Numerical Modelling and Validation for 3-D Boulder Transport Related to Tsunami

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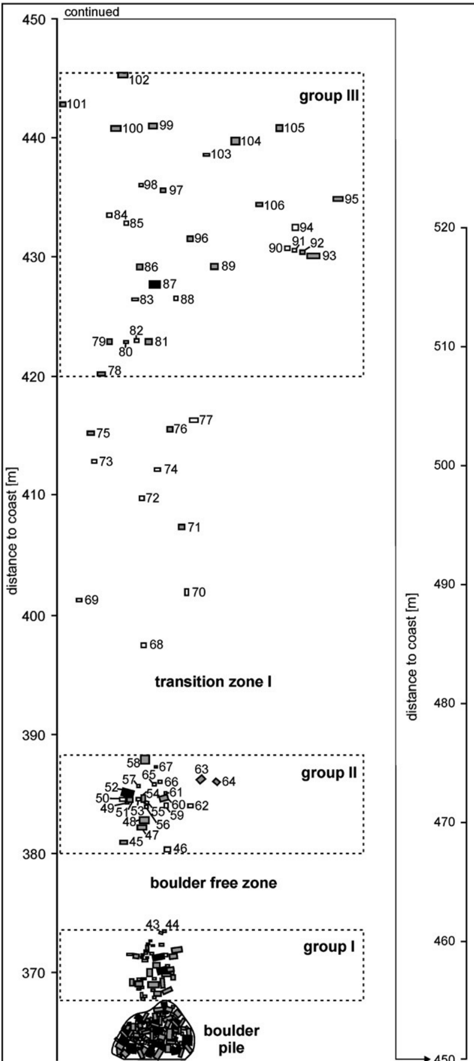
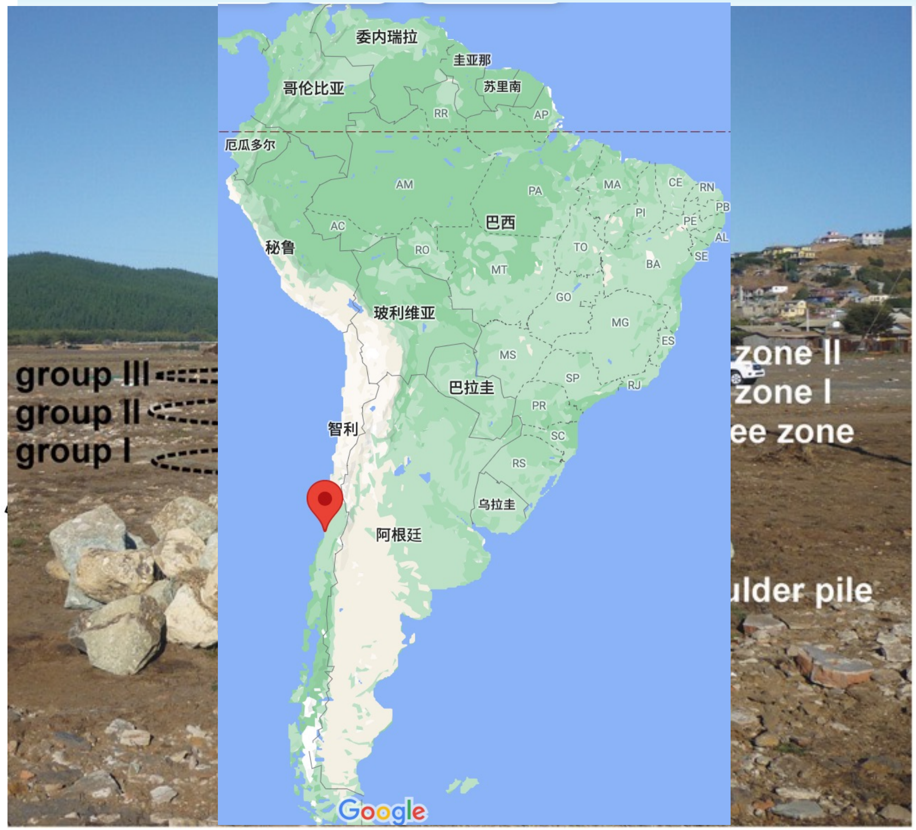
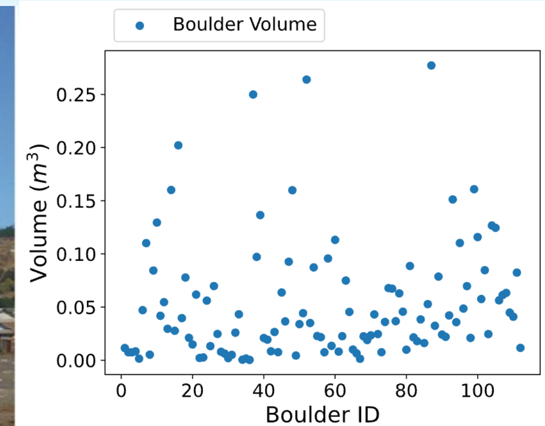
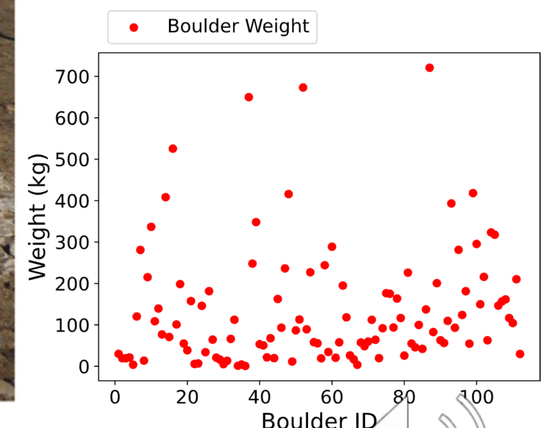
1. Background: Boulder Transport during Tsunami





