Pacific Drought Knowledge Exchange

Climate Change, Climate Variability, & Drought Portfolio

Mauna Kahālāwai Watershed Partnership

Pacific Islands Climate Adaptation Science Center

EAST-WEST CENTER

FOREST SERVICE U S DEPARTMENT OF AGRICULTURE

2021-10-01

Pacific Drought Knowledge Exchange

Climate change, climate variability, and drought (CCVD) will exert a growing impact on Hawai‘i's landscapes, watersheds, and nearshore areas in the future. Similar impacts will be felt across much of the Pacific as well. While managers are tasked with utilizing the best available science, they are often unaware of what datasets or products are available as there is no centralized, drought-focused information clearinghouse or mechanism to engage with scientists in research, planning, product development, and knowledge co-production. The Pacific Drought Knowledge Exchange (PDKE) funded by the Pacific Islands Climate Adaptation Science Center, focuses on facilitating knowledge exchange between the research community and resource managers and user groups, thereby expanding the utility of climate and drought-related products for resource managers.

EAST-WEST CENTER

Pacific Islands Climate Adaptation Science Center

Forest Service U.S. Department of Agriculture

Pacific RISA

Hawai‘i Water Resources Research Center

NOAA National Oceanic and Atmospheric Administration U.S. Department of Commerce

University of Hawai‘i

CCVD Portfolio

The climate change, climate variability, and drought (CCVD) portfolio is a comprehensive synthesis of climate and drought information developed specifically for Mauna Kahālāwai Watershed Partnership (MKWP). This portfolio is designed to provide both research scientists and land managers with relevant climate and drought information needed to inform land management and guide future research and extension.

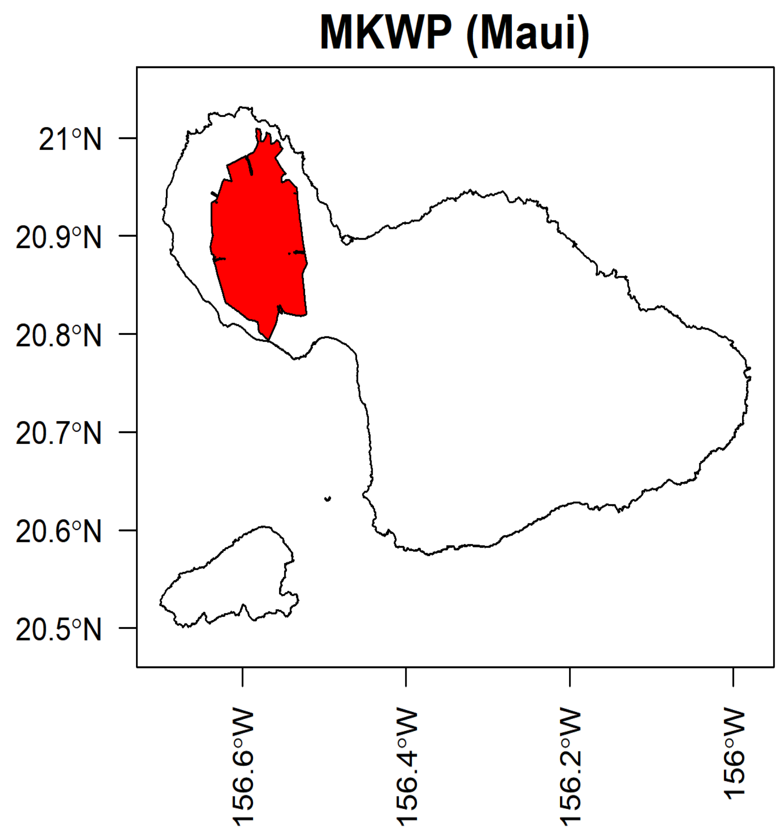


Figure 1. Map of MKWP.

Part 1: Climate Characteristics
MKWP

In developing this Portfolio, we relied on several gridded climate products available for the State of Hawai‘i. Both mean annual and mean monthly estimates of rainfall were are obtained from the Rainfall Atlas of Hawai‘i (http://rainfall.geography.hawaii.edu/). Gridded estimates of other climate variables are obtained from the Climate of Hawai‘i (http://climate.geography.hawaii.edu/). We retrieved all the data points that fell within the boundaries of MKWP from our 250 m resolution state-wide maps to support the presented analyses.

Elevation

MKWP is located on the Island of Maui and covers a vertical elevation range of 5728 ft. In Hawai'i, climate gradients can change significantly over short distances due to changes in elevation, topography, and orientation to the prevailing winds.

Elevation MKWP

Minimum = 55 ft
Mean = 2365 ft
Maximum = 5783 ft

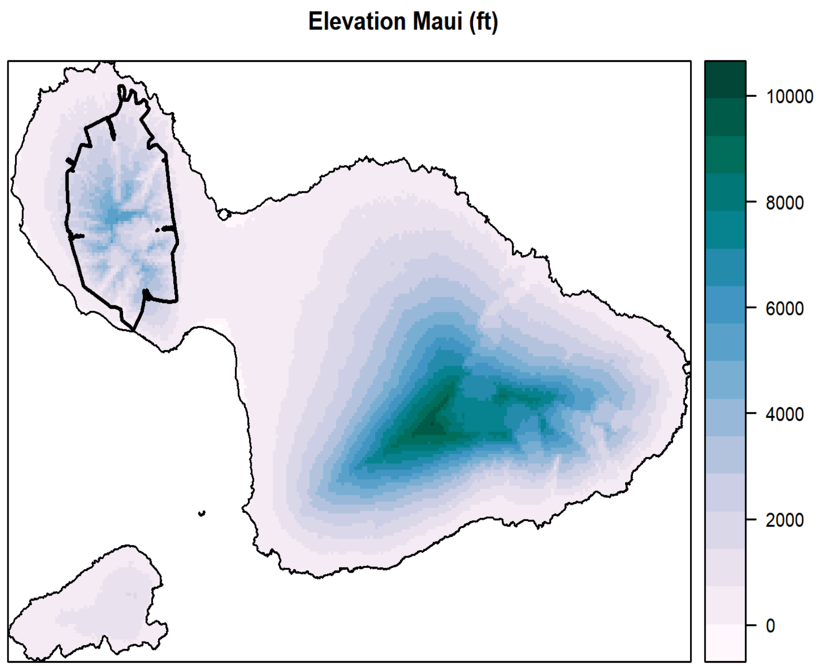


Figure 2. Elevation for the Island of Maui with MKWP outlined in black. The maps shown in the following slides will be for the MKWP area only.

