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Atmospheric Measurement Techniques
Discussions

Drone CO_2 Measurements During the Tajogaite Volcanic Eruption

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Abstract. We report in-plume carbon dioxide (CO_2) concentrations and isotope ratios during an active eruption of the Tajogaite Volcano. CO_2 measurements inform our understanding of volcanic contributions to the global climate carbon cycle, and the role of CO_2 in eruptions. Traditional ground-based methods of CO_2 collection are difficult and dangerous, as a result only 5% of volcanoes have been surveyed. We demonstrate that Unpiloted Aerial System (UAS) surveys allow for fast and relatively safe measurements. Using CO_2 concentration profiles we estimate total flux to be 1.19×10^6 to $2.80 \times 10^7\ \mathrm{t\,day^{-1}}$. Isotope ratios indicated a deep magmatic source, consistent with the intensity of the eruption. Our work demonstrates the feasibility of UASs for CO_2 surveys during active volcanic eruptions, particularly in calculating plume characteristics.

1 Introduction

Rapid and accurate measurements of volcanic CO_2 emissions during an eruption are critical because they can be used as a forecasting signal (Aiuppa et al., 2010). CO_2 is also a significant greenhouse gas making measurement of CO_2 emissions important for climate science (Arrhenius, 1896). CO_2 gas is second only to steam in abundance in magma and volcanic emissions (Giggenbach, 1996). Despite the significance and abundance of CO_2 in the Earth System in general and in magmatic systems in particular, measuring the emission rates of this gas from volcanic craters, diffuse sources, and low-level hydrothermal sites has remained a major challenge (Fischer and Aiuppa, 2020). As a result of these challenges, CO_2 surveys have been conducted at just 5% of volcanoes (Fischer et al., 2019).

We present a novel approach to surveying in-plume CO_2 concentrations and sample return during a major eruption using the Dragonfly UAS (Ericksen et al., 2022). The UAS transects the plume and employs an onboard infrared (IR) sensor to continuously obtain concentration readings. These readings are then used to estimate a 2D isotropic Gaussian concentration model. In-plume wind speed measurements in combination with the plume model allow us to estimate CO_2 flux. While our technique has similarities to the 'ladder traverse' technique utilizing large in-situ sensing equipment mounted on a piloted fixed-wing aircraft (Werner et al., 2013), it has the obvious advantages of being much less costly, logistically less challenging, and less hazardous. Since our approach extrapolates the plume it requires far fewer plume transects. Crucially, the Dragonfly UAS does not use a combustion engine, which previous work has shown to contaminate CO_2 measurements and samples with

Figure 1. A Dragonfly UAS returning from a CO_2 sample mission during the November 2021 eruption of Tajogaite volcano. The large volcanic ash plume is visible in the background which includes an invisible CO_2 plume, which was the mapping target of this drone.

organic carbon. The resulting concentration map is used to guide the UAS to a productive sample return location (Fischer and Lopez, 2016). CO_2 samples reveal information, such as magmatic depth, relevant to predicting the course of the eruption. We tested this technique during the 2021 Tajogaite volcanic eruption on La Palma Island, Spain, and compared the resulting flux estimates to the traditional ground based CO_2 to sulphur dioxide (SO_2) ratio method. Our technique could be widely used at passively degassing and erupting volcanoes to obtain near-real-time CO_2 flux measurements to better constrain the global volcanic CO_2 budget, and assess and forecast volcanic activity.

While global initiatives to directly determine CO_2 flux from biogenic sources, i.e. FLUXNET (Office of Science, US DOE, 2023) have advanced our understanding of the surface carbon cycle, estimates of volcanic flux are to a large extent obtained by combining SO_2 flux measurements with observed CO_2 to SO_2 ratios (Fischer and Aiuppa, 2020). This approach relies on two separate sets of measurements utilizing a ground-based or space-based remote sensing technique to determine the SO_2 concentration of the volcanic plume and a direct sampling or sensing technique to determine the CO_2 to SO_2 ratio. In almost all cases, these two separate sets of measurements are not made simultaneously and result in intrinsic uncertainties in CO_2 flux estimates (Burton et al., 2013). The main reason for this combined approach is that in contrast to SO_2, remote CO_2 sensing instruments are generally not sensitive enough to distinguish volcanic from atmospheric CO_2. Even space-based CO_2 instruments require favorable atmospheric conditions and satellite positioning to make the distinction (Schwandner et al., 2017). In addition to not being sensitive enough to plume CO_2 concentrations ground-based IR sensors are difficult to transport and expensive (Burton et al., 2013).

As we demonstrate, UASs provide a method for obtaining in-plume gas samples, concentrations, and wind velocity measurements. Together these data allow isotope ratios to be determined and estimation of CO_2 flux, furthering our understanding of volcano dynamics during an eruption and allowing predictions of eruption intensity and duration.

