IMUM24

21st International workshop on Multi-scale Unstructured mesh numerical Modeling for coastal, shelf, and global ocean dynamics

28-30 October 2024, Louvain-la-Neuve, Belgium

Forewords

> If you can't fly then run, if you can't run then walk, if you can't walk then crawl, but whatever you do you have to keep moving forward.
> **Martin Luther King**

We warmly welcome you to the *21st International workshop on Multi-scale Unstructured-mesh numerical Modeling for coastal, shelf, and global ocean dynamics* (IMUM), taking place from 28-30 October 2024 at UCLouvain in Louvain-la-Neuve, Belgium. The inaugural IMUM meeting was held in 2002, also at this university. At that time, unstructured-mesh ocean modeling was still a highly specialized, niche field, with early contributions to the workshop primarily focused on academic test cases and numerical discretization methods.

Since that first workshop, our field has undergone remarkable transformations, evolving from a fringe concept into a mainstream approach. This progress is particularly clear in the current workshop programme, with many contributions highlighting complex, cutting-edge applications that would have been unimaginable in 2002. Additionally, the strong presence of private-sector participants highlights the growing relevance and broad appeal of unstructured-mesh models in simulating ocean dynamic processes.

The conference program represents the efforts of many dedicated individuals. We would like to extend our heartfelt thanks to the members of the scientific and organizing committees for their help in making this conference a reality. We also wish to thank all the workshop participants, especially those who have traveled long distances to share their insights with us. Finally, we are grateful to our sponsors–UCLouvain, the Earth and Life Institute, and the Belgian Fund for Scientific Research (FRS-FNRS)–without whom this conference would not have been possible.

We hope this workshop will continue to stimulate research in multi-scale ocean modeling and foster connections between researchers and practitioners working across the spectrum of model development, application, and industrial outcomes. Like most marine ecosystems, the more connected we are, the more productive we can be!

Emmanuel Hanert, Eric Deleersnijder, Thomas Dobbelaere and Jonathan Lambrechts

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Oral presentations

Simulating the hydrodynamics of the Danube River, Delta and Black Sea continuum

Lauranne Alaerts[1,2], Jonathan Lambrechts[3], Ny Riana Randresihaja[1,2], Luc Vandenbulcke[1], Olivier Gourgue[4], Emmanuel Hanert[2,3], Marilaure Grégoire[1]

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The Danube, Europe's second-largest river, is the primary source of water and nutrients flowing into the Black Sea. The Danube Delta acts as an essential buffer zone between the river and the sea, playing a significant role in regulating biogeochemical processes along the land-sea continuum. Despite extensive modeling of the Black Sea, the Danube Delta has not yet been integrated into any existing models. Current models typically use climatic averages to represent the Danube's inputs to the sea, which can lead to inaccuracies in simulating coastal dynamics. This study aims to address this gap by developing a comprehensive model of the Danube Delta and evaluate its role within the land-sea continuum. A key starting point in this modeling process is to describe the bathymetry of the three main branches of the Danube inside the Delta, which has not been previously done in a unique dataset. To achieve this, we have combined four datasets and employed an anisotropic Inverse Distance Weighting interpolation method. We obtained a high-resolution bathymetric dataset produced on a hybrid curvilinear-unstructured mesh, with a resolution ranging from 2 m to 100 m. This is the first complete, high-resolution bathymetric product for the Danube Delta. This bathymetry, coupled with the Second-generation Louvain-la-Neuve Ice-ocean Model (SLIM), will allow for a detailed representation of the complex deltaic and coastal processes.

An adaptive finite element solver for the shallow water equations with irregular bathymetry

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We present the first step in the development of an adaptive finite element solver for the shallow water equations for coastal engineering applications, which also inherits the efficiency and robustness properties of the methods in "Casulli, A high-resolution wetting and drying algorithm for free-surface hydrodynamics (2009)". Our longer term goal is to implement an IMplicit EXplicit Runge Kutta (IMEX-RK) time discretization scheme, as already done for atmospheric models in "Orlando et al., An efficient IMEX-DG solver for the compressible Navier-Stokes equations for non-ideal gases (2022)", with an implicit treatment of the pressure gradient terms, thus guaranteeing numerical stability with time step restrictions based on velocity rather than celerity values. In this preliminary work we will restrict our attention to a second order IMEX time discretization that treats the pressure gradient term explicitly, while applying an implicit method to the friction term. The IMEX scheme is based on the combination of the stiffly accurate TR-BDF2 for the implicit part and an explicit three stages second order Runge-Kutta scheme specifically designed to match the coupling conditions. Within our finite element framework we focus on a robust and accurate treatment of the bathymetry, nowadays available with higher resolution than the mesh in coastal areas. This poses a series of challenges for higher order methods that work on quite coarse meshes: the mesh may not be perfectly aligned to large bathymetric gradients or jumps and the finite element method should be able to handle large gradients within an element or along an edge. We choose as prognostic variable the free elevation ?? which is smooth and for which we employ a finite element representation. Then, to compute the integrals necessary to assemble the mass-matrix and right-hand side, we postprocess the water depth as $h = \zeta + z_b$ (z_b the bathymetry) only in the quadrature nodes. The bathymetry at the quadrature node is directed evaluated from the reference data without any local modification. The bathymetry resolution can be increased by simply increasing locally the order of the quadrature formula. We show the robustness of this approach and that, for the opposite choice of the water depth as prognostic variable, a smoothing or a TVD limiting of the bathymetry is necessary to not incur in the Gibbs phenomenon. The spatial discretization is based on a Discontinuous Galerkin (DG) method as implemented in the deal.II library "Bangerth et al., deal.II: a general-purpose object-oriented finite element library (2007)". The deal.II library provides native parallelization templates and the DG method simply handles non-conforming meshes to implement both static and dynamic Adaptive Mesh Refinement (AMR) approaches. In this framework, we test the possibility to employ the non-conforming meshes handled by deal.II for coastal engineering purposes.