Average Annual Climate Characteristics

RF- Rainfall
Spatial Range: 15 to 366 in
RH- Relative humidity
Spatial Range: 71 to 86 %
SM- Soil moisture
Spatial Range: 0.21 to 0.9 Ratio
Mean TA- Average temperature
Spatial Range: 49.7 to 74.5 °F
Min TA- Average minimum temperature
Spatial Range: 42.6 to 67.6 °F
Max TA- Average maximum temperature
Spatial Range: 56.5 to 82.8 °F
CF- Cloud cover
Spatial Range: 0.69 to 0.69 Ratio
S- Solar radiation
Spatial Range: 130 to 231 W/m2
ET- Evapotranspiration
Spatial Range: 11 to 53 in

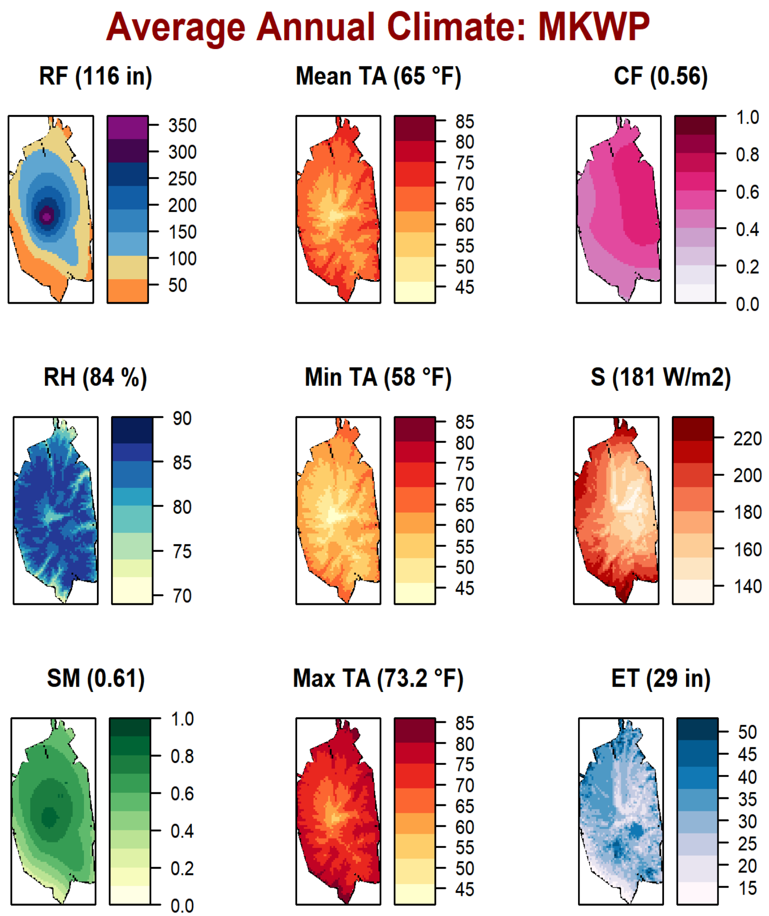


Figure 3. Mean annual climate of MKWP with area average shown in heading of each plot.

Giambelluca et al. (2013;2014)

Average Monthly Rainfall and Temperature

Average monthly rainfall and temperature patterns vary over the course of the year at MKWP. The highest monthly rainfall is received in March (13 in) and the lowest monthly rainfall is received in September (7 in). There is a 6°F annual variation in temperature with the warmest month occurring in August (68 °F) and the coolest month occurring in January (62 °F).

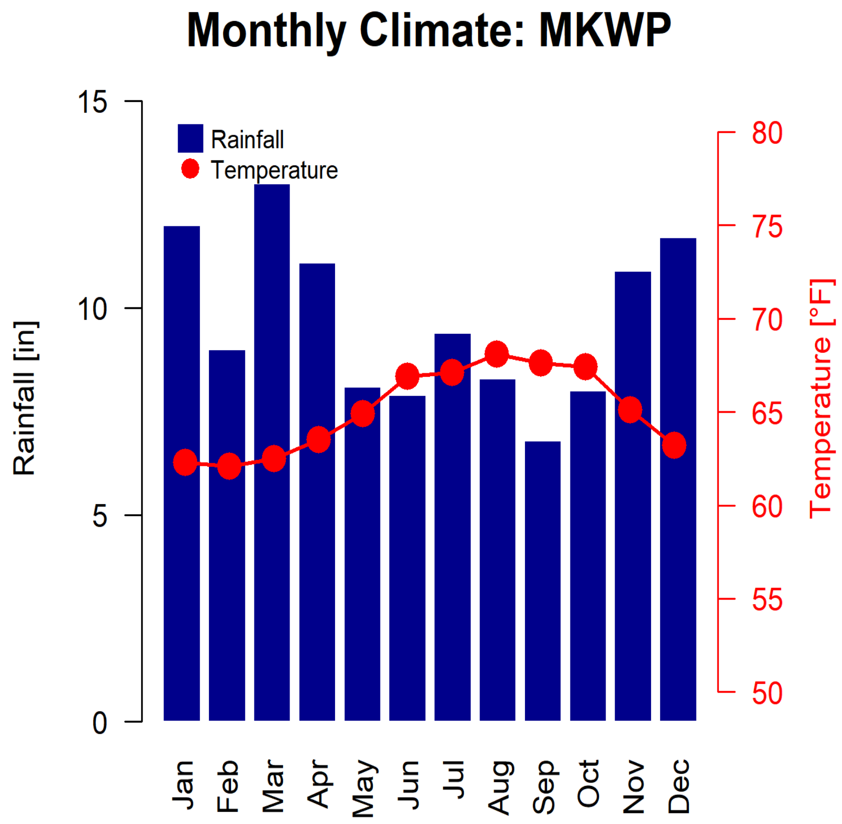


Figure 4. Mean monthly rainfall and temperature at MKWP.

Giambelluca et al. (2013;2014)

Average Monthly Climate

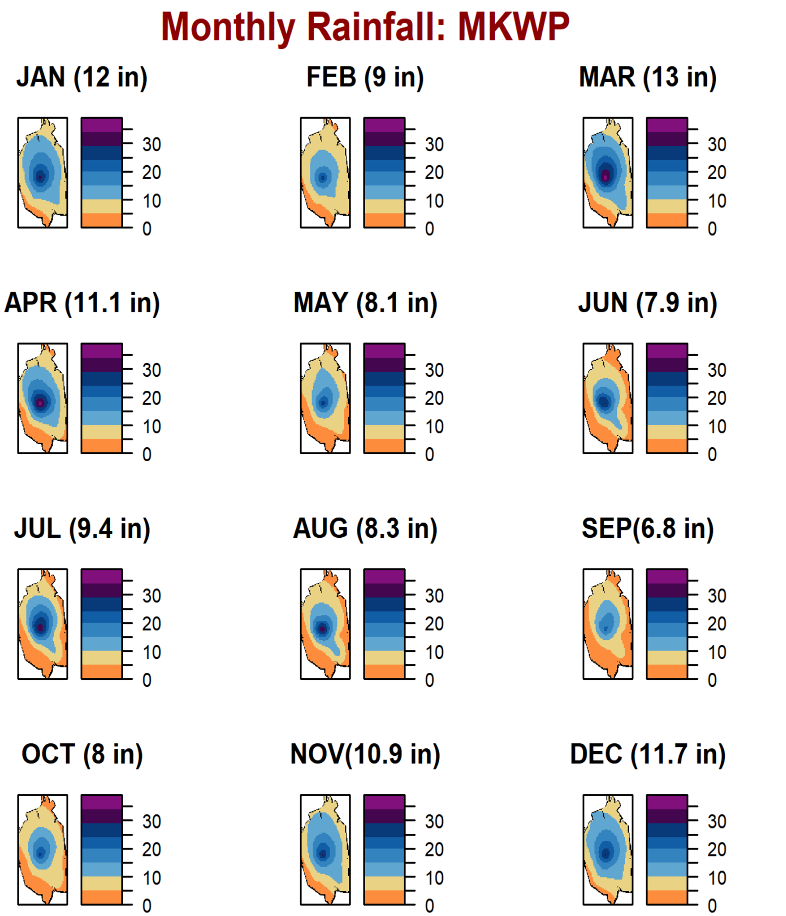


Figure 5. Mean monthly rainfall MKWP with area average shown in heading of each plot.