Background

La Palma Island is in Spain's Canary archipelago (Schmincke, 1982). The northern sector of the island hosts the oldest subaerial (on land) volcanism, characterized by repeated large lateral edifice collapses (Day et al., 1999; Acocella et al., 2015). Volcanism resulted in the formation of Garafía and Taburiente and then moved southward to form Cumbre Vieja volcano, at the southern part of the island. This southern system represents the last stage in the geological evolution of La Palma island, as volcanic activity has taken place exclusively on that part of the island for the last 123 ka (Carracedo et al., 1998). The most recent volcanic eruption of Cumbre Vieja is Tajogaite (2021) (Carracedo et al., 2001; Ward and Day, 2001), preceded by that of Teneguía in 1971 (Fernández et al., 2021) and San Juan in 1940 (Fernández et al., 2021; Albert et al., 2016). At 14:10 UTC on September 19, 2021 Tajogaite volcano erupted from a vent on the western side of La Palma Island, in the vicinity of the Llano del Banco eruptive center of the San Juan eruption of 1949 (Instituto Geográfico Nacional, 2022). The eruption was forecast using seismic, geodetic and geochemical techniques by Spanish researchers who alerted the civil protection officials several days before the start of the eruption (De Luca et al., 2022). The monitoring network of diffuse CO_2 emissions on La Palma detected magmatic CO_2 several months before the eruption (León et al., 2022; Rodríguez-Pérez et al., 2022). This monitoring activity took advantage of extensive previous work characterizing diffuse CO_2 emissions on La Palma. This work provided key insights into the dynamics of magmatic CO_2 degassing on the island (Padrón et al., 2015). The eruption itself began with an explosive phase that ejected ash to an altitude of 5 km, then transitioned to fire fountains, violent strombolian activity, and the production of highly fluid lava flows. Within 24 hours of the initial eruption a 3 km long lava flow was evident (Instituto Geográfico Nacional, 2022). The eruption lasted for more than 85 days and built a pyroclastic cone of about 225 m in height. Over the period of the eruption, the volcano showed dynamic and changing activity with new vents frequently opening on the active cone. These vents produced explosive and effusive eruptions of varying intensity (Castro and Feisel, 2022). Bulk tephra, matrix glass and glass inclusions have a basanitic-tephritic composition of 43 to 46 wt%.

Since the onset of the 2021 Tajogaite eruption on September 19, we performed frequent measurements of SO_2 emission rates using miniDOAS traverses by car, ship, and helicopter. Using this data we estimated a flux of over $5\,\mathrm{kt\,day^{-1}}$ of SO_2 (Pérez et al., 2022). Daily monitoring of SO_2 gas emissions occurred before and throughout the eruption using Sentinel 5 satellite data (Copernicus SO_2 satellite monitoring, Smithsonian Institution's Global Volcanism Program 2021). The range of measured emissions rates depended upon wind direction and velocity, as well as eruptive style and activity. The measured SO_2 flux ranged from 3×10^4 to $5 \times 10^4\ \mathrm{t\ day^{-1}}$ at the beginning of the eruption and a mean of $10^4\ \mathrm{t\ day^{-1}}$ over the duration of the active eruption (Albertos et al., 2022). These SO_2 emission rates are likely different from CO_2, but provide the best available proxy for CO_2 emissions and are a useful point of comparison for the UAS-based flux estimates.

Additional gas monitoring techniques included stationary multiGAS and FTIR-based plume gas composition measurements as well as carbon isotope analyses of plume CO_2 in collaboration with the international volcanic gas community (Pérez et al., 2022).

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Table 1. Measured CO_2 concentrations and $\delta^{13}C$ from ground and UAS.

Date	CO_2 [ppm]	$\delta^{13}C$ VPDB ‰	Collection method/site
2021-11-21	435.42	-7.46	Ground
2021-11-21	471.54	-8.34	Ground
2021-11-21	436.74	-7.65	Ground
2021-11-21	416.00	-8.00	Ground
2021-11-28	671.17	-4.44	UAS
2021-11-30	1029.73	-3.65	Ground
2021-11-30	2998.42	-2.12	Ground
2021-11-30	2863.47	-2.15	Ground
2021-12-01	4458.80	-2.03	Ground
2021-12-01	2722.40	-1.47	Ground
2021-12-01	1326.11	-2.40	Ground

2 Results

2.1 Plume Transect CO_2 Concentrations

The maximum CO_2 concentrations of the 10 transects, the corresponding plume widths based on these transects, and the measured wind speeds corresponding most closely in time to the transects are shown in 1. The wind speed measured by UAS hover-drift test was 10.7 ms^{-1}.

The CO_2 concentrations and $\delta^{13}C$ values of plume gas samples are also given in 1. Samples collected from the ground at the UNM multiGAS site show background CO_2 concentrations 4.16×10^2 to 4.71×10^2 ppm CO_2 with $\delta^{13}C$ values of -8‰ (relative to Peedee belemnite) which is close to that of air. The sample collected by UAS has a CO_2 concentration distinctly elevated from air of 6.71×10^2 ppm and a heavier $\delta^{13}C$ value of -4.44 ‰. Samples collected from the ground closer to the vent have even higher CO_2 concentrations from 1.03×10^3 to 4.46×10^3 ppm with $\delta^{13}C$ values from -2.40 to -1.47 ‰.