Application of an unstructured model with an ensemble Kalman filter to make a coastal sea-level reanalysis dataset in the Mediterranean Sea

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In the last year, following the requirements of a national project (CoastClim, PNRR-MER), we started to run simulations with an unstructured hydrodynamic model and an Ensemble Kalman Filter, to obtain a reanalysis dataset of the sea level, in the Mediterranean Sea. The dataset will cover the period 1994-2020 and is obtained using a two-dimensional barotropic configuration of the model with the tidal potential. The simulations are forced with surface wind and pressure fields from the CERRA high-resolution reanalysis dataset (Copernicus project), which proved superior to ERA5 in the Mediterranean Sea. The Ensemble Kalman filter was tested in several configurations, and we chose the best one, assimilating all the available data from sea-level tide gauges in the Mediterranean Sea. Preliminary results show an excellent improvement with respect to the hindcast simulations (no data assimilation). The project will produce also wave data in the same period, using the WaveWatch III model, and the same forcing.

On high order interpolation for Semi-Lagrangian schemes on unstructured triangular meshes

W. Alexander Breugem

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Semi-Lagrangian schemes are often used as advection scheme. In these schemes, a streamline is calculated back in time from each node in the mesh. The advection of a variable is then calculated by determining the value of this variable at the feet of the characteristics by spatial interpolation. The advantage of Semi-Lagrangian schemes is that they do not pose a strict CFL criterium, thus allowing large time steps. Further, they can be very fast, especially for situations, where the velocity field remains constant in time or when a large number of variables is advected with the same velocity field. The reason for this is that the calculation of the streamlines, which is usually the slowest part of the calculation, then needs to be performed only occasionally and is reused for many interpolations.

Because of the speed and unconditional stability, semi-Lagrangian schemes can be used in the TELEMAC model for the advection of momentum as well as scalar properties, and it is the only available advection scheme in the spectral wave model TOMAWAC. In these models the scheme is applied on an unstructured mesh with $P_1 - P_1$ elements, meaning that linear interpolation is used, which leads to a scheme that is only first order accurate.

In the present presentation, the results of experiments are shown, which have the aim to increase the order of accuracy of the scheme, while keeping the same P1-P1 mesh schematisation, and which still allow for fast calculations of the advection term. Thereto, a new interpolation methods was developed. In this scheme, first a stencil is made using an element in combination with nodes from the surrounding elements. A least-square fit is then performed, to fit a polynomial through the nodes of these elements (in this work, second, third and fourth order polynomials were used). This leads to an overdetermined matrix equation for each element. In order to speed up the calculation, the Moore-Penroose inverse is determined in the preprocessing stage, such that the matrix equations need to be solved only once. This leads to a new set of coefficients, that only needs to be updated when the velocity field changes. This interpolation scheme is combined with a min-max limiter, in order to prevent the generation of artificial wiggles.

In this presentation, the scheme is applied to the rotating cone test case, where it is demonstrated that in this way the advection scheme shows a higher order of accuracy.

Analysis of discrete variance decay and spurious mixing

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Advection schemes used in ocean models generally have a dissipative truncation error. The accompanying dissipation is numerical and leads to an additional mixing as compared to the physical mixing described by physical parameterizations. Computations of the discrete variance decay (DVD) rate allow one to compare the contributions coming from horizontal and vertical advection and diffusion. Only vertical diffusion is physical, all others are of numerical origin. In the case of simplified equation of state, which depends on a single scalar field (e.g. temperature), the estimates of the DVD rate characterize diapycnal mixing. Test analyses show that in many cases the DVD rate due numerical mixing is comparable to the DVD rate from physical mixing. We discuss a new approach to computing the DVD rate. It is directly based on the discrete equation for scalar fields.

Seabed Mobility for Offshore Wind Farm Development

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In coastal waters where wind farm are being developed, regular currents and/or extreme events have the potential to mobilise the seabed sediment and consequently affect the seabed level, which may cause problems in terms of turbine installation and cable burial. It is therefore crucial to assess the seabed mobility potential over a project lifetime. To assess the seabed level evolution over multi-decade periods at a high resolution with a limited amount of available data is very challenging. For that purpose, a comprehensive multi-factor methodology has been developed. Since many uncertainties control the migration processes over a period of 30 years, the main idea is to use relatively independent tools and evaluate their outcomes into an integrated answer to the mobility assessment. Those different tools include the evaluation of mobility potential through analytical assessment of the Shields parameter controlling the sediment motion, the comparison of bathymetry historical dataset evolution, the analysis of the different bedform length scales and their associated mobility and the explicit numerical modelling of the sediment migration and seabed morphology using the coupled current-wave-sediment Delft3D model. Through this presentation, this methodology and its different tools will be detailed through the evaluation of the seabed mobility in the storm-dominated environment of the Atlantic Offshore Continental Shelf.

Assessing the performances of SLIM3D for multi-GPU simulations

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SLIM is a high-performance ocean modeling toolkit developed at UCLouvain, based on the Discontinuous Galerkin Finite Element Method (DG-FEM) with a split-explicit temporal integration scheme. In line with trends in the high-performance computing (HPC) community, the latest version of SLIM has been optimized for parallelization, with a particular emphasis on GPU acceleration. While GPUs are highly suited for large-scale simulations, they tend to be less efficient with smaller problem sizes, as not all of the GPU's resources can be fully utilized. This inefficiency is compounded when scaling across multiple GPUs due to their inherent latency, which limits strong scaling. Moreover, the split-explicit nature of the computation introduces an additional challenge, as the external (2D) mode requires numerous small iterations for every computationally intensive internal (3D) mode iteration. In this work, we address the challenge of efficiently distributing computations across multiple GPUs, presenting techniques designed to minimize latency and maximize throughput. We then assess the performance and scaling of SLIM3D from a single core on a laptop to hundreds of GPUs on a supercomputer. Based on this analysis, we highlight the conditions necessary to achieve optimal performance and scaling on different types of hardware from NVIDIA and AMD as well as CPUs.

