National Aeronautics and Space Administration

Automated Mapping and Planning to Improve Assessment of Coral Reef Health

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Program: SURP

Rationale

The global economic valuation of the direct and indirect use of coral reefs has been estimated near $10 trillion annually [*Costanza et al. 2014*]. 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.

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.

Approach

The method of hypothesis mapping begins with a priori information, such as wide-area remote sensing data [*Candela et al. 2017*]. It estimates the information value of new samples with respect to the remote sensing interpretation, using metrics including maximum entropy or mutual information. As samples are collected and interpreted the value of information in remaining actions is reevaluated so that the plan dynamically adjusts to new information. This is dynamic experimental design. The outcome is that the minimal, most informative sequence of actions is taken to maximize the accuracy of the remote sensing interpretation. In this way, we can take fewer measurements but produce a better model (Figure 1).

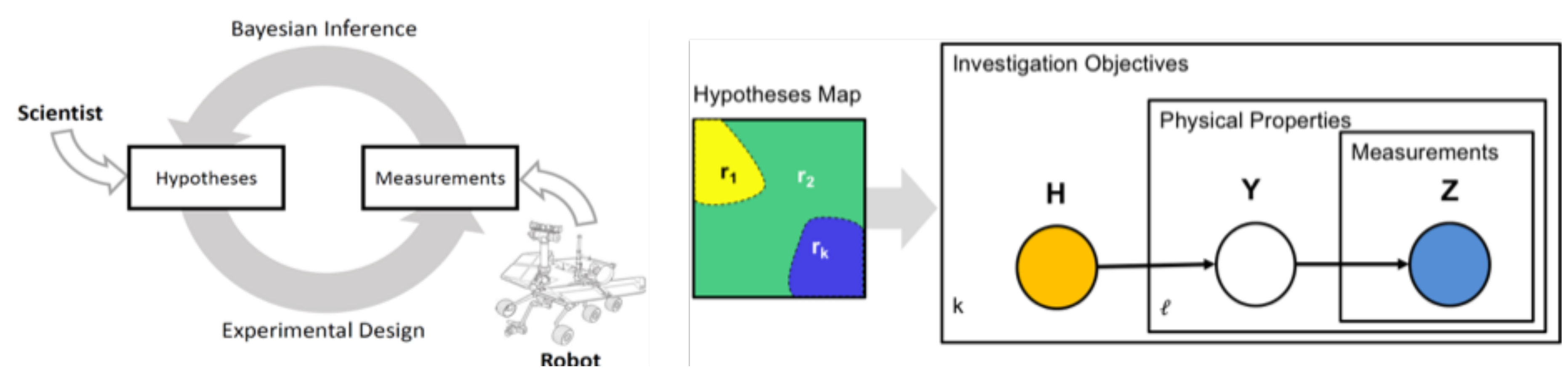

Figure 1. *Hypothesis mapping method (left) begins with scientist generated hypotheses encoded as a map of potential class boundaries, for this case the location of coral, distinguished by health condition and possibly by family/species. These hypotheses and associated likelihoods lead to an experiment design that specifies sampling locations. When those measurements are collected, Bayesian inference is used to refine map and the process continues. The hypothesis map (right) is a spatially distributed class likelihood function, P(H|Z), and Bayesian inference can be applied to update the hypothesis (H) through classification of spectra (Y) given the measurements (Z).*

FY19 Results

Data from the NASA/JPL Portable Remote Imaging SpectroMeter (PRISM) as part of the NASA EVS-2 COral Reef Airborne Laboratory (CORAL) mission were used for two primary study sites, Heron Island, Australia and Kaneohe Bay in Oahu, Hawaii.

Preliminary development of machine learning methods of orbital data classification evaluated six classification algorithms**:** Naïve Bayes, Gaussian Classifier, Linear Discriminant Analysis, Support Vector Machine, Logistic Regression, and Simple Neural Network. Initial results of learning the spectral signature of different classes and classifying coral, algae, and sand show very good classification rates (Table 1, Figures 2 and 3). Preliminary hypothesis mapping is shown in Figure 4.