Location: Bucalemu





Michaela Spiske. University of Münster, Institute of Geology and Paleontology.

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2. Modelling and simulation framework

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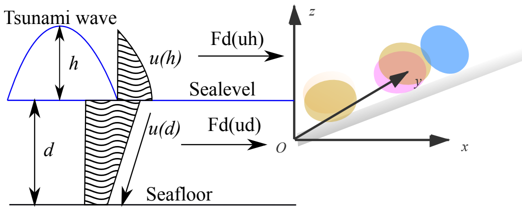
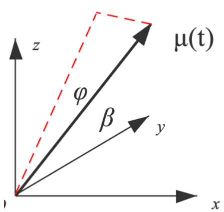
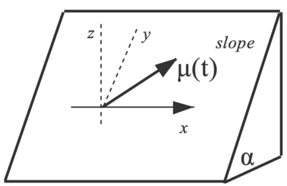
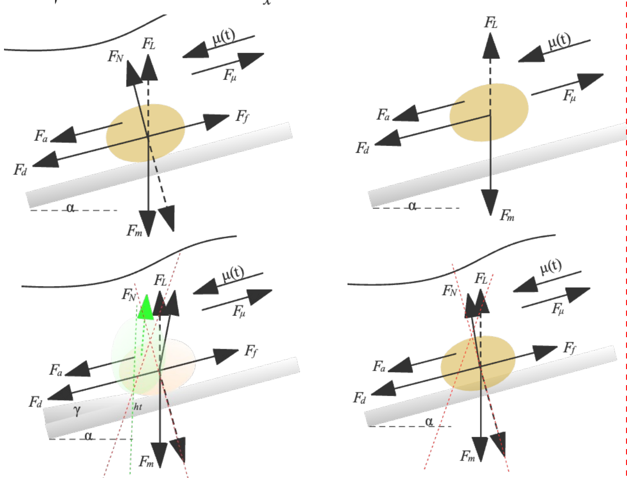
(1) Force balance on boulder









(2) Movement condition

Drag force | Buoyant weight | Damping force

$$F = F_d + F_a \pm F_m - F_f - F_\mu$$

Impulsive force | Frictional force

The total force balance on the boulder(sliding):

$$F_s = \frac{1}{2} C_d A_y \rho_f \left(u(t)cos(\beta-\alpha) - \frac{ds}{dt} \right)^2 + k\rho_f V \left(a(t)cos(\beta-\alpha) - \frac{d^2 s}{dt^2} \right)$$

$$-\left(F_m cos\alpha - \frac{1}{2} C_d A_y \rho_f (u(t)\sin(\beta-\alpha))^2 - k\rho_f V a(t) sin(\beta-\alpha) \right)\lambda - F_m sin\alpha$$

From the force balance we can get:

$$0 \le \left(\frac{1}{2Lg} C_d (u(t))^2 + k\frac{a(t)}{g}\right)(cos^2(\beta-\alpha) + \lambda\, sin^2(\beta-\alpha)) - \left(\frac{\rho_s}{\rho_f} - 1\right)(\lambda + sin\alpha)$$

