

Understanding basaltic volcanic processes by remotely measuring the links between vegetation health and extent, and volcanic gas and thermal emissions using HypsIRI-like VSWIR and TIR data

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Report for Period of Performance
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Summary:

The following is a final report of the accomplishments for this project achieved over the course of the study. This includes completion of the field component of the study that involved substantial vegetation and soil gas emission data collection in and around the Puhimau and Steam Vent geothermal features near the active Kilauea caldera, Hawaii. We continue to finalize data processing, analysis and interpretation this data and expect to present the results of this study at both conferences and as submitted manuscripts by the end of this year to early next year.

Project Objectives 2017-2018:

Dr. Isabella Mariotto will continue working with Dr. Deering, his MSc student, Christie Torres, and the MTRI team to accomplish the remaining Objectives of proposal (*see below*) from available AVIRIS images and field work data, and publish papers with the project team.

Objective 1: Develop hyperspectral vegetation indices (HVIs) and optimized hyperspectral narrowbands (HNBs) that can characterize biophysical and biochemical properties of vegetation and consequent characterization of healthy and CO₂, H₂S, and SO₂ stressed vegetation located in non-active and active volcanoes areas.

Objective 3: Map the local vegetation cover type by identifying the HVIs and HNBs that best separate the major vegetation types/species, and compare them with the models and maps developed using broadbands (BBs) from MASTER and Landsat OLI.

Objective 4: Build a hyperspectral library of healthy and CO₂, H₂S, and SO₂ stressed vegetation for each vegetation type using AVIRIS data and field spectroradiometer data.

Objective 5: Reduce the high dimensionality (or *Hughes phenomenon*) of hyperspectral data by detecting and eliminating redundant bands.

Objective 6: Establish a plant stress gradient model from both the hyperspectral and multispectral data integrated into an open source visualization tool with GIS capable of mapping potential volcanic activity hazards.

Objective 7: Determine the accuracy of the plant stress gradient models derived independently from the hyperspectral and multispectral data from *in situ* vegetation type and condition data.

Objective 9: Map the spatial and temporal relationship between surface temperature, gaseous emissions, and surface vegetation cover.

In Year 2, fieldwork was completed in Hawai'i Volcanoes National Park to collect in-situ vegetation and gaseous fluxes for three and half weeks during February and March 2017. MTRI completed the vegetation field collection using an ASD FS3 Spectroradiometer for field spectra for comparison to AVIRIS data, as well as vegetation species identification, soil color and moisture, in-situ weather conditions, and land-cover/land-use type within the field plots. If the averaged spectra for each target counted as one, Dr. McCarty and Assistant Research Scientist Grimm collected 194 Spectralon panel measurements, 25 sky irradiance measurements, and 183 ground cover targets. 12 complete plots, comprised of 9 subplots each, were collected for spectra. An additional 33 plots were characterized for the multispectral analysis.

In Year 2, MTRI continued collecting and archiving all related AVIRIS, Landsat 5 and 7, and 500 m and 1 km MODIS surface reflectance from 2010 to present day to begin development of the automated vegetation health

change detection algorithm. Landsat 8 and VIIRS data was added to this list. EO-1 ALI and Hyperion data through 2016 has also been added as well as ASTER overpasses during the time of the ER-2 flight. These data have also been implemented into the visualization tool (discussed below).

Tool Development by MTRI Co-Is and Collaborators:

In Year 1, development of a prototype hyperspectral visualization web application has been completed (Figure 1). The purpose of the web application is to aid in exploratory data analysis of the collected imagery. The prototype features an interactive geospatial map using Leaflet that can be used to pan and zoom around the Hawaii study domain. A MapServer instance has been configured to serve the hyperspectral imagery via WMS, which can be accessed by Leaflet. With HypSIRI imagery for the study area not yet available, multiband AVIRIS, Landsat, and MODIS were used for initial development/demonstration. By the end of the project, in situ data from degassing and the spectroradiometer as well as MASTER and AVIRIS data from the planned flights will be accessible via this tool. The tool also features pixel querying (via mouse click) that loads a spectrogram showing intensity values for each band across the spectrum for the selected pixel. This graphing is achieved using the D3.js library. Ongoing development tasks include: configuring for HypSIRI data; also adding configurations for NDVI and MODIS data; refining graph labels; refining default display of imagery (i.e. display RGB or CO₂-relevant bands instead of single-band gray scale); adding titles, help information, and branding; adding non-gridded data. Anticipated completion is December 2018.

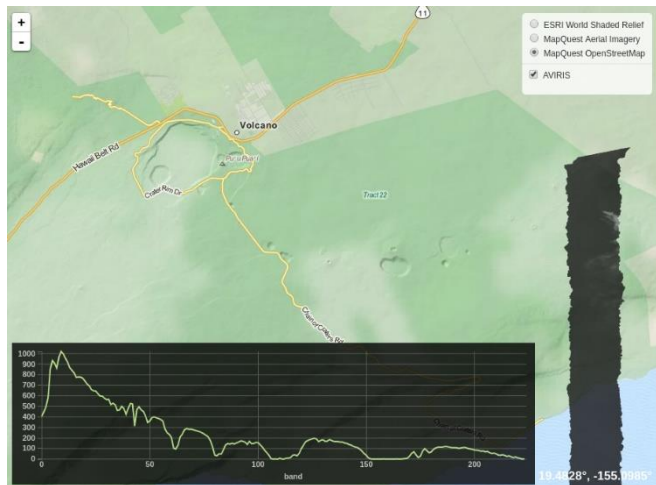


Figure 1. Screenshot of prototype hyperspectral visualization web application.