Investigating the link between the Port of Miami dredging and the onset of the stony coral tissue loss disease epidemics

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Since 2014, the stony coral tissue loss disease (SCTLD) has been decimating corals in the Caribbean. Although the trigger of this outbreak remains elusive, evidence suggests waterborne sediment-mediated disease transmission. The outbreak reportedly initiated in September 2014 at a reef site off Virginia Key (VKR), during extensive dredging operations at the Port of Miami. Here we use a high-resolution ocean model to identify the potential driver of the outbreak by simulating the dispersal of dredged sediments, wastewater plumes and disease agents. Our results suggest that VKR could have been impacted by fine sediments produced by dredging operations, especially those involving non-conventional rock-chopping techniques. Wastewater contamination was unlikely. Additionally, our connectivity analysis indicates potential disease transmission from other affected reefs to VKR. Our results therefore suggest that dredging operations might be responsible for the onset of the epidemics. This underscores the need for stricter operational guidelines in future dredging projects.

A convolution method to assess subgrid-scale interactions between flow and patchy vegetation in biogeomorphic models

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Interactions between water flow and patchy vegetation are critical to the functioning of many ecosystems. However, numerical models that simulate these interactions at the submeter scale to predict geomorphological and ecological outcomes at landscape scales (up to several square kilometers) remain computationally intensive. In this study, we introduce a novel and efficient convolution technique that

integrates biogeomorphic feedbacks into numerical models across multiple spatial scales, ranging from less than 1 m^2 to several km^2. Our methodology allows for the spatial refinement of coarse-resolution hydrodynamic simulations of flow velocities (on the order of meters) around fine-resolution vegetation patterns (on the order of centimeters). While our approach does not replicate flow perturbations around each vegetation cell with the same accuracy as finer-resolution models, it significantly improves the spatial refinement of coarse-resolution models by effectively resolving subgrid-scale flow velocity patterns within and around vegetation patches. Additionally, we demonstrate that this approach substantially improves the representation of key biogeomorphic processes, such as subgrid-scale effects on net sedimentation rates and the habitable surface area for vegetation. Furthermore, we estimate that substituting a fine-resolution model with a coarse-resolution model combined with our convolution technique could reduce the computational time of real-life fluctuating flow simulations by several orders of magnitude. This represents a significant advancement in computationally efficient multiscale biogeomorphic modeling.

The influence of vertical resolution on the circulation using a 3D barotropic model

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We use the Toulouse Unstructured Grid Ocean Model (T-UGOm) in an experimental 3D barotropic time-stepping mode to look at how the circulation changes with different specified vertical resolutions in tidal and meteorological driven scenarios. We examine in particular the changes at the surface and bottom as these layers are better resolved.

Adjoint-based optimisation for calibration of a Thetis shallow-water equation model for tidal array design

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Numerical models are critical tools in understanding the behaviour of coastal ocean systems. In particular, tidal stream energy deployments are set to expand in capacity by over 1200% in the next 4–5 years and thus determining the spatial distribution of the resource is warranted. An accurate calibration of coastal models can reduce uncertainty and improve confidence for investors. In shallow-water equation models, the field typically used to improve agreement with measured values is the bottom friction, which invariably must account for broader physical and numerical dissipation processes that arise at unresolved spatiotemporal scales. This has ordinarily been performed through enumeration of a set of reasonable parameters, assuming a uniform value across the domain. However, both skin friction and form

drag will vary spatially and therefore other representations have been proposed including simple spatial segmentation, mapping based on bed sediment particle size data, and an 'independent points scheme'. Resource models are typically only validated with simple sensitivity approaches to provide high-level assessments, but wider-use coastal ocean models have been formally calibrated based on altimetry or tidal gauge (depth) data using adjoint-based techniques, Bayesian inversion and Kalman filtering. However, tidal stream deployments are sensitive to the velocity field which is much more challenging to reproduce accurately. Thus, numerical models now need to be calibrated based on Acoustic Doppler Current profiler data to allow layouts to be correctly micro-sited. This requires the development of effective strategies to frame the optimisation problem. This talk investigates the use of adjoint-based optimisation of the bed friction field in the *Thetis* coastal ocean model considering various forms of friction representation. This begins with idealised setups using the various methods of friction representation, increasing in complexity to the site of an upcoming tidal array deployment. This talk will focus on the progress made and the challenges faced in using this method.

Changes in tide-driven transport in intertidal environments in response to rising sea levels. Case study of Sylt-Rømø Bight

Gaziza Konyssova[1,2], Alexey Androsov[1], Lasse Sander[2], Sergey Danilov[1], Sara Rubinetti[1,3], Karen H. Wiltshire[2,4], Vera Sidorenko[1,2]

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This study investigates the complex interactions between sea-level rise (SLR), tidal dynamics, and geomorphology in the Wadden Sea, with a focus on the case study of the Sylt-Rømø Bight – a semienclosed basin in the Wadden Sea separated from adjacent basins by artificial dams on both sides. Using the coastal hydrodynamic model FESOM-C and its Lagrangian module FESOM-Cdrift, the research simulates hydrodynamic response to SLR under low and high emission scenarios (SSP1-2.6 and SSP5-8.5) on intertidal dynamics and tide-driven transport patterns.

