TÉCNICO LISBOA

SedNet2013

Mathematical modelling of transport of coal stockpiles by tsunami at Sines port

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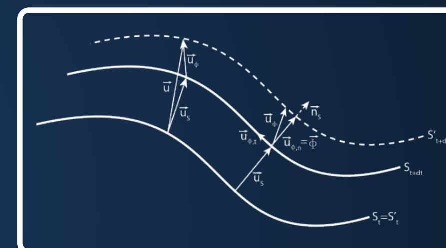
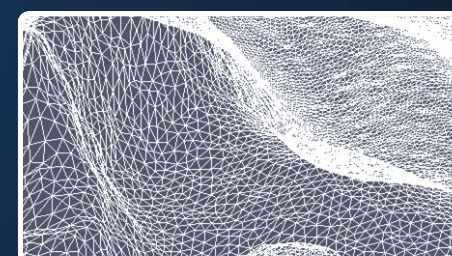
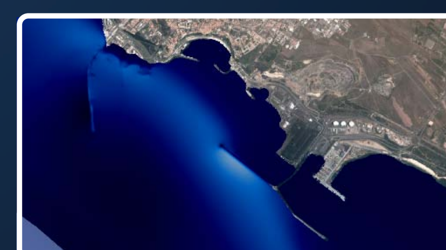
- Lagrangian-Eulerian coupling
- Smoothed-Particle Hydrodynamics



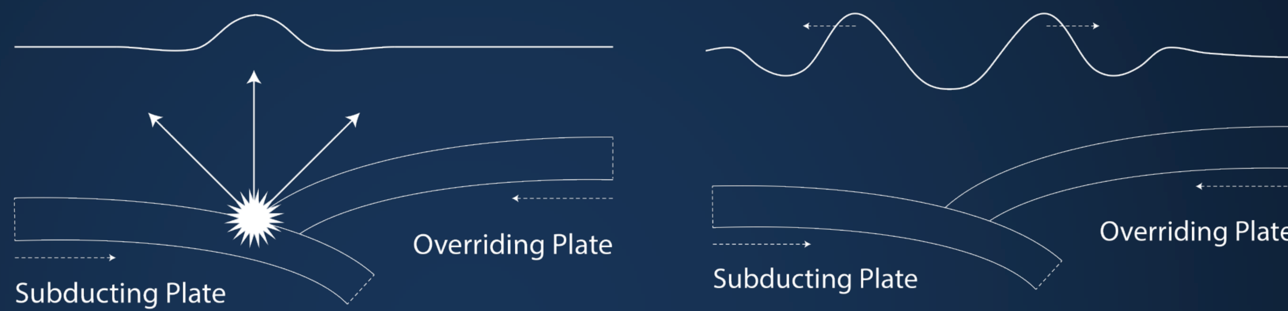




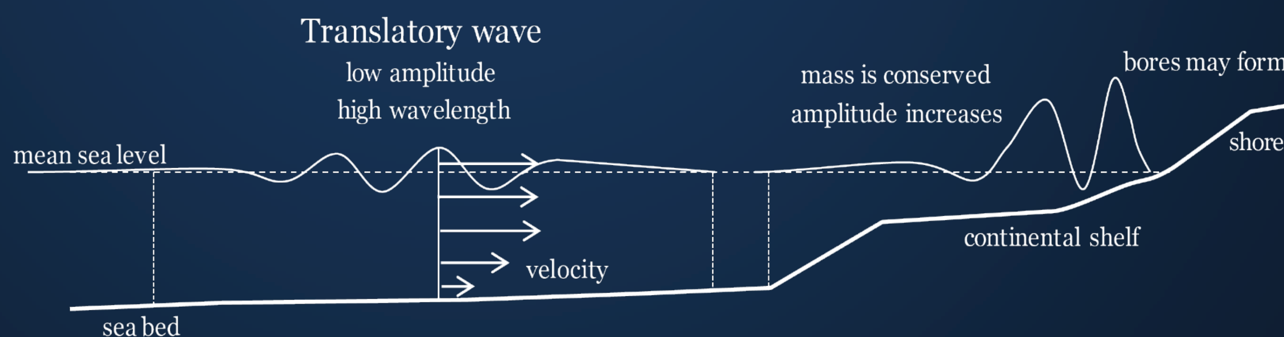
- **Introduction**
- STAV2D Model
- Results
- Conclusions
- Future Developments

What is a tsunami?

