Sulphur dioxide emission rates from Yasur volcano, Vanuatu archipelago

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[1] Yasur volcano has long been suspected as one of the volcanic emission sources responsible for a significant contribution of sulphur dioxide to the atmosphere. But due to its isolation in the south Pacific region, very little is known about its emission rates. We report here sulphur dioxide flux measurements, obtained on Yasur, using ultraviolet spectroscopy, from April 2004 to November 2005. We found an average flux of 7.9 kg.s^{-1} of SO_2, which constitutes some 1–2% and 1.5–2.5% of estimated global time-integrated volcanic emissions to the atmosphere and troposphere, respectively. **Citation:** Bani, P., and M. Lardy (2007), Sulphur dioxide emission rates from Yasur volcano, Vanuatu archipelago, *Geophys. Res. Lett.*, *34*, L20309, doi:10.1029/2007GL030411.

1. Introduction

[2] SO_2 emission rates are important indicators of volcanic activity and are routinely measured at a number of volcanoes in support of hazard assessment. These emissions can also have important impacts on the atmosphere and climate at various temporal and spatial scales. For instance, volcanic sulphur emissions have been implicated in tropospheric cooling, stratospheric heating, stratospheric ozone depletion, and alteration in stratospheric global circulation patters, due to radiative and chemical interactions [*Robock and Oppenheimer*, 2003]. Volcanic SO_2 clouds are measured from above by spaceborne instruments, and from below by traversing, or scanning the plume from fixed positions, with correlation spectrometers (COSPECs) [*Stoiber et al.*, 1983], or more recently with miniature ultraviolet spectrometers, by differential optical absorption spectroscopy (DOAS) [*Galle et al.*, 2003; *McGonigle et al.*, 2002]. The product of these flux estimates and mass ratios of other plume species to SO_2 (i.e., X/SO_2) yields to the fluxes of other components (e.g., CO_2, HCl, HF).

[3] In the compilations of global volcanic SO_2 output [*Andres and Kasgnoc*, 1998], Yasur volcano in Vanuatu archipelago appears in the top ten of a list of forty-nine continuous volcanic SO_2 emitters. However, until this work, the flux estimates for Yasur were based on comparisons of plume size with other volcanoes [*Nairn*, 1988; *Lardy and Marty*, 1990]. The only field SO_2 flux measurements were performed in July 1999 with a correlation spectrometer but constrained to weather condition [*Gauthier*, 1999]. Thus Yasur gas discharge is arguably one of the least well constrained of all those reported in global flux budgets. We present here a series of SO_2 flux measurements results, obtained between April 2004 and November 2005 on Yasur volcano using a DOAS instrument.

2. Geologic Setting

[4] The island Tanna lies approximately 150 km east of New Hebrides trench and 150 km above the Benioff zone [*Louat et al.*, 1998]. It covers 550 km^2 and is built up by Pliocene to recent subaerial and subaqueous basaltic and andesitic volcanic units and reef limestone. The volcanic units belong to three major groups (Figure 1): the upper Pliocene to Pleistocene Green Hill group to the north and east, the Pleistocene Tukosmeru group to the south, and the upper Pleistocene to Recent Siwi group in the easternmost part within a 24 km^2 caldera [*Carney and Macfarlane*, 1979; *Coulon and Maury*, 1981; *Robin et al.*, 1994]. The Green Hill Group and Tukosmeru group are predominantly basaltic or basaltic andesite in composition while Siwi group are basaltic andesite to andesite in composition. An uplift of more than 150 m has occurred in the eastern portion of Siwi group forming the Yenkahe Horst [*Chen et al.*, 1995]. Yasur, a small scoria cone volcano (361 m above sea level) which occupies the western part of the Yenkahe Horts, is characterised by a sustained degassing with a continuous strombolian to vulcanian type activity.

