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Summary of findings from JPL/NASA VEREX I deployment to Kilauea Crater, Hawaii Volcanoes National Park

David Pieri, JPL, Principal Investigator

During February 2017, a joint JPL/NASA/University of Costa Rica/UCLA deployment of small free-flying unmanned aircraft (UAVs) and tethered aerostats (kites) was conducted at Kilauea Summit within the Hawaii Volcanoes National Park, in close cooperation with staff from the United States Geological Survey and the United States National Park Service as part of our so-called *Volcanic Emissions Retrieval Experiment (VEREX I)*. The deployment was successful and demonstrated that in situ volcanogenic gas sampling can be effectively accomplished with small free-flying and tethered airborne platforms, providing a new kind of data that is essentially not obtainable by other means. The lessons learned and data acquired will now permit us to create roadmaps to even more effectively utilize these resources in the future for volcanogenic hazard mitigation as well as basic volcano science. In addition, the operational lessons learned, including those from nine successful flights and the loss of one small UAV due to a suspected electronic autopilot component failure, give us confidence that our safety plan is adequate to respond to anomalous events. Thus, we feel that the deployment was of great value and a success. In September 2017, the NASA Ames Research Center presented our VEREX Team with a Team Achievement Award—the VEREX honorees included our JPL participants, our NASA ARC and Goddard Spaceflight Center participants, our University of Costa Rica and UCLA participants, our USGS HVO/CVO colleagues, our NPS HAVO colleagues, and Ms. Lani Petrie of Kapapala Ranch.

Our objectives were:

- *In situ validation* of remote sensing derived (e.g., ASTER, ER2-based MASTER/HyTES and AVIRIS-ng) gas and aerosol retrievals using free-flying UAV-based, aerostat-based, and ground instrumentation.
- Characterize the *near surface extent, distribution, constituents, and dispersion characteristics of gas and aerosol emissions*, especially SO₂ hydrolysis at Kilauea Volcano.
- Improve accuracy of local SO₂ and CO₂ flux estimates using in situ airborne data.
- Improve approaches to statistical representation of UAV data.
- Improve knowledge of local volcanic phenomena to mitigate hazards to local residents, park visitors, and staff.
- Validate and improve transport models (applications to mitigation of local VOG hazard).
- Facilitate instrument development, especially miniaturization, to enable improved observations from future UAV and aerostat platforms.

Our accomplishments and preliminary results from VEREX I were:

- NASA Dragon Eye UAVs successfully acquired airborne SO₂ and CO₂ concentration data, and ambient atmospheric profile data between the ground and approximately 1200ft AGL for emissions from the active Kilauea summit vent during the period 12-21 Feb 2017. Ground-based SO₂ and CO₂ data were also acquired along the rim of Halemaumau Crater on the ground by portable instruments carried by team members.
- Nine successful flights were accomplished. One flight terminated with the total destruction of the aircraft and payload estimated to be within the active Kilauea lava lake. Four flights were accomplished at Kilauea Summit; five flights were accomplished over Kapapala Ranch, 23km distant from the summit, along the lower slopes of Mauna Loa.
- Near-field SO₂ levels ranged up to 250ppmv within the summit plume; CO₂ levels ranged up to 500ppmv within the summit plume (approximately 100ppmv above ambient background values).

Ambient non-plume UAV CO₂ were slightly elevated (+10ppm) vs NOAA values (probably from diffuse volcano emissions across the summit crater and surroundings).

- Far-field observations captured SO₂ concentrations in the range of 0.1-1.0ppmv at altitudes up to 1500ft AGL with ambient atmospheric profile data. These values are closely consistent with Hawaii State air quality predictions for the operational area.
- Comparisons with ASTER and MASTER data are ongoing. Due to operational restrictions, only one MASTER-UAV simultaneous data set was acquired in the far-field. UAV-based data were acquired during the ASTER overpass on 12 February 2017.
- Analysis is ongoing, especially comparisons of UAV in situ data to the remote sensing data, as well as reverse flux modeling as we have accomplished with our UAV data from Turrialba Volcano, Costa Rica (e.g., Xi et al., 2016, JVGR).

Rationale for VEREX II (February 2018)

We have several main goals for a second VEREX deployment of an aerostat at Kilauea summit to build on data from VEREX I and to accomplish additional tasks that were not completed during that deployment. This time we will emphasize inherently operationally less complicated tethered aerostat (blimp-balloon) observations, which are complementary to the areally more extensive free-flying UAV observations made during VEREX I. Time-series aerostat observations at-a-station are fundamentally different kind of observation than an area-wide UAV sampling activity.

Our goals are:

- to support multiple HyTES/MASTER/AVIRIS/ASTER HypsIRI analog overflights, of which **we were only able to accomplish one simultaneous MASTER-AVIRIS-UAV data acquisition last time;**
- to understand the time variability of near-vent airborne SO₂ and CO₂ emissions, **which was not possible last time;**
- to conduct simultaneous and continuous measurements of the CO₂/SO₂ concentration ratios in time-series fashion—**simultaneous airborne gas ratio data were not possible with our UAV instrumentation last time;**
- acquire vertical atmospheric temperature, pressure, and relative humidity profiles along with time series of SO₂/CO₂ ratios and concentrations at altitudes up to 400m AGL within the plume adjacent to the summit crater and over the USGS FlySpec DOAS array south of Kilauea summit (to provide cross-instrument calibration/validation data)—**last time it was not possible to conduct overflights above the array;**
- acquire data (simultaneously with aerostat acquisitions at the same sites) utilizing the University of Hawaii Thermal Infra-Red Compact Imaging Spectrometer (TIRCIS—Rob Wright, UofH, PI) to conduct multi/hyper-spectral thermal imaging observations concurrent with our in situ concentration measurements to provide additional near-field remote sensing observations related to the chemistry and dynamics of the plume—**this valuable instrument was not available to us during VEREX I.**

We look forward to a very productive second deployment at Kilauea in February 2018, on the heels of our successful 2017 deployment. We believe that the aerostat approach to time-series data acquisitions at a station will give us key additional complementary insights as to the variability of crater emissions that will be directly applicable and useful to hazards-related research important to the NPS, as well as basic volcano and remote sensing-based science, and will support continued collaborations with NPS, USGS, NASA, and university colleagues.