The results reveal a shift in tidal dynamics as sea levels rise, with spatially varying changes in current velocities. While overall current velocities increase (∼3 cm/s by 2050 under high SLR), different areas of the basin experience contrasting trends: maximum velocities rise in shallow areas due to increasing bathymetry and reduced bottom friction, whereas deeper tidal channels experience a slight reduction in current strength. These spatial variations are also found in thickness-weighted average velocities and tidal asymmetry, suggesting a reduction in tidally induced net transport of particles after a single ebb-flood cycle, as well as a decrease in the overall transport from the basin to the open sea. This points to a shift toward a more lagoon-like system. Lagrangian particle dispersion experiments further support this hypothesis, showing a decrease in overall outflowing transport of particles by $\sim$9.8% and outflow of unique tracers by $\sim$6.2%, along with reduced connectivity between the northern and southern parts of the basin. These findings underscore the importance of understanding the complex interplay of the hydrodynamic processes driving coastal dynamics and habitat change.

Models of flow around windmill foundations and primary production in an Arctic fjord

Janus Larsen, Vibe Schourup-Kristensen, Marie Maar

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At department of Ecoscience, Aarhus University, Denmark a major research topic is understanding, describing and modelling how natural variation and human activity affect the nature and environmental quality of our marine areas. To support this, we have, during the last decade, developed the marine modelling framework FlexSem. It is a 3D unstructured modeling system, that specializes in smaller areas of complex geometry such as bays and estuaries. The system has modules for hydrodynamics, pelagic and benthic equation solvers for biogeochemistry and dynamic energy budget models (shellfish growth), sediment transport and an agent-based model. We have used the system to set up models for more than 20 areas to model systems from pollution in the coral reefs around Zanzibar, Tanzania to arctic ecology in Young Sound, Northeast Greenland, seamounts in the Atlantic Ocean and multiple fjords in Denmark. We will look at a high-resolution model of flow around a windmill foundation and parameterization of the effects in courser model setups. Furthermore, we will also look at results from a setup of the Young Sound Fjord in north-east Greenland - a sill fjord dominated by total ice cover from November to May and large freshwater inflow in the brief summer.

Deep Reinforcement Learning for Adaptive Mesh Refinement

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Adaptive mesh refinement (AMR) can preferentially resolve regions containing important features during simulation. However, spatial refinement strategies are often heuristic and rely on domain-specific knowledge or trial-and-error. We treat the process of adaptive mesh refinement as a local, sequential decision-making problem under incomplete information, formulating AMR as a partially observable Markov decision process. Using deep reinforcement learning, we train policy networks for AMR strategy directly from numerical simulations. The training process does not require a high-fidelity ground truth, an exact solution to the partial differential equation, or a pre-computed training dataset. The local nature of our reinforcement learning allows the policy network to be trained inexpensively on much smaller problems than those on which they are deployed. The methodology is not specific to any partial differential equation, problem dimension, or numerical discretization, and can flexibly incorporate diverse problem physics. To that end, we apply the approach to a diverse set of partial differential equations, using a variety of high-order discontinuous Galerkin and hybridizable discontinuous Galerkin finite element discretizations. We show that the resultant deep reinforcement learning policies are competitive with common AMR heuristics, generalize well across problem classes, and strike a favorable balance between accuracy and cost such that they often lead to a higher accuracy per problem degree of freedom.

Adaptive Nonhydrostatic-Hydrostatic Hybridizable Discontinuous Galerkin Ocean Solver

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To simulate and study ocean phenomena involving complex dynamics over a wider range of scales, from regional to small scales (e.g., thousands of kilometers to meters), resolving submesocale features, nonlinear internal waves, subduction, and overturning where they occur, non-hydrostatic (NHS) ocean models are needed, at least locally. The main computational burden for NHS models arises from solving a globally coupled elliptic PDE for the NHS pressure. To address this challenge, we start with a high-order hybridizable discontinuous Galerkin (HDG) finite element NHS ocean solver that is well suited for multidynamics systems. We present a new adaptive algorithm to decompose a domain into NHS and HS dynamics subdomains and solve their corresponding equations, thereby reducing the cost associated with the NHS pressure solution step. The NHS/HS subdomains are adapted based on new numerical NHS estimators, such that NHS dynamics is used only where needed. We compare and explore choices of boundary conditions imposed on the internal boundaries between subdomains of different dynamics. We evaluate and analyze the computational costs and accuracy of the adaptive NHS-HS solver using idealized NHS dynamics with internal solitary waves. We then complete more realistic NHS-HS simulations of Rayleigh-Taylor instability-driven subduction events by nesting with our MSEAS realistic and operational data-assimilative HS ocean modeling system.

The ICON Mesh Splitter

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The grid generation software "ICON Mesh Spitter" (IMS) and its applications for the ocean model ICON-O are presented. The questions of whether global models should use irregular grids at all and whether regional models should always be nested are addressed. Finally, future IMS developments, including a coastal model, are discussed.

Adaptive Meshing for Mitigating Numerical Dilution in Sediment Plume Modeling of Moving Dredgers

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While various techniques are available to avoid numerical dilution associated with the modelling of stationary sediment plume sources, addressing numerical dilution for moving sources such as those originating from Trailing Suction Hopper Dredgers is more complex.

Approaches exist that integrate parametric near-field models with far-field models, allowing the resolution of the far-field model to be set appropriately at the boundary between the active and passive phases of the plume. However, in complex environments with moving dredgers, changing bathymetry, currents, and variable dredger production (spill rate and composition), the application of parametric near-field models becomes computationally impractical for extended scenarios. For jurisdictions where regulators require simulation of the entire dredge program, an alternative approach to addressing near-field numerical dilution is needed.

