Automated Mapping and Planning to Improve Assessment of Coral Reef Health

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Program: FY21 SURP **Strategic Focus Area: Water and carbon cycles**

Objective

This project will develop technologies for automating data analysis and mission planning of coral reef ecosystems. This strategy represents a fundamental change in how we understand coral reefs and assess their health. Instead of small, infrequent, uncorrelated studies of isolated locations, we will begin to measure coral reefs globally, updating often, and seeing worldwide patterns.

Rationale/Background

The global economic valuation of the direct and indirect use of coral reefs has been estimated near $10 trillion annually. There is great concern about the current state of reefs, as well as their future. Yet very little of the world's reef area has actually been studied quantitatively (i.e., 0.01-0.1%) since virtually all reef assessments rely on human in-water survey techniques that are laborious, expensive, and limited in spatial scope. The result may not be representative of the reef under study, and in any case, it is unknown whether it is representative of global ecosystems.

Benefit to JPL and NASA

The proposed investigation will advance the state of the art in site mapping of coral reef ecosystems, improving the accuracy of marine ecology and increasing the efficiency of coral reef assay. It aligns with the needs and directions of NASA and their missions (e.g., CORAL and SBG). The proposed investigation will impact JPL's technical capabilities in aquatic systems, potentially leveraging in-house investments and capabilities (e.g., CARACaS) and cross-lab expertise (robotics, autonomy, and science). It will extend JPL's and CMU's expertise to problems in oceanography through in-situ exploration and characterization of ocean biochemistry.

