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Short communication

High time resolution fluctuations in volcanic carbon dioxide degassing from Mount Etna

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ABSTRACT

We report here on the first record of carbon dioxide gas emission rates from a volcano, captured at ≈1 Hz. These data were acquired with a novel technique, based on the integration of UV camera observations (to measure SO_2 emission rates) and field portable gas analyser readings of plume CO_2/SO_2 ratios. Our measurements were performedat the North East crater of Mount Etna, southern Italy, and the data reveal strong variability in CO_2 emissions over timescales of tens to hundreds of seconds, spanning two orders of magnitude. This carries importantimplications for attempts to constrain global volcanic CO_2 release to the atmosphere, and will lead to an increased insight into short term CO_2 degassing trends. A common oscillation in CO_2 and SO_2 emission rates in addition to the CO_2/SO_2 ratios was observed at periods of ≈89 s. Our results are furthermore suggestive of an intriguing temporal lag between oscillations in CO_2 emissions and seismicity at periods of ≈300–400 s, with peaks and troughs in the former series leading those in the latter by ≈150 s. This work opens the way to the acquisition of further datasets with this methodology across a range of basaltic systems to better our understandingof deep magmatic processes and of degassing links to manifest geophysical signals.

1. Introduction

Carbon dioxide (CO_2) is among the most abundant constituents of volcanic gases (Carroll and Holloway, 1994), and exsolves from magmas deeper than other common volatiles such as sulphur dioxide (SO_2) and water vapour (H_2O) (Giggenbach, 1996). Knowledge of CO_2 emissions can therefore contribute significantly to our understanding of the movementof magmas in deep volcanic plumbing systems. Hitherto, the measurement of CO_2 emission rates has been challenging due to the difficulty of resolving volcanogenic CO_2 above high background atmosphericlevels. In consequence, attempts to routinely measure plume CO_2 emission rates, particularly at high time resolution, havebeen rather limited (Aiuppa etal., 2006, 2010). Therefore, notwithstandingthe significant contributions made in constraining CO_2 emission rates of volcanic plumes at targets such as Mt. Erebus, Antarctica (Wardell etal., 2004), Ol Doinyo Lengai, Tanzania (Koepenick etal., 1996), White Island, New Zealand (Werner etal., 2008), Ruapehu, New Zealand (Werner etal., 2006), Redoubt, Alaska (Werner etal., 2012a,b), Stromboli, Italy (Aiuppa etal., 2010, 2011), Mt. Etna, Italy (Allard etal., 1991) and Kilauea, USA (Poland etal., 2012), these data remain relatively spartan, and in general lack information regarding temporal changes. This remains a fundamental weakness in attempts to constrain global volcanogenic CO_2 emission rate budgets, in view of which there is a pressing demand for the developmentand application of novel methodologies to improve constraintson spatio-temporal volcanic CO_2 degassing and our comprehensionof volcanic systems.

Recently, the Multi-GAS technique (Aiuppa etal., 2005; Shinohara, 2005) has been pioneered to enable rapid measurements of volcanic plume chemical compositions, including CO_2/SO_2 gas ratios, leading to significant advances in our understanding of degassing processes. Furthermore,in the last years, UV camera imagery has been applied in volcanology, enabling acquisition of SO_2 emission rates with time resolutionsof ≈1 Hz, many orders of magnitude faster than possible in the past (e.g., Mori and Burton, 2006; Tamburello etal., 2011a). Here we report on the first volcanic deployment of a novel technique, by which volcanic CO_2 emission rates are captured with an acquisition frequency of ≈1 Hz, based on the integration of the above two approaches.Such a capability will increase the future potential of linking degassing to geophysical data on unprecedented timescales with significant applicability in improving hazard analysis (Gerlach etal., 2002) and eruption forecasting measures (Aiuppa etal., 2007; Poland etal., 2012).

The CO_2 emission rate data were captured during a field campaign on Mt. Etna (37.734°N, 15.004°E), an alkaline strato-volcano whose CO_2-rich magmas (Spilliaert etal., 2006) result in the volcano being the largest time averaged contributor to global volcanic emissions of CO_2 (Allard etal., 1991; Gerlach, 1991). Etna currently has four

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degassing summit areas: the South-East crater (SEC), the Central Craters (Bocca Nuova and Voragine), and the North-East crater (NEC) (Fig. 1). Our study is based on passive emissions from the NEC, in recent times one of the most actively degassing vents on Etna (Aiuppa etal., 2008) and the site of recurrent eruptive activity in the last few decades (Allard etal., 2006).

2. Methodology

The SO_2 emission rates were captured using two Apogee Alta U260 cameras, fitted with 16 bit 512 × 512 pixel Kodak KAF-0261E thermoelectrically cooled CCD array detectors. A Pentax B2528-UV lens of $f = 25$ mm was attached to the front of each camera, providing ≈24° field of view. The lenses were fitted with filters of 10 nm FWHM (Asahi Bunko Inc.), one centred around 310 nm, where plume SO_2 absorbsincident UV radiation, and the other at 330 nm, where no such absorption occurs. Qualitative plume absorbances captured in the camera plume images were converted to column amounts via a calibration procedure involving four quartz cells containing known SO_2 columnamounts: 100, 200, 1000, 2000 ppm m; SO_2 values within the plume were always within this range. The calibrations were performed at the time of measurement, by viewing clear sky adjacent to the plume, resulting in R^2 values >0.99 for the linear fitting. As the measurement conditions were favourable: e.g., the plume was transparent, the background sky was cloudless and the plume was <4 km distant, additional DOAS based calibrations were not performed, as there is an excellent match between DOAS and cell based calibrations under such conditions (Lübcke etal., 2013). Under such circumstances we speculate that the measurement error was low, however, as radiative transfer has yet to become a routinely considered element of UV camera retrievals it is hard to provide an exact error budget in this case (e.g., Kern etal., 2009). For full details on all data capture, retrieval and calibration procedureslease see Kantzas etal. (2010). All of these protocols were executedusing the Vulcamera code (Tamburello etal., 2011b).

