Emulating the estuarine morphological evolution using a Convolutional Neural Network

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1. Introduction

- Forecasting estuarine morphological evolution is crucial for flood management.
- This work proposes a methodology to speed up estuarine morphological evolution simulations using a deep learning based emulator, implemented in the TensorFlow framework.
- The emulator uses 2D hydrodynamics results of a physical-based numerical model as input and forecasts the erosion and sedimentation trends.
- The implemented numerical model solves the Reynolds equations applied to incompressible fluids and the transport equations that describe the motions of sediments due to water currents. Table 1 presents these equations.

$$\rho\left(\frac{\partial \hat{u}}{\partial t}+\frac{\partial \hat{u}\hat{u}}{\partial x}+\frac{\partial \hat{u}\hat{v}}{\partial y}+\frac{\partial \hat{u}\hat{w}}{\partial z}\right)=\rho F_x-\frac{\partial \hat{p}}{\partial x}+\mu\left(\frac{\partial^2 \hat{u}}{\partial x^2}+\frac{\partial^2 \hat{u}}{\partial y^2}+\frac{\partial^2 \hat{u}}{\partial z^2}\right)-\frac{1}{p}\left(\frac{\partial \overline{u'u'}}{\partial x}+\frac{\partial \overline{u'v'}}{\partial y}+\frac{\partial \overline{u'w'}}{\partial z}\right) \quad (1)$$

$$\rho\left(\frac{\partial \hat{v}}{\partial t}+\frac{\partial \hat{v}\hat{u}}{\partial x}+\frac{\partial \hat{v}\hat{v}}{\partial y}+\frac{\partial \hat{v}\hat{w}}{\partial z}\right)=\rho F_y-\frac{\partial \hat{p}}{\partial y}+\mu\left(\frac{\partial^2 \hat{v}}{\partial x^2}+\frac{\partial^2 \hat{v}}{\partial y^2}+\frac{\partial^2 \hat{v}}{\partial z^2}\right)-\frac{1}{p}\left(\frac{\partial \overline{v'u'}}{\partial x}+\frac{\partial \overline{v'v'}}{\partial y}+\frac{\partial \overline{v'w'}}{\partial z}\right) \quad (2)$$

$$\rho\left(\frac{\partial \hat{w}}{\partial t}+\frac{\partial \hat{w}\hat{u}}{\partial x}+\frac{\partial \hat{w}\hat{v}}{\partial y}+\frac{\partial \hat{w}\hat{w}}{\partial z}\right)=\rho F_z-\frac{\partial \hat{p}}{\partial z}+\mu\left(\frac{\partial^2 \hat{w}}{\partial x^2}+\frac{\partial^2 \hat{w}}{\partial y^2}+\frac{\partial^2 \hat{w}}{\partial z^2}\right)-\frac{1}{p}\left(\frac{\partial \overline{w'u'}}{\partial x}+\frac{\partial \overline{w'v'}}{\partial y}+\frac{\partial \overline{w'w'}}{\partial z}\right) \quad (3)$$

$$\frac{\partial c^{(l)}}{\partial t}+\frac{\partial u\cdot c^{(l)}}{\partial x}+\frac{\partial v\cdot c^{(l)}}{\partial y}+\frac{\partial (w-{w_s}^{(l)})\cdot c^{(l)}}{\partial z}-\frac{\partial}{\partial x}\left(\varepsilon_{s,x}^{(l)}\cdot\frac{\partial c^{(l)}}{\partial x}\right)-\frac{\partial}{\partial y}\left(\varepsilon_{s,y}^{(l)}\cdot\frac{\partial c^{(l)}}{\partial y}\right)-\frac{\partial}{\partial z}\left(\varepsilon_{s,z}^{(l)}\frac{\partial c^{(l)}}{\partial z}\right)=\mathbf{0} \quad (4)$$

Table 1: Reynolds equations in the directions *x* (1), *y* (2) and *z* (3) and sediment transport equation (4).

2. Methodology

- The estuary numerical model was implemented in the Delft3D software by Elmilady *et al.* (2022), which studied the evolution of long-term morphodynamic of a sandy channel shoal system dominated by intertidal sandy shoals, considering the effects of wind and waves.
- The emulator used a branched architecture with convolutional layers (Santhanam *et al.* 2016).

