Volcano Co-robot Adaptive Natural algorithms (VolCAN)

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https://volcan.cs.unm.edu

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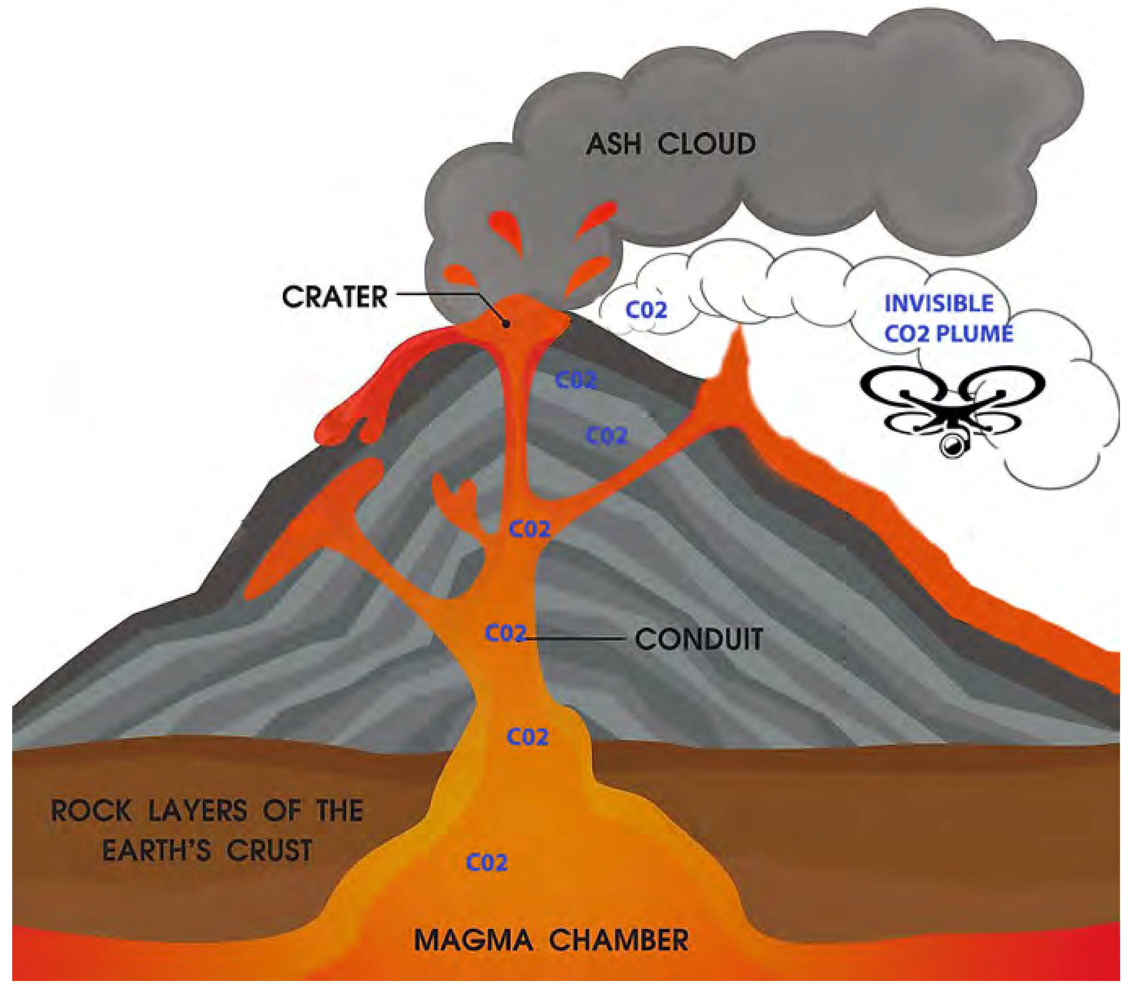
Challenge: CO_2 Survey

Measure invisible CO_2 concentrations in plumes to predict eruptions & inform climate models



•Identify largest plumes fast, •Estimate plume volume, •Find maximum CO2 source

Theory

Objective: Assuming a fixed step length ϵ of the movement of the drone, estimate the plume area upto some approximation error with optimal flight and turn complexity.

