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Estimating Climate-Change Impacts on Groundwater Recharge for the Island of Maui, Hawai'i

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Pacific Islands Water Science Center

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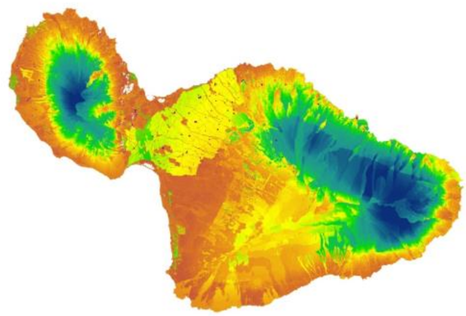

U.S. Department of the Interior
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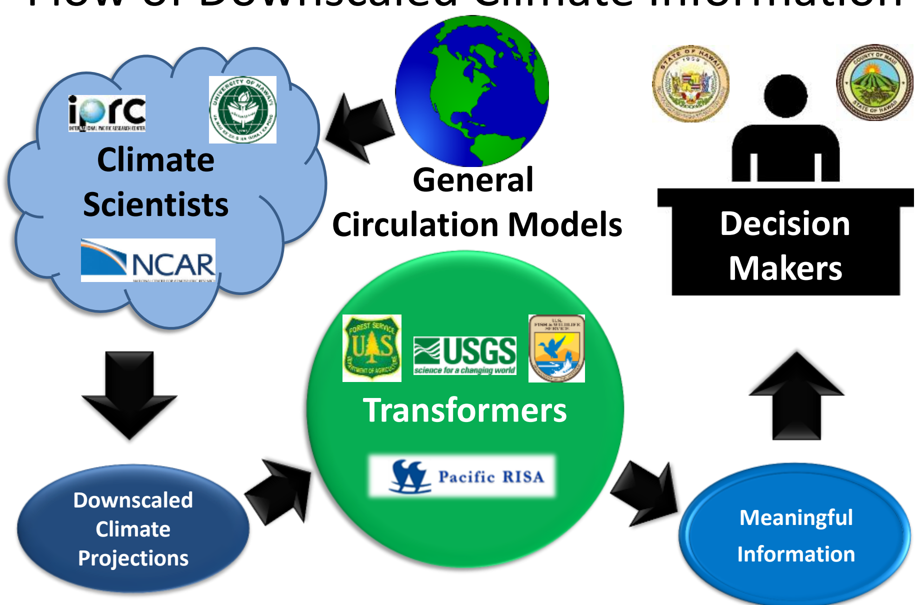
Flow of Downscaled Climate Information



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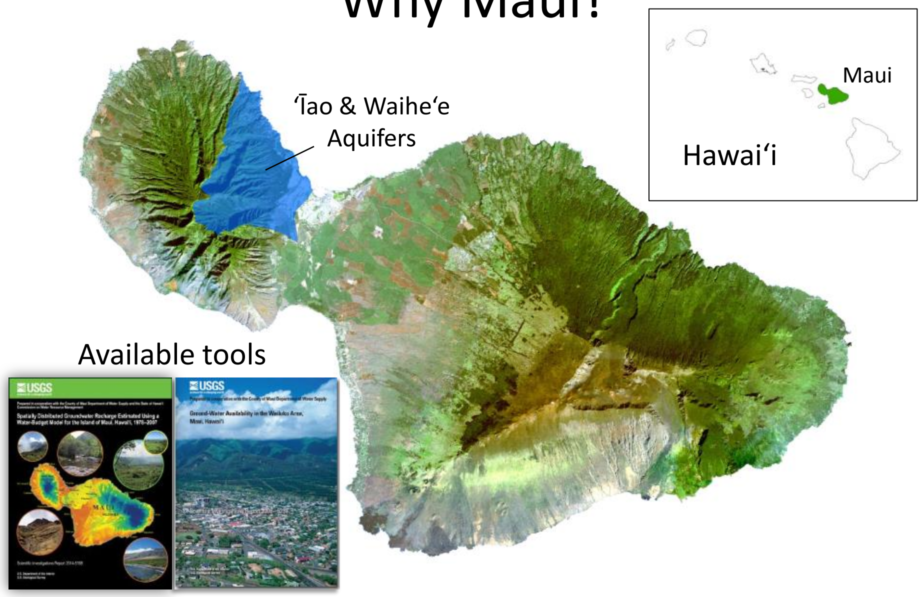
Objectives

- Estimate spatial distribution of groundwater recharge for projected future climate conditions
  – Groundwater recharge is critical input to groundwater models used to assess groundwater availability
  – Groundwater recharge is used by State of Hawaiʻi, Commission on Water Resource Management to compute sustainable yield
- Quantify differences in groundwater-recharge estimates between control (current) climate and future climate

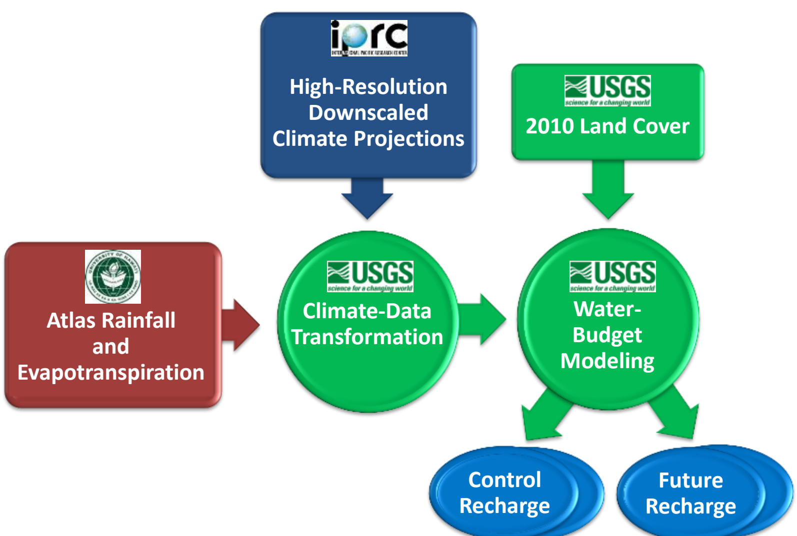
Highlights for Maui

Water-Budget Component - Mean Annual	**Island-Wide Percentage Change**	
	Projected Dry Climate	Projected Wet Climate
Rainfall (from climate models)	***-20%***	***+20%***
Runoff	***-18%***	***+34%***
Total evapotranspiration	***-12%***	***+5%***
Groundwater recharge	***-21%***	***+21%***

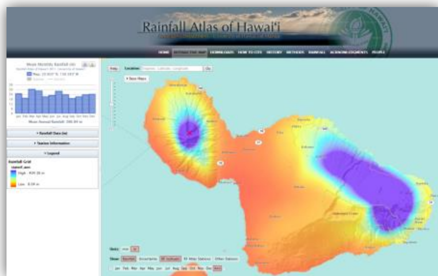
Why Maui?