Table 1. *Classification accuracy of Kaneohe Bay in Oahu, HI.*

Input	NB	GC	LDA	SVM	LR	NN
Radiance	$76.9 \pm 0.5\%$	**$92.6 \pm 0.4\%$**	$91.9 \pm 0.8\%$	$82.0 \pm 0.4\%$	$86.9 \pm 0.4\%$	$81.4 \pm 0.3\%$
Water L. Ref.	$75.5 \pm 0.7\%$	$88.1 \pm 0.6\%$	$89.9 \pm 0.5\%$	$81.7 \pm 0.6\%$	$89.5 \pm 0.5\%$	**$92.1 \pm 0.5\%$**
Benthic Ref.	$83.7 \pm 0.6\%$	$97.9 \pm 0.3\%$	$96.2 \pm 0.3\%$	$96.7 \pm 0.5\%$	**$99.2 \pm 0.2\%$**	$98.5 \pm 0.2\%$

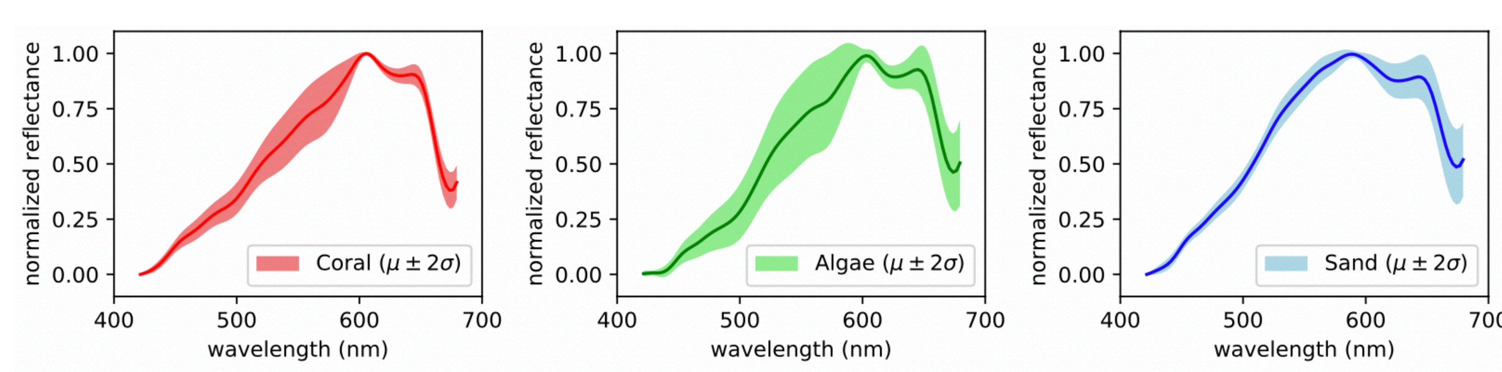

Figure 2. *Learned Mean and Variance of Coral, Algae, and Sand from PRISM using Gaussian Classifier.*

