Advanced Engineering Days

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Implementing unmanned aerial systems equipped with Sniffer4D payloads for volcanic gas detection and data analysis used for forecasting volcanic eruptions

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Cite this study: Godfrey, I., Brenes, J. P., & Cruz, M. M. (2022). Implementing unmanned aerial systems equipped with Sniffer4D payloads for volcanic gas detection and data analysis used for forecasting volcanic eruptions. 4th Advanced Engineering Days, 81-84

Keywords
Gas Detection
Atmospheric Chemistry
Volcanology
Climate Change
Volcanic Plume
Sniffer4D

Abstract

A consistent volcanic monitoring program is crucial to the safety of the population and the efficiency of the nation. Costa Rica´s National Commission for Risk Prevention the CNE helps manages this responsibility. Universidad Nacional Costa Rica the National Observatory for Volcanoes OVSCORI-UNA and the Atmospheric Chemistry Laboratory LAQAT-UNA all have a strategic interest in monitoring and tracking volcanic activity. One aspect of monitoring volcanoes is tracking the active emissions being released from the craters and fumaroles. For this study the Sniffer4D gas detection payload was deployed on an UAS and flown directly into the active West Crater of the Turrialba volcano in 2022 for readings of active emissions. The Turrialba volcano is located 40 km or 25 miles East of San José the Capital city of Costa Rica where the majority of the population live. In 2017 an eruption column emerged 3,000 meters or 9,842.5 feet above the summit crater of the Turrialba volcano and dispersed ash in the capital resulting in airport closures. So monitoring the Turrialba volcano is of great importance to the country. The UAS system deployed carried the Sniffer4D which tested for Temperature, Humidity and 9 additional parameters - Sulfur Dioxide SO_2 (μg/ m^3), Volatile Organic Compounds VOCs (ppm), Carbon Monoxide CO (mg/m^3), Carbon Dioxide CO_2 (%), Ozone O^3(μg/ m^3), Nitrogen Dioxide NO_2 (μg/ m^3), O^3+NO_2 and Particulate Matter - PM 1.0, 2.5 & 10. Particulates – also known as atmospheric aerosol particles, atmospheric particulate matter, particulate matter (PM), or suspended particulate matter (SPM) – are microscopic particles of solid or liquid matter suspended in the air. The term aerosol commonly refers to the particulate/air mixture, as opposed to the particulate matter alone. The main objective of launching this payload into the West Crater of Turrialba was completed by Ian Godfrey in 2022.

Introduction

Volcanic eruptions have long term effects of the atmospheric chemistry of the Earth. Water vapor H_2O, Carbon dioxide CO_2, are the two most abundant gases being released from active volcanoes. These two gases along with Sulfur dioxide SO_2, Hydrogen chloride HCI, Hydrogen fluoride HF, Hydrogen sulfide H_2S are the most common volcanic gases being emitted from active volcano vents. Still there are other trace species such as Hypobromite BrO, One-carbon molecules, Nitrogen dioxide NO_2, Carbon monoxide CO, Carbon oxysulphide COS, Silicon tetrafluoride or tetrafluorosilane SiF_4 [1].

Researching all aspects of Sulfur dioxide and secondary sulfate aerosols is of strategic importance to the Laboratory of Atmospheric Chemistry because the microphysical dynamics of these particles in active eruption columns is essential to comprehending the radiative properties of these natural volcanic emissions and this is a key to understanding how they affect climatic changes across our planet. Measuring volcanic gases offers insight into subterranean processes happening deep within the Earth's interior [2].

The data collected with the Sniffer4D does contribute to the collective knowledge of the entire scientific community, and the SO_2 tracking data can be cross referenced to the NASA Atmospheric Chemistry and Dynamics Laboratory, Copernicus Atmospheric Monitoring Service European Commission and Global Network of Observation of Volcanic & Atmospheric Change (NOVAC). Active volcanoes releasing emissions have a direct impact on the Earth's atmospheric chemistry, and climatic patterns; therefore, monitoring eruption columns with UAS and gas detection payloads is of extreme importance to climatologists.

H_20 is normally the most abundant gas deriving from a magmatic source and like CO_2 it is relatively abundant in the atmosphere of the Earth. Other volcanic gases such as SO_2, HCI & HF derive from the same source but are not normally present in the atmosphere unless there is an eruption vent releasing these gas species into the nearby proximity. CO_2 is the second most common gas species being naturally emitted from volcanoes. At the Poás and Turrialba volcanoes in Costa Rica diffuse degassing of CO_2 represents approximately 10% of total emissions abundant in magmatic gas. Diffuse degassing occurs when gas species pass through openings from porous volcanic edifice permeable to rainwater [3].