Figure 5 shows that all plume samples collected from the ground define a set of mixing lines in $\delta^{13}C$ versus CO_2^{-1} space, i.e. in a Keeling plot (Keeling, 1958) that allows for the extrapolation of the $\delta^{13}C$ value of the pure CO_2 being emitted from the volcanic vent. The sample collected by UAV lies slightly above this set of mixing lines and extrapolates to somewhat higher $\delta^{13}C$. The resulting volcanic $\delta^{13}C$ values taking into account all samples lies between -1.5 and +1.5 ‰. Despite these uncertainties, these values overlap with $\delta^{13}C$ data obtained from mantle xenoliths erupted at the nearby El Hierro Volcano (Padrón et al., 2015) and are significantly heavier than values of cold CO_2 emissions on La Palma Island.

The MultiGAS CO_2/SO_2 ratios varied from 5 to 26 during the period of 2021-11-21 to 2021-11-25 (Albertos et al., 2022). We use reported SO_2 fluxes of 10^4 to 3×10^4 t SO_2 day^{-1} to obtain CO_2 fluxes ranging from 2.6×10^4 to $5.4\times10^4\mathrm{t}$ CO_2 day^{-1} for this period.

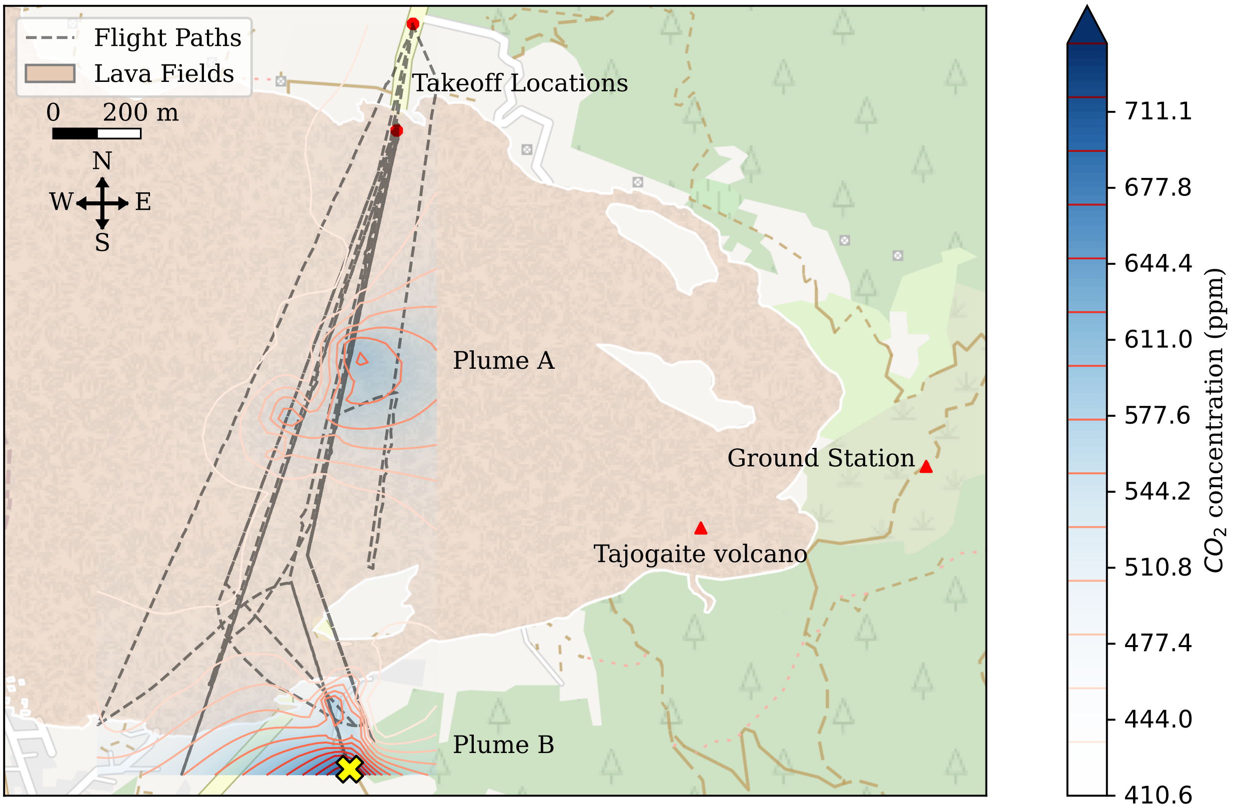

Figure 2. Top-down perspective map of all transect flight paths. Flights occurred over a four-day period during the 2021 eruption. This map includes a horizontal cross-section Kriging plot of the CO_2 concentration highlighted as the distinct Plumes A and B. The sample collection location is indicated by the yellow ×.

Table 2. CO_2 samples collected by UAS across plume A during the eruption.

