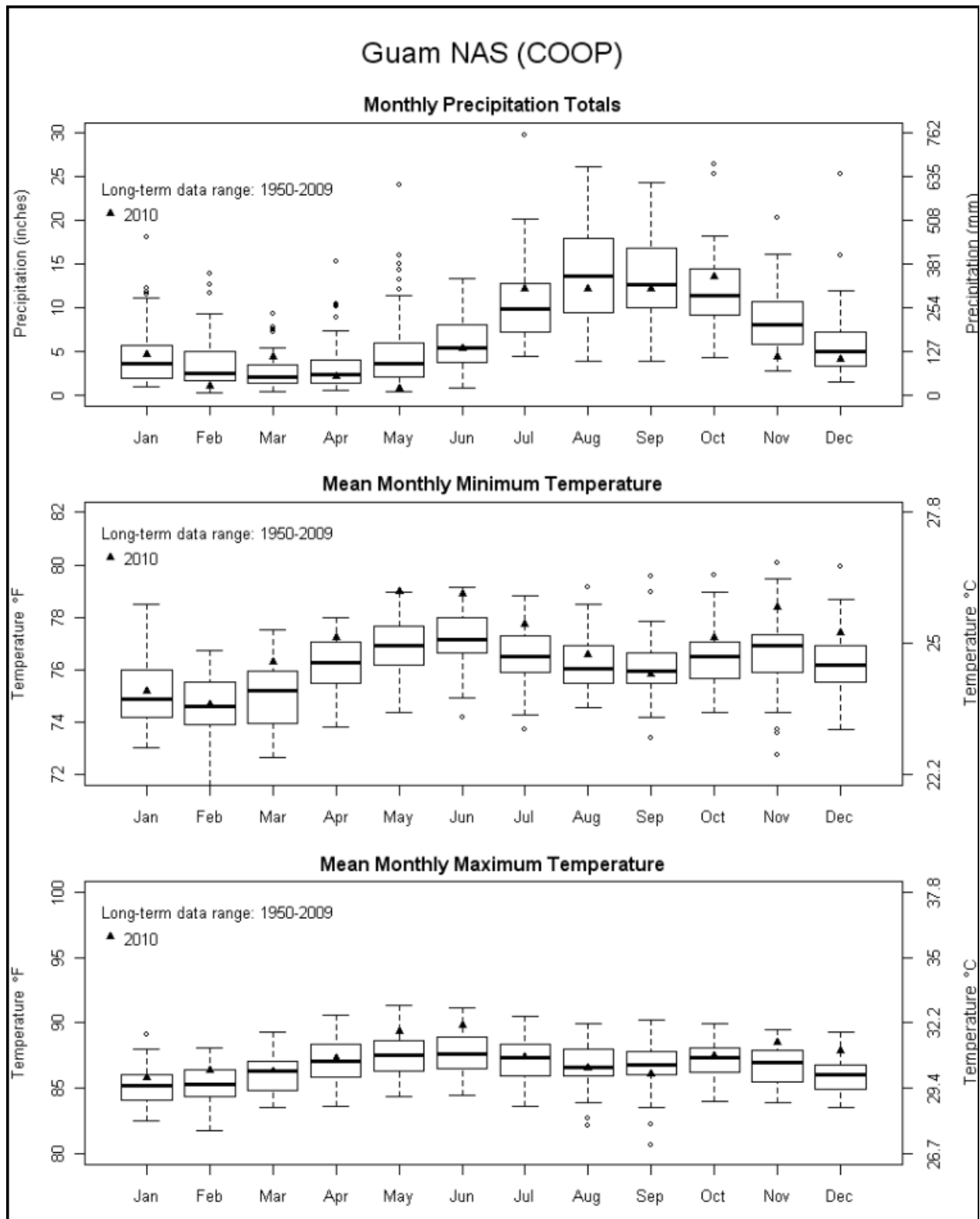


Figure 26. Boxplots of monthly precipitation and temperature data for Guam NAS (COOP), Guam.

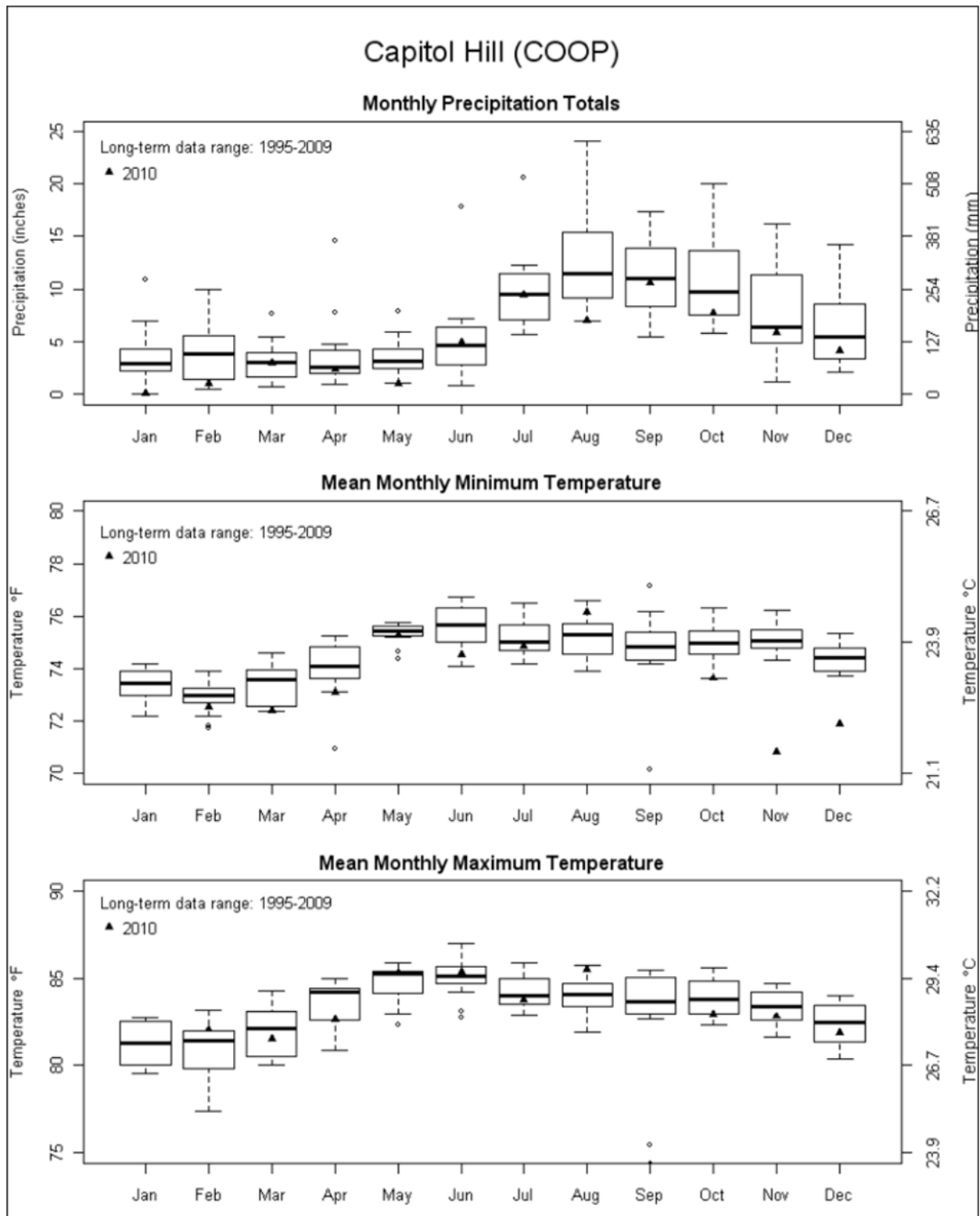


Figure 27. Boxplots of monthly precipitation and temperature data for Capitol Hill (COOP) near AMME, Saipan.

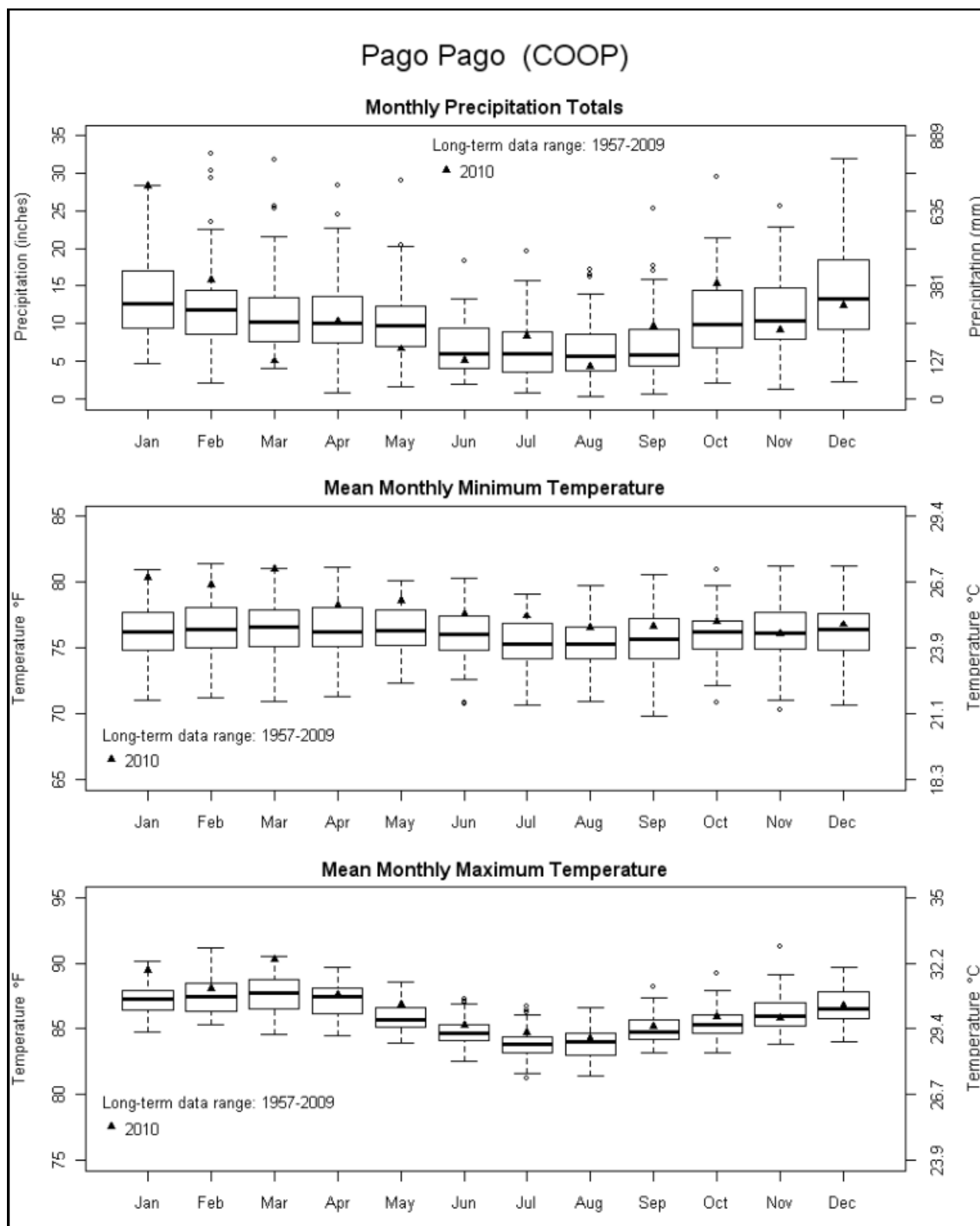


Figure 28. Boxplots of monthly precipitation and temperature data for Pago Pago WSO AP (COOP), Samoa.

Parks on Hawaii Island

Hawaii Volcanoes National Park (HAVO)

There are eight weather stations in HAVO at this time. Four are COOP stations, three are RAWS and one is a GPMN (Gaseous Pollutant Monitoring Network). Table 4 and Figures 29–36 present precipitation, temperature, relative humidity, and wind data for the two COOP stations and three RAWS. The two COOP stations are Hawaii Vol NP HQ 54 and Mauna Loa Slope Obs, the three RAWS stations are: Keaumo, Pali2, and the new converted from COOP to RAWS station, Kealakomo. Since data has been difficult to collect at the two other COOP stations, Mauka Reservoir 3.11 and Kahuku Mill Camp 6.3, these will be replaced in 2012 with PACN setting up two new Campbell Scientific weather stations in the Kahuku unit utilizing the automatic RAWS system.

Figure 37 displays wind data for the Pali 2 RAWS, clearly reflecting the predominant northeast trade winds. Monthly data show that this is the predominant wind direction throughout the year, with January, April, May and December the months with highest variability in wind directions. Data from the Keaumo RAWS (Figure 38) show the influence of the mountain resulting in more variable wind directions on the slopes of Mauna Loa, though northerly winds were most common throughout the year.

Table 4. Comparisons of precipitation and temperature data from 2010 with long term records for stations at Hawaii Volcanoes National Park (HAVO) Bold numbers show high temperature months. Comparisons are made with 1971-2000 normals for Hawaii Vol NP HQ COOP stations. For Kealakomo data are compared to the long-term means (period of record indicated, not including the last year) since normals are not available.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Hawaii Vol NP HQ 54 (1945-2009) COOP Park: HAVO Elev. 3,971 ft. (1,210 m)													
Precipitation (in)													
1971-2000 normal	10.78	9.13	14.1	10.38	6.29	5.23	7.21	6.31	6.01	6.83	14.06	11.01	107.34
2010 totals	0.78	1.25	8.49	7.33	2.72	1.77	1.81	1.24	1.07	4.63	6.72	11.74	49.55
% Normal	7%	14%	60%	71%	43%	34%	25%	20%	18%	68%	48%	107%	46%
Min. temp. (°F)													
1971-2000 normal	49.6	49.6	50.5	51.7	52.7	54.2	55.2	55.5	55.2	55	53.7	51.2	52.8
2010 means	40.8	46.2	46.5	44.1	51.3	48.4	50.3	54.5	44.1	50.0	52.5	48.5	48.1
Difference	-2.0	-12.8	-1.6	-3.8	-3.1	-1.6	-1.2	1.6	-0.5	-5.5	-4.9	-2.0	-3.1
Max. temp. (°F)													
1971-2000 normal	67.5	67.5	67.1	67.3	69	70.4	71.5	73	72.9	72	69.6	67.6	67.6
2010 means	59.5	66.6	62.4	58.7	67.9	64.2	67.4	72.6	61.1	67.6	70.2	64.7	65.2
Difference	-8.00	-0.90	-4.70	-8.60	-1.10	-6.20	-4.10	-0.40	-11.80	-4.40	0.60	-2.90	-2.40
Kealakomo 38.8 (1995-2007) COOP, (2008-on) RAWS Park: HAVO Elev. 290 ft. (88.4 m)													
Precipitation (in)													
Long-term mean	NA	NA	NA	1.38	10.33	4.01	6.37	0.99	0.02	0	0.1	0	NA
2010 totals	0.02	0	0.81	0.67	0.04	NA	NA	NA	NA	NA	3.17	10.63	NA
% Long-term	NA	NA	NA	38%	355%	193%	362%	50%	1%	2%	0%	0%	
Mauna Loa Slope Obs (1955-2009) COOP Park: near HAVO Elev. 11,150 ft. (3,398.5 m)													
Precipitation (in)													
1971-2000 normal	2.97	1.68	2.29	1.23	0.74	0.53	1.32	1.33	1.25	1.16	2.38	1.89	18.77
2010 totals	0.00	0.06	0.10	0.61	0.00	0.01	0.00	0.00	0.01	0.10	0.15	2.21	3.25
% Normal	0%	4%	4%	50%	0%	2%	0%	0%	1%	9%	6%	117%	17%
Min. temp. (°F)													
1971-2000 normal	33.9	33.7	34.1	35.1	37.4	40.3	39.6	39.7	39.1	38.6	37.3	35.2	37.0
2010 means	22.5	23.1	24.6	24.7	25.0	28.0	26.9	28.8	27.6	24.0	23.4	23.1	25.1
Max. temp. (°F)													
1971-2000 normal	50.0	50.2	51.0	52.2	54.2	57.5	56.5	56.6	55.4	54.8	52.6	51.1	53.5
2010 means	34.9	36.6	39.5	39.3	38.5	42.2	39.5	42.8	41.4	37.5	35.3	33.8	38.4
Keaumo (2000-2009) RAWS Park: HAVO Elev. 5,520 ft. (1,692 m)													
Precipitation (in)													
Long-term mean	5.87	5.19	6.45	2.37	2.09	0.89	2.06	2.29	2.93	3.20	8.58	5.94	47.89
2010 totals	0.19	0.16	2.23	1.67	0.10	0.27	0.15	0.04	0.03	2.70	2.96	5.79	16.29
% Long-term	3%	3%	35%	70%	5%	30%	7%	2%	1%	84%	34%	97%	34%

Table 4. Comparisons of precipitation and temperature data from 2010 with long term records for stations at Hawaii Volcanoes National Park (HAVO). Bold numbers show high temperature months (continued).

Min. temp. (°F)													
Long-term mean	42.4	42.4	43.9	44.9	45.4	47.5	49.4	48.3	48.1	47.8	46.3	43.9	45.8
2010 means	40.0	37.8	44.4	44.6	45.2	45.9	44.8	46.8	45.6	46.0	45.2	44.9	44.3
Difference	-2.4	-4.6	0.5	-0.3	-0.2	-1.6	-4.6	-1.5	-2.5	-1.8	-1.1	1.0	-1.5
Keaumo	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Max. temp. (°F)													
Long-term mean	68.5	68.3	67.3	68.4	71.2	73.5	75.7	76.3	73.3	73.1	72.2	70.0	71.5
2010 means	73.4	70.5	67.0	69.0	71.2	75.2	75.2	77.4	76.3	72.9	70.0	68.8	72.2
Difference	4.9	2.2	-0.3	0.6	0.0	1.7	-0.5	1.1	3.0	-0.2	-2.2	-1.2	0.7
Ave. temp. (°F)													
Long-term mean	54.1	54.1	54.5	55.6	57.7	60.0	62.0	61.5	59.7	59.1	57.8	55.4	57.6
2010 means	55.3	53.0	54.6	56.1	57.6	60.7	60.4	61.8	60.3	58.1	56.4	55.3	57.5
Difference	1.2	-1.1	0.1	0.5	-0.1	0.7	-1.6	0.3	0.6	-1.0	-1.4	-0.1	-0.1
Pali 2 (2000-2010)	RAWS			Park: HAVO							Elev. 2,780 ft. (856 m)		
Precipitation (in)													
Long-term mean	8.3	7.6	9.8	1.8	2.0	0.4	1.3	1.8	1.6	5.1	8.7	6.5	55.0
2010 totals	0.3	0.6	1.6	0.7	0.3	0.0	0.1	0.0	0.0	1.5	1.7	9.5	16.3
% Long-term	4%	8%	16%	39%	15%	0%	8%	0%	0%	29%	20%	146%	30%
Min. temp. (°F)													
Long-term mean	56.6	56.1	57.2	57.9	59.1	60.5	62.1	62.9	62.4	61.8	60.6	58.1	59.6
2010 means	55.7	55.5	56.8	57.6	58.9	59.3	60.1	61.1	60.6	60.6	59.2	57.9	58.6
Difference	-0.9	-0.6	-0.4	-0.3	-0.2	-1.2	-2.0	-1.8	-1.8	-1.2	-1.4	-0.2	-1.0
Max. temp. (°F)													
Long-term mean	71.4	71.1	71.0	72.5	74.7	77.0	79.2	79.5	78.1	76.7	75.0	72.2	74.9
2010 means	72.3	72.6	72.5	74.3	75.6	78.0	78.0	80.6	79.4	76.8	74.0	72.2	75.5
Difference	0.9	1.5	1.5	1.8	0.9	1.0	-1.2	1.1	1.3	0.1	-1.0	0.0	0.6
Ave. temp. (°F)													
Long-term mean	62.8	62.3	63.0	63.8	65.7	67.4	69.3	69.7	68.8	67.7	66.4	63.8	65.9
2010 means	63.1	62.4	62.8	64.2	65.7	67.3	67.7	69.1	68.2	67.1	65.2	63.7	65.5
Difference	0.3	0.1	-0.2	0.4	0.0	-0.1	-1.6	-0.6	-0.6	-0.6	-1.2	0.4	-0.5

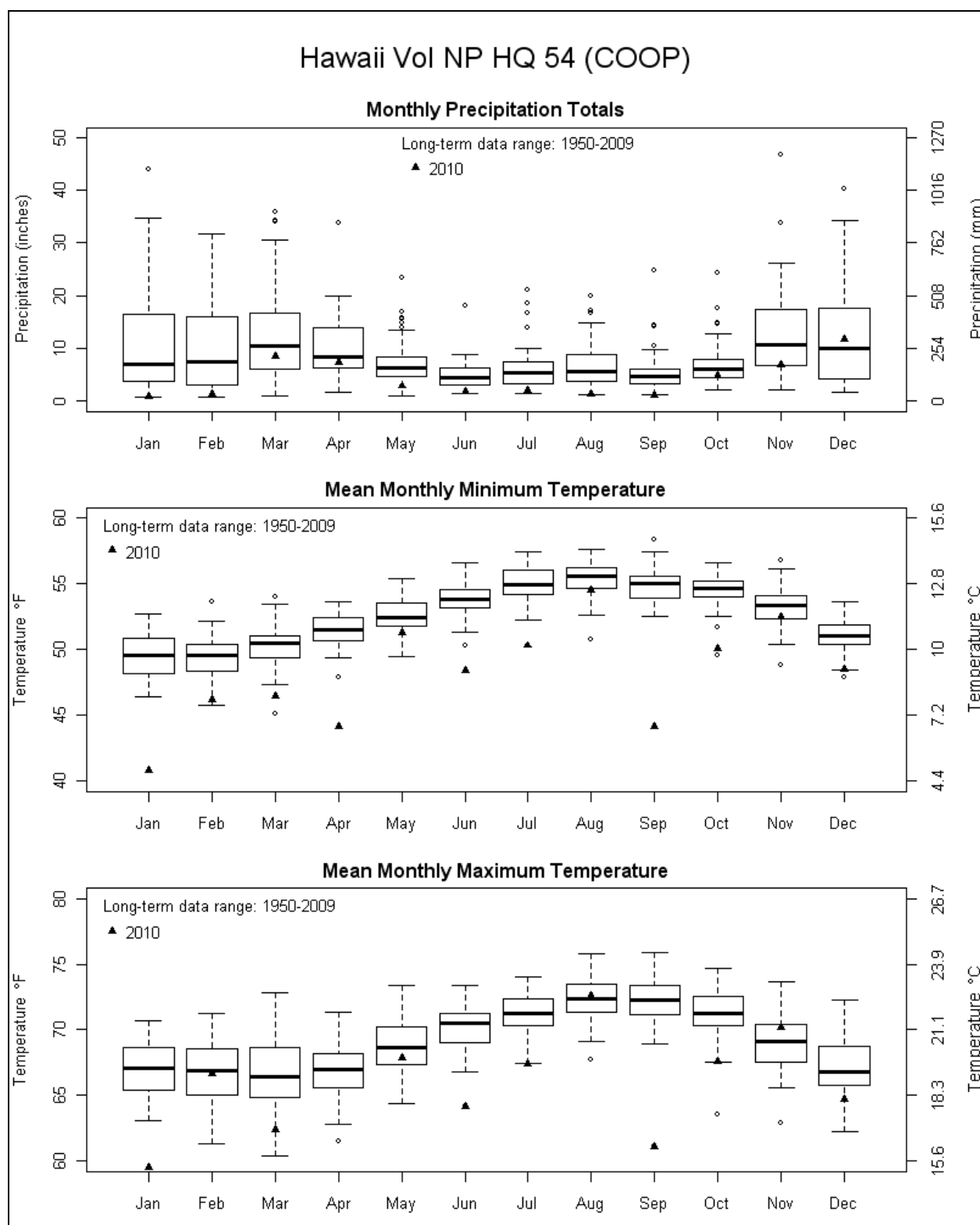


Figure 29. Boxplots of monthly precipitation and temperature data for Hawaii Vol NP HQ 54 (COOP), Hawaii.

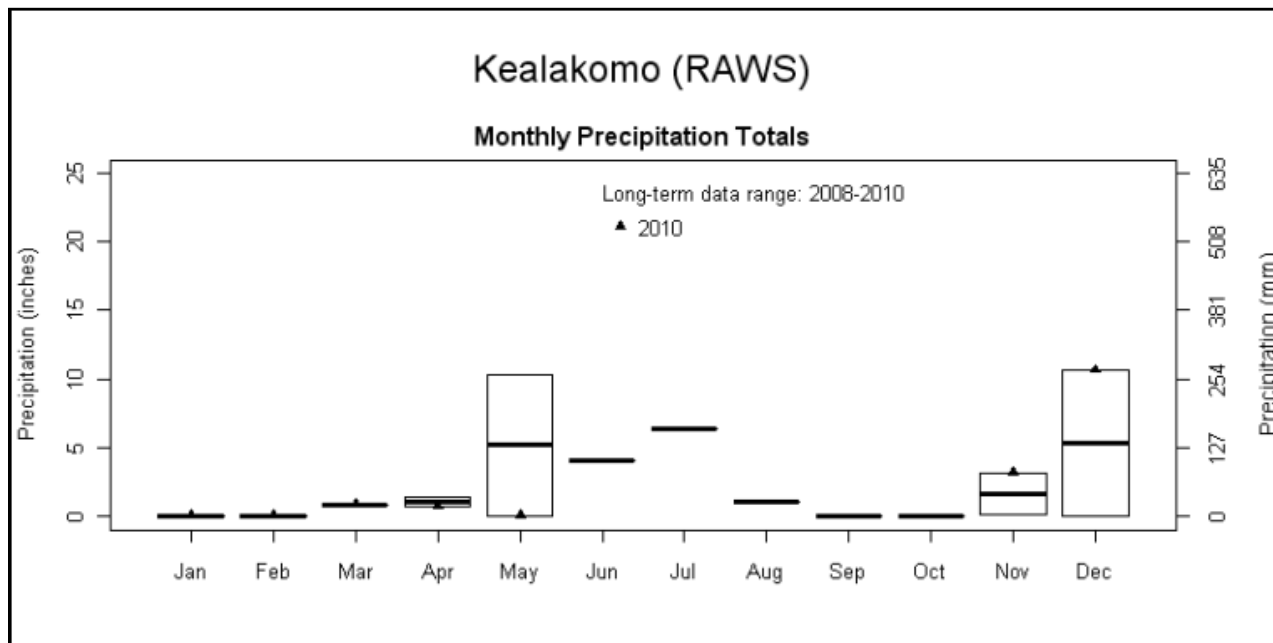


Figure 30. 2008 - 2010 data for the newly established Kealakomo RAWS, Hawaii station. Compare Kealakomo COOP data in following figure for long-term data.

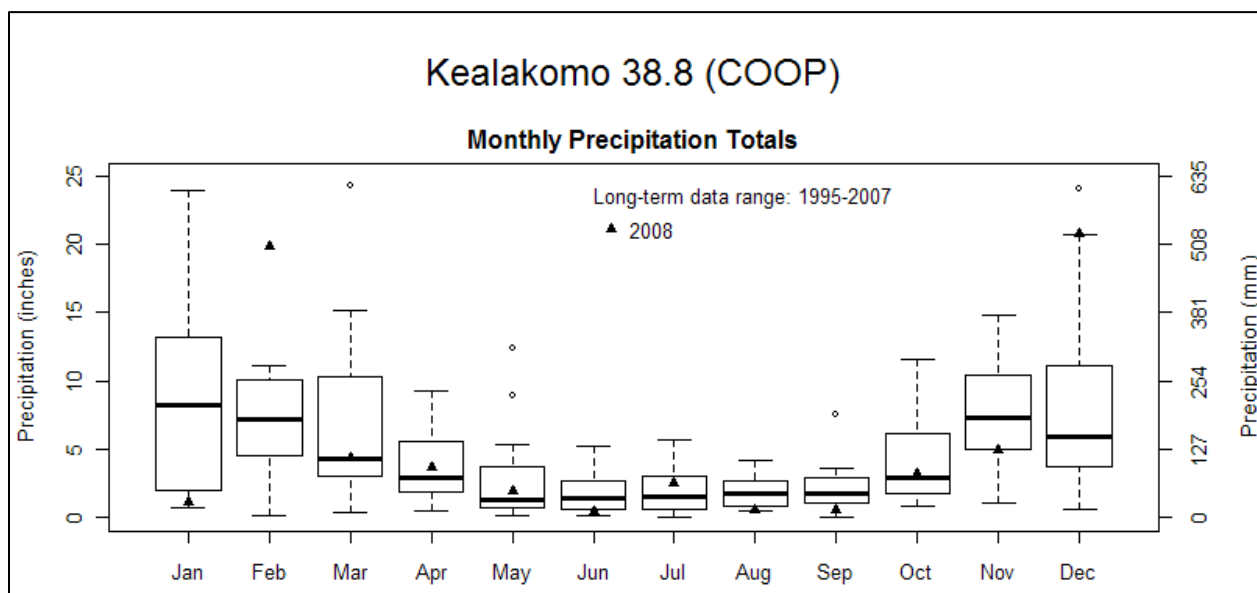


Figure 31. Boxplot of monthly precipitation data for Kealakomo 38.8 (COOP), Hawaii. In this timeframe (1995–2008) this station was a COOP station and this graph gives comparison data for the prior years (Figure 30).

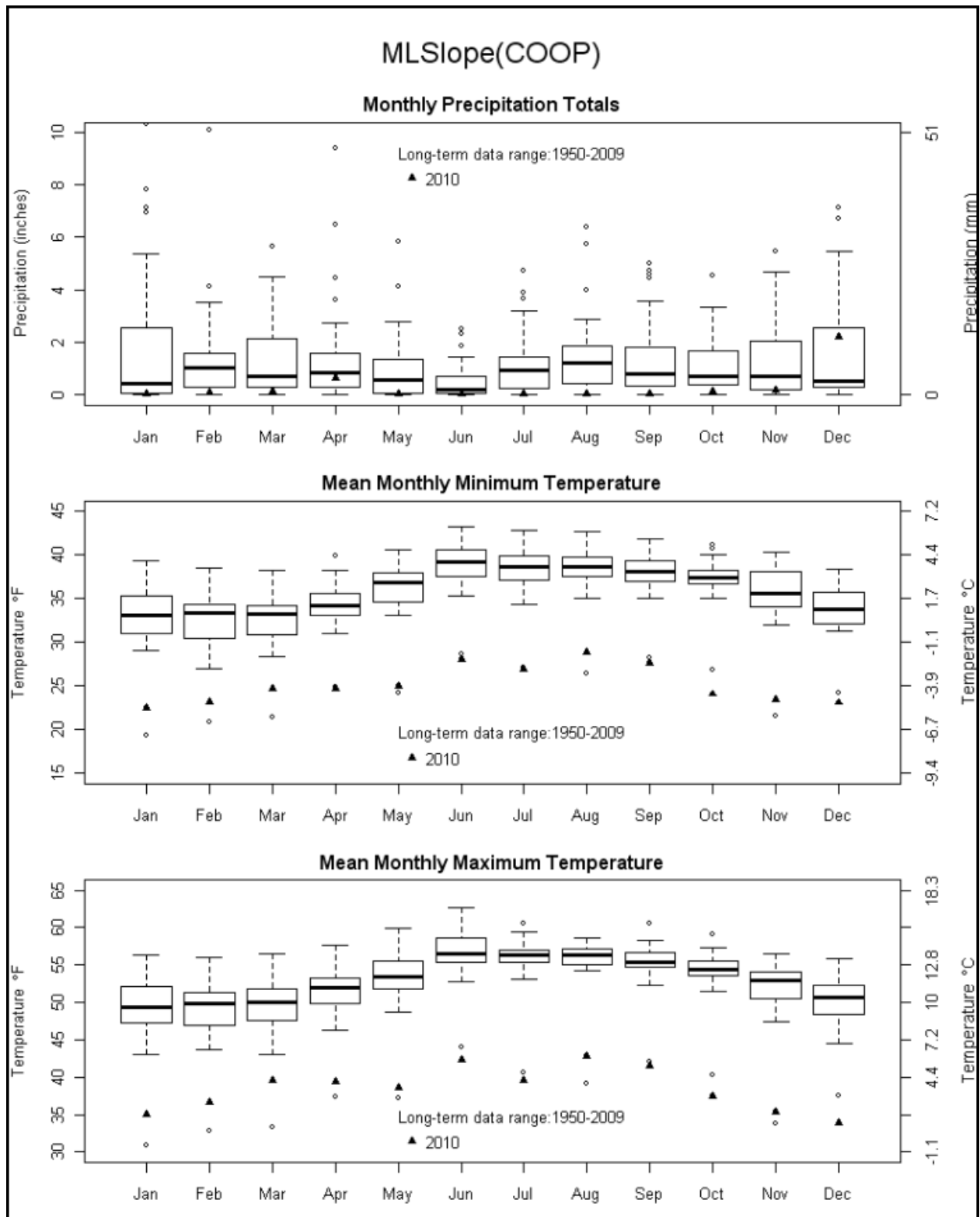


Figure 32. Boxplot of monthly precipitation data for Mauna Loa Slope Obs. 39, (COOP) Hawaii.