Material and Method

The Sniffer4D was attached to the Mavic 3 with an integration kit created with a 3D printer. The Sniffer4D is placed upside down and the 3D printed mounting bracket is placed on top of the bottom of the device. The mounting bracket is then attacked with 4 M2.5*6 screws in each corner. The Sniffer4D and attached mounting bracket are then placed onto the Mavic 3 drone and the assembly is permanently connected via 2 additional M2.5*6 screws at the bottom. The Sniffer4D is powered by the same battery as the UAS itself, via a power cable. The power cable aligns to the two outermost power connectors of the Mavic 3 battery. The power cable is secured with three small pieces of double-sided tape and is then attached to the Sniffer4D.The system has a total flight time of around 20 minutes depending on environmental conditions. There are two Sniffer4D Systems one designed for HAZMAT response the S4D and the other to log volcanic emissions S4V which can measure;

S4D - NO_2, SO_2, O_2, VOC's, CO_2, CO, PM 1.0, PM 2.5, PM 10, O_3, NO_2+O_3

S4V - SO_2, CO_2, H_2S, HF, HCI, CO, CxHy/CH_4/LEL, H_2

The Sniffer4D software program is named Mapper which can showcase the air quality and pollution dispersement as a grid, isoline or 3D plot. The drone was launched from the main lookout point of the Turrialba volcano on the southern edge of the Central Crater. The Sniffer4D can be used to showcase air quality data in real time via a SIM chip and associated data plan placed in the device which is connected to the local cellular network, allowing for real time pollution tracking. Monitoring the SO_2/CO_2 gas ratio is dangerous work, especially during times of increased activity.

In 2022 our team reached the summit of the Turrialba volcano on a dry day with clear visibility and no wind or any other harsh environmental conditions. We were caught in the mud about 4 kilometers or 2.4 miles from the summit crater. After a climb we reached the half-way point where we launched the drone to observe the last stretch of our pathway and make sure there was no significant degassing or explosive activity at the active West Crater. After the first UAS mission we continued our assent and reached the main lookout point for the Turrialba Volcano National Park. UAS remote sensing approaches have shown exponential potential in the field of volcanology; UAS applications at the Turrialba volcano are a perfect example. The main objective of our UAS survey was to observe the crater interior which we estimated to have crater walls which have slopes of approximately 55^o. The depth of the West Crater was estimated to be 410 feet to 722 feet or 125 meters to 220 meters. The West Crater was estimated to have a width of 620 feet or 189 meters.

The Sniffer4D and Mavic 3 system deployed at Turrialba can help reveal additional valuable data concerning volcanic degassing and emission levels. This measurement system is very useful to the entire scientific community concerning volcanic monitoring and gas emission tracking, volcanic unrest and hazard assessment. Drones using GNSS system fixed waypoints can maneuver around the fumarole location this strategy allows the system to periodically check areas of significant volcanic emission activity and return to the exact same location when necessary. H_2S/SO_2 gas ratios fluctuate depending on temperature, pressure and redox conditions. Significant amounts of SO_2 and H_2S emissions deriving from hydrothermal sources are controlled by this chemical equation: $H_2S + 2H_2O \rightarrow SO_2 + 3H_2$. Increase in SO_2/H_2S represents a potential increase in magmatic influence relative to volcanic emissions [4]. SO_2 emissions represent magmatic intrusion from within the volcanic edifice itself.

Figure 1&2. Sniffer4D Mapper Report from the Turrialba Volcano and Associated UAS Image

Results

Toxic gas emissions such as Sulfur dioxide or SO_2 which are the direct result of burning fossil fuels contribute to climate change and acid rain in the region. SO_2 is also released from active volcanoes during periods of eruption and UAS are positioned to greatly assist volcanologists measuring these gases from safe distances. UAS capabilities can now greatly assist climate scientists by providing an aerial observation perspective which allows for increased data collection with improved safety. UAS also reduce risks associated with climbing and venturing into regions of increased volcanic activity such as an active crater. The Sniffer4D detected and provided real time data to team of volcanologists and showcased 9 different gas emissions from one flight into the Turrialba volcano crater. The device also records temperature and humidity making it an extremely valuable UAS payload for volcanology. Total payload weight was less than 500 grams and can be deployed with gas sampling module which can retrieve volcanic ash and particulate matter which can then be analyzed in the lab. Quantifying total gas flux from an eruption column serves a greater importance than measuring general gas concentration because total gas flux corresponds to volcanic activity [5].

Discussion

UAS are allowing scientists to deliver new scientific equipment into the most extreme environments and take physical samples of water along with atmospheric parameters yielding a vast amount of valuable information not previously accessible before the implementation of UAS.

Conclusion

Ambient air monitoring and HAZMAT response have become some of the most prominent applications for miniaturized hardware payloads designed for UAS. Data of the volcanic plume and its effects of atmospheric chemistry are easily collected by the Sniffer4D and analyzed by the software program Sniffer4D Mapper which provides a quick, sustainable, safe and reliable way to quantify these emissions and develop a national baseline for volcanic activity in Costa Rica. Quantifications of critical ratios of gas emissions from the volcanos in Central Costa Rica showed no increased levels of activity. This investigation outlines UAS volcanic applications designed to detect and quantify different gases of volcanic origin in order to assist volcanologists with their eruption forecasts.

Acknowledgement

Ian Godfrey is a passionate explorer of the natural world, a writer, a Part 107 Remote Pilot and Thesis Advisor to the Laboratory of Atmospheric Chemistry Universidad Nacional Costa Rica. He has flown UAS into several high altitude active volcanic craters and a variety of industrial sites.

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