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Volcanic Airborne Gas Monitoring using the miniGAS and miniature Mass Spectrometer UAV based Systems (VAMOS-UAV)

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Scientific Report

MISSION TEAM

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1. Introduction and motivation

The current report focuses on the deployment carried out at Mt Etna, Italy integrating drones and portable gas sensing instruments to characterize the volcanic plume and degassing on this very important active volcano. The project was carried out in collaboration with INGV and JPL as part of the ENVRI TNA funded project titled: "***Volcanic Airborne Gas Monitoring using miniGAS and miniature Mass Spectrometer UAV based Systems" (VAMOS-UAV)*** which allowed access and INGV collaboration at Mt. Etna volcano from Oct 21 to 27 in Catania, Sicily.

2. Scientific objectives

Characterize the gas emission of Mt. Etna Volcano using the recently developed UAV ready miniature multiple Gas System (miniGAS) and miniature Mass Spectrometer System (mMS) targeted for in-situ volcanic gas emission analysis during ground and airborne campaigns. The mMS have been used to support earth science missions for both atmospheric and volcanic studies providing a robust and broad spectrum of in situ gas sampling with trace gas analysis capability (1 to 150 amu), combined with temperature, humidity, pressure, position, and particle characterization data for ash-driven volcanic plumes. The system has been tested in Costa Rica and Italy but Mt Etna represent a new and challenging target to characterize the gas emissions with in situ mass spectrometry, measure the different gas ratios among the different gases detected to assess the condition of the volcano and compare to other techniques used by the INGV, to better understand the geochemistry of the volcano. The deployment of the miniGAS and mMS systems at Mt. Etna will serve as a demonstration of the capabilities of the instrument under normal operating condition of a volcanic research center for solid earth and atmospheric studies.

3. Methodology and experimental set-up

Four different in-situ volcanic gas measuring payloads were deployed during the VAMOS mission: the miniGAS-PRO (GasLAB-UCR), miniGAS-NTX (INGV-Rome), miniGAS-Lite (Only SO2, GasLAB-UCR) and the miniature Mass Spectrometer (mMS, GasLAB-UCR) Each miniGAS uses NDIR and ECC bases single sensors and the mMS uses a modified XPR3 miniature quadrupole mass spectrometer (Inficon Inc.) and a light weight and rugged portable vacuum system (Pfeiffer Inc.). Also, a ground thermal camera (INGV Rome) and airborne optical camera/thermal camera package (INGV Napoli) were used in the UAV/ Drone flights. The drones and equipment were unpacked and assembled at INGV Catania facility) and then brought to the field the next day for initial testing. (Figure 1)

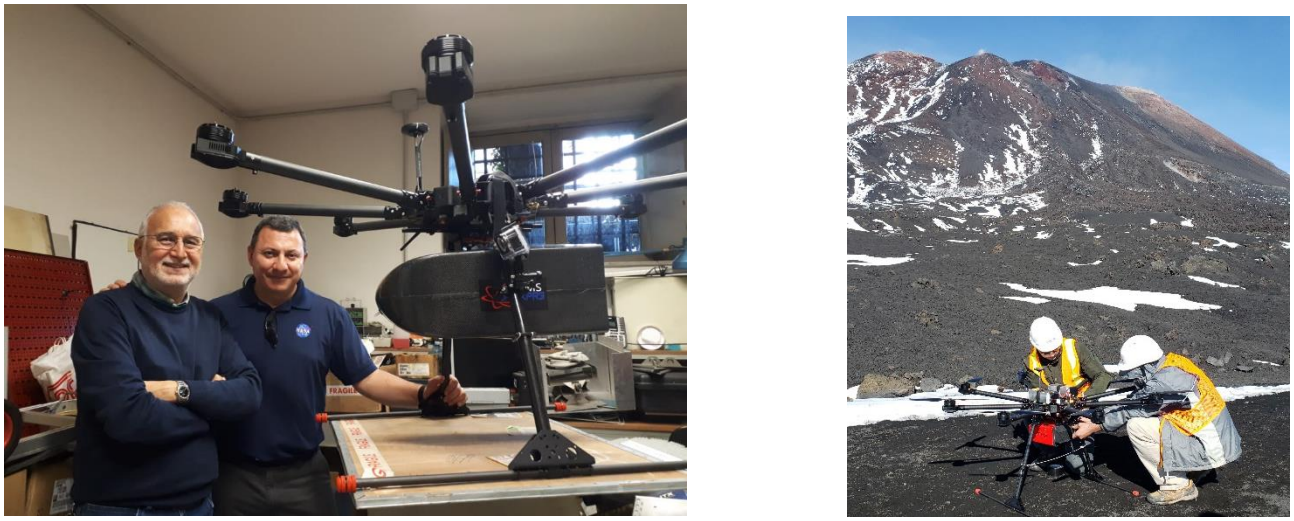

Figure 1: ***(Left) PI's Dr. Puglisi and Dr. Diaz at INGV Catania,*** where setting up the instruments and doing drone integration with gas analysis systems took place on first day. (Right): GasLab-UCR team setting up the miniGAS onboard Italdrone UAV at field for initial testing on day 2

