GPU-accelerated 2D sediment transport model for hyper-turbid events in partially mixed estuaries

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Resumen

Esturies are coastal environments modelling those environments is very important and requires numerous large scale and time data because of all the different parameters they imply. For this reason, a GPU based model representing the evolution of the water fluxes and sediment and solute fluxes has been tested using data from Guadalquivir estuary located to the southern part of Spain.

GPU base estuary models

Estuaries are highly complex environmental systems where freshwater from rivers meets salty ocean water. Part of the coastal environment, its hydrodynamic is reaged by tidal variations, and river discharge. River discharge is the main source of sediment particles in the estuary. Sediment transport within the estuary is a crucial process to consider when modeling hydrodynamic fluxes, as it plays a key role in various physical, morphological, biological, and chemical processes (Chapman and Wang, 2000).

Model description

A scalar transport model for Earth surface flows combining the two-dimensional Shallow Water Equations (SWE-2D) with the 2D advective-diffusive transport equation for suspended sediments was implemented in C++/CUDA for an existing SWE-2D model. The advective sediment transport is coupled with the 2D hydrodynamic fluxes (Martinez-Aranda et al., 2023), ensuring mass conservation and well-balance behaviour of the numerical scheme, while the turbulent diffusion contribution was discretized following the anisotropic model (Morales-Hernandez et al., 2018).

Equation 1. Sediment Transport Equation

$$\frac{\partial h\phi}{\partial t}+\frac{\partial hu\phi}{\partial x}+\frac{\partial hv\phi}{\partial y}=(Db-Eb)+\frac{\partial}{\partial x}\left(K_x h\frac{\partial \phi}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_y h\frac{\partial \phi}{\partial y}\right)$$

with h the flow depth, ϕ the sediment concentration, u and v the x and y component of the velocity, Db the sediment deposition on the estuary bed, Eb the sediment eroded from the estuary bed and, K_x and K_y the diffusion coefficient in x and y.

Guadalquivir Estuary

The model was tested using data from Guadalquivir estuary located in the the southwestern part of the Iberian Peninsula (figure 1). Its mouth is situated at Sanlúcar de Barrameda, extending inland to the Alcalá del Río dam, and it flows into the Gulf of Cádiz (Atlantic Ocean). More than being a large-scale estuary as needed for our model, the Guadalquivir has seasonals hyper- turbids events, cracterized by a large sediment plume going out of the mouth of the estuary (Megina et al., 2023). Its visibility on satellite images coupled by the numerous data available on the estuary make Guadalquivir a good test case for our model. The main parameters needed for the model were:

- River discharge of Guadalquivir in m3/s (station of Sevilla).
- Astronomical Tide from a Tide Gauge located at the mouth of the estuary.
- Initial concentrations of sediment along the estuary in mg/L.

The initial concentrations of sediments along the estuary are taken used satellite imagery treatment. The NDSSI indices (calculated with blue and infrared bands from Santinel2A: (B2-B8)/(B2+B8)) is extracted from the images and permited to get an estimation of the Suspended Sediment Concentration (SSC) (figure 2).

Results

The model successfully approximated the sediment plume. However, the simulated concentration is lower than observed in the real data and shows significant numerical diffusion, the overall shape of the plume is well captured. The computational

performance of the model was also evaluated (Table 1). The model simulates 24 hours of data in approximately 12 minutes, and 5 days in about 70 minutes.

Table 2. Computation time of the model every 24h data

	Computation Time in minutes
23/12/2019	12min 39s
24/12/2019	12min 46s
25/12/2019	12min 30s
26/12/2019	12min 31s
27/12/2019	12min 45s
28/12/2019	12min 33s
Total	75min 28s
Mean Value	12min 54s

Conclusiones

The proposed model was validated using satellite imagery and hydrodynamic data from the Guadalquivir Estuary, showing a good representation of sediment plumes and hydrodynamic associated with hyper-turbids events. Daily simulations were completed in approximately 12 minutes, highlighting the computational efficiency improvement thanks to GPU-based implementation. Future developments will include the incorporation of erosion and deposition processes (bed level variations), as well as a vertical multilayer transport scheme for solutes and sediments to simulate concentration dynamics within the water column.

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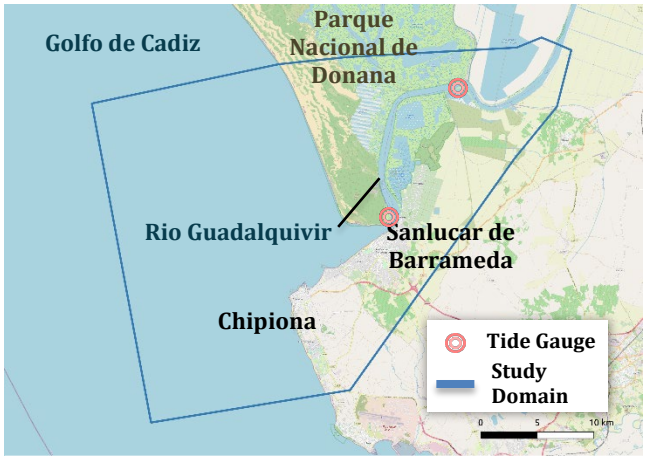

Fig. 1. Study Site (Guadalquivir Estuary). The bleu line represents the domain used for the study.

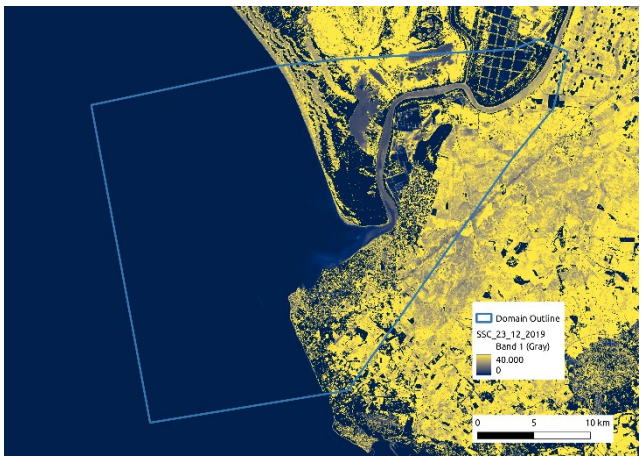

Fig. 2. SSC initial concentration. The bleu line represents the domain used for the study.