# A FEM model for evaporation and infiltration in unsaturated soils interacting with the atmosphere

## Predicting water, vapour and heat fluxes in response to extreme weather events using a robust soil-atmosphere coupled modelling approach

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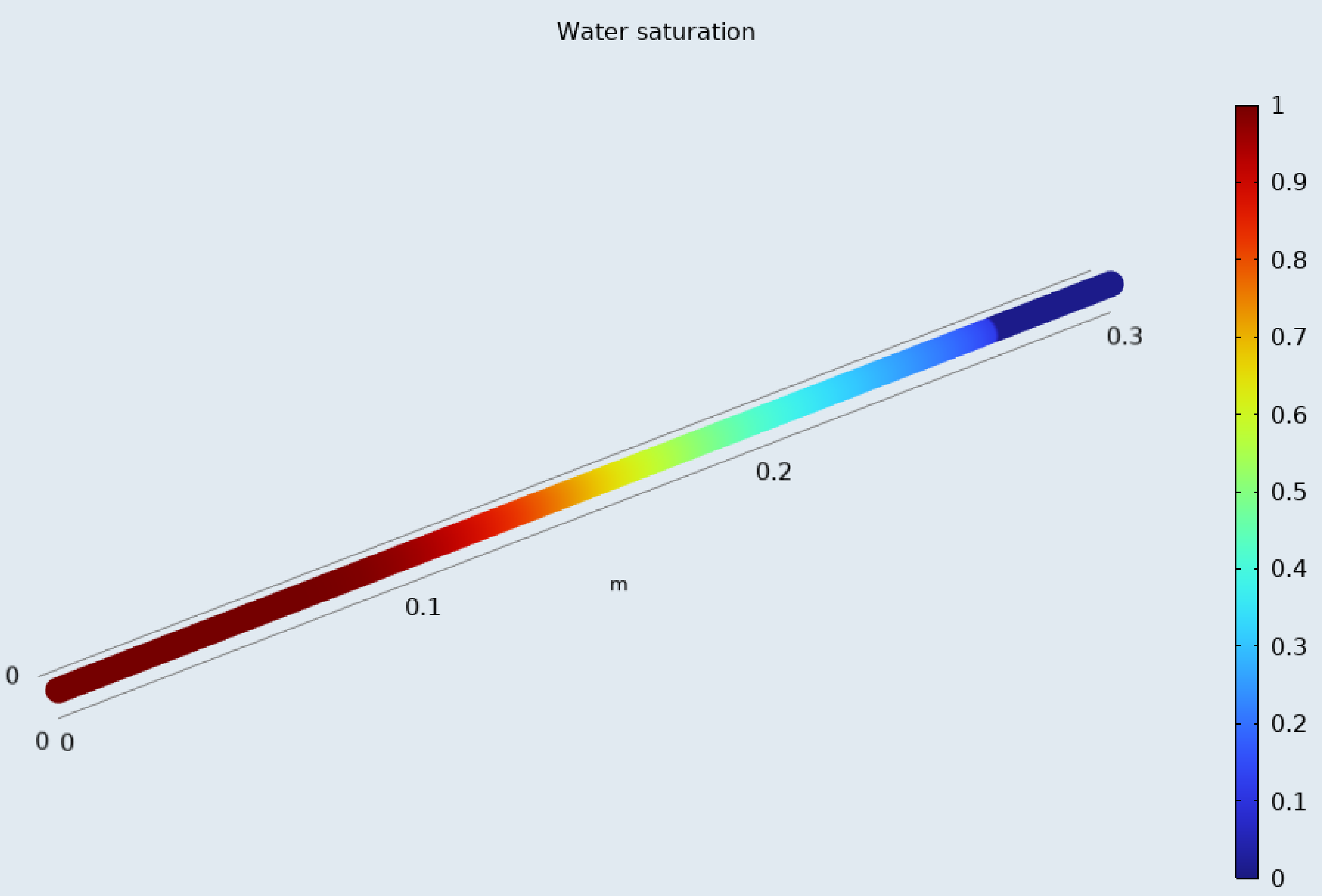

## Abstract

The pore water pressure in the vadose zone is controlled by the interaction between the soil and the atmosphere through evaporation and infiltration. These processes are strongly influenced by the soil's hydraulic conductivity and water retention and thermal properties (Guida *et al*., 2023). In this contribution, we propose a coupled model based on the mass balance equations of the air and water species by including a storage term accounting for the changes in the liquid degree of saturation and, if necessary, in porosity. Liquid water and vapour mass transport occur via advection and diffusion, respectively. Finally, the thermal energy balance is also considered, including the heat flux due to conduction and convection, to obtain the temperature field.