Numerical dilution in this context refers to the situation where the lateral size of the plume is smaller than the far-field cell size, resulting in artificial dilution due to the mixing volume of the computational cell. This can negatively impact subsequent transport and dispersion of the plume, reducing the flocculation potential near the source. These issues contribute to significant uncertainty in assessing the potential impact of sediment plume models.

An adaptive meshing approach is presented to address numerical dilution near a moving dredger. In this approach, a high-resolution mesh area is generated around the dredger's near-field by first creating the dredger path using the dredging plan file containing the dredger's location and speed. To control mesh growth from high to low resolution, several parallel buffer lines are created on each side of the dredger path at distances that ensure gradual mesh growth. A triangular mesh is generated using the Gmsh library in Python. To avoid computational heaviness, the dredger path is divided into sub-paths, with high-resolution meshes created for each subsection. To ensure continuous transition between meshes, overlap between paths is managed by artificially extending the path in each direction. This approach allows for a smooth transition to the far field without the computational overhead of using a linked parametric near-field model with a coarser far-field model.

An unstructured finite volume scheme for Boussinesq-type equations

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In this talk, we present the newly developed MIKE 21 Wave Model FM, which is based on the enhanced Boussinesq equations (Madsen and Sørensen, 1992) and suitable for dispersive wave propagation in harbours and coastal areas using unstructured meshes. Different spatial discretization schemes have been proposed for solving Boussinesq-type equations, however, a substantial number of these are applicable only to structured meshes. Furthermore, the formation of discontinuities during wave run-up and breaking may cause numerical schemes without shock-capturing capabilities to suffer from numerical stability issues. Finite volume schemes have shown to be highly beneficial for problems exhibiting shock-like behavior when implemented with suitable convective flux approximations. However, to the authors' knowledge, an unstructured cell-centered finite volume discretization of the enhanced Boussinesq equations has not previously been presented in the literature. Thus, we present an unstructured cell-centered finite volume discretization, which is applicable to structured as well as unstructured quadrilateral- and triangular meshes. Finally, the applicability of the model is illustrated by showcasing various test cases that include non-linear shoaling, wave propagation through porous media, wave run-up and breaking.

References

Madsen, P. A., & Sørensen, O. R. (1992). A new form of the Boussinesq equations with improved linear dispersion characteristics. Part 2. A slowly-varying bathymetry. Coastal Engineering, 18(3-4), 183-204.

Morphological Changes of Beaches on the Southwest Coast of India Due to Climate Change

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Thiruvananthapuram, located on the southwest coast of India, is a high-energy coastline significantly affected by wave activity during the southwest monsoon season. Recent years have seen an increase in cyclone frequency in the Arabian Sea, likely driven by rising sea temperatures associated with climate change. Cyclones such as Okhi (2017) and Tauktae (2021) have profoundly impacted the Thiruvananthapuram coast, transforming stable beaches into eroding areas and destabilizing popular tourist destinations. Artificial interventions have further exacerbated erosion issues in the region, particularly in Varkala, a key tourist attraction that has experienced significant cliff erosion and instability. To assess the impact of these

changes, detailed fieldwork was conducted along the 78 km coastline of Thiruvananthapuram in August 2022. The study involved collecting data on structural performance, identifying erosion and accretion sites using handheld GPS, and recording observations in Kobo Toolbox. The research proposes integrated management strategies for the entire sector, utilizing secondary data and updating the district's status through numerical modeling with unstructured meshes and ArcGIS support. Understanding these coastal changes is essential for managing high-energy coastlines affected by climate change, and the methodologies used in this study can be applied to similar beaches worldwide. The study combines direct field data, stakeholder input, and numerical modeling to provide a comprehensive understanding of the coastal dynamics in this region.

Modelling flood wave propagation in a small tropical estuary: the role of mangrove channel density

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The protection and restoration of mangroves has been increasingly recognized as cost-effective and sustainable strategies to mitigate the increasing flood risks in tropical coastal areas. As storm surge or tidal waves propagate landward from coastal seas, mangroves can attenuate propagation of high water levels by exerting friction on the water flow, resulting in within-wetland attenuation, and by providing flood storage, resulting in along-channel attenuation. While the impact of channels and vegetation on the friction effect has been studied before, the impact on the storage effect has not, nor their interactions. Here, we present a hydrodynamic model in a tropical estuary, calibrated and verified against field observations. Through a scenario analysis, we show that with a denser network of secondary channels and less dense vegetation, the storage effect becomes stronger, leading to higher along-channel attenuation. The opposite can be observed for the friction effect: we simulate lower within-wetland attenuation rates in case of higher channel density and lower vegetation density. If a wide 2-km mangrove band fringes the channels, we found the strongest along-channel attenuation in case of a dense network of secondary channels with low vegetation density. In contrast, when the mangrove extent is limited, for instance due to the partial replacement of mangroves by aquaculture, a dense network of channels or sparse vegetation can result in high water level amplification. Future conservation and restoration efforts should consider this trade-off between within-wetland and along-channel attenuation when implementing nature-based flood risk protection measures, in order to safeguard both human settlements behind unchanneled wetlands and along deltaic channels fringed by mangroves.

Quad- and Hex-meshing using Gmsh

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The generation of quadrilateral and hexahedral meshes is the main topic of this talk. Constructing computable quad meshes is of the same order of complexity as generating triangles. Yet, hex-meshing is much harder than that tet-meshing. Today, there is no robust method for generating hexahedral meshes in geometric domains of arbitrary complexity [1].

We'll start this talk by presenting methods for generating quadrilateral meshes. We will distinguish between so-called indirect methods, where a triangular mesh is transformed into a quad mesh, and direct methods, where the quadrilateral mesh is generated from a parameterization.

We will then show that, even if 2D ideas seem extensible to 3D, the 3D case – hex-meshing – is by no means harder that quad meshing.

