Supplementary material to "The radius of the umbrella cloud helps characterize large explosive volcanic eruptions "

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Supplementary Note 1

Summary of the 2450BP Pululagua eruption. Pululagua (3358 m.a.s.l.) is a dacitic caldera in the Northern Volcanic Zone of the Andean chain, just 15km north of Quito, Ecuador. Its eruptive history has been well documented by Papale and Rosi [1], Andrade and Molina [2] and Volentik et al. [3]. Here we model the deposit of the 2450 B.P. Plinian eruption that occurred in no-wind or negligible wind conditions [1,3]. The eruption was dacitic in composition and the stratigraphic sequence indicates that the event started with a series of small phreatomagmatic explosions (BGA) that lead to the initiation of the Plinian activity (BF1). The fallout deposit of the climactic phase (BF2 – modeled here) was followed by the deposition of a thinner deposit (BF3) and the end of the eruption was marked by the deposition of a thin white-ash layer (WA) [3]. Except BF2 layer that displays near-circular isopachs, all tephra layers associated with the other phases of the eruption display a NW dispersal axis.

The best previous estimates for the ESPs for the climactic phase (BF2) have been conducted by Volentik et al. (2010) using inversion techniques with the Tephra2 model [4,5], without the umbrella cloud source. The results indicated a total erupted mass of 4.5 x 10^{11} kg and a column height of 27 - 29 km. Previous estimates using statistical methods suggest a mass for BF2 of 3 x 10^{11} kg (exponential-fit [6]) and 5 ± x 10^{11} kg (power-law fit [7]), with a column height of 28km and 36 km based on the methods of Pyle [6] and Carey and Sparks [8].

Supplementary Table 1. Summary of the data used to plot the range of total erupted mass calculated with the umbrella cloud model in figure 2 of the main text. We also report the parameters estimated by other models for the same tephra deposit. The erupted mass (*kg*) refers to the mass of tephra of the climactic phase of the eruption. The column height (*km*) refers to the volcanic plume height estimated by other models and the height of the umbrella cloud in our model.

Method	Erupted mass (*kg*)			Column height (*km*)		
	Minimum	Best fit	Maximum	Minimum	Best fit	Maximum
Umbrella cloud model	1.5 x 10^{11}	2.5 x 10^{11}	5 x 10^{11}	20	25	30
Tephra2 inversion [3]		4.5 x 10^{11}			10 – 30km*	
Exponential fit [6]		3 x 10^{11}			-	
Power law [7]		5 ± 1.5 x 10^{11}			-	
C&S [8]		-			36	
Exponential fit [6]		-			28	

*Volentik et al. [3] used inversion with Tephra2 model to obtain a range of column heights by inverting for individual grainsizes.

Supplementary Table 2. Summary of the parameters used in the simulations with different source term geometries. The results are plotted in figure 3 of the main text and show the variations in deposit thickness with distance according to each source term.

Source term model	Erupted mass (kg)	Column height (km)	Diffusion coefficient (m^2s^{-1})	Radius (km)
Disk source	2.5 x 10^{11}	25	9500	10
Point source	2.5 x 10^{11}	25	9500	-
Line source	2.5 x 10^{11}	20 – 25*	9500	-

*the line source term was described by a series of stacked point sources along a vertical line between 20 and 25 km above the vent. The erupted mass was divided equally along the line.

Supplementary References

1 Papale, P. & Rosi, M. A case of no-wind plinian fallout at Pululagua caldera (Ecuador): implications for models of clast dispersal. *Bulletin of Volcanology* **55**, 523, doi:10.1007/bf00304594 (1993).

2 Andrade, D. & Molina, I. *Pululahua caldera: dacitic domes and explosive volcanism. Field guide for the COV4 meeting in Quito (2006).* (2006).

3 Volentik, A. C. M., Bonadonna, C., Connor, C. B., Connor, L. J. & Rosi, M. Modeling tephra dispersal in absence of wind: Insights from the climactic phase of the 2450BP Plinian eruption of Pululagua volcano (Ecuador). *Journal of Volcanology and Geothermal Research* **193**, 117-136, doi:https://doi.org/10.1016/j.jvolgeores.2010.03.011 (2010).

4 Connor, L. J. & Connor, C. B. in *Statistics in Volcanology* Vol. 231-242 (eds H. Mader, S.C. Coles, C.B. Connor, & L.J. Connor) (Geological Society, 2006).

5 Bonadonna, C. *et al.* Probabilistic modeling of tephra dispersal: Hazard assessment of a multiphase rhyolitic eruption at Tarawera, New Zealand. *Journal of Geophysical Research: Solid Earth* **110**, doi:10.1029/2003JB002896 (2005).

6 Pyle, D. M. The thickness, volume and grainsize of tephra fall deposits. *Bulletin of Volcanology* **51**, 1-15, doi:10.1007/BF01086757 (1989).

7 Bonadonna, C. & Houghton, B. F. Total grain-size distribution and volume of tephra-fall deposits. *Bulletin of Volcanology* **67**, 441-456, doi:10.1007/s00445-004-0386-2 (2005).

8 Carey, S. & Sparks, R. S. J. Quantitative models of the fallout and dispersal of tephra from volcanic eruption columns. *Bulletin of Volcanology* **48**, 109-125, doi:10.1007/BF01046546 (1986).