Book of Abstracts

The 16th **I**nternational workshop on **M**ulti-scale (**U**n)-structured mesh numerical **M**odeling for coastal, shelf, and global ocean dynamics (IMUM)

Aug 29 – Sep 1, 2017
Stanford University
Stanford, CA, USA

Financial support provided by the Stanford Department of Civil and Environmental Engineering and the Stanford Institute for Computational and Mathematical Engineering

Conference co-chairs:
Oliver Fringer
Frank Giraldo

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Overview

The 16th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics (IMUM 2017) was held at Stanford University during August 29-September 1, 2017. Following the tradition of alternating between Europe and North America every year, IMUM 2016 was held at LEGOS Ocean Science Laboratory in Toulouse, and IMUM 2015 was held at the Center for Coastal Margin Observation and Prediction (CMOP) in Portland.

The IMUM workshops bring together researchers working on the development and implementation of multiscale methods for simulation of oceanic processes over a wide range of scales ranging from global ocean modeling to small-scale, nonhydrostatic modeling. Although unstructured grids are ideally suited to multiscale ocean modeling problems, the workshop also includes discussion on application of multiscale structured grid methods (such as model nesting, quad/oct-tree methods, and adaptive mesh refinement). Topics of discussion range from application of multiscale models to numerical methods and computational algorithms, as well as grid generation, graphical visualization, data analysis, and implementation of software packages.

Invited speakers

Ethan Kubatko, Ohio State University
Sigrun Ortleb, University of Kassel
Natalja Rakowsky, Alfred Wegener Institute
Guus Stelling, Delft University of Technology
Jenny Suckale, Stanford University
Phillip Wolfram, Los Alamos National Laboratory

Local organizing committee

Oliver Fringer, Stanford University
Frank Giraldo, Naval Postgraduate School

International scientific committee

Antonio Baptista, Oregon Health & Science University
Sergey Danilov, Alfred Wegener Institute for Polar and Marine Research
Clint Dawson, University of Texas at Austin
Eric Deleersnijder, Universitè Catholique de Louvain
Pierre Lermusiaux, Massachusetts Institute of Technology
Florent Lyard, LEGOS, University of Toulouse
Julie Pietrzak, Delft University of Technology
Matthew Piggott, Imperial College London
Todd Ringler, Los Alamos National Laboratory
Jenny Suckale, Stanford University
Joannes Westerink, University of Notre Dame

Acknowledgments

Carmen Torres made everything happen and flow smoothly! Thank you Carmen! Also special thanks to Wenhao Chen and Yun Zhang who created the abstract book and helped out during the workshop.

Financial support was provided by the Stanford Department of Civil and Environmental Engineering and the Stanford Institute for Computational and Mathematical Engineering

Ateljevich, Eli et al.: Bathymetric representational error and smoothing in terrain conforming coordinates

Eli Ateljevich[1], Rueen-fang Wang[1], Fei Ye[2] and Yinglong Zhang[2]

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Bathymetry is a fundamental forcing in shallow water hydrodynamics, and technology such as multi-beam sonar and lidar have burgeoned to the point where a typical numerical simulation in a major estuary spans a mosaic of oversampled and undersampled geometry. Grid processing techniques vary depending on the topology of the numerical mesh, centering of variables in the numerical discretization and type of vertical coordinate system. Here we consider two sources error that can occur in the configuration of terrain-conforming meshes using a mesh of finite precision over a detailed bathymetry. We will review how simple point sampling at nodes generates aliasing, noise and shoal-channel bias on a terrain-conforming mesh. We introduce anisotropic smoothing techniques and vertical meshing strategies we employ in the San Francisco Bay Delta to mitigate these problems, smoothing subgrid variation in a way that preserves topological connectivity, respects most important moments (volumes, areas, centroids) in 2D and 3D and avoids numerical mesh-induced dissipation that varies with depth. We compare these techniques to smoothing techniques often used in terrain-conforming coordinates to avoid pressure gradient errors, the Hannah-Wright filter. Using the Chesapeake Bay we describe how this type of filtration distorts channel-shoal geometry and results in spurious physics.

Citation: Ateljevich, E., Wang, R., Ye, F. and Y. Zhang, 2017, Bathymetric representational error and smoothing in terrain conforming coordinates, The 16th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, Stanford, CA, USA, Aug 29-Sep 1.