Finally, we present the state-of-the-art in direct and indirect hex-meshing methods. In the indirect case, we will present Gmsh's ability to generate hex-domiant meshes and possible paths that will eventually lead to full hex unstructured meshing [2]. We will present as well a very recent result on the integrability of 3D frame fields, which opens the way to the automatic generation of hexahedral block-structured meshes [3].

References:

[1] Pietroni, N., Campen, M., Sheffer, A., Cherchi, G., Bommes, D., Gao, X., ... & Livesu, M. (2022). Hex-mesh generation and processing: a survey. ACM transactions on graphics, 42(2), 1-44.

[2] Verhetsel, K., Pellerin, J., & Remacle, J. F. (2019). Finding hexahedrizations for small quadrangulations of the sphere. ACM Transactions on Graphics (TOG), 38(4), 1-13.

[3] Couplet, M., Chemin, A., & Remacle, J. F. (2024). Integrable Frame Fields using Odeco Tensors. In Proceedings of the 2024 International Meshing Roundtable (IMR) (pp. 53-65). Society for Industrial and Applied Mathematics.

Assessing the impact of bridge construction and land reclamation on water residence time in Kuwait Bay

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Over the past few decades, Kuwait Bay has experienced significant water quality decline due to growing anthropogenic pressures, including oil and gas extraction and extensive coastal developments, leading to severe eutrophication and marine life mortality. Additionally, the recent construction of a 36 km-long causeway and related land reclamation projects has disrupted the Bay's natural flushing processes, allowing pollutants and excess nutrients to accumulate more readily. However, the impact of these new infrastructures on the Bay's circulation patterns and water renewal capacity remains unquantified. Here, we use the multi-scale ocean model SLIM to simulate the fine-scale flow patterns in Kuwait Bay and evaluate water residence time distribution, focusing on its spatial and seasonal variability. By further comparing pre- and post-construction scenarios, we quantify the causeway's influence on Kuwait Bay's hydrodynamics and flushing properties. We find a complete renewal of the Bay within 150-320 days, driven by significant spatial and seasonal variations in water residence time, largely influenced by the prevailing winds and strong tidal flows interacting with the Bay's shallow depths. The introduction of the artificial structures extends the average residence time by 1.29 days (+3.49%), with significant local variations ranging from -66 to +56 days, underlining the causeway's role as a physical barrier, and amplifying the risks of water quality degradation in some regions. From a broader perspective, our findings highlight the large-scale impact of fine-scale hydrodynamic changes in a semi-enclosed coastal system on its flushing processes and water quality.

On modelling 50,000 years of storm surges around Australia

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Globally, many organisations seek to understand the coastal flood risk from low-frequency, high-severity storm surge events, chief among them re/insurance companies, large multinationals and governments. Here, we use an unstructured-mesh, 2D hydrodynamic model at the heart of our approach to estimate the long-term flooding risk around Australia, by running 100,000s of simulations of storm events representing 50,000 years of Tropical Cyclone (TC) activity in the region. This requires an optimised computational domain; we aim to optimise mesh parameters, resolution and roughness data using detailed sensitivity analyses. Our model is coupled to an overland inundation model to estimate overland flood risk. In this talk we discuss some of the challenges and opportunities of this catastrophe modelling approach.

New subgrid-scale process models for sediment-laden flows solved with the finite-element modelling suite TELEMAC-MASCARET

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The TELEMAC-MASCARET suite for hydraulic engineering, originally developed at EDF (France), has become open source in 2012 and is currently managed by a larger international group of research institutes. It is freely available from `www.openTELEMAC.org`. It contains various modules for 2D depth-averaged and 3D hydrodynamics, tracer and sediment transport, water quality, and a spectral wave model (TOMAWAC). It is widely used and frequently updated (at least once a year) and extended with new functionalities.

The KU Leuven started to use this software since 2012 to implement their new process models for sediment-laden flow and test them in real coastal and estuarial conditions. Not much later, this software was also selected by Flanders Hydraulics, the Flemish Government research institute which uses numerical models to make decisions regarding the management of the Scheldt Estuary and the Belgian coast.

The KU Leuven model is used in various research projects funded by EU H2020, Flanders Research Fund (FWO), Belgian Science Policy Office (BELSPO) and Flanders Innovation & Entrepreneurship (VLAIO)/Blue Cluster. Within these projects, new physics-based modules for subgrid-scale processes are developed, implemented and tested in real life conditions. Subgrid-scale processes parameterize processes that happen at scales smaller than the scales resolved by the grid size and the time step. The following processes are studied: energy dissipation mechanisms (e.g. effective bottom roughness by bed forms, vegetation, biogenic reefs and sediment transport), bed-load transport and associated low-Reynolds turbulence (applied to the inner boundary layer), multi-fractional particle transport (applied to sand-mud mixtures and plastic litter, accounting for varying size distributions, including floc aggregation and break-up), non-linear wave interactions (a.o. infragravity waves), and a new, robust and accurate drying-wetting method. The development of these physics-based closures starts from the fundamental conservation equations for a two-phase mixtures of water and solid particles with a new low-Reynolds turbulence closure model, adopted for two-phase media. Because of the scarcity of useful experimental data, additional data is generated with a high-resolution multiphase CFD code for resolved free-surface water-sediment mixtures, Mixt3SedFOAM (Ouda & Toorman, 2019), developed in the OpenFOAM framework, used as a virtual laboratory. The results from these simulations are integrated and upscaled to parameterizations for TELEMAC applied to large-scale applications.

Reference:

Ouda M., Toorman E.A. (2019). Development of a new multiphase sediment transport model for free surface flows. International Journal of Multiphase Flow, 117(8): 81-102.

