A Lagrangian Model for Microplastics Transport in Rivers

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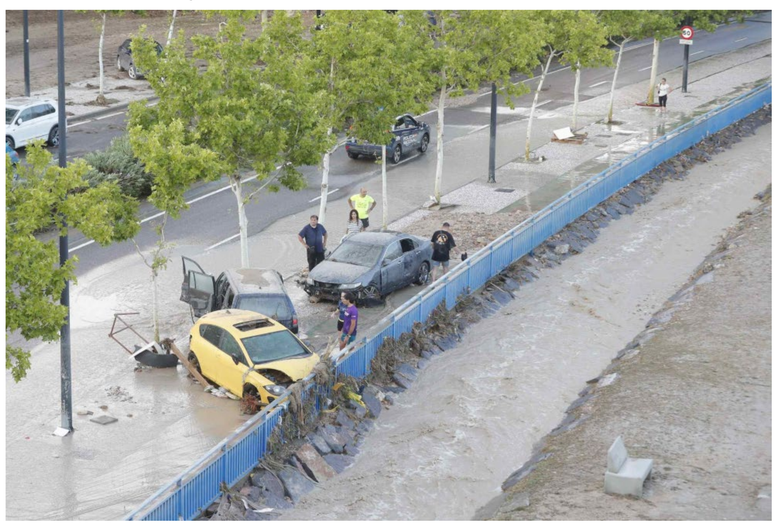
ABSTRACT. Natural geophysical flows, such as those caused by floods, often involve complex multi-physics models. In addition, the **release of pollutants such as plastics, microplastics or pesticides in rivers** is an environmental hazard and therefore, a tool capable of predicting their temporal and spatial evolution is needed. **The purpose of this work is to develop a mathematical model to simulate debris transport in rivers**. This model is implemented in the SERGHEI framework [1], **aiming to create an open-source, high-performance computing (HPC) modeling tool for surface hydrodynamics**.

MOTIVATION. **Floods**, either due to rising river levels or extreme rainfall, **are occurring more frequently and causing a greater number of damages** [2]. In addition, **environmental catastrophes** due to the **dumping of plastics** into rivers and seas is a daily occurrence, such as the recent one off the Spanish coast of the Galicia region. Thus, the development of a debris transport model that can predict how large objects move and how the flow evolves, is something that solves the current problems of our society.



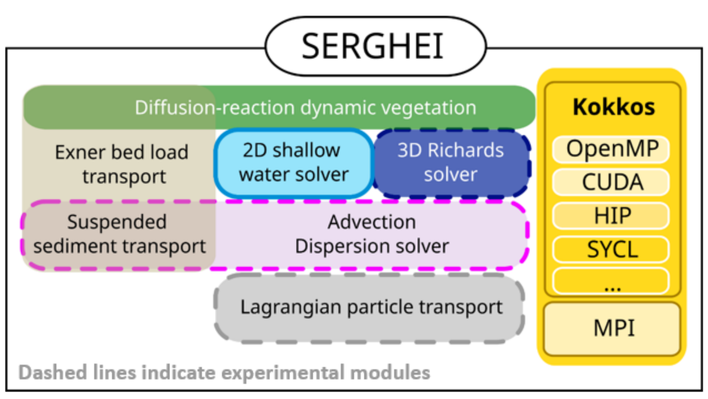
July 2023. Zaragoza, Spain. [Source: Heraldo]

September 2023. Makrinitsa, Greece. [Source: France24]

Discharge of plastics. Dic 2023, Spain. [Source: Arousa]

SERGHEI FRAMEWORK.

SERGHEI is an **open-source** project, implemented using **MPI** and **Kokkos**, being an **accurate** and **performance-portable** tool for flood forecasting [1].



Modules in SERGHEI.

CURRENT MODEL. Passive particle-tracking: without interactions between them, with a negligible mass/volume, and adding a turbulence term [3], buoyancy/deposition and degradation:

$$\mathbf{r}_\mathbf{p}^{n+1} = \begin{cases} x_\mathbf{p}^{n+1} = x_\mathbf{p}^n + u_i^n \Delta t^n + R_{\mathbf{p},x}^n \left(2\sigma^{-1} K_{h,x}^n \Delta t^n\right)^{1/2} \\ y_\mathbf{p}^{n+1} = y_\mathbf{p}^n + v_i^n \Delta t^n + R_{\mathbf{p},y}^n \left(2\sigma^{-1} K_{h,y}^n \Delta t^n\right)^{1/2} \\ z_\mathbf{p}^{n+1} = z_p^n + R_{\mathbf{p},z}^n (2\sigma^{-1} K_v^n \Delta t^n)^{1/2} - \omega_s^n \Delta t^n \end{cases}$$

where:

BUOYANCY/DEPOSITION

$$\omega_s^n = \begin{cases} \dfrac{\pi}{2\nu} \dfrac{g(\rho_p - \rho_w)}{\rho_w} \dfrac{D^n L^n}{55.238 L^n + 12.691} & \textbf{CYLINDER} \\ \dfrac{\nu}{D^n} d_*^{n3} \left(38.1 + 0.93 d_*^{n12/7}\right)^{-7/8} \text{ with } d_*^n = D^n \left(g \dfrac{(\rho_p - \rho_w)}{\rho_w \nu^2}\right)^{1/3} & \textbf{SPHERE} \end{cases}$$