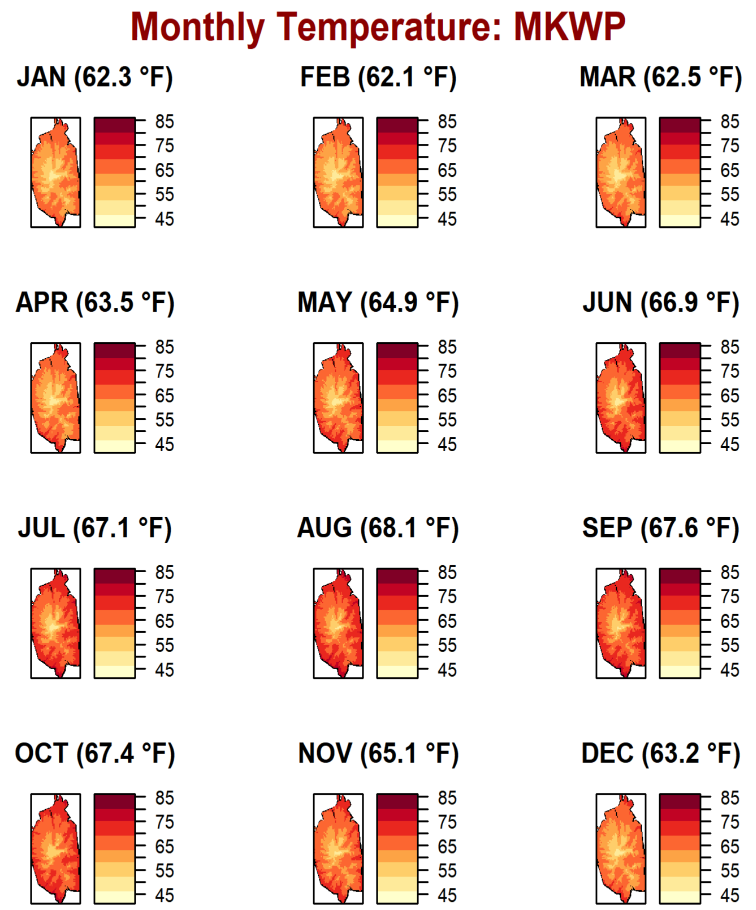


Figure 6. Mean monthly temperature at MKWP with area average shown in heading of each plot.

Giambelluca et al. (2013;2014)

Average Seasonal Rainfall

Hawai'i has two distinct 6-month seasons of rainfall. The Dry season runs from October to May and the Wet season runs from November to April. At MKWP, dry season rainfall averages 8.1 inches per month (48 inches total) and wet season rainfall averages 11.2 inches per month (67 inches total). Across the entire unit, rainfall ranges from 0.3 to 28.7 inches per month (2 to 172 total) during the dry season and 2.2 to 32.3 during the wet season (13 to 194 total).

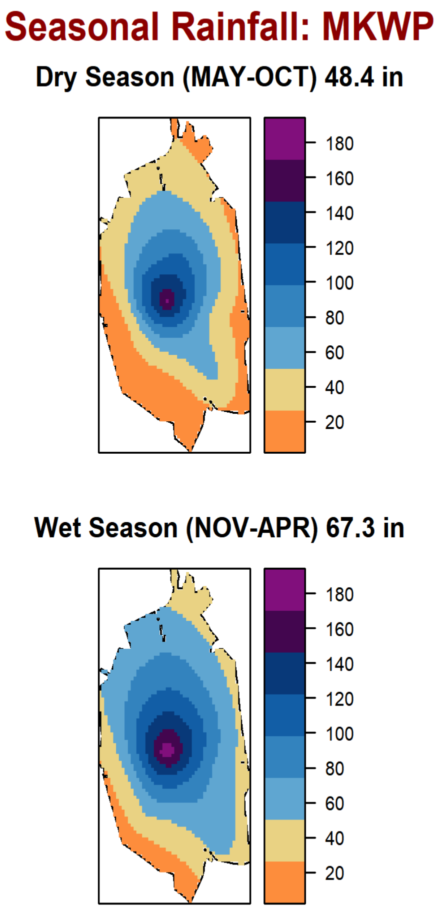


Figure 7. Dry and Wet season total rainfall at MKWP.

Giambelluca et al. (2013)

Average Monthly Climate Table

MKWP

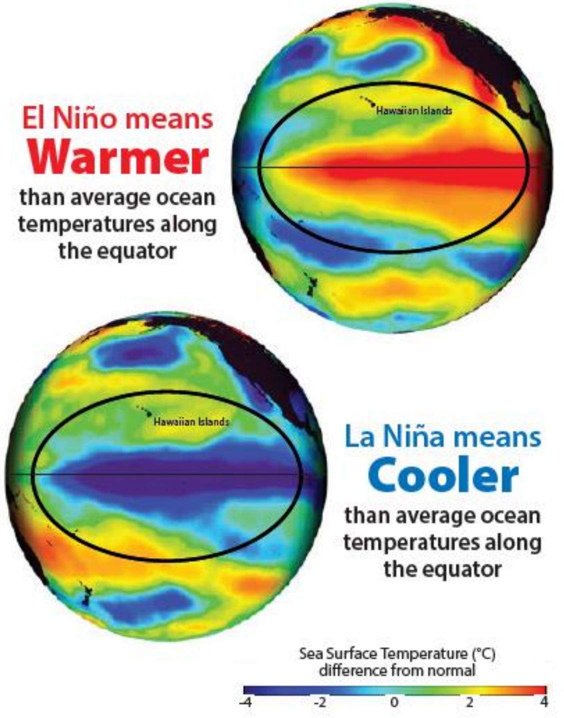
Variable	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
RF [in]	12.0	9.0	13.0	11.1	8.1	7.9	9.4	8.3	6.8	8.0	10.9	11.7	116.0
Min TA [°F]	55.1	55.0	55.5	56.6	57.9	59.7	60.3	61.0	60.4	60.0	58.6	56.6	58.0
Mean TA [°F]	62.3	62.1	62.5	63.5	64.9	66.9	67.1	68.1	67.6	67.4	65.1	63.2	65.0
Max TA [°F]	71.3	70.9	71.1	71.4	72.8	74.8	74.8	76.1	76.4	75.7	73.2	71.4	73.2
RH [%]	82.0	82.0	84.0	86.0	85.0	86.0	85.0	84.0	84.0	84.0	83.0	82.0	84.0
CF [%]	53.0	60.0	65.0	63.0	58.0	55.0	54.0	50.0	45.0	55.0	57.0	53.0	56.0
ET [in]	2.0	2.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.0	2.0	2.0	29.0
SM [%]	66.0	64.0	65.0	65.0	61.0	56.0	56.0	56.0	55.0	56.0	62.0	65.0	61.0
S [W m/2]	147.0	162.0	179.0	193.0	207.0	216.0	209.0	211.0	205.0	169.0	142.0	138.0	181.0

Table 1. Average monthly climate variables characteristics at Mauna Kahālāwai Watershed Partnership. Where, RF is rainfall; Min TA is average minimum air temperature Mean TA is average air temperature; Max TA is average maximum air temperature; RH is relative humidity; CF is cloud frequency; ET is evapotranspiration; SM is soil moisture; S is shortwave downward radiation: ANN, is annual total for rainfall and annual average for all other variables.

Part 2: Inter-Annual Rainfall

MKWP

Rainfall in Hawai'i can vary greatly from year-to-year due to natural modes of climate variability such as the El Niño-Southern Oscillation (ENSO). ENSO can be explained as an interaction between the atmosphere and the ocean in the tropical Pacific that results in a somewhat periodic variation between below-normal and above-normal sea surface temperatures. In Hawai'i, wet season rainfall is typically low during the warm (El Niño) phase of ENSO and high during the neutral and Cool (La Niña) Phases. This pattern is reversed in the dry season although it is not as pronounced as in the wet season. ENSO is the dominant mode of climate variability in Hawai'i.