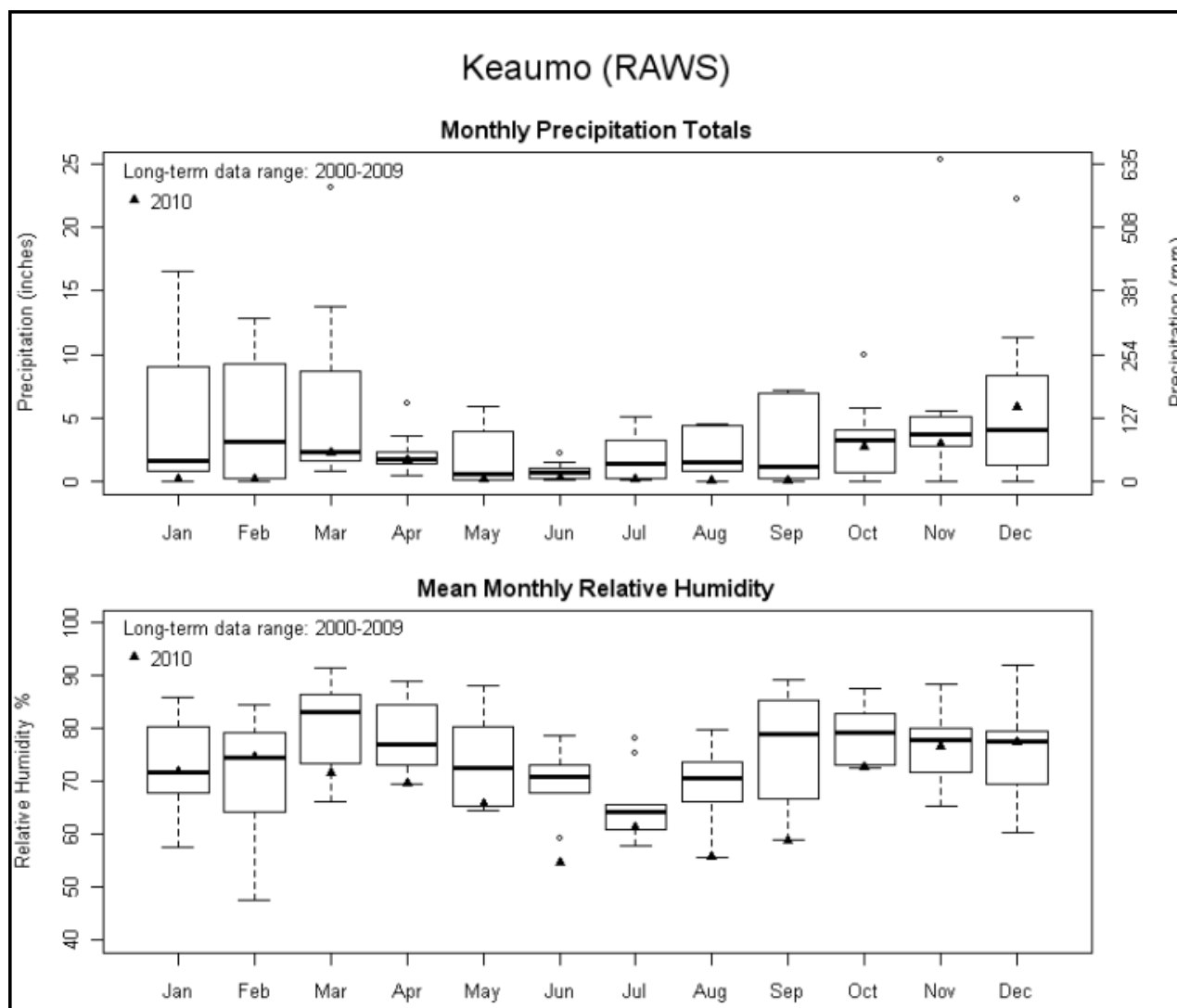


Figure 33. Boxplots of monthly precipitation and relative humidity for Keaumo (RAWS) Hawaii.

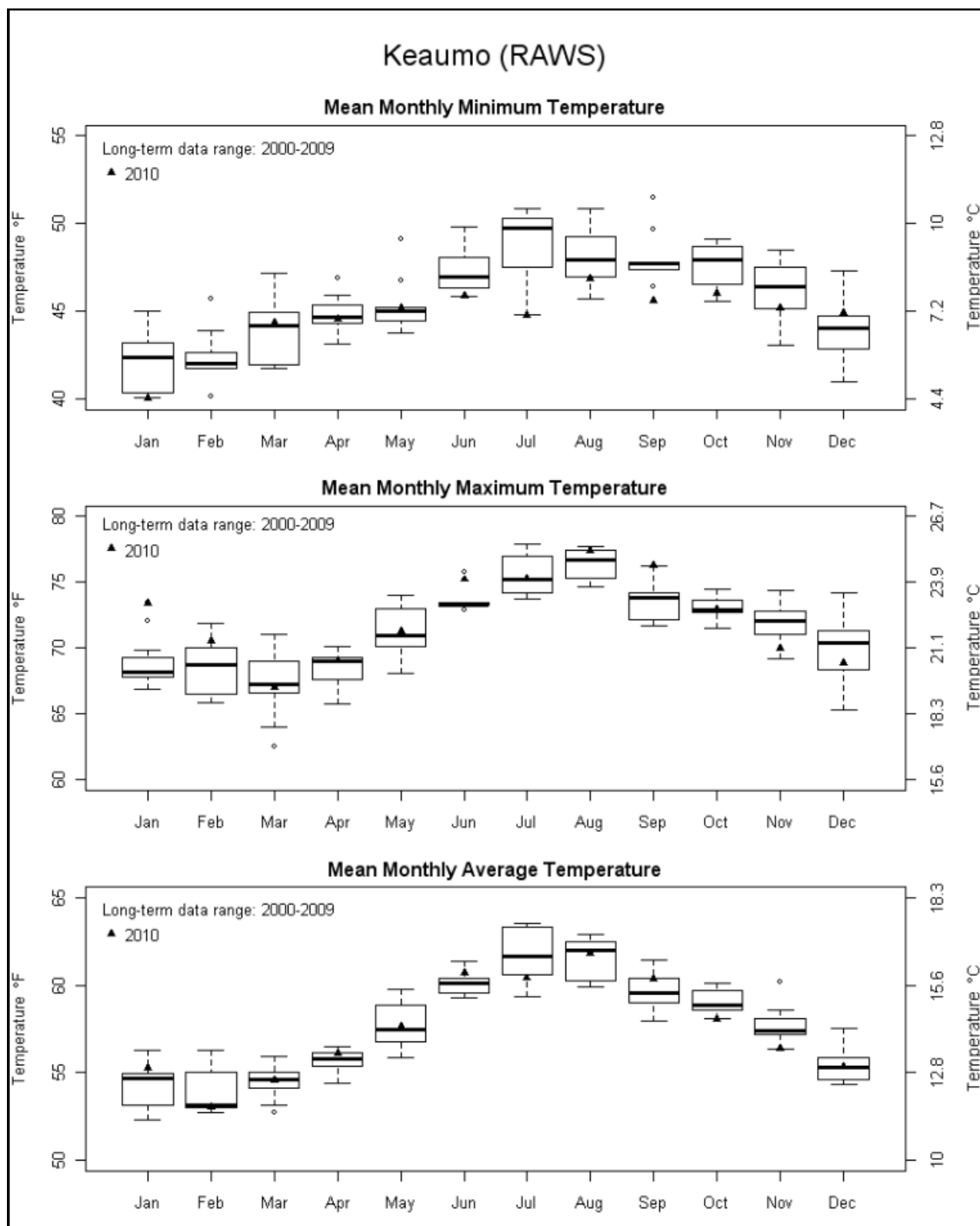


Figure 34. Box plots of monthly temperature data for Keaumo, (RAWS), Hawaii.

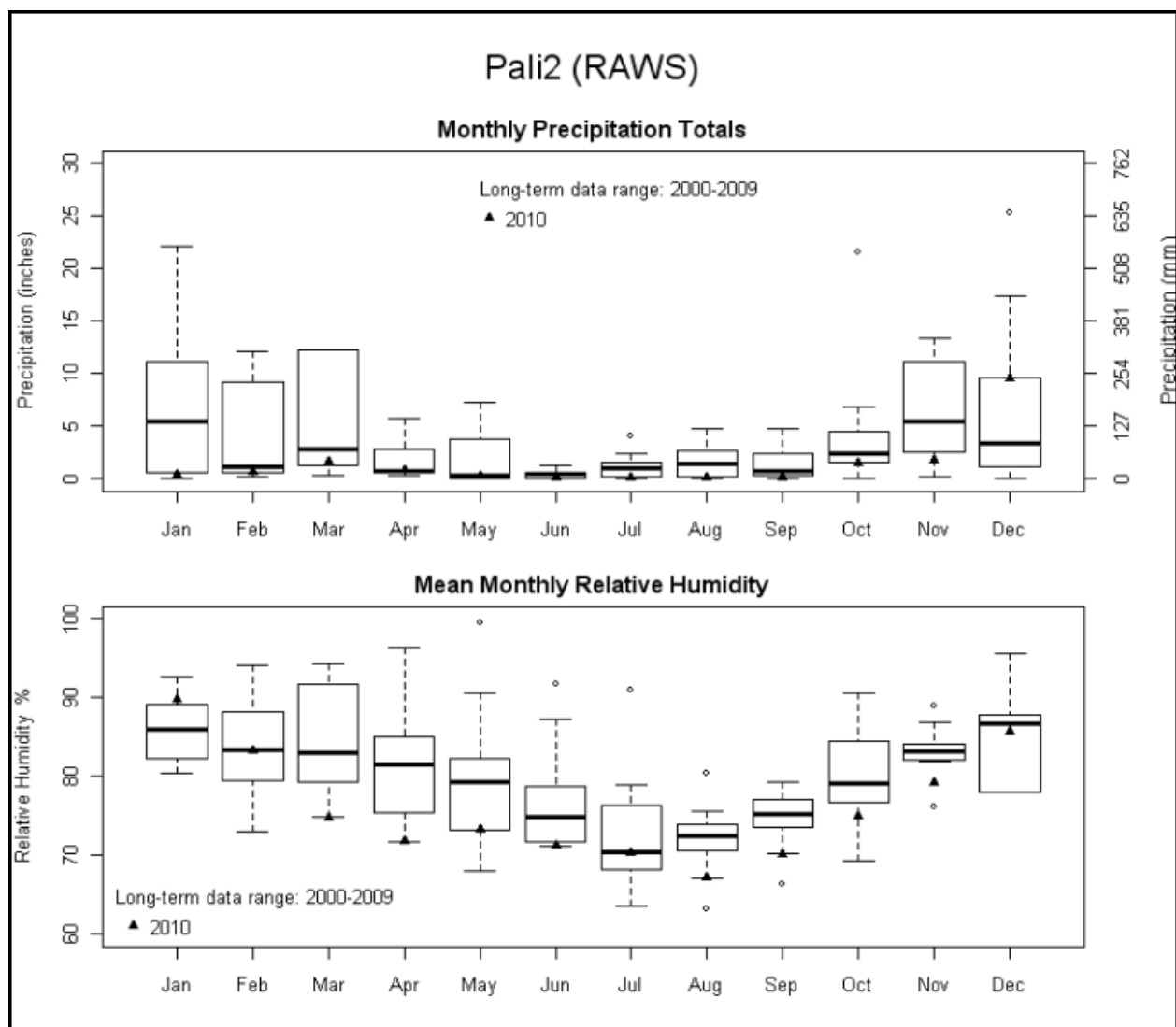


Figure 35. Boxplots of monthly precipitation and relative humidity data for Pali2 (RAWS), Hawaii.

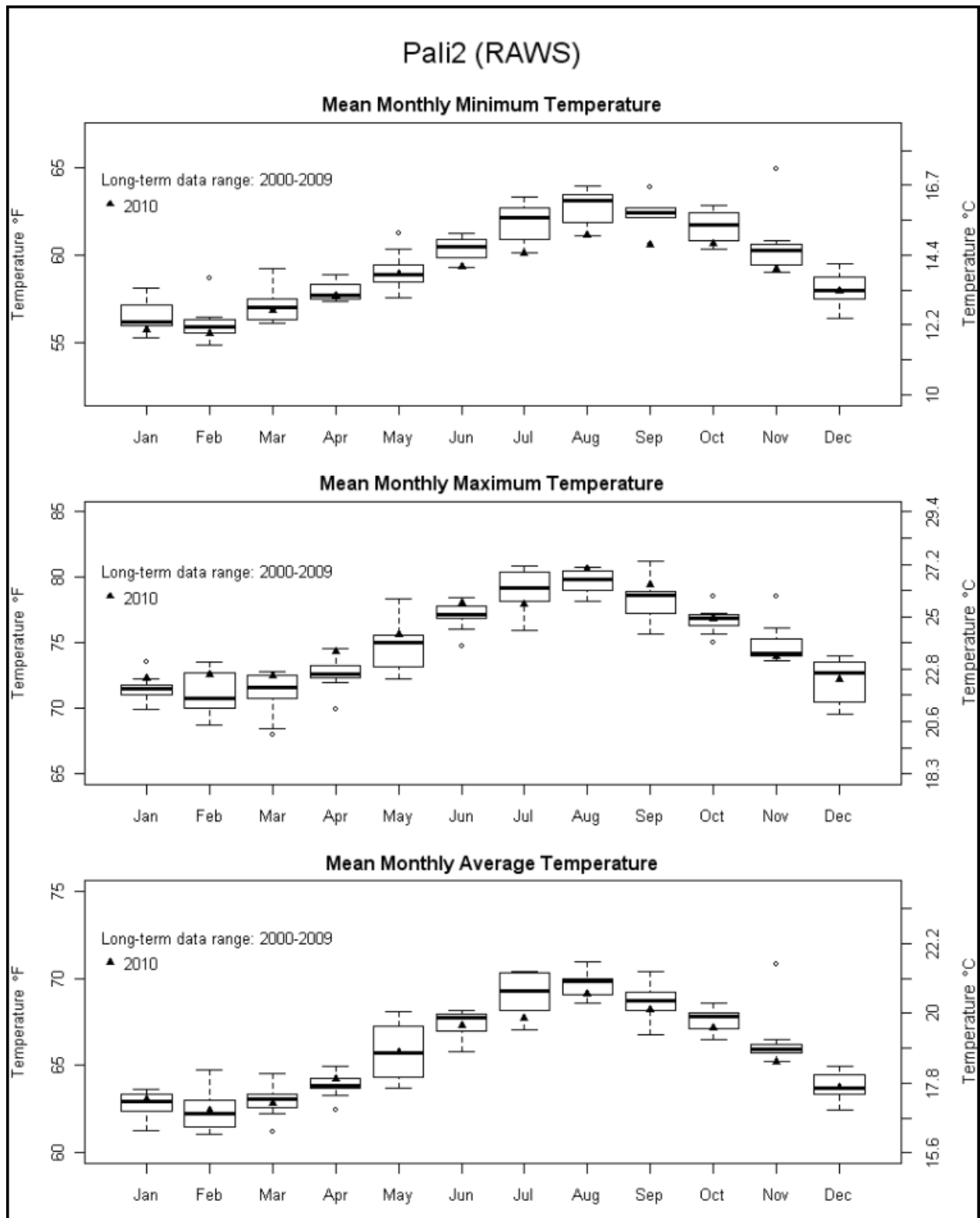


Figure 36. Boxplots of monthly temperature data from Pali 2, (RAWS), Hawaii.

Pali 2 Hawaii

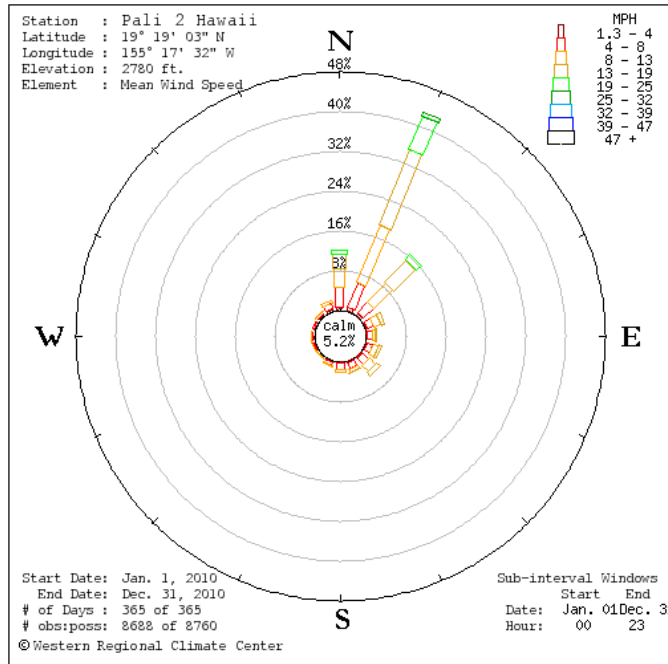


Figure 37. Wind Rose Graph for 2010 data for Pali 2 (RAWS), Hawaii.

Keaumo Hawaii

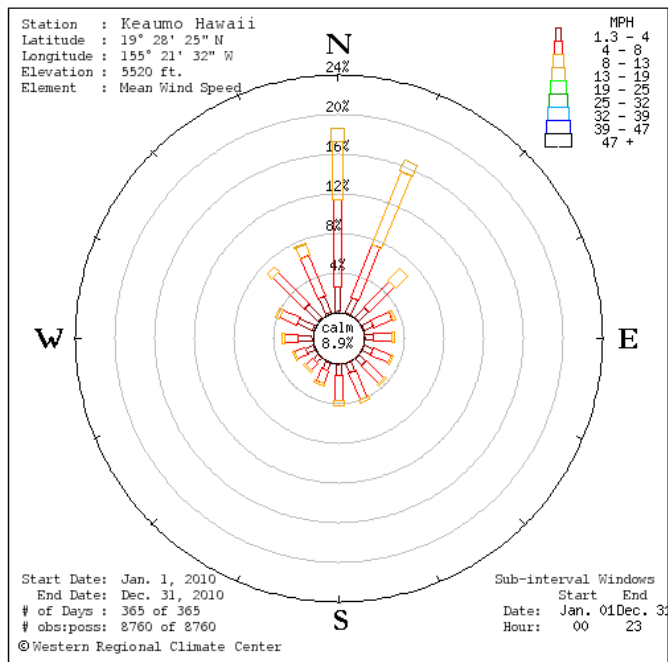


Figure 38. Wind Rose Graph for 2010 data for Keaumo, (RAWS) Hawaii.

Tables 5-9 and Figures 39-42 provide precipitation, temperature, relative humidity and wind data for the three west Hawaii national parks. The COOP stations at PUHE and KAHO only record precipitation.

Puuhonua o Honaunau National Historical Park (PUHO)

Puuhonuaohonaunau 27.4 had 83% of potential weather records for 2010. Seventeen weekends and the whole month of October were not recorded in 2010. In 2012, this WeatherHawk station at PUHO will be replaced by a Campbell Scientific automated station using the RAWS network. It will provide data via satellite to WRCC so will not have to be checked daily. It will be in a very slightly different location so data will be mostly comparable from previous years.

Kaloko-Honokohau National Historical Park (KAHO)

The Kaloko RAWS station measured precipitation data from January through December, with a servicing error in March, when the rain gauge needed adjusting. Water added to test the gauge was not deleted from the data set by WRCC and therefore the number is faulty. This has been noted (NA) in Tables 7 and 8 where the data is presented.

This year the Honokohau Harbor COOP station (Table 8), 2700 meters away from the Kaloko-Honokohau RAWS station registered precipitation throughout the year. This is the first year that the precipitation data between the two stations have been similarly recorded. In the past two years, there has been quite a discrepancy of total amount of precipitation in each month and consequently at the end of the year between the two stations. With some data lacking on both stations, the difference between last year's (2009) precipitation counts was 4.9 inches, a 26% difference. For the first three months in 2009, there was a 46% discrepancy, with 1.9 inches at the RAWS station and 3.5 at the COOP. The 2008 data were also different, with monthly totals varying by half again as much at the RAWS than the COOP (Table 5).

Table 5. 2008 data at Kaloko-Honokohau RAWS and the Honokohau Harbor COOP stations.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	
0.3	0.8	0.7	0.7	1.2	2.7	1.2	1.2	1.1	1.4	0.2	2.6	13.9	RAWS
0.7	1.08	NA	1.65	1.67	3.7	4.7	1.19	2.29	1.42	0.4	NA	NA	COOP
2.3	1.4	NA	2.4	1.4	1.4	3.9	1.0	2.1	1.0	2.0	NA	NA	Difference

Puukohola Heiau National Historic Site (PUHE)

Further north, Puukohola Heiau National Historic Site had a slightly wet November and December, and the rest of the year precipitation was less than normal in all but one month. Maximum temperatures were below normal all year, with minimum temperatures also showing less than normal. This COOP station will also be replaced by a new automated Campbell Scientific station which will be located about 100 m south of the extant station. Long term data will probably be comparable due to the small shift in location.

Table 6. Precipitation data from 2010 from Puuhonua o Honaunau National Historical Park.

	Jan	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
Puuhonuaohonaunau 27.4 (1971-2010) COOP Park: PUHO Elev. 15 ft. (4.6 m)													
Precipitation (in)													
1971-2000 normal	2.52	1.64	1.85	1.68	2.30	2.37	2.83	2.55	2.69	2.46	1.53	1.58	26.00
2010 totals	0.0	0.0	0.8	2.4	2.1	0.4	1.5	1.6	1.2	0.0	2.7	3.5	16.0
% Normal	0%	0%	43%	140%	91%	17%	53%	63%	45%	0%	176%	222%	62%

Table 7. Comparison of precipitation and temperature data from 2010 of Kaloko-Honokohau National Historical Park. Comparison is made with the long-term mean (only 5 years) for the RAWS

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Kaloko-Honokohau (2006-2010) RAWS Park: KAHO Elev. 25 ft. (7.6 m)													
Precipitation (in)													
Long-term mean (5 years only)	0.7	1.4	1.1	0.2	1.0	1.1	1.9	0.3	1.4	1.7	0.6	2.9	14.3
2010 totals	0.2	NA	0.1	3.3	0.3	0.3	1.4	1.1	0.2	0.5	0.9	4.6	NA
% Long-term	29%	NA	9%	1375%	31%	27%	74%	367%	14%	29%	150%	159%	NA
Min. temp. (°F)													
Long-term mean	66.3	65.8	67.7	67.9	64.9	71.6	72.2	72.7	71.8	71.7	69.7	67.5	69.2
2010 means	67.5	67.1	67.6	68.4	70.6	70.8	70.7	70.8	70.9	71.3	70.3	68.0	69.5
Difference	1.2	1.3	-0.1	0.5	5.7	-0.8	-1.5	-1.9	-0.9	-0.4	0.6	0.5	0.3
Max. temp. (°F)													
Long-term mean	82.1	81.4	81.5	82.3	82.3	84.3	85.2	86.0	85.4	85.7	84.4	83.4	83.7
2010 means	83.2	82.6	82.2	81.4	82.4	83.6	83.1	84.4	85.1	84.9	83.4	82.7	83.2
Difference	1.1	1.2	0.7	-0.9	0.1	-0.7	-2.1	-1.6	-0.3	-0.8	-0.9	-0.7	-0.4
Ave. temp. (°F)													
Long-term mean	74.5	73.7	75.1	75.9	76.2	77.9	78.7	79.3	78.3	78.3	76.9	75.6	76.7
2010 means	73.2	73.5	72.7	74.1	71.8	79.2	79.8	80.9	80.1	80.1	76.8	74.9	76.4
Difference	-1.3	-0.2	-2.4	-1.8	-4.4	1.3	1.1	1.6	1.8	1.8	-0.1	-0.7	-0.3

Table 8. These two tables compare the precipitation at two stations near Kaloko-Honokohau 2,700 m apart. Comparison is made with the long-term mean from 1971 – 2000 at the COOP station. This is the first year in three that the measurements are close, if you substitute 0.0 for the precipitation in February.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Honokohau Harbor 68.14 (1991-2009) COOP Park: KAHO Elev. 30 ft. (9.1 m)													
Precipitation (in)													
1971-2000 normal	2.12	0.78	1.44	2.21	0.77	1.10	1.02	1.12	1.50	1.47	0.72	1.06	15.31
2010 totals	0.1	0.0	1.3	2.2	0.0	0.0	0.3	2.1	0.8	0.3	0.9	5.0	12.9
% Normal	3%	0%	90%	100%	0%	0%	28%	187%	51%	20%	125%	474%	84%
Kaloko-Honokohau (2006-2009) RAWS Park: KAHO Elev. 25 ft. (7.6 m)													
Precipitation (in)													
Long-term mean (5 years only)	0.7	1.4	1.1	0.2	1.0	1.1	1.9	0.3	1.4	1.7	0.6	2.9	14.3
2010 totals	0.2	NA	0.1	3.3	0.3	0.3	1.4	1.1	0.2	0.5	0.9	4.6	NA
% Long-term	29%	NA	9%	1375%	31%	27%	74%	367%	14%	29%	150%	159%	NA

Table 9. Puukohola Heiau COOP station data. Comparison is made with the long-term mean from 1971 – 2000 at this COOP station. Numbers in bold show the high temperature months of the year.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Puukohola Heiau 98.1 (1977-2009) COOP Park: PUHE Elev. 33 ft. (40.5 m)													
Precipitation (in)													
1971-2000 normal	1.8	1.05	1.02	0.75	0.47	0.58	0.34	0.62	0.65	0.67	0.97	1.68	10.60
2010 totals	2.2	0.00	0.64	0.32	0.90	0.32	0.04	0.35	0.00	0.00	0.99	0.48	6.26
% normal	127%	0%	67%	22%	243%	82%	11%	73%	0%	0%	100%	25%	56%
Min. temp. (°F)													
1971-2000 normal	64	64.1	65.4	66.9	67.8	69.2	70.3	70.9	70.5	70.4	68.4	66	67.8
2010 means	65.1	64.1	NA	66.3	68.2	68.4	69.5	69.9	69.1	69.4	68.0	66.0	67.6 ¹
Difference	1.1	0.0	NA	-0.6	0.4	-0.8	-0.8	-1.0	-1.4	-1.0	-0.4	0.0	NA
Max. temp (°F)													
1971-2000 normal	78.6	78.7	80.4	81.5	82	83.2	83.8	84.7	84.7	83.7	81.1	79.4	81.8
2010 means	78.4	78.9	NA	79.3	80.3	81.6	81.5	81.6	81.3	81.5	79.8	78.2	80.2 ¹
Difference	-0.2	0.2	NA	-2.2	-1.7	-1.6	-2.3	-3.1	-3.4	-2.2	-1.3	-1.2	NA

¹ Average temperature of the 11 months for which data were collected.

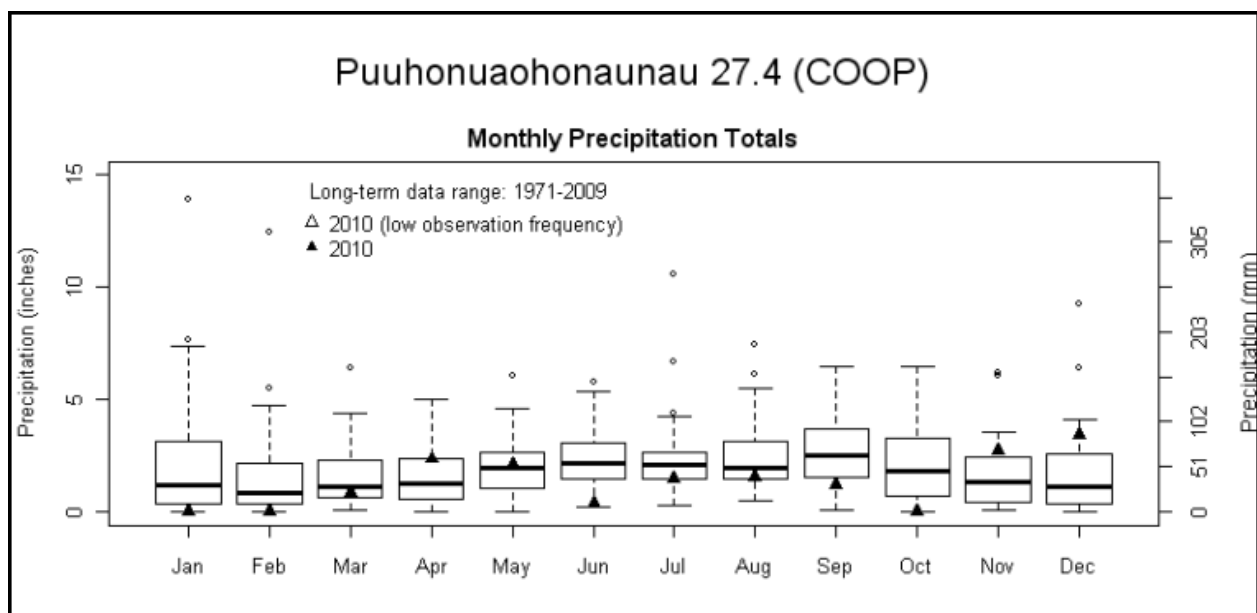


Figure 39. Boxplot of monthly precipitation data for Puuhonuaohonaunau 27.4 (COOP), Hawaii.

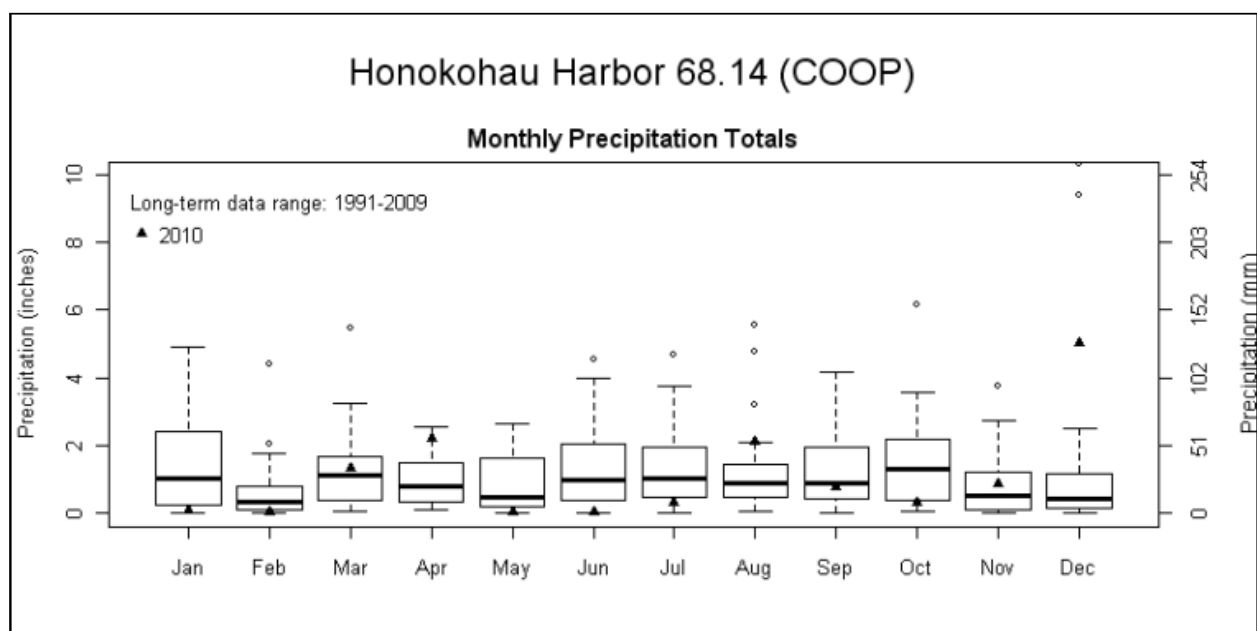


Figure 40. Boxplot of monthly precipitation data for Honokohau Harbor 68.14 (COOP), Hawaii.

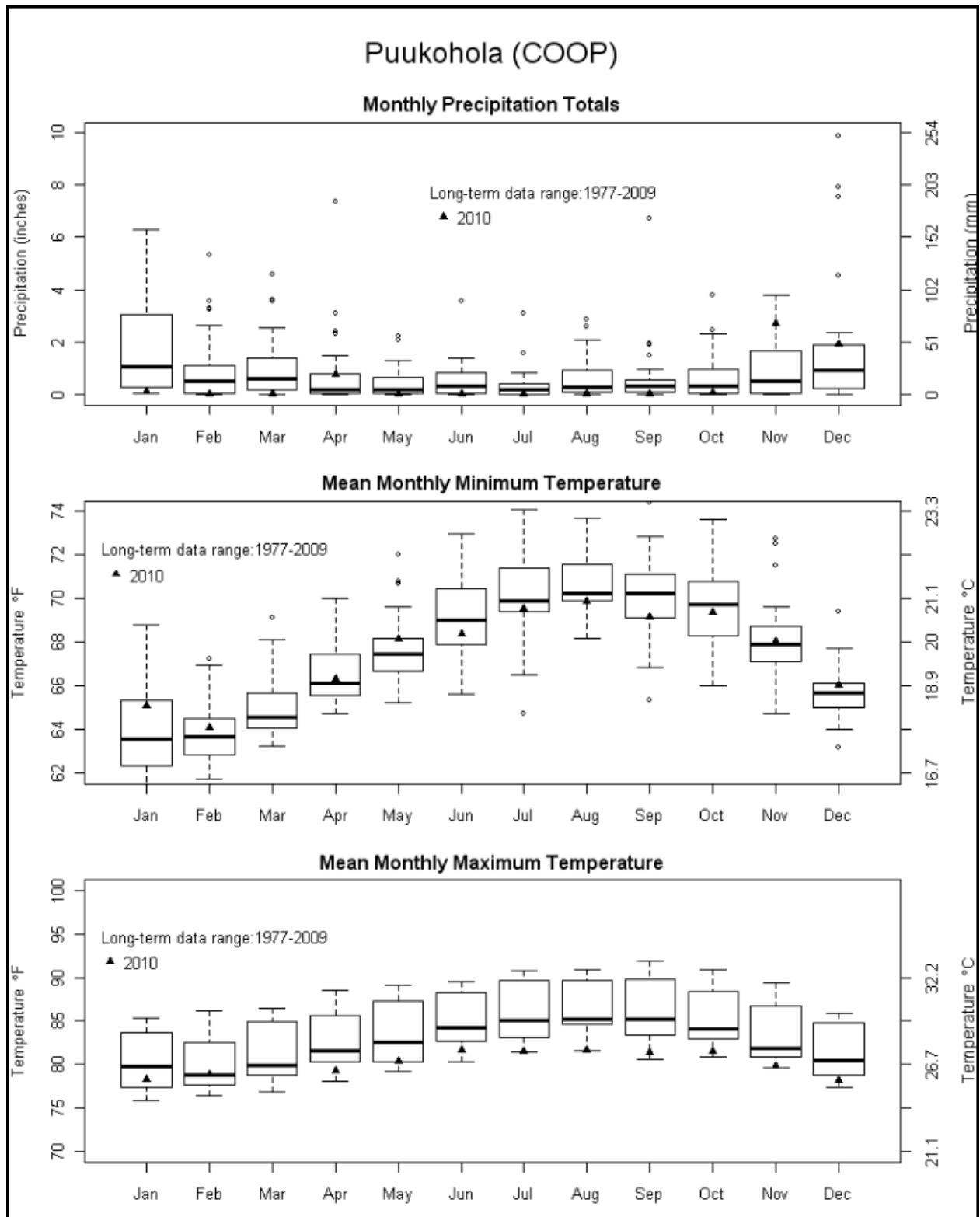


Figure 41. Boxplots of monthly precipitation and temperature data for Puukohola Heiau 98.1 (COOP), Hawaii.