3. Methodology

[5] Fluxes were obtained by traversing on a 4WD vehicle underneath the plume with a USB2000 miniature ultraviolet spectrometer which spanned the spectral interval 280–400 nm with a spectral resolution of 0.5 nm. Exposure time for individual spectra was 200 ms, and we co-added 8 spectra to enhance the signal-to-noise ratio. This device was coupled to a vertically pointing telescope of 8 mrad field of view with an optic fibre bundle. A USB cable connected the spectrometer to a laptop computer, providing power and data transfer. Software control of the USB2000 was achieved using Jscript executed in DOASIS software [*Kraus*, 2001] to save and analyse spectra, providing real time concentration readings. The position of each UV spectrum was determined from a continuously recording GPS unit. These spectrometers have also been used for measurements of volcanic BrO [*Bobrowski et al.*, 2003, 2007; *Oppenheimer et al.*, 2006], H_2S [*O'Dwyer et al.*, 2003] and NO_2 [*Oppenheimer et al.*, 2005]. Details of the DOAS routine used in concentration evaluation are given by *Platt* [1994] and/or *Galle et al.* [2003]. Fluxes were obtained from the retrieved SO_2 columns and the GPS track

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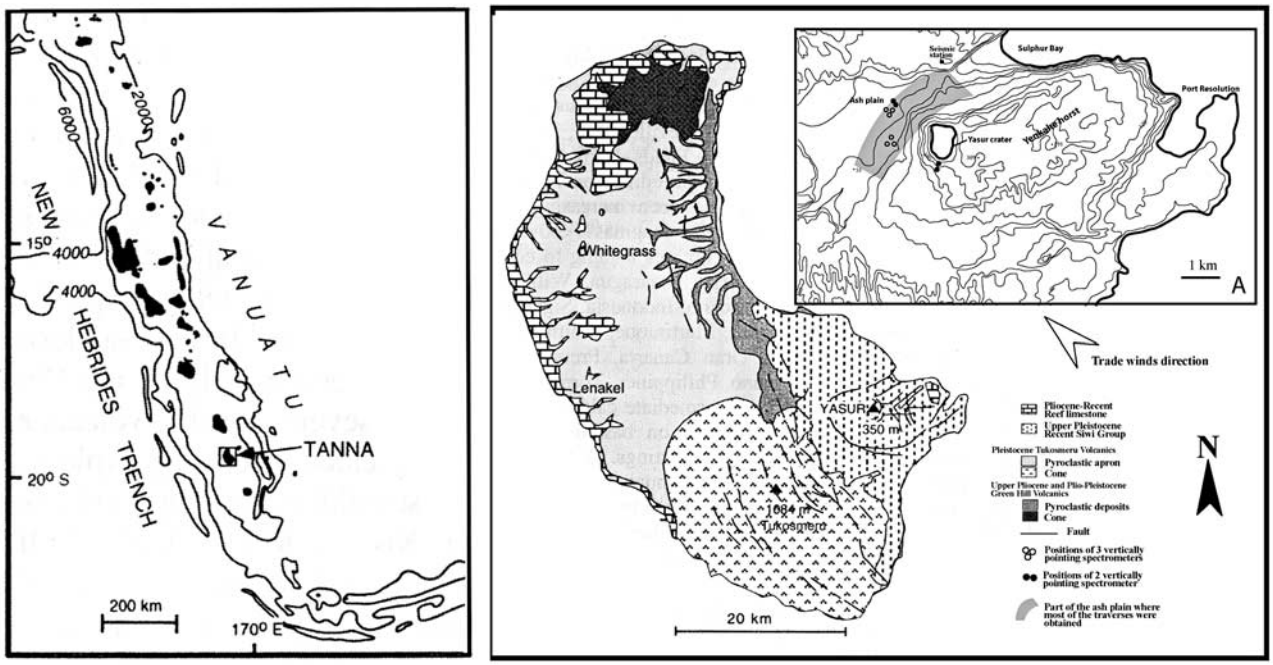