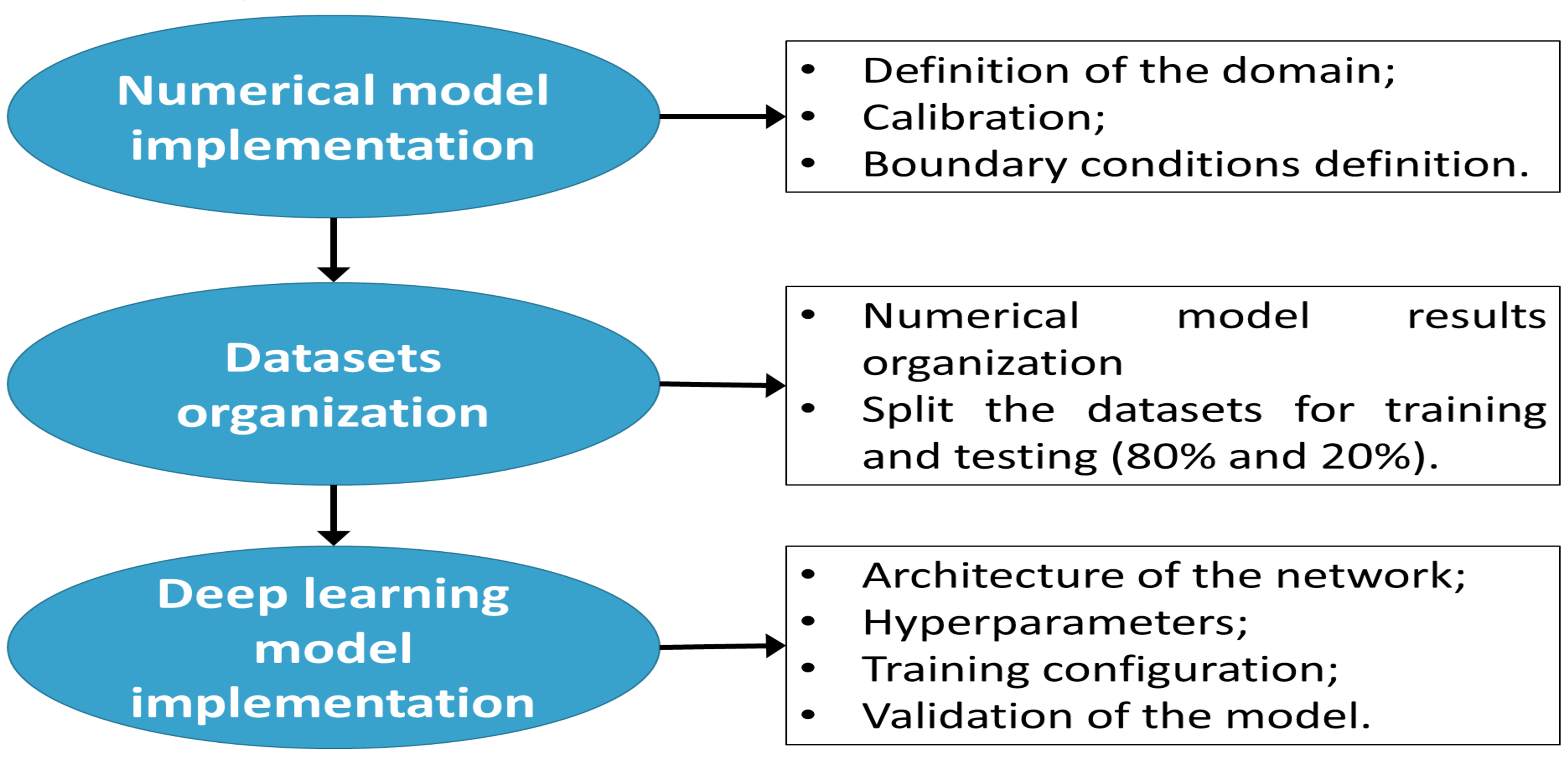

Figure 1: Methodological framework.