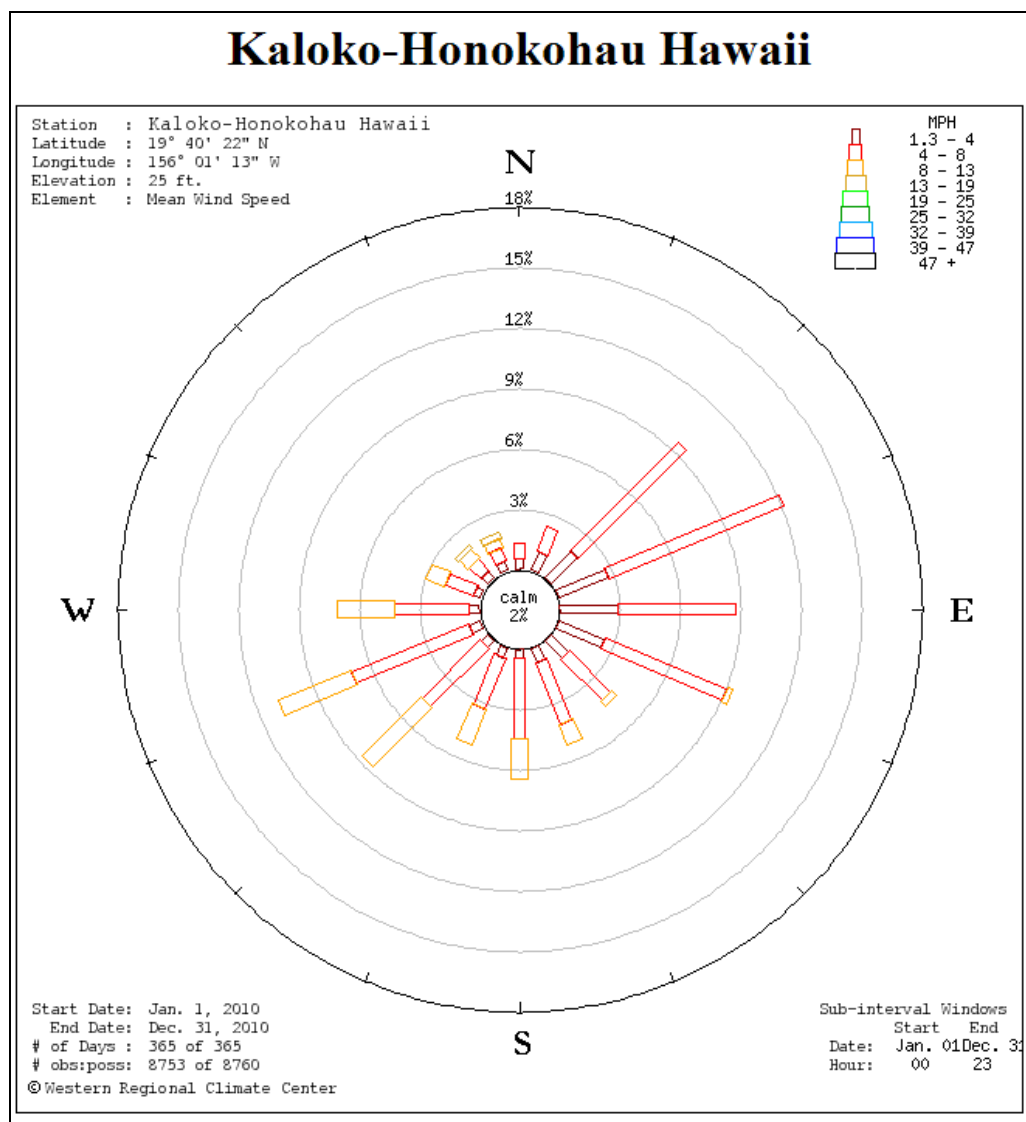


Figure 42. Wind Rose Graph of 2010 data for Kaloko-Honokohau (RAWS), Hawaii.

Maui and Molokai National Parks

Kalaupapa National Historical Park (KALA)

Table 10 and Figures 43 - 45 present precipitation, temperature, and relative humidity data for a COOP station and a RAWS located on the Kalaupapa peninsula. The Kalaupapa COOP station currently only collects precipitation data, but through the long station record there have been intermittent years during which temperature data were also recorded. The Kalaupapa COOP station had low observation frequencies (<85%) for all months in 2010. Data flags indicated that subsequent days reported accumulated data. To provide at least some information about rainfall in this area, data for all months are shown in figure 43. Wind graphics (Figure 46,) illustrate the often intense wind conditions on the peninsula. In January and February winds came out of the north or northeast, but during the rest of the year the predominant wind direction was directly from the east. Two more Campbell Scientific RAWS weather stations are going to be set up at KALA in early 2012.

Table 10. Comparison of precipitation and temperature data from 2010 with long-term records for stations at Kalaupapa National Historical Park, Molokai, Hawaii. For the COOP station 2010 data for all months had low observation frequencies (<85%) thus only 1971-2000 normals are presented. For the RAWS comparisons are made and with long-term means (period of record indicated, not including the last year). Bold numbers are high temperature months for this station.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Kalaupapa 563 (1949-2009) COOP Park: KALA Elev. 30 ft. (9.1 m)													
Precipitation (in)													
1971-2000 normal	5.53	4.24	5.10	4.74	2.96	1.47	2.20	2.11	1.54	3.00	4.60	5.89	43.38
2010 totals	1.6	3.2	4.5	4.1	0.3	0	2.4	1.9	1.7	0.8	5.3	5.2	31
% Normal	29%	75%	88%	86%	10%	0%	109%	90%	110%	27%	115%	88%	71%
Makapulapai (1994-2009) RAWS Park: KALA Elev. 75 ft. (22.9 m)													
Precipitation (in)													
Long-term mean	4.30	1.86	6.78	1.84	1.75	0.75	0.94	1.33	1.08	1.75	4.59	3.41	30.40
2010 totals	1.64	1.30	1.75	1.66	0.36	0.42	NA	0.00	0.00	0.00	2.02	4.49	NA
% Long-term	4%	70%	26%	90%	21%	56%	NA	0%	0%	0%	44%	132%	NA
Min. temp. (°F)													
Long-term mean	67.7	67.6	68.1	69.5	71.7	73.6	74.2	74.7	73.8	73.7	71.3	69.5	71.3
2010 means	67.3	66.1	68.1	68.8	71.2	72.4	NA	73.0	73.0	73.4	70.4	67.9	70.1 ¹
Difference	-0.4	-1.5	0.0	-0.7	-0.5	-1.2	NA	-1.7	-0.8	-0.3	-0.9	-1.6	NA
Max. temp. (°F)													
Long-term mean	79.2	78.0	78.5	79.3	82.2	84.0	84.7	85.5	84.7	84.2	81.2	79.9	81.8
2010 means	80.6	78.1	78.0	78.3	81.4	82.8	NA	84.5	84.9	84.1	81.9	82.0	81.5 ¹
Difference	1.4	0.1	-0.5	-1.0	-0.8	-1.2	NA	1.0	0.2	-0.1	0.7	2.1	NA
Ave. temp. (°F)													
Long-term mean	73.0	72.5	72.9	73.9	76.6	78.3	78.9	79.6	78.8	78.4	75.8	74.4	76.1
2010 means	73.5	71.9	72.5	73.1	75.9	77.2	NA	78.3	78.4	78.2	75.7	74.3	75.4 ¹
Difference	0.5	-0.6	-0.4	-0.8	-0.7	-1.1	NA	-1.3	-0.4	-0.2	-0.1	-0.1	NA

¹ Average temperature of the 11 months where there was data collected.

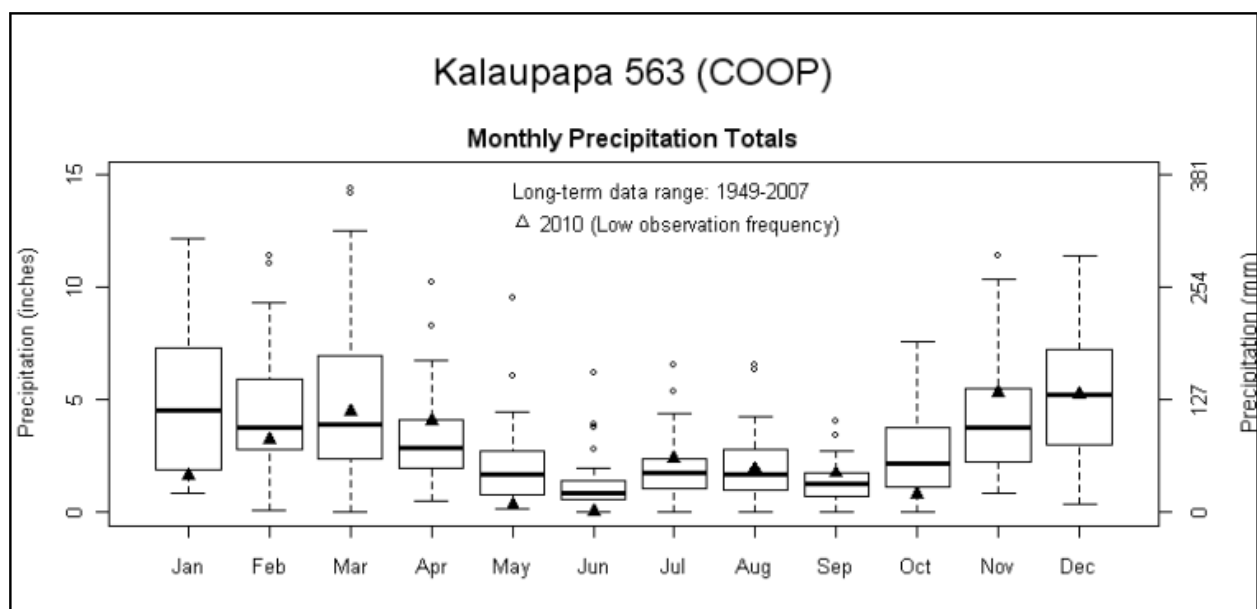


Figure 43. Boxplots of monthly precipitation data for Kalaupapa 563 (COOP), Molokai, Hawaii. All months in 2010 had low observation frequencies.

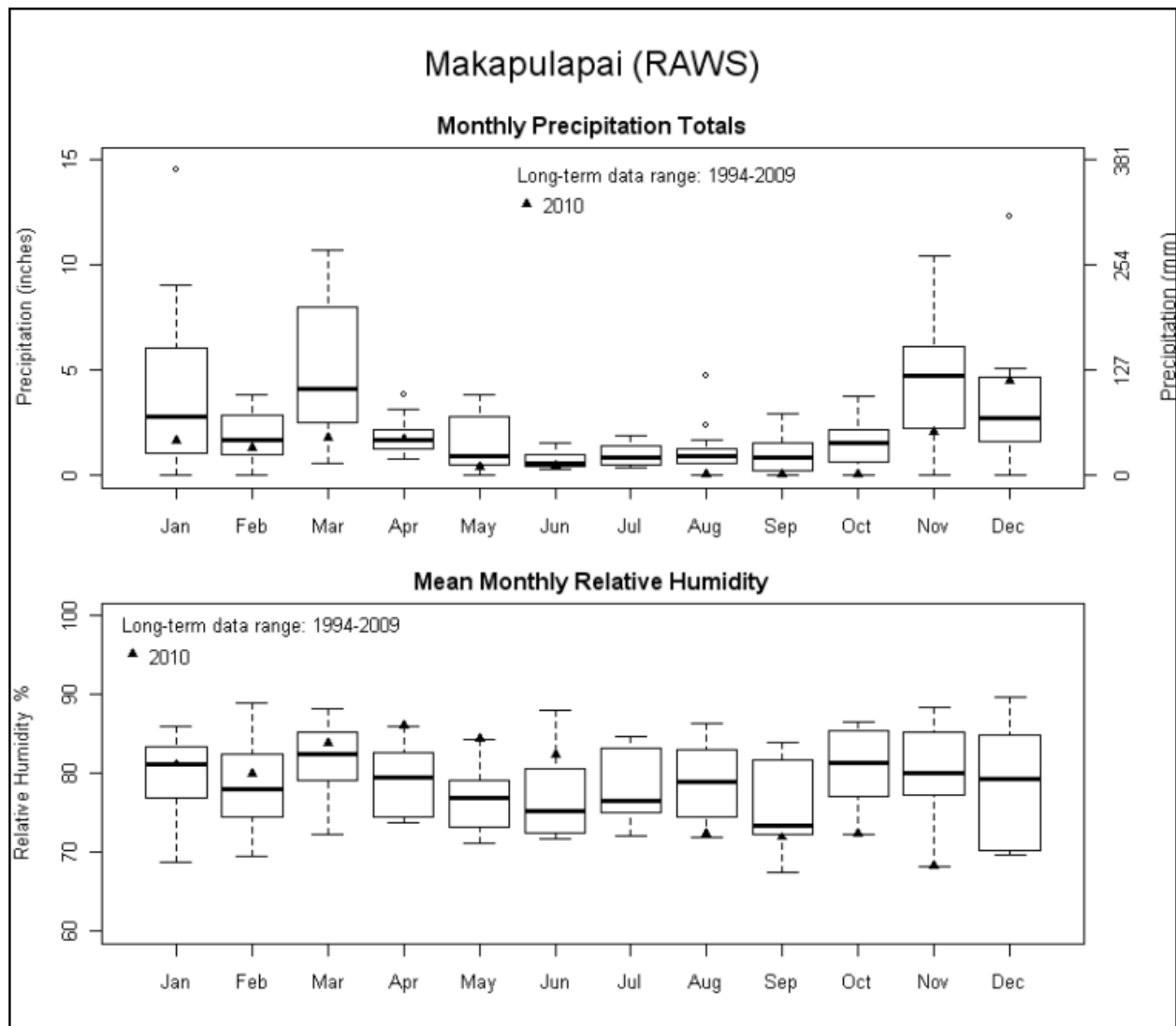


Figure 44. Boxplots of monthly precipitation and relative humidity data for Makapulapai (RAWS), Molokai, Hawaii.

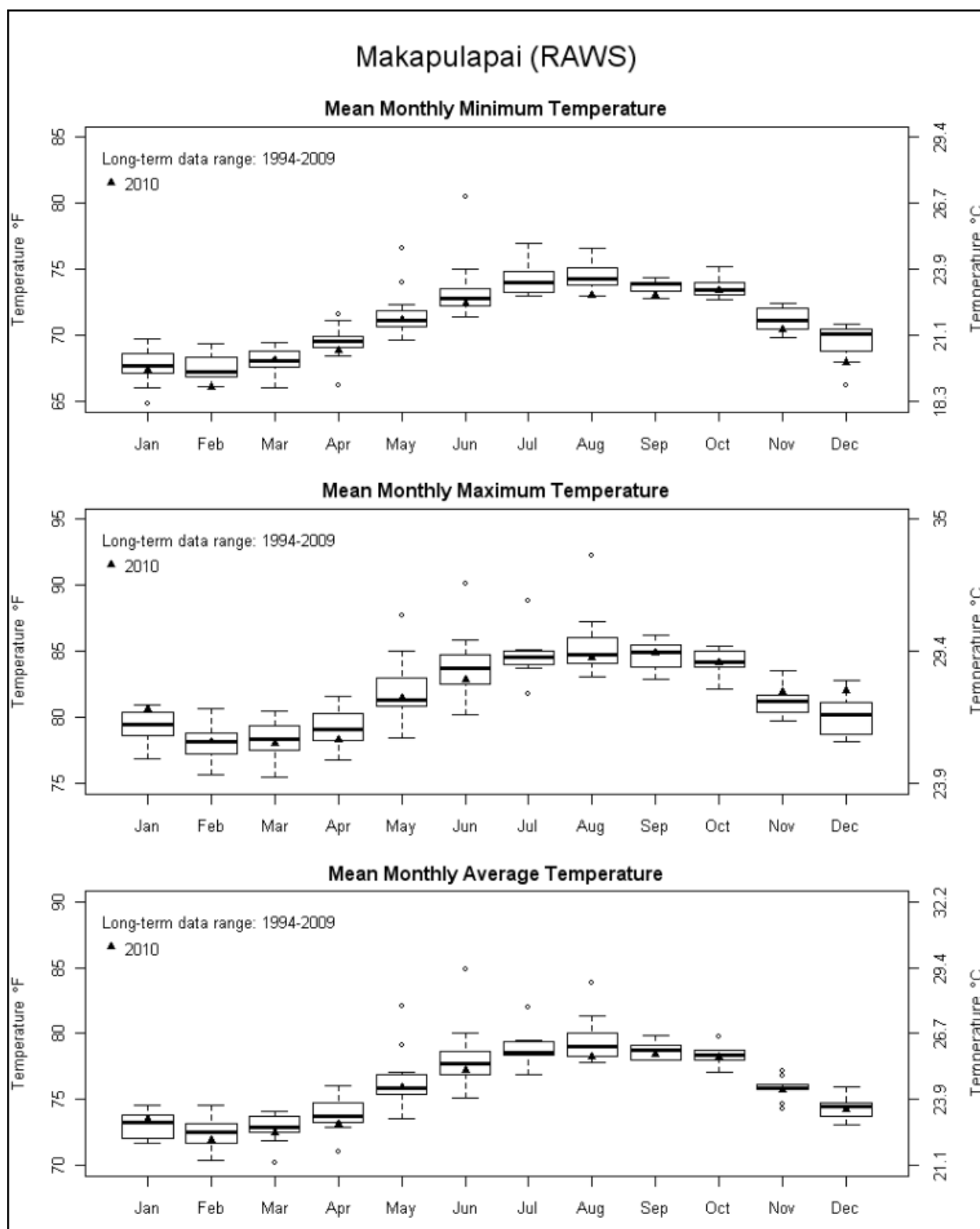


Figure 45. Boxplots of monthly temperature data for Makapulapai (RAWS), Molokai, Hawaii.

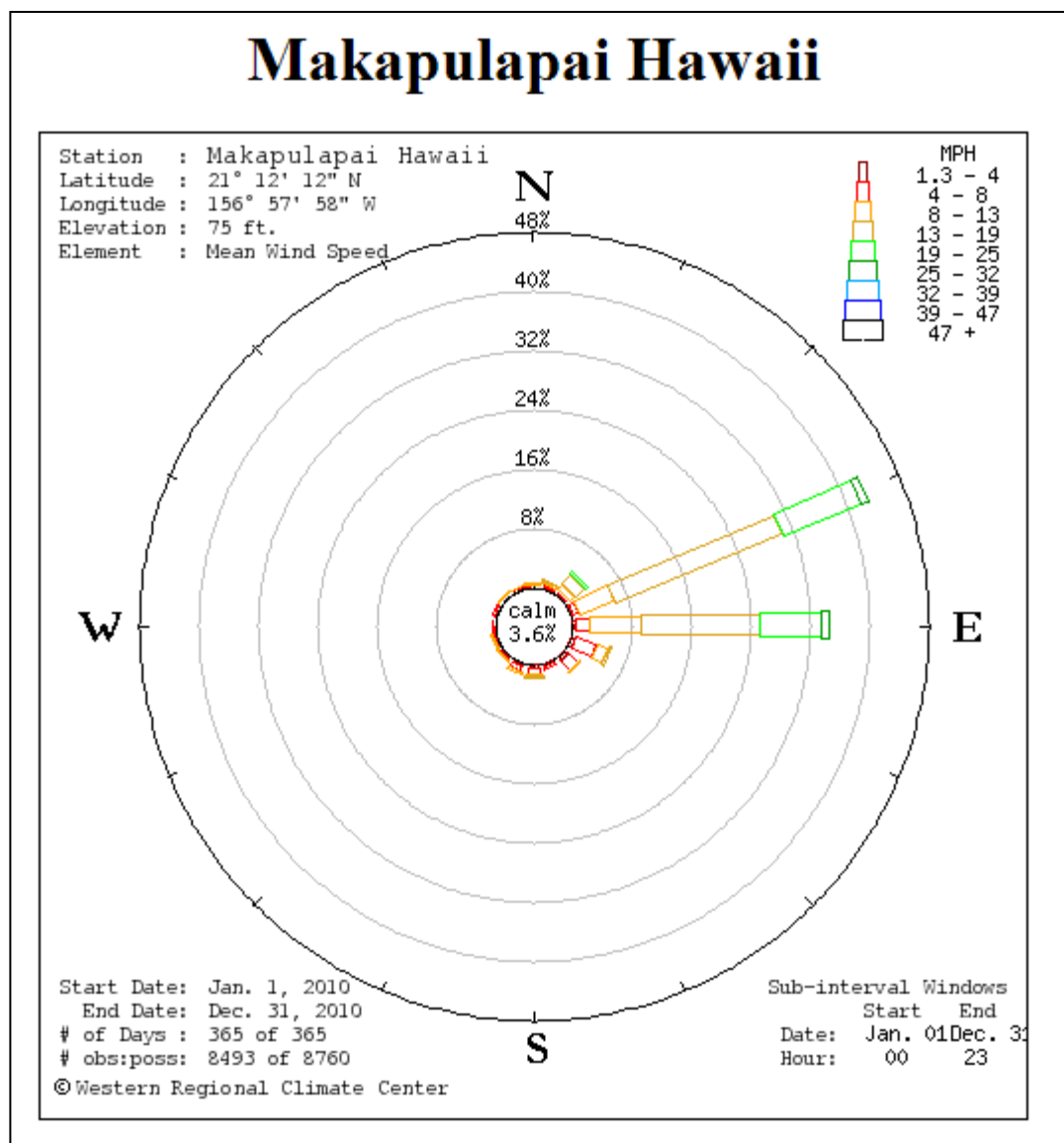


Figure 46. Wind Rose Graph of 2010 data for Makapulapai (RAWS), Molokai, Hawaii.

Haleakala National Park (HALE)

Table 11 and Figures 47–50 present precipitation, temperature, and relative humidity data for two COOP stations and one RAWS at HALE. A tropical depression hit the islands in March causing flooding on Oahu, Molokai, Maui and the Big Island. But the rain only somewhat helped to alleviate the drought and precipitation was only 51% of the annual norm for on Maui (Figure 57).

Figure 51 illustrates the wind data for the Kaupo Gap RAWS, showing that while the trade winds have a heavy influence in this area, wind direction is variable and southerly winds are also very common. Northerly winds tend to have the highest wind speeds.

Table 11. Comparison of precipitation and temperature data from 2010 with long-term records for stations at Haleakala National Park, Maui, Hawaii. Long-term means are based on the period of record indicated for each station, not including the last year. Bold numbers are high temperature months.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Haleakala RS 338 (1949-2009)	COOP			Park: HALE					Elev. 6,960 ft. (2,121.4m)				
Precipitation (in)													
1971-2000 normal	9.17	6.2	8.59	5.18	1.76	1.43	2.37	2.08	2.27	2.75	5.43	5.89	53.12
2010 totals	0.71	0.49	5.22	1.88	0.52	0.05	0.44	0.25	0.55	6.61	4.73	3.87	25.32
% Normal	8%	8%	61%	36%	30%	3%	19%	12%	24%	240%	87%	66%	48%
Min. temp. (°F)													
1971-2000 normal	42.0	41.3	42.2	42.6	44.0	46.5	47.7	47.8	46.8	46.4	45.9	43.5	44.7
2010 means	47.84	41.93	36.19	41.97	42.19	48.57	45.55	47.22	47.33	45.23	42.23	43.81	44.17
Difference	5.84	0.63	-6.01	-0.63	-1.81	2.07	-2.15	-0.58	0.53	-1.17	-3.67	0.31	-0.53
Max. temp. (°F)													
1971-2000 normal	60.0	59.1	59.7	60.1	62.3	65.1	65.5	66.1	64.8	64.4	63.2	61.2	62.6
2010 means	65.68	60.57	51.68	57.33	59.03	66.47	63.39	64.13	65.07	59.16	56.9	57.97	60.61
Difference	5.68	1.47	-8.02	-2.77	-3.27	1.37	-2.11	-1.97	0.27	-5.24	-6.30	-3.23	-1.99
Oheo (1998-2009)	COOP			Park: HALE					Elev. 120 ft. (36.6 m)				
Precipitation (in)													
1971-2000 normal	7.79	5.67	8.49	7.01	5.05	5.43	6.96	6.83	6.41	7.84	8.75	7.11	83.34
2010 totals	0.86	1.34	0.00	5.83	3.71	4.44	5.55	5.24	3.51	7.03	11.80	6.40	55.71
% normal	11%	24%	0%	83%	73%	82%	80%	77%	55%	90%	135%	90%	67%
Min. temp. (°F)													
Long-term mean	65.9	63.1	66.9	66.8	69.1	69.8	70.5	71.2	71.1	70.8	69.8	67.4	68.5
2010 means	56.9	50.1	NA	68.1	70.2	68.5	65.7	69	66.3	69.7	68	62.5	65 ¹
Difference	-9	-13	NA	1.3	1.1	-1.3	-4.8	-2.2	-4.8	-1.1	-1.8	-4.9	NA
Max. temp. (°F)													
Long-term mean	77	73.5	77.8	77.4	80.1	80.2	80.7	81.4	81.6	81.5	80.6	78.2	79.2
2010 means	68.9	65.3	NA	78.2	80.4	78.3	76.1	79.2	77.2	79.5	78.1	73.2	75.9 ¹
Difference	-8.1	-8.2	NA	0.8	0.3	-1.9	-4.6	-2.2	-4.4	-2	-2.5	-5	NA

¹ Average temperature of the 11 months where there was data collected.

Table 11. Comparison of precipitation and temperature data from 2010 with long-term records for stations at Haleakala National Park, Maui, Hawaii. Long-term means are based on the period of record indicated for each station, not including the last year (continued).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Kaupo Gap (1991-20109)	RAWS			Park: HALE				Elev. 4,030 ft. (1,228.3 m)					
Precipitation (in)													
1971-2000 normal	12.18	5.68	12.14	4.22	1.91	1.24	0.98	2.32	3.13	5.08	5.29	4.14	58.31
2010 totals	NA	NA	8.81	2.95	2.00	0.38	0.32	0.09	0.30	1.29	3.35	7.96	NA
% Normal	119%	122%	99%	37%	63%	108%	30%	305%	23%	125%	NA	NA	NA
Min. temp. (°F)													
Long-term mean	53.6	52.2	53.9	54.4	55.4	57.4	59.0	59.2	59.1	58.6	57.8	55.1	56.3
2010 means	NA	NA	52.7	53.3	54.3	55.0	54.9	55.9	55.8	56.7	55.5	54.6	56.3
Difference	NA	NA	-1.2	-1.1	-1.1	-2.4	-4.1	-3.3	-3.3	-1.9	-2.3	-0.5	NA
Max. temp. (°F)													
Long-term mean	67.5	67.2	68.0	69.5	71.4	73.6	75.9	76.4	75.2	74.0	71.9	68.8	71.6
2010 means	NA	NA	69.0	70.1	71.5	74.0	74.6	76.8	75.9	74.1	71.4	69.8	NA
Difference	NA	NA	1.0	0.6	0.1	0.4	-1.3	0.4	0.7	0.1	-0.5	1.0	NA
Ave. temp. (°F)													
Long-term mean	59.6	58.7	59.9	60.9	62.6	64.7	66.7	66.9	65.9	65.1	63.7	60.8	63.0
2010 means	NA	NA	59.8	60.6	61.9	64.0	64.3	65.3	64.8	64.0	61.8	60.9	NA
Difference	NA	NA	-0.1	-0.3	-0.7	-0.7	-2.4	-1.6	-1.1	-1.1	-1.9	0.1	NA

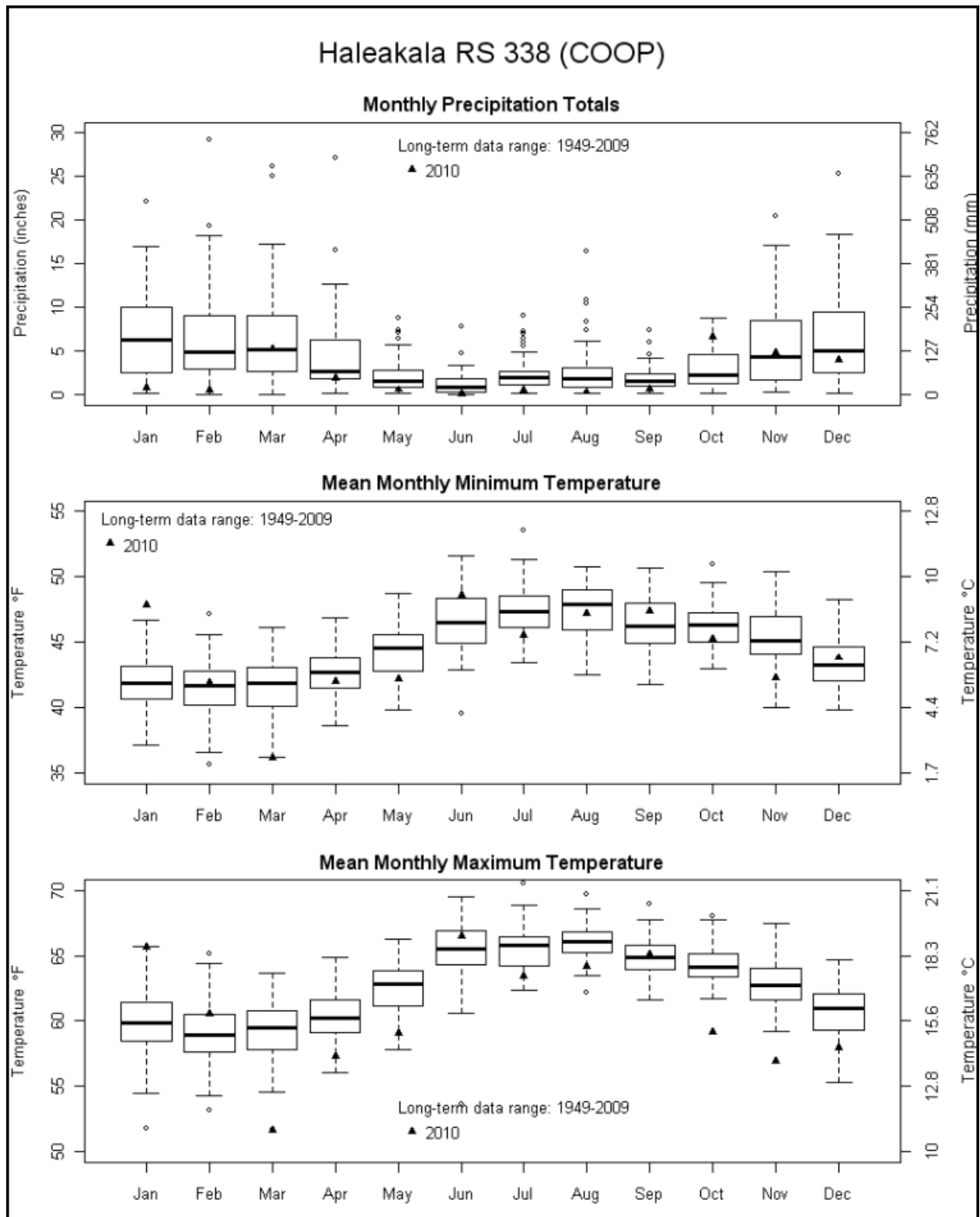


Figure 47. Boxplots of monthly precipitation and temperature data for Haleakala RS (COOP), Maui, Hawaii.