Work in Progress: If the plume boundary is approximated by a polygon, then there is an algorithm that computes the area upto a multiplicative error of ϵ, with $O(\ell)$ flight and $O(\phi)$ turn complexity, where ℓ is the perimeter of the plume boundary and ϕ is the sum of the exterior angles of the polygon.

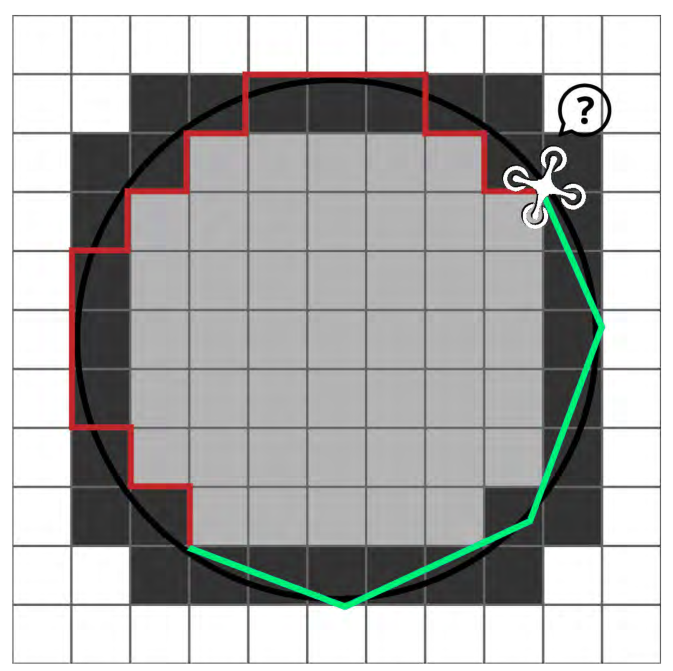
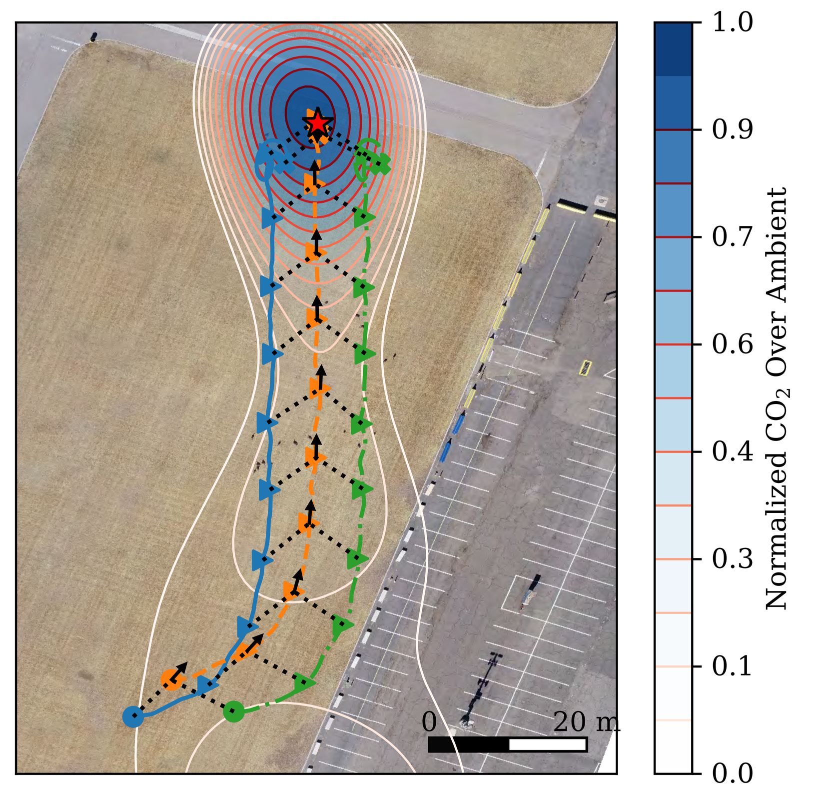