Water-Budget Modeling Framework



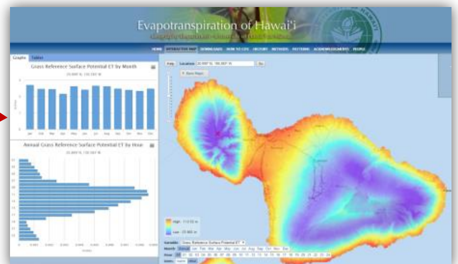
Atlas Rainfall and Evapotranspiration



http://rainfall.geography.hawaii.edu/

Rainfall
- Interpolated maps of monthly rainfall during 1978-2009
- Daily rain-gage data for synthesizing daily rainfall

Evapotranspiration (ET)
- Interpolated maps of mean monthly reference ET for grass



http://evapotranspiration.geography.hawaii.edu/

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High-Resolution Downscaled Climate Projections

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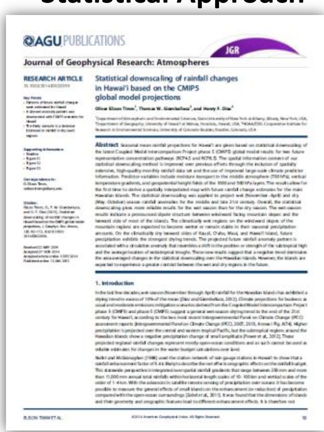
Statistical Approach


AGU PUBLICATIONS

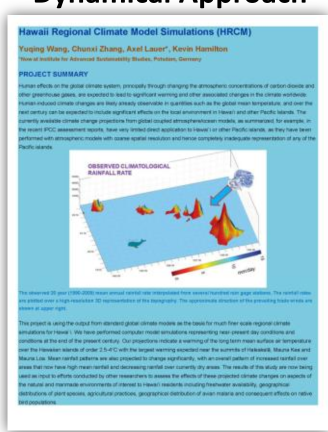
Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE

Statistical downscaling of rainfall changes in Hawai'i based on the CMIP5 global model projections