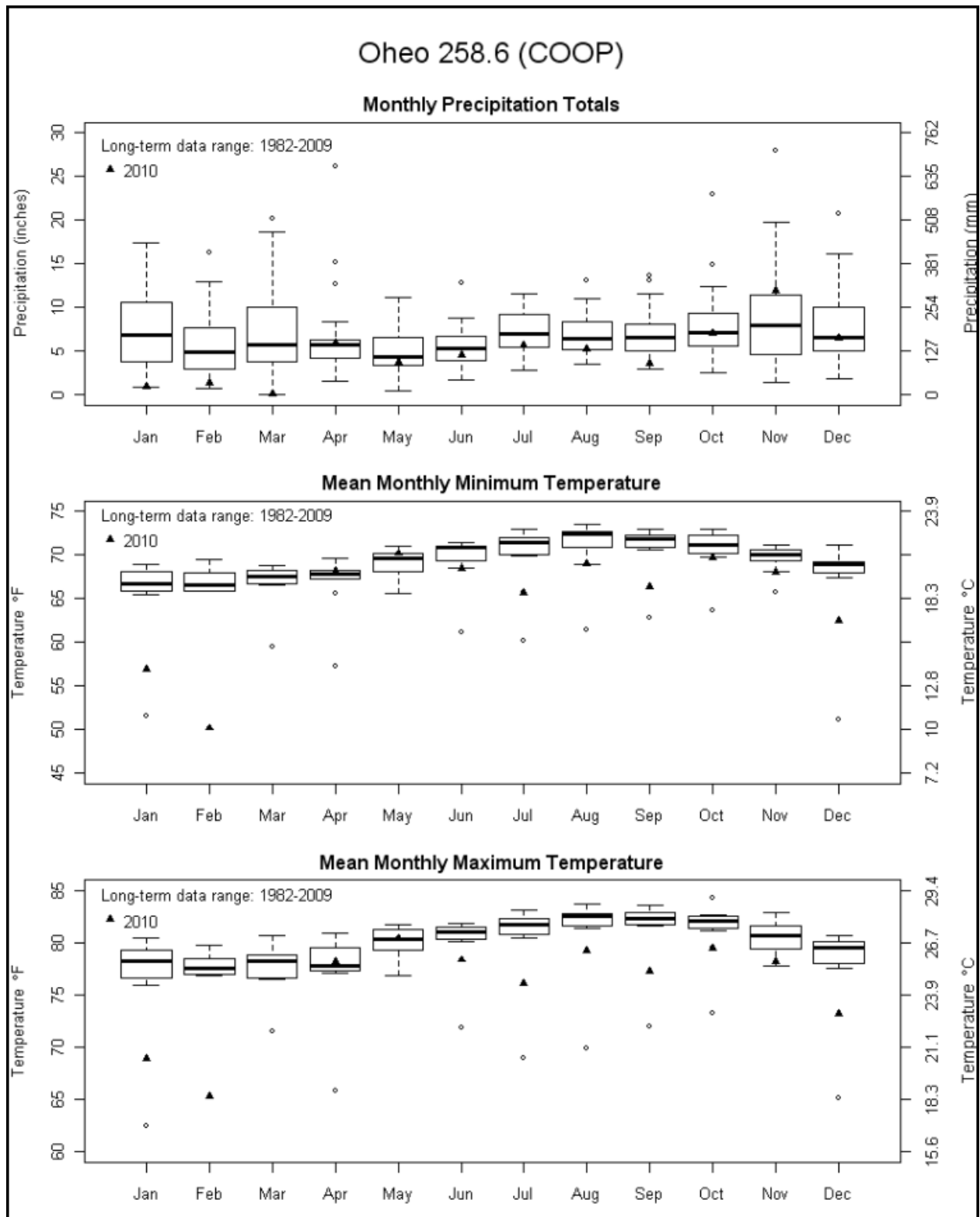


Figure 48. Boxplots of monthly precipitation and temperature data for Oheo 258.6 (COOP), Maui, Hawaii.

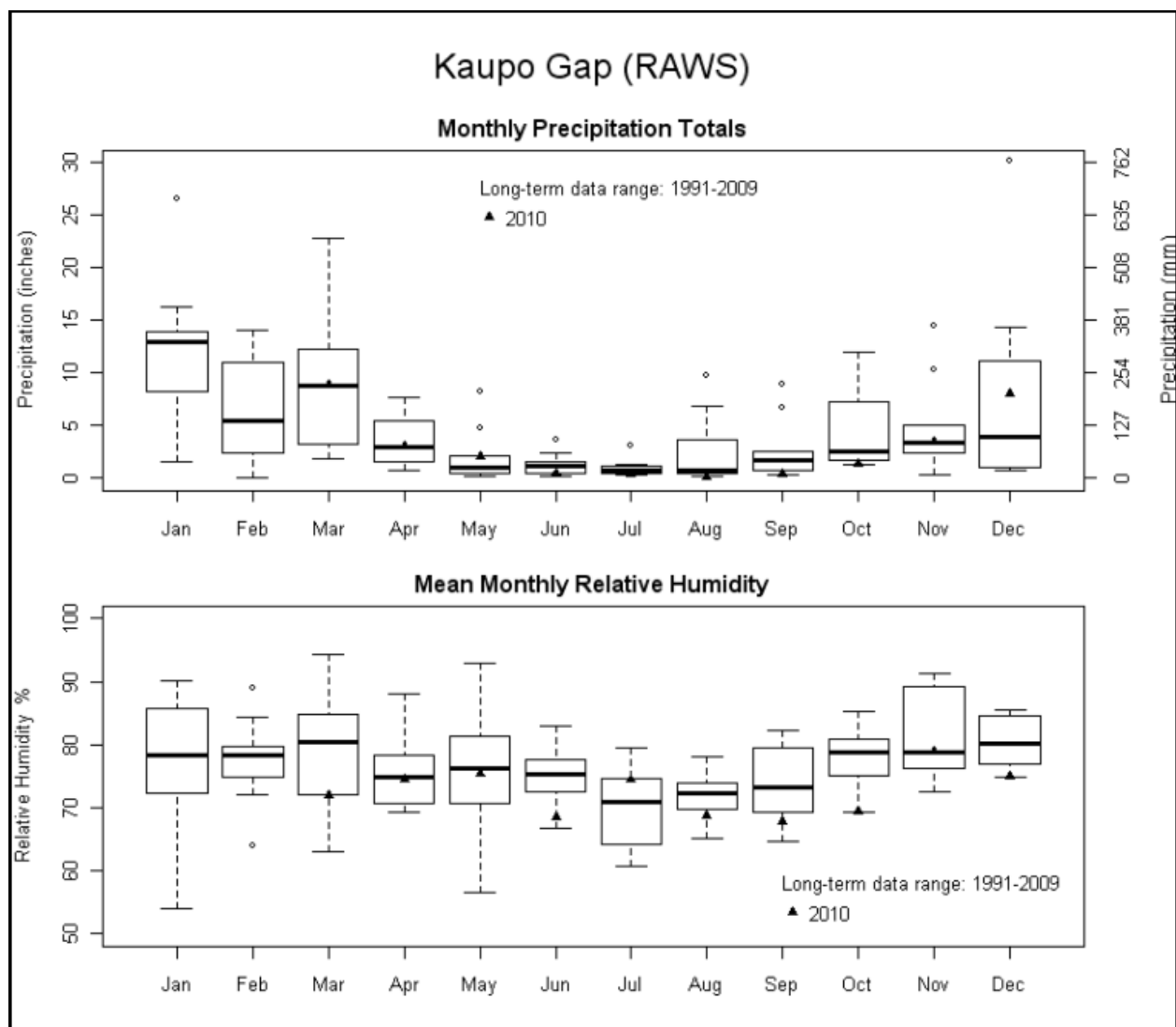


Figure 49. Boxplots of monthly precipitation and relative humidity data for Kaupo Gap (RAWS), Haleakala, Maui.

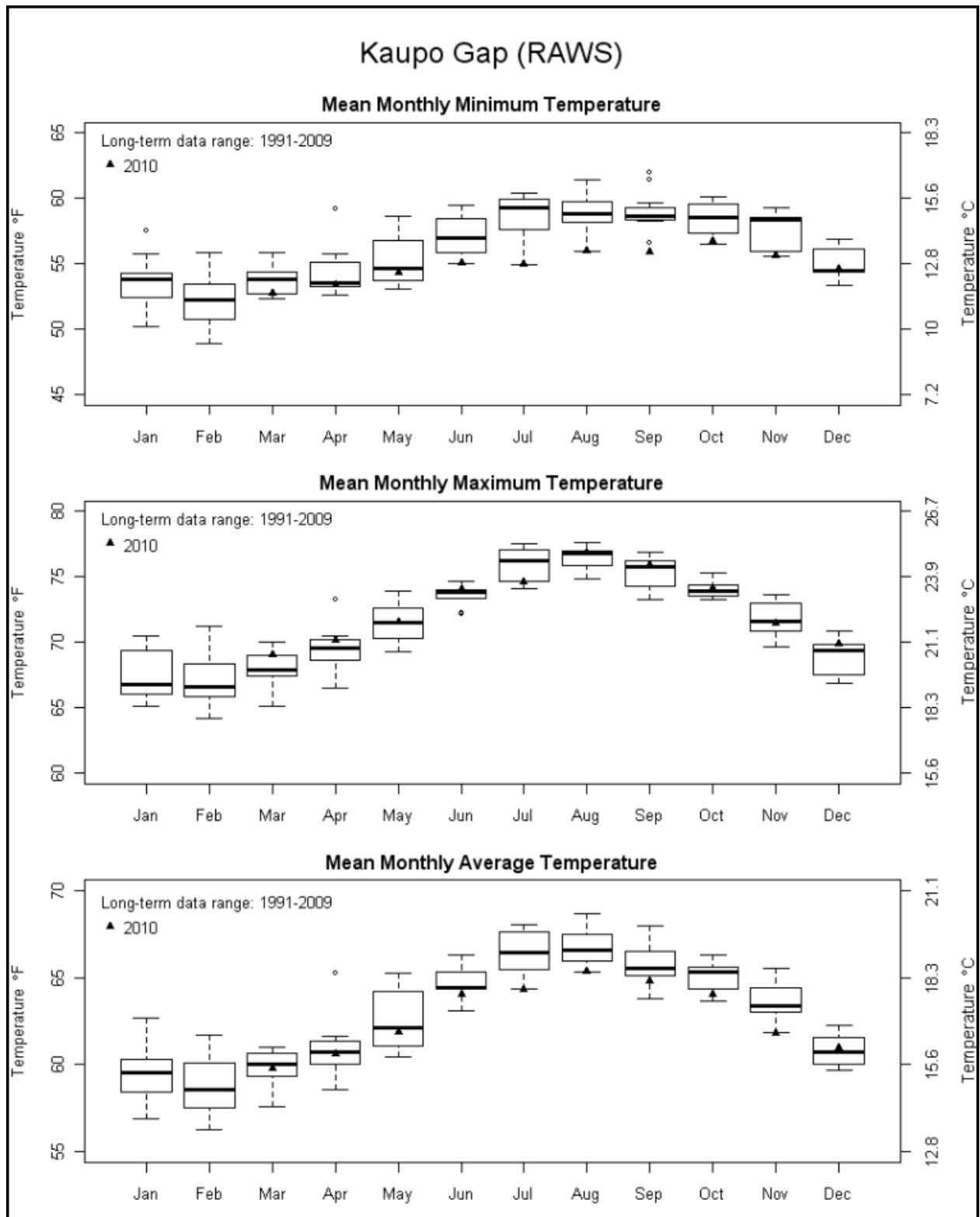


Figure 50. Boxplots of monthly temperature data for Kaupo Gap (RAWS), Haleakala, Maui, Hawaii.

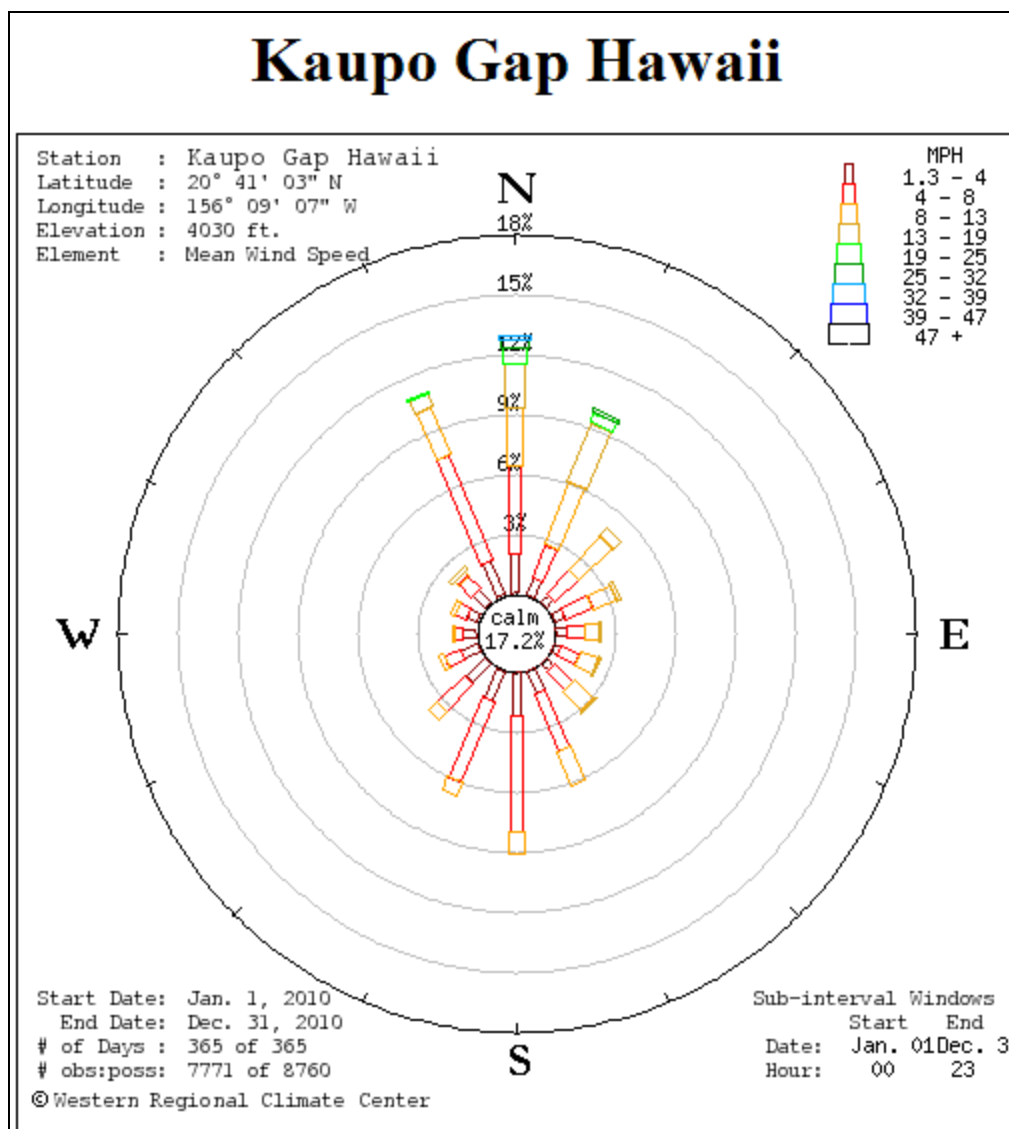


Figure 51. Wind Rose Graph of 2010 data for Kaupo Gap (RAWS), Haleakala, Maui, Hawaii.

Hawaii Drought Conditions

As part of a comprehensive drought monitoring effort between the USDA, NOAA, and the National Drought Mitigation Center, the Drought Monitor publishes weekly updates of drought conditions in graphics form for all 50 states. The Hawaii Drought Monitor, also makes these graphics available in addition to state-specific news on drought impacts and available assistance programs. Hawaii drought conditions are illustrated for bi-monthly time points throughout 2010 (Figures 52-55). Locations of the national parks could not be overlaid since the graphics were created using the Drought Monitor archive tool, but can be referenced using the maps in Appendix C. The year started with extreme drought conditions in northwestern Hawaii in January, while conditions worsened through February and March to exceptional drought in northwest Hawaii and extreme drought on Molokai and the south coast of Maui. Conditions worsened through October, when rains came in November to finally lessen drought severity.

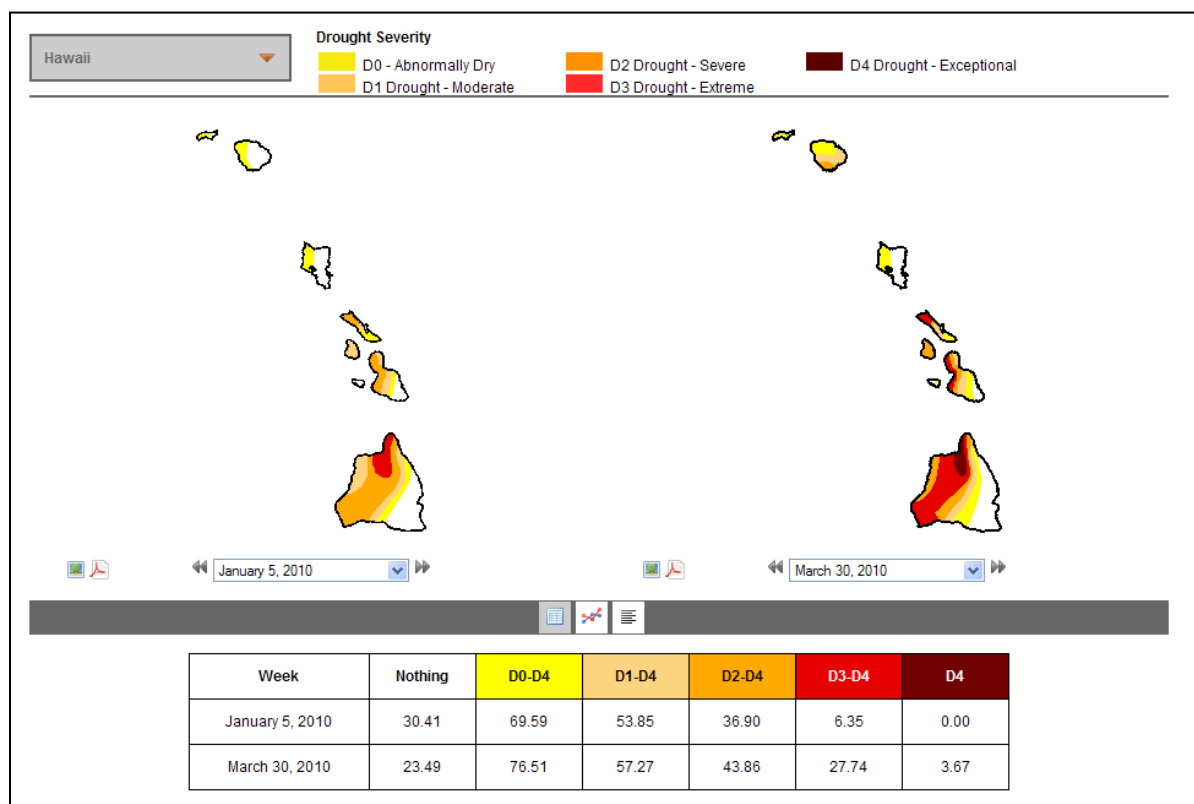


Figure 52. Drought conditions in the State of Hawaii in early January and early March 2010. Figure reproduced from the Hawaii Drought Monitor (2011).

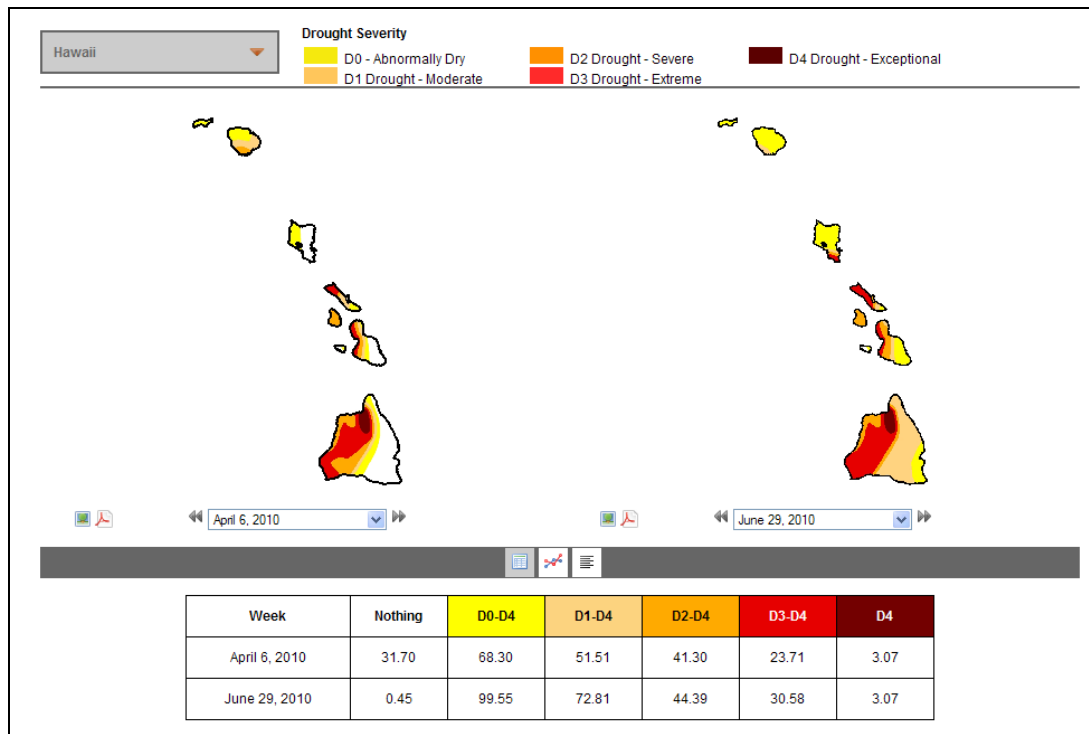


Figure 53. Drought conditions in the State of Hawaii in early April and late July 2010. Figure reproduced from the Hawaii Drought Monitor (2011).

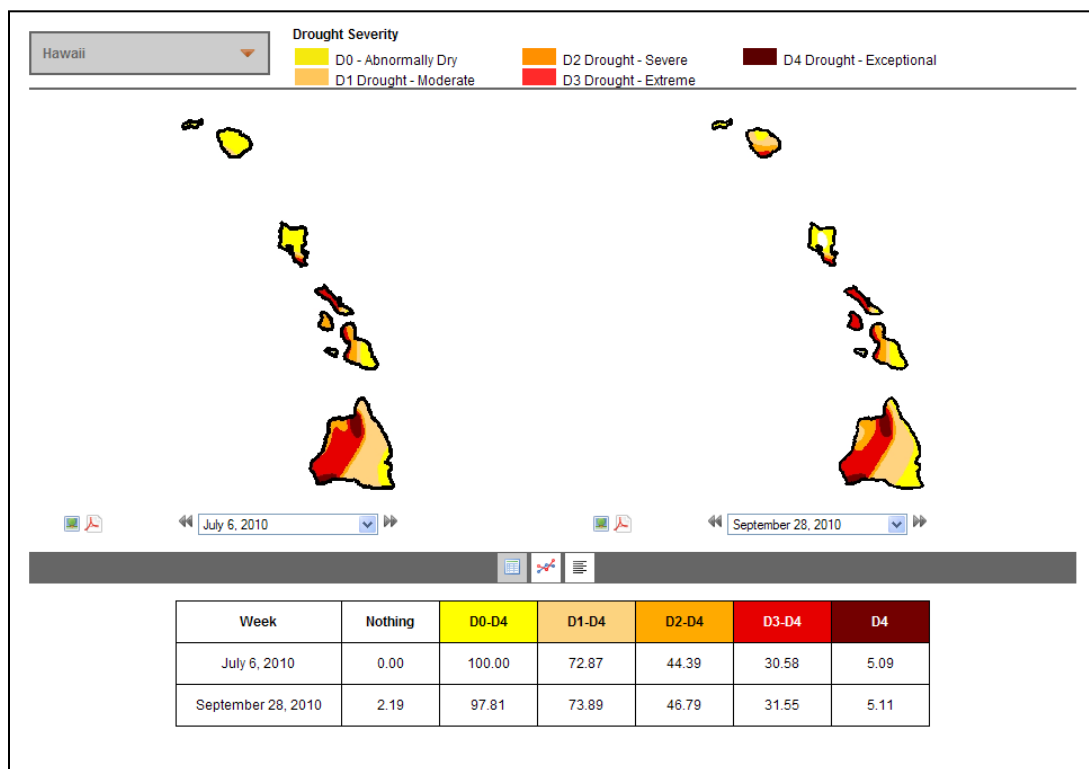


Figure 54. Drought conditions in the State of Hawaii in early July and late September 2010. Figure reproduced from Hawaii Drought Monitor (2011).

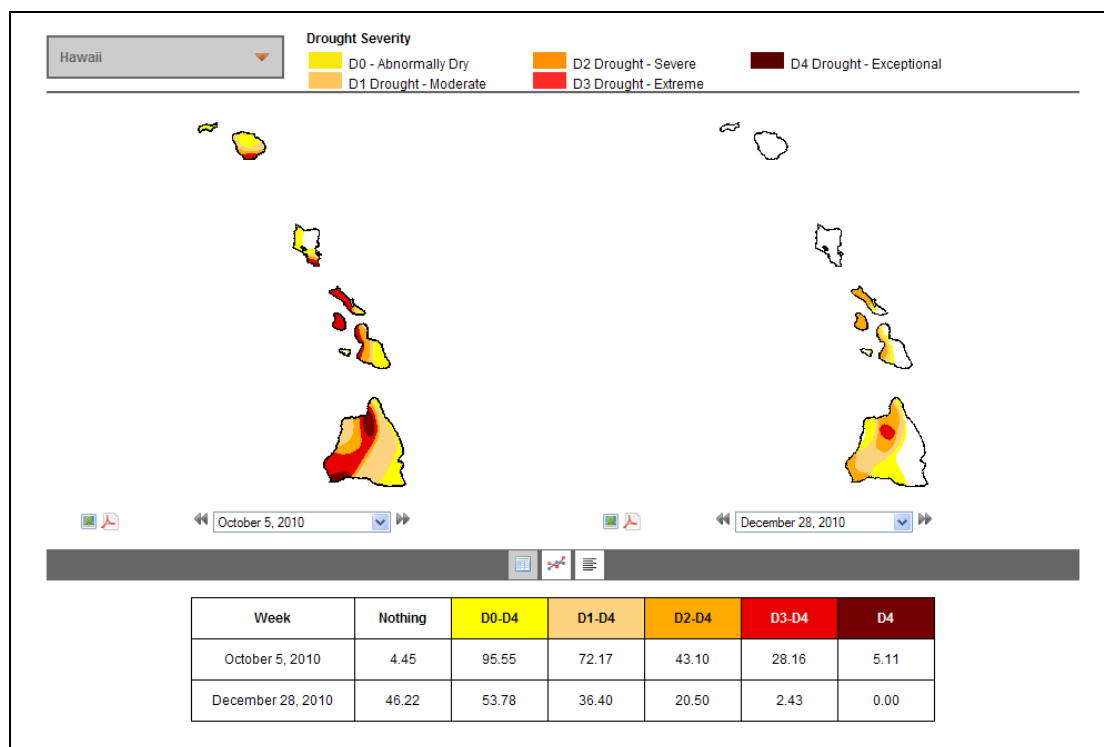


Figure 55. Drought conditions in the State of Hawaii in early October and late December 2010. Figure reproduced from Hawaii Drought Monitor (2011).

Discussion

The October through April “wet” season in Hawaii for 2010 was the driest in 30 years. The northern area of Kohala on the Big Island was classified in the exceptional drought category; the first time any area in the state has been classified as such (Figures 52-54).

Rainfall and temperature data for the islands in the PACN show the strong El Niño conditions maturing until April 2010 with a transition to La Niña conditions as spring progressed. A La Niña watch was initiated on June 24, 2010, expecting conditions to change in the weeks following, which it did. This change was anticipated by following the rainfall activities on seven long term weather reporting stations across the state (Figure 57).

The Pacific Basin progressed to moderate to strong La Niña conditions from August through the end of the year (Figure 56). December’s standardized Tahiti-minus-Darwin sea-level pressure (The NOAA version of the Southern Oscillation Index -- SOI) value of +3.2 is the highest monthly value of the SOI in the CPC archive, which goes back to 1951 (PEAC 2011).

In Hawaii, late season rain fell at nearly normal monthly rates and abated drought conditions in most areas. With the beginning of the wet season in October 2010, pastures and general vegetation conditions greatly improved. A record daily maximum rainfall total of 5.41 inches fell at the Honolulu International Airport on Sunday, December 19th, breaking the old record of 5.28 inches set in 1955. This one day event doubled December’s monthly rainfall total to 11.73 inches, set the monthly percent of normal precipitation to 412%, and pushed the annual total much closer to normal (PEAC 2011).

The number of tropical cyclones in the North Pacific Basin during 2010 was far fewer than has ever been recorded, making 2010 a very remarkable year.

For Guam, Saipan and other islands in the west Pacific precipitation patterns during La Niña are less likely to follow a clear pattern compared to other areas of the Pacific, though in the majority of La Niña events winter and spring are wetter than normal (Ropelewski and Halpert 1989). For our parks, Figure 57 shows some of the anomalies for AMME (Saipan) and WAPA (Guam). Even the Hilo anomalies are of interest to HAVO on the east side of the Big Island of Hawaii.

The boxplots place the 2010 data in a useful context within the long-term station record and provide information about the range of variability as well as extremes for any given station. However, the data presented graphically and in tabular form need to be interpreted carefully given that many of the comparisons are made with long-term means (as opposed to 1971-2000 long term averages) and considering that the record length varies significantly between stations.

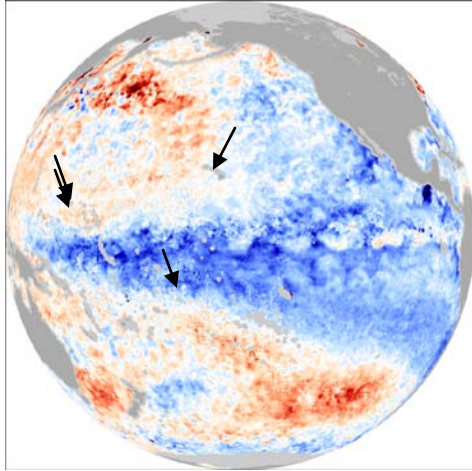


Figure 56. Sea surface temperatures (SST) during La Niña, December 2010, (blues are cooler; reds are warmer) (NASA Science 2005). Arrows point to Guam and Saipan (left), Samoa (bottom), and Hawaii (right).

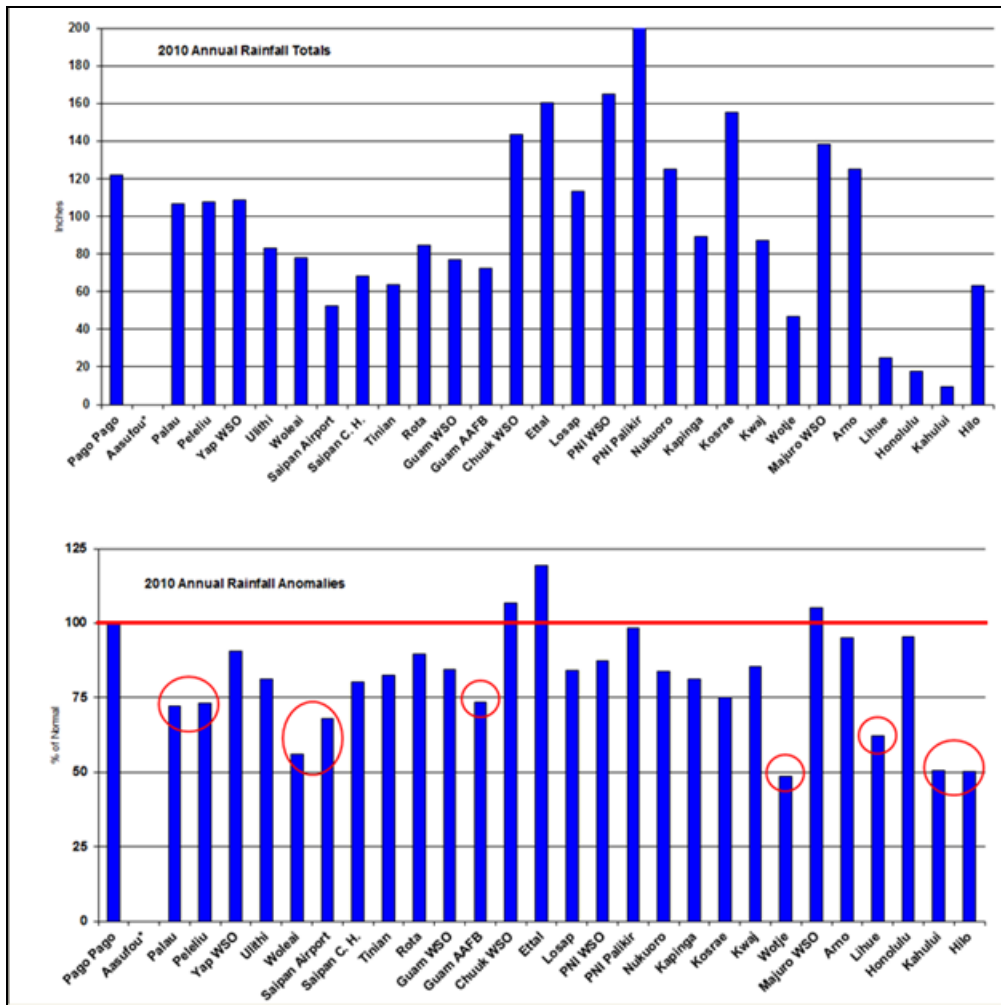


Figure 57. 2010 Rainfall totals across the western Pacific (PEAC 2011). Red circles are weather stations near PACN parks.

Literature Cited

- Alexander, M. A., I. Blade, M. Newman, J. R. Lanzante, N-C. Lau, J. D. Scott. 2002. The atmospheric bridge: the influence of ENSO teleconnections on air-sea interaction over the global oceans. *Journal of Climate* 15(16):2205-2231.
- Alexander, M., A. C. Penland. 1996. Variability in a mixed layer ocean model driven by stochastic atmospheric forcing. *Journal of Climate* 9(10):2424–2442.
- Angove, M. and R. Falvey. 2011. Annual Tropical Cyclone Report 2010, U.S. Naval MaritimeForecast Center, Joint Typhoon Warning Center, Pearl Harbor, Hawaii.
- Chu, P.-S. 2004. ENSO and tropical cyclone activity. Pages 297-332 *in* R. J. Murname and K.-B. Liu, editors. *Hurricanes and typhoons: past, present and future*. Columbia University Press, New York, New York.
- Chu, P.-S., and H. Chen. 2005. Interannual and interdecadal rainfall variations in the Hawaiian Islands. *Journal of Climate* 18:4796-4813.
- Chu, P.-S., and J. Wang. 1997. Tropical cyclone occurrences in the vicinity of Hawaii: are the differences between El Niño and non-El Niño years significant? *Journal of Climate* 10:2683-2689.
- CPC. 2011. El Niño/Southern Oscillation (ENSO) Diagnostic Discussion. National Weather Service, Climate Prediction Center. Available at http://www.cpc.noaa.gov/products/analysis_monitoring/enso_advisory/ (accessed on 5 July 2010).
- DAR. 2005. Wikipedia. La Niña. Available at <http://en.wikipedia.org/wiki/File:LaNina.png> (accessed 14 September 2011).
- Davey, C. A., K. T. Redmond, and D. B. Simeral. 2006. Weather and Climate Inventory, National Park Service, Pacific Island Network. Natural Resource Technical Report NPS/PACN/NRTR—2006/003. National Park Service, Fort Collins, Colorado.
- Deser, C., M. A. Alexander, M. S. Timlin. 2003. Understanding the persistence of sea surface temperature anomalies in mid-latitudes. *Journal of Climate* 16(12):57–72.
- Edkins. 2010. Wikipedia:Wikipedia Project Tropical cyclones/tracks. Available at http://en.wikipedia.org/wiki/File:2010_Pacific_typhoon_season_summary.png#filehistory (accessed 9 September 2010).
- Gentleman, Robert and Ross Ihaka, 1997. R Statistics, Univ of Auckland, New Zealand, <http://www.r-project.org> (accessed 4 October 2010).
- Guttman, N. B. 1989. Statistical Descriptors of Climate. *Bulletin of the American Meteorological Society* 70:602-607.