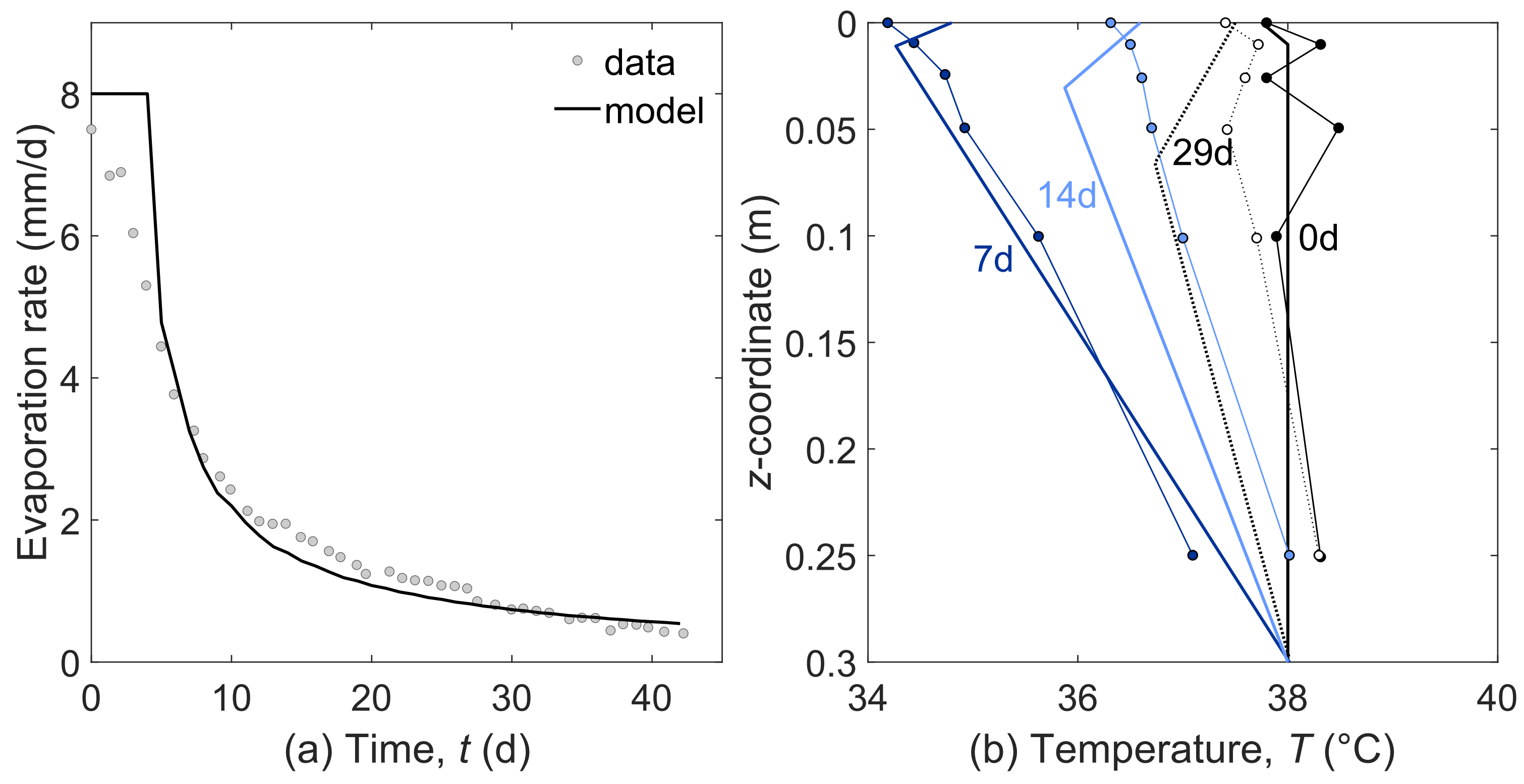

FIGURE 1 Simulation of evaporation from a sand specimen (Wilson *et al.*, 1994): (a) evolution with time of the evaporation rate; (b) profiles with depth of temperature at different time instants. In both cases, the comparison between the model prediction and experimental data is shown.

## Methodology

The numerical model has been implemented using the Coefficient Form PDE interface available in the Mathematics module of the COMSOL Multiphysics® software. Then, it has been validated by reproducing experimental data of evaporation and infiltration processes. The implemented mass and energy balance equations are:

$$\frac{\partial}{\partial t}\left[\phi\left(S_l c_l^w + S_g c_g^w\right)\right] + \nabla\cdot\left(c_l^w \mathbf{q}_l + c_g^w \mathbf{q}_g + \phi S_l \mathbf{J}_l^w + \phi S_g \mathbf{J}_g^w\right) = 0$$

$$\frac{\partial}{\partial t}\left[\phi\left(S_l c_l^a + S_g c_g^a\right)\right] + \nabla\cdot\left(c_l^a \mathbf{q}_l + c_g^a \mathbf{q}_g + \phi S_l \mathbf{J}_l^a + \phi S_g \mathbf{J}_g^a\right) = 0$$

$$\frac{\partial}{\partial t}\left(E_s \rho_s (1-\phi) + E_l \rho_l S_l \phi + E_g \rho_g S_g \phi\right) + \nabla\cdot\left(\mathbf{i}_c + \mathbf{j}_{E_l} + \mathbf{j}_{E_g}\right) = 0$$

## Results

Experimental data from an evaporation test on sands (Wilson *et al.*, 1994) were successfully predicted, in terms of evaporation rate (Figure 1a) and of temperature distribution (Figure 1b), proving the effectiveness of the coupling of the energy balance in the model.