The Non-hydrostatic Model SWASH as an Engineering Tool for Wave Propagation in Coastal and Port Environments

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Phase-resolving numerical models have been used for over three decades to predict wave transformation in coastal regions. With the increasing vulnerability of these areas due to climate change and the intensified storm activity, the accuracy of model predictions is more crucial than ever. Recent advances in computational power have made it possible to apply the non-linear, phase-resolving wave propagation model SWASH to study extended sea states in large coastal regions and port environments. SWASH is an open-source non-hydrostatic wave propagation model. The governing equations of the model are based on the Navier-Stokes (or Euler) equations for an incompressible fluid with a free surface and a constant density. In contrast to the Boussinesq-type wave models, non-hydrostatic wave models can directly resolve the vertical and horizontal flow structure by retaining the 3D momentum equations and consequently can simulate rotational flows. Additionally, they can improve their wave dispersion and the degree of non-linearity by making use of a few vertical layers rather than increasing the order of derivatives of the dependent variables like Boussinesq-type wave models. Recently, the linear and non-linear properties of SWASH model were defined in detail for all dependent variables of the governing equations, and the wave generation boundary conditions were improved and extended to higher order. During the IMUM2024 workshop, we will present the latest developments of the SWASH model and how we apply it within DEME as a tool to evaluate port layout designs and determine workability for our vessels operating in coastal and port environments.

Posters

Ocean biogeochemistry in the coupled ocean-sea ice-biogeochemistry model FESOM2.1-REcoM3

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The cycling of carbon in the oceans is affected by feedbacks driven by changes in climate and atmospheric CO2. Understanding them is therefore an important prerequisite for projecting future climate. Marine biogeochemistry models are a useful tool but, as with any model, are a simplification and need to be continually improved. In this study, we coupled the Finite-volumE Sea ice-Ocean Model (FESOM2.1) to the Regulated Ecosystem Model version 3 (REcoM3) that operates on unstructured meshes. While mesh flexibility allows for a realistic representation of small-scale dynamics in key regions at an affordable computational cost, the model FESOM2.1-REcoM3 accommodate central parts of the biogeochemistry model, such as carbonate chemistry, including water vapour correction, an extended food web that includes macrozooplankton and fast-sinking detritus. We assess the ocean and biogeochemical state simulated in a global set-up at relatively low spatial resolution forced with JRA55-do (Tsujino et al., 2018) atmospheric reanalysis. The focus is on the recent period (1958-2021) to assess how well the model can be used for present-day. It is found that FESOM2.1-REcoM3 is a skilful tool for ocean biogeochemical modelling applications due to increased computational efficiency and reduced bias in the global ocean-atmosphere preindustrial CO2 flux present in the previous model version.

Application of machine learning error estimation in goal-oriented mesh adaptation to tidal turbine array modeling

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In emerging renewable energy markets, numerical simulations play an important role in navigating the scale-up challenges of generating energy from complex and non-linear sources such as wind and tidal. Effectively discretizing over the multiple spatial scales inherent in such geophysical fluid dynamics problems, while also targeting a reasonable level of accuracy for meaningful results, can come at a high computational cost, compromising the ability to use a simulation-based approach for design optimisation and uncertainty quantification. We propose a workflow combining goal-based mesh adaptation and machine learning error estimation designed to reduce computational cost while focusing discrete resolution where it most directly impacts the quantity of interest for the tidal array modelling problem, namely the extracted power at the turbines. We explore surrogates for the costly dual-weighted residual error estimation step in mesh adaptation, such as CNN and GNN methods, which incorporate additional patch-based or nearest neighbour information and have realistic scope to generalise. A series of tidal turbine array cases simulating wake interaction and impact on turbine power generation will be considered. The discussion is focused on trade-offs between accuracy preservation and efficiency gain for the machine learning based surrogate methods.

Eliminating smoothing and depth distortion need for management of sigma-pressure gradient errors in Salish Sea fjord setting using SCHISM and LSC2 Coordinate System

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The Salish Sea Model developed using the unstructured grid Finite Volume Community Ocean Model (FVCOM) has served the hydrodynamic simulation needs of this estuary for over a decade. The model is mature and has successfully reproduced tidal baroclinic circulation, exchange with the Pacific Ocean, inter-basin connectivity, and biogeochemical cycles with a sufficient level of accuracy for informing ecosystem management decisions and nearshore restoration feasibility assessments. The unstructured grid framework and sigma-coordinate allows resolution of the domain with complex shorelines and islands, and intertidal regions efficiently. However, the use of σ-coordinate system has required a major compromise in the form of extensive smoothing and depth distortion to function within the method limits ($\Delta\sigma/\sigma < \Delta H/H$) to avoid pressure gradient induced error. It has also required that the number of vertical layers be limited to as small as possible (10). Without these measures, the pressure gradient error dominates leading to spurious mixing,

breakup of stratification, and incorrect exchange magnitudes. These corrective measures of smoothing and depth-distortions cause tidal amplitudes for water surface elevations and currents to significantly overshoot the measurements during the ebb as well as flood. While this is acceptable for biogeochemical simulations, the performance needs improvement for use in navigation and emergency response, that require higher level of accuracy in reporting water surface elevations and current magnitude and directions. In this study we assess the feasibility of eliminating the need for smoothing and depth-distortion using SCHISM and the LSC2 (Localized Sigma Coordinates with Shaved Cell) system over the same grid. Our goal is to use accurate bathymetry, increase the number of layers from 10 to 20-30, without compromising on the performance requirements and model skill. We present the results of these tests and discuss the finding providing relative comparison between traditional σ-coordinate implementation of FVCOM and the SCHISM LSC2 version over the same grid using monthly monitoring data from 26 stations. Results will be used to recommend the next steps and a path forward for future and continuing development of the Salish Sea Model to NOAA and U.S. EPA.