- Halpert, M. S., and C. F. Ropelewski. 1992. Surface Temperature Patterns Associated with the Southern Oscillation. *Journal of Climate* 5:577-593.
- Hare, S. R., 1996. Low frequency climate variability and salmon production. Ph.D. dissertation, School of Fisheries, University of Washington, Seattle, Washington.
- Hawaii Drought Monitor. 2010. Commission on Water Resources Management, Department of Land and Natural Resources, Honolulu, Hawaii. Available at <http://www.drought.unl.edu/dm/archive.html> (accessed 4 April 2011).
- Hogan, C. M. 2010. Abiotic factor. *Encyclopedia of Earth*. eds Emily Monosson and C. Cleveland. National Council for Science and the Environment. Available at http://www.eoearth.org/article/Abiotic_factor?topic=49461 (accessed 22 September 2011).
- Jin, F. 1997. "A Theory of Interdecadal Climate Variability of the North Pacific Ocean–Atmosphere System". *Journal of Climate* 10(8): 1821–1835.
- JISAO. 2000. Pacific Decadal Oscillation. Available at <http://jisao.washington.edu/pdo/> (accessed 7 September 2011).
- Lander, M. A. 2004. Rainfall climatology for Saipan: distribution, return-periods, El Niño, tropical cyclones, and long-term variations. Water and Environmental Research Institute of the Western Pacific, University of Guam, Agana, Guam.
- Lander, M. A., and C. P. Guard. 2003. Creation of a 50-year rainfall database, annual rainfall climatology, and annual rainfall distribution map for Guam. Water and Environmental Research Institute of the Western Pacific, University of Guam, Agana, Guam.
- Madden, R. A., and P. R. Julian. 1994: Observations of the 40-50 day tropical oscillation: a review. *Mon. Weather. Rev.*, 122, 814-837.
- NASA Science. 2005. A curious Pacific wave. Available at http://science.nasa.gov/science-news/science-at-nasa/2002/05mar_kelvinwave/ (accessed 31 August 2011).
- NASA. 2007. La Niña. Available at Sea surface temperature [http://en.wikipedia.org/wiki/File:Sea_Surface_Temperature - November 2007.jpg](http://en.wikipedia.org/wiki/File:Sea_Surface_Temperature_-_November_2007.jpg) (accessed 9 September 2011).
- NASA. 2006. Typhoon Saomai. Available at http://earthobservatory.nasa.gov/NaturalHazards/natural_hazards_v2.php3?img_id=13754 (accessed on 6 September 2011).
- NASA. 2008. NASA image by Jesse Allen, AMSR-E data processed and provided by Chelle Gentemann and Frank Wentz, Remote Sensing Systems. Available at <http://earthobservatory.nasa.gov/IOTD/view.php?id=8703> (accessed 6 September 2011).

- NASA 2009. Earth Global Circulation. Available at http://en.wikipedia.org/wiki/File:Earth_Global_Circulation.jpg#file (accessed 12 September 2011).
- NASA 2010a. Super Typhoon Megi. Available at <http://rapidfire.sci.gsfc.nasa.gov/gallery/?2010290-1017/Megi.A2010290.0500.250m.jpg> (accessed 19 September 2011).
- NASA 2010b. Tropical Cyclone Rene. Available at http://eoimages.gsfc.nasa.gov/images/imagerecords/42000/42662/rene_tmo_2010043_lrg.jpg (accessed on 19 September 2011).
- Nilfanion, 2006. Wikipedia:WikiProject Tropical cyclones/Tracks The background image is from NASA. Available at http://en.wikipedia.org/wiki/File:Omeka_2010_track.png#file (accessed 9 September 2011).
- NOAA 2001. Geophysical Fluid Dynamics Laboratory. Walker Circulation. Available at http://www.windows2universe.org/earth/Atmosphere/walker_circulation.html (accessed 9 September 2011)
- NOAA. 2002. Climatology of the United States No. 81. Monthly station normals of temperature, precipitation, and heating and cooling degree days 1971-2000. National Oceanic and Atmospheric Administration, National Environmental Satellite, Data, and Information Service, National Climatic Data Center, Asheville, North Carolina.
- NOAA. 2006. The Madden-Julian oscillation Available at: http://en.wikipedia.org/wiki/Madden%E2%80%93Julian_oscillation (accessed on 31 August 2011).
- NOAA. 2006. Another Kelvin Wave strengthens El Niño: Available at <http://earthobservatory.nasa.gov/IOTD/view.php?id=7192> (accessed 7 September 2011).
- NOAA. 2007. GFDL Climate Monitoring Research Highlights. Available at http://www.gfdl.noaa.gov/cms-filesystem-action/user_files/kd/pdf/gfdlhighlight_vol1n3.pdf (accessed 6 September 2011).
- NOAA. 2008. National Weather Service, Jetstream: Cross section of the two main jet streams, by latitude. Available at <http://en.wikipedia.org/wiki/File:Jetcrosssection.jpg> (accessed 6 September 2011).
- NOAA- National Weather Service. 2010. Tropical cyclone structure. Available at: http://www.srh.noaa.gov/jetstream/tropics/tc_structure.htm (accessed 6 September 2011)
- NOAA 2010. ENSO Technical discussion. Available at <http://www.ncdc.noaa.gov/teleconnections/enso/enso-tech.php> (accessed 12 September 2011).

- NOAA. 2011. El Niño. Available at <http://www.ncdc.noaa.gov/oa/pub/data/special/maxtemps.pdf> (accessed on 6 September 2011).
- NOAA-NASA GOES project, 2011. Satellite photography. Available at <http://earthobservatory.nasa.gov/IOTD/view.php?id=703> (accessed on 5 September 2011).
- PEAC 1997. ENSO and sea level. Available at <http://www.soest.hawaii.edu/MET/Enso/peu/update.dir/2ndQtr97-UHSLC.html> (accessed 9 September 2011).
- PEAC 2009. Pacific ENSO update, Vol 15. Available at http://www.prh.noaa.gov/peac/peu/2009_4th/current_conditions.php. (accessed on 19 September 2011)
- PEAC 2010. Pacific ENSO update, Vol. 16. Available at http://www.prh.noaa.gov/peac/peu/2010_4th/current_conditions.php (accessed on 19 September 2011).
- PEAC. 2011. Pacific ENSO Update, Vol. 17. Bulletin of the Pacific El Niño -Southern Oscillation (ENSO) Applications Climate Center, National Weather Service, Weather Forecast Office, Honolulu, Hawaii. Available from: http://www.prh.noaa.gov/peac/peu/2010_3rd/current_conditions.php (accessed 22 July 2011).
- PEAC-NOAA. 2011. Sea Level. Available at http://www.prh.noaa.gov/peac/peu/2011_3rd/sea_level.php (accessed 7 September 2011).
- Ropelewski, C. F., and M. S. Halpert. 1987. Global and regional scale precipitation patterns associated with the El Niño/Southern Oscillation. *Monthly Weather Review* 115:1606-1626.
- Saravanan, R. J. C. McWilliams. (1998). Advective Ocean–Atmosphere Interaction: An Analytical Stochastic Model with Implications for Decadal Variability. *Journal of Climate* 11 (2):165–188.
- Schlappa K., P-S. Chu, Y. Ruan, and K. Kozar. 2011. Weather/climate monitoring protocol – Pacific Island Network: Version 1.0. Natural Resource Report NPS/PACN/NRR—2011/435. National Park Service, Fort Collins, Colorado.
- Tukey, J. W. 1977. *Exploratory data analysis*. Addison-Wesley, Reading, Massachusetts.
- Weier, J. 2003. A delicate balance. Signs of change in the tropics. Available at : <http://earthobservatory.nasa.gov/Features/DelicateBalance/printall.php> (accessed 31 August 2011). Windrim, D. 2004. Hadley cell cross-section. The Hadley cell is one of three atmospheric circulation cells which transport heat poleward and drive Earth's

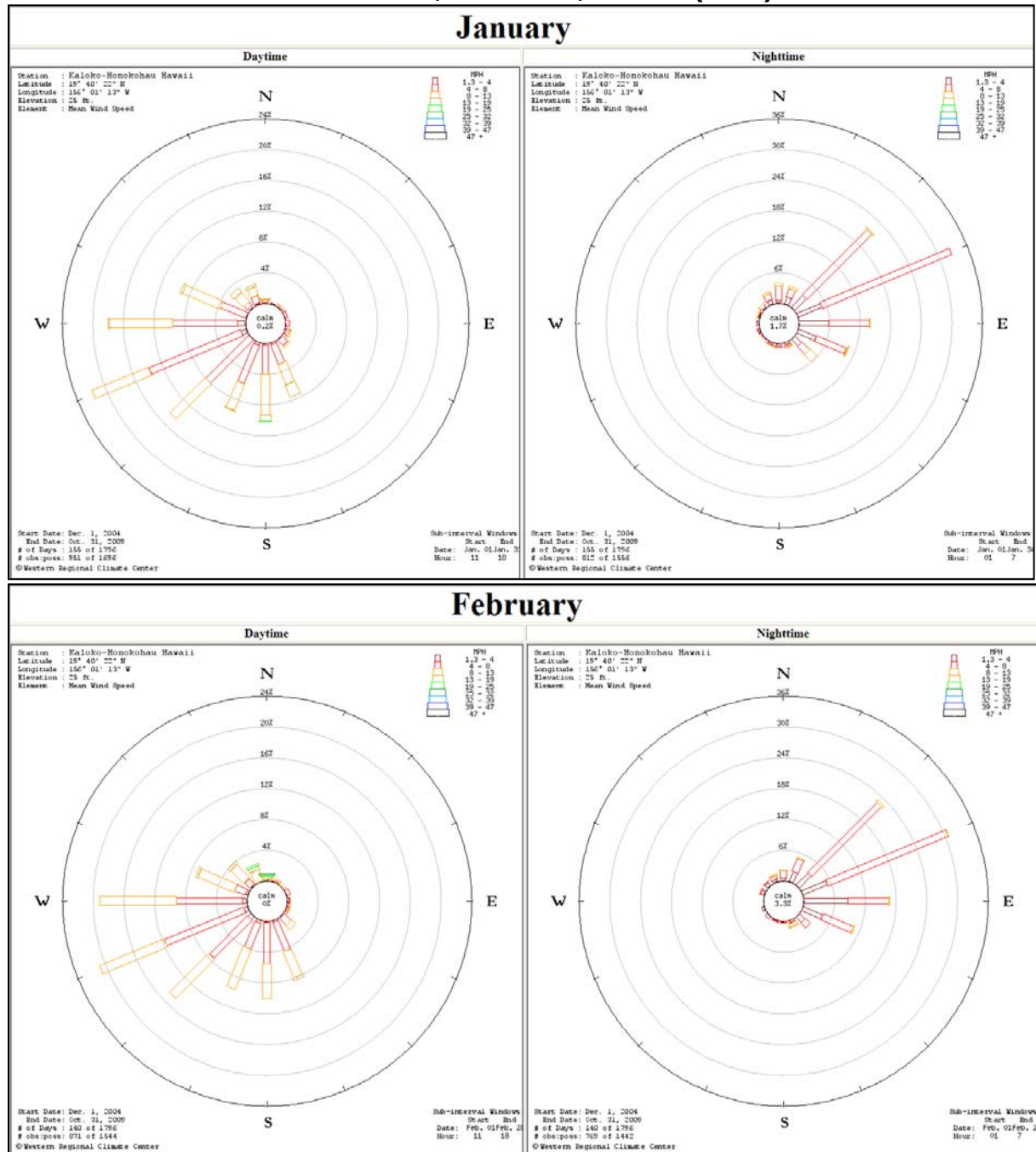
weather. Created with Photoshop. <http://en.wikipedia.org/wiki/File:HadleyCross-sec.jpg> (accessed August 30, 2011).

Xinhua. 2010. "Typhoon Megi Causes 2.8 Bln Yuan in Economic Losses in E. China". CRI English. <http://english.cri.cn/6909/2010/10/25/2681s601011.htm>. Retrieved October 25, 2010 from Wikipedia (accessed 6 September, 2011).

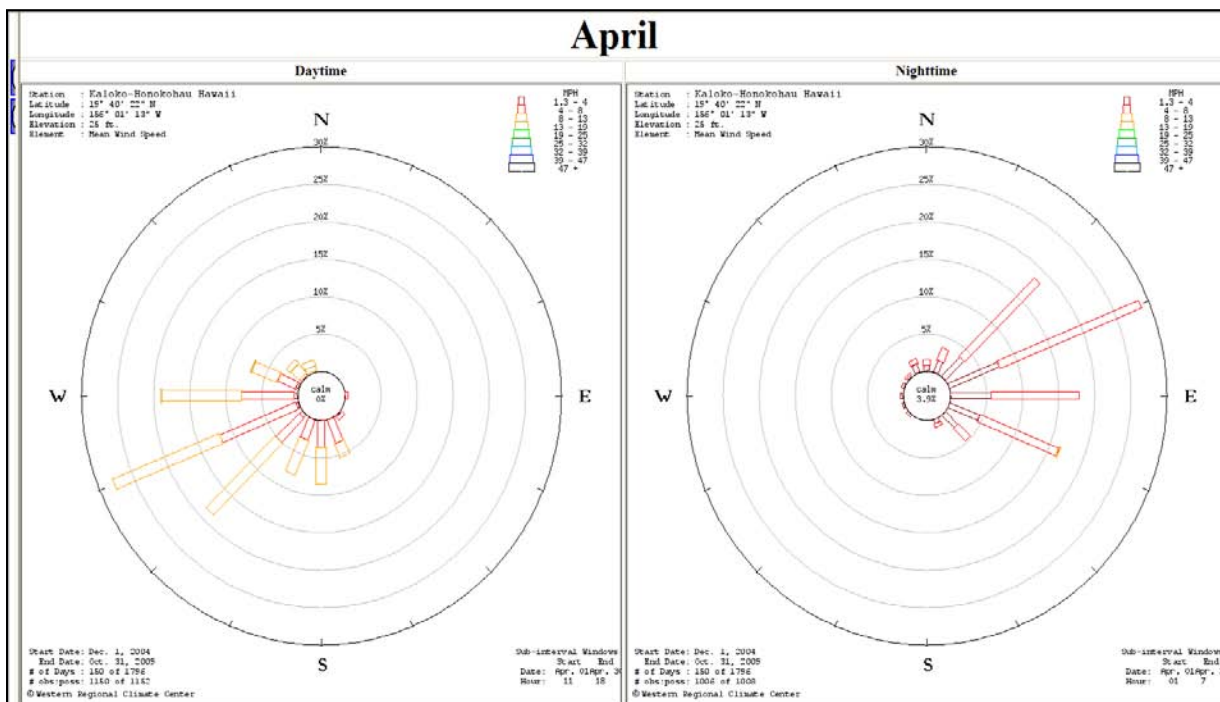
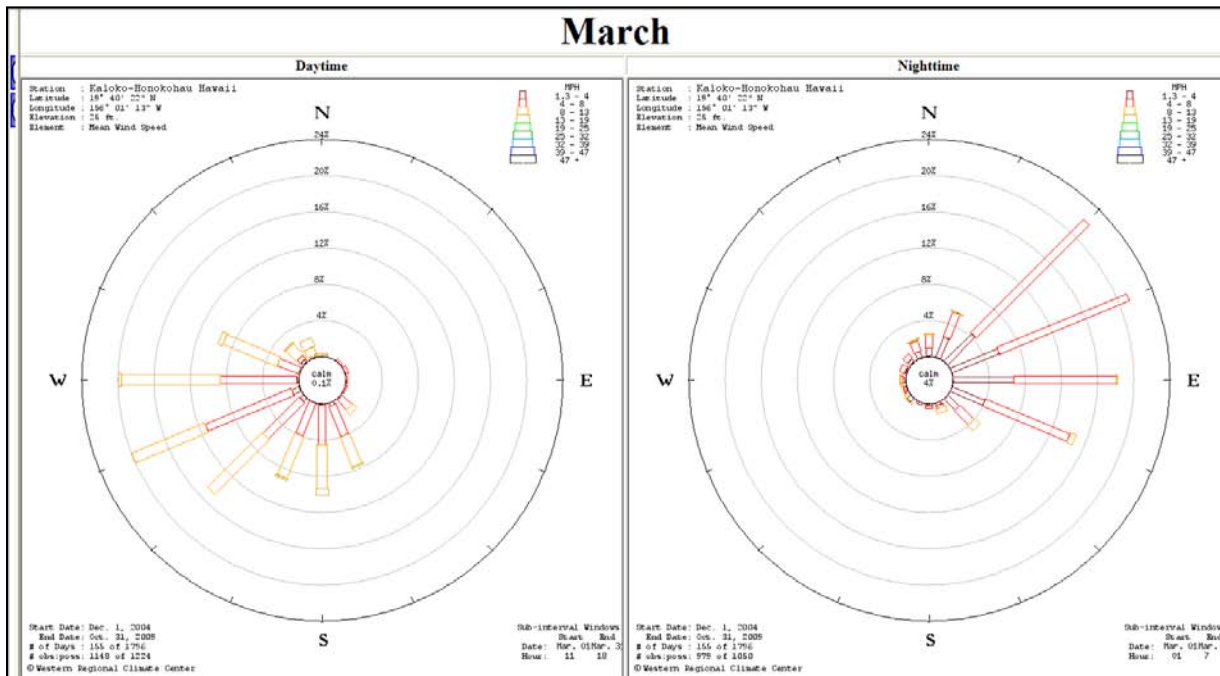
Appendix A: Examples of wind rose graphs for day and night.

These graphs illustrate the phenomenon of the wind direction temporal switch due to land temperature differences during the day and night.

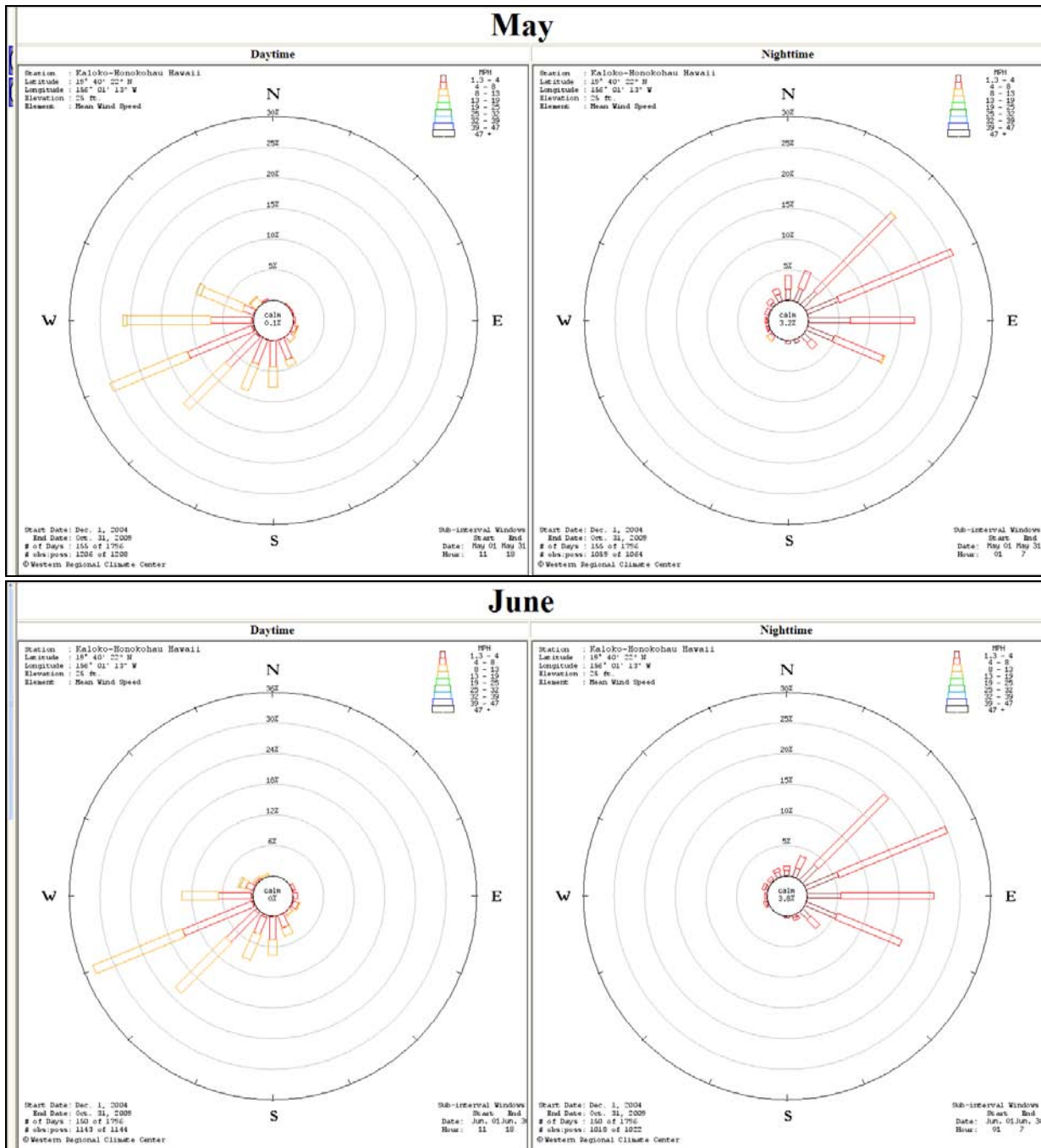
KAHO Kaloko-Honokohau RAWS, Jan – Dec, el. 25 ft (7.6m)



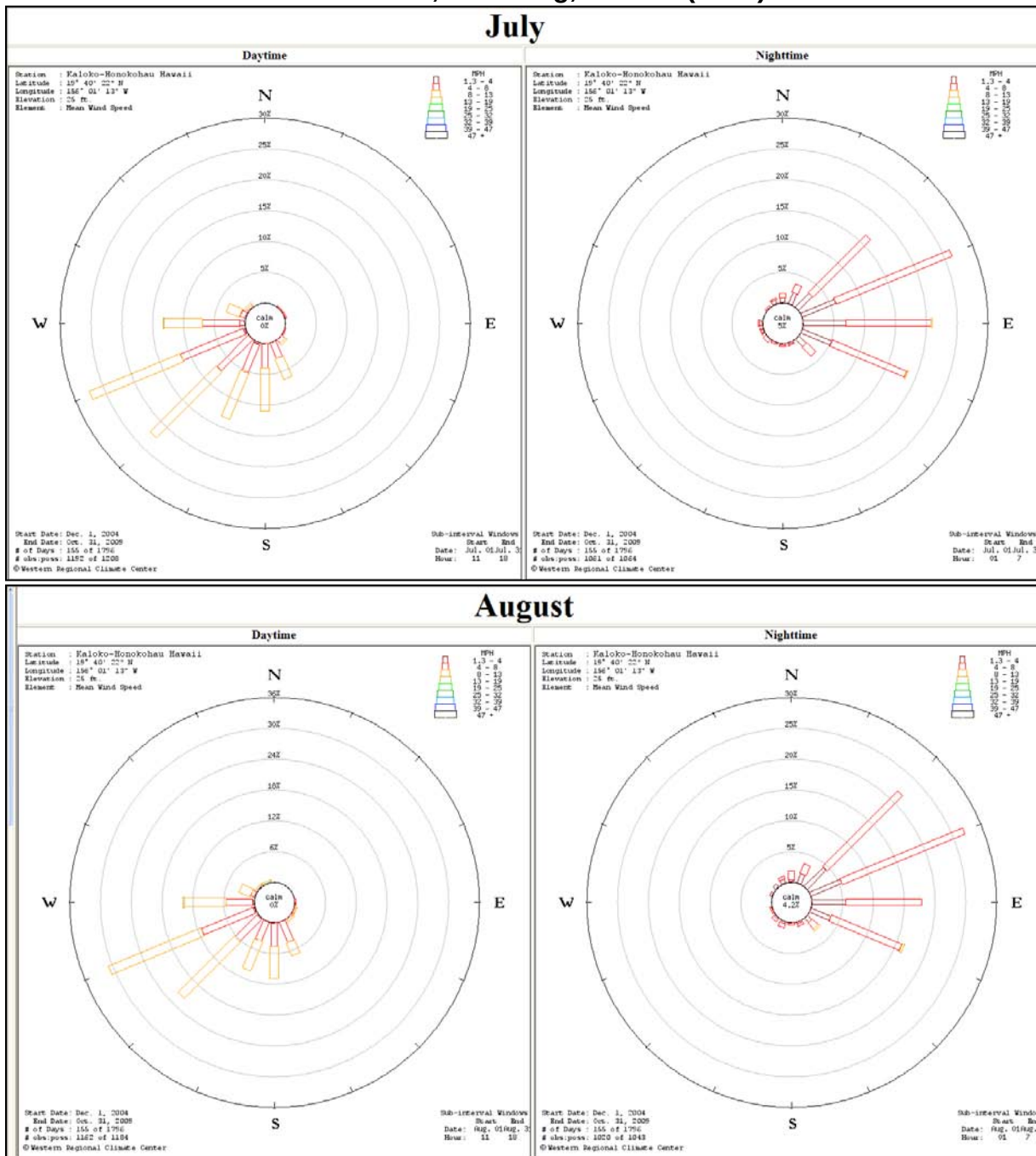
KAHO Kaloko-Honokohau RAWS, Mar – Apr, el. 25 ft (7.6m)



KAHO Kaloko-Honokohau RAWS, May – Jun, el. 25 ft (7.6m)

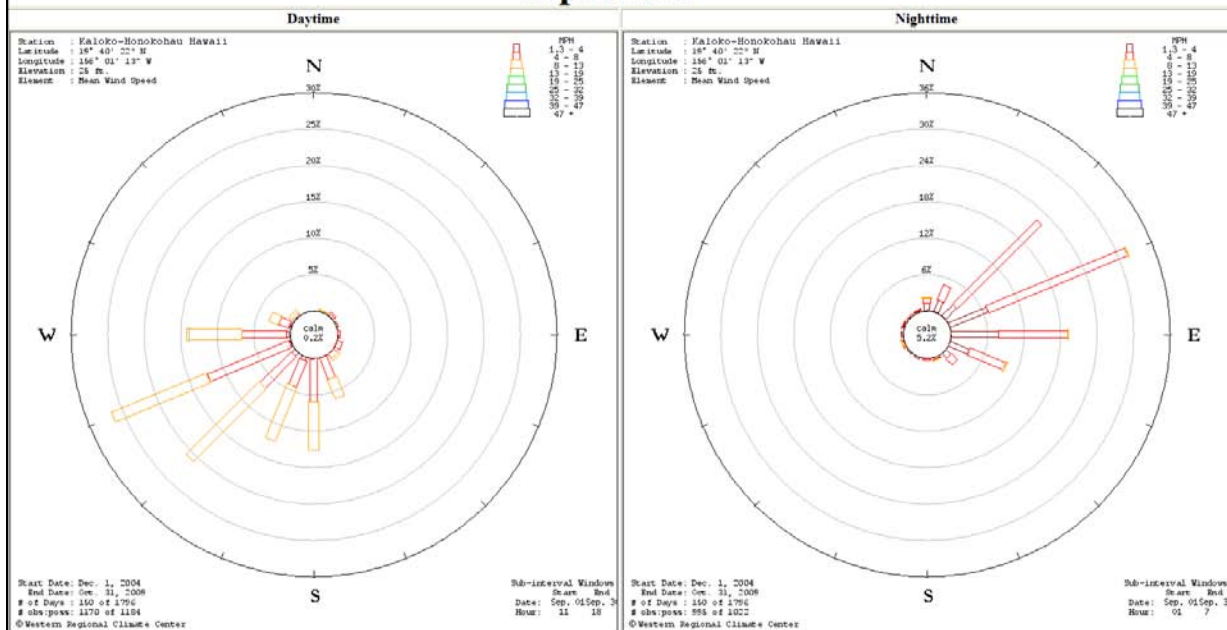


KAHO Kaloko-Honokohau RAWS, Jul – Aug, el. 25 ft (7.6m)

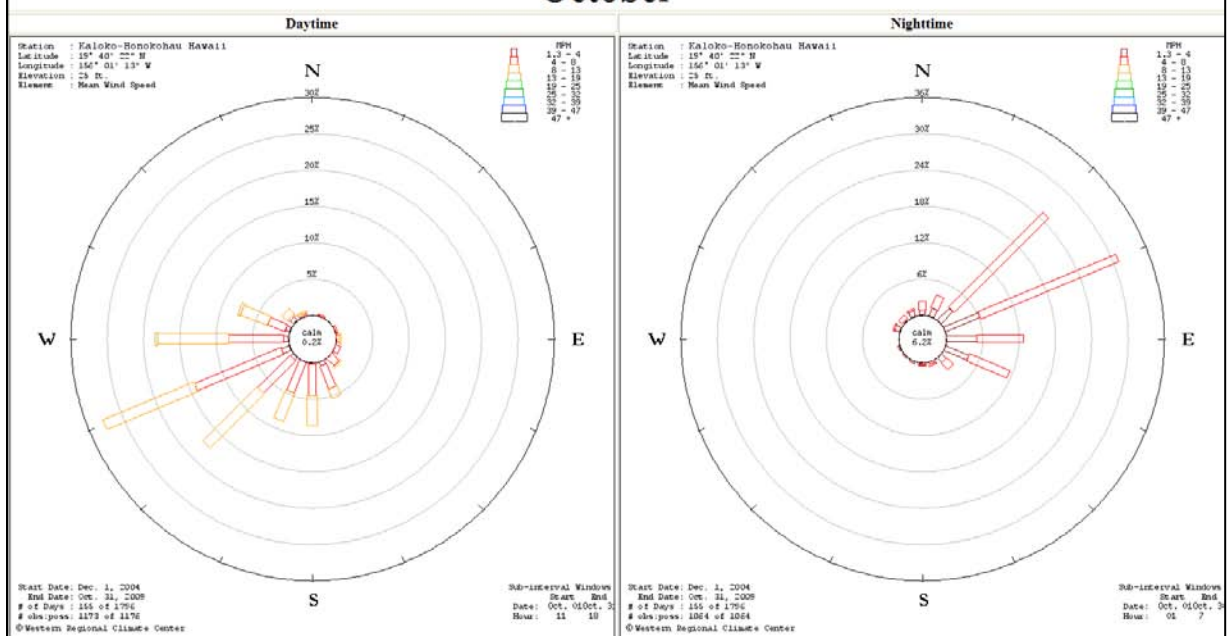


KAHO Kaloko-Honokohau RAWS, Sep – Oct, el. 25 ft (7.6m)

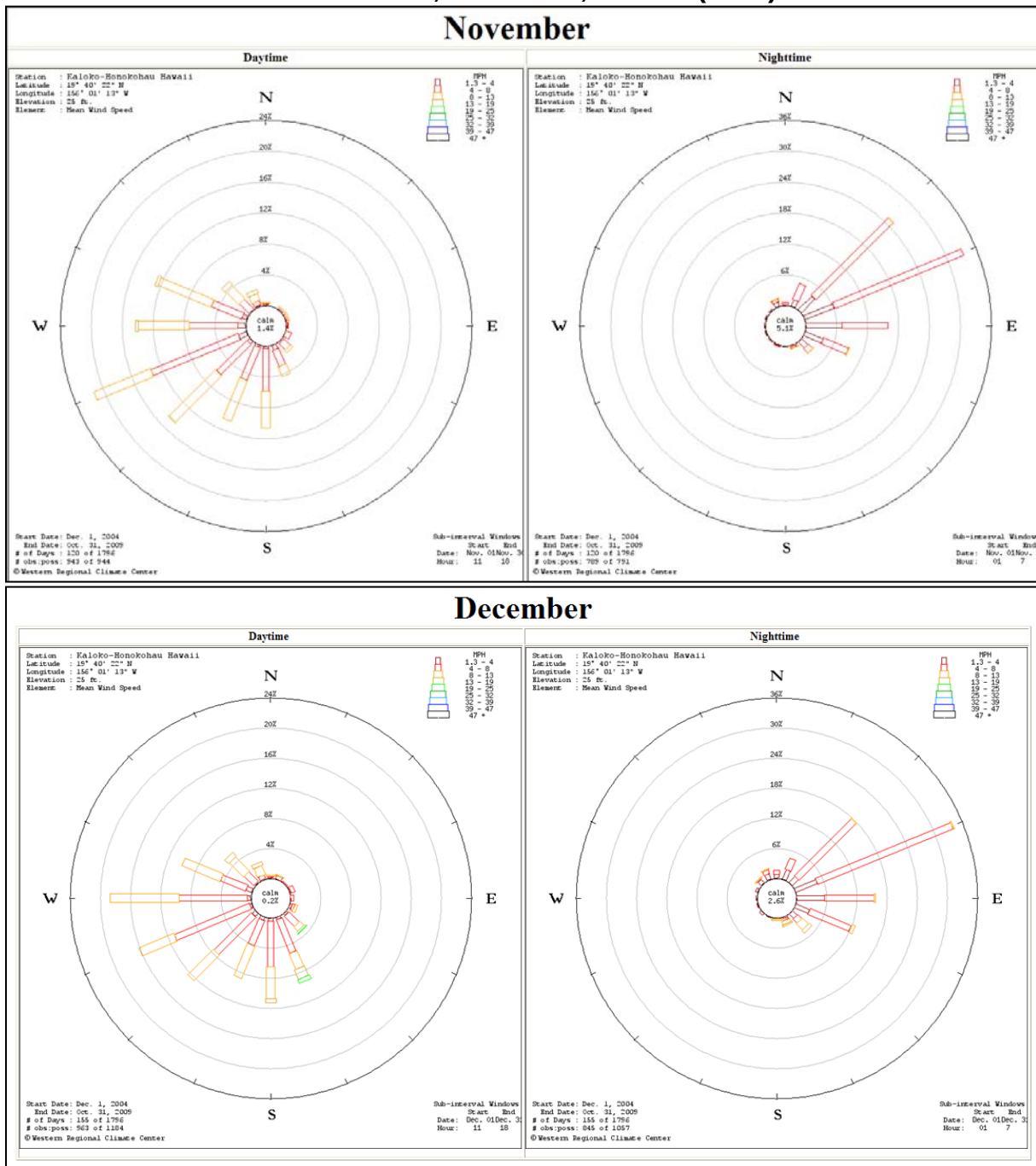
September



October



KAHO Kaloko-Honokohau RAWS, Nov – Dec, el. 25 ft (7.6m)



