

Supporting Information for

Assessing minimum PDC volume from a large explosive volcanic eruption impacting critical infrastructures: an example from Aso Caldera (Japan)

Andrea Bevilacqua⁽¹⁾, Alvaro Aravena⁽²⁾, Willy Aspinall⁽³⁾, Antonio Costa⁽⁴⁾, Sue Mahony⁽³⁾, Augusto Neri⁽¹⁾, Stephen Sparks⁽³⁾, Brittain Hill⁽⁵⁾

¹Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Pisa, Pisa, Italy.

²Laboratoire Magmas et Volcans, Université Clermont Auvergne, CNRS, IRD, OPGC, Clermont-Ferrand, France.

³University of Bristol, School of Earth Sciences, Bristol, United Kingdom.

⁴Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Bologna, Bologna, Italy.

⁵University of South Florida, School of Geosciences, Tampa, FL, United States.

Additional Supporting Information (Files uploaded separately)

Caption for Text S1 to S2

Contents of this file

Table S3 to S6

Figure S7 to S8

Text S1. Notes on the analytic solution of box model equations for gravity-driven particle currents with constant volume.

We summarize the physical equations and analytic solutions of three versions of the box model equations, suitable for the integral formulation of axisymmetric gravity-driven particle currents with constant volume. The first model is based on a simple constant resisting stress, while the second and third models assume flow dilution by particle deposition. The third model is characterized by assuming an interstitial fluid lighter than the ambient fluid. All the calculations are performed on a flat topography. Ambient fluid entrainment and cooling effects are not considered. All particles are assumed to deposit at the same velocity.

Text S2. Log of scientific email exchanges between co-authors and other colleagues: December 2018 – February 2019.

We summarize the knowledge exchanges that involved five of the co-authors, concerned with assessing the probability of an Aso4-scale future eruption and four other colleagues providing detailed volcanological support. All names have been anonymized.

No topographic effects modelled				
<i>MinVol</i>: Minimum PDC volume [km³] required to reach the TS2				
Model	5%ile	50%ile	mean	95%ile
Model 1: Elicited inputs	29.6	294	504	1650
Model 2a: Elicited inputs	11.3	61.8	86.2	250
Model 2b: Modified inputs*	8.08	18.5	19.2	33.2
Model 2c: Elicited inputs	7.55	48.3	71.3	222
<i>MinMass</i>: Minimum PDC mass [10¹² kg] required to reach the TS2				
Model	5%ile	50%ile	Mean	95%ile
Model 1: Elicited inputs	31.4	303	500	1580
Model 2a: Elicited inputs	19.2	106	147	431
Model 2b: Modified inputs*	13.9	31.6	32.8	56.2
Model 2c: Elicited inputs	12.6	82.4	123	385
With topographic effects included				
Minimum PDC volume [km³] required to reach the TS2				
Model	5%ile	50%ile	mean	95%ile
Model 1: Elicited inputs	156	1550	2660	8710
Model 2a: Elicited inputs	49.6	271	378	1100
Model 2b: Modified inputs*	35.4	81.0	84.4	146
Model 2c: Elicited inputs	33.1	212	313	974
Minimum PDC mass [10¹² kg] required to reach the TS2				
Model	5%ile	50%ile	mean	95%ile
Model 1: Elicited inputs	165	1600	2640	8340
Model 2a: Elicited inputs	84.1	465	646	1890
Model 2b: Modified inputs*	60.9	139	144	247
Model 2c: Elicited inputs	55.5	361	540	1690

* Modified ϕ_0 and w_s based on MDR modelling and Sauter diameter of analogues (see Table 1).

Table S3. Numerical results of the minimum PDC volume and mass needed to reach the TS2, with and without consideration of topographic effects (see Section 4.4).