Elison Timm and others, 2015

Dynamical Approach



Zhang and others, 2012; http://apdrc.soest.hawaii.edu/projects/HRCM/

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Statistical Approach

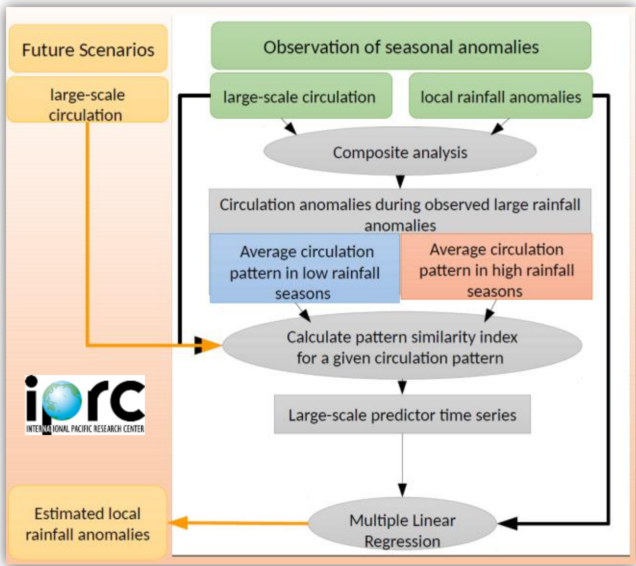

Figure from O.E. Timm

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Dynamical Approach

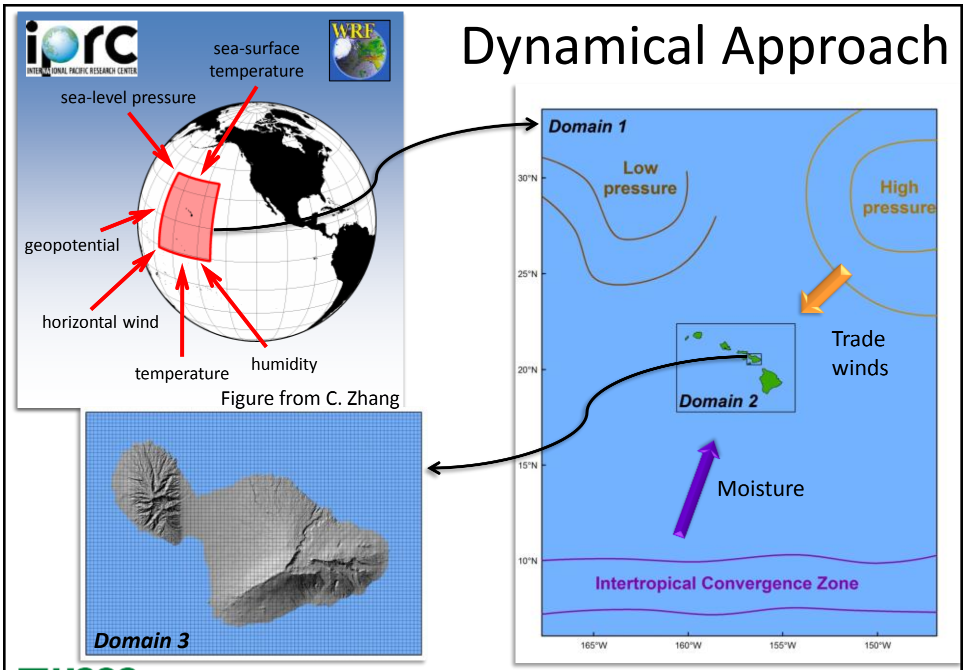

Figure from C. Zhang

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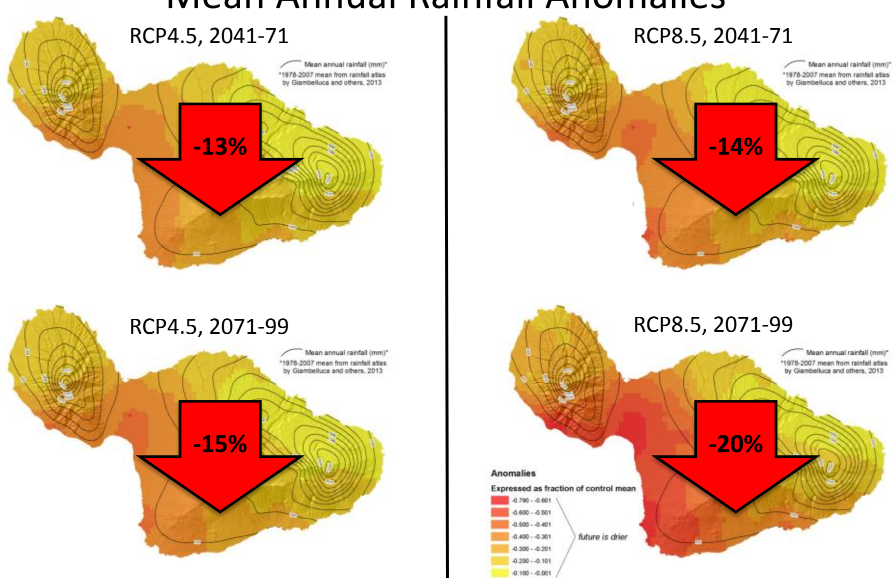
Downscaled Climate Datasets

Feature	Statistical Approach	Dynamical Approach
Coupled Model Intercomparison Project (CMIP) Phase	Phase 5 (CMIP5)	Phase 3 (CMIP3)
Control Climate	Atlas mean monthly rainfall during 1978-2007	Simulated climate during 1990-2009
IPCC Scenario	Representative Concentration Pathway (RCP) 4.5 & 8.5	Special Report on Emissions Scenario (SRES) A1B
Projection Periods	2011-2041, 2041-2071, and 2071-2099	2080-2099

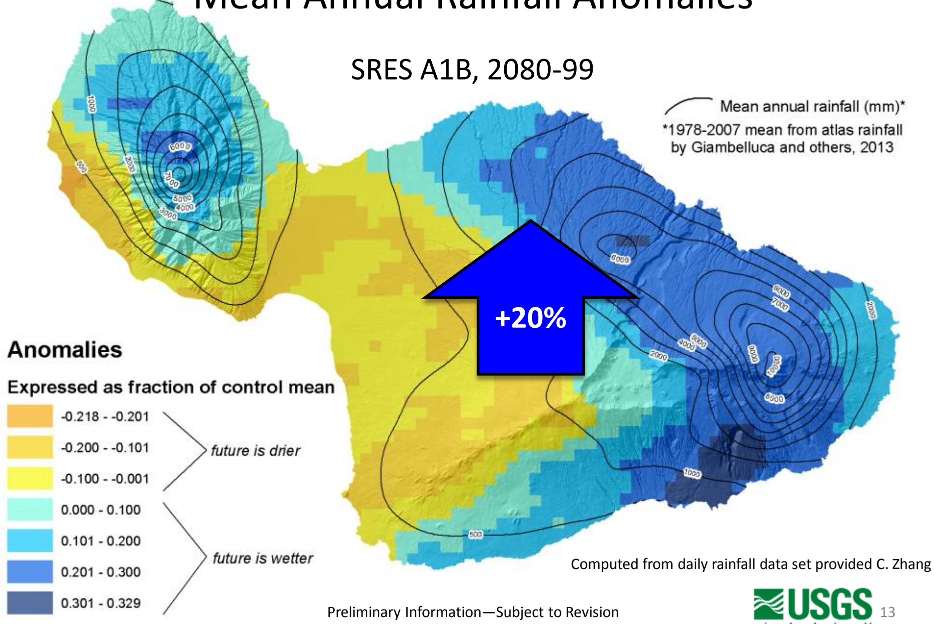
Statistical Approach – Mean Annual Rainfall Anomalies



Elison Timm and others, 2015;
250-m grid maps provided by O.E. Timm

Dynamical Approach – Mean Annual Rainfall Anomalies

SRES A1B, 2080-99



Computed from daily rainfall data set provided C. Zhang

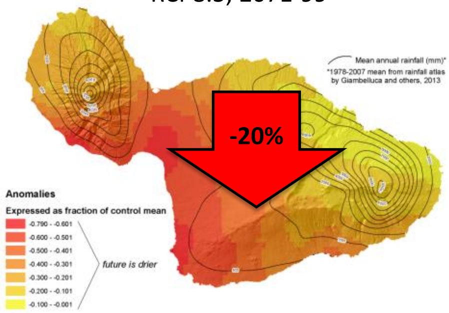
Which set of future rainfall projections should be used for water-resource planning?

- Statistical approach and dynamical approach show opposite trends in mean annual rainfall in many areas
- Simulating the driest and wettest rainfall conditions captures the range of uncertainty in existing set of climate projections

Selected Future Climate Scenarios

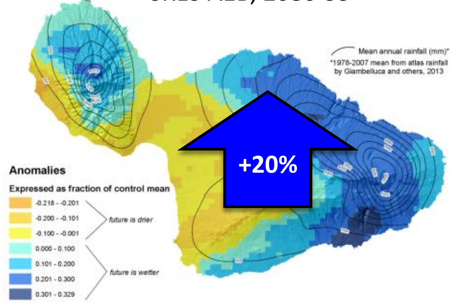
Projected
“Dry” Climate Scenario

Statistical Approach
RCP8.5, 2071-99



Projected
“Wet” Climate Scenario

Dynamical Approach
SRES A1B, 2080-99



Other Challenges with Estimating and Comparing Hydrologic Impacts

- Issues related to dynamical approach
  - Represents only one emission scenario (SRES A1B)
  - Represents only one future time period (2080-2099)
  - Planning horizon for water managers typically less than 30 years
- Issues related to statistical approach
  - Method is not process-based
  - Does not provide all climatological elements needed for simulating water budget; independent estimates of future reference ET are needed
- Different control climate periods
  - Statistical approach uses 30-year period during 1978-2007
  - Dynamical approach uses 20-year period during 1990-2009

