Examining Groundwater and Surface Water Interactions to Determine the Effects of Anthropogenic Nutrient Loading on Streams and Coastal Water Quality

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Introduction

- **Submarine groundwater discharge (SGD)** is an essential source of land-derived nutrients for coastal waters, but excess anthropogenic nutrient loading (e.g. from agriculture or cesspools) can significantly degrade coastal ecosystems.
- Groundwater is insulated from the sun, so temperature gradients exist between discharging groundwater and receiving surface water bodies. These temperature differences are easily detectable by thermal infrared (TIR) imaging.
- Recent studies have utilized aircraft and/or ground-based TIR to survey coastal areas, estuaries, and rivers/streams for groundwater inputs. However, these methods have significant limitations, as Aircraft-TIR can be limited by cloud cover, and ground-based TIR is impractical for surveying large areas.
- **UAV-TIR** is ideal for surveying SGD on a small scale because it allows unprecedented data collection flexibility and high-resolution below-cloud TIR imaging.

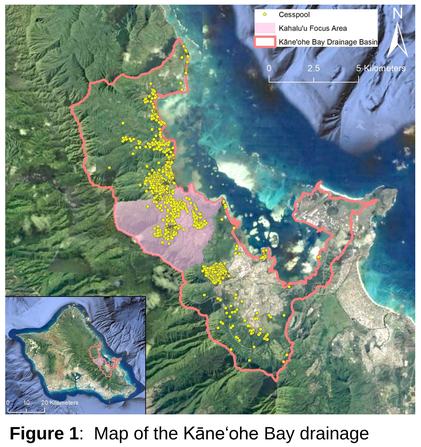

Figure 1: Map of the Kāne‘ohe Bay drainage basin showing the distribution of cesspools, a potential source of anthropogenic nutrients in groundwater.

Figure 2: Beach closure sign within the study area. Beach closure due to high bacteria levels potentially derived from cesspool leachate in SGD. (Image by KHON2)

Goals

- **Identify locations of submarine groundwater discharge in Central Kāne‘ohe Bay**, based on thermal contrast between groundwater and surface water.
- Previous studies (Lee et al., 2016; Kennedy et al., 2017) utilized UAV-TIR as a follow-up to Aircraft-TIR studies. The goal of this study is to **demonstrate effective independent use of UAV-TIR for locating and mapping SGD**.

Methods

Equipment

UAV Platform	3DR X8+ Octocopter
Power	14.8V Lithium Polymer batteries
Autopilot	Pixhawk
TIR Camera	FLIR Tau 2 640
Focal Length	13 mm
Pixel Resolution	0.2 m
Temperature Resolution	0.04° C
Image Capture	TeAx Thermal Capture

Data Collection

- 10-12 minute flights, 120 meter altitude
- Flights conducted during low tide to maximize hydraulic gradients, and late in the day to maximize thermal gradients
- In-situ thermistors deployed during flights to ground-truth TIR data
- Thermal imagery collected at a rate of 9 Hz (9 frames per second)
- Spatial data attached to each image via on-board GPS unit
- Data relayed to ground station monitor for real-time analysis

Figure 3: UAV-TIR field operations in Kāne‘ohe.

Figure 4: Field viewing screen provides real-time analysis of results.

Post-Processing

- ThermoViewer – raw thermal files converted to grayscale JPEGs
- Adobe Lightroom – vignette corrections applied to grayscale JPEGs
- Microsoft ICE – image mosaicking with corrected grayscale JPEGs
- ArcGIS – grayscale mosaics converted to temperature rasters

Paired Methods

- UAV-TIR provides the potential for locating, mapping, and analyzing the areal extent of SGD. Pairing UAV-TIR with other methods (e.g. simultaneous radionuclide tracer measurements, simultaneous vertical temperature profiling, follow-up geochemical studies) can provide further quantitative characterization of SGD. Numerical groundwater modeling can also be used as a complementary method to predict and/or confirm SGD locations.

Results

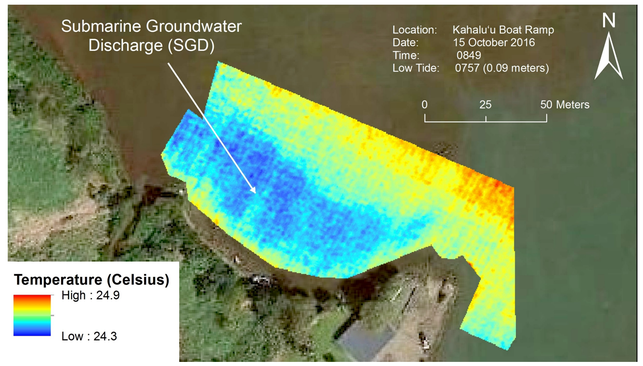

Figure 5: Submarine groundwater discharge at Kahalu‘u Boat Ramp in Kāne‘ohe Bay. Caution signs were posted at this location by the Hawai‘i State Department of Health due to unusually high bacteria and nutrient levels in the water.

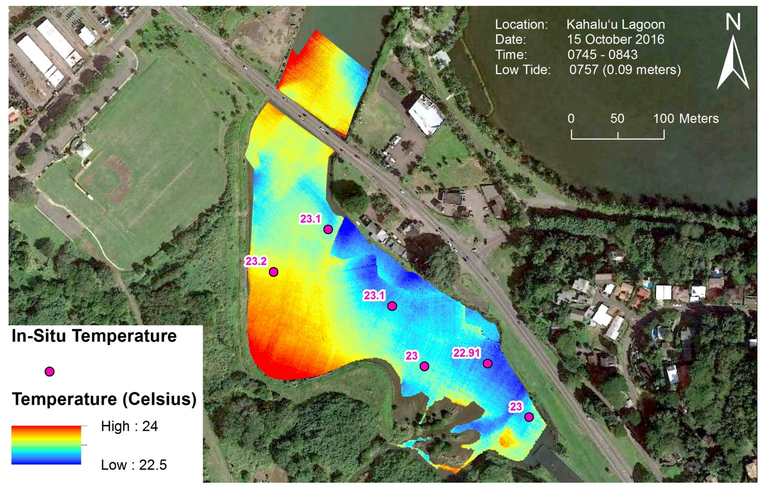

Figure 6: Thermal infrared map of Kahalu‘u Lagoon, a tide-dominated estuarine confluence of three streams (Kahalu‘u, Waihe‘e, Ahuimanu) in the study area.

Conclusions / Future Work

The use of UAV-TIR in Kāne‘ohe Bay has allowed us to easily locate submarine groundwater discharge, identify the areal extent of SGD, distinguish between point-source and diffuse discharge, and quantify temperature gradients. UAV-TIR is a flexible and cost-effective tool for mapping and monitoring SGD, independent of Aerial-TIR surveys.

Future Work

- Map the entire Central Kāne‘ohe Bay coastline
- Follow-up geochemical studies to characterize SGD
- Apply these methods to detect stream baseflow

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