Date	**Transect**	**Altitude**	**Gaussian Fit Amplitude**	χ^2	**Flux [t day^{-1}]**
2021-11-26	2 Plume A	200 m	1.25×10^4	2.07×10^4	4.71×10^5
2021-11-27	6 Plume A	100 m	3.97×10^4	4.25×10^5	4.73×10^6
2021-11-27	8 Plume A	300 m	1.57×10^4	2.77×10^5	7.43×10^5

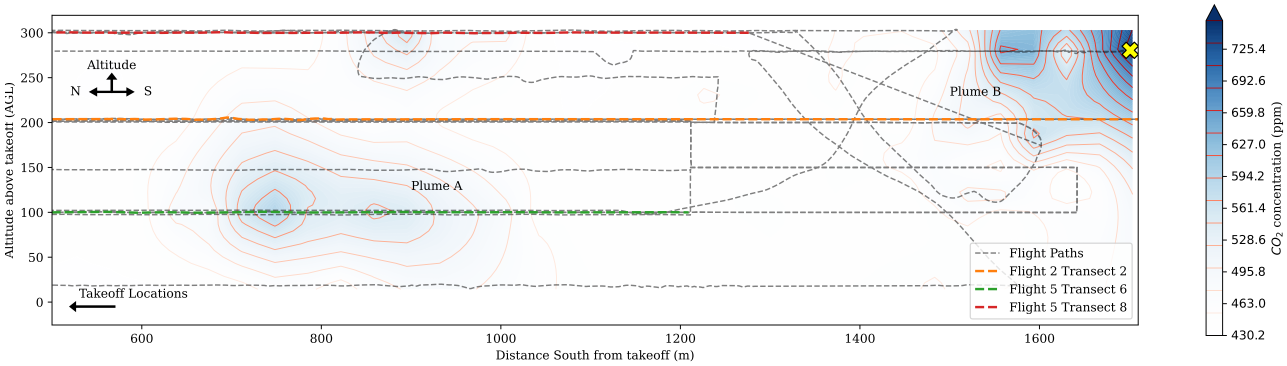

Figure 3. Lateral perspective kriging map of all transects plotted in Figure 2. The plot indicates two separate plumes in the vertical cross-section labeled Plume A and Plume B. The sample collection location is indicated by the yellow ×.

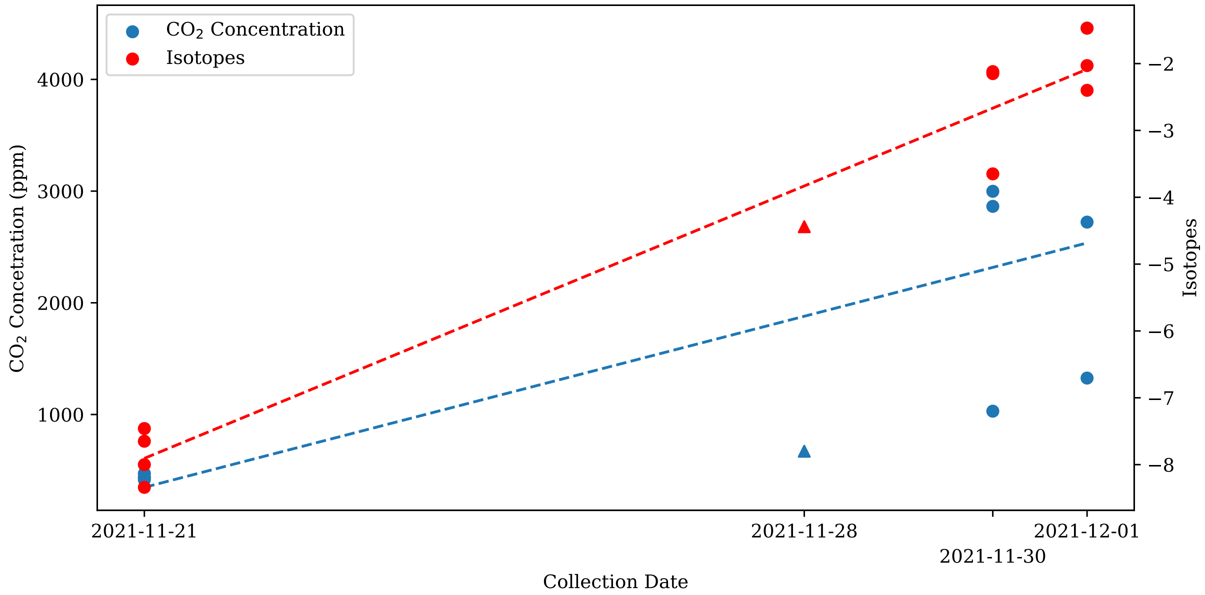

Figure 4. CO_2 concentration in compared with $\delta^{13}C$ isotope readings over time. The circle markers indicate ground-based readings and the triangle markers represent the readings collected by UAS on 2021-11-28. The trend lines show a linear increase in both CO_2 and $\delta^{13}C$ over the eruption.

Table 3. CO_2 samples collected by UAS across plume B during the Tajogaite eruption. * Indicates transect with samples collected into Tedlar bags and analyzed by Infrared Isotope Ratio Spectroscopy.

Date	**Transect**	**Altitude**	**Gaussian Fit Amplitude**	χ^2	**Flux [t day^{-1}]**
2021-11-27	7 Plume B	100 to 250 m	1.23×10^4	1.96×10^6	4.51×10^5
2021-11-28	9 Plume B*	300 m	8.82×10^4	1.81×10^7	2.33×10^7

Table 4. SO_2 and CO_2 flux calculated from multiGAS ratios of CO_2 to SO_2 based on the give SO_2 flux.