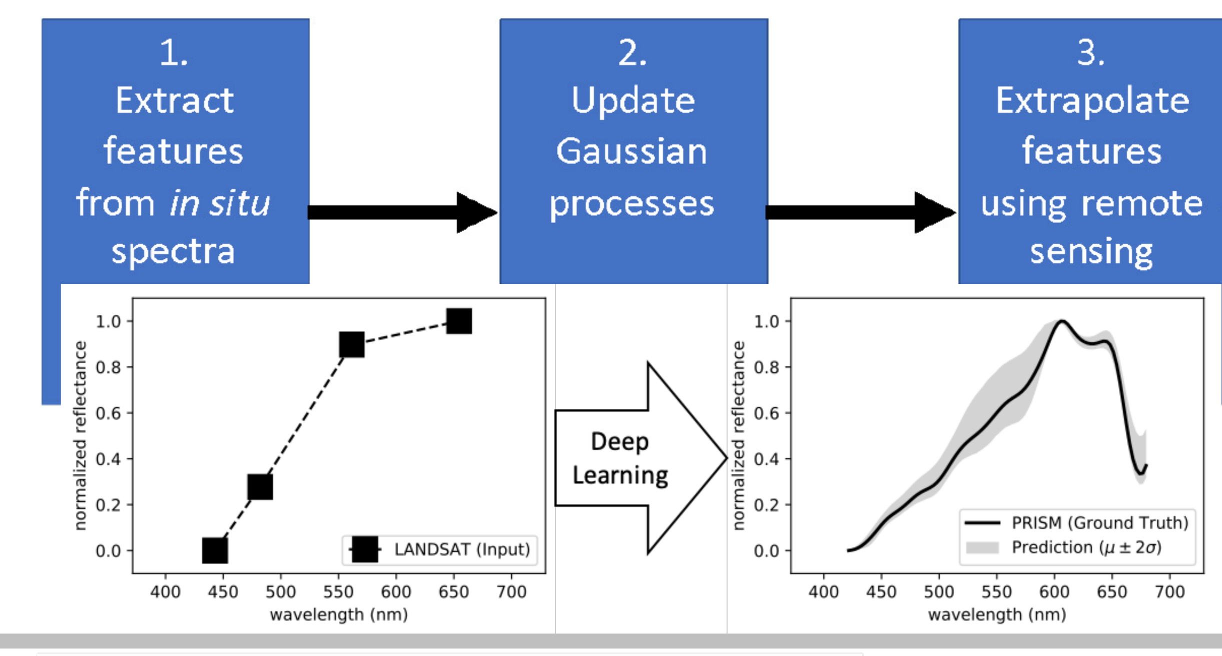
Publications

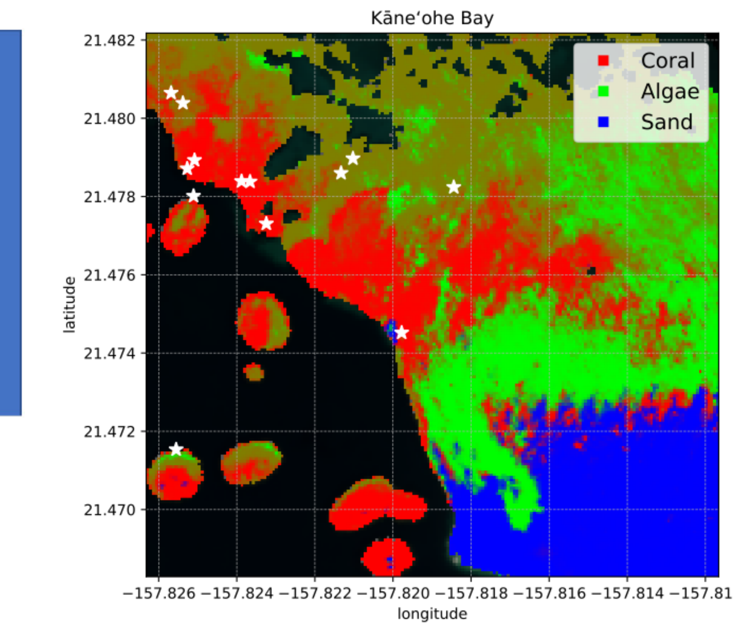
A. Candela, K.. Edelson, M.M. Gierach, D.R. Thompson, G. Woodward, and D. Wettergreen, 2021: Using remote sensing and in situ measurements for efficient mapping and optimal sampling of coral reefs, *Frontiers in Marine Science*, https://doi.org/10.3389/fmars.2021.689489.

Approach and Results

Year 1 (FY19) ✓

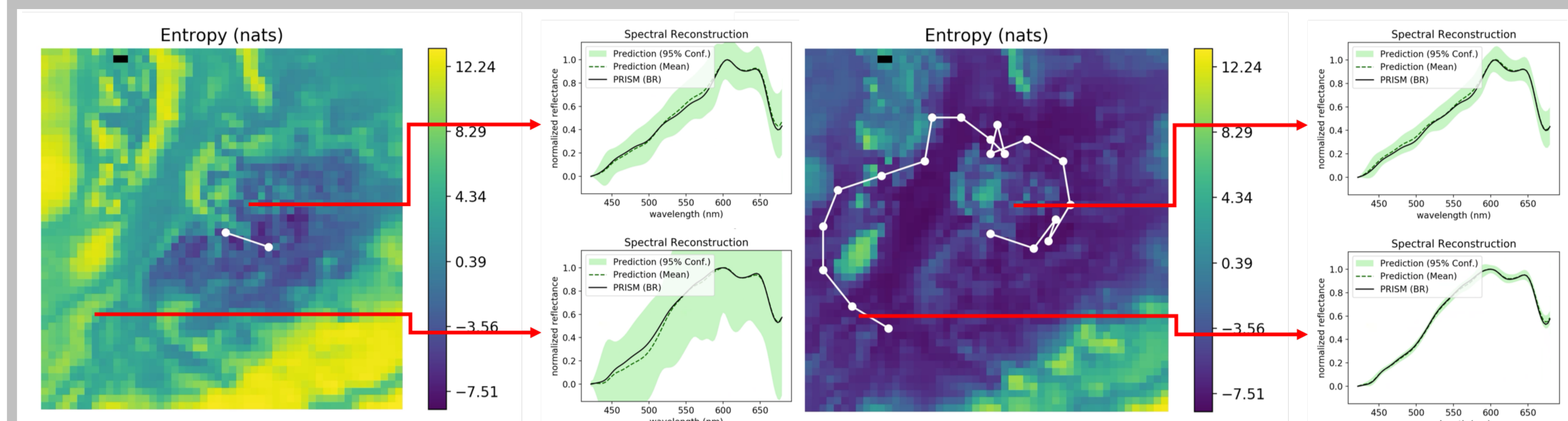
- Develop active coral reef mapping methods (i.e., machine learning methods for spectral and endmember mapping)