Generation mechanism



Propagation and inundation



The Port of Sines

- **Open deep-sea port located in Sines, 150Km south of Lisbon.**
  - Began operating in 1978
  - 75 M€ investment over the last 10 years
  - Future plans for further expansion

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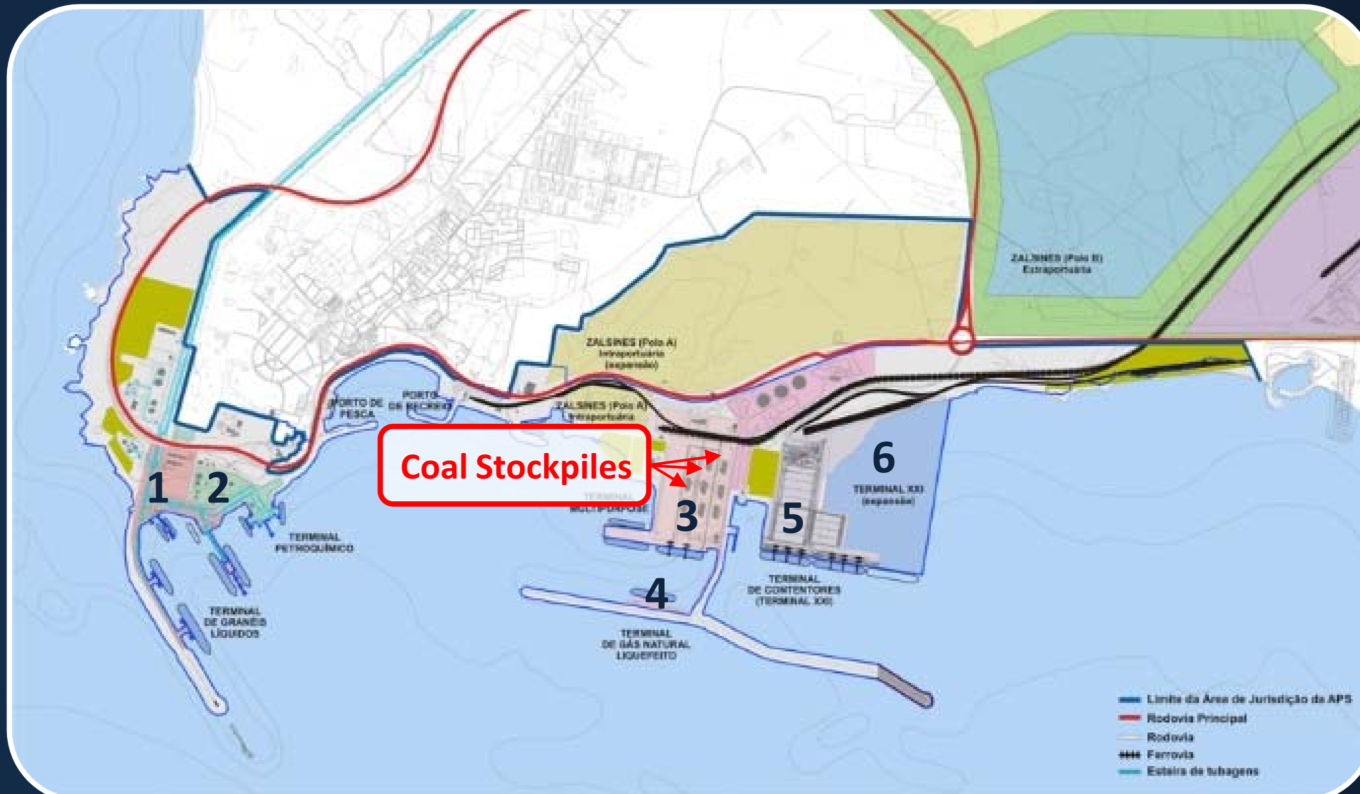
The Port of Sines