Comparison of different vertical layer discretization for Saltwater Intrusion in the Po Delta River using SHYFEM

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The Po River Delta (PDR), a critical ecological and agricultural region in Italy, faces increasing threats from saltwater intrusion (SWI), exacerbated by climate change-induced droughts. Understanding and predicting these dynamics is essential for sustainable management of the delta's resources. In this study, we utilize the SHYFEM model over an unstructured mesh to simulate and analyze SWI in the Po River Delta, focusing on the effectiveness of different vertical discretization schemes.

Our research compares four distinct vertical discretization methods within SHYFEM: the traditional z-layer (used for the PDR for the SWI of 2017 by Bellafiore et al. in 2019), three different approaches using: z^*-layer, and two different hybrid z^*-layer (Arpaia et al., 2023). These innovative approaches are specifically adapted to address the complex hydrodynamics of the Po Delta. By applying these techniques, we aim to enhance the model's predictive accuracy concerning SWI, particularly during critical events such as the severe 2022 drought, which caused marine waters to intrude up to 40 km upstream along the river branches.

The study's outcomes were benchmarked against in-situ measurements, providing a detailed evaluation of each vertical discretization method's performance in reproducing SWI phenomena. The results highlight the strengths and limitations of each approach, offering insights into their applicability for large-scale estuarine and coastal systems. Furthermore, these vertical discretizations are discussed in the context of multiscale unstructured mesh modeling, emphasizing their role in improving the stability and accuracy of numerical simulations under challenging environmental conditions.

Assessing the sensitivity of storm surge simulations to the atmospheric forcing resolution across the land-sea continuum

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Storm surges pose significant risks to coastal regions worldwide, including the North Sea. However, accurately modeling storm surge dynamics in complex estuarine environments, such as the Scheldt estuary, remains challenging. Conventional models of the land-sea continuum often apply atmospheric forcing data with spatial resolutions typically of the order of tens of kilometers and temporal resolution of a few hours, which may be insufficient for capturing the finer-scale processes of estuarine systems. In this study, we evaluate the impact of spatial and temporal resolution of atmospheric forcing on storm surge modeling in the Scheldt land-sea continuum. Atmospheric forcings were incorporated at varying spatial resolutions, ranging from 2 km to 30 km, and at temporal resolutions from 15 min to 6 h. Using a multiscale modeling approach, we assessed how these variations influenced the accuracy of the storm surge simulations. Our findings indicate that increasing spatial resolution significantly improved the accuracy of peak surge predictions in the estuarine areas, while finer temporal resolution further enhanced model performance only at the finest spatial resolution. The effect of temporal resolution diminishes as the spatial resolution becomes coarser. This suggests that spatial resolution plays a more critical role in improving storm surge forecasts for estuaries like the Scheldt. The timing of peak surges remained consistent across all configurations. Our study highlights the importance of incorporating high-resolution atmospheric forcing in storm surge models, especially in estuaries, to improve surge predictions and inform coastal risk management.

Preliminary assessment of the environmental impact of NEOM coastal developments on the Northern Red Sea coral reefs

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In the context of a warming world, annual bleaching events are becoming more likely and threaten coral reefs on a global scale, leading to a growing interest in identifying local-scale thermal refuge. However such shallow reef refuge are predicted to disappear in a +2.0 °C climate world. Yet, hope remains as Northern Red Sea (NRS) corals could act as a thermal refuge until the end of the century. While being virtually immune to climate change, these so-called "super-corals" are not immune to anthropogenic stressors such as the NEOM mega-project. Here, we used a three-dimensional multi-scale ocean model coupled with a Lagragian Particle Tracker (LPT) model to simulate sediment dispersal originating from coastal development sites and assess the environmental impact of the NEOM project on NRS corals. We show that fine sediments ($< 32\mu$m) have a high potential to impact the entire Gulf of Aqaba (GoA) and part of the NRS, as they can remain suspended in the water column for up to one month and can settle 200 km away from their release site. We identified the most exposed reefs located within 10 km of Sindalah and along 45 km of the Oxagon coastline. Furthermore, we highlight that all the most exposed reefs are located in the NRS; none are within the GoA. To our knowledge, this work is the first to quantitatively assess the environmental impact of the NEOM project on NRS and GoA shallow coral reefs. Based on our results, we expose the need for the implementation of mitigation measures to ensure sustainable coastal development. In a broader way, our model could provide further insights into marine pollution (e.g. desalination plants brines, heavy metals) and mesophotic-shallow reef interaction.

Multi-scale modelling of the water and sediment fluxes from the Nile Delta to the Suez Canal

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The Suez Canal holds a pivotal role in global navigation and supply chains by facilitating the movement of goods between the East and West. Around 50 vessels navigate the canal daily. However, a pressing concern threatens its operational stability: the escalating sediment deposition that necessitates frequent canal dredging. While these sediments originate from diverse sources like land erosion in the northern Sinai and tributaries to the canal, a significant portion could originate from the Nile Delta. This sediment influx results from heightened erosion in the Nile delta, a consequence of reduced Nile River discharge. Multiple factors contribute to this

discharge reduction, including upstream damming activities, intensified water usage for agriculture, and population growth in the Nile Basin. The grounding of the Ever Given container ship in 2021 illustrated the consequences of a congested Suez Canal, potentially causing substantial delays and economic losses in global trade. This research project aims to comprehensively grasp the dynamics of sediment transfer from the Nile Delta to the Suez Canal, considering the potential effects of current and future Nile River damming. To fulfill this goal, an integrated framework will be established, bridging the gap between alterations in Nile River discharge, sediment origins in the Nile Delta, and their accumulation in the Suez Canal. This framework will facilitate the quantification of sediment proportions reaching the canal and the assessment of navigation risks posed by these sediments under existing conditions and future discharge scenarios.

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