Rolling:

$$0 \le \left(\frac{1}{2Lg} C_d (u(t))^2 + k\frac{a(t)}{g}\right)(cos^2(\beta-\alpha) + \lambda\, sin^2(\beta-\alpha)) - \left(\frac{\rho_s}{\rho_f} - 1\right)(\lambda + sin\alpha)$$

Suspension:

$$0 \le \left(\frac{1}{2Lg} C_d (u(t))^2 + k\frac{a(t)}{g}\right)cos\varphi sin\beta - \left(\frac{\rho_s}{\rho_f} - 1\right)$$

(3) Boulder Movement

$$F = F_d + F_a - F_m - F_\mu = \left(\frac{7}{5}\rho_s + C_m \rho_f\right) V a(t)$$

$$\begin{cases} F_x = \frac{u(t)sin\varphi - dx/dt}{|u(t)sin\varphi - dx/dt|}\frac{1}{2} C_d A_x \rho_f \left(u(t)sin\varphi - \frac{dx}{dt}\right)^2 + k\rho_f V\left(a(t)sin\varphi - \frac{d^2x}{dt^2}\right) - \\ \lambda\left(\frac{u(t)cos\varphi sin\beta - dz/dt}{|u(t)cos\varphi sin\beta - dz/dt|}\frac{1}{2} C_d A_z \rho_f \left(u(t)cos\varphi sin\beta - \frac{dz}{dt}\right)^2 + \right. \\ \left. k\rho_f V\left(a(t)cos\varphi sin\beta - \frac{d^2z}{dt^2}\right) - F_m\right)cos\alpha \frac{x_{n-1} - x_n}{\sqrt{(s_{n-1}-s_n)^2 + (x_{n-1}-x_n)^2}} \\ F_y = \frac{u(t)cos\varphi cos\beta - dy/dt}{|u(t)cos\varphi cos\beta - dy/dt|}\frac{1}{2} C_d A_y \rho_f \left(u(t)cos\varphi cos\beta - \frac{dy}{dt}\right)^2 + k\rho_f V\left(a(t)cos\varphi cos\beta - \frac{d^2}{dt}\right. \\ \lambda\left(\frac{u(t)cos\varphi sin\beta - dz/dt}{|u(t)cos\varphi sin\beta - dz/dt|}\frac{1}{2} C_d A_z \rho_f \left(u(t)cos\varphi sin\beta - \frac{dz}{dt}\right)^2 + \right. \\ \left. k\rho_f V\left(a(t)cos\varphi sin\beta - \frac{d^2z}{dt^2}\right) - F_m\right)cos\theta \frac{y_{n-1} - y_n}{\sqrt{(y_{n-1}-y_n)^2 + (x_{n-1}-x_n)^2}} \\ F_z = \left(\lambda\left(\frac{u(t)cos\varphi sin\beta - dz/dt}{|u(t)cos\varphi sin\beta - dz/dt|}\frac{1}{2} C_d A_z \rho_f \left(u(t)cos\varphi sin\beta - \frac{dz}{dt}\right)^2 + \right.\right. \\ \left. k\rho_f V\left(a(t)cos\varphi sin\beta - \frac{d^2z}{dt^2}\right) - F_m\right)(1 - \lambda sin\alpha) \\ F_N = (F_{dz} + F_{az} - F_m) \end{cases}$$

$$\begin{cases} y_{i+1} = y_i + \frac{1}{6}(k_1 + 2k_2 + 3k_3 + k_4) \\ k_1 = hf(x_i, y_i) \\ k_2 = hf\left(x_i + \frac{1}{2}h, y_i + \frac{1}{2}k_1\right) \\ k_3 = hf\left(x_i + \frac{1}{2}h, y_i + \frac{1}{2}k_2\right) \\ k_4 = hf(x_i + h, y_i + k_3) \\ y_0 = y(a), i = 0,1,\cdots,n-1 \end{cases}$$

Discretize the equation and solve the boulder transport model by numerical method

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3. Boulder initialization and parameter study

