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

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

Interface constraints:
- Continuity in mass flux, and
- Continuity in momentum flux.

Methodology:
- Modify the interface trial ($\phi$) & test ($\psi$) spaces. E.g., for node column ($2^D$, 4, 5, 6) in Fig. 1, set the new trial function, $\phi_2^{\text{cpl}}$, as
  \[ \phi_2^{\text{cpl}}(x) = \begin{cases} \phi_2^{2D}(x), & \forall x \in \Omega^{2D} \\ \sum_{i=1}^{6} \phi_i^{3D}(x), & \forall x \in \Omega^{3D} \end{cases} \]
- and likewise, the test function $\psi_2^{\text{cpl}}$.
- Conservation guaranteed.

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

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: $\eta(x, 0) = 0$, and $u(x, 0) = 0$.

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


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