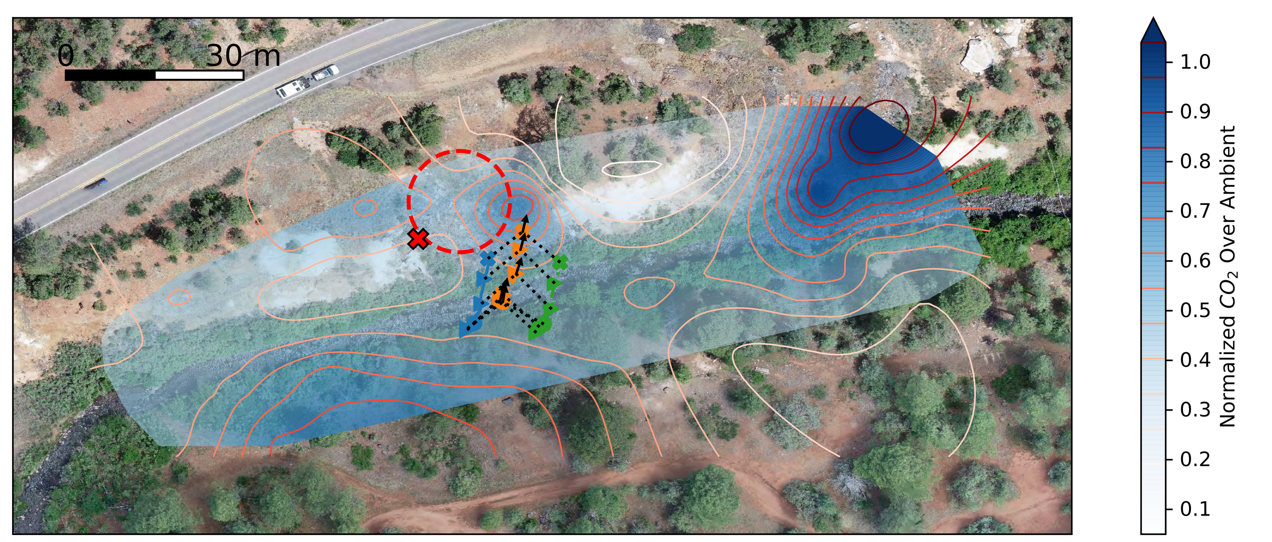
Figure 1: Two possible motions in red and green, the red path traces the plume boundary (dark circle) with $\pi/2$ radians turned in many steps, whereas the green path is a significant improvement over all constraints.

Solution: Collaborative Autonomous Robots

Solution: Collaborative capabilities allow multiple UAVs to share data in real-time, acting as one re-configurable scientific instrument. Algorithms are tested in simulation, evaluated in local field sites, and finally leveraged to gather data on expedition at active volcano sites.