Statistical Approach - Climate-Data Transformation

- Rainfall
  - Apply seasonal rainfall anomalies to time series of monthly rainfall maps (Frazier and others, 2015)
  - Assume no change in rainfall frequency
- ET
  - Assume no change in reference ET
  - Assume no change in mean evaporation-to-rainfall rates
- Runoff
  - Modify runoff-to-rainfall relations to reflect projected rainfall and approximate changes in runoff-to-rainfall relations

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Dynamical Approach - Climate-Data Transformation

- Rainfall
  - Apply mean monthly rainfall anomalies to time series of monthly rainfall maps (Frazier and others, 2015)
  - Develop input datasets to characterize daily rainfall frequency during control and projected climate scenarios
- ET
  - Estimate reference ET for control and projected climate scenarios, and compute mean monthly reference ET anomalies
  - Apply mean monthly reference ET anomalies to mean monthly reference ET maps (Giambellucca and others, 2014)
  - Develop mean evaporation-to-rainfall rates for projected climate scenario
- Runoff
  - Modify runoff-to-rainfall relations to reflect projected rainfall and approximate changes in runoff-to-rainfall relations

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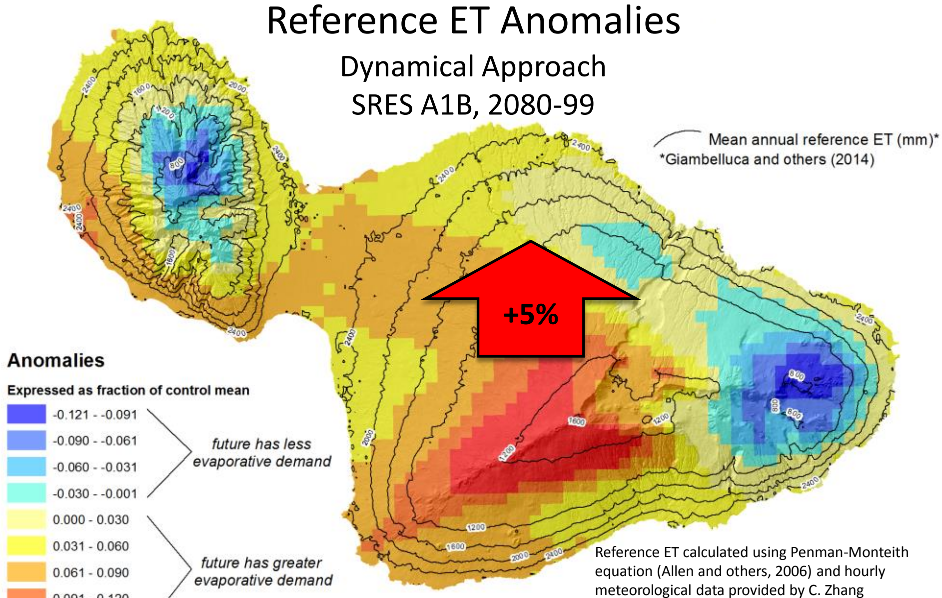
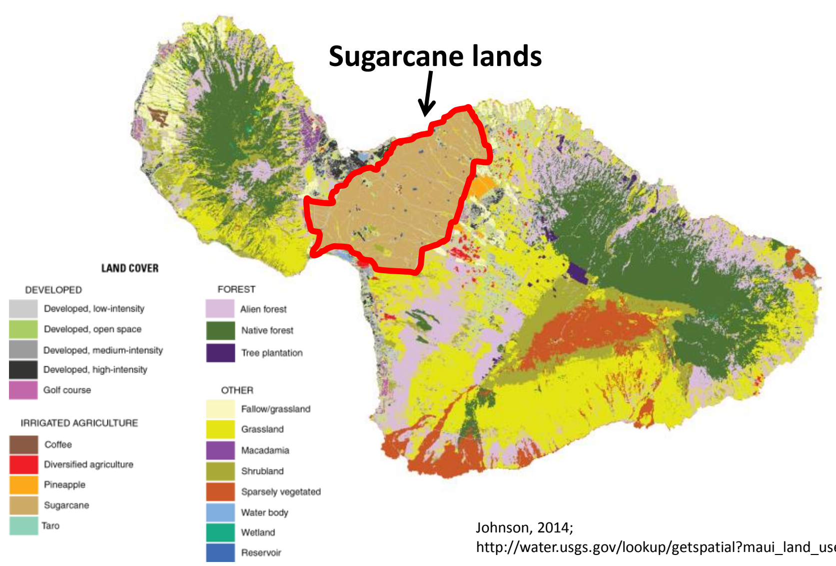
Projected "Wet" Climate Scenario – Mean Annual Reference ET Anomalies

Dynamical Approach
SRES A1B, 2080-99



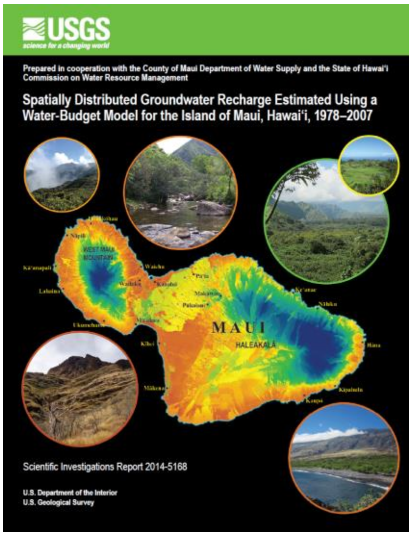
Reference ET calculated using Penman-Monteith equation (Allen and others, 2006) and hourly meteorological data provided by C. Zhang