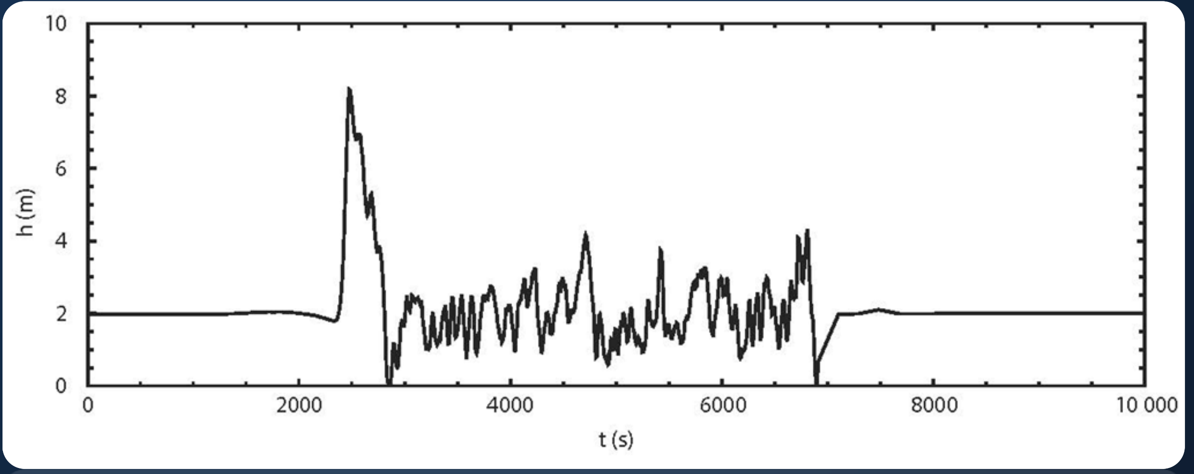


1 - Liquid Bulk Terminal
2 - Petrochemical Terminal
3 - Multipurpose Terminal
4 - Liquified Natural Gas Terminal
5 - Container Terminal (Terminal XXI)
6 - Container Terminal Expansion

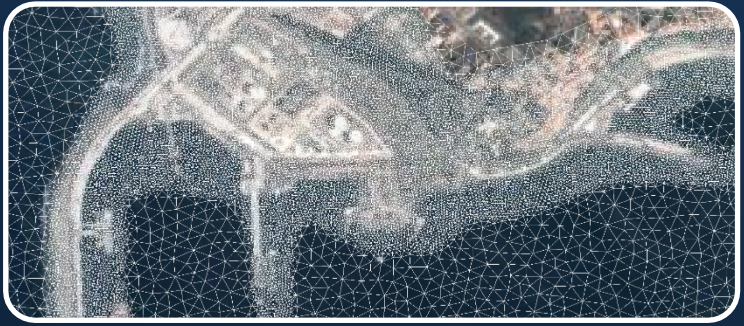
Initial and Boundary Conditions

- **High-tide scenario, approximately 2.0 m above mean sea level.**

- **Tsunami wave configuration similar to the one that struck Lisbon on the 1st November 1755.**
  - First wave measuring nearly 6 m above mean sea level



