

Supplementary Material for: The Role of Moisture Gradients and Time Scales in Wood Mechanosorption

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1 Numerical Implementation Details

This supplementary material summarizes the numerical procedures used to implement the coupled moisture-transport and DD-SS-FBM framework. The adopted strategies were designed to ensure numerical stability, accurately resolve the nonlinear stick-slip dynamics, and maintain computational efficiency across the large simulation campaigns performed in this work.

1.1 Moisture Transport Implementation

The diffusion process was solved only on a triangular domain corresponding to one-eighth of the fiber bundle cross-section, representing the minimal symmetry group of the square lattice. This reduced domain was used to decrease computational cost and memory usage. The resulting moisture fields were subsequently mirrored and mapped onto the full bundle geometry for the coupled mechanical simulations.

The moisture field was updated incrementally using the explicit discretization of Eq. 10,

$$\varphi_i^{t+\Delta t} = \varphi_i^t + \frac{\chi_i^t \Delta t}{\Delta l^2} \sum_{j \in \mathcal{N}_i} (\varphi_j^t - \varphi_i^t), \quad (1)$$

where $\mathcal{N}_i$ denotes the set of nearest neighbors of fiber i , and Δl is the spatial discretization distance between adjacent fibers. The bundle geometry was normalized such that $\Delta l = 1$.

Numerical stability of the explicit scheme was ensured through the Courant–Friedrichs–Lewy condition,

$$\Delta t \leq \frac{0.25}{\Delta l^2 \max(\chi_i)}. \quad (2)$$

At each diffusion step, the fiber with the highest local diffusivity, $\max(\chi_i)$, was used to determine the admissible time increment. Within this stability bound, the diffusion time step was adaptively updated throughout the simulation to maximize computational efficiency.

1.2 Mechanical Solver and Coupled Time Integration

To accurately resolve the nonlinear stick–slip response of the DD-SS-FBM, the bundle’s initial mechanical loading was precomputed using an event-driven algorithm: the most critical fiber was identified, the minimum load increment required to trigger slip was applied, the slipped fiber was updated, and the redistributed load field was recalculated until no further slips occurred, this lowest-threshold loading procedure was repeated until bundle failure. This procedure was repeated for the bundle on dry and wet states, the resulting slip and load evolution on dry state were stored and used as initialization data for subsequent simulations at prescribed load levels. The critical load and strain on the wet state were used to normalize all reported stresses and strains.

The coupled hygro-mechanical evolution was then solved incrementally in time. Moisture histories were resampled into 100 increments per moistening/drying segment. At each increment, the updated moisture field was applied, viscoelastic strains were updated, forces were redistributed, and the slip criterion was evaluated. To properly resolve slip avalanches occurring within a time increment, an adaptive recursive sub-stepping scheme was employed. Whenever multiple slip events were triggered within a single step, the step was bisected and the solution repeated using moisture fields obtained by linearly interpolating the local moisture of each fiber. Recursive bisection was allowed up to 10 times; beyond this limit, the step was accepted to avoid excessive computational cost. Depending on the severity of avalanche activity, a single moisture cycle could therefore require up to 10^5 effective time steps.

2 Simulation Seed Comparison

To ensure representation of the analyzed results in this work, the simulations analyzed in Sec. 3.2 were repeated for 3 different seeds to generate the Weibull slip threshold distribution. The result of Fig 7 is repeated with all seeds, and the result in [ESM1](#) shows that the result is consistent throughout all tested seeds.

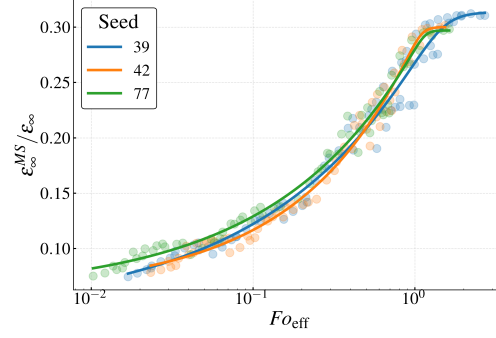


Fig. ESM1: Comparison of Fo_{eff} calculation for different seeds to generate the slip threshold distribution. The blue curve is the seed used through the manuscript (39), while the others were used for this comparison.