Aso-3		
Model	TE⁺: No	TE⁺: Yes
Model 1: Elicited inputs	24.9% (14.4 – 34.8%)	3.3% (1.1 – 5.4%)
Model 2a: Elicited inputs	56.6% (37.7 – 70.4%)	10.4% (3.8 – 18.3%)
Model 2b: Modified inputs*	100.0% (99.9 – 100.0%)	41.0% (11.2 – 71.8%)
Model 2c: Elicited inputs	65.5% (46.8 – 76.8%)	17.8% (8.6 – 26.6%)
Aso-4 (volume per Takarada and Hoshizumi, 2020)		
Model	TE⁺: No	TE⁺: Yes
Model 1: Elicited inputs	79.0% (59.0 – 89.9%)	30.0% (15.3 – 41.5%)
Model 2a: Elicited inputs	100.0% (94.5 – 100.0%)	71.2% (45.9 – 84.0%)
Model 2b: Modified inputs*	100.0% (100.0 – 100.0%)	100.0% (100.0 – 100.0%)
Model 2c: Elicited inputs	100.0% (96.3 – 100.0%)	77.4% (55.3 – 87.7%)
Aso-4 (volume per Aspinall et al., 2021)		
Model	TE⁺: No	TE⁺: Yes
Model 1: Elicited inputs	57.9% (47.0 – 80.1%)	14.7% (9.5 – 31.0%)
Model 2a: Elicited inputs	93.7% (84.5 – 100.0%)	44.5% (31.6 – 72.4%)
Model 2b: Modified inputs*	100.0% (100.0 – 100.0%)	100.0% (98.1 – 100.0%)
Model 2c: Elicited inputs	95.8% (88.0 – 100.0%)	53.9% (40.6 – 78.3%)

⁺ TE: Topographic effects.

* Modified ϕ_0 and w_s based on MDR modelling and Sauter diameter of analogues (see Table 1).

Table S4. Numerical results of the probability that a PDC derived from a caldera-forming eruption similar to Aso-3 and Aso-4 reaches the TS₂, with and without topographic effects. For each eruption, we present the values of the cumulative curves displayed in Figure 2 at the central point of the variation range of the PDC mass, while between parentheses we include the results at the extremes of these variation ranges.

No topographic effects modelled				
<i>MinVol</i>: Minimum PDC volume [km³] required to reach the TS3				
Model	5%ile	50%ile	mean	95%ile
Model 1: Elicited inputs	36.7	365	625	2050
Model 2a: Elicited inputs	13.7	74.8	104	303
Model 2b: Modified inputs*	9.78	22.4	23.3	40.2
Model 2c: Elicited inputs	9.14	58.4	86.3	269
<i>MinMass</i>: Minimum PDC mass [10¹² kg] required to reach the TS3				
Model	5%ile	50%ile	Mean	95%ile
Model 1: Elicited inputs	38.9	375	619	1960
Model 2a: Elicited inputs	23.2	128	178	521
Model 2b: Modified inputs*	16.8	38.3	39.6	68.0
Model 2c: Elicited inputs	15.3	99.6	149	465
With topographic effects included				
Minimum PDC volume [km³] required to reach the TS3				
Model	5%ile	50%ile	mean	95%ile
Model 1: Elicited inputs	137	1360	2330	7640
Model 2a: Elicited inputs	44.2	241	337	978
Model 2b: Modified inputs*	31.6	72.1	75.1	130
Model 2c: Elicited inputs	29.5	188	279	867
Minimum PDC mass [10¹² kg] required to reach the TS3				
Model	5%ile	50%ile	mean	95%ile
Model 1: Elicited inputs	145	1400	2310	7320
Model 2a: Elicited inputs	74.9	414	575	1680
Model 2b: Modified inputs*	54.2	123	128	220
Model 2c: Elicited inputs	49.4	322	481	1500

* Modified ϕ_0 and w_s based on MDR modelling and Sauter diameter of analogues (see Table 1).

Table S5. Numerical results of the minimum PDC volume and mass needed to reach the TS₃, with and without consideration of topographic effects (see Section 4.4).

Aso-3		
Model	TE⁺: No	TE⁺: Yes
Model 1: Elicited inputs	20.0% (11.4 – 28.4%)	4.0% (1.5 – 6.4%)
Model 2a: Elicited inputs	49.0% (31.5 – 62.8%)	12.8% (5.0 – 21.6%)
Model 2b: Modified inputs*	100.0% (98.0 – 100.0%)	51.1% (16.1 – 81.8%)
Model 2c: Elicited inputs	58.3% (40.5 – 70.6%)	20.6% (10.2 – 30.2%)
Aso-4 (Takarada and Hoshizumi, 2020)		
Model	TE⁺: No	TE⁺: Yes
Model 1: Elicited inputs	72.0% (53.0 – 84.8%)	33.9% (17.7 – 45.1%)
Model 2a: Elicited inputs	99.6% (90.4 – 100.0%)	75.4% (50.4 – 87.1%)
Model 2b: Modified inputs*	100.0% (100.0 – 100.0%)	100.0% (100.0 – 100.0%)
Model 2c: Elicited inputs	99.9% (93.0 – 100.0%)	80.5% (59.7 – 90.2%)
Aso-4 (Aspinall et al., 2021)		
Model	TE⁺: No	TE⁺: Yes
Model 1: Elicited inputs	51.9% (41.1 – 73.0%)	17.0% (11.0 – 34.8%)
Model 2a: Elicited inputs	89.5% (79.0 – 99.8%)	48.9% (35.3 – 76.4%)
Model 2b: Modified inputs*	100.0% (100.0 – 100.0%)	100.0% (99.7 – 100.0%)
Model 2c: Elicited inputs	92.2% (83.5 – 99.9%)	58.3% (44.4 – 81.4%)