Collaborators from University of Hawai'i Hilo:

The Michigan Tech research team also welcomed eight undergraduate students from the Department of Geography and Environmental Science at University of Hawai'i Hilo (<https://hilo.hawaii.edu/depts/geography/>), advised by collaborator Dr. Ryan Perroy (<http://spatial.uhh.hawaii.edu/index.htm>). The students helped collect Leaf Area Index, GPS locations, canopy closure, plant identification, CO₂ degassing, and soil temperature data. UH Hilo Collaborator Dr. Becky Ostertag, a Professor of Botany (<https://hilo.hawaii.edu/faculty/ostertag/OstertagLabGroup.php>), accompanied the students and Michigan Tech research team, identifying hard-to-ID endemic plants and providing a natural history perspective on the plant adaptation to volcanic environments.

This fieldwork was highlighted by IEEE EarthZine (<https://earthzine.org/>) in an article under review titled “Data and volcanoes: Ground-truthing volcanic emissions’ effects on plants to feed data to a satellite mission” by staff writer Kelley Christensen.

Dr. Mariotto created a geodatabase in GIS platform (ArcGIS 10.5) of GPS data points taken in the field on vegetation data, CO₂ and H₂S gas fluxes, and soil temperature measurements (including control points). She has created shapefiles, projected data to a common projection to match the Hawaii state layers including major roads, SDOT county routes, and vegetation/land cover type that she has acquired. She has mapped vegetation type and vegetation height in the study area. She has mapped all the AVIRIS lines for the Big Island in ArcGIS. She prepared data layers to correlate vegetation data to gas and temperature measurements. A raster map of continuous values of gas and temperature data was interpolated from point data values across the study area through geostatistical analyses in ArcGIS. To determine the relationship between vegetation health and CO₂ and H₂S gas fluxes, and soil temperature, a series of regression analyses were computed, such as Stepwise regression in SAS Statistics, and spatial regression, hot spot, and cluster analyses in ArcGIS.

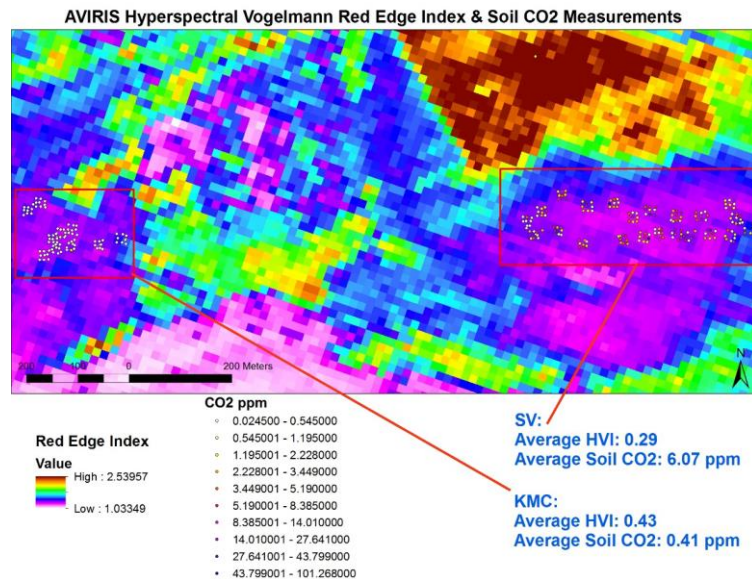


Figure 2. AVIRIS hyperspectral Vogelmann Red Edge Index & Soil CO₂ Measurements.

The following was accomplished in 2018 (includes field campaign and completed and ongoing data analysis) with the final analysis and presentation as papers published in internationally peer-reviewed journals. Conducted and completed entire field work on vegetation measurements with the help of a field assistant in the Volcano National Park, Steam Vents (SV) and KMC study areas, in February 2018 during the NASA AVIRIS flight campaign. Data was collected for the following: chlorophyll

index measurements, vegetation fraction, plant size, vegetation health, and plant species. Twenty-five hyperspectral vegetation indices (HVIs) were developed ranging from VIS to SWIR spectral range, including sensitivity to water, nitrogen, cellulose, lignin, carotenoids, and other pigments. A spatial regression analysis of one of the HVIs, the red-edge vegetation index (Figure 2), and soil CO₂ was carried out for both SV and KMC study areas.

Dr. Mariotto is currently evaluating the other HVIs to evaluate senescence, amount of cellulose and lignin, carotenoids, anthocians, and other pigments to find the best correlation with soil CO₂, H₂S, and temperature. She will develop the best HypsIRI-like AVIRIS HVIs and best narrow bands that correlate to soil CO₂, H₂S, and temperature. She will apply the same analyses to AVIRIS historical images, to potentially detect a rapid change in vegetation stress before the Kilauea volcano eruption of May 2018. She will then produce a change detection geospatial analysis. The best hyperspectral bands and best HVIs capable to detect rapid change of vegetation stress, which will be suggested for future application to the HypsiRI satellite. She will also create spectral signatures for stressed and non-stressed vegetation, and create a spectral library of healthy and stressed vegetation

Dr. Deering presented the results of the hyperspectral analyses at the 2018 HypsIRI Science and Applications Workshop in Washington D.C. on 15-17 August.