Mesh generation and refinement



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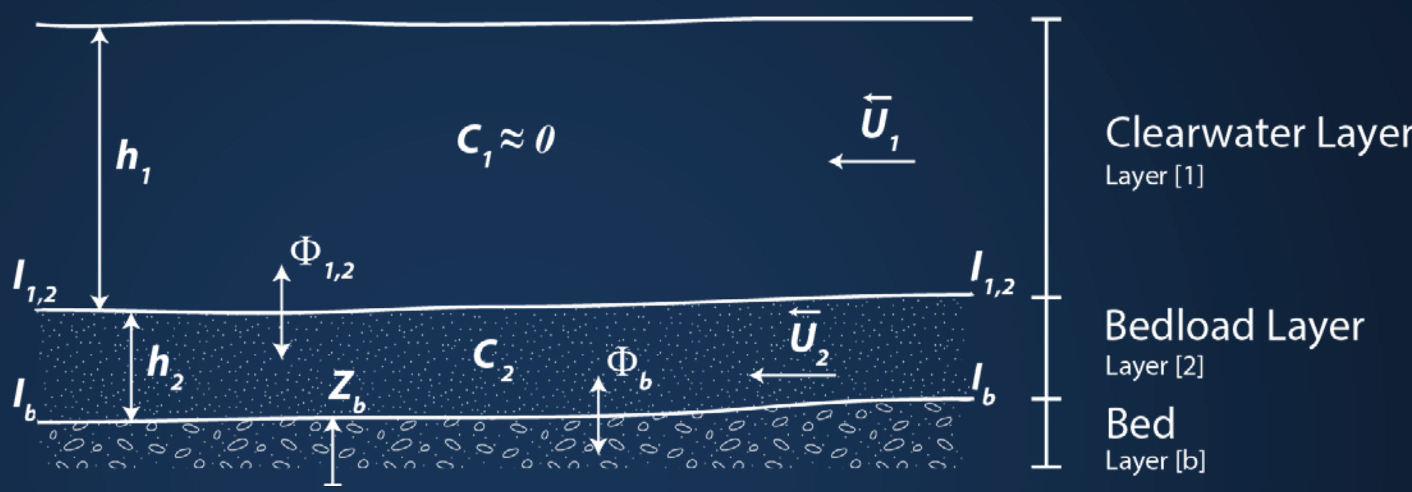
Conceptual Model



- **Clearwater Layer**
  - Negligible solid transport
- **Bedload Layer**
  - High concentration of solid material
  - Non-Newtonian rheological behavior

References: Ferreira (2005); Ferreira (2009); Canelas (2013) and Conde (2013)

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STAV2D Model

Results

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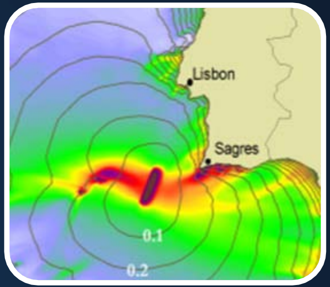
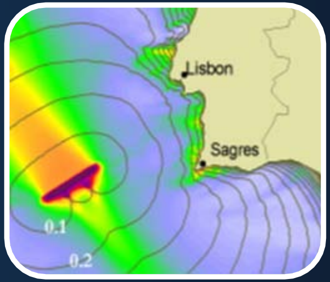
Modelled scenarios

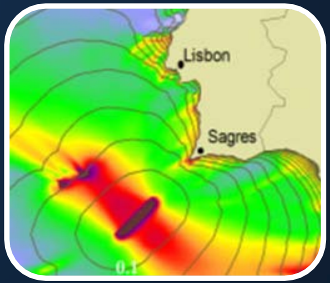
- **Tsunami propagating from Southwest**
  - Tsunami generated in the Marquês de Pombal fault.



- **Tsunami propagating from West**
  - Tsunami generated in the Gorringe bank.



- **Worst case scenario**
  - Tsunami generated in the Horseshoe and São Vicente faults.



Tsunami propagating from Southwest (SW)

Possible tsunami source: Marquês de Pombal fault

Tsunami propagating from Southwest (SW)

Possible tsunami source: Marquês de Pombal fault

Tsunami propagating from West (W)