Date	**Mean CO_2 SO_2^{-1} [M]**	**SO_2 flux [t day^{-1}]**	**CO_2 flux [t day^{-1}]**
2021-11-21	26±15	$2 \pm 1 \times 10^4$	$2.6 \pm 1.8 \times 10^5$
2021-11-22	10±2	"	$1.4 \pm 6.8 \times 10^4$
2021-11-23	5±2	"	$7.3 \pm 3.7 \times 10^4$
2021-11-24	7±2	"	$9.5 \pm 4.8 \times 10^4$
2021-11-25	16	"	$2.3 \pm 1.1 \times 10^5$

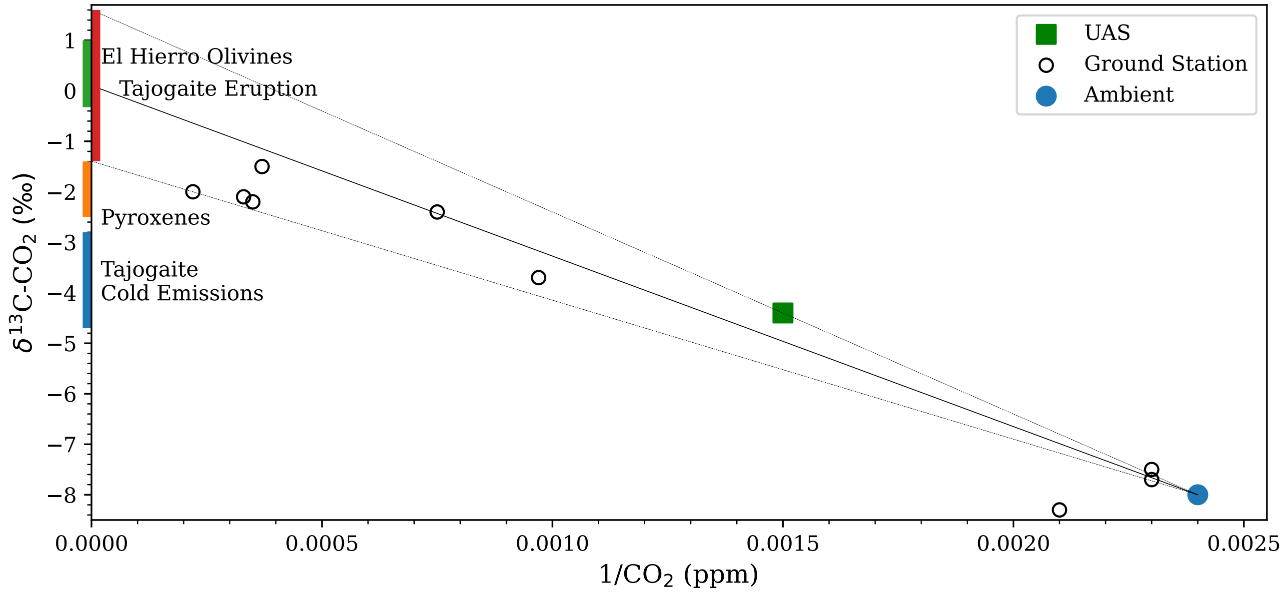

Figure 5. Keeling plot showing standard air, samples collected on the ground, and with the UAS. Linear extrapolation indicates a volcanic $\delta^{13}C - CO_2$ value of -1.40 to 1.60 ‰. Also shown are data from olivines and pyroxenes collected at the El Hierro Volcano (Sandoval-Velasquez et al., 2021) and the composition of cold CO_2-rich gas discharges on La Palma Island.

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3 Discussion

3.1 Carbon Isotopes

The carbon isotope data obtained from the UAS-captured samples and the samples collected from the ground are generally consistent and show mixing of air-derived CO_2 with a deep magmatic source. Extrapolation of all these data results in a $\delta^{13}C$ value of $0.1 \pm 1.5‰$. Despite the uncertainties, this value is consistent with CO_2 being primarily derived from a mixture of mantle CO_2 ($-5 \pm 3‰$) and CO_2 derived from a carbonate source (0‰) (Sano and Marty, 1995). Notably the carbon isotope values are significantly heavier than those measured in cold CO_2-rich gas discharges from springs on La Palma (Rodríguez-Pérez et al., 2022) and within the range of values measured in olivines and pyroxenes of xenoliths from El Hierro Island (Sandoval-Velasquez et al., 2021). These authors suggested that the heavy values of the xenoliths are related to recycling of crustal carbon, likely derived from carbonates into the mantle source of the Canary Islands hot spot. Our data suggests that the magmatic system that is driving the Tajogaite eruption taps into this deep CO_2, rather than remobilizing CO_2 that feeds the cold degassing springs on the island. More work at erupting volcanoes is needed to better constrain the sources of magmatic CO_2 emitted during heightened activity of volcanic systems.

