Supplementary material for "Integrating generative AI with physics-based simulations for probabilistic modelling of volcanic clouds"

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S1 Contents of the supplementary material

This supplementary material accompanies the manuscript entitled "Integrating generative AI with physics-based simulations for probabilistic modelling of volcanic clouds" submitted to *Atmospheric Chemistry and Physics* (ACP), Copernicus manuscript reference egusphere-2025-6097. It provides additional information on the ensemble configuration used in the numerical experiments and lists the ancillary files and repositories required to reproduce the simulations and figures.

S2 Ensemble configuration

S2.1 Sampling technique

Each ensemble was simulated by perturbing the Eruption Source Parameters (ESPs) and wind components, widely recognised as some of the most sensitive parameters/inputs for volcanic ash transport models (Devenish et al., 2012; Poulidis et al., 2018). To efficiently sample the parameter space, we used Latin Hypercube Sampling (LHS, McKay et al., 1979), a space-filling ensemble technique that requires fewer samples than purely random Monte Carlo sampling to achieve comparable coverage. LHS was used to generate combinations of source-term and meteorological perturbations for the FALL3D simulations.

S2.2 Synthetic experiment

Table S1 lists the reference value and sampling range for each perturbed parameter. The top height of the eruption column was sampled around the central value 9 km above the vent level with a perturbation range of 30% and was assumed to be constant during the simulations for each ensemble member. The vertical distribution of the source term was also modified by perturbing the Suzuki parameter A_s controlling the maximum emission height (see Folch et al., 2020, for more information). In addition, the horizontal wind components were perturbed considering a sampling range of 25%. The corresponding FALL3D model configuration is provided in the supplementary file `garachico2025.inp`.

Table S1. Ensemble configuration for the synthetic experiment. The perturbed model parameters are: eruption column height (H), mass eruptive rate (MER), Suzuki parameter A_s, and the wind horizontal components.

Parameter	Reference value	Distribution	Sampling range
H	9 km avl[†]	Uniform	±30%
MER	$\sim 1.6 \times 10^6$ kg s^{-1}[‡]	Uniform	±25%
A_s	4	Uniform	1
Winds	GFS[§]	Uniform	±25%

[†] Height given in km above the vent level;

[‡] Estimated from H according to Woodhouse et al. (2016);

[§] Global Forecast System (GFS) weather forecast from NCEP.

S2.3 Etna experiment

For the Etna 24 December 2018 case, each ensemble was simulated by perturbing the eruptive column-top height and the horizontal wind components by 20%. As in the synthetic experiment, the perturbations were generated using LHS to obtain an efficient sampling. A time-dependent eruptive column height was defined in the simulations, as shown in Fig. S1. The corresponding FALL3D model configuration is provided in the supplementary file `etna2018.inp`.