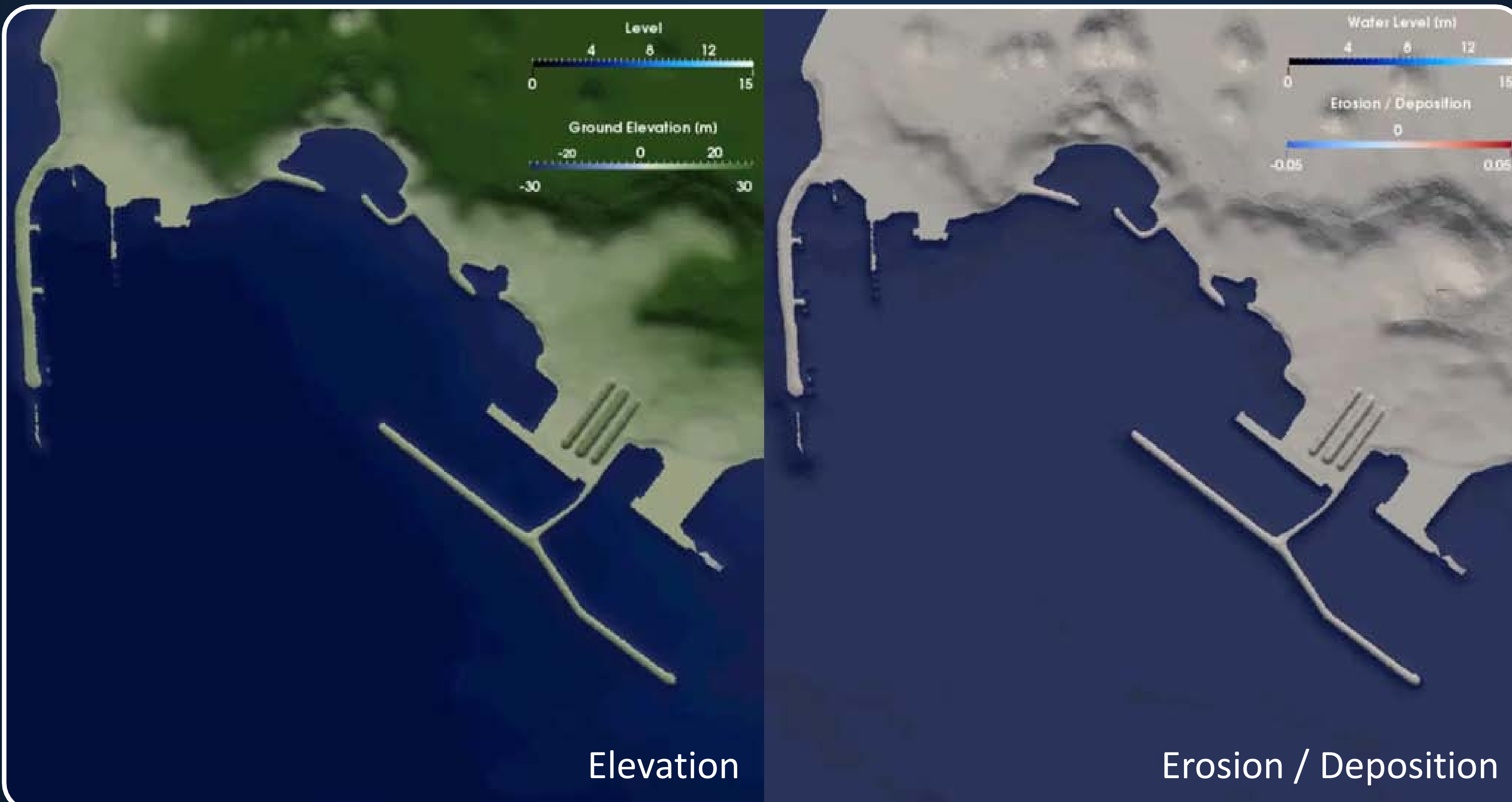
Possible tsunami source: Gorringe bank fault

Tsunami propagating from West (W)

Possible tsunami source: Gorringe bank fault

Worst case scenario (SW and S)

Possible tsunami source: Combination of Horseshoe thrust fault and São Vicente fault



Worst case scenario (SW and S)

Possible tsunami source: Combination of Horseshoe thrust fault and São Vicente fault

Conclusions

- **Regarding the inundation extent, all terminals are severely affected in all modelled scenarios.**