Wet Season Rainfall vs El Niño/La Niña

93-years of monthly wet season rainfall (1920-2012) are compared with the Multivariate ENSO Index (MEI) to determine how rainfall is influenced by five different ENSO phases. During the strong El Niño phase, average monthly wet season rainfall (8 in/month) is 29% drier than the long-term average (11.2 in/month).

Table 2. ENSO phases and abbreviations corresponding to Figure 8.

SEL	Strong El Niño
WEL	Weak El Niño
NUT	Neutral
WLA	Weak La Niña
SLA	Strong La Niña

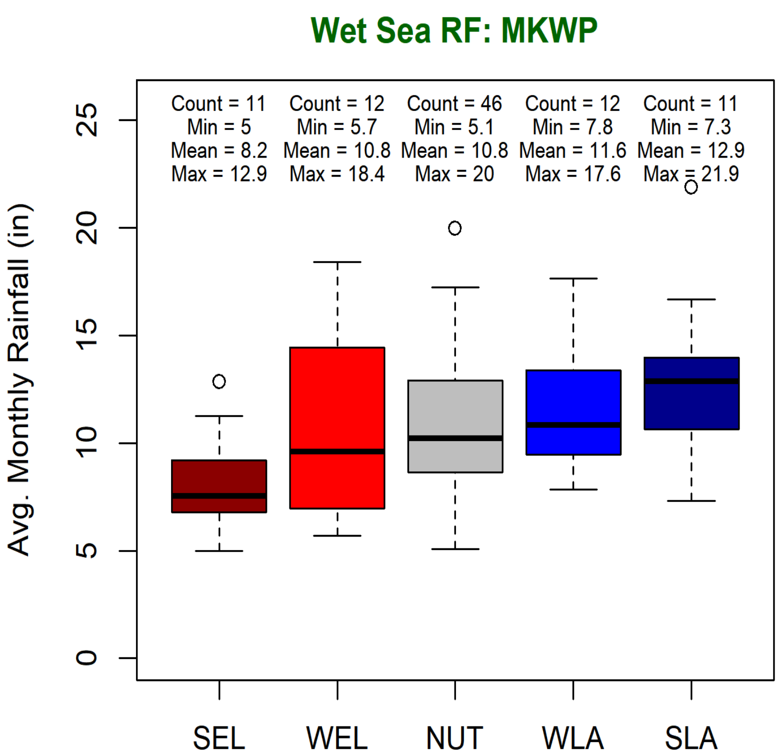


Figure 8. Boxplot of wet season monthly rainfall grouped by ENSO category. MKWP.

Frazier et al. (2016); Wolter and Timlin (2011)

Long-Term Trends in Rainfall

Linear trends in annual, wet season, and dry season rainfall are calculated over a 100-year record at MKWP for six different periods in the record. Each trend period has a unique start year, but they all end in 2019. When the p-value is less than 0.05, the trend is determined to be statistically significant.

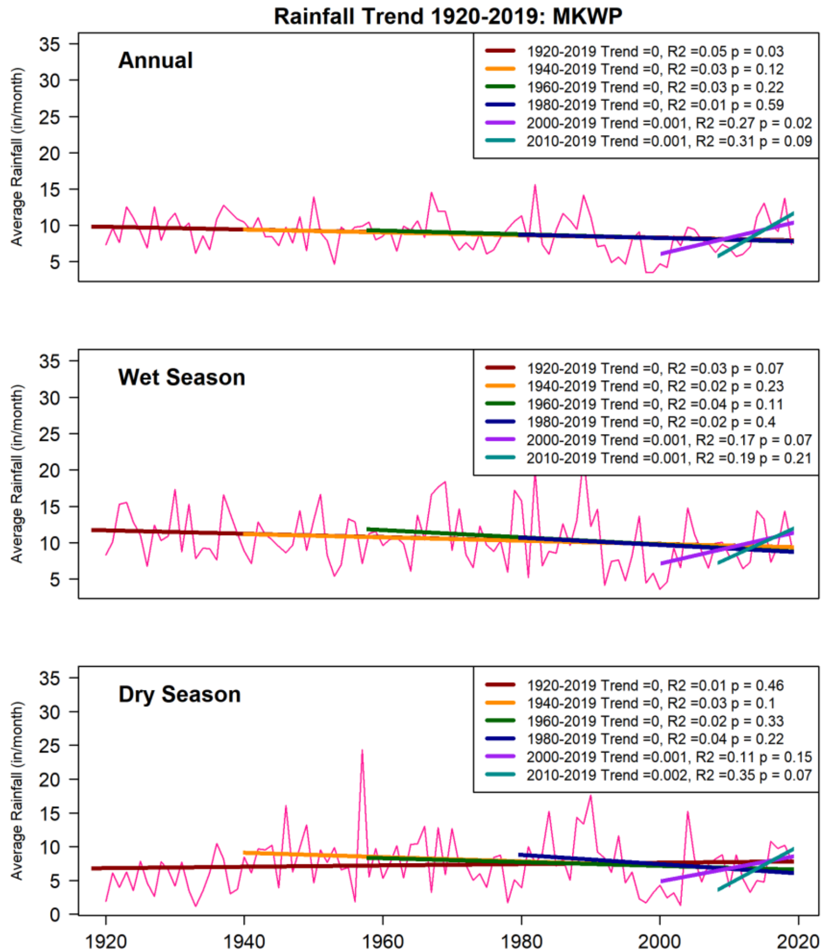


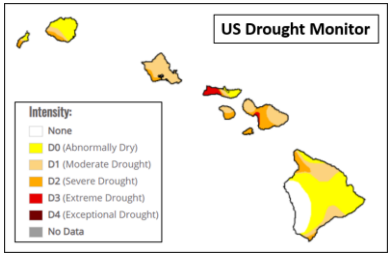
Figure 9. 100-year (1920-2019) rainfall time series at MKWP with linear trends calculated over six unique periods in the record; Trend is the slope (inches per year); R2 is the strength of the trend; p is a measure of the statistical significance.

Frazier et al. (2016); Lucas et al. (In Prep); See Annex I

Part 3: Drought and Fire History
MKWP

Drought is a prominent feature of the climate system in Hawai'i and can cause severe impacts across multiple sectors. Droughts in Hawai'i often result in reduced crop yields, loss of livestock, drying of streams and reservoirs, depletion of groundwater, and increased wildland fire activity. These impacts can cause substantial economic losses as well as long-term damage to terrestrial and aquatic habitats.

5-Types of Drought



Meteorological Drought.
Defined as a lack of rainfall

Ecological Drought
Includes any impacts to ecosystems including an increase in wildfire occurrence

Agriculture Drought
Refers to a period of declining soil moisture and subsequent crop failure

Socio-Economic Drought
Includes impacts to social and economic systems, including increased costs or revenue losses, and impacts on public health and safety

Hydrological Drought
Expressed as decreased streamflow and sub-surface water storage

Frazier et al. (2019)

Identifying Droughts Using the Standard Precipitation Index

The Standardized Precipitation Index (SPI) is one of the most widely used drought indices. SPI compares rainfall with its multi-year average, and because droughts are generally defined relative to the local normal, this standardized index allows wet and dry climates to be represented on a common scale. Here, Here, 100-years of monthly rainfall are used to used to calculate SPI-12, which compares how a 12-month period compares with all 12-month periods in the record. SPI-12 is a good measure of sustained droughts that affect hydrological processes at MKWP.

