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Modelling tephra dispersal and ash aggregation: The 26th April 1979 eruption, La Soufrière St. Vincent

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ABSTRACT

On the 26th April 1979, La Soufrière St. Vincent volcano (West Indies) erupted producing a tephra fallout that blanketed the main island and the neighboring Bequia Island, located southwards. Using deposit measurements and the available observations reported in Brazier et al. (1982), we estimated the optimal Eruption Source Parameters, such as the Mass Eruption Rate (MER), the Total Erupted Mass (TEM) and the Total Grain-Size Distribution (TGSD) by means of a computational inversion method. Tephra transport and deposition were simulated using the 3D Eulerian model FALL3D. The field-based TGSD reconstructed by Brazier et al. (1982) shows a bi-modal pattern having a coarse and a fine population with modes around 0.5 and 0.06 mm, respectively. A significant amount of aggregates was observed during the eruption. To quantify the relevance of aggregation processes on the bulk tephra deposit, we performed a comparative study in which we accounted for aggregation using three different schemes, computing ash aggregation within the plume under wet conditions, i.e. considering both the effects of air moisture and magmatic water, consistently with the eruptive phreatomagmatic eruption features. The sensitivity to the driving meteorological model (WRF/ARW) was also investigated by considering two different spatial resolutions (5 and 1 km) and model output frequencies. Results show that, for such short-lived explosive eruptions, high-resolution meteorological data are critical. Optimal results best-fitting all available observations indicate a column height of ~12 km above the vent, a MER of $\sim 7.8 \times 10^6$ kg/s which, for an eruption duration of 370 s, gives a TEM of $\sim 2.8 \times 10^9$ kg. The optimal aggregate mean diameter obtained is 1.5Φ with a density of 350 kg/m^3, contributing to ~22% of the deposit mass.

1. Introduction

Volcanic plumes generated from explosive eruptions can rise up to tens of kilometers above the vent (hereinafter a.v.) injecting large amounts of tephra into the atmosphere. The erupted particulate material has diameters (d) varying by several orders of magnitude. Tephra is classified according to fragment diameter differentiating blocks ($d > 64$ mm) from lapilli (2 mm $< d <$ 64 mm) and ash ($d <$ 2 mm). Ash is further classified as coarse ash for particles with 64 μm $< d <$ 2 mm, fine ash for $d <$ 64 μm, and very fine ash for $d <$ 31 μm (Rose and Durant, 2009). The particle Grain-Size Distribution (GSD) together with the atmospheric conditions control the sedimentation processes and, consequently, the tephra residence time in the atmosphere. However, particle-particle interactions leading to aggregation can occur thereby affecting the transport dynamics. In addition, aggregation processes can potentially increase the hazards induced by tephra fallout on infrastructures and inhabitants in the vicinity of a volcano. Tephra dispersal models neglecting aggregation phenomena may result on a significant ground loading underestimation at proximal areas and overestimation at distal locations (Brown et al., 2012; Van Eaton et al., 2012; Folch et al., 2016).

On 26th April 1979, La Soufrière St. Vincent volcano (West Indies) produced a phreatomagmatic eruption due to interaction between the shallow aquifer and magma. The phreatomagmatic phase of the eruption produced a significant amount of aggregates, which were observed in-situ during fallout and were also evident from the grain-size features of the collected samples. Indeed, tephra deposits showed a rich fine ash composition at proximal and medial locations (Brazier et al., 1982, 1983). Despite these observations, quantifying aggregation formed within a volcanic plume from field data is a challenging task due to the aggregates tendency to disaggregate when impacting the ground (Brazier et al., 1982). At the end of the eruption, 33 field samples were collected providing tephra loadings at each location (Fig. 1a). These samples are valuable to constrain simulations and quantify the role of ash aggregation combining field measurements and models.