- **Coal is expected to be transported inland; this will cause economical losses and may cause negative environmental impacts.**

- **The drawdown stage will drive coal to the ocean, where it may be transported by oceanic currents (not modelled) or form underwater deposits.**

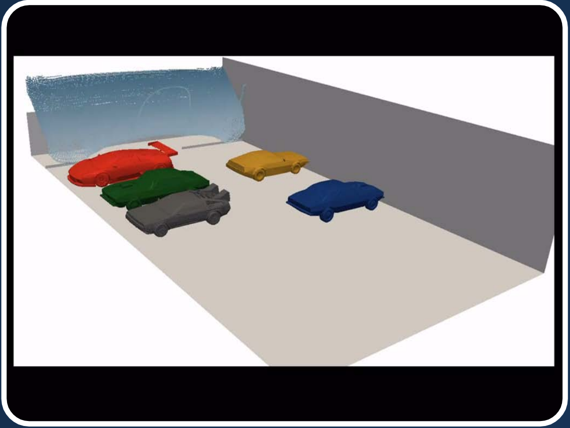
Future Developments

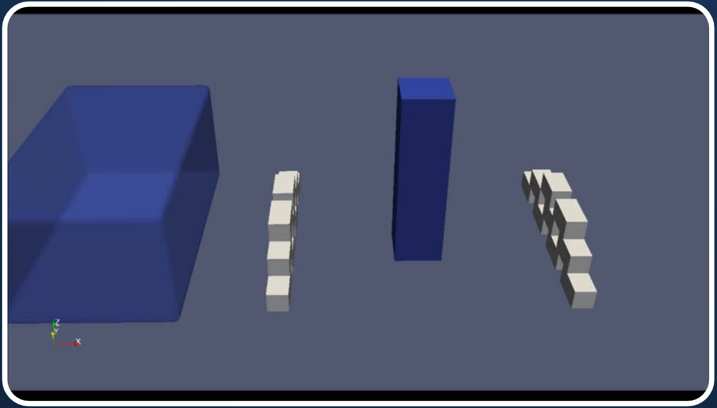
- **Lagrangian-Eulerian Coupling**

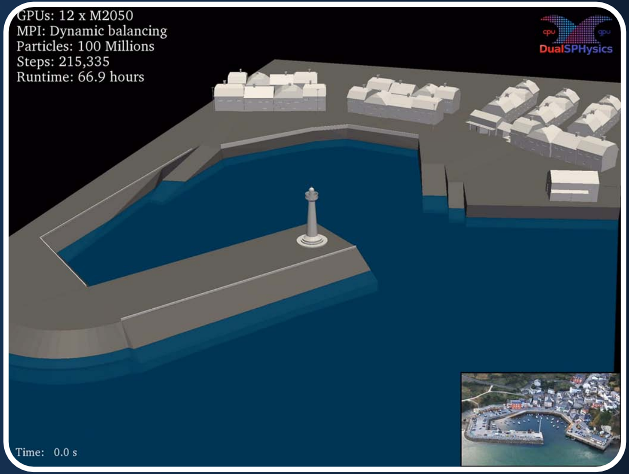
  Simulating container transport at Terminal XXI

Future Developments

- **Smoothed-Particle Hydrodynamics with solid-fluid interactions**







Thank you!

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Conservation Laws

- **Conservation of total mass**

$$\frac{\partial}{\partial t}[\rho_L h_L]+\frac{\partial}{\partial x}[\rho_L U_L h_L]+\frac{\partial}{\partial y}[\rho_L V_L h_L]=\Phi_{L_u}\ \rho|_{z=L_u} - \Phi_{L_l}\ \rho|_{z=L_l}$$