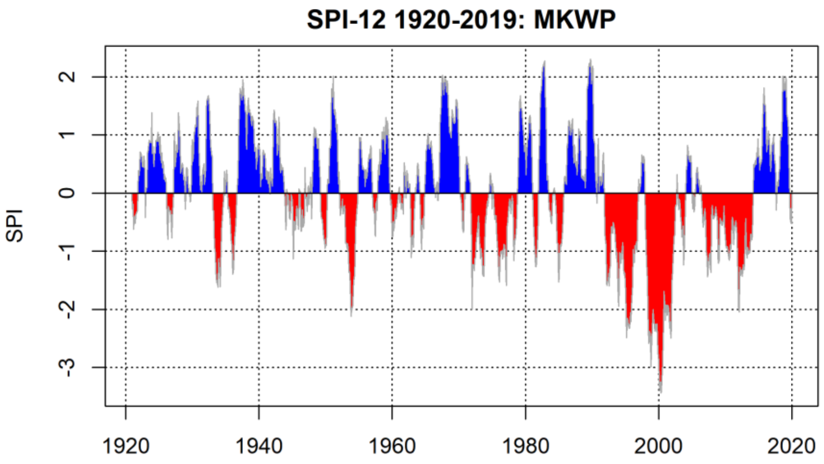


Figure 10. 100-year (1920-2019) SPI-12 time series at MKWP positive SPI (blue) indicate wet periods, negative SPI (red) indicate dry periods.

Frazier et al. (2016); Lucas et al. (In Prep)

A 100-Year History of Drought

Negative SPI values (dry periods) are inverted to show a complete drought timeseries at MKWP. Dashed lines and corresponding color coding indicates instances of Moderate (SPI > 1), Severe (SPI > 1.5), and Extreme (SPI > 2) drought.

A total of 13 Droughts were observed over the 100-year record with total of 8 drought events of severe strength or greater. The longest drought lasted for a total of 101 months (see Table 2 on next slide).

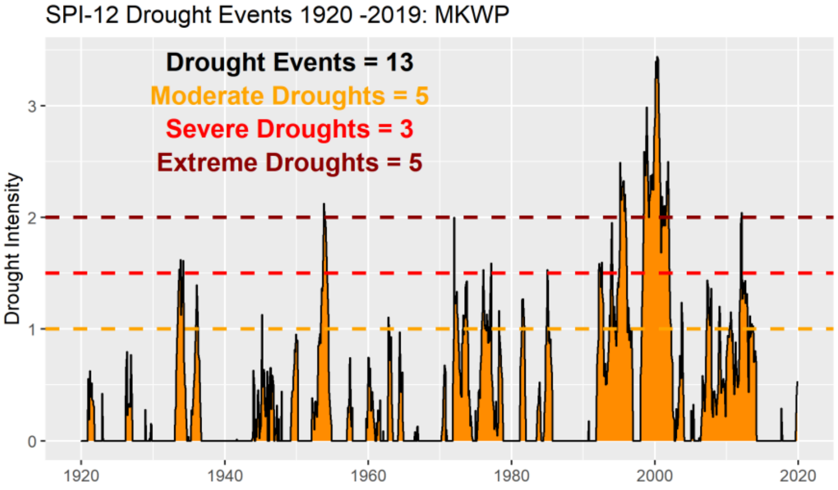


Figure 11. 100-year (1920-2019) SPI time series (reversed axis) at MKWP. Dashed lines show, moderate (yellow), severe (red), and extreme (dark red), drought thresholds.

Frazier et al. (2016); Lucas et al. (In Prep)

Drought Events (1920-2019)
MKWP

Start Date	End Date	Duration (months)	Average Intensity	Peak Intensity	Magnitude
1920-12	1934-10	49	0.6	1.6	30.0
1934-12	1936-10	18	0.6	1.4	11.3
1941-09	1946-01	25	0.3	1.1	8.7
1946-04	1954-12	59	0.7	2.1	42.8
1957-02	1963-07	41	0.4	1.1	16.2
1964-03	1974-08	53	0.7	2.0	35.9
1975-01	1978-11	45	0.7	1.6	30.9
1981-03	1982-01	10	0.9	1.3	8.7
1983-07	1985-10	23	0.6	1.5	14.4
1990-10	1997-01	63	1.2	2.5	78.9
1998-01	2002-10	57	2.1	3.4	117.7
2002-12	2004-03	15	0.5	1.2	7.0
2005-02	2014-04	101	0.8	2.0	76.6

Table 2. SPI-12 drought characteristics at Mauna Kahālāwai Watershed Partnership identified in the SPI-12 timeseries. Duration is the number of months the drought persisted; Average Intensity is the average absolute SPI; Peak Intensity is the highest SPI value calculated during the drought Magnitude is sum of absolute SPI values during the drought.

Short-term vs Long-term Droughts

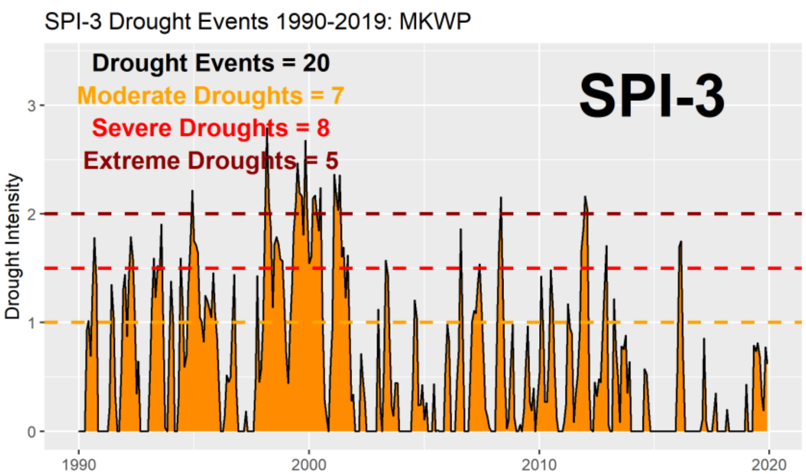


Figure 12. 30-year (1990-2019) SPI-3 time series (reversed axis) at Mauna Kahālāwai Watershed Partnership.

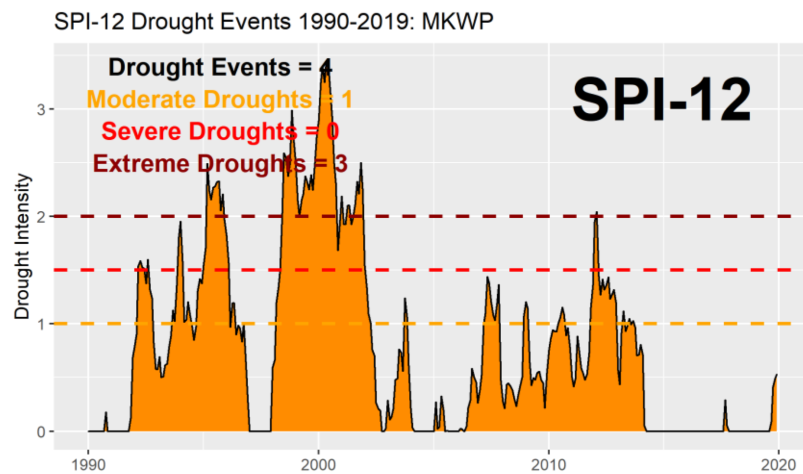


Figure 13. 30-year (1990-2019) SPI-12 time series (reversed axis) at Mauna Kahālāwai Watershed Partnership.

The SPI-3 provides a comparison of the precipitation over a specific 3-month period and reflects short- and medium-term moisture conditions over the 30-year period (1990-2019). A total of 20 droughts were observed at MKWP. Over this same time period, only 4 droughts were identified when looking at the SPI-12 timeseries. It is important to compare the 3-month SPI with longer time scales. A relatively normal 3-month period could occur in the middle of a longer-term drought that would only be visible at longer time scales. Looking at longer time scales would prevent a misinterpretation that a drought might be over.