Appendix B: Precipitation and/or temperature annual summaries by station (all graphs by WRCC, 2011)

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South Pacific Islands, Western Pacific
Guam - War in the Pacific National Historical Park (WAPA), (AGAT, COOP)

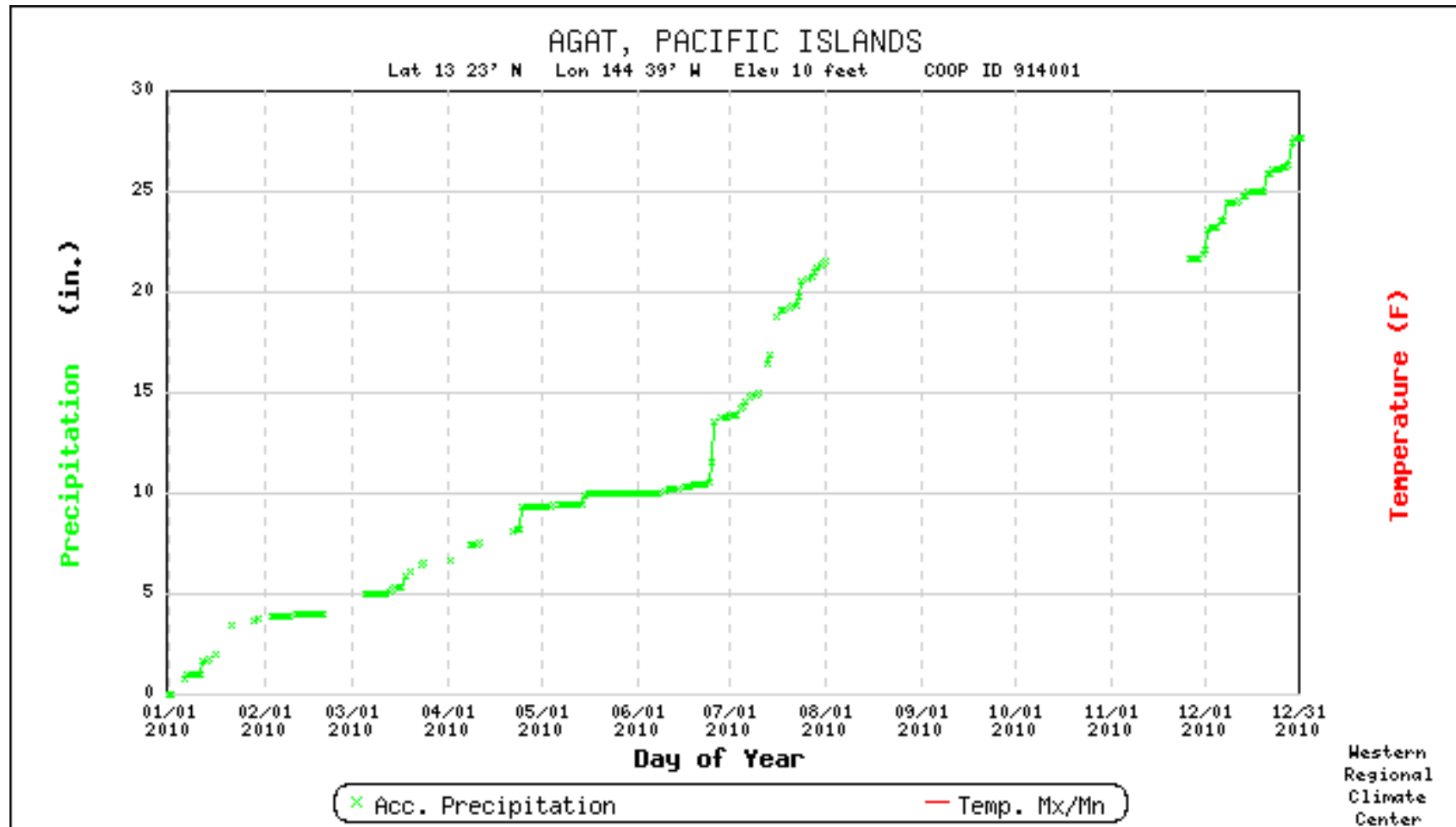


Figure B1. Accumulated precipitation data for AGAT, COOP station for 2010.

Guam, War in the Pacific National Historical Park (WAPA), Guam NAS (COOP)

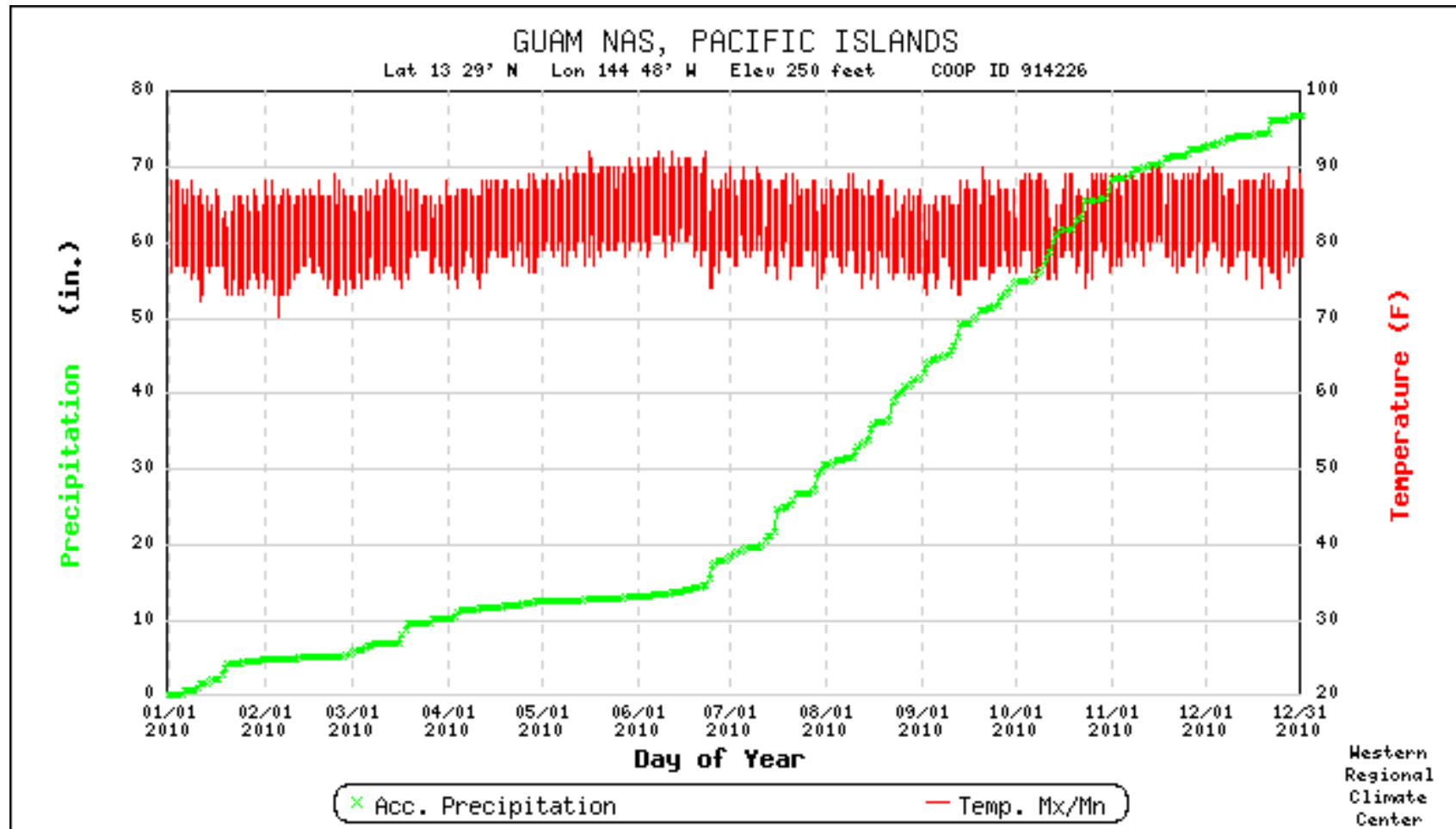


Figure B2. Accumulated precipitation and high and low temperature data for Guam NAS COOP station for 2010.

Saipan, Commonwealth of the Northern Mariana Islands, American Memorial Park (AMME) (COOP)

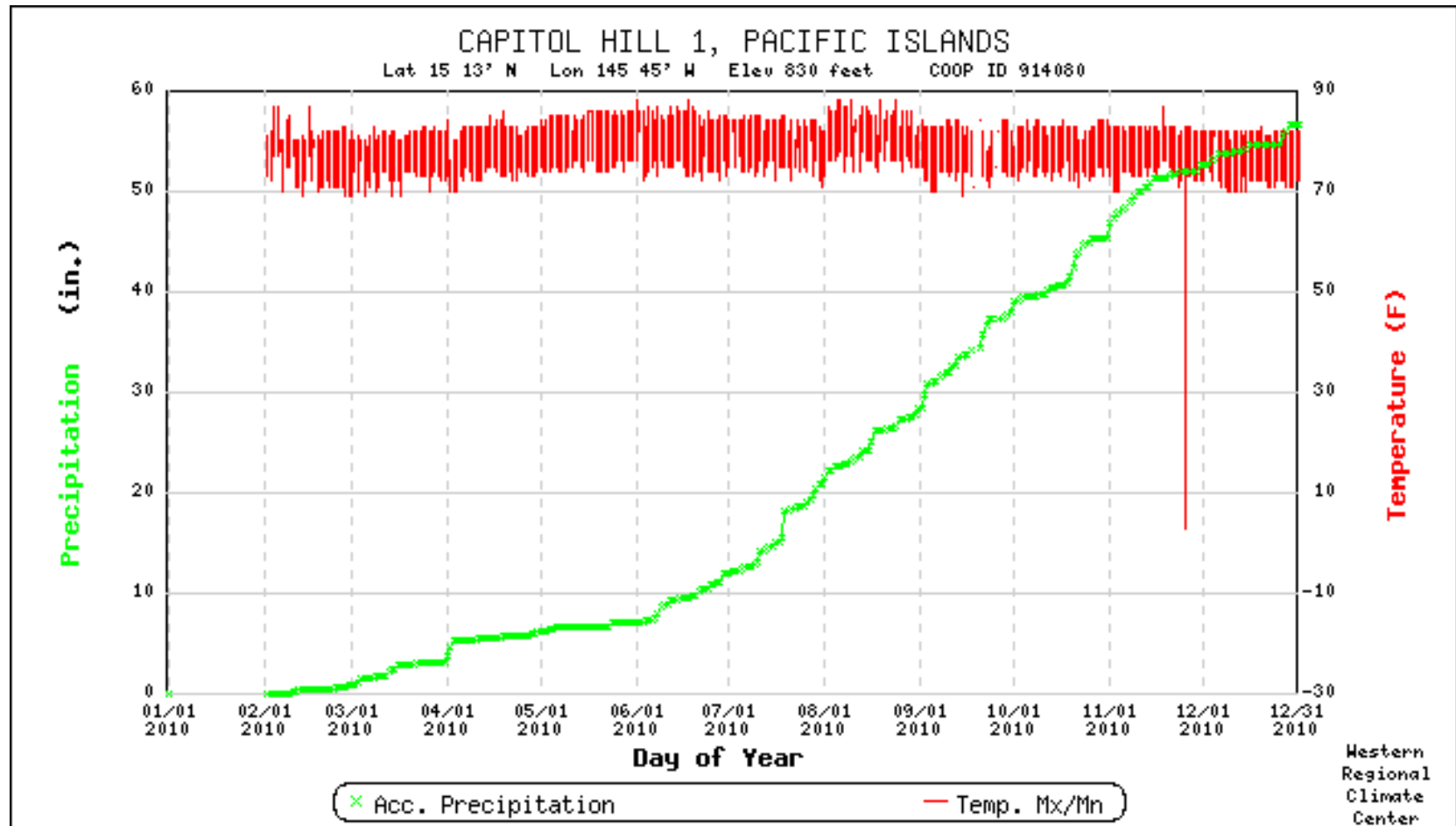


Figure B3. Accumulated precipitation and high and low temperature data for Capitol Hill COOP station on Guam for 2010. Looks like someone may have put ice on the thermometer in late November.

American Samoa, National Park of American Samoa (NPSA), PAGO PAGO (COOP)

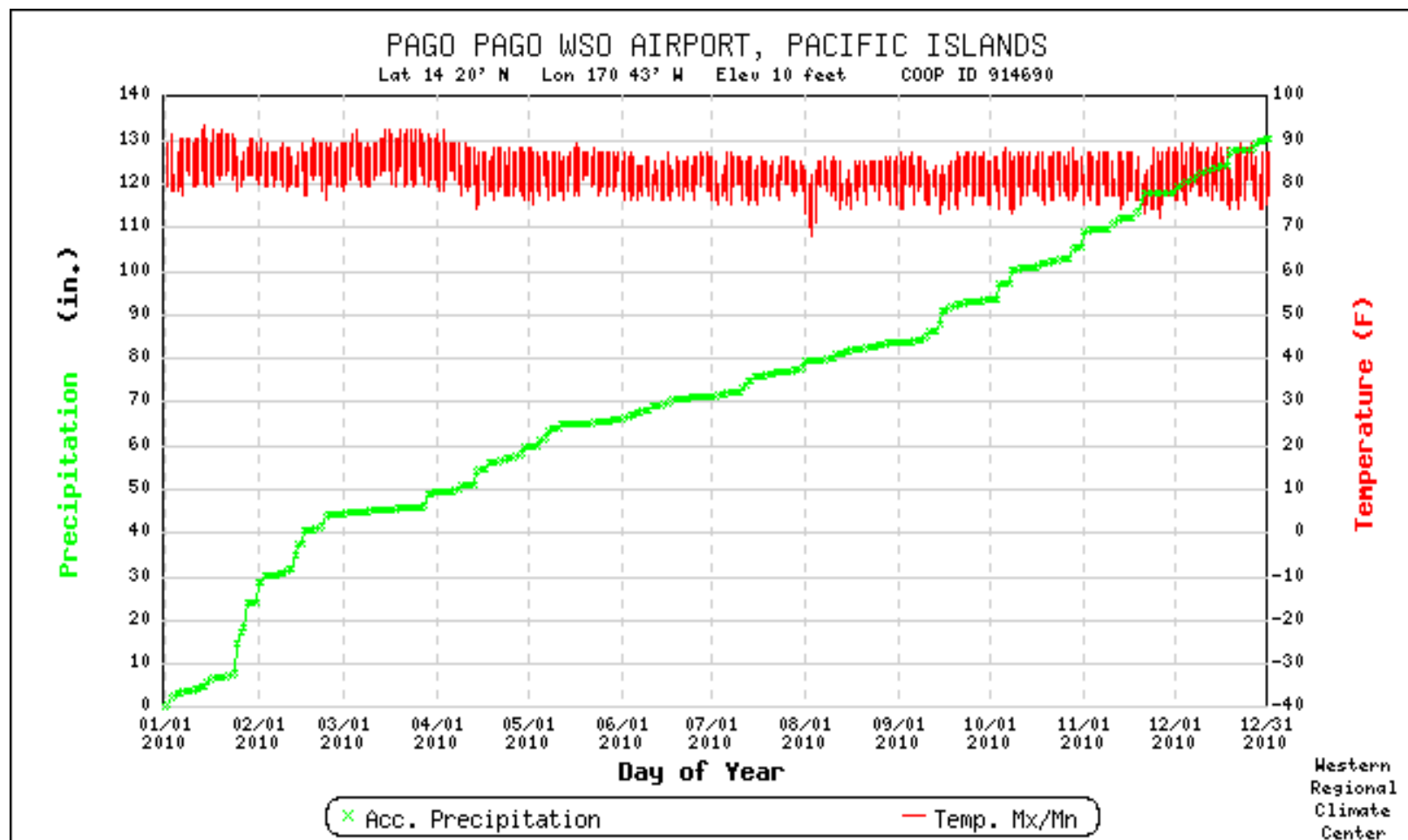


Figure B4. Accumulated precipitation and high and low temperature data for Pago Pago COOP station on Tutuila, Samoa, for 2010. Note the low temperatures in August, showing the southern hemisphere reversal of seasons.

Hawaii, Hawaii Volcanoes National Park (HAVO) Hawaii Vol NP HQ 54 (COOP)

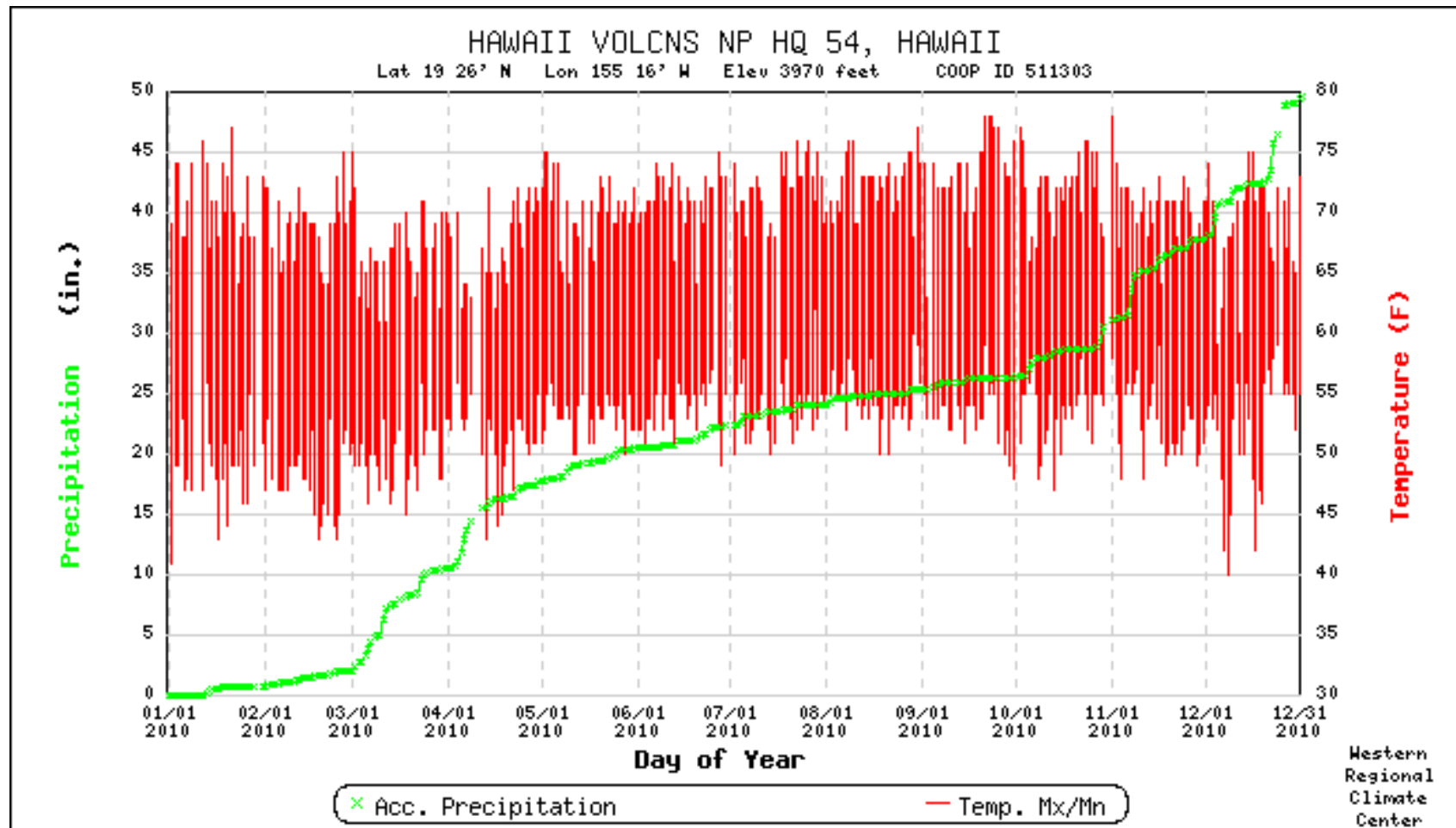


Figure B5. Accumulated precipitation and high and low temperature data for Hawaii Volcanoes National Park Headquarters 54 COOP station on the island of Hawaii for 2010. The elevation of nearly 4,000 feet accounts for the wide daily variation in temperatures throughout the year.

Hawaii, Hawaii Volcanoes National Park (HAVO) Kealakomo (RAWS)

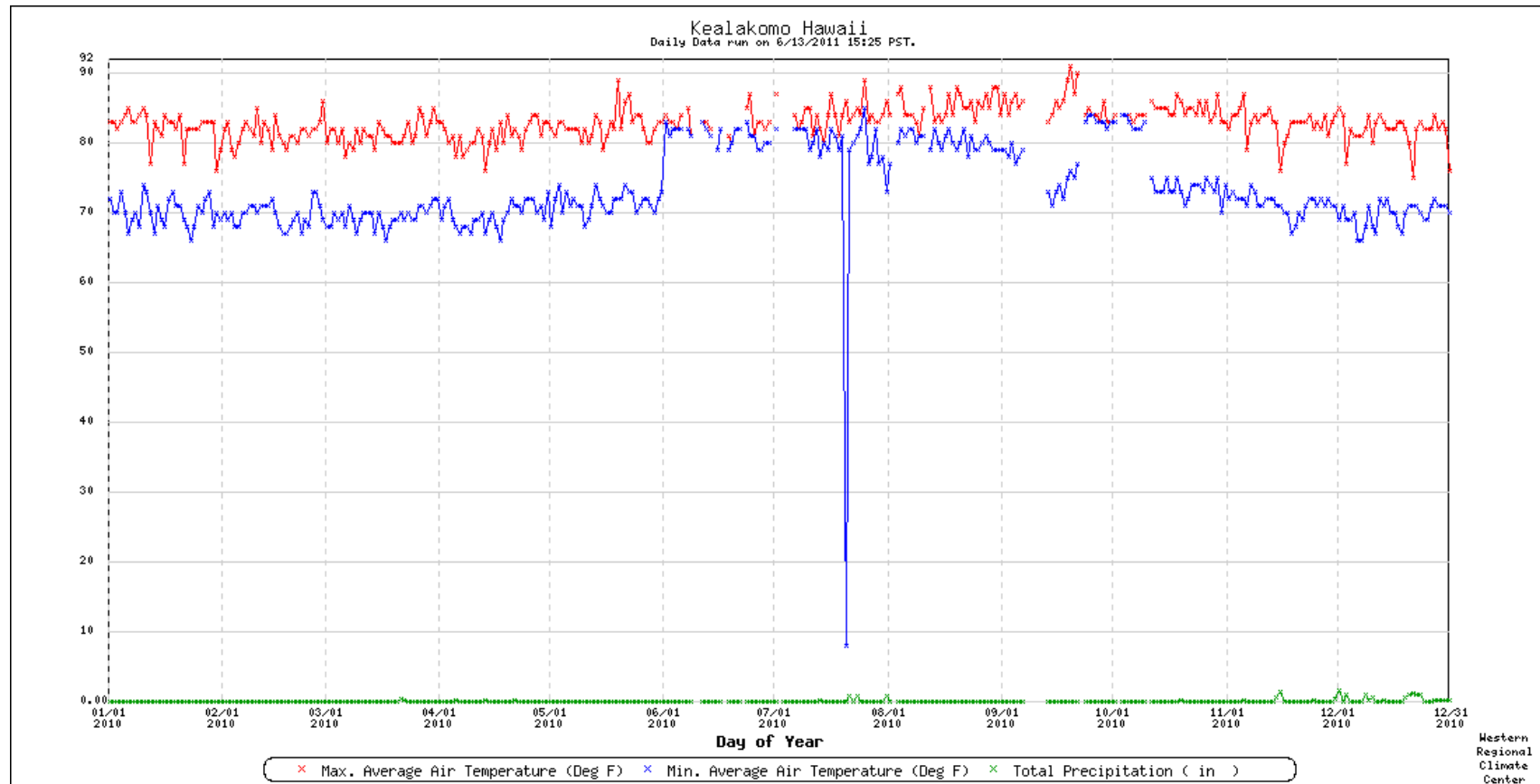


Figure B6. Total precipitation and high and low temperature data for Kealakomo RAWs station on the island of Hawaii for 2010. The person with the ice cube must have visited this site in late July.

Hawaii Volcanoes National Park (HAVO) Mauna Loa Slope Observatory (COOP)

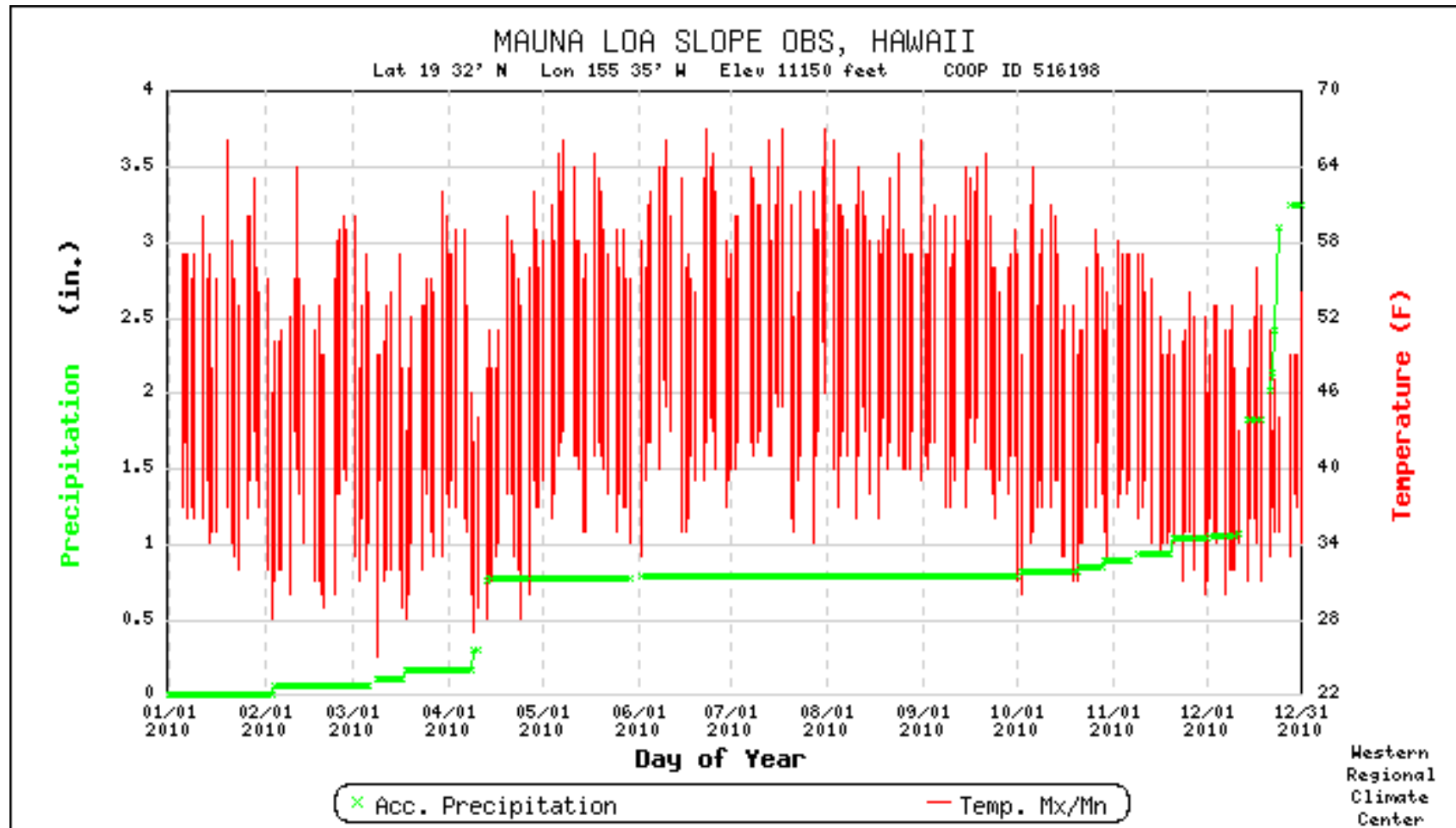


Figure B7. Accumulated precipitation and high and low temperature data for Mauna Loa Slope Obs, a RAWS station on the island of Hawaii for 2010.

Hawaii Volcanoes National Park (HAVO) Keaumo (RAWS)

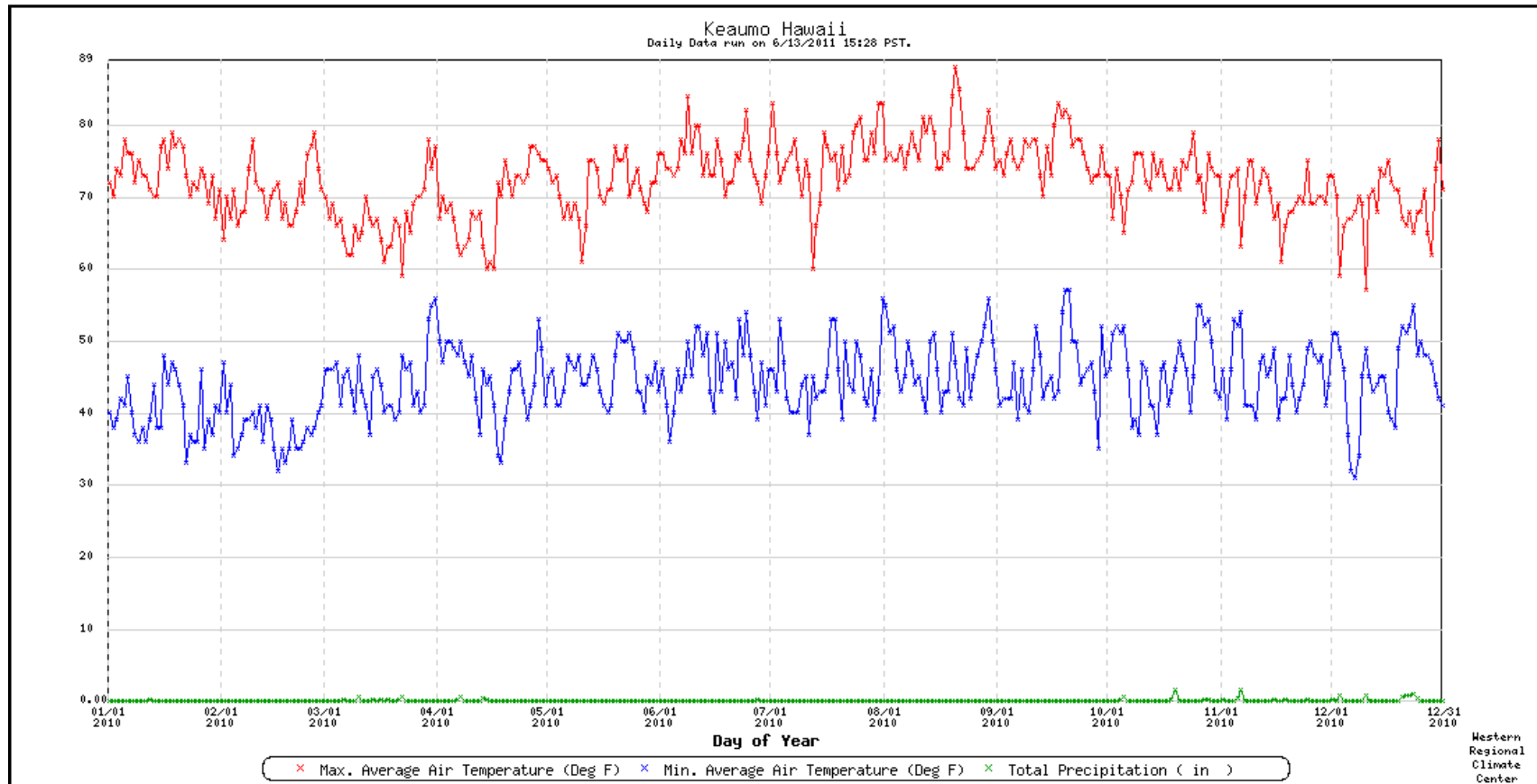


Figure B8. Total precipitation and high and low temperature data for Keaumo, a RAWS station on the island of Hawaii for 2010.

