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## Numerical modelling of the surge-derived pyroclastic flow of 25 June 1997 at Soufriere Hills Volcano, Montserrat

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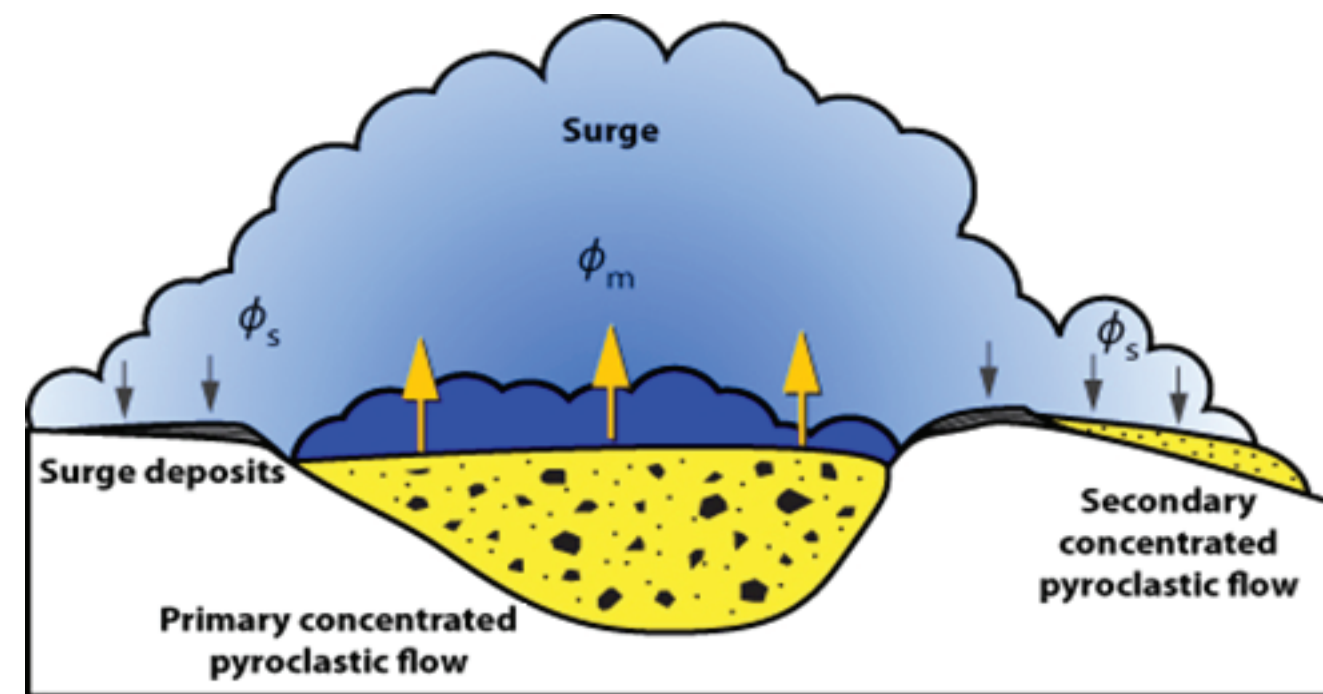
## Introduction

Pyroclastic density currents (PDCs) are volcanic flows usually composed of 2 distinct parts: the pyroclastic flow and the overriding ash-cloud surge. Deposits from ash-cloud surges associated with dome-collapse block-and-ash flows (BAFs) can be immediately remobilized to form surge-derived pyroclastic flows (SDPF). SDPFs, such as those generated on 25 June 1997 at Soufrière Hills, Montserrat, are hazardous because they can follow drainages different from those exploited by the BAF. Better understanding of their mechanism of formation is essential for risk mitigation. SDPFs have never been reproduced numerically in the past.

### Aims

- ➔ Simulating the eruption of the 25 June 1997 at Soufrière Hills, Montserrat, because the SDPFs have been well described.
- ➔ Investigating in the numerical model the conditions that favor the generation of SDPFs during dome-collapse events.