Fire Occurrence Maui

Ecological drought in Hawai‘i is often drives an increase in wildfire occurrence. In Hawai‘i, wildfires are most extensive in dry and mesic non-native grasslands and shrublands. During drought events, wildfire risk in grasslands increases rapidly. Changes in land use that shift agricultural land to non-native cover of fire-prone grasses and shrubs combined with recurring incidences of drought are expected to increase the risk of future wildfire in Hawai‘i.

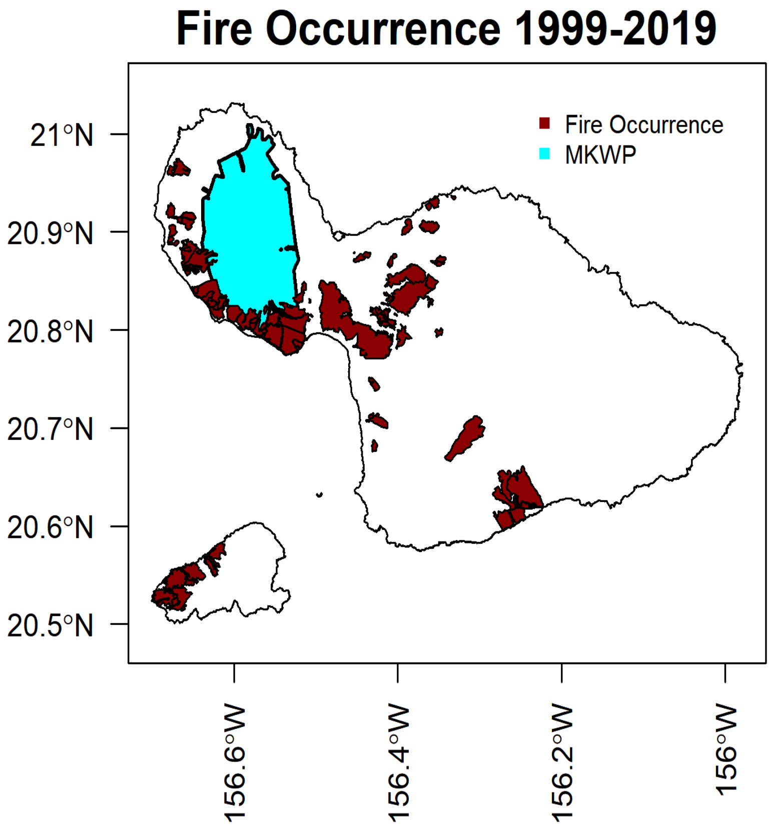


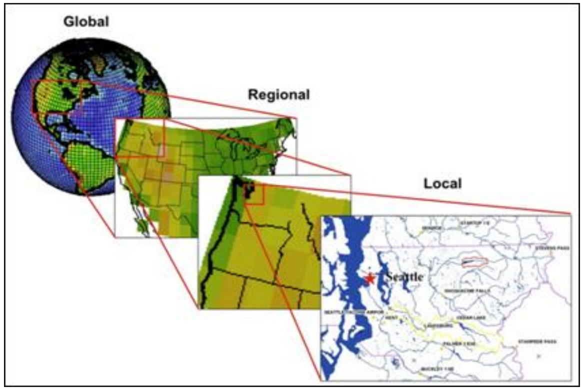
Figure 14. The map shows wildfires that have occurred on the island of Maui between 1999 and 2019.

Trauernicht, 2019; Frazier et al. (In Review)

Part 4: Future Climate
MKWP

To simulate future rainfall and temperature, Global Climate Models are used. These can simulate future conditions under different scenarios for how much carbon dioxide we emit into the air. Two common scenarios are used: RCP 4.5 which assumes we reduce our carbon emissions, and RCP 8.5, a high emissions scenario. The outputs from global models are too coarse to accurately capture changes over the complex terrain of Hawai'i. Therefore, we use an additional step called Downscaling to relate the global-scale information down to the local island scale.

In Hawaiʻi, two types of downscaled projections are available.
Dynamical Downscaling (End of Century)
Statistical Downscaling (Mid & End of Century)
Results for both types of downscaling and both scenarios will be shown here.



See Annex II

Average Rainfall Change 2100 Year 2100

Rainfall in the Year 2100

Annual
-30 to 1 in/year
(-26 to 1 % Change)
Dry Season
-3 to 0 in/month
(-32 to 3 % Change)
Wet Season
-3 to -1 in/month
(-23 to -5 % Change)

The range in projections include estimates for both low emissions (RCP 4.5) and high emissions (RCP 8.5) scenarios, and for both Dynamical and Statistical Downscaling approaches.

Dynamical and Statistical DS RCP 8.5, 2100

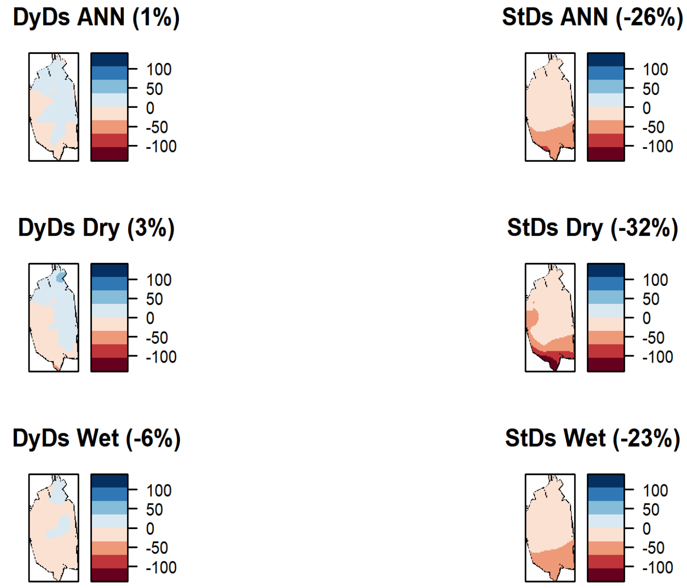


Figure 15. Downscaled future rainfall projections (% Change; (2100) at MKWP, Dynamical Downscaling (DyDS), Statistical Downscaling (StDs), for annual (ANN), dry season (DRY) and wet season (WET).

Elison Timm et al., 2015; Zhang et al., 2016; See Annex II

Average Rainfall Change 2040-2070

Rainfall for Years 2040-2070

Annual
-22 to -20 in/year
(-19 to -17% Change)
Dry Season
-2 to -1 in/month
(-25 to -18% Change)
Wet Season
-2 to -2 in/month
(-16 to -16% Change)

The range in projections include estimates for both low emissions (RCP 4.5) and high emissions (RCP 8.5) scenarios, for the Statistical Downscaling approach.