The model also reproduced well an infiltration test on sands (Siemens *et al.*, 2014; Figure 2a). The good agreement was achieved because it captured the air pressure buildup expected during the process (Figure 2b).

The model was also used to simulate both evaporation and water uptake on cement-bentonite mixtures, by introducing the hysteresis of the retention properties of the material (Musso *et al.*, 2023).

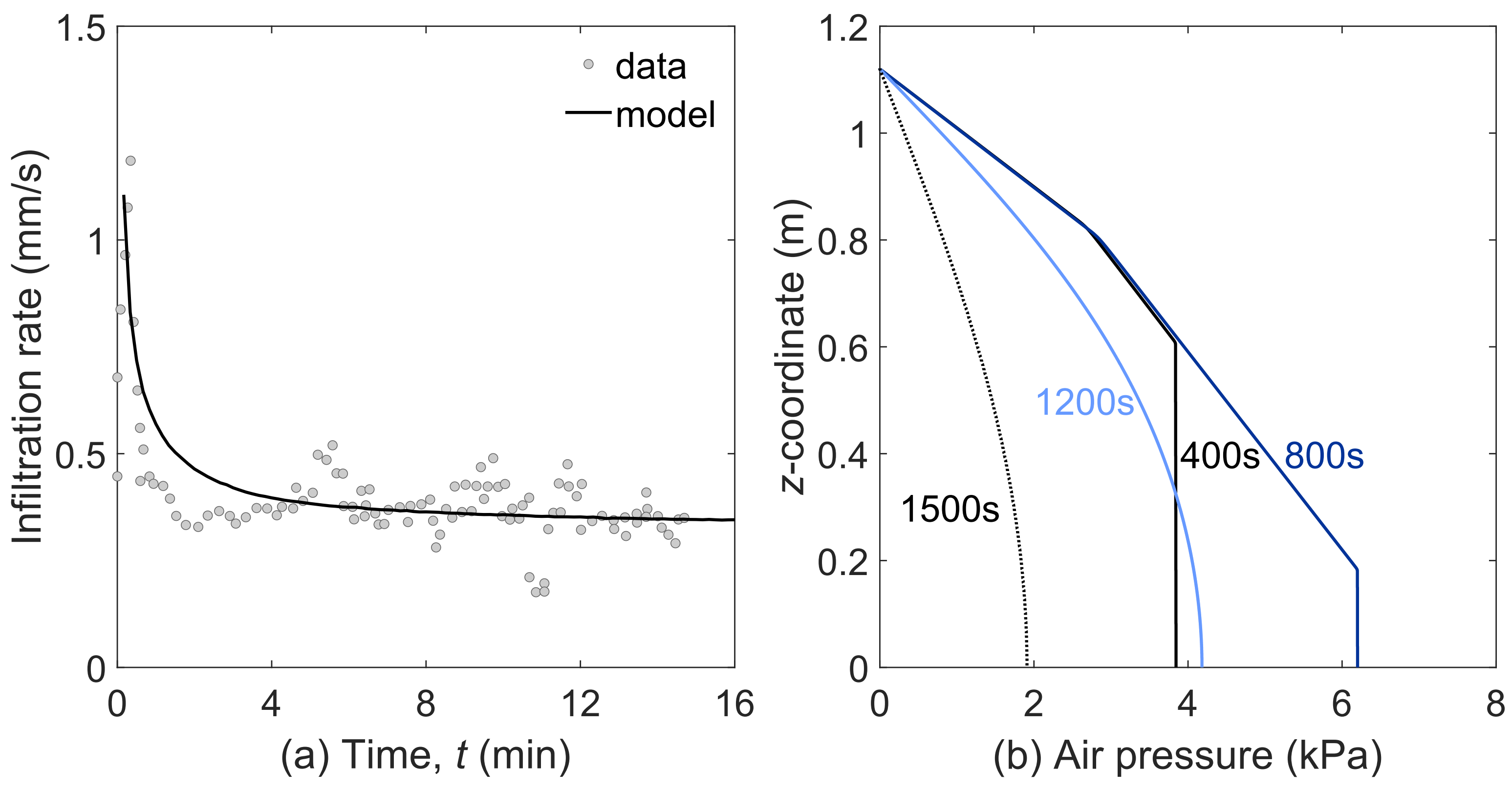

FIGURE 2 Simulation of infiltration in a sand specimen (Siemens *et al.*, 2014): (a) model prediction versus experimental data of the evolution with time of the infiltration rate; (b) profiles with depth of air pressure at different time instants.

## REFERENCES

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