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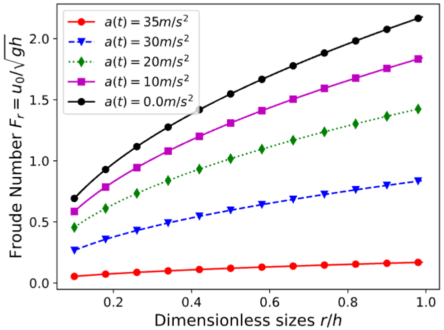
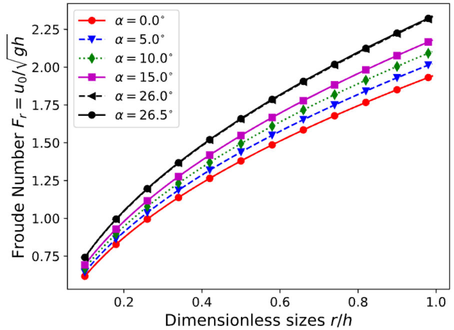
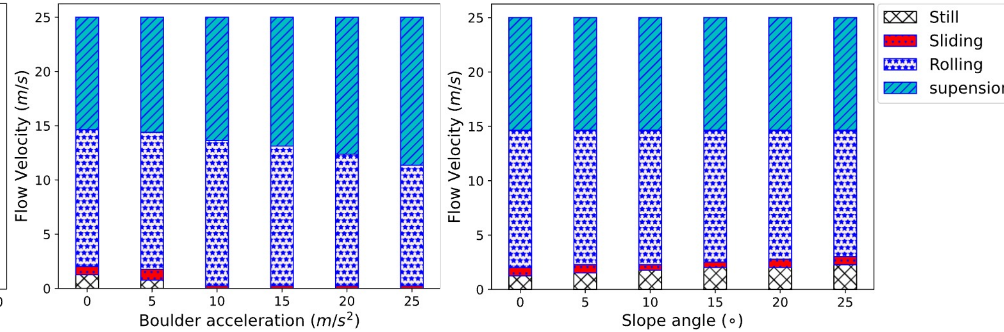
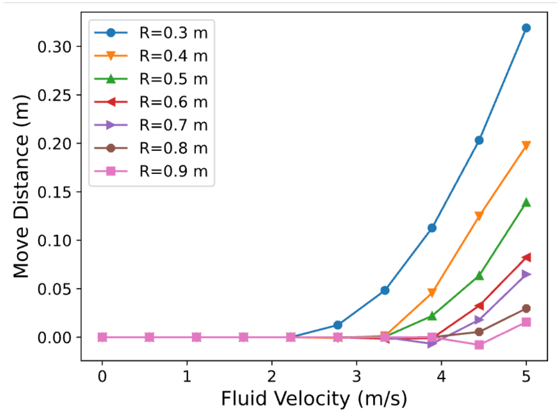
Boulder initial and critical condition

