Co-producing a Mauka (Mountain) to Makai (Sea) Interconnected Systems Modeling Framework for Informed Management in a Changing Climate

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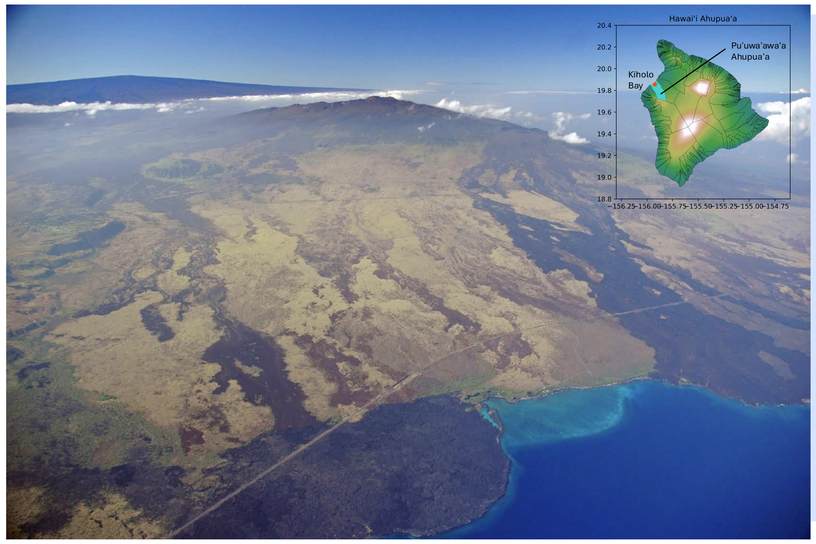
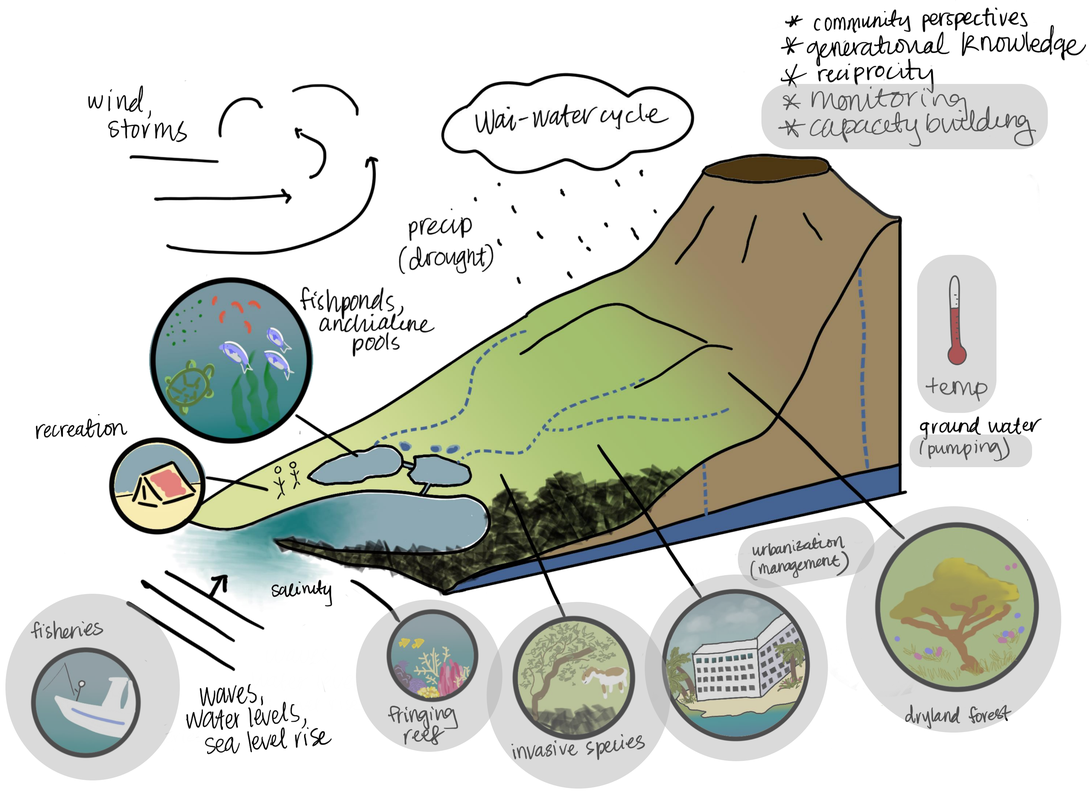
Motivation: Traditional Hawaiian approaches to land management emphasize interconnected relationality and reciprocity between environmental systems. Here, we present a model framework, developed in partnership with local stewardship organizations to support **culturally-relevant 'mauka to makai' land management and adaptation** within the Pu'uwa'awa'a ahupua'a, with an initial focus on Kīholo State Park Reserve.