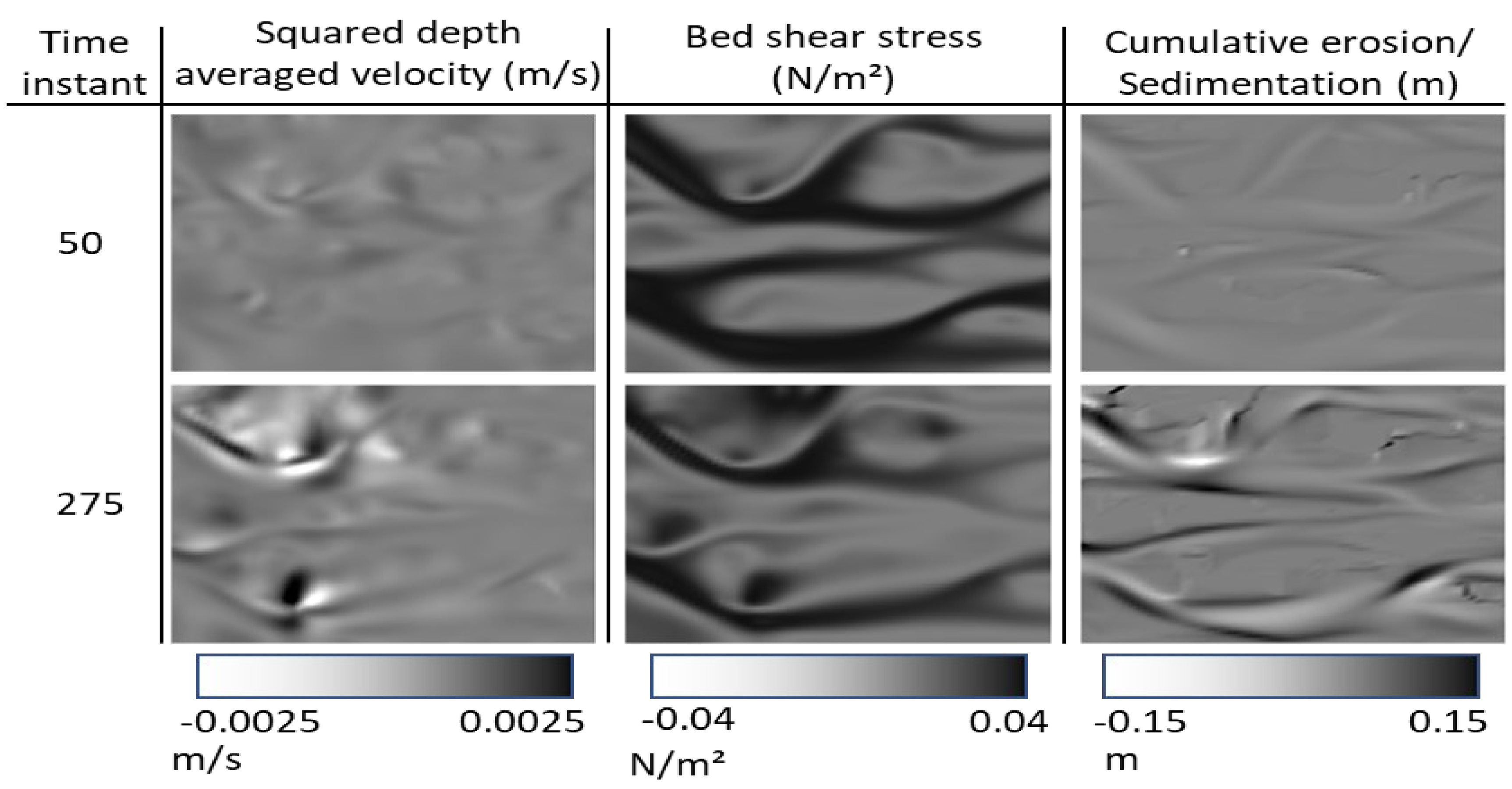

Figure 2: Examples of numerical model results used as input and output by the emulator.

3. Results

- The emulator underestimated the numerical model results (Figure 3 – b).
- The emulator was able to reproduce the morphological evolution of the main channels of the estuary (Figure 3 - c). The mean RMSE obtained was 0.58 centimetres in the testing dataset.