TURBULENCE

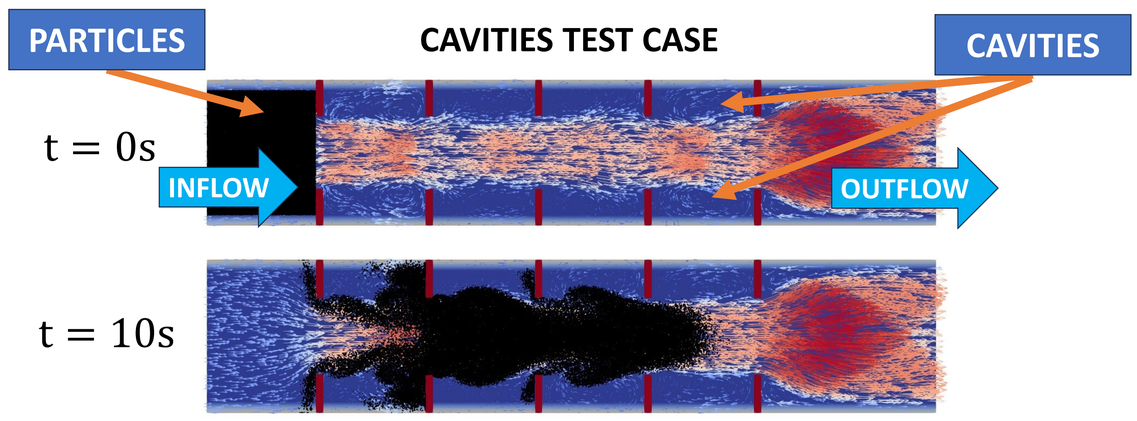
$$K_{h,x}^n = \epsilon_L h_i^n |u_i^{*n}|, \quad K_{h,y}^n = \epsilon_T h_i^n |u_i^{*n}|, \quad K_v^n = 0.0067 h_i^n |u_i^{*n}|,$$

$$\text{with } |u_i^{*n}| = n_i \sqrt{g \frac{u_i^{n2} + v_i^{n2}}{h_i^{n1/3}}}$$

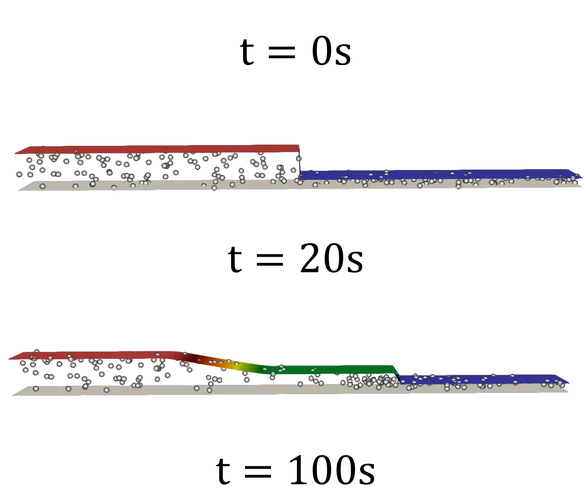
DEGRADATION

$$D^n = D_0 \left(1 - \frac{\alpha_D (t^n - t_{0D})}{100}\right), \; L^n = L_0 \left(1 - \frac{\alpha_L (t^n - t_{0D})}{100}\right)$$

VALIDATION (IN PROGRESS). The current model has been validated by simulating **experimental test cases** and **real events**.



DAMBREAK TEST CASE



EXPERIMENTAL SETUP

CONCLUSIONS AND FUTURE WORK. The results provide valuable information about how small objects are transported by the flow, leading to the conclusion that the model implemented can be combined with the SERGHEI framework as a tool for environmental risk prediction. However, **more experiments should be sought/performed to further validate the model**, so that it can be corrected and improved. **Future work** is planned to **extend the model to large debris**, such as cars, waste containers or boulders.

References

[1] Caviedes-Voullième, D., Morales-Hernández, M., Norman, M.R., & Özgen-Xian, I. (2023). SERGHEI (SERGHEI-SWE) v1.0: a performance-portable high-performance parallel-computing shallow-water solver for hydrology and environmental hydraulics. *Geosci.Model Dev.*, **16(3)**, 977-1008.

[2] Ripple, W.J., Wolf, C., Newsome, T.M., Barnard, P., & Moomaw, W.R. (2020). World Scientists' Warning of a Climate Emergency. *BioScience*, **70**, 8–12.

[3] Jalón-Rojas, I., Wang, X.H., & Fredj, E. (2019). A 3D numerical model to Track Marine Plastic Debris (TrackMPD): Sensitivity of microplastic trajectories and fates to particle dynamical properties and physical processes. *Mar. Pollut. Bull.*, **141**, 256-272.