Strongly coupled 2D & 3D shallow water models

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Introduction

Most 3D shallow water (SW) models cannot handle wetting-drying (w/d), whereas there are over 10 methods for w/d in 2D SW models. We propose using 'algebraically' or 'strongly' coupled 2D-3D shallow water models to take advantage of 2D w/d techniques and avoid implementation of 3D w/d. Mass and momentum conservation across the 2D-3D interface is guaranteed by strong coupling. Preliminary results for a 2D-3D Galveston Bay test case are given.

Theory

<u>Assumptions</u>:

- Interface Location: Placed in a region governed by 2D SWE.
- Conformity: Nodes aligned vertically (as shown in Fig. 1.).

<u>Interface constraints</u>:

- Continuity in mass flux, and
- Continuity in momentum flux.

<u>Methodology</u>:

- Modify the interface trial (ϕ) & test (ψ) spaces. E.g., for node column $\{2^{2D}, 4, 5, 6\}$ in Fig. 1, set the new trial function, ϕ_2^{cpl}, as

$$\phi_2^{cpl}(\boldsymbol{x}) = \begin{cases} \phi_2^{2D}(\boldsymbol{x}), & \forall \boldsymbol{x} \in \Omega^{2D} \\ \sum_4^6 \phi_i^{3D}(\boldsymbol{x}), & \forall \boldsymbol{x} \in \Omega^{3D} \end{cases},$$

and likewise, the test function ψ_2^{cpl}.

- Conservation guaranteed.

<u>Outcome</u>:

- A single, large coupled system has to be solved each time step.