Candy, Adam S. et al.: A multiscale analysis of the stability of Caribbean coastal ecosystems through the biogeomorphic modelling of its complex bays and inlets

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The Dutch Caribbean consists of two island groups, the Leeward Antilles off of the Venezuelan coast separated from the Windward Islands east of Puerto Rico over distances of the scale of the Caribbean Sea itself. Future changes in climate are predicted to impact the Caribbean Sea with rising sea levels, warming waters and changing eddy fields. Warming waters lead to an increase in the intensity and occurrence of tropical storms and hurricanes, and are linked to an increased risk of surge flooding. Changing eddy fields are likely to affect the path of storm tracks. All of which further influence the environment of the Caribbean and stability of its ecosystems.

Climate change will potentially have a significant effect on the biogeomorphological development of bays and lagoons here. It is a challenge to predict the consequences of such extreme events, as well as of more gradual changes and their impact on the islands of the Dutch Caribbean, and their marine ecosystems. To analyze the effect of the resultant stressors, including changes in regional sea level, wave climate, flushing of bays and lagoons, warming and biogeomorphic feedbacks, we apply a novel strategy: downscaling from climate simulations, to a regional ocean model including waves, to biogeomorphodynamic modelling at the scale of the local bays and lagoons. These effects are driven by global scale processes, yet have a regional impact at the scale of the entire Caribbean Sea, as well as at the scale of the individual bays and lagoons.

The wide range of spatial and temporal scales linking the large global-scale dynamics down to the local effects on Caribbean ecosystems demands a multiscale modelling approach. In this presentation we will detail how this challenge is being tackled by an international multi-disciplinary team — lead by the three Dutch institutes: TU Delft, IMAU and NIOZ — in order to establish a connection between global climate changes and local ecosystem effects, and evaluate the impact to ecosystems in small-scale lagoons and bays.

Citation: Candy, A. S., Pietrzak, J. D., Zijlema, M. and SCENES team, 2017, A multiscale analysis of the stability of Caribbean coastal ecosystems through the biogeomorphic modelling of its complex bays and inlet, The 16th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, Stanford, CA, USA, Aug 29-Sep 1.

Chen, Wenhao et al.: An unstructured-grid, cut-cell model for scour simulation

Wenhao Chen, Sarah L. Billington and Oliver B. Fringer

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We propose a new unstructured-grid, cut-cell, Reynolds-average Navier-Stokes model based on SUNTANS to simulate scour formation. Unstructured grids are utilized in the horizontal direction to model complex natural and built geometries. For the vertical discretization, a z-level grid is employed with the use of cut cells to ensure that the bottom faces of the bottom-most cells are aligned with the bottom. Such an approach is particularly useful for the simulation of extensive scour for which bottom-following grids may not be suitable owing to the potential for high grid skewness. We employ a finite-volume discretization for the suspended sediment which is defined at cell centers, along with an Exner equation for the bed height which is defined at the cell nodes. The discretization is guaranteed to conserve suspended sediment and bed mass, both locally and globally, in the presence of scour and a moving free surface. The model is validated against several laboratory experiments including scour around a circular cylinder, in a curved channel, and beneath a sluice gate.

Citation: Chen, W., Billington, S. L. and O. B. Fringer, 2017, An unstructured-grid, cut-cell model for scour simulation, The 16th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, Stanford, CA, USA, Aug 29-Sep 1.

Choudhary, Gajanan et al.: Algebraic coupling of 2D and 3D shallow water finite element models

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Baroclinicity in oceans may necessitate the use of 3D shallow water (SW) models for accurate description of physics. Particularly for baroclinic flows near coastal areas where frequent wetting and drying occurs due to tides and wind, we need a 3D SW model that can handle wetting and drying. Various methods for wetting and drying are available for 2D SW models, but it remains a challenge for 3D SW models. In this presentation, we propose using non-overlapping coupled 2D-3D models for taking advantage of well- tested 2D wetting-drying techniques and avoiding the complexities of 3D wetting and drying. We develop a theory for algebraic coupling of 2D and 3D SW models in a conforming, continuous Galerkin finite element framework, with mass and momentum conservation across the 2D-3D interface built into the coupling. We verify 2D-3D coupling against two test cases with known analytical solutions and also compare the results with those of equivalent full-2D and full-3D SW models. We will also demonstrate an application of 2D-3D coupling that involves wetting and drying.