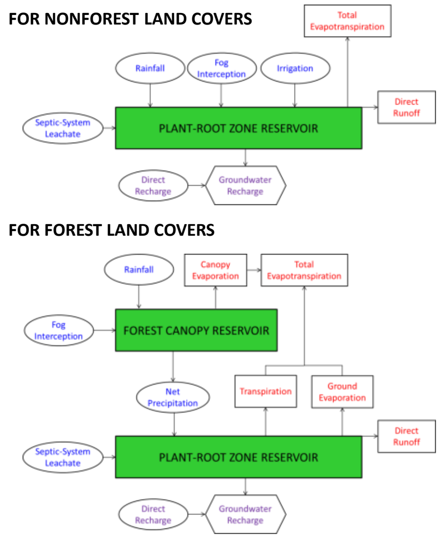
2010 Land Cover



Johnson, 2014;
http://water.usgs.gov/lookup/getspatial?maui_land_use_circa_2010

Water-Budget Model





Johnson and others, 2014;
http://dx.doi.org/10.3133/sir20145168

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Water-Budget Model Development

- Model developed for islands to estimate spatially distributed groundwater recharge
- Model has been applied in Hawai'i, American Samoa, and Guam
- Required model input datasets:
  - Rainfall
  - Reference ET
  - Direct runoff
  - Land cover
  - Soil properties
- Since 2005, model has been modified to accommodate improved rainfall and reference ET datasets, and more robust methods to estimate canopy interception, total ET, and direct runoff

← ***These datasets are modified during climate-data transformation for estimating climate-change impacts*** (Rainfall, Reference ET, Direct runoff)

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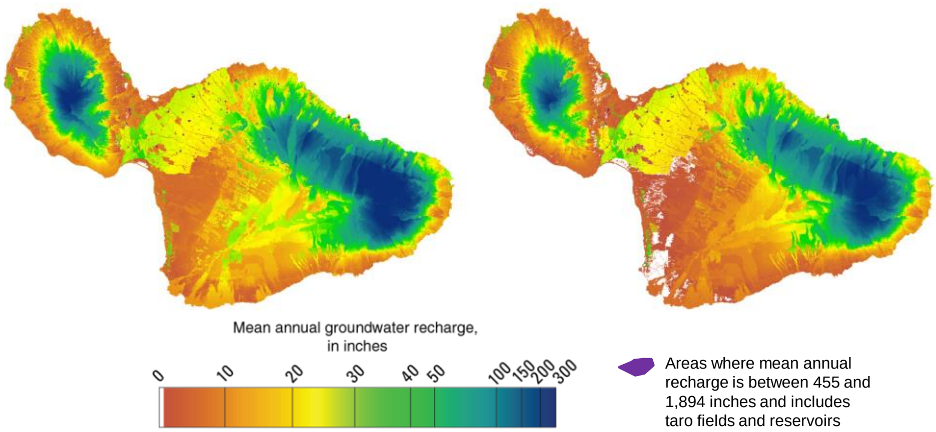
Groundwater Recharge Decreases by 21% for Projected Dry Climate Scenario

1978-2007 Climate

Statistical Approach
RCP8.5 2071-2099 Climate



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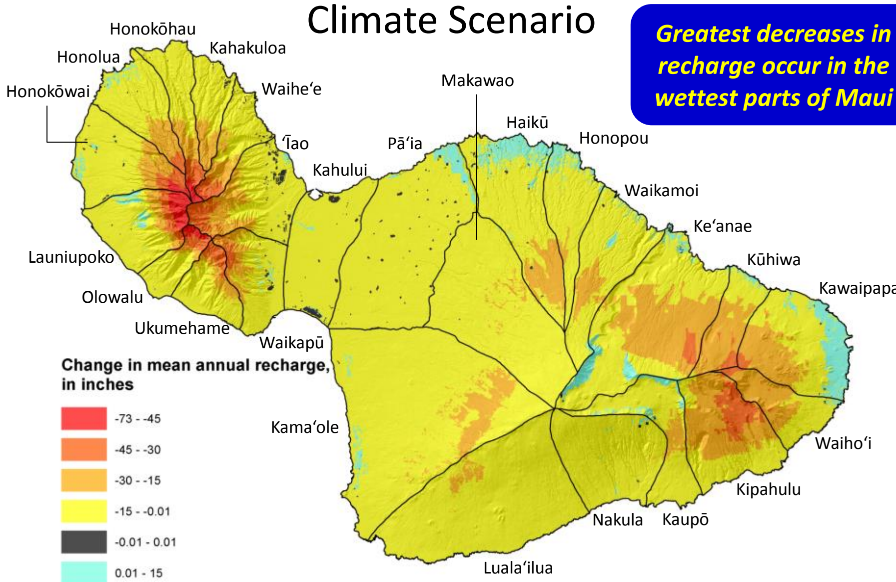
Change in Mean Annual Recharge for Projected Dry Climate Scenario

Greatest decreases in recharge occur in the wettest parts of Maui



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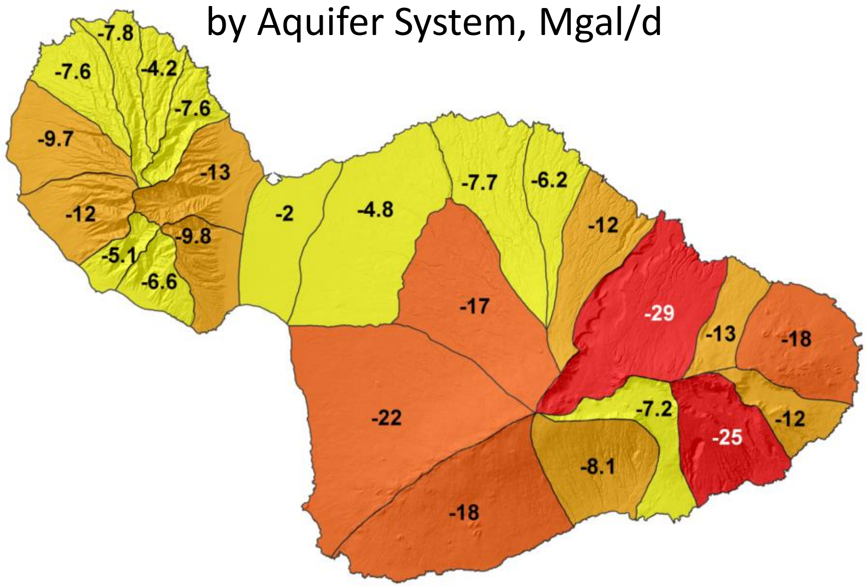
Change in Recharge by Aquifer System, Mgal/d