Four drones were employed during the VAMOS-UAV project: 2 octocopters: ItalDrone from GasLab-UCR and FlyBit (IDS) from INGV Napoli; and 2 Quadcopters: The VulcanDrone from GasLab-UCR and the Colibri (IDS) from INGV-Napoli, each one with its own characteristics and capabilities described in Figure 2.

Flybit, Octocopter Drone (INGV) + miniGAS NTX
Range: 3km. . Flight Time: 1 hour
Payload: miniGAS NTX or Thermal cam (1.2kg max)

ItalDrone: Octocopter Drone (GasLab) + mMS
Range: 3km, Flight Time: 20m/mMS & 45m/miniGAS
Payload: miniGAS PRO or mMS-XPR3: (6 kg max)

VulcanDrone: ***Quadcopter (GasLab)+ miniGAS-Lite***
Range: 2km. Flight Time: 15 min
Payload Capacity: miniGAS Lite (700gr max)

Colibri: ***Quadcopter Drone (INGV) + Thermal/Optical Camera***
Range: 2km/ Flight Time: 40 min
Payloads: Optical and Thermal Camera. 1kg max

Figure 2: UAVs and payloads used at VAMOS-UAV Mt Etna deployment

The deployment conducted 4 test flights with no instruments to test the Drones at high altitude without risking the payloads: (2 with Vulcan Drone, 1 with FlyBit and 1 with Italdrone). The site conditions were harsh: cold weather and high wind was persistent though the week, plus the active plume sometimes went through the launch site, making it necessary to use gas masks.

4. Preliminary results and conclusions

The success criteria established by the PI's for the VAMOS-UAV deployment was to get at least 2 successful flights with gas sensing instruments crossing the Mt Etna Volcano plume. The VAMOS-UAV team conducted 10 flights with UAV borne instrumentation: 3 Flybit flights: 1 with Optical/Thermal cameras and with 2 miniGAS-NTX payload; 2 Vulcan Drone flights with miniGAS-Lite payload; 4 Italdrone flights: 1 with mMS and 3 with miniGAS-PRO payloads and 1 Colibri UAV flight with Optical/Thermal cameras. In addition to the UAV flight, the miniGAS PRO systems was used for ground survey using both the car as mobile platform and hand held for crater ground surveying. Results are shown in Figure 3. The car transected the plume which was blowing low that day, affecting the areas normally walked by the

tourist. The system measured SO2 concentration up to 11 ppm in the road and 9 ppm in the craters. (above 2ppm is considered harmful).