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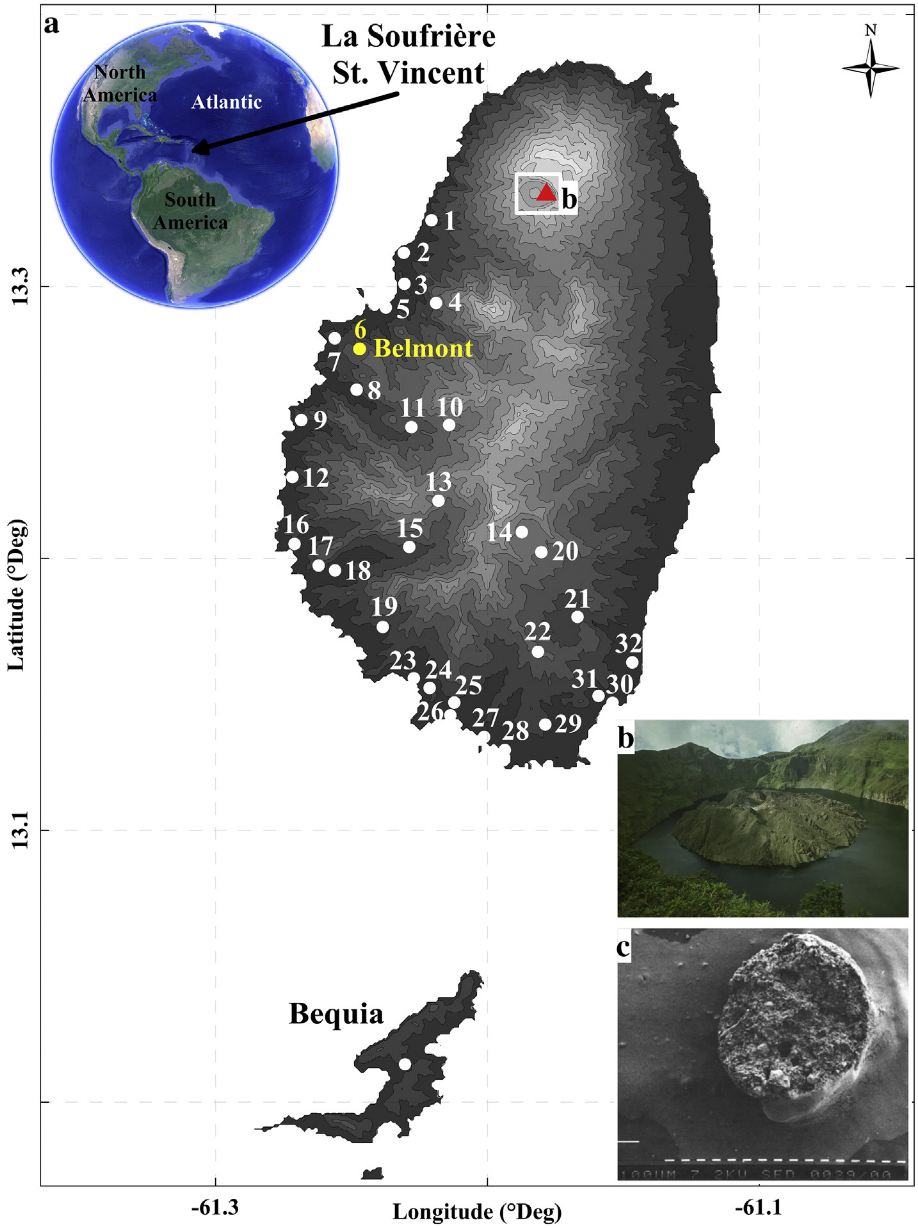

Fig. 1. a) Location of La Soufrière St. Vincent volcano (West Indies). White dots are sample locations (detailed in Table 1) from the vent (red triangle) to Bequia Island. Location n°6 refers to the Belmont observatory (yellow dot). b) Photo of the permanent lake inside the summit crater before the April 1979 eruptive activity. Source: André Guyard. c) Example accretionary lapillus observed during the eruption. White bars are 100 μm in length. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
(Modified from Brazier et al., 1982)

Eruption Source Parameters (ESP) such as the eruption column height, the Total Grain-Size Distribution (TGSD), the eruption start time and duration are needed as inputs by tephra dispersal and deposition models. This study uses FALL3D (Costa et al., 2006; Folch et al., 2009, 2012), a 3D time-dependent Eulerian model based on the numerical solution of the advection-diffusion-sedimentation equation to best-fit the ESPs using the available measurements. Simulations are initialized using, for each ESP, a range of values derived from Brazier et al. (1982) and a high resolution meteorological model (at 1 km horizontal resolution) as driver of the FALL3D model. The TGSD description is highly dependent on the sampling distance from the vent (Costa et al., 2016a) but also on the spatial distribution of samples and the density of outcrops (Bonadonna et al., 2015; Spanu et al., 2016).

This paper investigates the relevance of aggregation processes on the bulk tephra deposit for the 26th April 1979 La Soufrière St. Vincent eruption. Different TGSDs are evaluated, including: i) the field-based TGSD derived from the sample analysis; ii) a parameterization of the latter using a bi-lognormal distribution and; iii) using a bi-Weibull distribution (Costa et al., 2016a, 2017). Simulations also account for aggregation by considering three different aggregation schemes implemented in FALL3D. Results are compared with simulations in which aggregation is neglected. ESP optimal values are obtained through a computational inversion method previously presented by Folch et al. (2010) and Martí et al. (2016). Simulation results are compared with field measurements by employing a criterion as the goodness-of-fit measure test, which selects consistent results that better reproduce the measured tephra loadings.

Section 2 provides a short overview of the eruption. In Section 3, we describe the computational model and methodology. Section 4 presents the results of the comparative study on different TGSDs and aggregation schemes. Finally, Section 5 discusses the results in terms of effect of the parameterization used to reconstruct the main features of a short-lived explosive eruption.

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