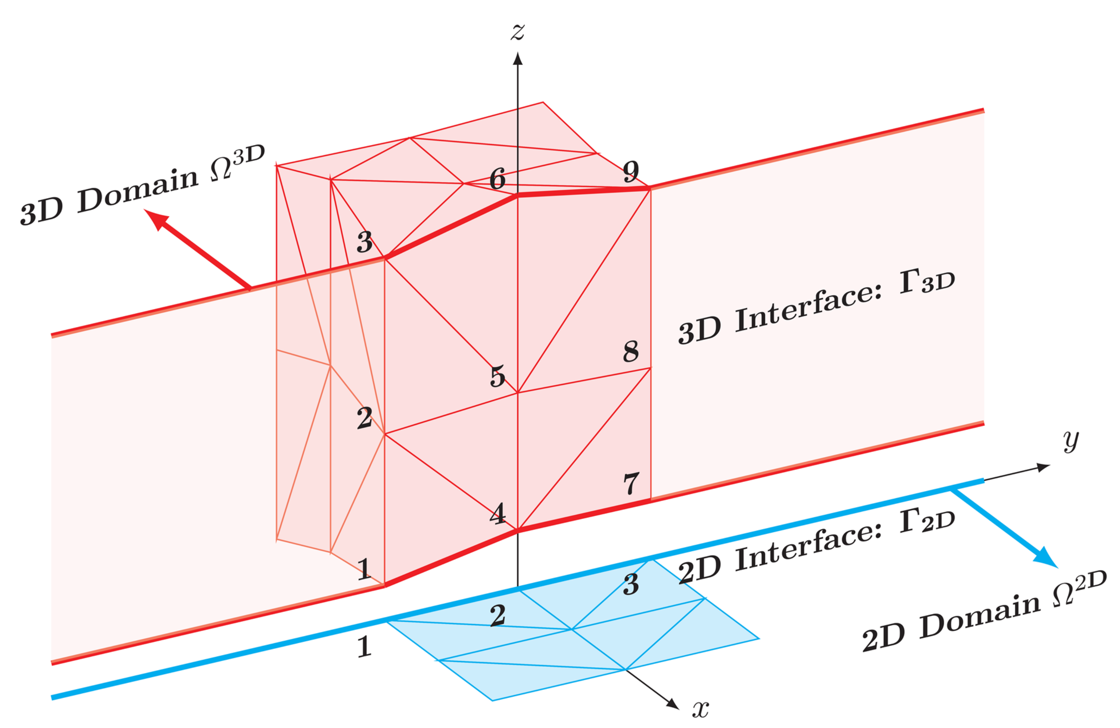

Fig. 1. Example of a coupled 2D-3D shallow water finite element model

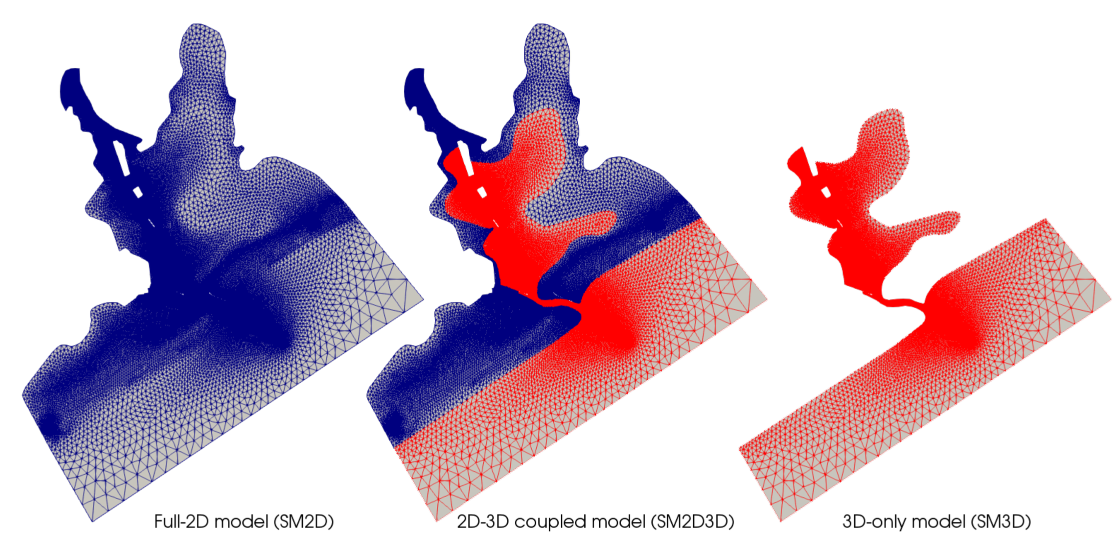

Fig. 2. Full-2D (L), 2D-3D (C), & 3D-only (R) meshes

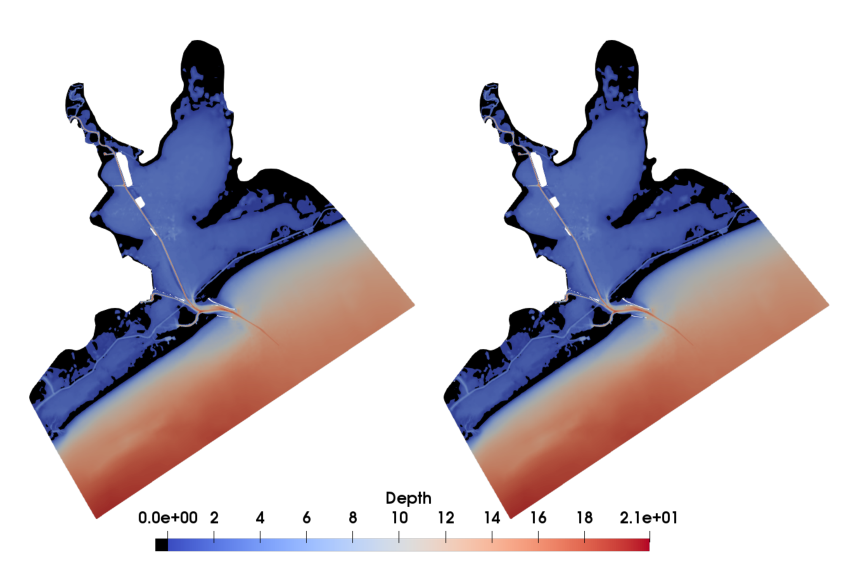

Fig. 3. Depth at time t=24 hrs.: Full-2D (L) & 2D-3D (R) models

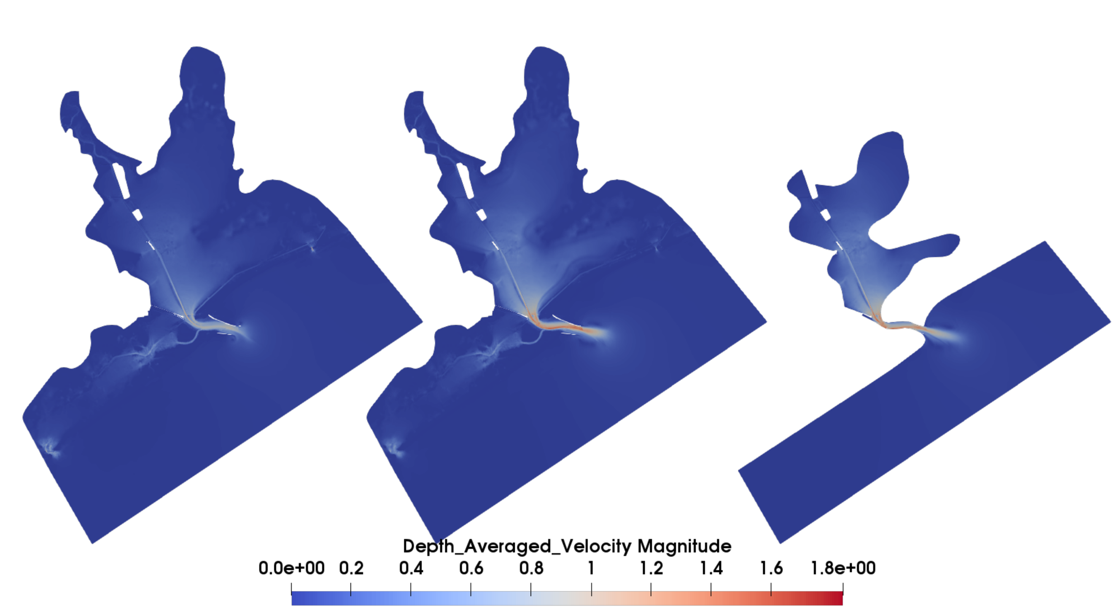

Fig. 4. Depth avg. velocity at t=24 hrs.: Full-2D (L), 2D-3D (C), & 3D-only (R) models

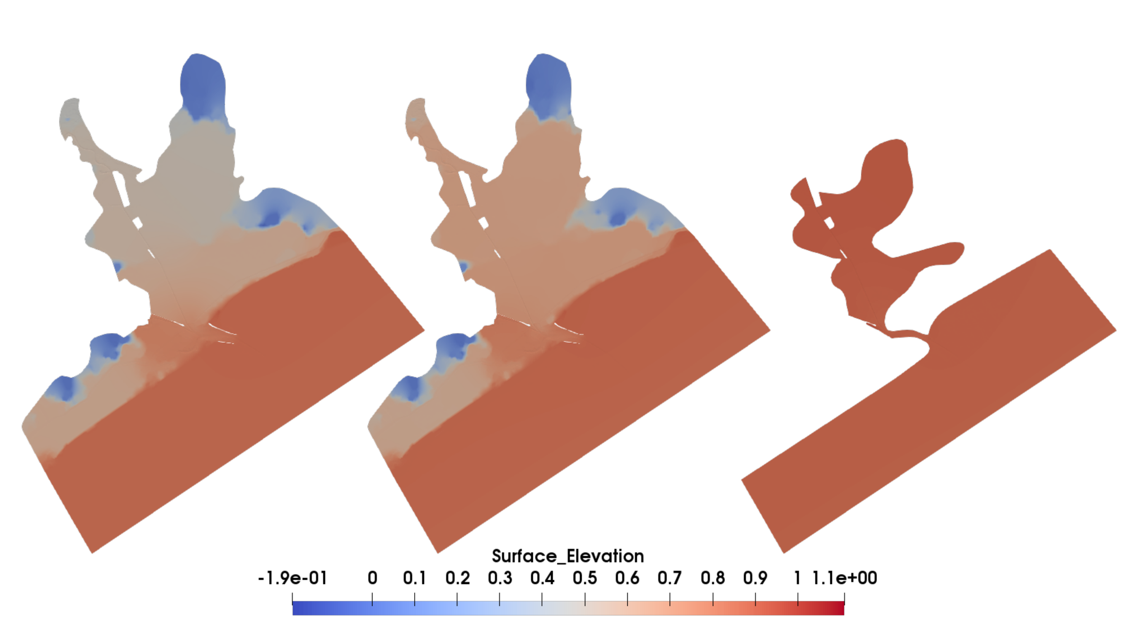

Fig. 5. Surface elevation at time t=18 hrs.: Full-2D (L), 2D-3D (C), & 3D-only (R) models

2D-3D Galveston bay case

- Neumann pressure BC with water elevation $\eta = 0.5(1 - \cos 2\pi t/T)\ [m]$, where $T = 1$ day, to simulate tides.
- No flow Neumann BCs elsewhere.
- ICs: $\eta(\boldsymbol{x}, 0) = 0$, and $\boldsymbol{u}(\boldsymbol{x}, 0) = 0$.

Results

- W/d locations and extents (Fig. 3) within full-2D and 2D-3D models agree well.
- Outflow velocity jet extent and magnitude at Texas City Channel (Fig. 4) within 2D-3D and 3D-only models matches well.
- Elevations (Fig. 5) predicted by 2D-3D model are higher in this case.

Conclusions

Strongly/algebraically coupled 2D-3D SW models are a good alternative to complex 3D w/d. Future work is to:

- Allow a velocity profile across the 2D-3D interface,
- Perform validation, convergence and parallel scaling studies, and
- Simulate 2D-3D storm surges.

Reference

Choudhary, G.K. (2017). *Algebraic coupling of 2D and 3D shallow water finite element models* (Master's report). University of Texas at Austin.

Acknowledgments

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