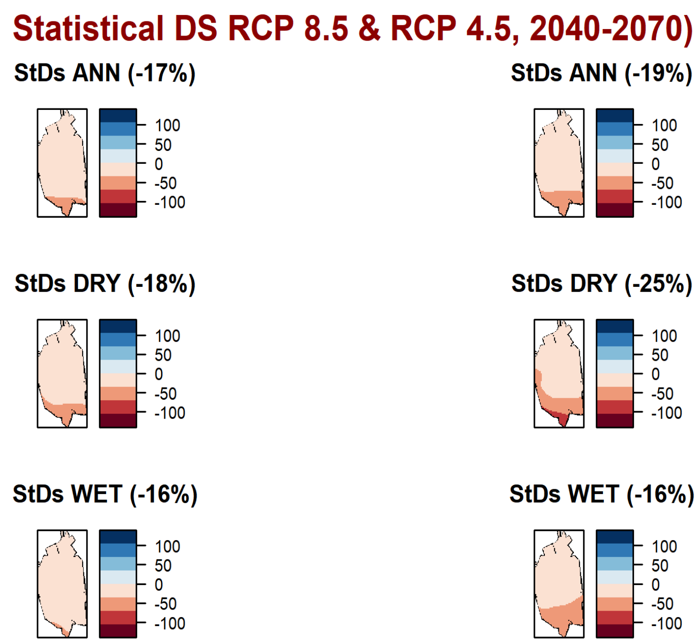


Figure 16. Downscaled future rainfall projections (% Change; 2040-2070) at MKWP, for the Statistical Downscaling (StDs) approach, for annual (ANN), dry season (DRY), and wet season (WET) for RCP 4.5 (left) and RCP 8.5 (right).

Elison Timm et al., 2015; See Annex II

End-of-Century Change in Temperature

Mean Temperature Now
65°F

Mean Temperature 2100
68°F to 70.8°F
(3°F to 5.8°F Change)

The range in projections include estimates for both low emission (RCP4.5) and high emissions (RCP8.5) scenarios, for both the Dynamical and Statistical Downscaling approaches.

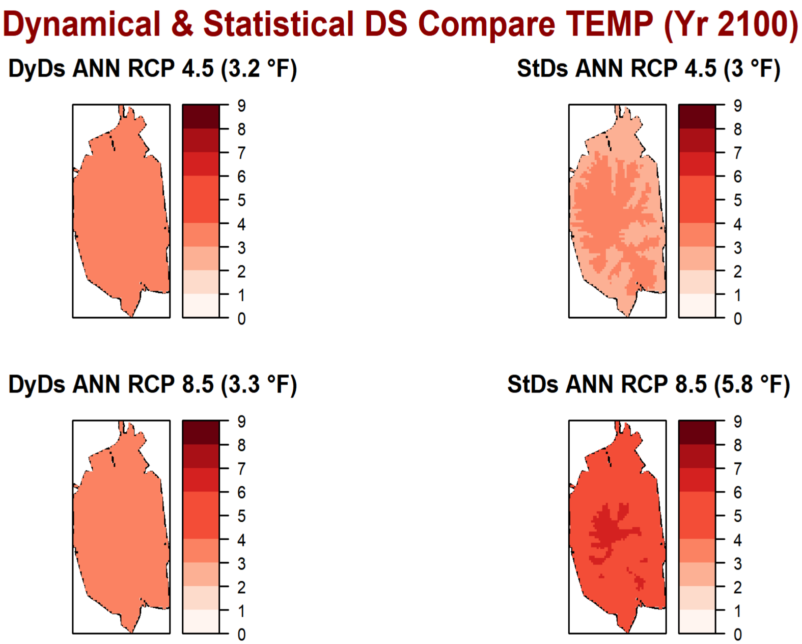


Figure 17. Downscaled projected change in mean temperature (Year 2100) at MKWP, Dynamical Downscaling (DyDs), Statistical Downscaling (StDs).

Elison Timm 2017; Zhang et al., 2016; See Annex II

Mid-Century Change in Temperature

Mean Temperature Now
65°F

Mean Temperature 2040-2070
67.3°F to 68.3°F
(2.3°F to 3.3°F Change)

The range in projections include estimates for both low emission (RC 4.5) and high emissions (RCP 8.5) scenarios, for the Statistical Downscaling approach.

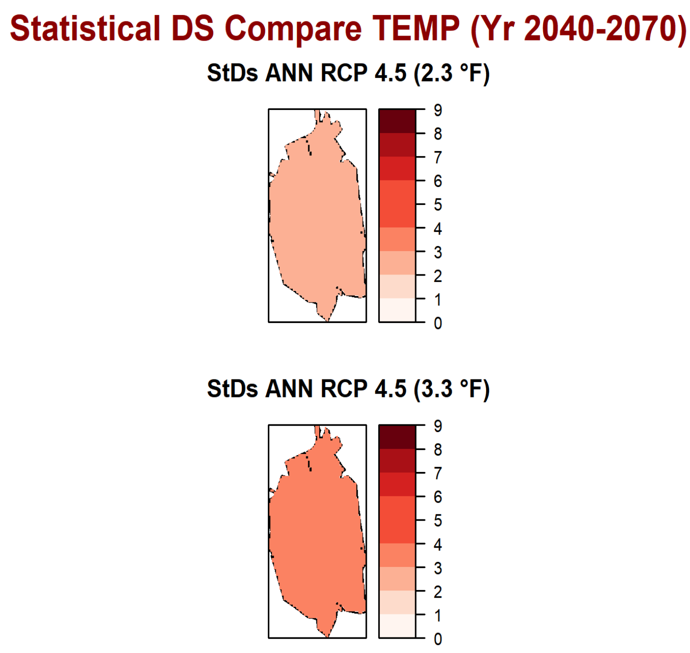


Figure 18. Downscaled Future temperature projections (2040-2070) at MKWP for the Statistical Downscaling (StDs) approach.

Part 5: CCVD Summary

MKWP

Mauna Kahālāwai Watershed Partnership (MKWP) is located on the island of Maui at mean elevation of 2365 ft (range: 55 to 5783 ft). Rainfall varies over the course of the year with a maximum of 13 inches, occurring in March and a minimum of 7 inches occurring in September. On average, wet season months (Nov-Apr) receive 3.1 in of more rainfall than dry season months (May-Oct). Seasonal rainfall can vary within the unit as well, with dry season rainfall ranging from 2 to 172 inches and wet season rainfall ranging from 13 to 194 inches across the 5728 ft elevation gradient. Rainfall can also vary considerably from year-to-year with the driest years occurring during a Strong El Niño event, when on average, 29% less rainfall is received, relative to the long-term average. The average temperature at MKWP is 65°F but temperature ranges from 62°F to 68°F over the course of the year. Drought is a reoccurring feature in the climate system of MKWP with a total of 13 occurring over the record which is approximately 1.3 per decade. A total of 8 drought events were at severe strength or greater and the longest drought lasted for a total of 101 consecutive months. Future projections of rainfall are uncertain, with end-of-century annual changes ranging from -26 to 1% and more pronounced changes occurring during the wet and dry seasons. Future projections of temperature suggest an increase of 2.3°F to 3.3°F by mid century (2040-2070) and an increase of 3°F to 5.8°F by the end of the century (2100).

External Resources

<u>**For more Information**</u>

US Drought Monitor
https://droughtmonitor.unl.edu/

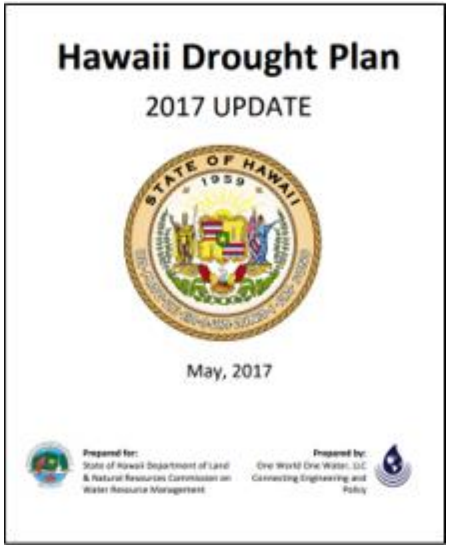
State of Hawai‘i Drought Plan
https://files.hawaii.gov/dlnr/cwrm/planning/HDP2017.pdf

Rainfall Atlas of Hawai‘i
http://rainfall.geography.hawaii.edu/

Climate Of Hawai‘i
http://climate.geography.hawaii.edu/

ENSO Current Phase and Discussion
https://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory/ensodisc.shtml

Pacific Fire Exchange
https://www.pacificfireexchange.org/



Acknowledgements

Mari-Vaughn Johnson, Heather Kerkering, Darcy Yogi (PI-CASC), Victoria Keener, Laura Brewington (East-West Center Pacific-RISA), Melissa Kunz, Clay Trauernicht (NREM, UH Manoa), Katie Kamelamela (USDA, Forest Service), Thomas Giambelluca (WRRC, UH Manoa), and John Marra (NOAA).