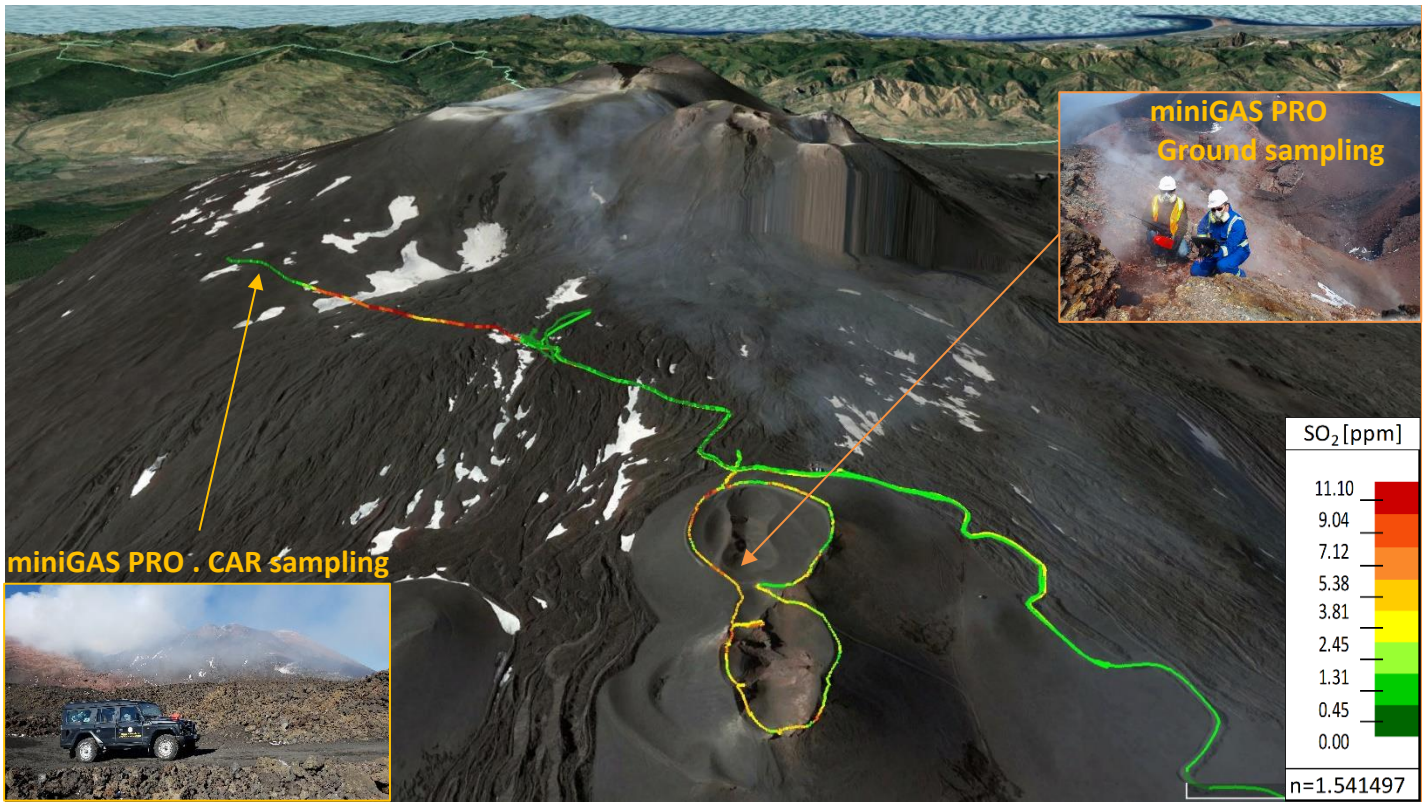

Figure 3: miniGAS PRO on INGV 4x4 car ride and hand-held walk to characterize SO2/ H2S concentrations on open Mt Etna paths for tourists

Figure 4: miniGAS PRO and mMS payloads (Pict Insert) onboard flying Italdrone UAV at Mt Etna , Catania for 3D Volcanic Plume Characterization. VAMOS-UAV Mission 2018