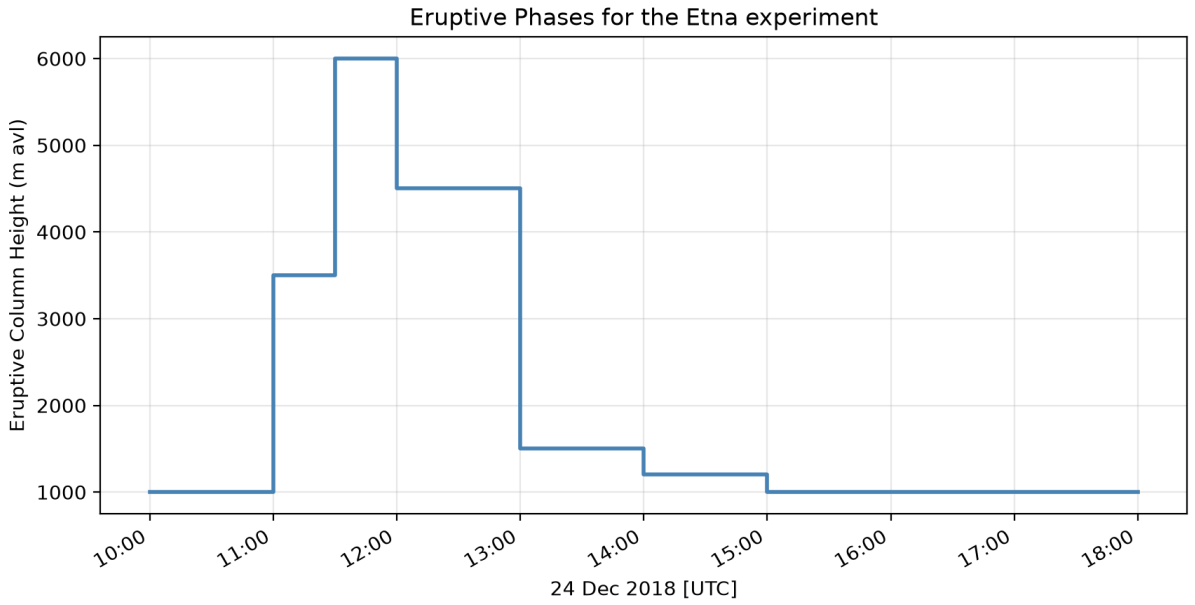


Figure S1. Eruptive phases defined for the Etna experiment. The simulations assumed a time-dependent eruptive column height (in meters above vent level).

S3 Ensemble mean of the test dataset

The test dataset used in the synthetic experiment consists of 2048 physics-based numerical simulations and is used to assess the performance of the VAE. Figure S2 shows the ensemble mean of the test dataset, which is used as a reference for the computation of several metrics. The figure also indicates the locations of the points used to construct the histograms.

S4 Additional files and external repositories

S4.1 Model configuration files

The FALL3D model input files distributed with this supplementary material are:

- `garachico2025.inp`: model configuration file for the synthetic experiment;
- `etna2018.inp`: model configuration file for the Etna 24 December 2018 experiment.

S4.2 Code and archived repositories

The scripts used to post-process the ensemble simulations, VAE training, ensemble sampling, and generate the figures are available from archived repositories:

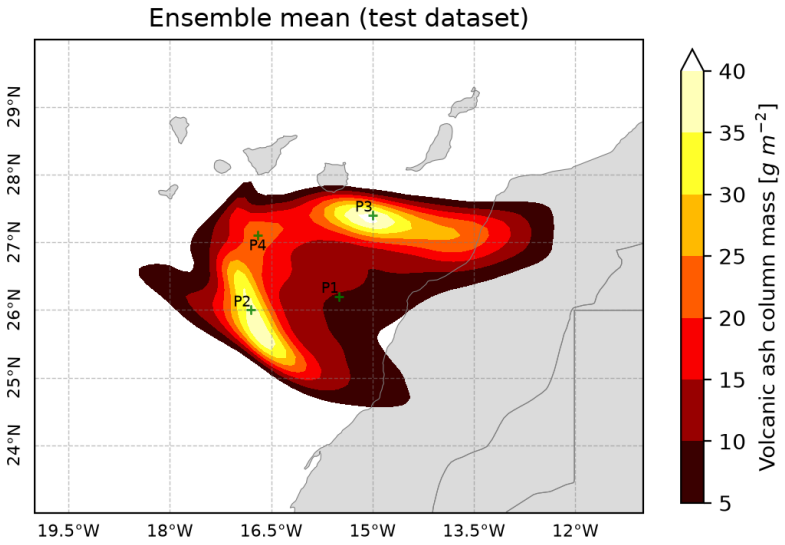


Figure S2. Ensemble mean of the test dataset for the synthetic experiment, consisting of 2048 physics-based numerical simulations generated by the FALL3D dispersal model.

- Synthetic experiment code Zenodo DOI 10.5281/zenodo.22759580 (Mingari, 2026b); repository: https://github.com/lmingari/egusphere-2025-6097-synthetic
- Etna experiment code Zenodo DOI 10.5281/zenodo.22759573 (Mingari, 2026a); repository: https://github.com/lmingari/egusphere-2025-6097-etna

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