Hawaii Volcanoes National Park (HAVO) Pali 2 (RAWS)

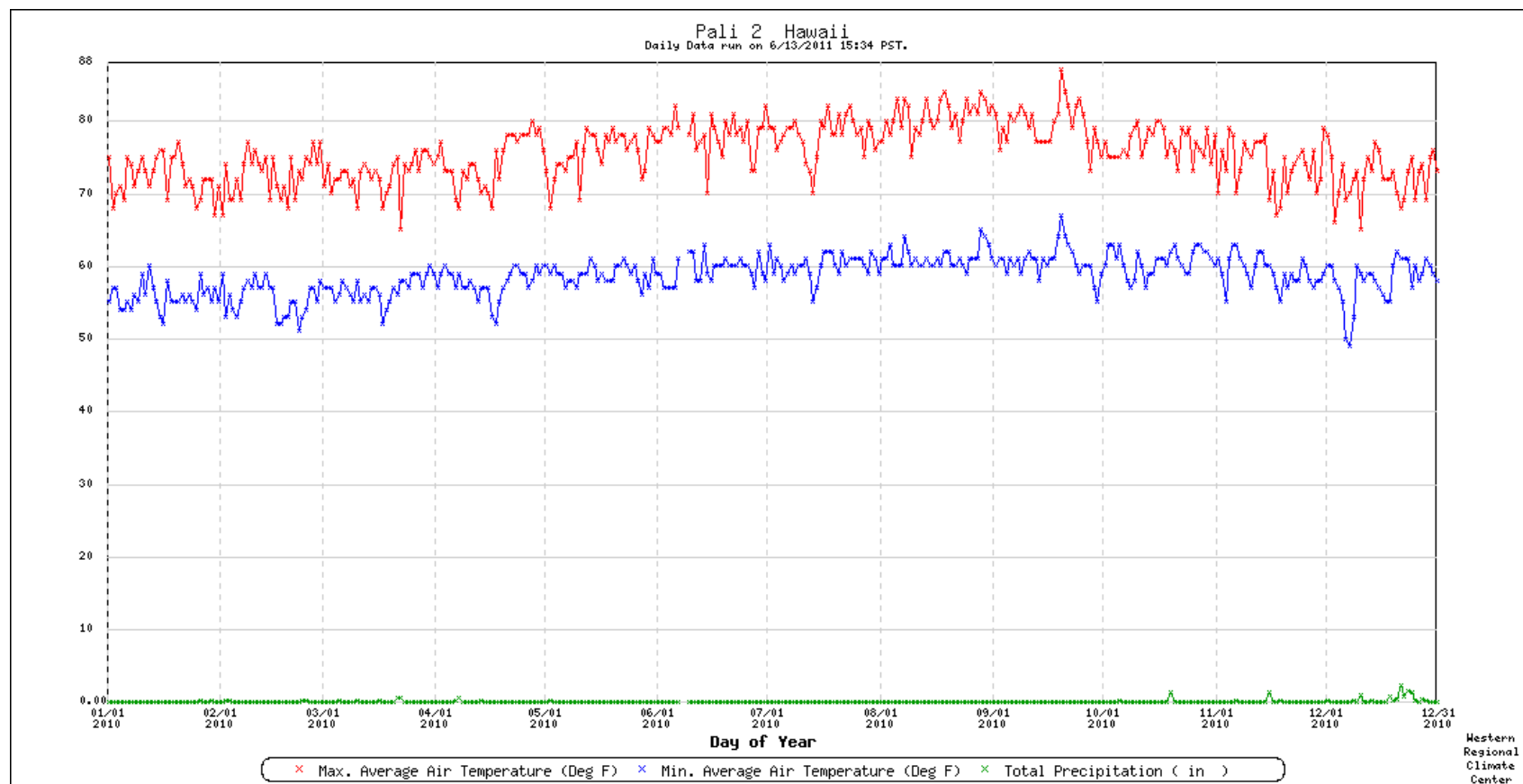


Figure B9. Total precipitation and high and low temperature data for Pali 2, a RAWS station on the island of Hawaii for 2010.

Puukohola Heiau National Historical Site (PUHE) Puukohola Heiau 98.1 (COOP)

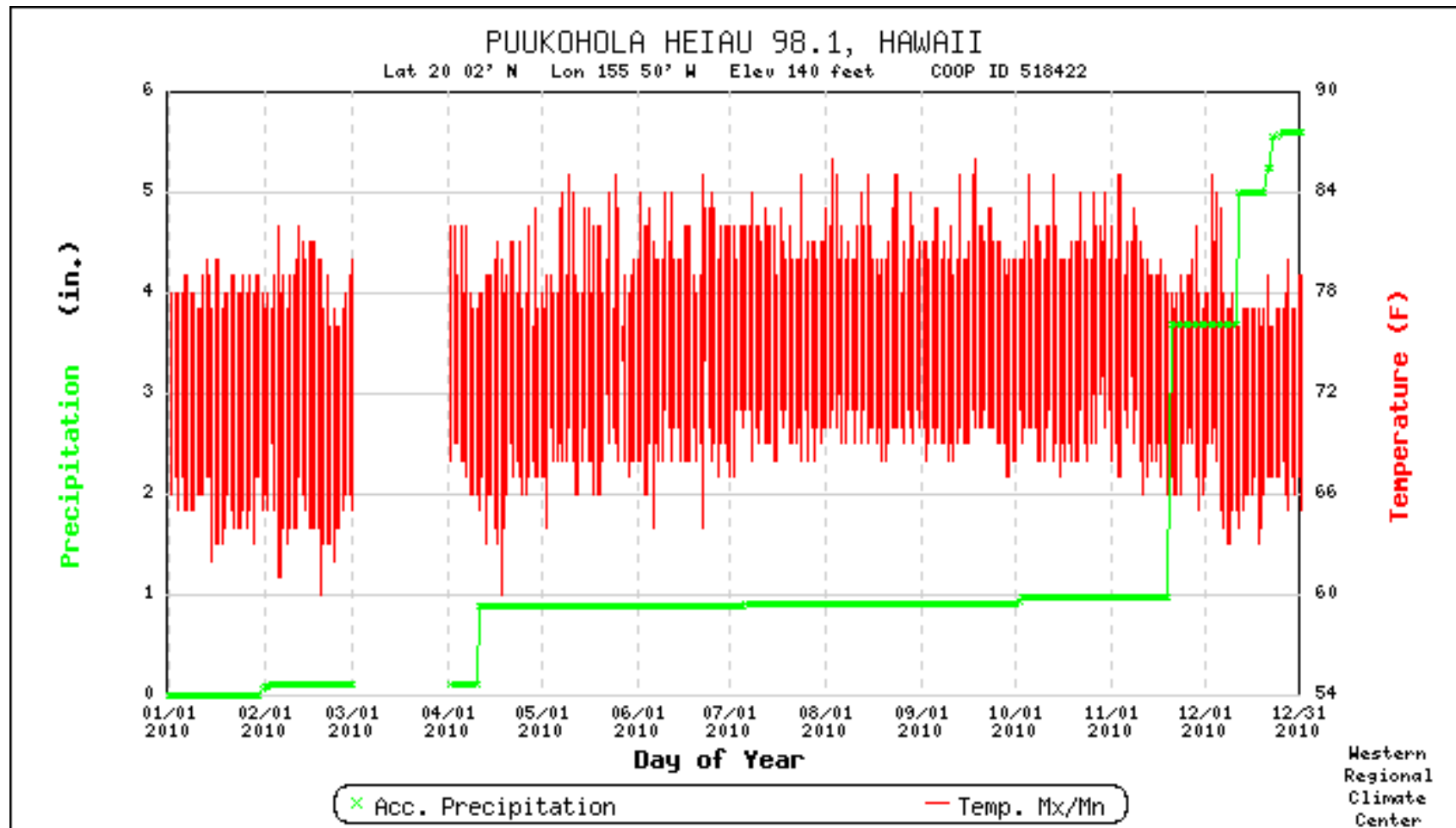


Figure B10. Accumulated precipitation and high and low temperature data for Puukohola Heiau 98.1, a COOP station on the island of Hawaii for 2010. This station is being replaced with a Campbell Scientific Inc RAWS weather station in February of 2012.

Kaloko-Honokohau National Historical Park (KAHO) Kaloko-Honokohau (RAWS)

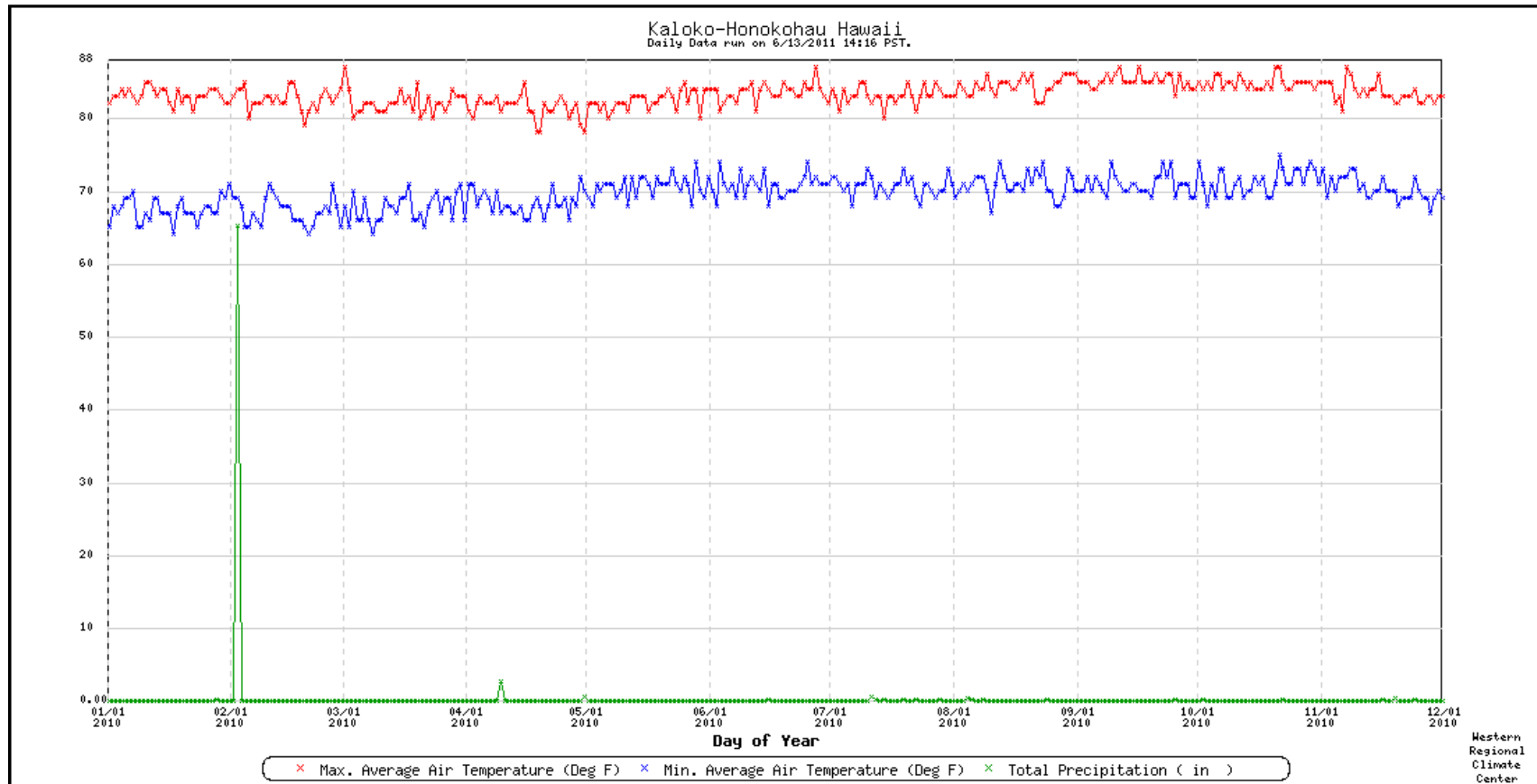


Figure B11. Total precipitation and high and low temperature data for Kaloko-Honokohau, a RAWS station on the island of Hawaii for 2010. The spike in February was caused by maintenance on the rain gauge; added water to test the gauge is usually deleted by WRCC if notified.

Puuhonua o Honaunau National Historical Park (PUHO) (COOP)

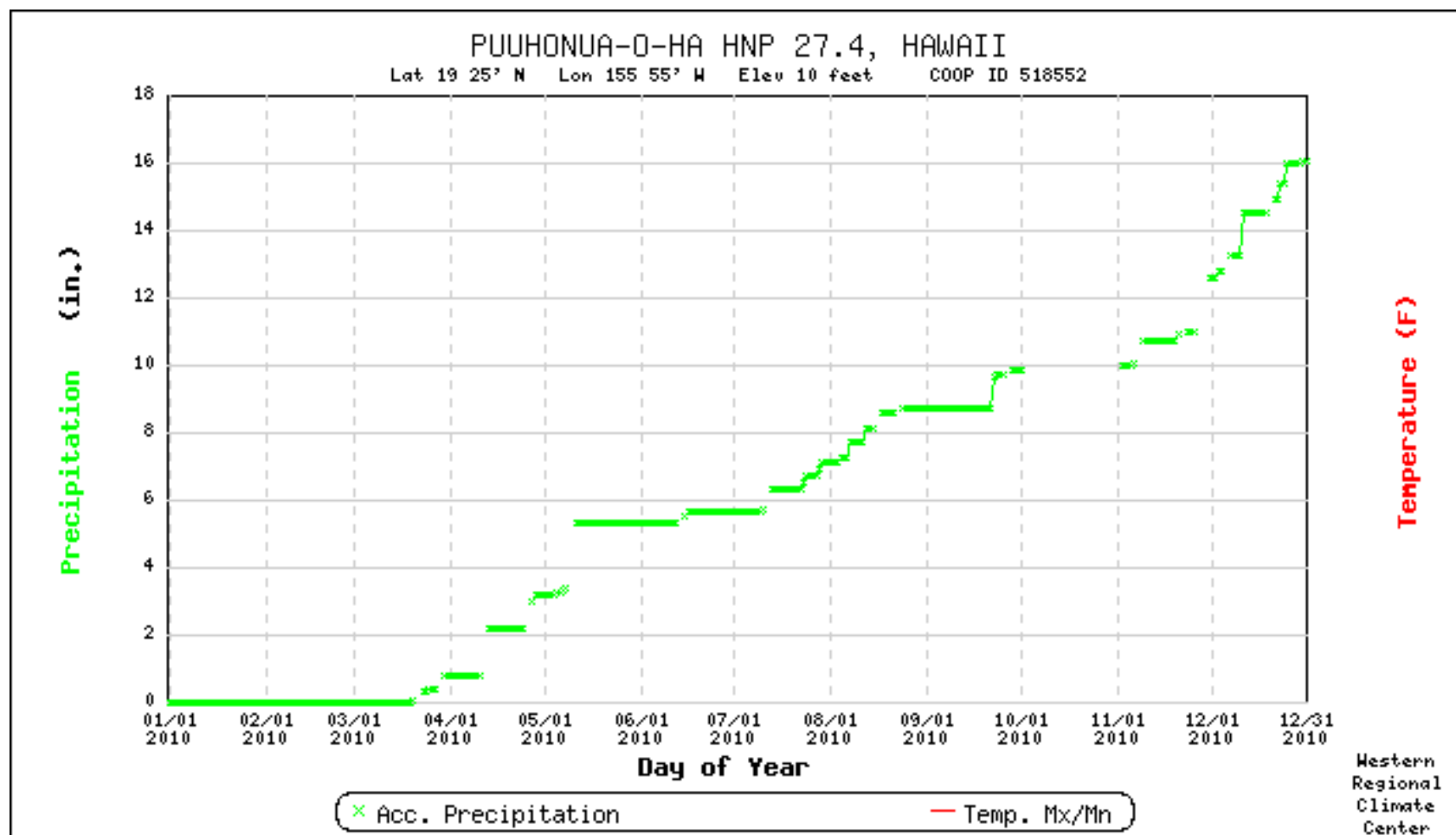


Figure B12. Accumulated precipitation data for Puuhonua o Honaunau HNP 27.4, a COOP station on the island of Hawaii for 2010. This station is being replaced by a Campbell Scientific Inc. RAWS weather station in Feb. 2012.

Kalaupapa National Historical Park (KALA), Molokai, Hawaii, Kalaupapa 563 (COOP)

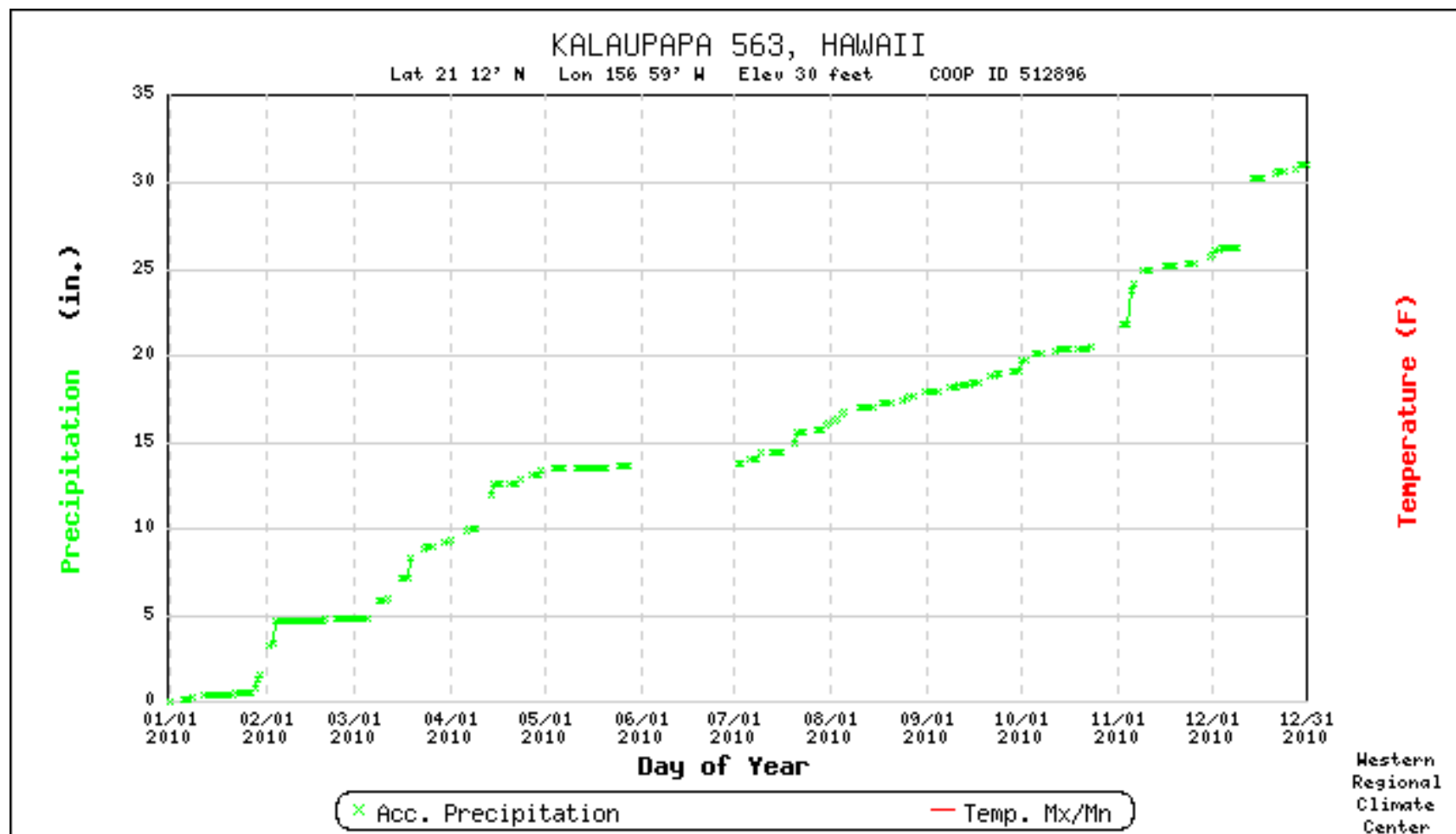


Figure B13. Accumulated precipitation data for Kalaupapa 563 a COOP station on the island of Molokai for 2010.

Kalaupapa National Historical Park (KALA), Molokai, Hawaii (continued) Makapulapai RAWS

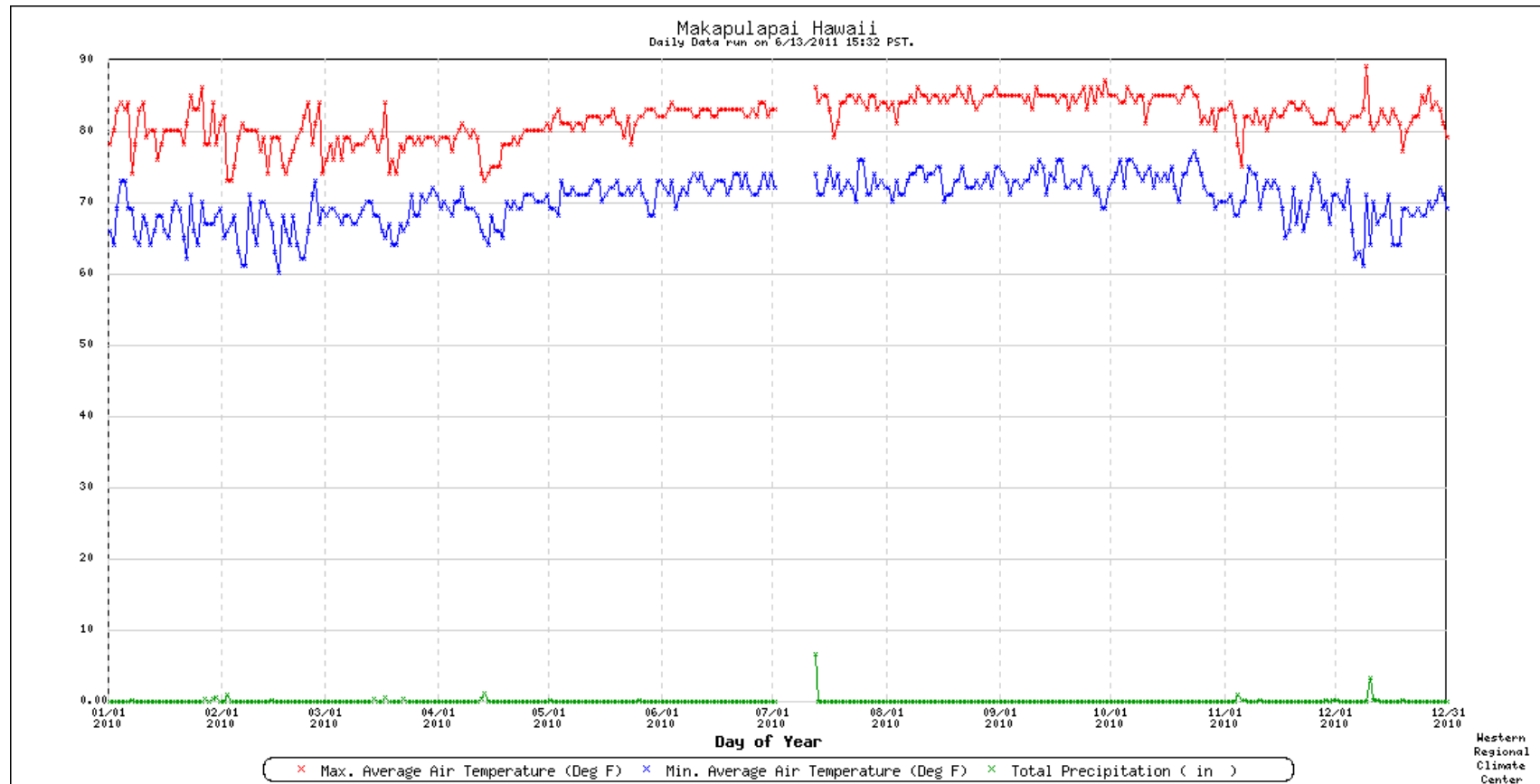


Figure B14. Total precipitation and high and low temperature data for Makapulapai, a RAWS station on the island of Molokai for 2010.

Outer Island Parks: Maui
Haleakala National Park (HALE), Maui, Hawaii. Haleakala R S 338 (COOP)

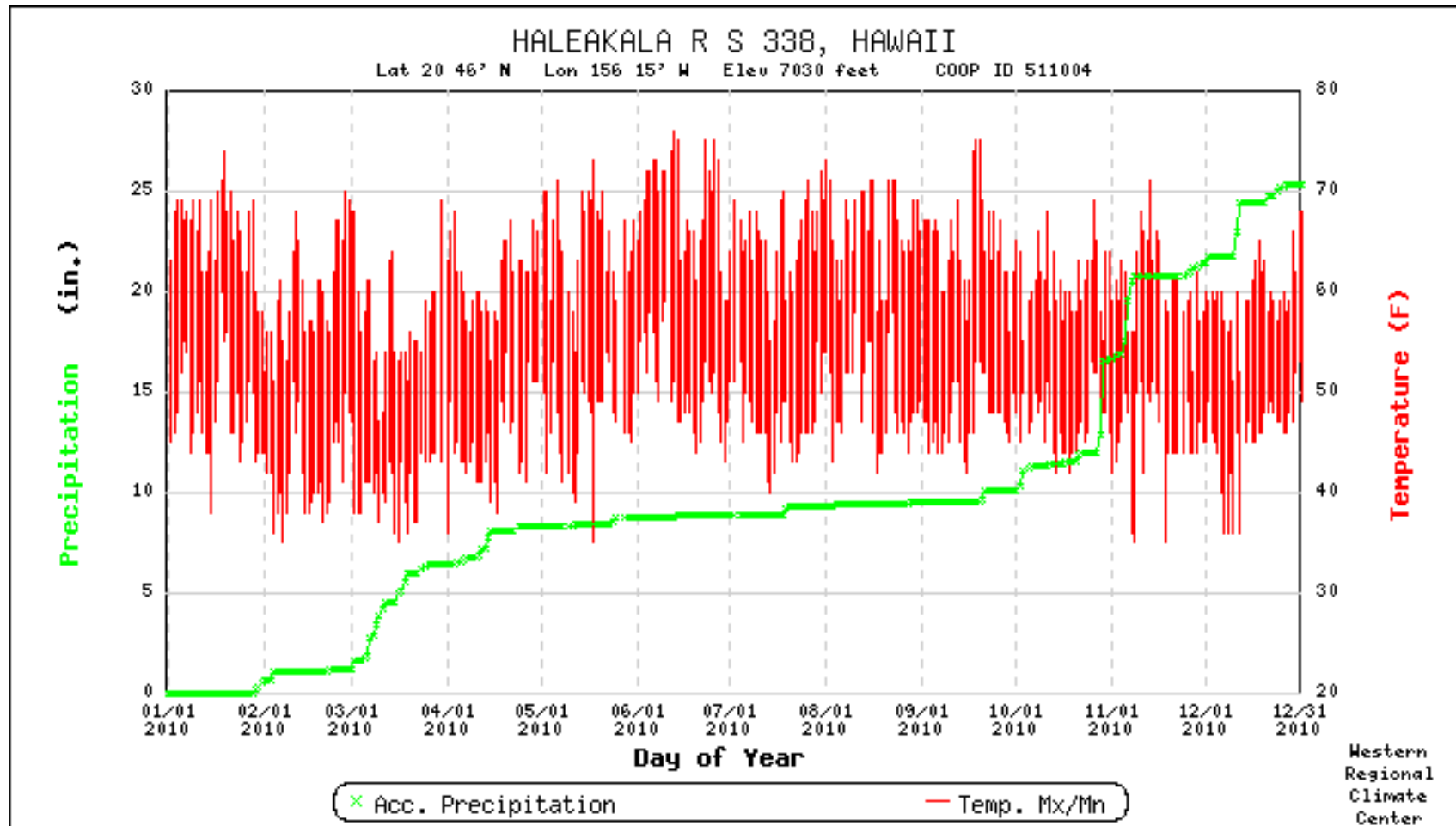


Figure B15. Accumulated precipitation and high and low temperature data for Haleakala R S 338, a COOP station on the island of Maui for 2010.

Haleakala National Park (HALE), Maui, Hawaii (continued) Oheo 258.6 (COOP)

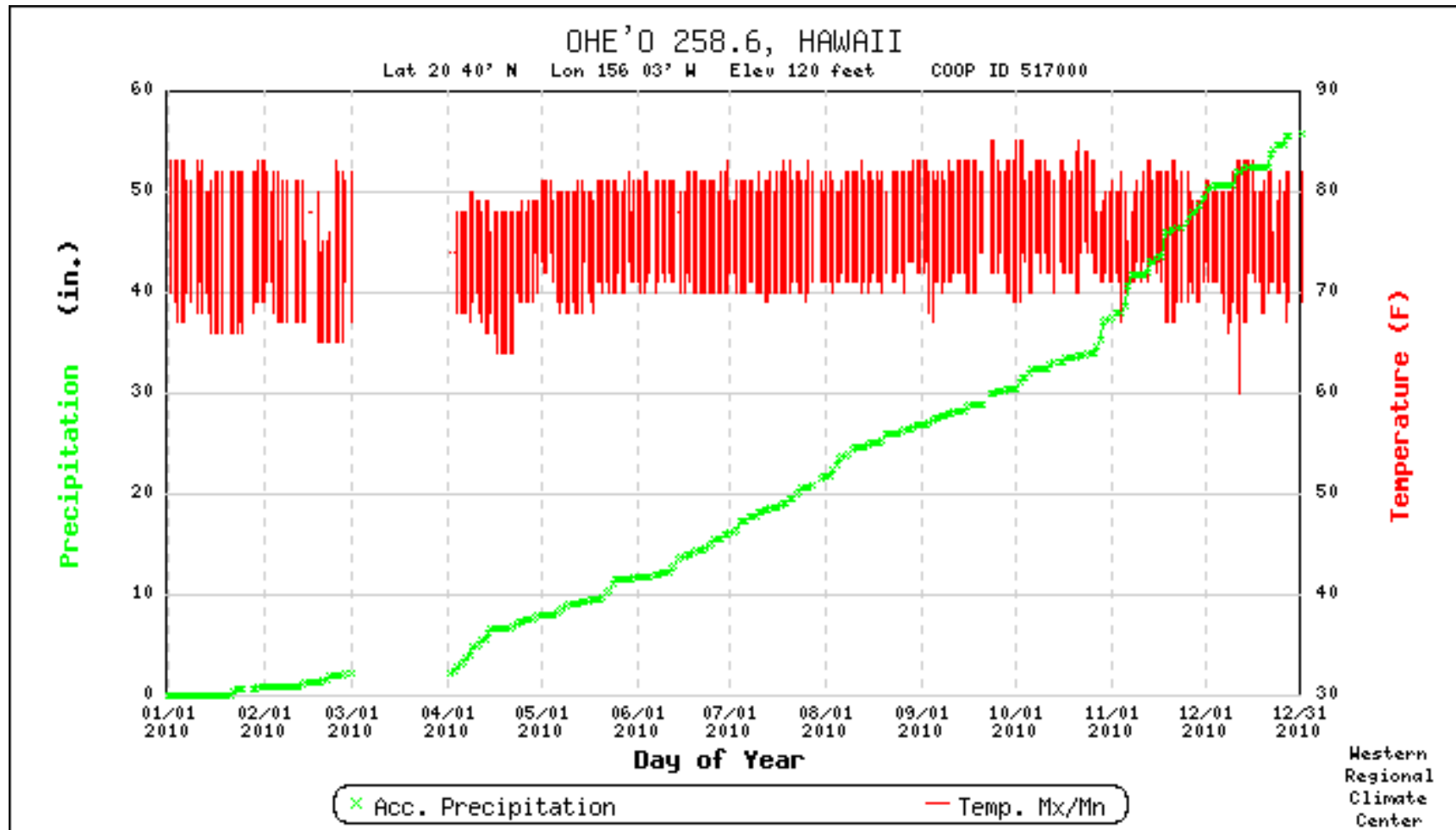


Figure B16. Accumulated precipitation and high and low temperature data for Oheo 258.6, a COOP station on the island of Maui for 2010.

Haleakala National Park (HALE), Maui, Hawaii (continued) Kaupo Gap (RAWS)

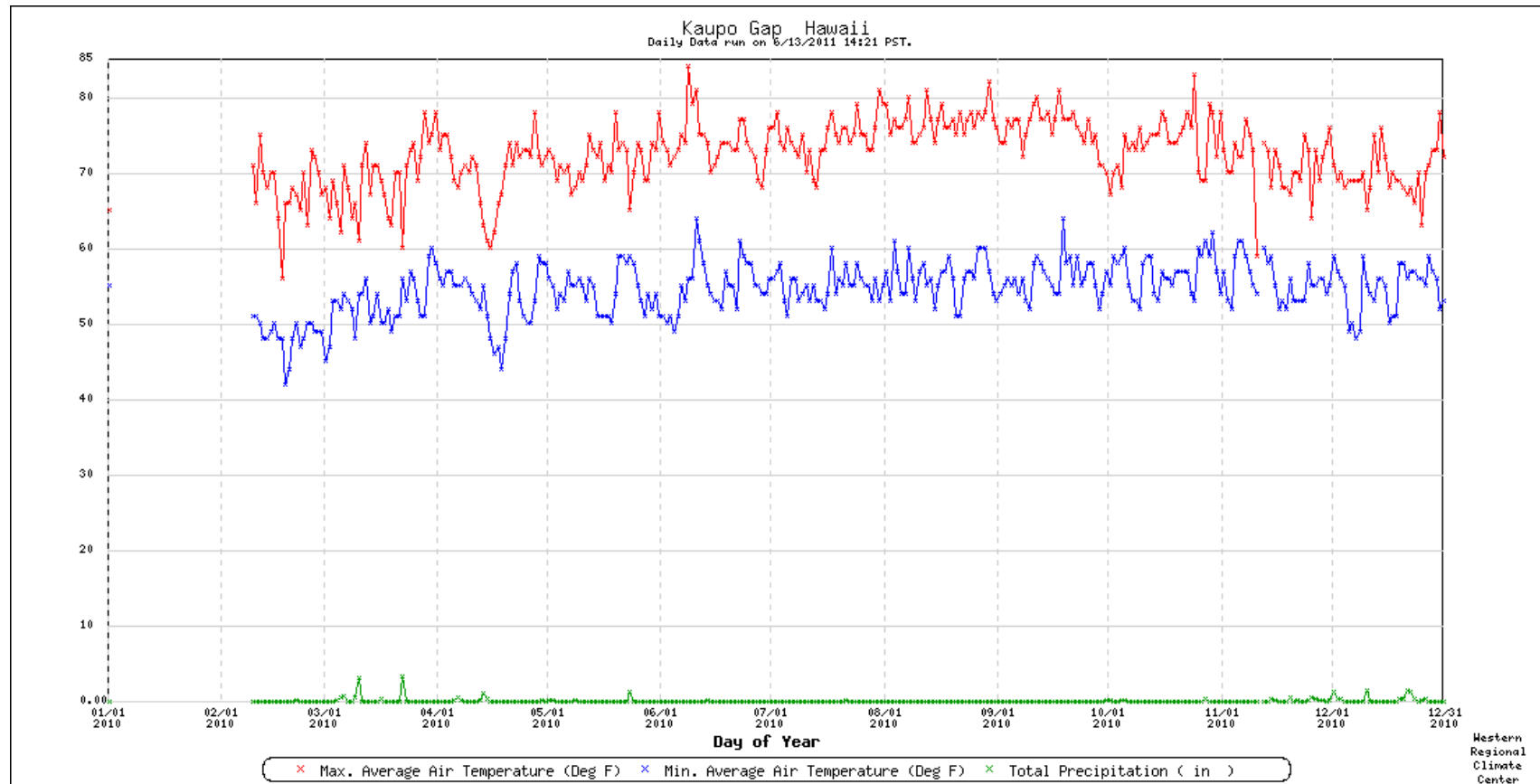


Figure B17. Total precipitation and high and low temperature data for Kaupo Gap, a RAWS station on the island of Maui for 2010.