⁺ TE: Topographic effects.

* Modified ϕ_0 and w_s based on MDR modelling and Sauter diameter of analogues (see Table 1).

Table S6. Numerical results of the probability that a PDC derived from a caldera-forming eruption similar to Aso-3 and Aso-4 reaches the TS₃, with and without topographic effects. For each eruption, we present the values of the cumulative curves displayed in Figure 2 at the central point of the variation range of the PDC mass, while between parentheses we include the results at the extremes of these variation ranges.

Probability distribution of MinMass

Topographic effects: No

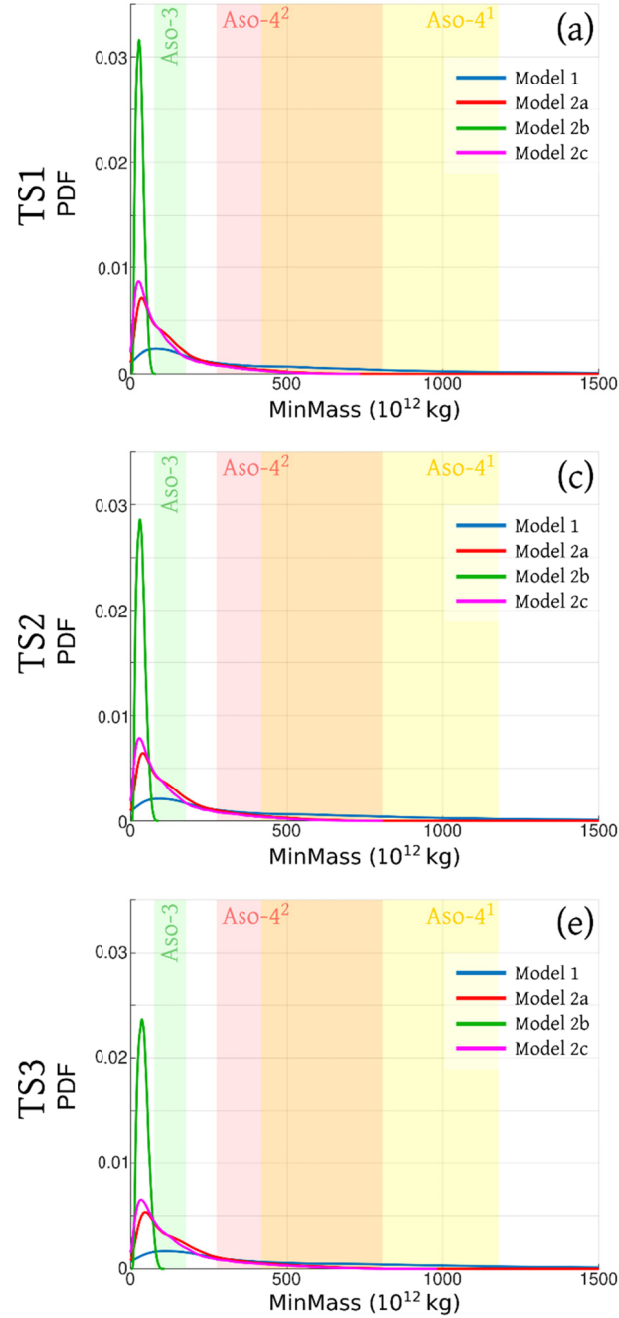


Figure S7. Probability density functions of the variable MinMass, calculated using Models 1, 2a, 2b, 2c and their combination. MinMass represents the mass of pyroclasts in a PDC flow required to invade the different target sites, related to maximum runout distances equal to those of the target sites. Estimates of the mass associated with the PDCs produced during the two largest caldera-forming eruptions of Aso are included: Aso-3 in green (Matsumoto et al., 1991; Crosweller et al., 2012). Aso-41 in yellow: per Takarada and Hoshizumi, 2020. Aso-42 in light red: per Aspinall et al., 2021. The overlap of the latter two is orange-colored.