## Physical model

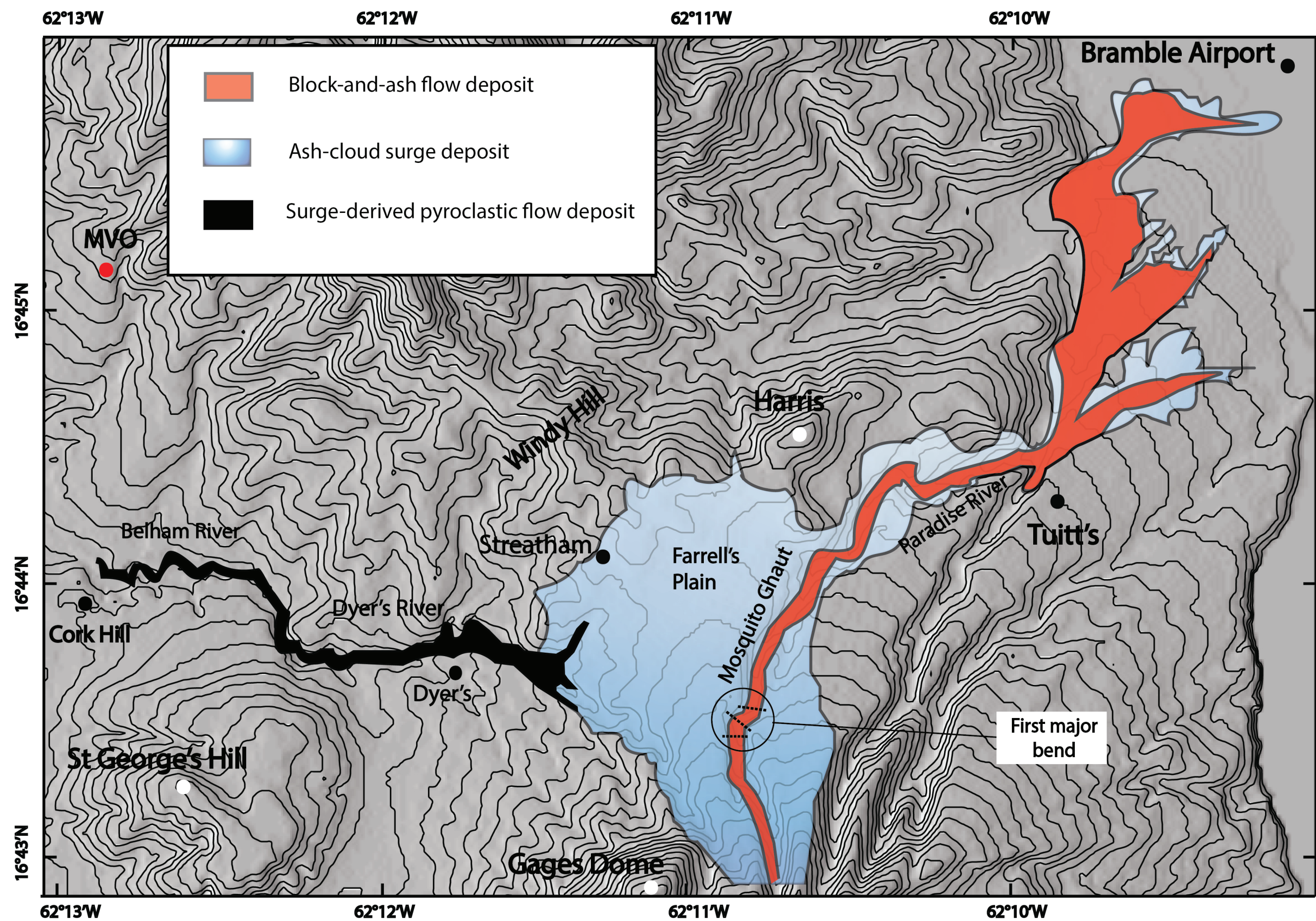


Our model **simultaneously simulates** the two parts of the PDCs: the pyroclastic flow, and the overriding ash-cloud surge:

- The pyroclastic flow is simulated using three main rheologies: the **plastic rheology**, the **frictional velocity-weaking rheology**, and **frictional rheology**.
- The surge is simulated with a **turbulent gas rheology**. It gains mass by particle entrainment from the underlying flow, and loses mass by sedimentation, and lift-off. Sedimented particles either fall back into the pyroclastic flow, or form a deposit on the land surface.
- If the thickness of the deposit from the surge exceeds the **critical threshold** for the material rheology, the deposit immediately remobilises to form a SDPF with assumed the pyroclastic flow rheology.