- **Conservation of momentum**

$$\frac{\partial}{\partial t}\left[\rho_L U_{i_L} h_L\right]+\frac{\partial}{\partial x_j}\left[\rho_L U_{i_L} U_{j_L} h_L\right]+\Phi_{L_l}\left[\rho u_i\right]|_{z=L_l} - \Phi_{L_u}\left[\rho u_i\right]|_{z=L_u} =$$

$$-\frac{\partial}{\partial x_i}P_L - \frac{\partial L_l}{\partial x_i}p|_{z=L_l} + \frac{\partial L_u}{\partial x_i}p|_{z=L_u} + \frac{\partial}{\partial x_j}T_{L_{ij}}h_L + \frac{\partial L_l}{\partial x_j}\tau_{ij}|_{z=L_l} - \frac{\partial L_u}{\partial x_j}\tau_{ij}|_{z=L_u}$$

- **Conservation of bedload solid mass**

$$\frac{\partial}{\partial t}[C_L h_L]+\frac{\partial}{\partial x}[C_L U_L h_L]+\frac{\partial}{\partial y}[C_L V_L h_L]=C_L\ \Phi_{L_u}\frac{\rho}{\rho_s}|_{z=L_u} - C_L\ \Phi_{L_l}\frac{\rho}{\rho_s}|_{z=L_l}$$

- **Conservation of mobile bed solid mass**

$$\frac{\partial}{\partial t}Z_b = -\frac{C_{Z_b}\ \Phi_{Z_b}\ \rho|_{z=Z_b}}{(1-p)}$$

Closure Equations

- **Bedload layer dynamics (Ferreira, 2005)**

$$\frac{h_2}{d_s} = m_1 + m_2\,\theta \qquad U_2 = U_1 \left(\frac{h_2}{h_1}\right)^{1/6}$$

- **Flow resistance**

$$\tau_{b_i} = C_f\,\rho \,\| \vec{u} \|\, u_i \qquad C_f = \frac{g h^{1/3}}{K_s^2} \qquad C_f = \frac{\| \vec{u} \|\, d_s}{h \omega_s}$$

$$\tau_i = \tau_y + \mu \frac{\partial u_i}{\partial z} + \rho d_s^2 c_f \left(\frac{\partial u_i}{\partial z}\right)$$

$$T_{ij} = \rho \nu_T \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)$$

- **Bed morphology**

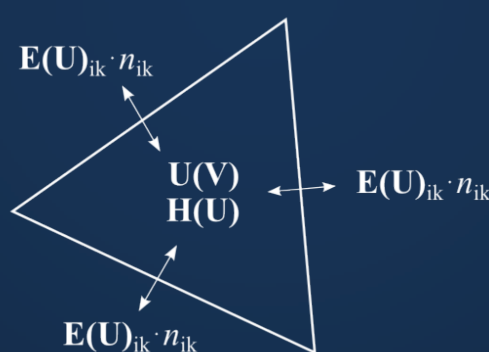
$$\frac{\partial Z_b}{\partial t} = \frac{q_s - q_s^*}{\Lambda}(1-p)^{-1}$$

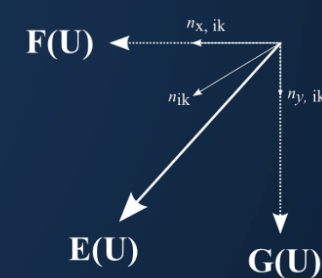
Discretization Scheme

- **Finite Volume Method**

$$\partial_t \mathbf{U}(\mathbf{V}) + \partial_x \mathbf{F}(\mathbf{U}) + \partial_y \mathbf{G}(\mathbf{U}) = \mathbf{H}(\mathbf{U})$$

$$\partial_t \int_{\Omega_i} \mathbf{U}(\mathbf{V})dS + \oint_{\Gamma_i} \mathbf{E}(\mathbf{U})\cdot\mathbf{n}dl = \int_{\Omega_i} \mathbf{H}(\mathbf{U})dS \qquad \mathbf{E}\cdot\mathbf{n} = \mathbf{F}\, n_x + \mathbf{G}\, n_y$$





$$\partial_t A_i \langle \mathbf{U}_i \rangle + \sum_{k=1}^{N} L_k \langle \mathbf{E}\cdot n \rangle_{ik} = A_i \langle \mathbf{H}_i \rangle$$