Suggested Citation

Longman, R.J, Frazier, A.G., Giardina, C.P (2021). Climate Change, Climate Variability and Drought Portfolio Mauna Kahālāwai Watershed Partnership Pacific Drought knowledge Exchange CCVD Series Version 2.1, 32pp.

For the most up-to-date version of this portfolio contact Ryan Longman: rlongman@Hawai'i.edu for more information.

Works Cited

Elison Timm, O., 2017: Future warming rates over the Hawaiian Islands based on elevation-dependent scaling factors. *Int. J. Climatol.*, **37**, 1093–1104, doi:10.1002/joc.5065.

——, T. W. Giambelluca, and H. F. Diaz, 2015: Statistical downscaling of rainfall changes in Hawai'i based on the CMIP5 global model projections. *J. Geophys. Res.*, **120**, 92–112, doi:10.1002/2014JD022059.

Frazier, A. ., and Coauthors, A century of spatial and temporal patterns of drought in Hawai'i across hydrological, ecological, and socioeconomic scales. *In Review. Sci. Total Environ.*,.

Frazier, A. G., T. W. Giambelluca, H. F. Diaz, and H. L. Needham, 2016: Comparison of geostatistical approaches to spatially interpolate month-year rainfall for the Hawaiian Islands. *Int. J. Climatol.*, doi:10.1002/joc.4437.

Giambelluca, T. W., Q. Chen, A. G. Frazier, J. P. Price, Y. L. Chen, P. S. Chu, J. K. Eischeid, and D. M. Delparte, 2013: Online rainfall atlas of Hawai'i. *Bull. Am. Meteorol. Soc.*, **94**, 212–316, doi:10.1175/BAMS-D-11-00228.1.

Giambelluca, T. W., and Coauthors, 2014: Evapotranspiration of Hawai'i Final Report.

Lucas, M. P., R. J. Longman, T. W. Giambelluca, A. F. Frazier, and J. H. Lee, Mapping 30-years of monthly rainfall using an automated kriging approach. *In Review. Data*,.

Trauernicht, C., 2020: Hawaii Fire Occurrence Map (2000-2019). *Unpublished*,.

Wolter, K., and M. S. Timlin, 2011: El Niño/Southern Oscillation behaviour since 1871 as diagnosed in an extended multivariate ENSO index (MEI.ext). *Int. J. Climatol.*, **31**, 1074–1087, doi:10.1002/joc.2336.

Zhang, C., Y. Wang, K. Hamilton, and A. Lauer, 2016: Dynamical downscaling of the climate for the Hawaiian islands. Part II: Projection for the late twenty-first century. *J. Clim.*, **29**, 8333–8354, doi:10.1175/JCLI-D-16-0038.1.

Annex I: 100-Year Rainfall

The 100-year monthly rainfall dataset was drawn from two unique gridded products. We used data from Frazier et al. (2016) for the period 1920-1989 and Lucas et al. (In Review) for the period 1990-2019. Given that two unique data sets and methods were used to make these two products we show the 1:1 Statistical relationship between the two products for a 23-year overlap (1990-2012) with the datasets and associated error metrics.

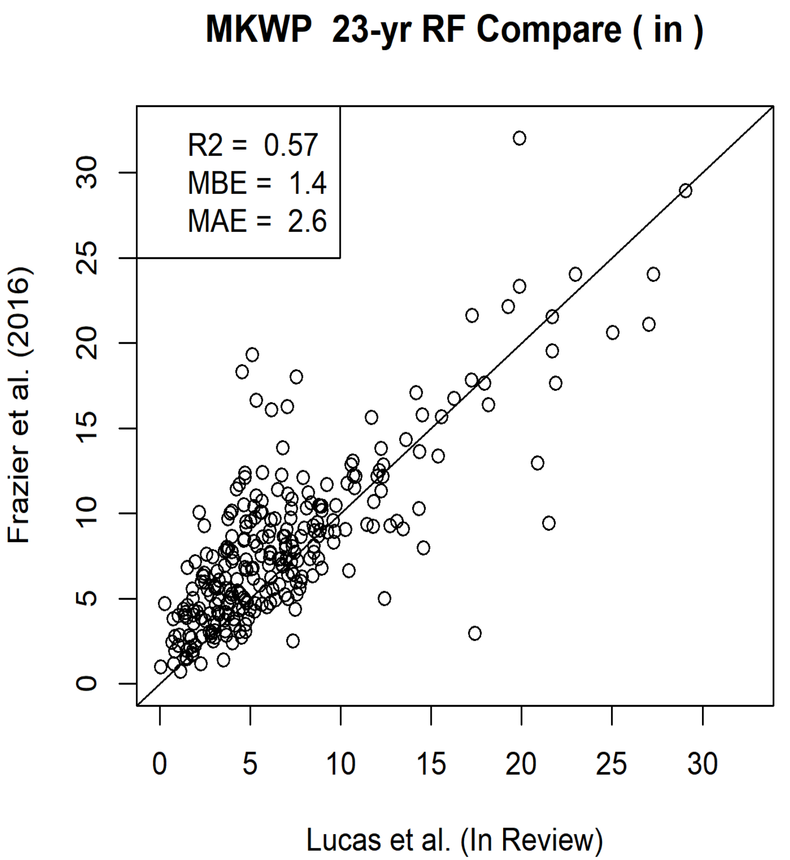
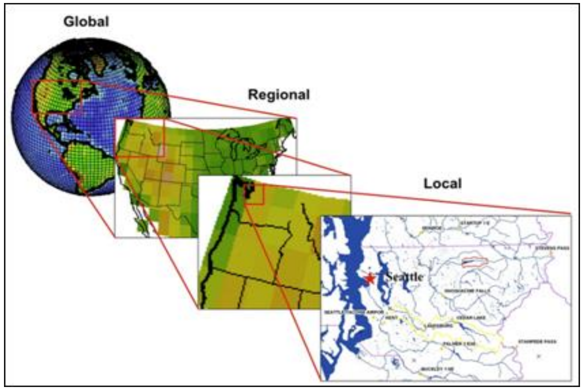


Figure A1: One to one comparison of 23-years (1990-2012) of monthly rainfall from two unique datasets for MKWP, and associated error metrics; R2, is the coefficient of determination, MBE, is the mean bias error, MAE, mean absolute error.

Frazier et al., 2016; Lucas et al., (In Review)

Annex II: Climate Downscaling in Hawai‘i

Two types of downscaling products were used in this analysis. Here we explain some of the nuances between the two. Dynamical Downscaling (Zhang et al., 2016), feeds GCM output into a regional model that can account for local topographic and atmospheric phenomena at much finer resolutions (e.g. 1 km). End-of-century projections (2100) encompass the period 2080-2099. Statistical Downscaling (Elison Timm et al., 2015, Elison Timm, 2017), develops a relationship between GCM model output and station data for a historical period and then uses this established relationship to make projections for two future scenarios. End-of-century projections (2100) encompass the period 2070-2099 (2100), Mid-century projections encompass the period 2040-2070.



Pacific Drought Knowledge Exchange