3.2 CO_2 Emissions

Our UAS-based CO_2 emission measurement technique allowed us to obtain CO_2 fluxes utilizing one type of measurement by one instrument. Our data show the challenges associated with UAS-based plume measurements. One major challenge is to transect the gas plume completely during the dynamic movement of such plumes during eruptions. In several of our transects, especially for the more distant Plume B, we were not successful in flying the UAS far enough to get to background CO_2 at the far side of the plume. Related to the dynamic nature of gas plumes during eruptions is that they change shape and direction on short-time scales. While ideally, we would like to perform several flights at various altitudes through a plume in order to obtain a complete CO_2 concentration map of the plume, this is challenging for wide or distant plumes because of limited UAS flight times and the need to know the plume's location and extent a priori. To address this challenge we assume a Gaussian plume and fit a Gaussian curve to our data. We then rotate the Gaussian fit to obtain a 2D concentration slice which is multiplied with observed wind speed to yield the flux. This approach produces the most accurate results if we transect the plume through its widest part. However, identifying the the widest part and then transecting the plume before the plume changes will require teams of collaborating UASs. Our data show that for Plume A, transect 6 (Figure 3) represents the widest plume and results in the highest CO_2 flux value of 4.73×10^6 t day^{-1}, an order of magnitude higher than the other two Plume A transects. This transect was flown at the lowest altitude (100 m) of the three, implying that the other two transects only captured the upper parts of the plume. Comparison with CO_2 fluxes obtained by combining SO_2 fluxes with CO_2 to SO_2 ratios measured 1 km from the vent gives fluxes ranging from 1.4×10^4 to 3.6×10^5 t day^{-1}. While comparing these two approaches is helpful, our experiment was not designed to make a direct comparison. At face value, the discrepancy could be due to a significantly varying CO_2 emission rate during eruptions, an underestimate of the SO_2 flux, or the lack of validity of the 2D Gaussian extrapolation approach. More work needs to be performed in the future to better assess these sources of discrepancy with new and coordinated measurements at passively degassing and erupting volcanoes. However, even with such discrepancies, it is clear that the Tajogaite eruption in November 2021 produced a CO_2 flux up to 2×10^5 $\mathrm{t\,day^{-1}}$ or even 4×10^6 $\mathrm{t\,day^{-1}}$. Even the 4×10^6 $\mathrm{t\,day^{-1}}$ would be only 4% of the daily CO_2 emitted by the burning of fossil fuels (Conlen, 2021).

The use of UAS is revolutionizing volcano science by enabling the collection of data that previously required extensive, costly, and hazardous aerial surveys using piloted fixed-wing aircraft or helicopters. Especially in the field of volcanic gases, recent UAS-based campaigns showed the value of utilizing UAS to make gas flux and gas composition measurements and also collect plume samples for subsequent chemical and isotopic analyses (Liu et al., 2020; Galle et al., 2021). Our work during the explosive and hazardous eruption of Tajogaite Volcano shows that CO_2 emission measurements and plume gas samples can be collected even during these heightened periods of volcanic activity. We demonstrated that a UAS capable of autonomous navigation and automated sampling can be guided by the expert knowledge of scientists in the field to collect valuable data that would be impossible with robots or scientists alone. The collected data provide key insights into the volcano's state and the course of an eruption. Future work is needed to increase UAS autonomy in choosing flight paths to more completely capture data from dynamic plumes, but, as we have demonstrated, the present approach works for volcano monitoring during eruptions and can provide much-needed information about eruptive gas emissions.

4 Methods

Our aim was to measure CO_2 concentrations, calculate the resulting flux and to obtain isotope data from samples taken within the plume. TO achieve this goal we utilized the Dragonfly UAS, with an approximate battery life of 50 min. This extended flight time enables data collection during flights transecting the entire approximately 1 km wide plume. CO_2 concentrations were measured by PP Systems SBA-5 IR sensor mounted on the Dragonfly with data transmitted to the pilot in real-time (Ericksen et al., 2022). Wind speeds were measured hand-held anemometer from a high point on the ground close to the launch point and the UAS drift method (Liu et al., 2020; Galle et al., 2021).

We used the drift test estimate of wind velocity within the plume B, since it had the highest CO_2 concentration, to parameterize the flux estimation (2). A Dragonfly was instructed to maintain its altitude but not its lateral position. This allowed the Dragonfly to drift with the plume. The resulting estimate of gas velocity is 10.7 $\mathrm{ms^{-1}}$.

At the location with the highest measured CO_2 concentration, a timed trigger activated a small pump and a plume gas sample was collected into a Tedlar bag (Figures 2 and 3). We also collected gas samples of the plume from the ground when plume direction was favorable and activity permitted. For ground-based plume sampling, we transferred gas into the Tedlar bags with a 5cl syringe. All samples were analyzed by Infrared Isotope Spectroscopy with a Delta Ray located on La Palma at the INVOLCAN Volcano Observatory following the procedure described previously (Fischer and Lopez, 2016; Ilanko et al., 2019). The error on the δ^{13}C measurements is $< 0.1‰$ for all analyses.

We also placed a multiGAS instrument at an accessible and safe location about 1km to the north of the Crater. Data from this instrument recorded CO_2 and SO_2 concentrations in the gas plume. The ratios were calculated using the Ratiocalc software and we report averages for each day of the experiment.

Crosswind transects were flown downwind of the eruption to encounter the plume. CO_2 was sampled at 10 hz during flight across the width of the plume at specified altitudes relative to the launch altitude. Each sample was correlated to the latitude, longitude, altitude, and time of the UAS during flight, giving a CO_2 concentration cross-section of the plume.

To estimate the total flux of the plume, we perform the following procedure.