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Parks in the Western North Pacific and the South Pacific

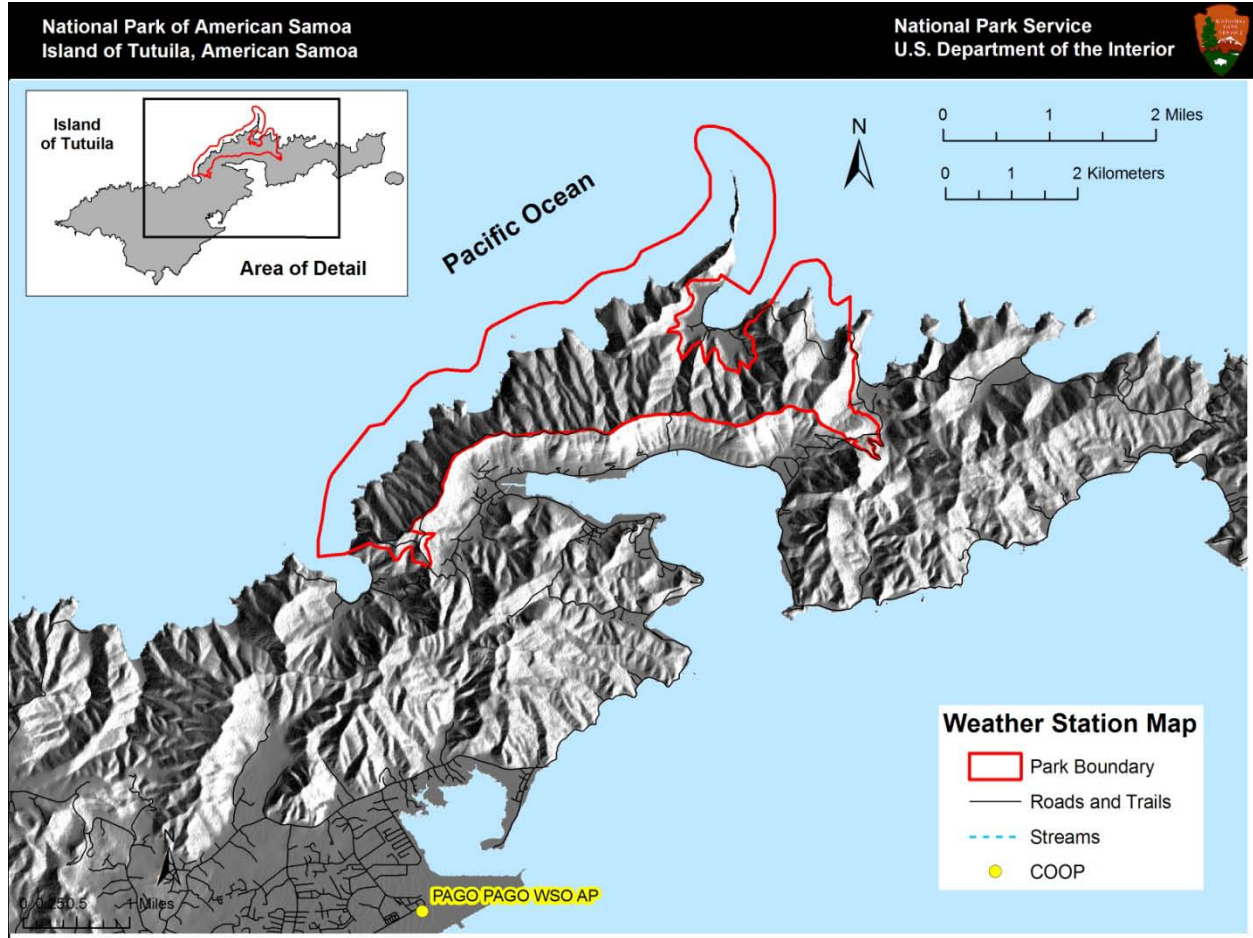


Figure C1. Pago Pago WSO AP COOP weather station on the island of Tutuila, Samoa. Two new Campbell Scientific Inc. RAWS weather stations will be set up in NPSA (The National Park of American Samoa) in early 2012.

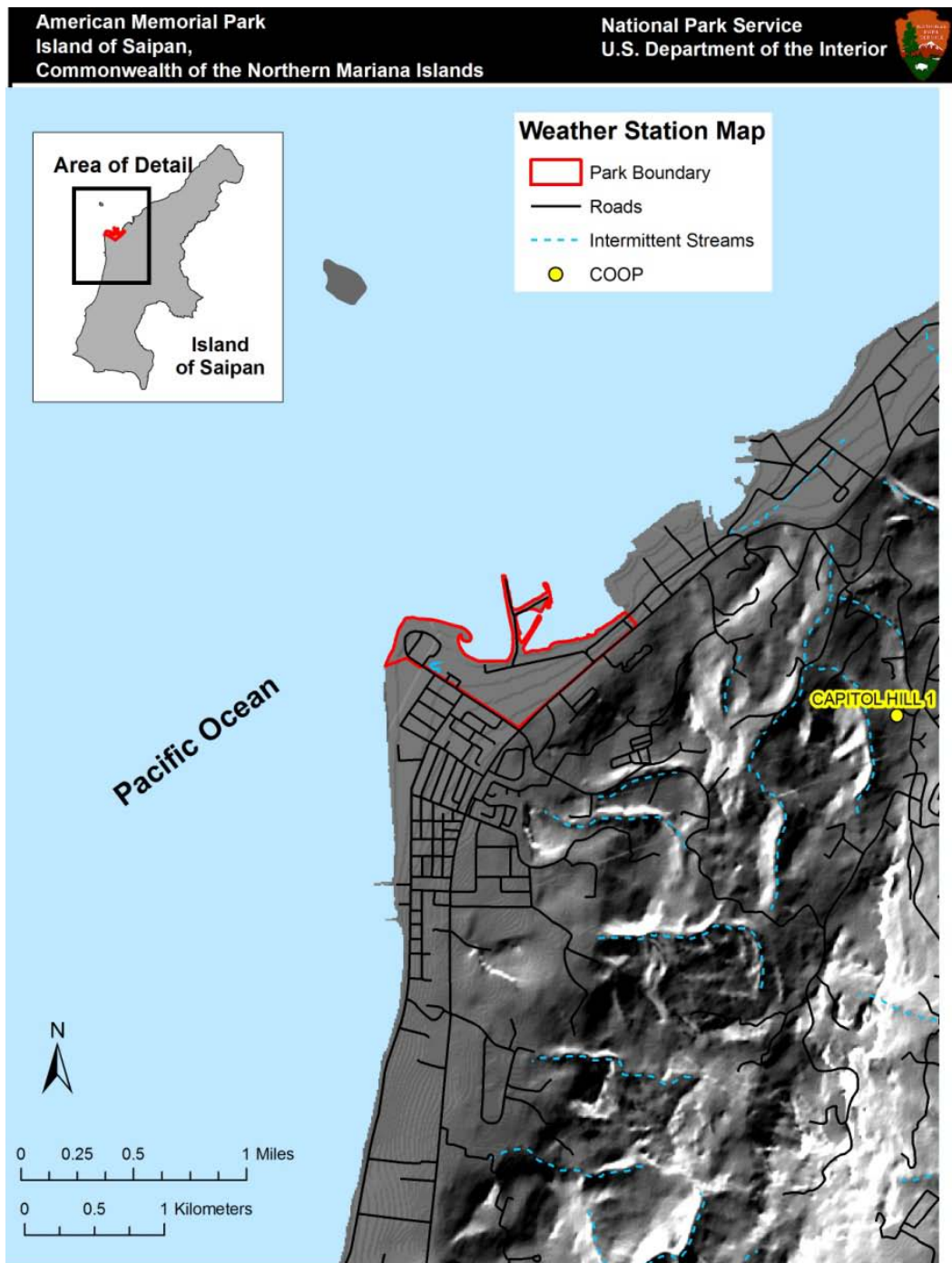


Figure C2. Capitol Hill COOP station is currently used for weather information for American Memorial Park (AMME), but a new Campbell Scientific Inc. RAWS station will be set up in 2012 in the park.

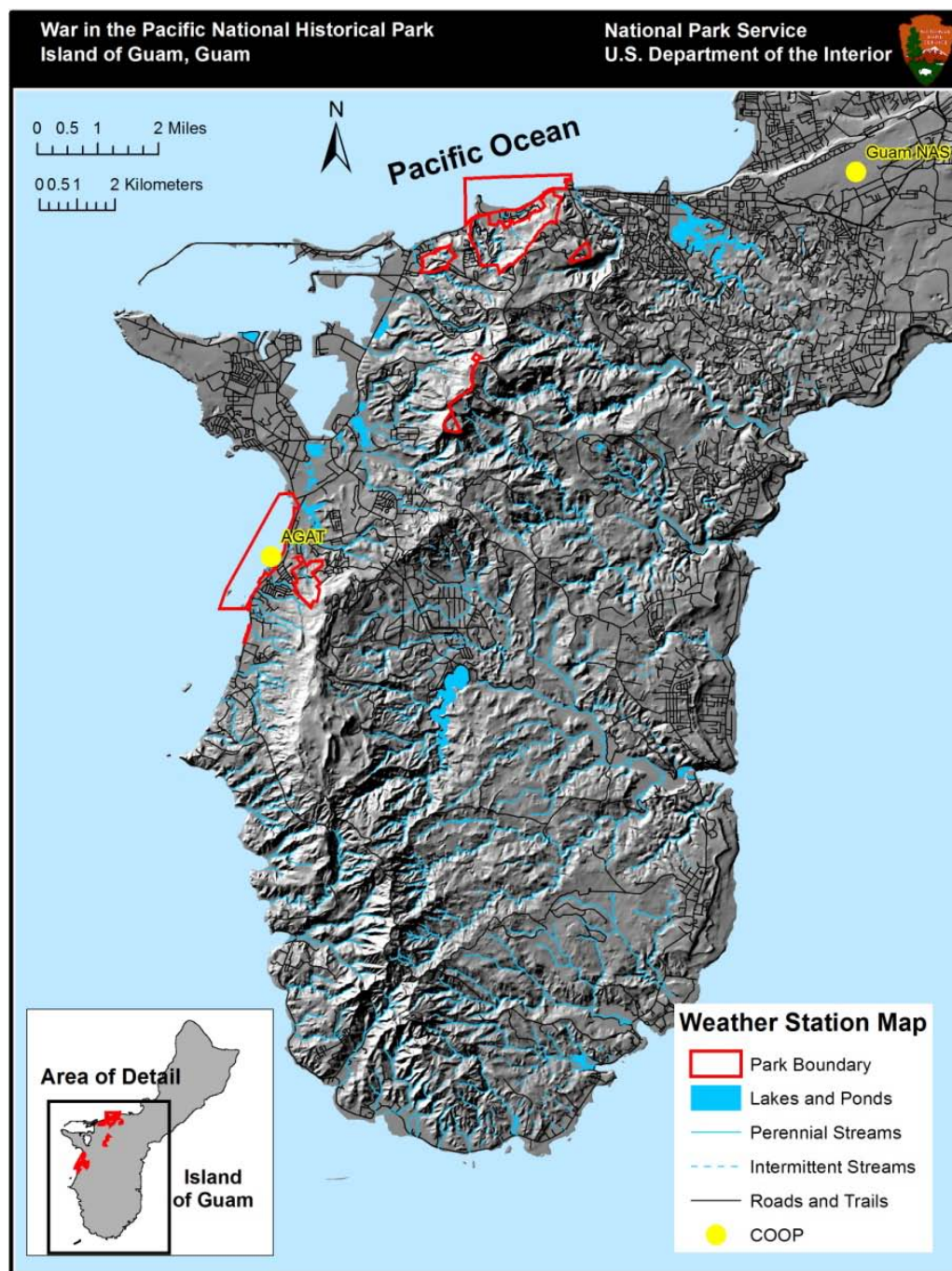


Figure C3. AGAT COOP and Guam NAS COOP stations are currently used for temperature and precipitation data for War in the Pacific National Historical Park (WAPA) on the island of Guam.

Parks on Hawaii Island

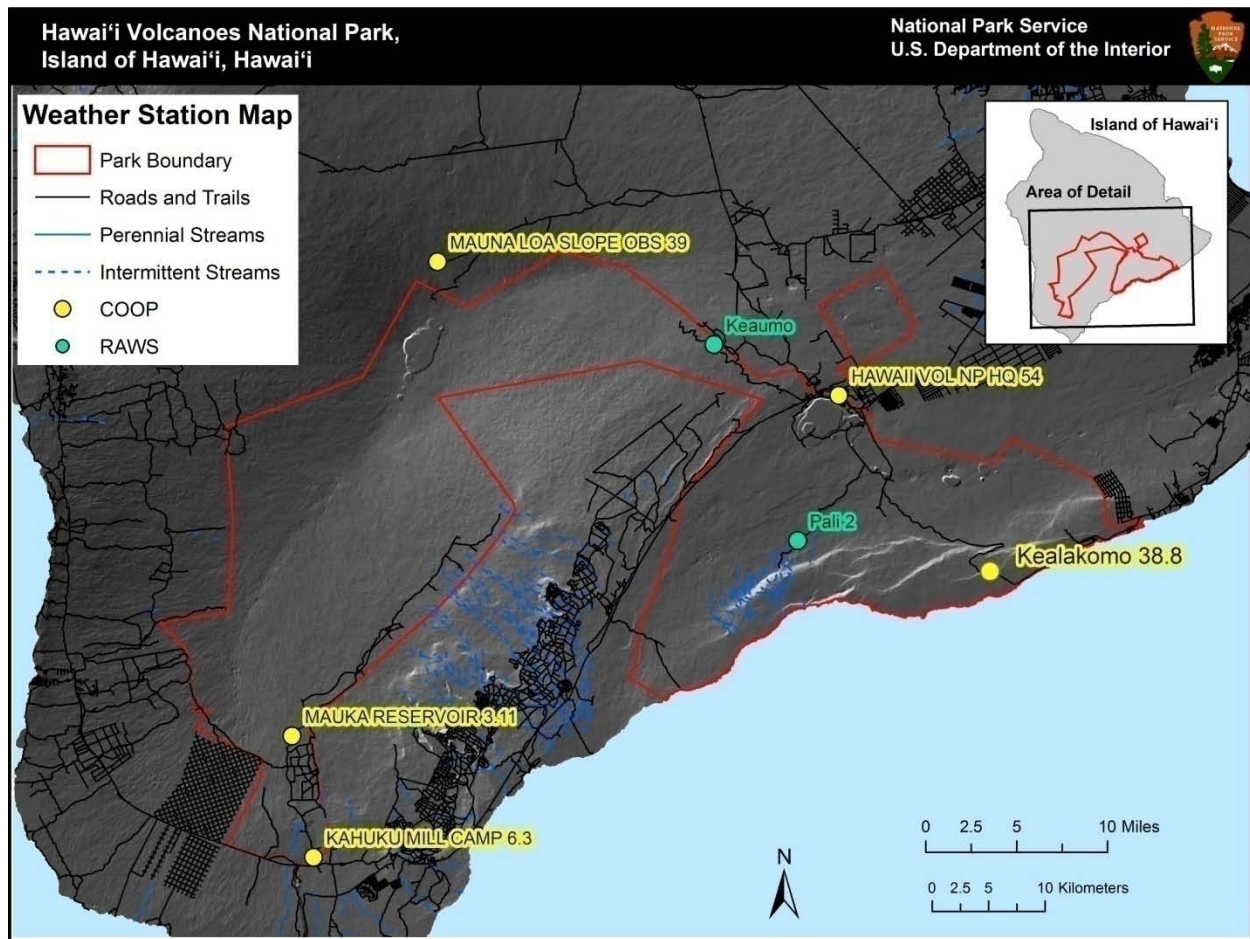


Figure C4. Five COOP (yellow dots) stations and two RAWS (green dots) stations are currently used for temperature and precipitation data for Hawaii Volcanoes National Park (HAVO) on the island of Hawaii. Because the two southerly stations, Mauka Reservoir and Kahuku Mill Camp are intermittently checked, two new Campbell Scientific Inc. RAWS stations are being installed at the 6,000 and 3,000 foot levels in the Kahuku section of HAVO in early 2012.

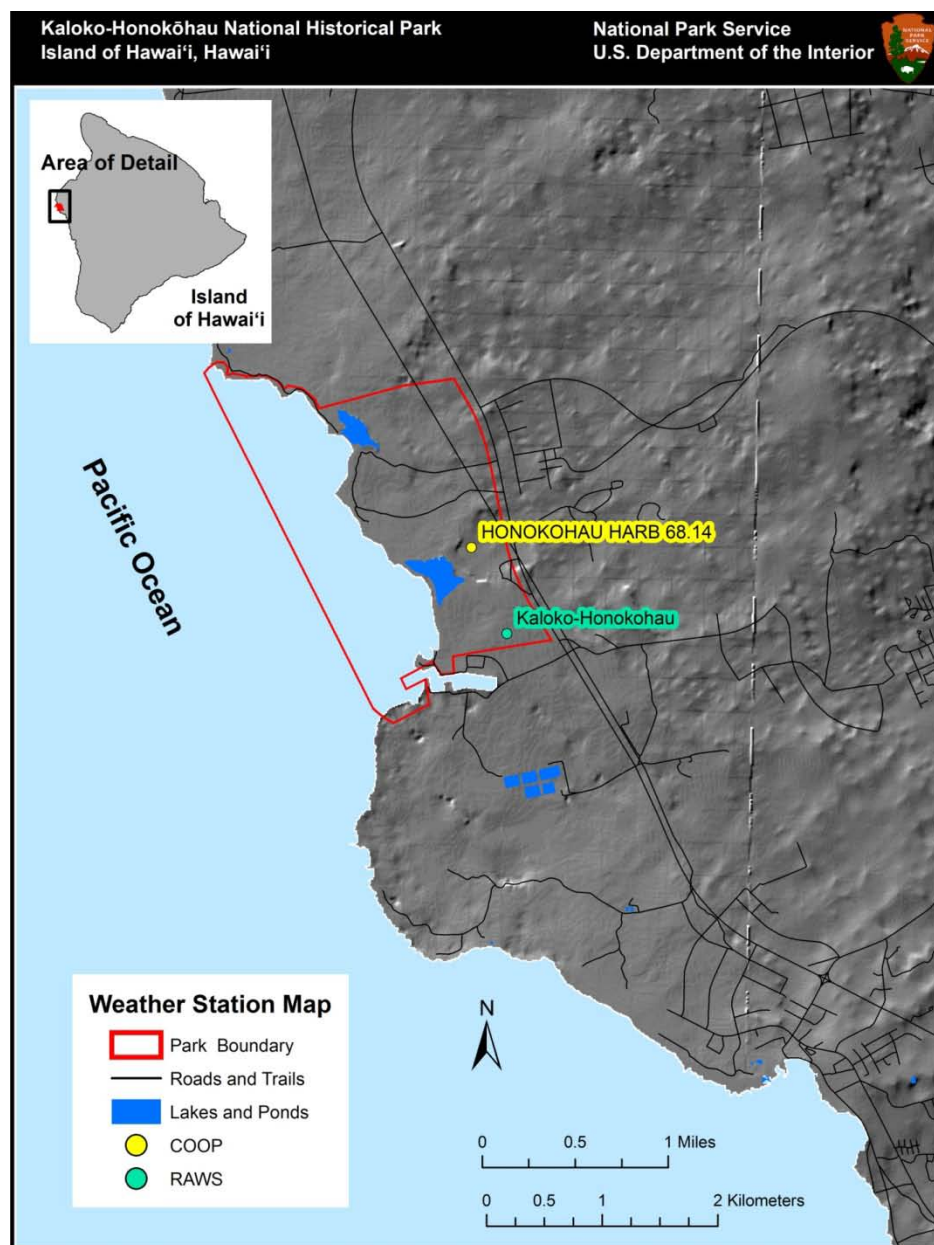


Figure C5. Honokohau Harbor (COOP) and Kaloko-Honokohau (RAWS) stations are currently used for temperature and precipitation data for Kaloko-Honokohau National Historical Park (KAHO) on the island of Hawaii.

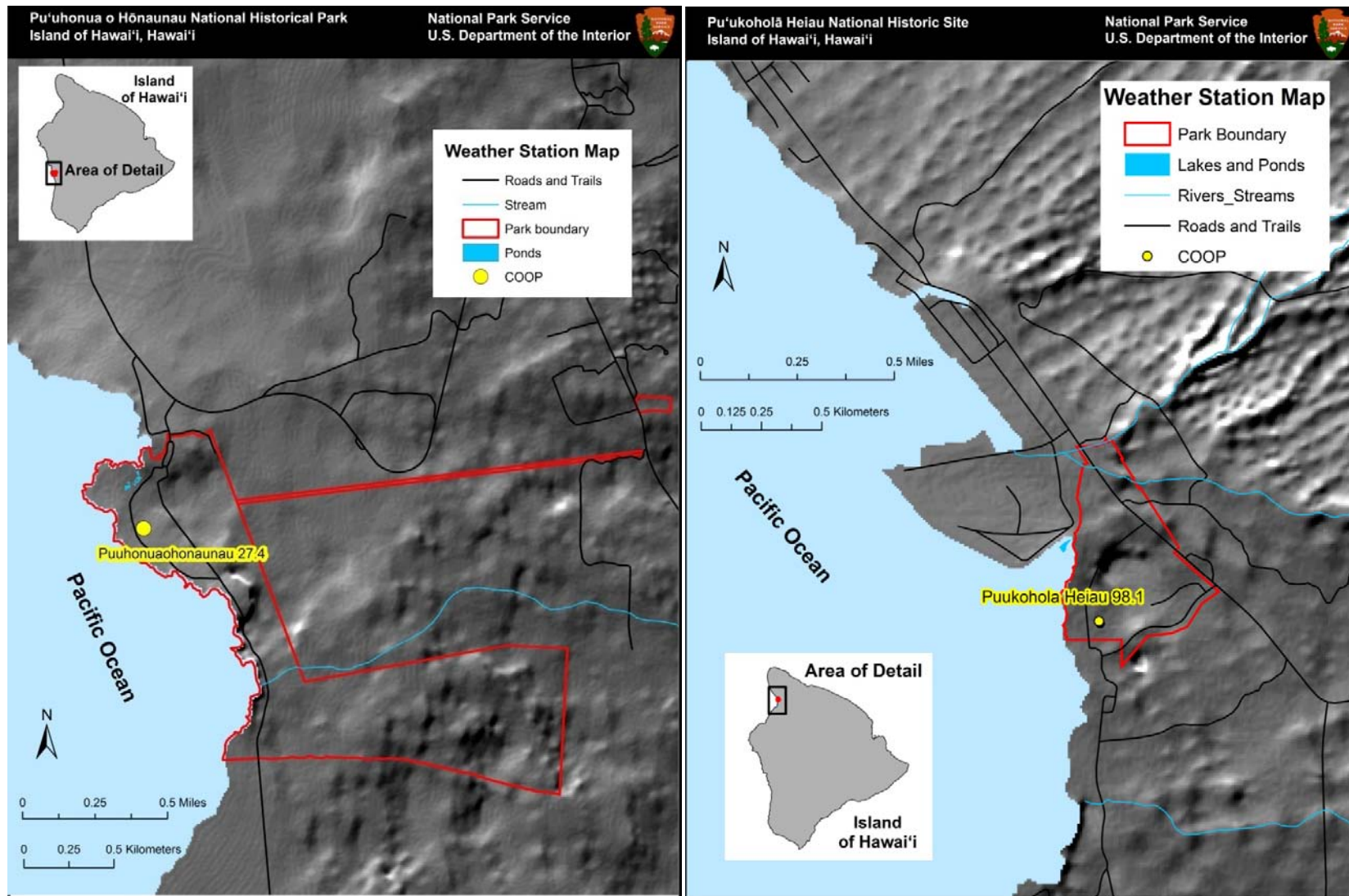


Figure C6. Puuhonuaohonaunau 27.4 COOP (left map) and Puukohola Heiau 98.1 COOP (right map) stations are currently used for temperature and precipitation data at Puuhonua o Honaunau National Historical Park (PUHO) and Puukohola Heiau National Historical Park (PUHE). Two new Campbell Scientific Inc. RAWS weather stations are being installed to replace these stations in early 2012.

Haleakala National Park, Maui, Hawaii

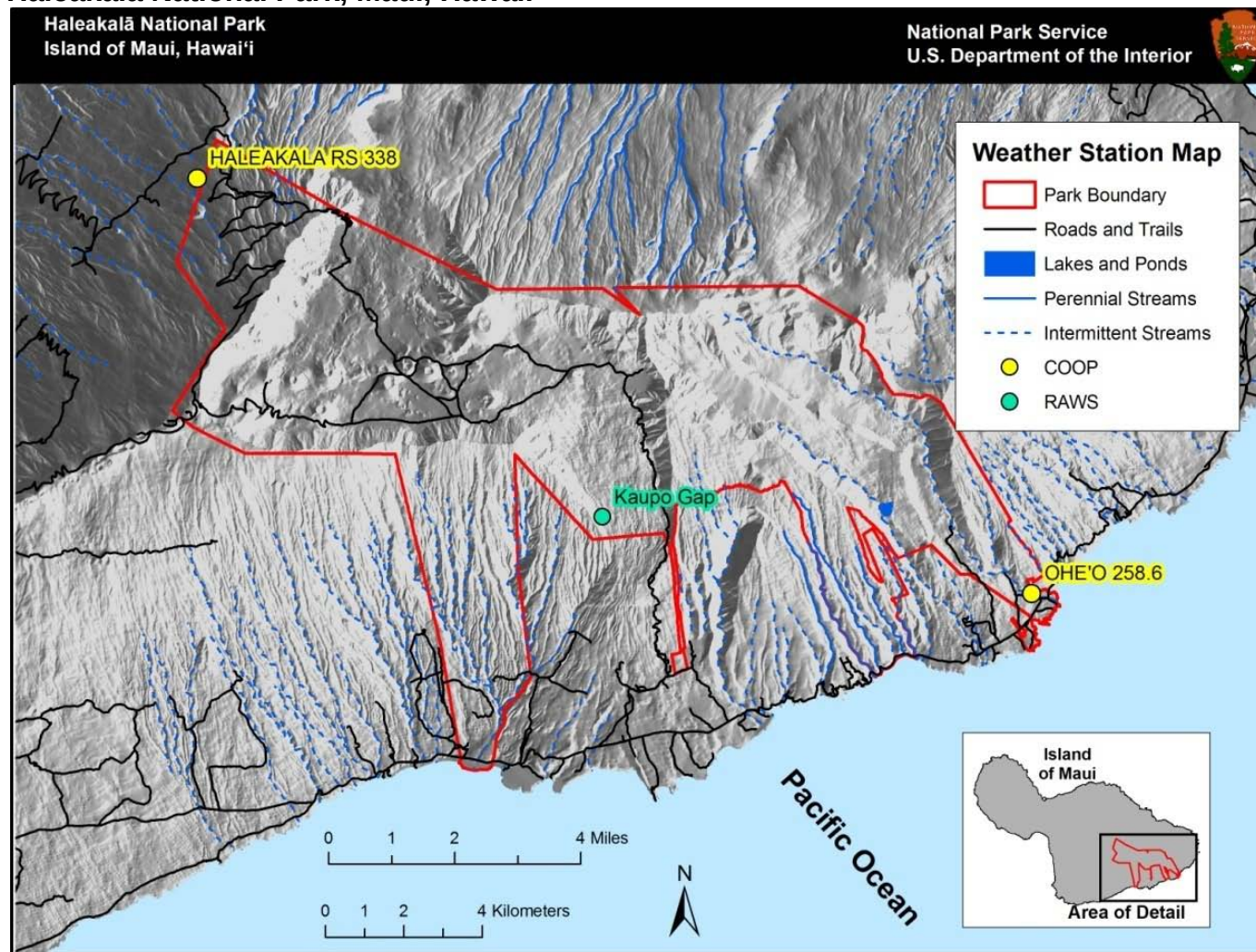


Figure C7. Haleakala RS 338 and Oheo 258.6 COOP stations as well as Kaupo Gap RAWS station are currently used for temperature and precipitation data for Haleakala National Park (HALE) on the island of Maui, Hawaii.

Kalaupapa National Historical Park, Molokai, Hawaii.

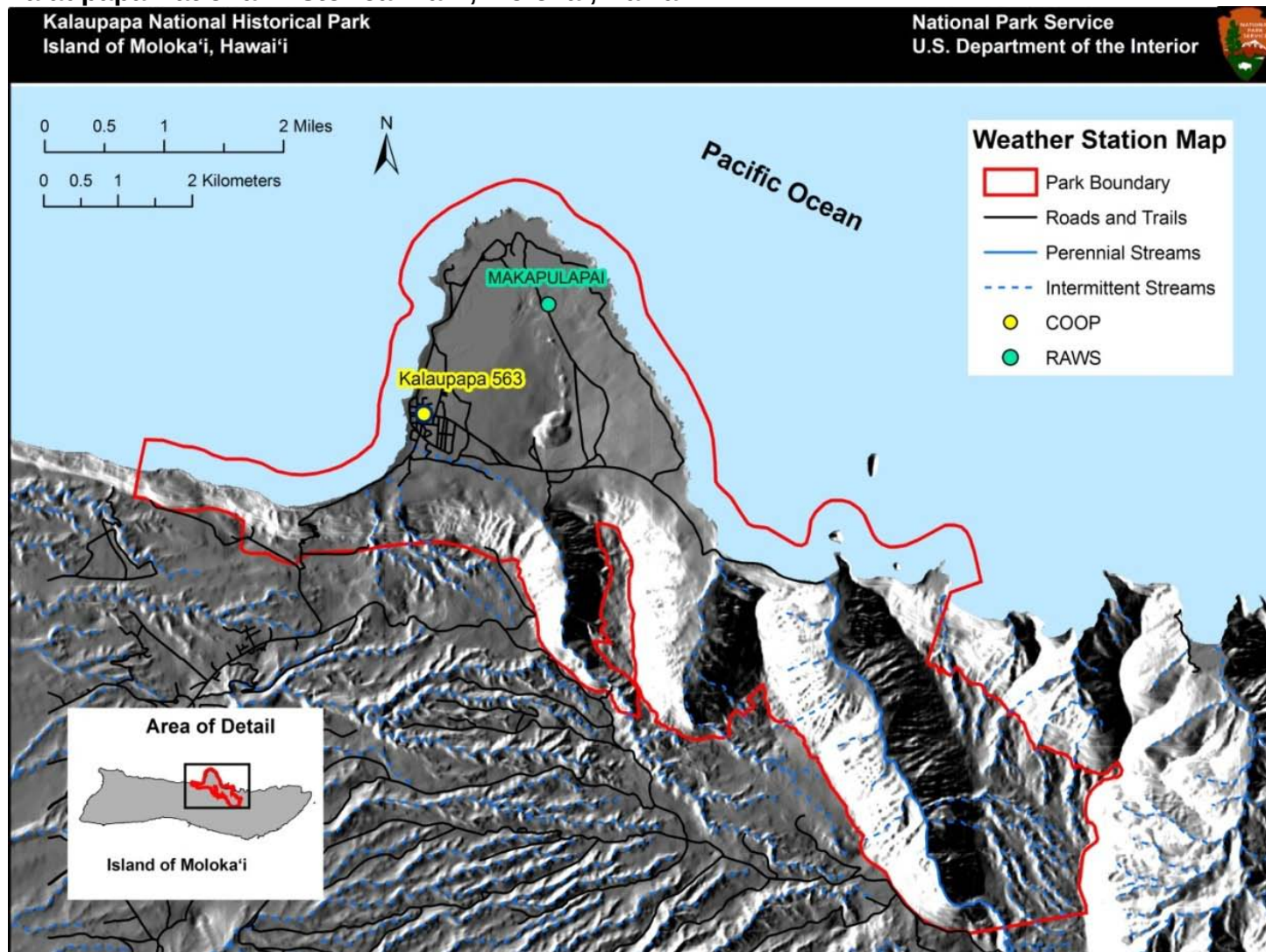


Figure C8. Kalaupapa 563 COOP and Makapulapai RAWS stations are currently used for temperature and precipitation data for Kalaupapa National Historical Park (KALA) on the island of Molokai, Hawaii. Two more Campbell Scientific Inc. RAWS stations will be set up in 2012.