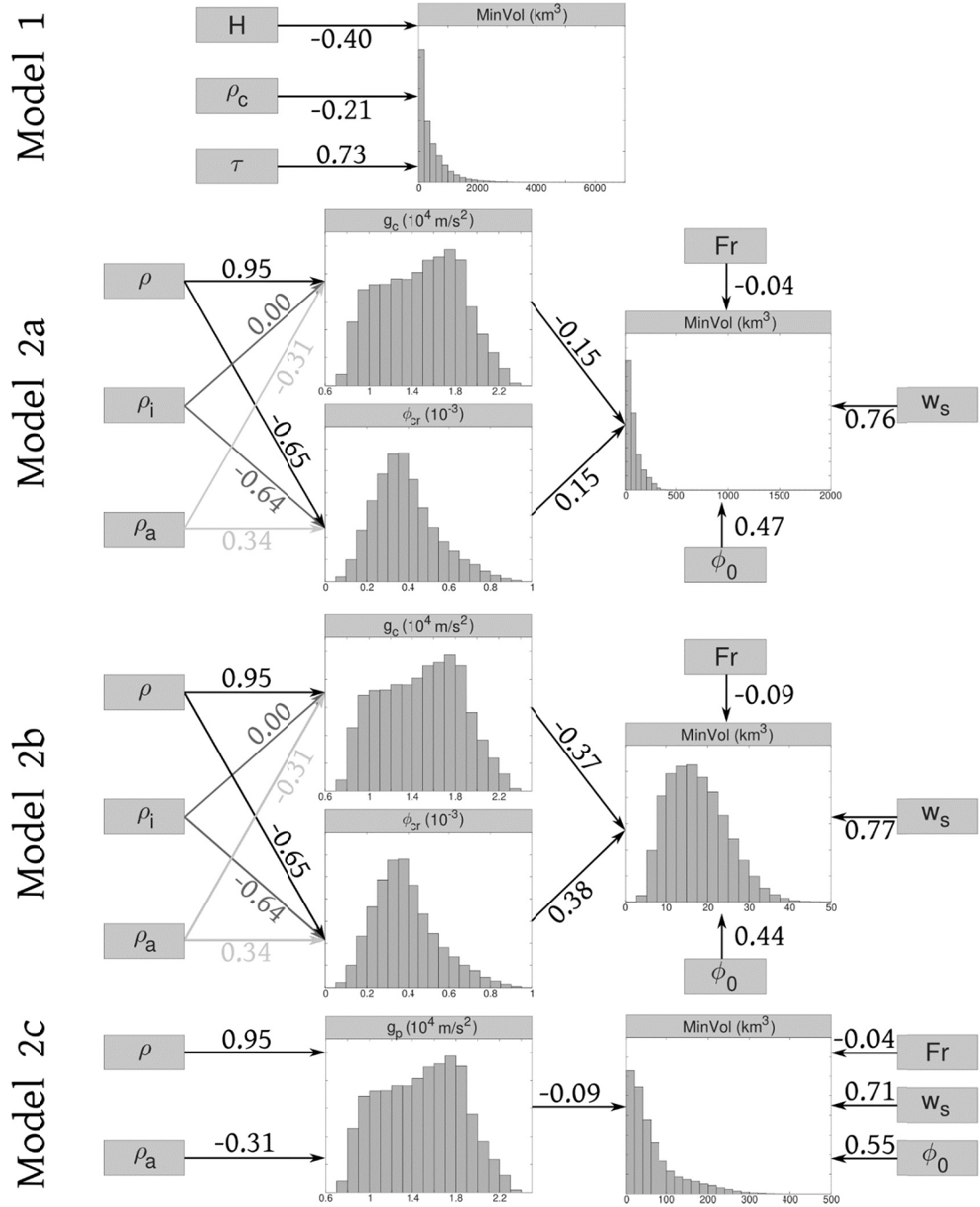


Figure S8. Sensitivity analysis of the parameter MinVol in the different models used in this work. Gray boxes indicate the input parameters, and the arrows indicate the correlation coefficients.