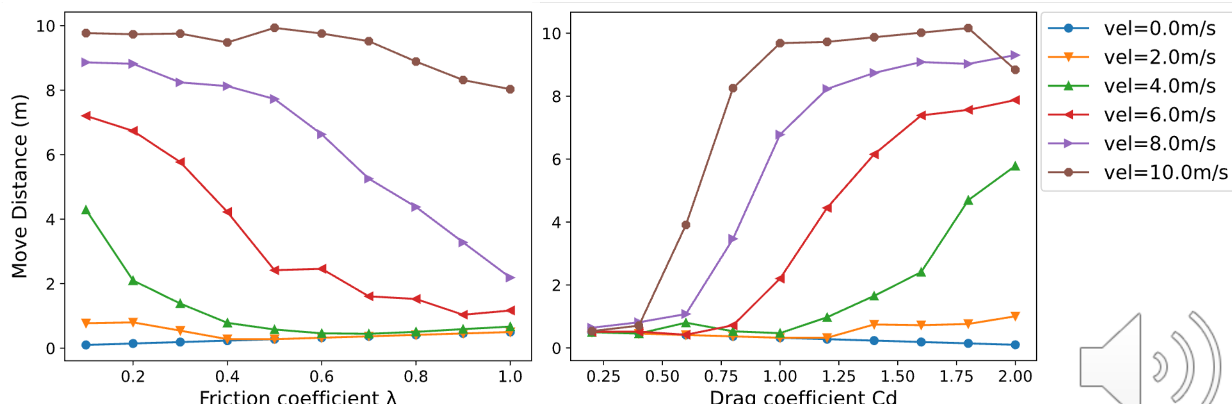






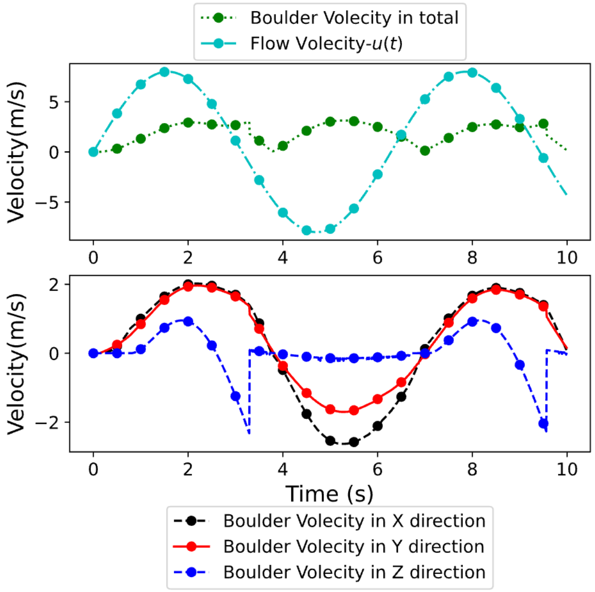
Boulder transport parameter study

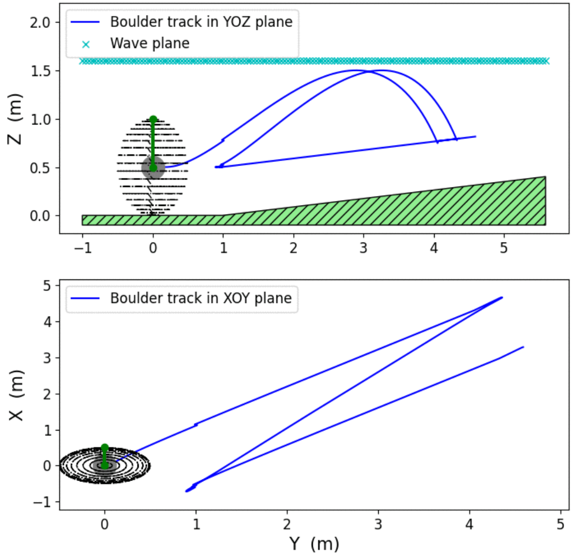


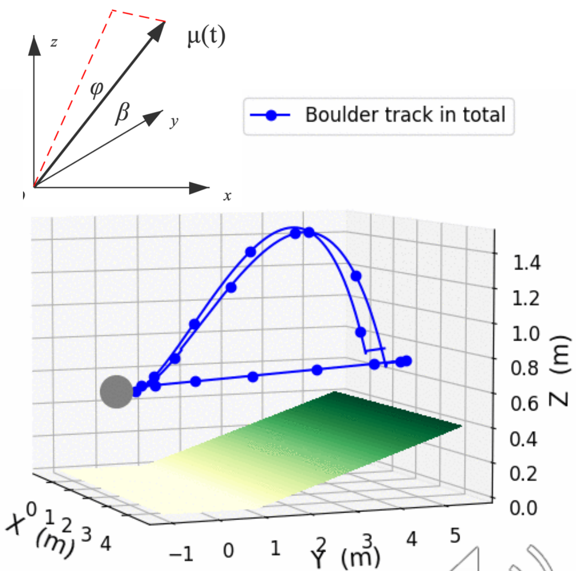


4. Boulder movement in 3D mode

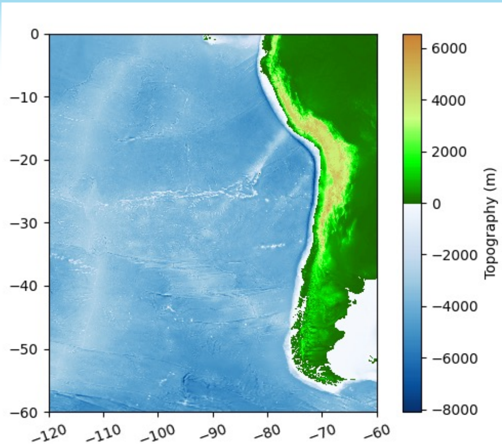
Boulder diameter—d (m)	1.0	Slope angle—α (°)	5	Impulsive coefficient—k	0.5
Boulder density—ρ_s (Kg/m^3)	2500	Fluid direction angle—φ/β (°)	**45/45**	Water depth—h (m)	1.6
Water density—ρ_s (Kg/m^3)	1030	Friction coefficient—λ	0.5	Flow velocity—$u(t)$ (m/s)	**4*sin(t)**
Drag coefficient—C_d	1.0	Froude number—$u_0/(gh)^{0.5}$	0~1	Flow acceleration—$a(t)$ (m/s^2)	**4*cos(t)**

