Deltares

Memo

To
People involved in the HDM software renewal

Date
6 December 2023

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Subject
SMART numerics -- propositions and conjectures, version 1.0

Reliability and Accuracy

1. Data- and solution-based insight in numerical modeling errors is indispensable for obtaining reliable simulation results by an adequate and optimal use of computational model resources, including adequate grid design and grid optimization.
2. A numerical implementation should guarantee solutions that are accurate and reliable, not solutions that are wiggle-free, monotone, positive, conservative, …. By definition, the former implies that the latter holds to a sufficiently large degree when and where applicable.
3. The accuracy of the numerical implementation of all relevant types of boundary conditions[1] must match that of the numerical implementation used inside the domain.
4. The only numerical method known to provide measurable and interpretable information about solution accuracy is an FVE discretization method in combination with physics-based and discretization-error-dependent regularization[2].

Flexibility

5. The best compromise between modeling flexibility on the one hand, and accuracy, efficiency, error insight and reliability on the other hand is obtained with an (overlapping?) non-matching block-structured grid approach using smooth curvilinear grids per block, flexible DD couplings, and an accurate cut-cell technique to handle complex-shaped boundaries.
6. Establishing sufficient flexibility requires IBM via cut-cell (MVP: forcing instead of cut-cell).
7. Irregular/unstructured grids introduce modeling flexibility at the expense of accuracy, efficiency and error insight.

Efficiency

8. The use of switches[3] in computational models (to select upwind direction, to set grid cells wet and dry, to turn on/off certain terms, …) has severe consequences for the maximum attainable efficiency.
9. Once fully developed and implemented, a fully nonlinearly implicit time integration method can yield up to O(100) times faster simulations.

see overleaf

[1] Besides ‘standard’ boundary conditions like specification of water level or flow velocity, this includes the specification of zero, partial or full wave reflection, or of zero, partial or full slip.
[2] Regularization typically consists of artificial viscosity/diffusion (compare with LES) and data smoothing.
[3] Switches also create a rather high sensitivity to round-off errors (loss of reliability).

10. Unstructured grids are less efficient because of indirect addressing, no full optimization of iterative solvers possible, and a relatively large amount of regularization[4].
11. As an intermediate step toward full efficiency, a Minimum Viable Product (MVP) can be developed based on explicit Forward-Backward Euler[5] or using a semi-implicit scheme where only waves are handled implicitly.

Numerical implementation, general

12. For a numerical implementation of the 2DH shallow-water equations, the best performance[6] is obtained when the equations are formulated in depth-integrated velocity $q = hu$ and the logarithm of the water depth $\ln h$. The latter also ensures positive water depths.
13. When aiming for high-quality versatile hydrodynamic computational models, the advantages of using staggering do not outweigh the disadvantages.

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[4] Unstructured/irregular grids do not allow for the error analysis that is essential for meaningful regularization. As a result, (too) much regularization/smoothing needs to be applied, to ensure that it is sufficient.
[5] An explicit approach still requires solving mass matrix problems and perhaps systems of equations for regularization. Because of the diagonal dominance this can be done very efficiently.
[6] This also applies in 3D, provided that the 3D equations formulated in (x,y,z,t) are transformed to 'boundary-fitted' coordinate system (x,y,σ,t) with $z = \zeta + (\zeta - z_b)\,\sigma$, $-1 \le \sigma \le 0$. This is because the transformed equations can straightforwardly be formulated (as far as I have seen; full derivation pending) in the velocity variables $\partial z/\partial\sigma\, \boldsymbol{u} = (\zeta - z_b)\, \boldsymbol{u} = h\, \boldsymbol{u}$.