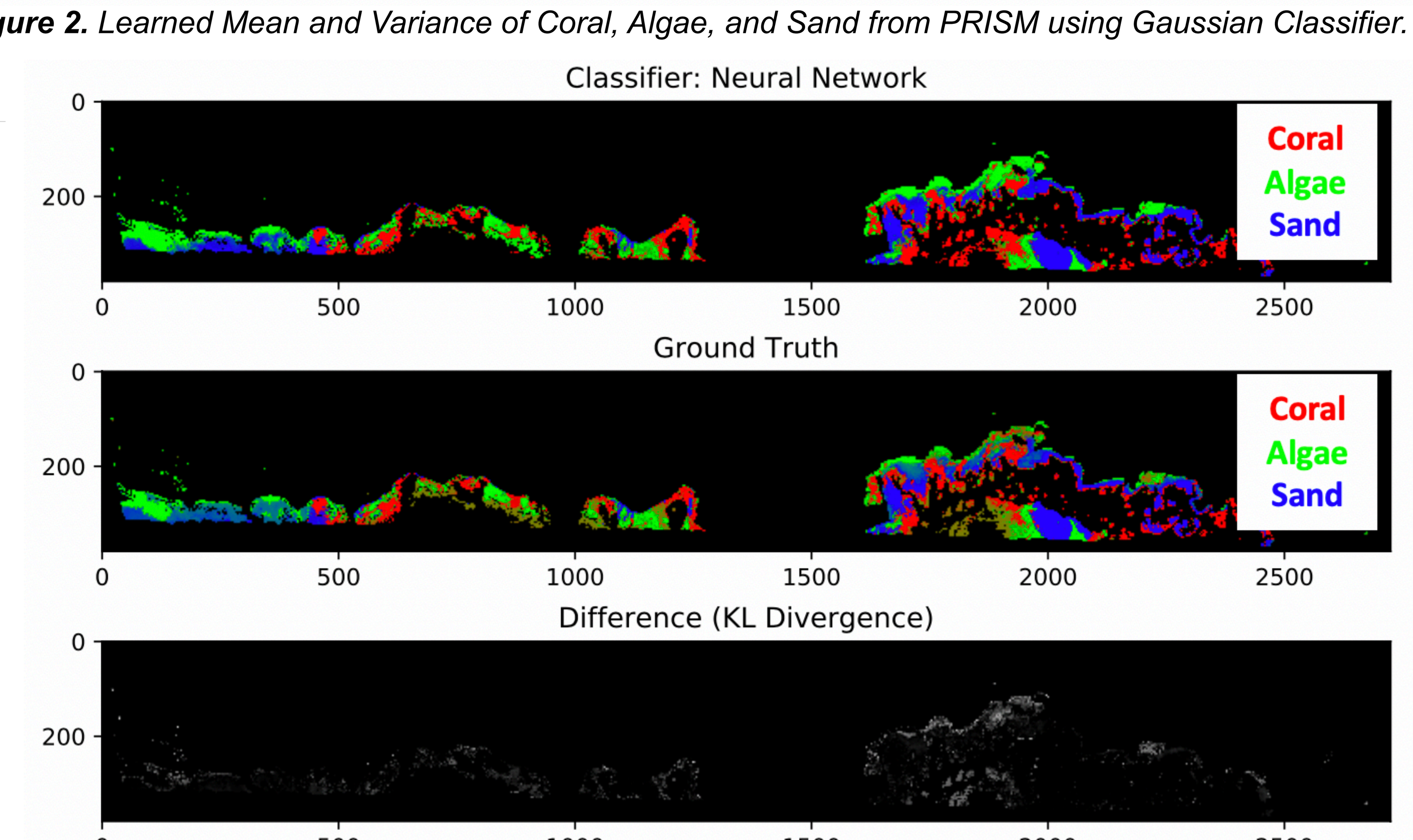

Figure 3. *Learned Classification of Kaneohe Bay in Oahu, HI from PRISM. Classification using trained Neural Network (top), ground truth classification (middle) and difference computed as KL divergence (bottom). As noted in Table 2, the accuracy is 98%.*