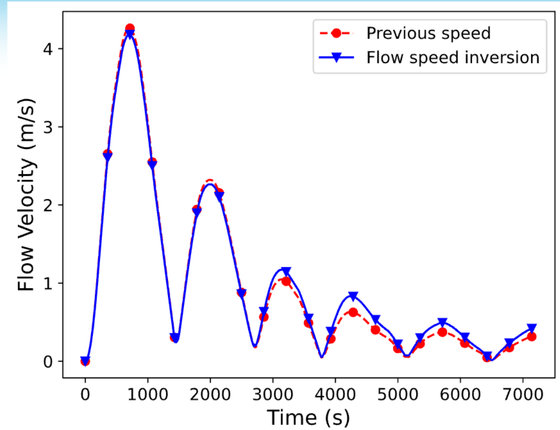


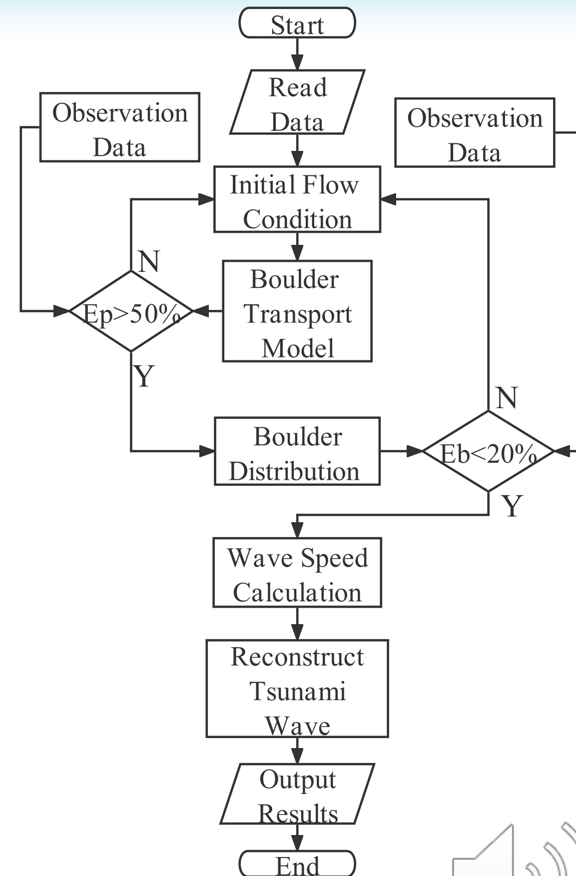


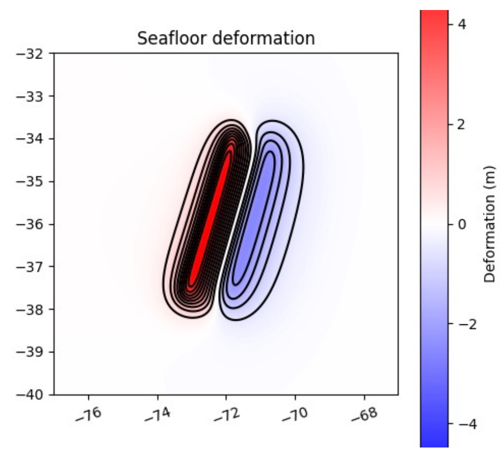


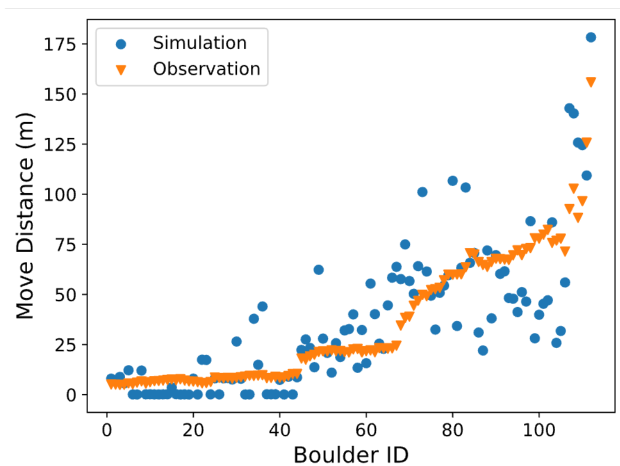
5. Validation and inversion in field observation data