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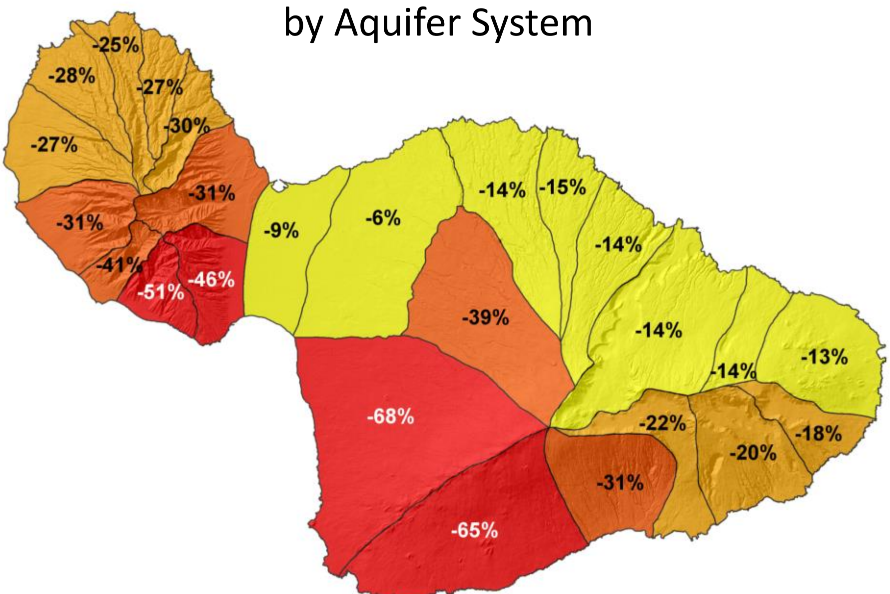
Percentage Change in Recharge by Aquifer System



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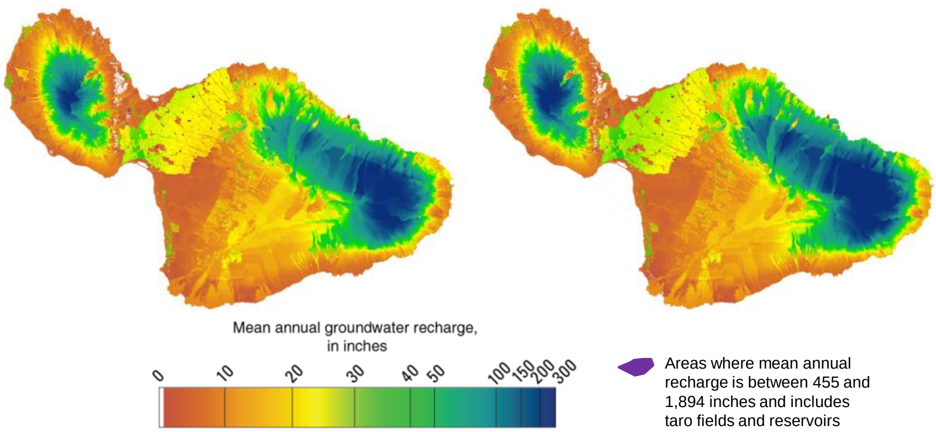
Groundwater Recharge Increases by 21% for Projected Wet Climate Scenario

1990-2009 Climate

Dynamical Approach SRES A1B 2080-2099 Climate



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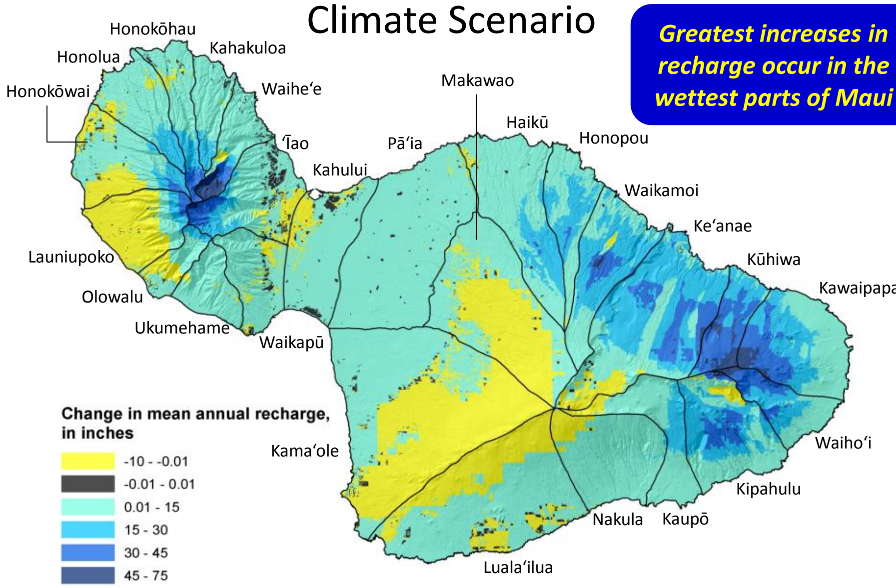
Change in Mean Annual Recharge for Projected Wet Climate Scenario