1. Normalise the transect span by combining latitude and longitude into distance away from launch location in meters.
2. Isolate the plume by setting an ambient CO_2 threshold and removing data points that fall less than that threshold.
3. Fit a Gaussian curve to the data set as follows.
    (a) Calculate the mean μ and standard deviation σ of the CO_2 across the transect.
    (b) Scale the gaussian curve to fit the data by choosing a constant amplitude a using gradient descent to minimize the χ^2 difference between the model and plume sample data.

$$\text{model1D}() = a \int \frac{e^{-\frac{1}{2}(\frac{x-\mu}{\sigma})^2}}{\sigma\sqrt{2\pi}} dx = a \tag{1}$$

4. Rotate the calculated gaussian curve to produce an estimated two-dimensional cross section modelling the plume's diffusion in space.

$$\text{model2D}() = a \int \frac{e^{-\frac{1}{2}(\frac{x-\mu}{\sigma})^2}}{\sigma\sqrt{2\pi}} dx \, a \int \frac{e^{-\frac{1}{2}(\frac{y-\mu}{\sigma})^2}}{\sigma\sqrt{2\pi}} dy = a^2 \tag{2}$$

5. Integrate the two-dimensional gaussian and multiply by the measured wind speed v gives the flux of the plume in $\text{mgS}^{-1}\text{m}^{-2}$. Multiplying this again by the number of seconds in a day, and the number of mg in a ton gives the flux in $t\,day^{-1}$.

$$\text{flux}(a, v) = v\,a^2 \tag{3}$$

Estimated flux for each transect across the plume is given in Table 3.

Code and data availability. Additional data and plot generation code is available at https://github.com/BCLab-UNM/lapalma-expedition/tree/2021_tajogaite_eruption. UAS code available at https://github.com/BCLab-UNM/dragonfly-dashboard https://github.com/BCLab-UNM/dragonfly-controller.

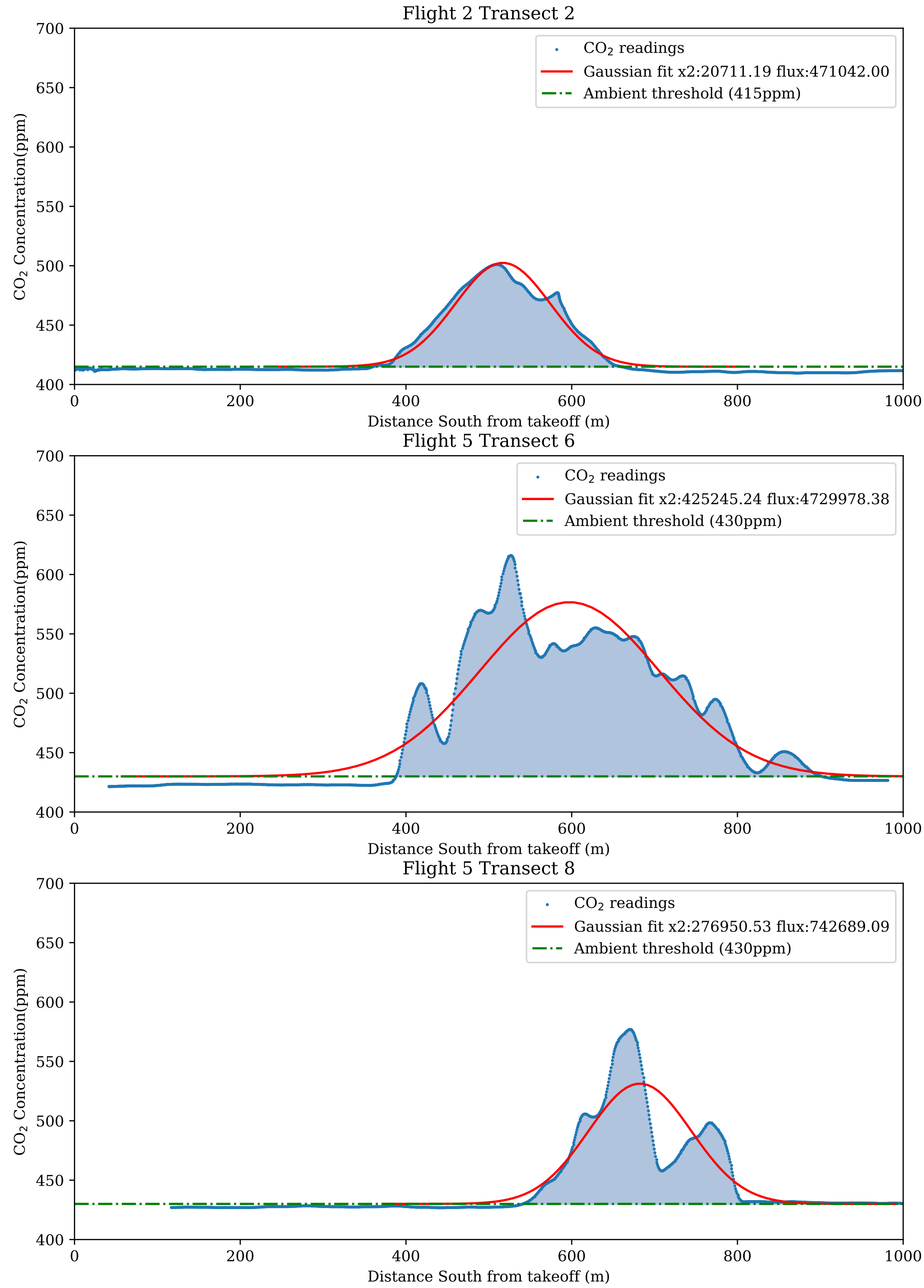
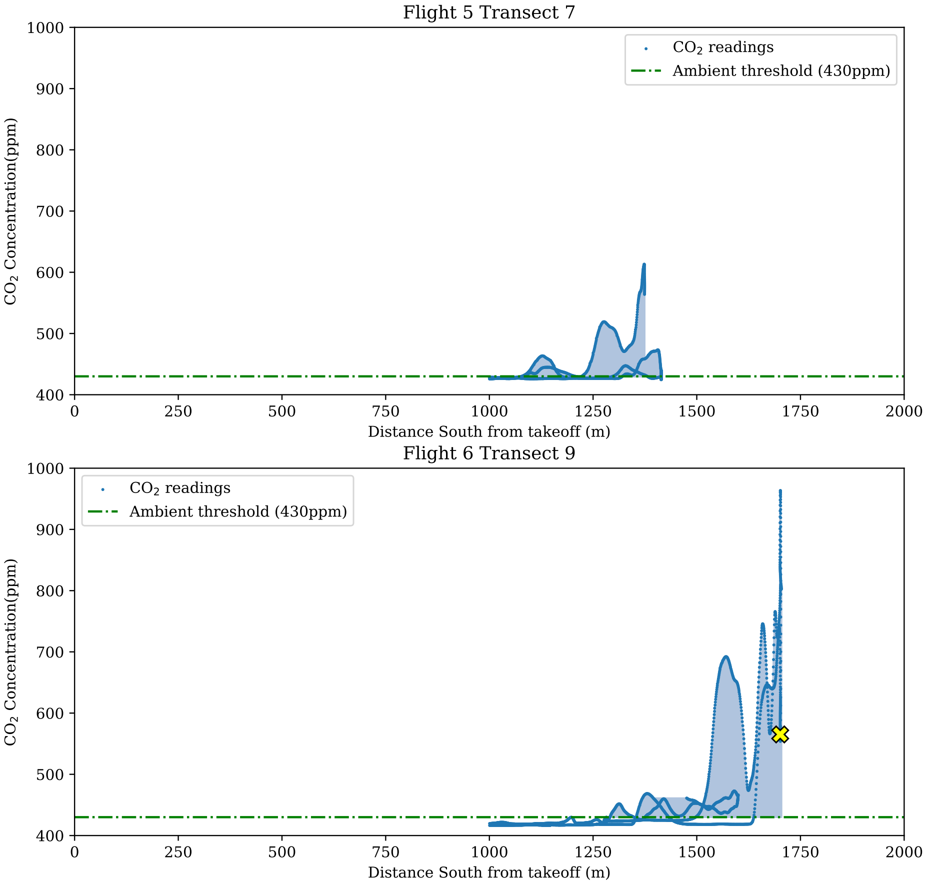