Figure 1. (left) Map of Vanuatu, showing Tanna Island and the New Hebrides Trench. (right) The geology of Tanna, redrawn after *Carney and Macfarlane* [1979]. (a) Map of eastern Tanna, showing the Yenkahe horst, the Yasur crater, the ash plain where most of the traverses were obtained and the positions of spectrometers in the plume speed measurements. Note that on the 10th January 2005 the plume dispersion was to the south due to the presence of cyclone Kerry located 1800 km southwest of Vanuatu at that time.

by multiplying the distance traversed perpendicular to the plume transport direction corresponding to each spectrum by that spectrum's column amount, summing these products across the whole plume and multiplying the total by the estimated plume speed. For Yasur the traverses were performed on the ash plain (Figure 1) and plume speeds were obtained either from a hand held anemometer on top of Yasur, or from simultaneously recording overhead SO_2 time series from underneath the plume, using 2 and 3 spectrometers (Table 1). These devices are situated between 0.5 and 1.0 km from the source and between 80–150 m from each other (Figure 1). Peaks and troughs obtained from the series, corresponding to overhead transit of plume structure, have been cross-correlated, using methods described by *McGonigle et al.* [2005] and *Williams-Jones et al.* [2006], to find the plume speed.

Table 1. SO_2 Fluxes From Yasur Volcano Measured During 2004–2005

Measurement Period	Date, day/month/year	Number of Traverses	Measurement Period Mean Flux, $kg.s^{-1}$	Method Used for Plume Speed
P1	02–04/04/04	26	5.3 ± 1.0	Anemo.
P2	11–14/07/04	33	12.3 ± 2.2	Anemo.
P3	19/09/04	5	4.9 ± 0.9	Anemo.
P4	29/10/04	6	5.3 ± 0.9	Anemo.
P5	10/01/05	4	11.2 ± 2.1	2 spectro
P6	18/03/05	1	2.5 ± 0.5	Anemo.
P7	02/07/05	5	6.1 ± 1.1	2 spectro.
P8	01–02/11/05	6	13.5 ± 2.5	3 spectro.

4. Results and Discussion

[6] From April 2004 to November 2005 a total of 86 traverses were accomplished under the plume less than 2 km

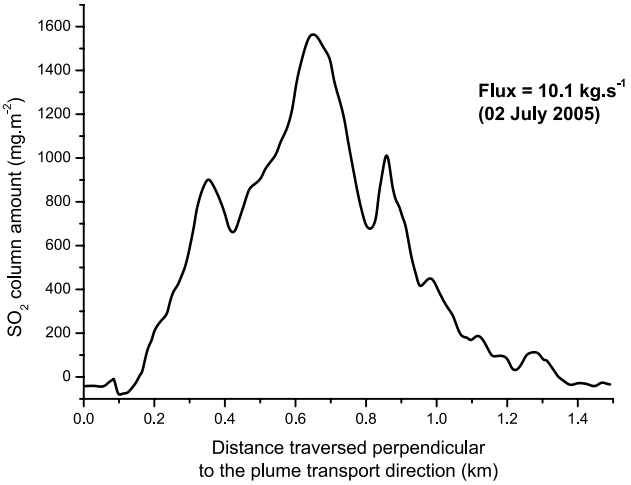

Figure 2. Representative plot of a cross sectional profile of SO_2 concentration for one traverse obtained under the Yasur plume in July 2005. The three peaks correspond to individual plumes emitted from the three active vents in the crater.