Greatest increases in recharge occur in the wettest parts of Maui



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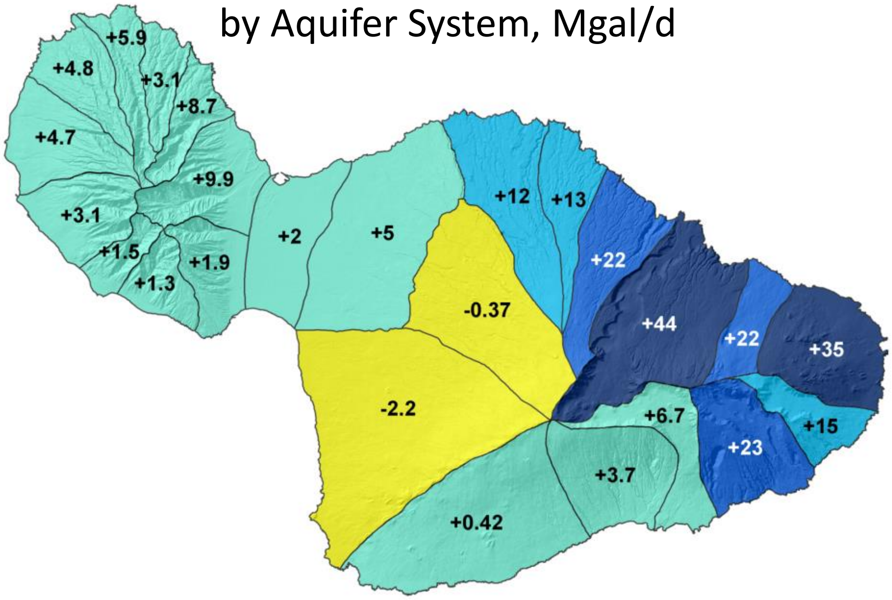
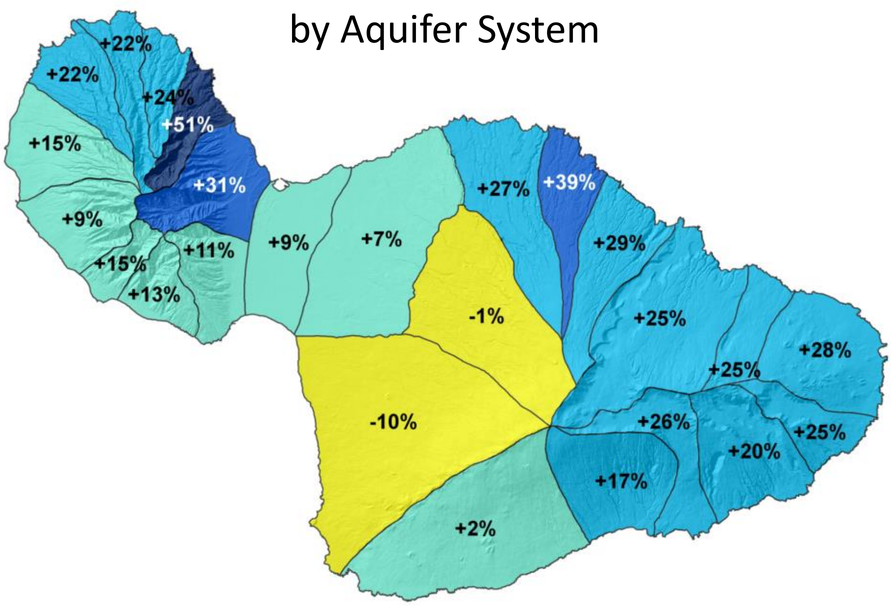
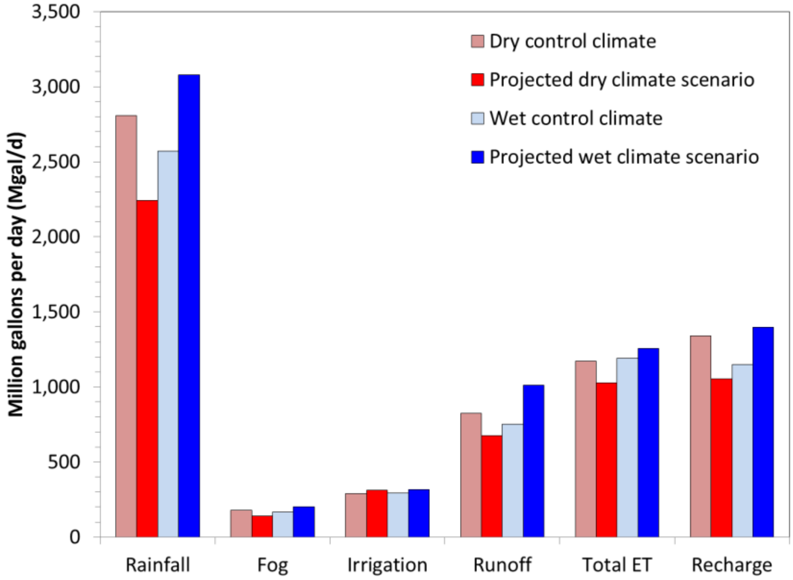
Change in Recharge by Aquifer System, Mgal/d



Percentage Change in Recharge by Aquifer System



Island –Wide Comparison: Mgal/d



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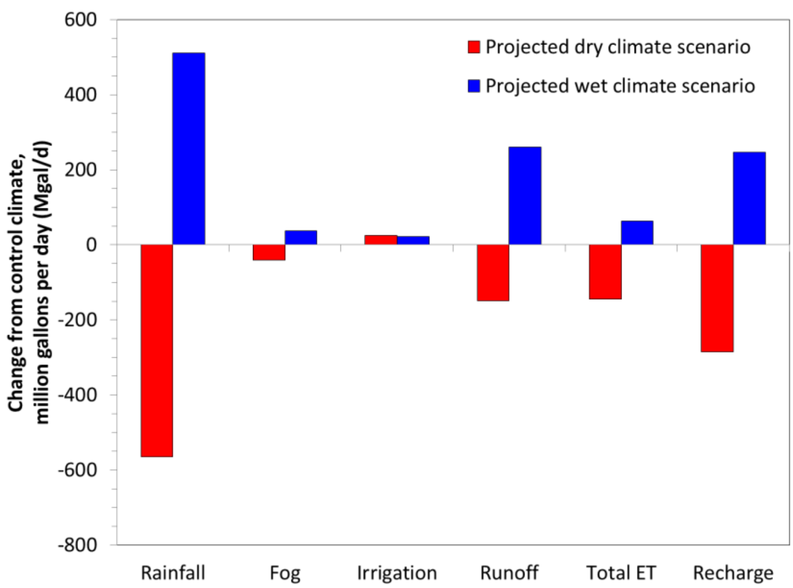
Island-Wide Comparison: Change in Mgal/d