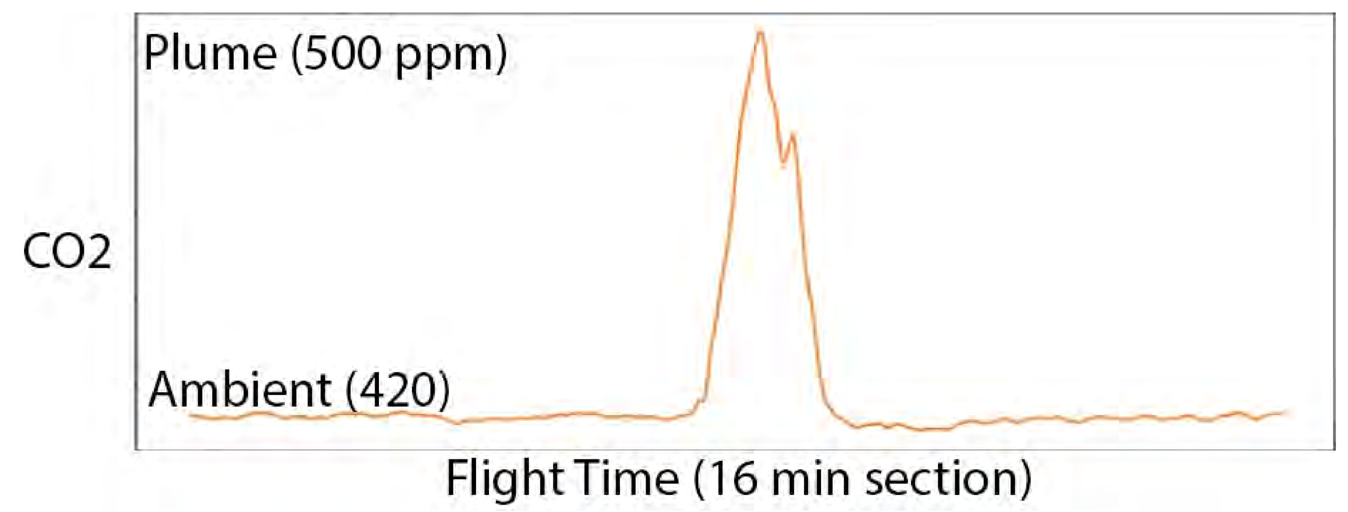
Valles Caldera Field Site



Valles Caldera supervolcano field tests, NM identified multiple CO_2 hot-spots corresponding to ground sources. Data was collected collaboratively by flying multiple flocking Dragonflies to rasterize the region and perform gradient descent to quickly identify a local maximum.

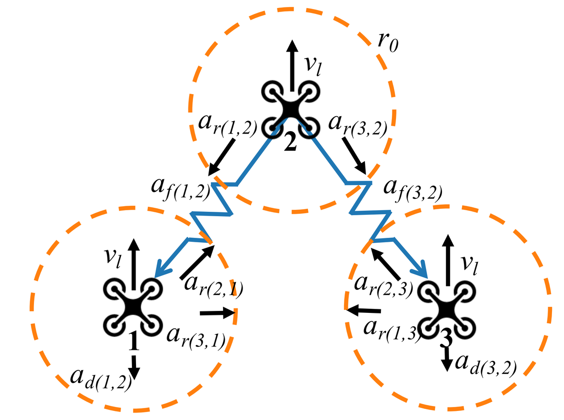
La Palma Expedition

We tested the dragonfly platform at the catastrophic eruption on La Palma island in November of 2021. The drones were able to located the CO_2 plume and retrieve a sample of magmatic gas.