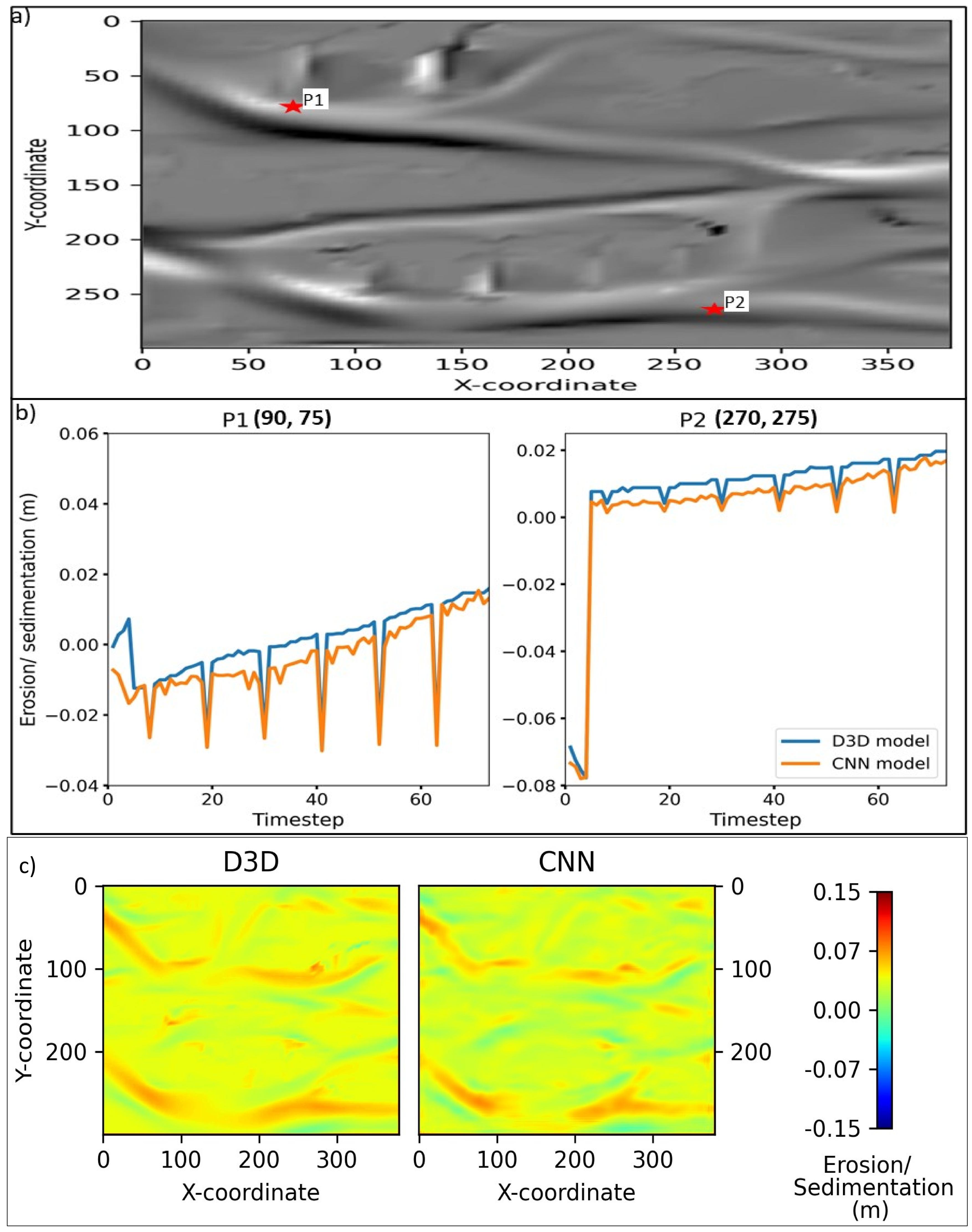

Figure 3: Comparison between the results of the numerical model and the emulator.
a) Domain of the numerical model and localization of observation points P1 and P2;
b) Results of the emulator in the points P1 and P2; c) Results comparison between the numerical model (D3D) and the emulator (CNN).

4. Conclusions

- The emulator could reproduce the morphological evolution of the main channels of the estuary, however, the results presented a noisy behaviour.
- The numerical model simulated 74.5 years in 15 hours, while the emulator needed only 5 seconds (testing dataset size).
- The performance of the emulator allows to increase the network architecture complexity in order to reduce the forecasting error.

5. References

Elmilady, H., van der Wegen, M., Roelvink, D., & van der Spek, A. (2022). Modeling the Morphodynamic Response of Estuarine Intertidal Shoals to Sea-Level Rise. *Journal of Geophysical Research: Earth Surface*, *127*(1), 1–26. https://doi.org/10.1029/2021JF006152

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