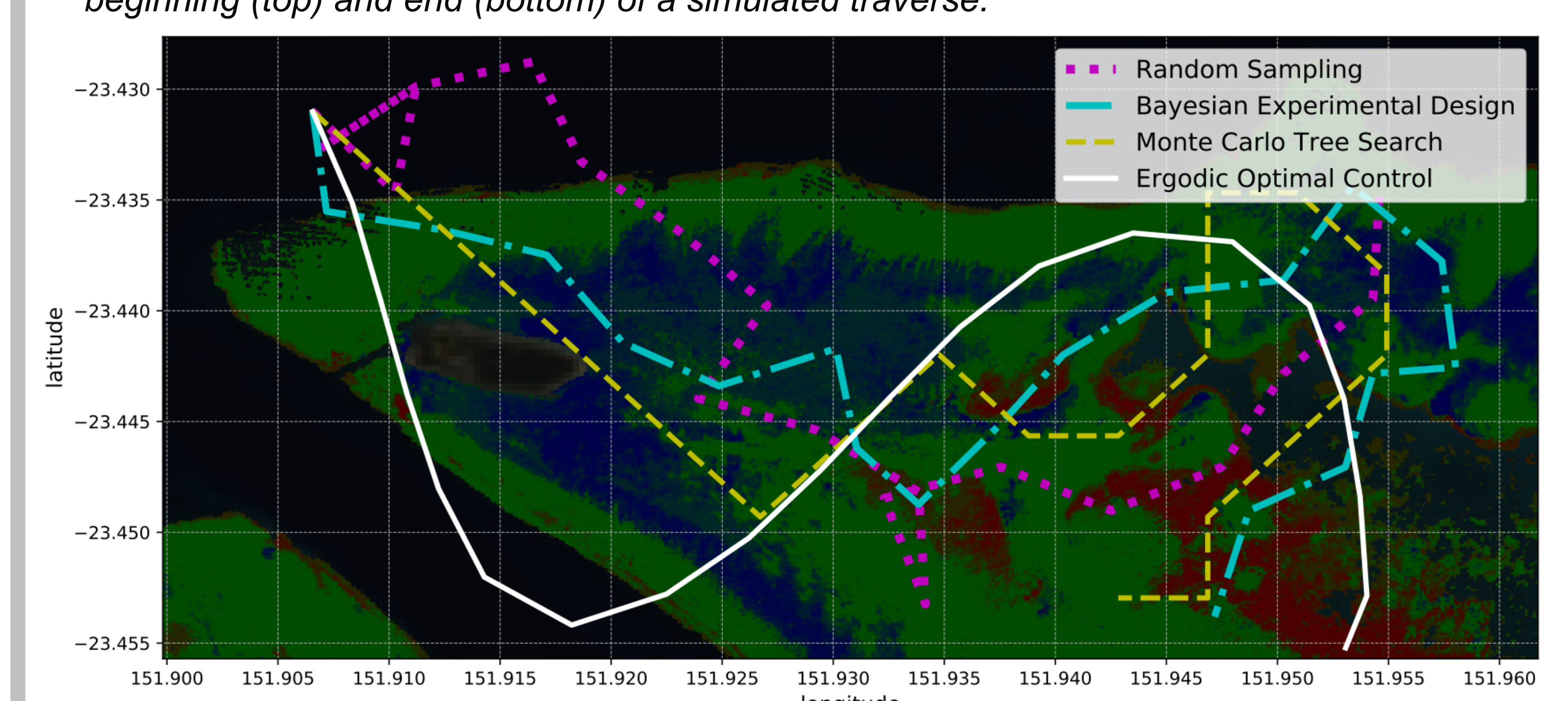


Year 2 (FY20) ✓

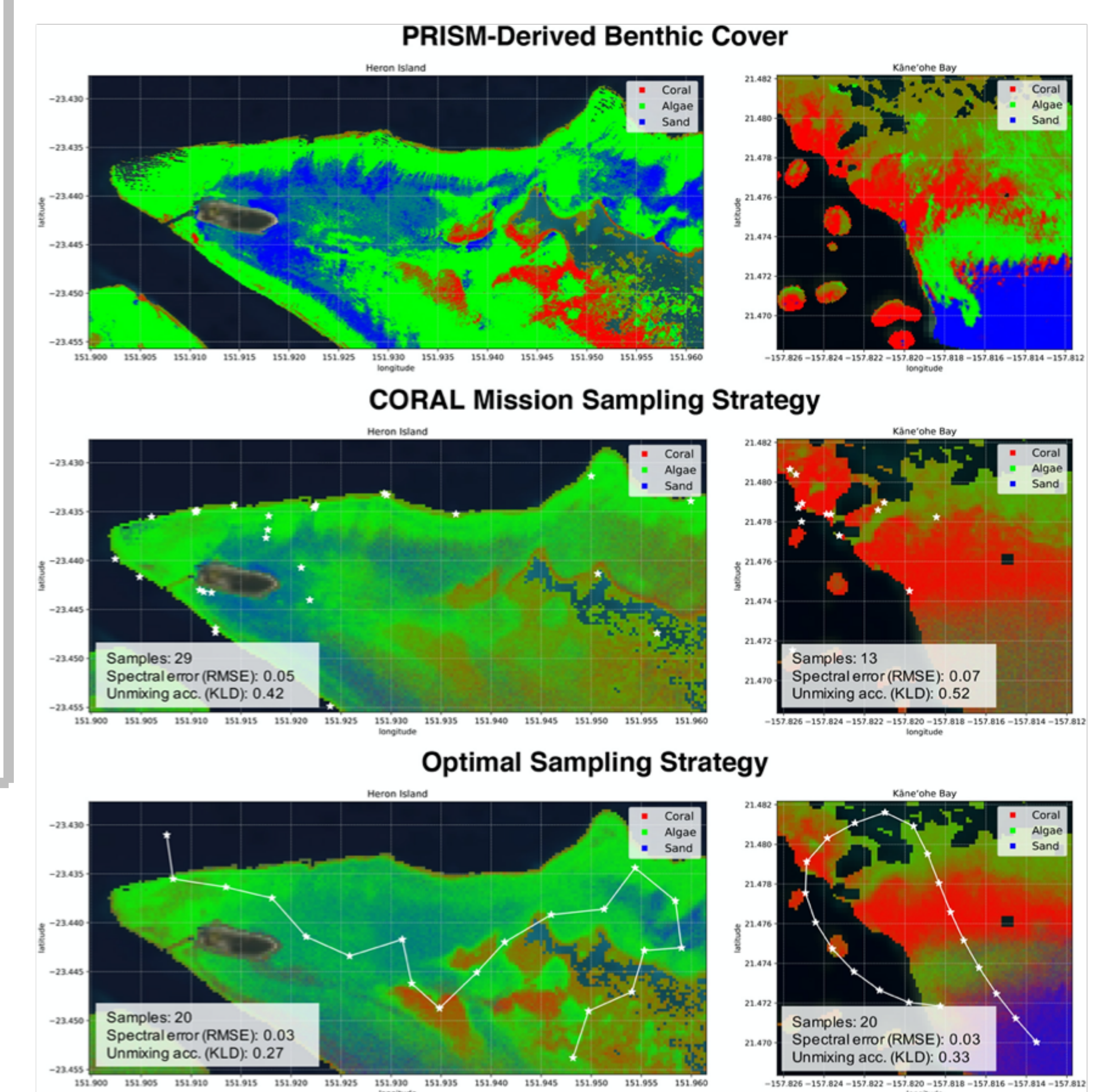
- Develop path planning for coral reef sampling



Example of the underlying entropy (uncertainty) map that guides the planning algorithms. Entropy maps and spectral predictions at the beginning (top) and end (bottom) of a simulated traverse.



Four sampling strategies for coral reef mapping: random sampling, Bayesian experimental design, Monte Carlo tree search, and ergodic optimal control. Random sampling is the simplest approach since it ignores how useful future samples might be. Bayesian experimental design provides a probabilistic framework for identifying the most informative samples and planning paths accordingly. Monte Carlo tree search combines random sampling with a tree search that focuses on the most promising actions. Ergodic optimal control not only selects informative samples, but also generates smooth trajectories that can be suitable for boats or AUVs.



Year 3 (FY21) ✓

- Compare hypothesis-map studies with prior field studies
- Publish results

*Experimental setting for the simulation study. A subregion of 6 x 3 km in Heron Island is shown on the left, whereas a region of 1.5 x 1.5 km in Kaneohe Bay appears on the right. **Top row:** abundance maps from the CORAL mission, serving as the ground truth in this study. **Middle row:** predicted abundances using the sampling strategy followed during the CORAL mission. **Bottom row:** predicted abundances using paths generated by two optimal sampling strategies, Maximum Information Gain (left) and Spectral Multi-scale Coverage (right). White asterisks indicate sampling locations. In this example, the optimal sampling strategies produce more accurate maps both as a function of spectral reconstruction error , in terms of Root Mean Squared Error (RMSE), and unmixing accuracy, in terms of the Kullback-Leibler Divergence (KLD).*

It is apparent that the planning algorithms, together with previous probabilistic models, allow for accurate spectral reconstruction and coral reef mapping, outperforming typical scuba diving methods. Results and methods from this 3-year SURP project can directly improve management of coral reef ecosystems given (1) its potential to fill gaps among sparse *in situ* observations, especially in remote, unpopulated, or inaccessible areas, and (2) its ability to aid in design and refinement of a monitoring program – informing key locations for *in situ* surveys. The NASA EVS-2 CORAL mission and future ecosystem missions would greatly benefit from these planning algorithms.

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