## Results

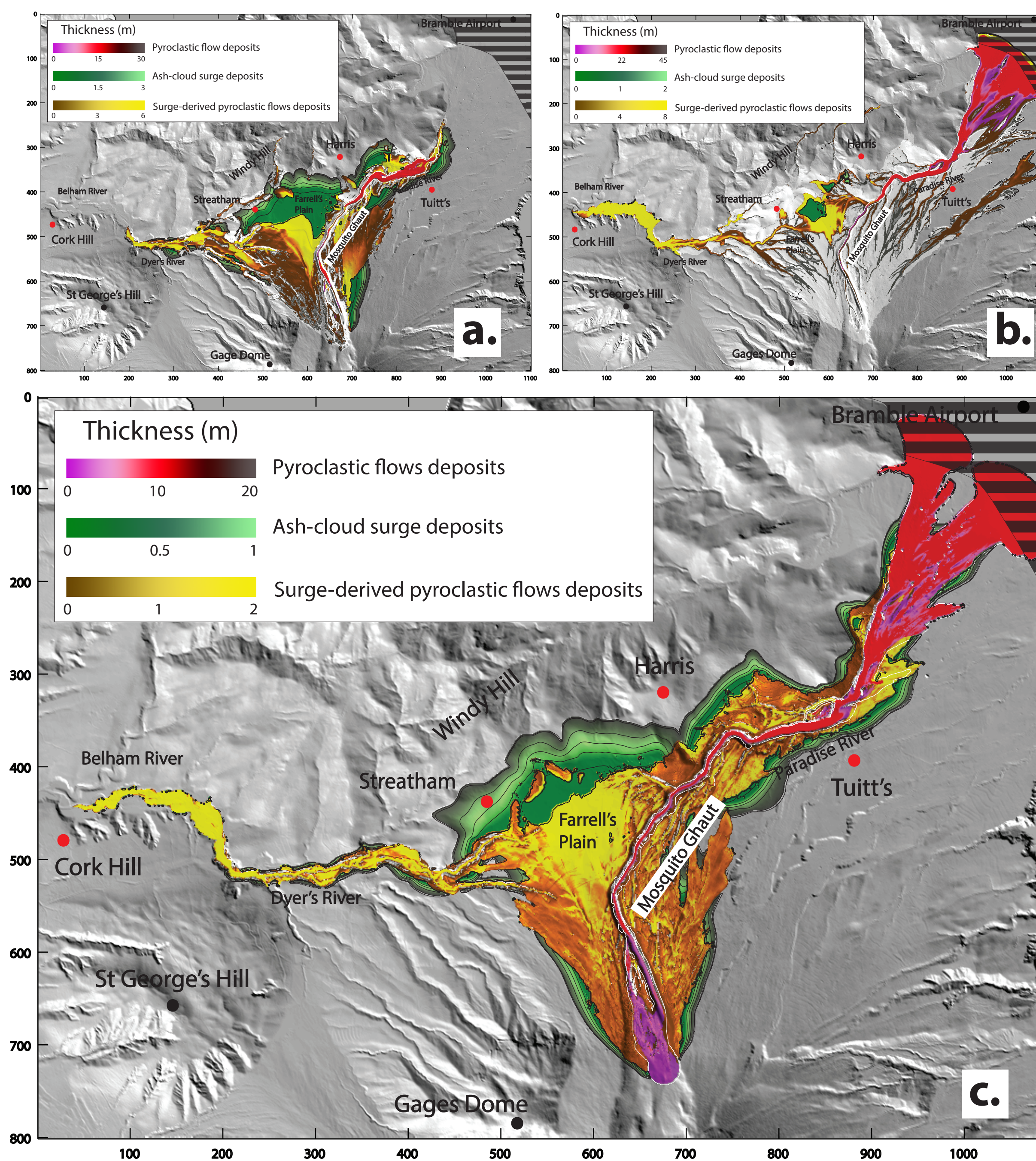
Deposit map from the 25 June 1997 Soufrière Hills dome collapse (Montserrat)



Results of simulations for the three different rheologies used for the pyroclastic flow:  
**a.** Frictional velocity-weakening rheology  
**b.** Frictional rheology  
**c.** Plastic rheology

Even if the accuracy is not the same, **each rheology reproduces** the SDPFs.

The **best result** is obtained with the **plastic rheology** ➔



➔ The simulation highlights a mechanism of surge derived-pyroclastic flow formation, highly dependent of the topography :

- First**, the major bend in the Mosquito Ghaut valley allows the surge detachment and a strong sedimentation on the Farrell's plain.
- Second**, the accumulation of surge deposits on steep slopes generates destabilizations related to each rheology. These small destabilizations in deposits transform into small surge-derived pyroclastic flows.
- Third**, due to the valley shape, the SDPFs amalgamate into a single flow in the Belham valley. This SDPF travels 3 km in the opposite direction of the main BAF and becomes a significant hazard in its own right.

## References

Kelfoun, K. (2017), A two-layer depth-averaged model for both the dilute and the concentrated parts of pyroclastic currents, *J. Geophys. Res. Solid Earth*, 122, doi:10.1002/2017JB014013.

Kelfoun, K., V. Gueugneau, J.-C. Komerowski, N. Aisyah, N. Cholikh, and C. Merciecca (2017), Simulation of block-and-ash flows and ash-cloud surges of the 2010 eruption of Merapi volcano with a two-layer model, *J. Geophys. Res. Solid Earth*, 122, doi:10.1002/2017JB013981.