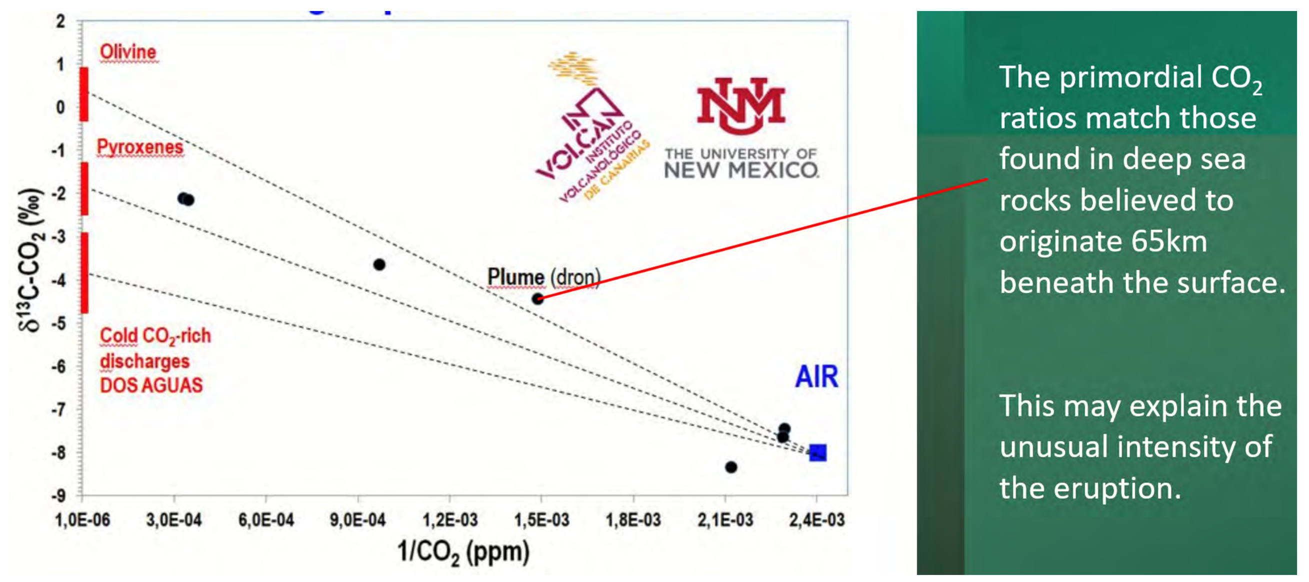
The Dragonflies sampled CO_2 (ppm) from the plume emanating from the active La Palma. Multiple missions collected direct plume CO_2 samples. The elevated CO_2 of the plume is clearly visible against ambient CO_2. Carbon isotope analyses were done on the collected CO_2 gases in La Palma which showed that the gases have correlated to known deep-sea sources originating from deep within the earth's mantle. This may explain the violence and duration of the eruption.

Dragonfly Robots



Custom built robotic flocking platform running ROS and capable of on-board CO_2 concentration analysis and multi-agent coordination.

GeoScience Impacts



- Drone-based methods seek to reduce the risk to volcanologists who historically have had to sample gases by hand.
- Taking in-plume gas samples allows scientists to validate CO_2 flux estimates based on satellite SO_2 fluxes using known C/S ratios.
- Sampling in-plume gases allows for carbon isotope analyses which can help start discerning source(s) of CO_2 i.e. magmatic, organic and carbonate rocks, or a combination.

Scientific and Broader Impacts

Scientific Impact: Advance understanding of autonomous adaptive co-robot algorithms & scientist in-the-loop environmental sensing in harsh environments

Broader Impact: Help geologists predict volcanic eruptions with potential to save thousands of lives; previously impossible at most of Earth's 1500 active volcanoes.

Publications

Ericksen, John, G. Matthew Fricke, Scott Nowicki, Tobias P. Fischer, Julie C. Hayes, Karissa Rosenberger, Samantha R. Wolf, Rafael Fierro, and Melanie E. Moses. "Aerial Survey Robotics in Extreme Environments: Mapping Volcanic CO2 Emissions with Flocking UAVs". In: Frontiers in Control Engineering (2022)

Z. Miao, H. Zhong, J. Lin, Y. Wang and R. Fierro, "Geometric Formation Tracking of Quadrotor UAVs Using Pose-Only Measurements," IEEE Transactions on Circuits and Systems II: Express Briefs, vol. 69, no. 3, pp. 1159-1163.

G. A. Cardona, D. S. D'Antonio, R. Fierro, and D. Saldaña, "Adaptive Control for Cooperative Aerial Transportation Using Catenary Robots," IEEE Aerial Robotic Systems Physically Interacting with the Environment (AIRPHARO), Croatia, Oct. 4-5, 2021, pp. 1-8.

Ericksen, John, Abhinav Aggarwal, G Matthew Fricke, and Melanie E Moses. "LOCUS: A MultiRobot Loss-Tolerant Algorithm for Surveying Volcanic Plumes". In: IEEE Robotics and Computing Conference (IRC). IEEE, 2020.