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5. Validation and inversion in field observation data

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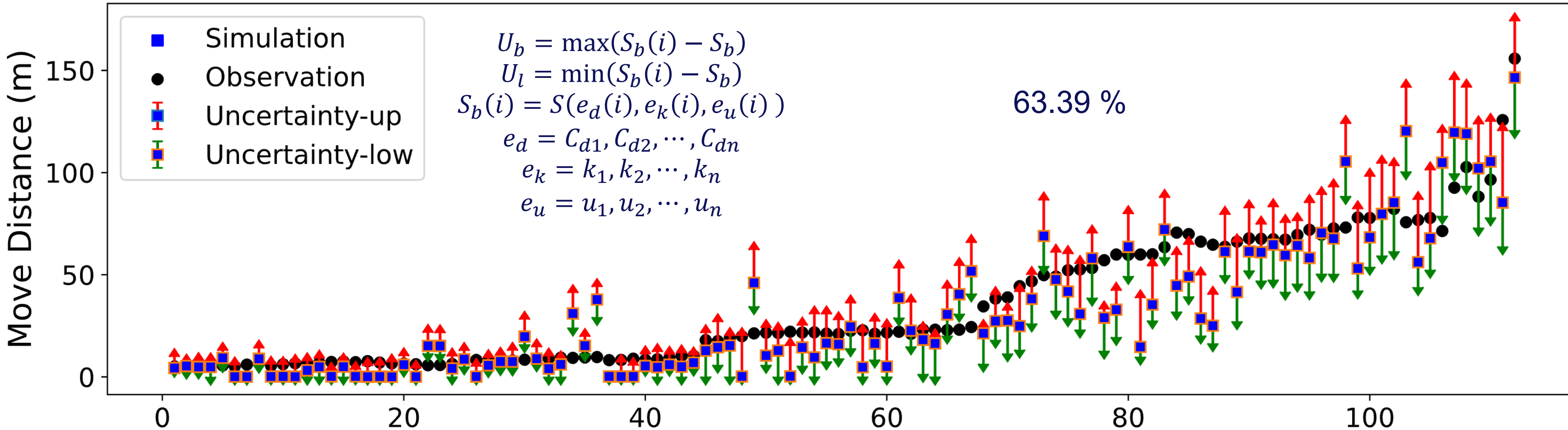