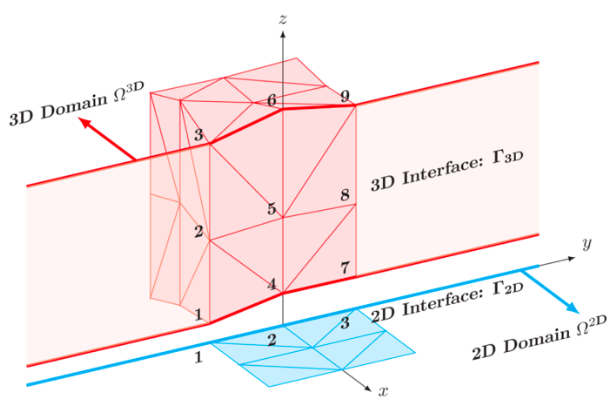

Figure 1. Example of a non-overlapping, conforming, coupled 2D-3D shallow water finite element model

Citation: Choudhary, G., Trahan, C., Pettey, L., Farthing, M. and C. Dawson, 2017, Algebraic coupling of 2D and 3D shallow water finite element models, The 16th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, Stanford, CA, USA, Aug 29-Sep 1.

Dresback, Kendra et al.: A coupled meteorologic-hydrologic-hydrodynamic model for an integrated scenario-based evacuation framework

Kendra Dresback[1], Randall Kolar[1], Rachel Davidson[2], Brian Blanton[3], Brian Colle[4], Tricia Wachtendorf[2], Linda Nozick[5], Humberto Vergara[1], Yang Hong[1], Kun Yang[2], Sarah DeYoung[6] and Nicholas Leonardo[4]

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In hurricane evacuation, three important aspects must be considered: 1) there is great uncertainty in how they evolve, 2) there are many interactions within and across the natural, infrastructure, and human systems, and 3) they are dynamic. Evacuation decisions tend to be complex due to the inherent uncertainty within the hurricane events and the interconnectivity of the evolutions of the system. There has been significant research into hurricane forecasting and evacuations; however, none of these have looked at the connection of these three important aspects – dynamics, uncertainty, and system interactions. Our work has developed a new integrated modeling framework, which works to explicitly capture these three important aspects. This framework models the hazards associated with the hurricane using an ensemble of probabilistic scenarios for the possible ways a hurricane may evolve. For each scenario, the system develops time-dependent, total water level and wind speed maps, along with capturing the dynamic decision-making of emergency managers and residents, and the dynamic movement of residents over the course of the event. Within the framework, we use a multi-stage stochastic programming model that integrates the hazards, resident behavior, and traffic modeling to support the dynamic decision-making of the emergency managers. The system provides information on when and where to issue evacuation orders during an event. In this presentation, we will provide an overview of the component parts of the framework, how they are dynamically coupled, and the results it provides in the context of a case study based on Hurricane Isabel in 2003.

Citation: Dresback, K., Kolar, R., Davidson, R., Blanton, B., Colle, B., Wachtendorf, T., Nozick, L., Vergara, H., Hong, Y., Yang, K., DeYoung, S. and N. Leonardo, 2017, A coupled meteorologic-hydrologic-hydrodynamic model for an integrated scenario-based evacuation framework, The 16th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, Stanford, CA, USA, Aug 29-Sep 1.

Greenberg, David: What can you do with a 2D model?

David Greenberg

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Large scale climate change predictions and detailed biological models require ocean simulations that include full consideration of vertical and horizontal of structures in the temperature and salinity fields as well as 3D dynamics. These tend to be expensive and time consuming to run, limiting the experimentation and parameter exploration that can be easily performed. In this presentation we use the Toulouse Unstructured Grid Ocean model (T-UGOm) in 2D time-stepping mode in short runs on a desktop computer to make preliminary examinations of two scenarios. In a channel in the southern Canadian Arctic Archipelago, biological hot spots are related to areas of strong tidal currents. In the Northwest Atlantic, boundary and tidally driven flows are seen to produce several features of the mean circulation.

Citation: Greenberg, D., 2017, What can you do with a 2D model?, The 16th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, Stanford, CA, USA, Aug 29-Sep 1.