Figure A1. Three plots of encounters with plume A. CO_2 concentration (blue) over the encountered plume as a function of distance from takeoff location.



Flight 5 Transect 7

Flight 6 Transect 9

Figure A2. Encounters with plume B were not as well-fit as plume A encounters. These plots show the CO$_2$ readings collected during the two highest plume model fit. As with Figure A1, CO$_2$ concentration (blue) over the encountered plume as a function of distance from takeoff location. The sample collection location is indicated by the yellow ×.

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Table A1.

Date	Transect	Altitude	Gaussian Fit Amplitude	χ^2	Flux [t day^{-1}]
2021-11-26	1 Plume A	200 m	5.89×10^3	3.08×10^4	1.04×10^5
2021-11-26	2 Plume A	200 m	1.25×10^4	2.07×10^4	4.71×10^5
2021-11-26	3 Plume A	200 m	3.32×10^3	1.06×10^4	3.31×10^4
2021-11-26	4 Plume A	200 m	8.98×10^2	7.36×10^2	2.42×10^3
2021-11-27	5 Plume A	300 m	5.70×10^3	6.25×10^4	9.74×10^4
2021-11-27	6 Plume A	100 m	3.97×10^4	4.25×10^5	4.73×10^6
2021-11-27	7 Plume B	100 to 250 m	1.23×10^4	1.96×10^6	4.51×10^5
2021-11-27	8 Plume A	300 m	1.57×10^4	2.77×10^5	7.43×10^5
2021-11-28	9 Plume B*	300 m	8.82×10^4	1.81×10^7	2.33×10^7
2021-11-29	10 Plume A	300 m	2.35×10^3	1.42×10^5	1.65×10^4

Author contributions. Author contributions: JE, GMF, SN, and TF (UNM VolCAN team) performed UAS fieldwork for this paper. JE, NP, PHP, EPG (INVOLCAN team) and TF conducted the ground fieldwork. JE developed UAS software and hardware supervised by GMF and MEM. SN designed the sample collection device. JE, NP, PHP, EPG performed data analysis. TF performed isotope and gas analysis. JE, TF, GMF, SN, and MEM wrote the manuscript.

Competing interests. The authors declare that they have no competing interests. The authors give consent for publication. All data needed to evaluate the conclusions in the paper are present in the paper and/or the Supplementary Materials.

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