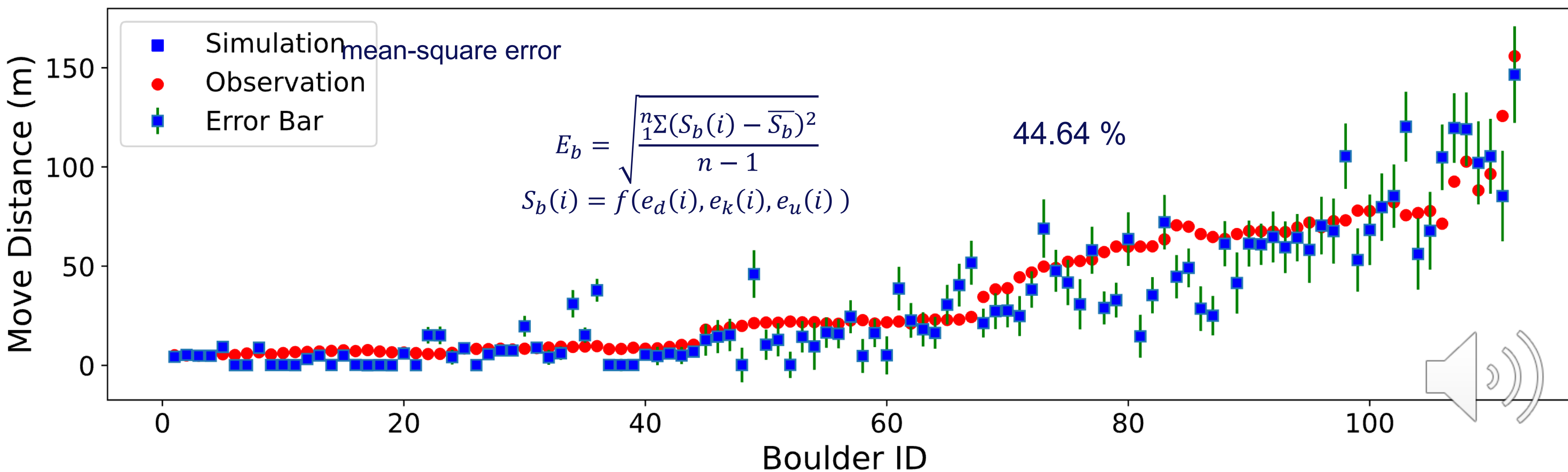

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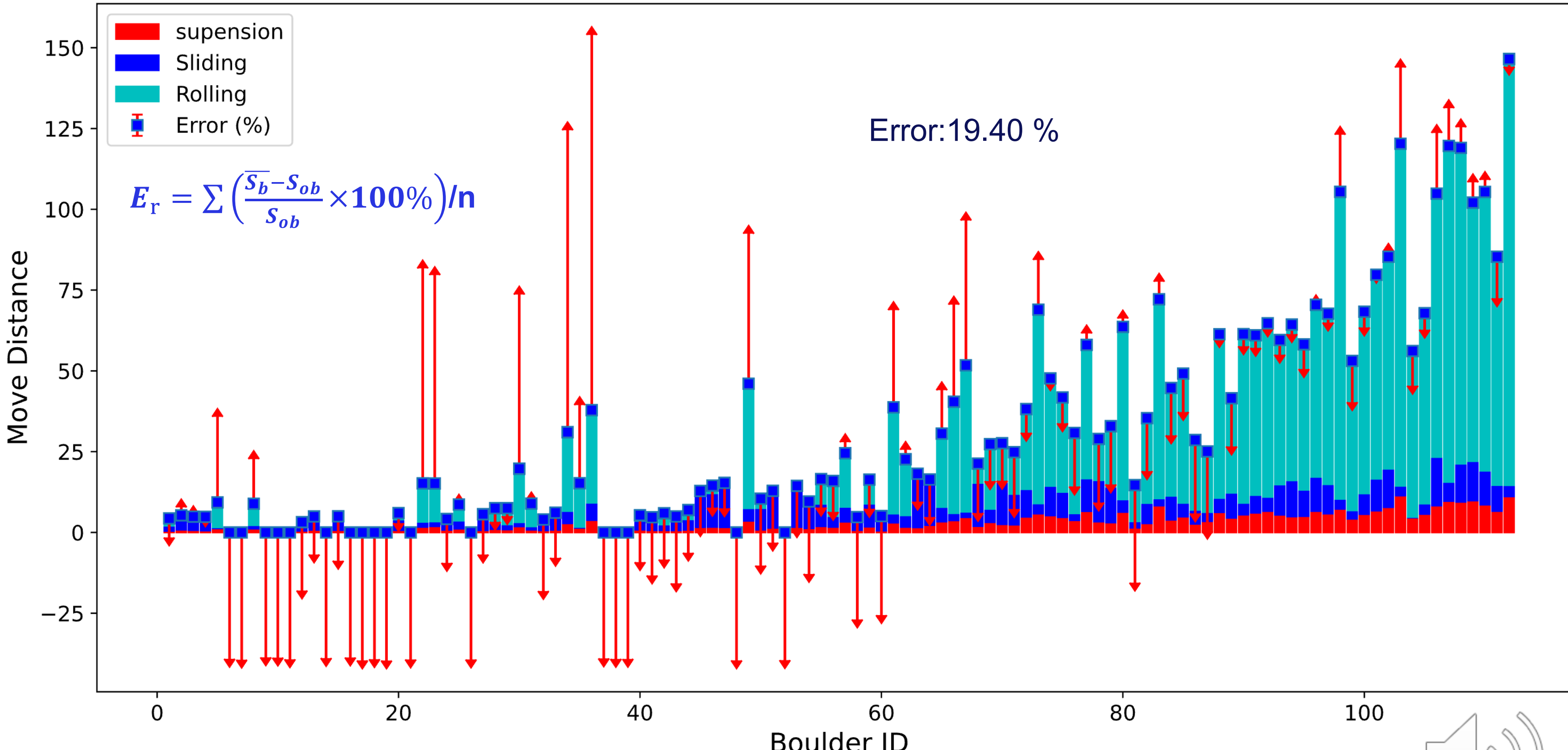

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