## Conclusion

- ➔ First numerical reproduction of surge-derived pyroclastic flows. Validation of the physical model.
- ➔ Highlights the mechanism of formation of SDPFs : a cycle of accumulation-remobilisation of surge deposits on a steep slope, channelised into one valley, forming a surge-derived pyroclastic flow.
- ➔ Highly dependent on the topography. The plastic rheology for the pyroclastic flow seems to be the more accurate.

## Numerical modelling

The simulation of the pyroclastic flows (both primary and secondary) is based on the resolution of mass and momentum balance equations (Kelfoun, 2017 ; Kelfoun et al., 2017):

$$\frac{\partial h_d}{\partial t} + \frac{\partial}{\partial x}(h_d u_x) + \frac{\partial}{\partial y}(h_d u_y) = \frac{\phi_s - \phi_m}{\rho_d}$$

$$\begin{aligned} & \frac{\partial}{\partial t}(h_d u_x) + \frac{\partial}{\partial x}(h_d u_x^2) + \frac{\partial}{\partial y}(h_d u_x u_y) \\ &= gh_d \sin \alpha_x - \frac{1}{2} \frac{\partial}{\partial x}(gh_d^2 \cos \alpha_x) + \frac{T_x}{\rho_d} + \frac{\phi_s}{\rho_d} v_x - \frac{\phi_m}{\rho_d} u_x \end{aligned}$$

$$\begin{aligned} & \frac{\partial}{\partial t}(h_d u_y) + \frac{\partial}{\partial x}(h_d u_x u_y) + \frac{\partial}{\partial y}(h_d u_y^2) \\ &= gh_d \sin \alpha_y - \frac{1}{2} \frac{\partial}{\partial y}(gh_d^2 \cos \alpha_y) + \frac{T_y}{\rho_d} + \frac{\phi_s}{\rho_d} v_y - \frac{\phi_m}{\rho_d} u_y \end{aligned}$$

The surge is also based on the resolution of mass and momentum balance equations, and we add a density balance equation:

$$\frac{\partial h_s}{\partial t} + \frac{\partial}{\partial x}(h_s v_x) + \frac{\partial}{\partial y}(h_s v_y) = \frac{\phi_m}{\rho_m}$$

$$\frac{\partial \rho_s h_s}{\partial t} + \frac{\partial}{\partial x}(\rho_s h_s v_x) + \frac{\partial}{\partial y}(\rho_s h_s v_y) = \phi_m - \phi_s$$

$$\begin{aligned} & \frac{\partial}{\partial t}(\rho_s h_s v_x) + \frac{\partial}{\partial x}(\rho_s h_s v_x^2) + \frac{\partial}{\partial y}(\rho_s h_s v_x v_y) = (\rho_s - \rho_a) gh_s \sin \beta_x \\ & - \frac{1}{2} \frac{\partial}{\partial x}((\rho_s - \rho_a) gh_s^2 \cos \beta_x) + R_x + \phi_m u_x - \phi_s v_x \end{aligned}$$

$$\frac{\partial}{\partial t}(\rho_s h_s v_y) + \frac{\partial}{\partial x}(\rho_s h_s v_x v_y) + \frac{\partial}{\partial y}(\rho_s h_s v_y^2) = (\rho_s - \rho_a) gh_s \sin \beta_y$$

$$- \frac{1}{2} \frac{\partial}{\partial y}((\rho_s - \rho_a) gh_s^2 \cos \beta_y) + R_y + \phi_m u_y - \phi_s v_y$$

The two flows are coupled through two empirical mass flux laws:

- ➔ From the flow to the surge :  $\phi_m = a_3 \cdot u^3$
- ➔ From the surge to the flow :  $\phi_s = (\rho_s - \rho_a) \cdot w_{sed}$

The resistive stresses are adaptable to each rheology :

$$\mathbf{T} = T_0 \frac{\mathbf{u}}{\|\mathbf{u}\|} - c_1 \rho_d \|\mathbf{u}\| \mathbf{u} \quad \text{or} \quad \mathbf{T} = h_d \rho_d \left( g \cos \alpha + \frac{u^2}{r} \right) \tan \varphi_{bed} \frac{\mathbf{u}}{\|\mathbf{u}\|} + c_1 \rho_d \|\mathbf{u}\| \mathbf{u}$$

plastic
frictional
frictional velocity-weakening

$$T_0 = cst \quad \tan \varphi_{bed} = cst \quad \tan \varphi_{bed} = \frac{\varphi_0 - \varphi_w}{(1 + \|\mathbf{u}\|/U_w)} + \varphi_w$$

## Contact

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 VolcFlow website : <http://lmv.univ-bpclermont.fr/volcflow/>