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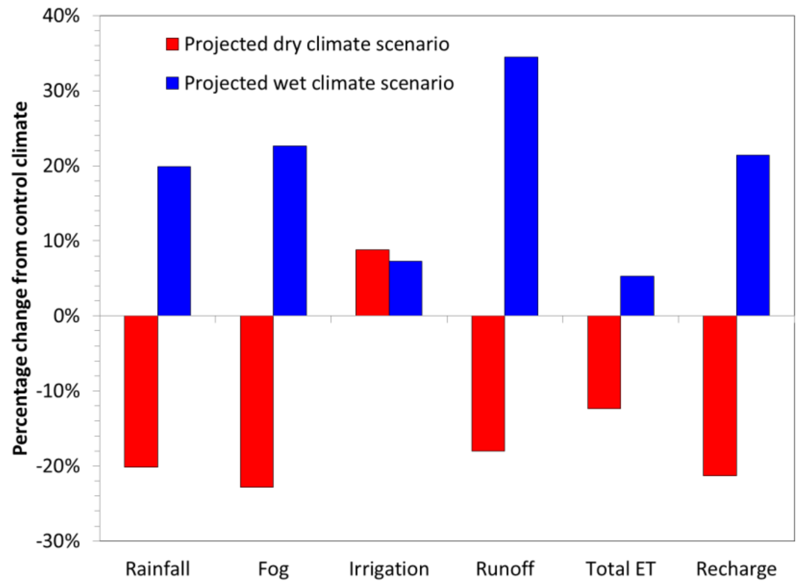
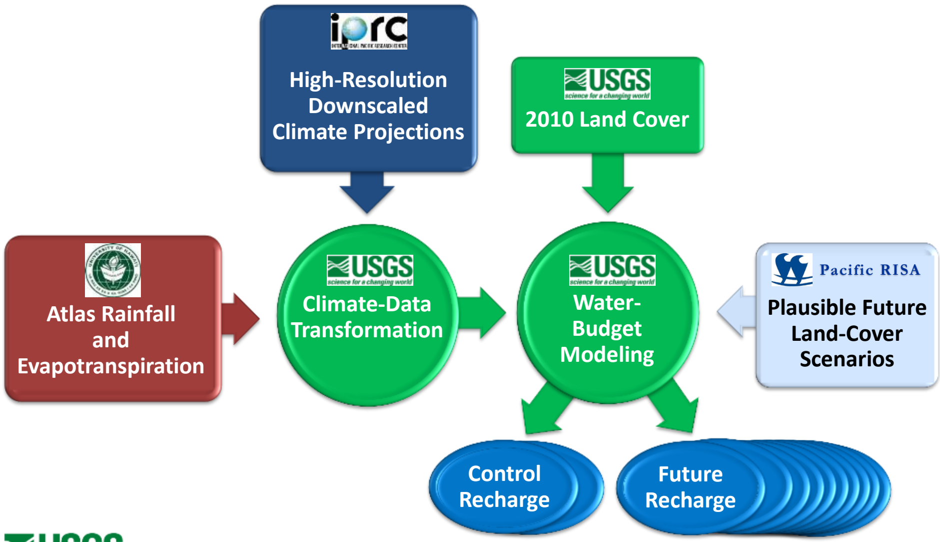
Island-Wide Comparison: Percentage Change



Summary for Maui

- Two existing projections indicate contrasting effects on estimated recharge across most of Maui
  - Estimated changes to recharge in ʻĪao and Waiheʻe aquifers vary from a decrease of 31% (ʻĪao) to an increase of 51% (Waiheʻe)
  - Estimated changes to island-wide recharge vary by plus or minus 21%
- Greatest changes to recharge occur in west Maui mountains and wet windward areas of Haleakalā
- Uncertainty in climate projections likely will improve over time, which will lead to better-defined actionable science directions

Next Steps – Water-Budget Modeling



Next Steps – Publishing

- Publish estimated impacts to groundwater recharge for future climate/land-cover scenarios in scientific journal article
- Publish geospatial datasets presenting water-budget modeling results for each climate/land-cover scenario
  – USGS water resources NSDI node

Next Steps – Reducing Uncertainty

- Additional set of climate projections being developed for Hawaiʻi by National Center of Atmospheric Research (NCAR)
  - Available by end of 2016 or early 2017
- Continued dialogue between climate scientists using statistical and dynamical downscaling approaches needed to better understand differences in projections

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Acknowledgments

- Chunxi Zhang, IPRC
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- Victoria Keener and Laura Brewington, Pacific RISA

QUESTIONS?

References

Allen, R.G., Pruitt, W.O., Wright, J.L., Howell, T.A., Ventura, F., Snyder, R., Itenfisu, D., Steduto, P., Berengena, J., Yrisarry, J.B., Smith, M., Pereira, L.S., Raes, D., Perrier, A., Alves, I., Walter, I., and Elliott, R., 2006, A recommendation on standardized surface resistance for hourly calculation of reference ETo by the FAO56 Penman-Monteith method: Agricultural Water Management, v. 81, no. 1–2, p. 1 – 22.

Elison Timm, O., Giambelluca, T.W., and Diaz, H.F., 2015, Statistical downscaling of rainfall changes in Hawaiʻi based on the CMIP5 global model projections, J. Geophys. Res. Atmos., 120, 92–112, *doi:10.1002/2014JD022059*.

Frazier, A.G., Giambelluca, T.W., Diaz, H.F., and Needham, H.L., 2015, Comparison of geostatistical approaches to spatially interpolate month-year rainfall for the Hawaiian Islands: International Journal of Climatology.

Giambelluca, T.W., Chen, Q., Frazier, A.G., Price, J.P., Chen, Y.-L., Chu, P.-S., Eischeid, J.K., and Delparte, D.M., 2013, Online rainfall atlas of Hawaiʻi: Bulletin of the American Meteorological Society, v. 94, no. 3, p. 313–316, *http://rainfall.geography.hawaii.edu/*.

Giambelluca, T.W., Shuai, X., Barnes, M.L., Alliss, R.J., Longman, R.J., Miura, T., Chen, Q., Frazier, A.G., Mudd, R.G., Cuo, L., and Businger, A.D., 2014, Evapotranspiration of Hawaiʻi: University of Hawaiʻi at Mānoa, *http://evapotranspiration.geography.hawaii.edu/*.

Johnson, A.G., 2014, Land use for the island of Maui, Hawaii, circa 2010: U.S. Geological Survey Spatial Data Set, *http://water.usgs.gov/lookup/getspatial?maui_land_use_circa_2010*.

Johnson, A.G., Engott, J.A., and Bassiouni, M., 2014, Spatially distributed groundwater recharge estimated using a water-budget model for the Island of Maui, Hawaiʻi, 1978–2007: U.S. Geological Survey Scientific Investigations Report 2014–5168, 53 p., *http://dx.doi.org/10.3133/sir20145168*.

Zhang, C., Wang, Y., Lauer, A., and Hamilton, K., 2012, Configuration and evaluation of the WRF model for the study of Hawaiian regional climate, Monthly Weather Review, 140, 3259-3277.