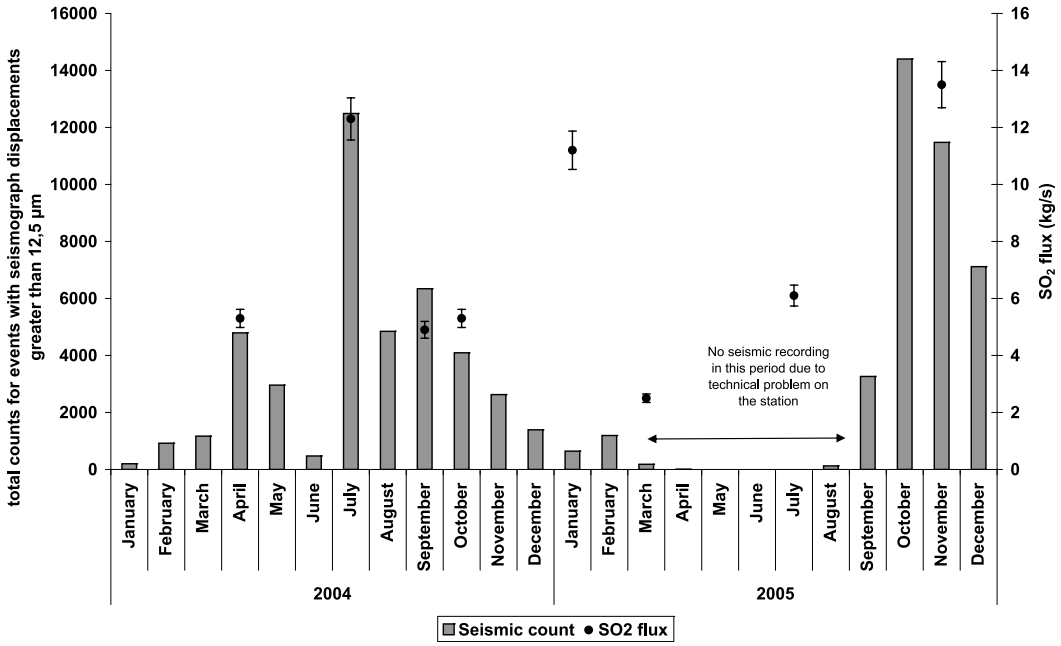

Figure 3. Correlation between seismic counts and SO_2 fluxes; volcanic events with seismograph displacements greater than 12.5 μm were recorded and plotted here from the period between January 2004 and December 2005. The SO_2 flux for each measurement period (P) is represented by circles.

downwind of Yasur volcano. The average fluxes from these measurements for each measurement period (P1 to P8) are shown in Table 1. Figure 2 shows a representative plot of concentration versus distance-traversed perpendicular to the plume transport direction. The profiles of the column amounts recorded on Yasur present frequently three maxima, and indicate the dispersion and overlap of individual plumes emitted from the three active vents within the crater. The overall average flux obtained for the traverses is 7.9 kg.s^{-1}, with individual fluxes ranging from 2.5 to 17.2 kg.s^{-1}. Apparent SO_2 fluxes from volcanoes can, and do, vary considerably, even on short timescales, so no direct agreement between these estimates made at different times is expected. However, the general flux fluctuation from P1 through P8 tend to be consistent with the volcanic behaviour of Yasur recorded by a permanent seismic monitoring station located 2 km from the volcano (Figure 3) where seismograph displacements greater than 12.5 μm