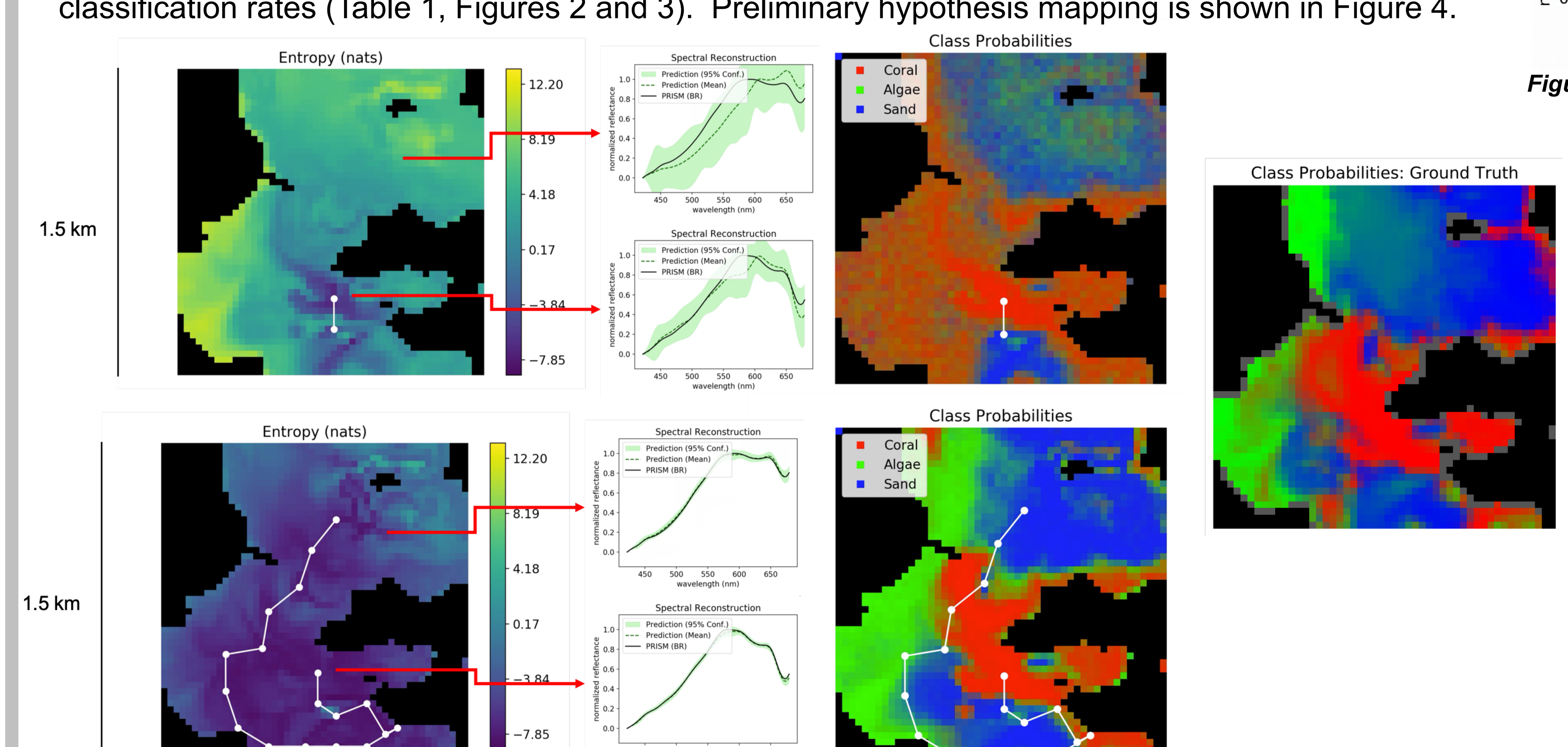

Figure 4. *Preliminary hypothesis mapping of Kaneohe Bay in Oahu, HI.*

Benefits to NASA and JPL

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 existing (CORAL) and upcoming missions (e.g., Surface Biology and Geology). 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, maritime autonomy for UUVs, 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, and has potential for future in-situ missions to liquid bearing worlds.

References

Candela, Alberto, David R. Thompson, Eldar Z. Noe Dobrea, and David S. Wettergreen. "Planetary Robotic Exploration Driven by Science Hypotheses for Geologic Mapping." IEEE International Conference on Intelligent Robots and Systems (IROS). Vancouver. September 2017.

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