The UV camera was located at the Pizzi Deneri observatory which provided a clear vantage point of the NEC plume, at a distance of ≈2 km (Fig. 1); the data were acquired between 08:45 and 09:45 GMT on the 12th of September 2012. Integrated column amount (ICA) values were determined by summing SO_2 concentrations over the plume profile, perpendicular to its transport vector (Fig. 1). The emissionrates (kg s^{-1}) were then found by multiplying ICAs by the plume transport speed, with the latter arising from cross-correlation analysis of the propagation of the plume across the field of view overa sequence of camera images (e.g. see McGonigle etal., 2005; Williams-Jones etal., 2006). The plume speed varied very little over the acquisition period (≈13.4 m s^{-1} throughout). The camera capture rate ranged between 0.5 and 1 Hz depending upon incident light levels, hence linear interpolation was applied, where necessary, to produce a uniform 1 Hz SO_2 emission rates dataset.

The CO_2/SO_2 degassing ratios of the NEC were measured with a field portable Multi-GAS unit (Aiuppa etal., 2005; Shinohara, 2005) located at ≈100 m downwind of the crater's vent, at a site chosen to avoid signal contamination from low-temperature fumarolic discharges (Shinohara etal., 2008). This unit extractively sampled the plume gases, providing CO_2 and SO_2 concentration readings at ≈0.5 Hz measurementfrequency. The SO_2 concentrations were measured with an electrochemical sensor (City Technology, sensor type 3ST/F), of calibration range of 0–200 ppm, and the manufacturer quoted accuracy of ± 2%, repeatability of 1% and a resolution of 0.5 ppm v. The CO_2 concentrations were measured with an infrared sensor (Edinburgh Instruments, Gascard II), of 0–3000 ppm v range, and with an accuracy of ± 2% and a resolution of 0.8 ppm v. Prior to the campaign, the Multi-GAS sensors were calibrated in the laboratory using standard gas cylinders of concentrations within the sensor ranges (e.g., 10 and 100 ppm SO_2 and 3000 ppm CO_2; all in nitrogen matrixes) and gas mixtures

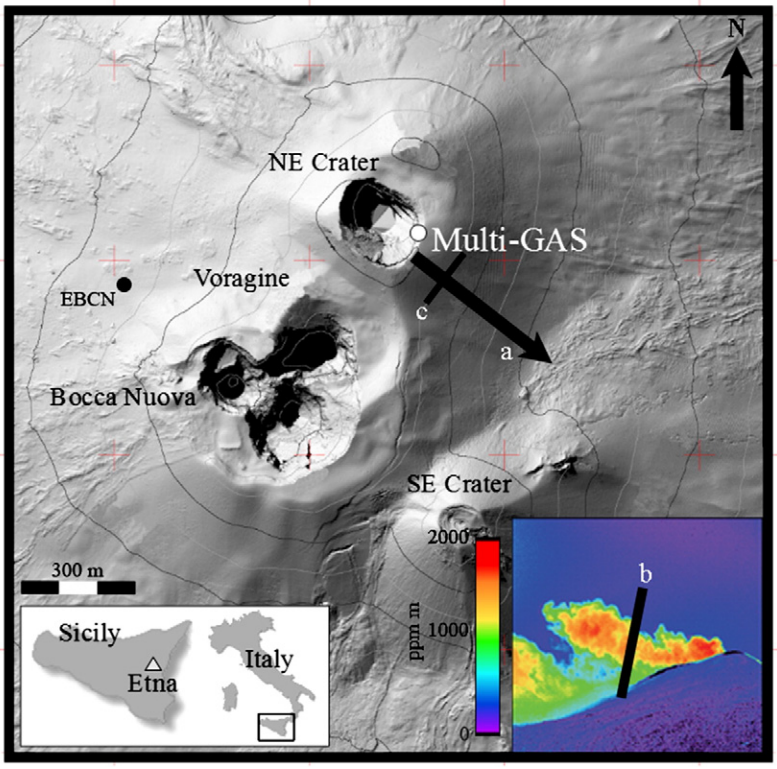

Fig. 1. Map of the summit of Mount Etna showing the craters (NE—North East crater, Voragine, Bocca Nuova, SE—South East Crater), EBCN seismic station, the Multi-GAS location and (a) the plume direction; the left inset shows the volcano location in Sicily; the right inset shows the NE crater plume on the acquisition day as viewed with the UV camera from Pizzi Deneri, with the colour scale indicating ppm m column amounts of SO_2 over the image pixels; (b) shows the plume cross-section used to determine the Integrated Column Amount (ICA) within this inset; and (c), within the main image, the viewing vector corresponding to this profile with respect to the Multi-GAS location.