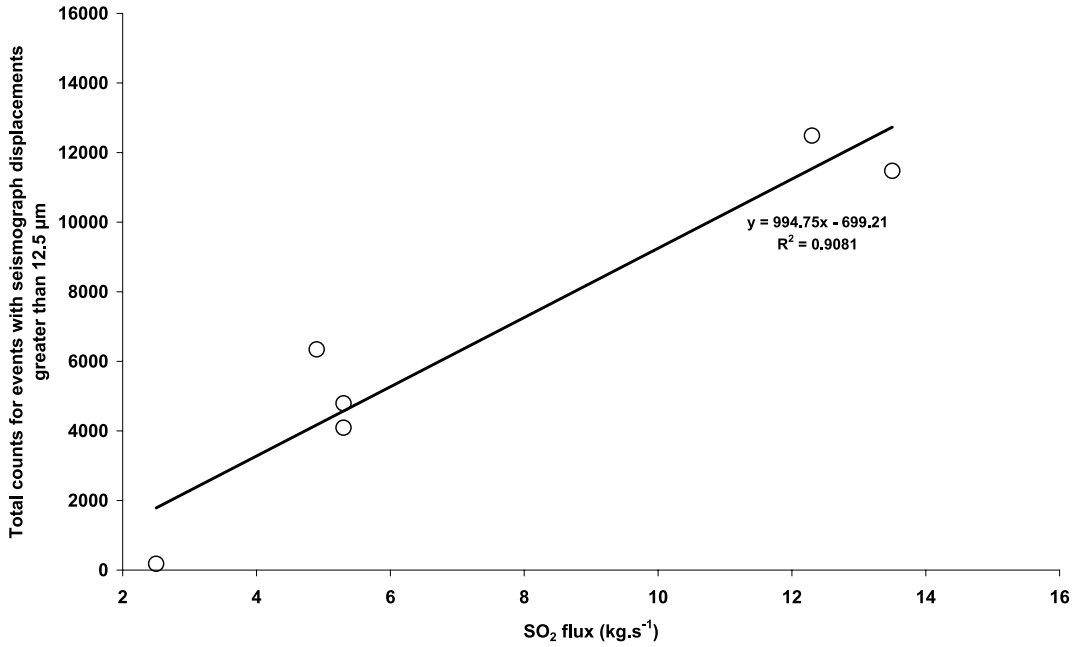

Figure 4. Correlation plot between seismic events and SO_2 emission rates. Emissions rate which correspond to P5 and P7 were omitted because of high gas discharge which occurred with no significant seismic events and lack of seismic data respectively.

gives a representative idea of the volcano's daily activity [*Tabbagh et al.*, 2002]. An exception in this general correlation appears in P5 where high gas discharge occurred with no sustained explosions which probably due to higher pressure in the magmatic feeding system as evidenced by the high level of magmatic column. The lowest gas discharge, measured in March 2005 (216 $t.d^{-1}$), and the maximum discharge rate, measured in July 2004 (1063 $t.d^{-1}$) and November 2005 (1166 $t.d^{-1}$), are correlated to the seismic activity of Yasur (Figure 4). This parallel variation of the SO_2 fluxes and the seismic activity records implies that the SO_2 emission rates from Yasur do vary with the volcanic activity. Similar correlations between volcanic seismicity and SO_2 have been observed on Etna [*Leonardi et al.*, 2000] or SoufriereHill [*Watson et al.*, 2000]. Thus during low activity phases Yasur SO_2 emission rates can be reduced to around 200 $t.d^{-1}$, while during high activity with virulent explosions, Yasur releases more than a thousand tons per day. High activity phases on Yasur usually last more than a month (Institut de Recherche pour le Développement, unpublished data, 1993–2005), and thus release regularly an equivalent of more than 30 kt of SO_2 into the atmosphere during one simple high activity phase.

[7] Our results confirm that Yasur is one of the largest point sources of SO_2 on Earth and constitutes 1–2% of the global time-integrated volcanic emissions to the whole atmosphere (425–665 $kg.s^{-1}$), and 1.5–2.5% of the total volcanogenic emission to the troposphere (308–540 $kg.s^{-1}$) [e.g., *Andres and Kasgnoc*, 1998; *Halmer et al.*, 2002].

5. Conclusions

[8] We have reported on SO_2 flux measurements made with a miniature ultraviolet spectrometer for Yasur volcano in Vanuatu archipelago. We obtained fluxes between 2.5 and 17.2 $kg.s^{-1}$ with a mean flux value of 7.9 $kg.s^{-1}$: equivalent to 1–2% of the time-integrated total global volcanic SO_2 emission. Such volcanic emissions merit greater attention in future, in order to provide better spatial and temporal constraints on global volcanic sulphur loading into the atmosphere.

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