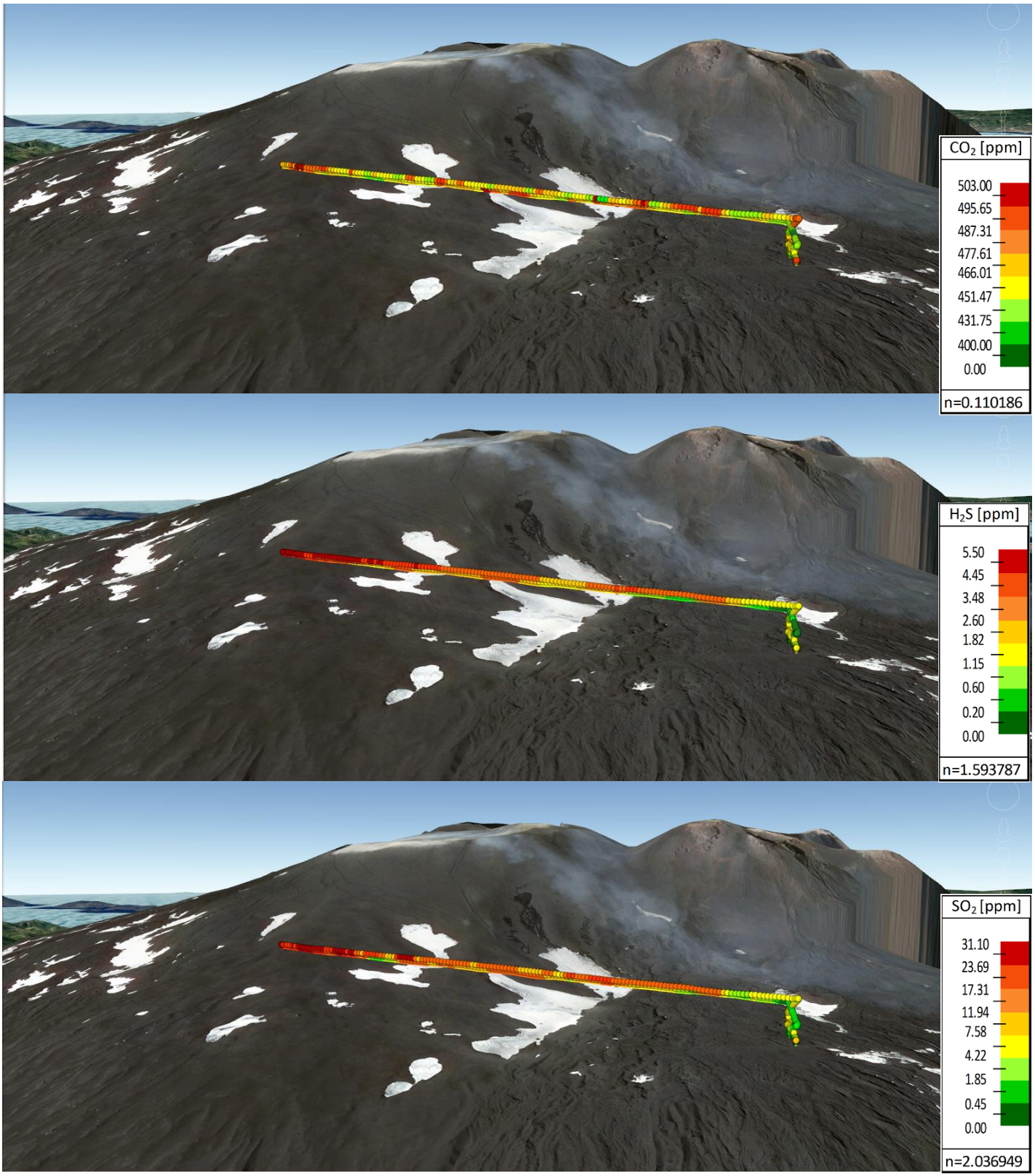

Figure 5: miniGAS PRO + ItalDrone UAV System. Preliminary 3D gas plume concertation. CO2 (top), H2S (Middle), SO2 (Bottom)

Figure 4 shows a picture of two of the actual UAV flights of the Italdrone carrying the miniGAS PRO and the mMS payloads. As an example of the data collected, Figure 5 shows the 3D plots for the first flight of the miniGAS-PRO going into the volcanic plume (increasing signal dots changing from green background levels) to red (high concentration). Similar plots were obtained for all the gas instruments flown and we are in the process to analyze the data.

5. Multidisciplinary approach

One of the achievements of the VAMOS -UAV 2018 mission is that it consolidated an international research collaboration that has been working together since 2014 with the first field tests using drones at Solfatara volcano in Napoli. The team is made from a consortium of research institutions in Italy, Costa Rica and USA, representing different fields: volcanology, remote sensing, physics, chemistry, geology, aerospace engineering and mechanical engineering, to solve the difficult task of developing in-situ airborne gas measuments at active volcanoes using UAVs. It is also good to point out the internal collaboration fostered with this project among the different INGV centers in which 4 locations interacted for the success of the mission: INGV-Catania, INGV-Rome, INGV-Napoli and INGV-Consenza.

6. Outcome and future studies

The deployment was a success and demonstrated the capabilities of the miniGAS instruments (PRO, NTX, Lite versions) for airborne in situ gas measurements using UAVs in complement with other techniques such as the thermal and optical cameras deployed by ONGV Rome and Napoli. The deployment provided a unique collection of Mt Etna's degassing concentrations to compare with both ground measurements stations and remote sensing instruments. It also provided a list of lessons learned to develop better and more robust systems for permanent monitoring of volcanic activity using drones and portable instruments. As an important note, to our knowledge, this is the first time a miniature mass spectrometer is flown in a small UAV at a volcano with the elevation of Mt Etna, which constitute a milestone in the Chemistry, Physics, Engineering and Volcanology fields but the instrument still requires more development in both the UAV platform and instrument fronts. We will produce at least 2 scientific papers form this deployment and several conference presentations and we hope to continue this area of work at Mt Etna in 2019 and other locations.

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Thank You Very Much / Grazie mille / Merci beaucoup / Muchas Gracias