Kīholo State Park Reserve:

- **Rich cultural legacy** (Kingdom-era fishponds, archeological sites)
- **Vulnerable ecosystems** (groundwater fed anchialine pools, wetlands, fringing coral reef)
- **Active community opportunities** (recreation, education, cultural practice)

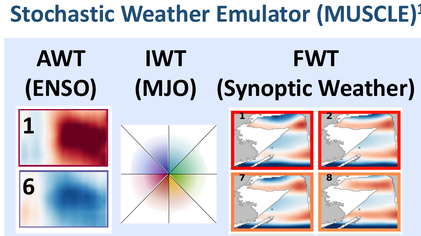


Key ecosystems, environmental drivers, and management concerns in the Pu'uwa'awa'a ahupua'a (traditional Hawaiian land division) that are included in this study. Grayed out sections represent components or concerns of the ahupua'a that are of high priority but not addressed in current work. These sections are instead highlighted as areas to build capacity toward through additional funding calls.

- **Goal:** Probabilistic assessment of Kīholo hazard exposure under different future scenarios to support management planning across diverse environmental systems and socio-cultural needs
- **Method:** Stochastic weather emulator + tailored metamodels + hazard analysis (2030-2100) guided by local stewards and community-based focus group feedback
- **What's new scientifically:** Weather emulator supports flexible incorporation of new environmental drivers[1,2] critical for interconnected systems modeling, direct exploration of future scenarios, and tailored hazard analysis based on resolution / level of certainty needed (e.g., proxies to high resolution) by steward organizations

Model Framework

Stochastic Weather Emulator (MUSCLE)[1,2]



Step 1: Weather Typing (WT) at multiple scales

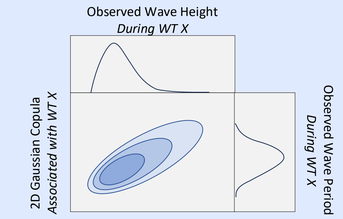
Techniques: *Principal Component Analysis, Hovmöller diagrams, K-means clustering*

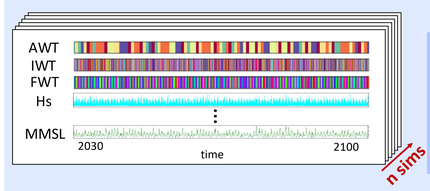
Input Datasets: *Sea Surface Temperature, Outgoing Longwave Radiation, Sea Level Pressure and Sea Level Pressure Gradients*

Step 2: Relate Weather Types and Observed Hydrodynamic Variables

Techniques: *N-Dimensional Copulas, Parameterized Wave Hydrographs, Linear Regression (MMSL)*

Input Datasets: *Astoria Tide Gauge (9439040), CAWCR Wave Hindcasts, Weather Types*





Step 3: Simulate New Chronologies

Techniques: *Auto Logistic Regression Model*

Input Datasets: *Weather Types, Copulas, MMSL Regression Model*

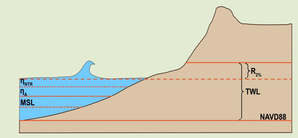
Impact Analysis

Flexible Integration of Hazard Drivers:

e.g., Total Water Level Calculation

Techniques: *Empirical Formulas, Metamodels, Box Models*

Input Datasets: *Stochastic Emulator Output, DEMs*



Hazard Proxy Calculation[3,4]

Techniques: *Number of Times / Percent of Time in Hazard Regime*

Input Datasets: *Total Water Level Output, Morphology Data, DEMs*

Example Hazard Metrics & Management Thresholds

Hazard	Proxy	Impact	Why important? (Impact to Ecosystem Services)	Management Thresholds
Fishpond Flooding	Fishpond wall overtopping (TWL> wall height)	Wall damage, Sediment accumulation in pond	Cultural practice - functionality of fishpond Sense of place - aesthetics & familiarity	Overtopped 3 times per season
Anchialine Pool Flooding	TWL> Anchialine Pool Elevation	Salinity imbalances – habitat health	Ecology – protection of endangered species Cultural practice – abundance of species used in traditional fishing techniques	Overtopped 10 times per season
Wetland Flooding	SLR> Wetland accretion rates	Habitat health Impact of investment on ecosystem conservation / rehabilitation efforts	Ecology – loss of existing habitat Ecology – formation of new habitat (Can we ID?)	
Beach safety	TWL makes beach narrower than (10m?) – reaches campground spaces	Encroach on accessibility of beach for humans and animals	Recreation - camping, hiking, Sense of place - aesthetics & familiarity Ecology-protection of endangered species (monk seal, green sea turtles)	Beach is too narrow for recreation 30% of year
Erosion	TWL interacts with dune / backshore feature?	Infrastructure or habitat destruction	Sense of place - aesthetics & familiarity Cultural practice - functionality of fishpond / structures	

*** Hazard metrics & management thresholds will be refined through co-production with stewardship partners**

References

1. Anderson, D., Rueda, A., Cagigal, L., Antolinez, J. A. A., Mendez, F. J., & Ruggiero, P. (2019). Time-Varying Emulator for Short and Long-Term Analysis of Coastal Flood Hazard Potential. *Journal of Geophysical Research: Oceans*, *124*(12), 9209–9234. https://doi.org/10.1029/2019jc015312
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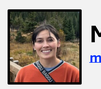
3. Sallenger, A. H. (2000). Storm Impact Scale for Barrier Islands. *Journal of Coastal Research*, *16*(3), 890–895. JSTOR.
4. Leung, M., Cagigal, L., Mendez, F., & Ruggiero, P. (2024). Projecting Future Chronic Coastal Hazard Impacts, Hotspots, and Uncertainty at Regional Scale. *Earth's Future*, *12*(12), e2024EF005523. https://doi.org/10.1029/2024EF005523



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