Hanert, Emmanuel et al.: High-resolution marine connectivity modelling in the Florida Coral Reef Tract

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High-resolution ocean circulation models are required to simulate the complex and multi-scale currents that drive physical connectivity between marine ecosystems. However, standard coastal ocean models rarely achieve a spatial resolution of less than 1km over the >100km spatial scale of dispersion processes. Here we use the high-resolution unstructured-mesh coastal ocean model SLIM that locally achieves a spatial resolution of 100m over the scale of the entire Florida Coral Reef Tract (FCRT). By coupling SLIM with a biophysical model of larval dispersal we can track the position of virtual larvae released into the simulated domain. Connectivity matrices are then generated from the positions of the particles at the start and at the end of the simulations. By using different connectivity measures and clustering methods, we can highlight the fine details of the connectivity patterns linking the different reefs of the FCRT. These indicators are then used to pinpoint the reefs that would need to be protected in priority and those that would be best suited to coral restoration projects. Our model is currently the first to simulate larval dispersal with such a high resolution between the thousand reefs composing the FCRT. By individually measuring each site's potential as a larval source or sink, we can provide new insights to reef restoration and protection strategies.

Citation: Frys, C., Henaff, M. L., Figueiredo, J., Lambrechts, J., Saint-Amand, A., Vallaeys, V. and E. Hanert, 2017, High-resolution marine connectivity modelling in the Florida Coral Reef Tract, The 16th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, Stanford, CA, USA, Aug 29-Sep 1.

Jain, Pushkar Kumar et al.: Dynamically adaptive data-driven simulation of extreme hydrological flows

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Hydrological hazards such as storm surges and tsunamis are physically complex events that are very costly in loss of human life and economic productivity. Such disasters could be mitigated through improved emergency evacuation in real-time, and through the development of resilient infrastructure based on knowledge of how systems respond to extreme events. Data-driven computational modeling is a critical technology underpinning these efforts. Our investigation will focus on the novel combination of methodologies in forward simulation and data assimilation. The forward geophysical model will be based on adaptive mesh refinement (AMR), a process by which a computational mesh can adapt in time and space to the current state of a simulation. The forward solution will be combined with ensemble based data assimilation methods, whereby observations from an event can be assimilated to improve the veracity of the solution. The novelty in our approach is the tight two-way coupling of AMR and ensemble filtering techniques. The technology will be tested with twin experiments and using actual data from the event of Chile tsunami of February 27, 2010.

Citation: Jain, P. K., Mandli, K., Hoteit, I., Knio, O., and C. Dawson, 2017, Dynamically adaptive data-driven simulation of extreme hydrological flows, The 16th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, Stanford, CA, USA, Aug 29-Sep 1.

Ju, Lili et al.: Fast CVT grid generation for ocean modeling: a Lloyd-preconditioned L-BFGS method in parallel

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Centroidal Voronoi tessellation (CVT) is a desired technique for creating high-quality Voronoi meshes and their dual Delaunay triangulations, which is particularly crucial in climate modeling using finite volume schemes. Current CVT techniques for generating meshes with high-regularity and high-resolution have limitations either in the iterative solvers or in parallelization: (1) The Limited-memory BFGS (LBFGS) method has been used to significantly speed up the classical Lloyd's method, but a further improvement using the graph Laplacian preconditioner can be troublesome for high-resolution grids due to its limitation on the thorough reduction of CVT energy and on the efficiency of solving large-scale linear system; (2) Deterministic CVT algorithms call for the determination of multiple Delaunay triangulations, but available Delaunay softwares are mostly serial ones. In this paper, we propose a Lloyd-preconditioned LBFGS method for CVT construction on sphere for ocean modeling, which is also applicable in general domains. Our algorithm is parallelized based on the overlapping domain decomposition, enabling excel- lent scalability in distributed systems. Various tests are presented, and the results show that compared with existing methods, computational times of our method could be one order of magnitude smaller in generating highly variable multi-resolution meshes, while providing significantly improved mesh quality. It is expected for our meshing method to play an important role in the next generation of climate modeling, where the overall spacing scale changes dramatically and could be as small as 100 meters.

Citation: Yang, H., Gunzburger, M. and L. Ju, 2017, Fast CVT grid generation for ocean modeling: a Lloyd-preconditioned L-BFGS method in parallel, The 16th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, Stanford, CA, USA, Aug 29-Sep 1.

Kleptsova, Olga and Pietrzak, Julie: High resolution tidal model of the Canadian Arctic Archipelago

Olga Kleptsova and Julie Pietrzak

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A high resolution tidal model of the Canadian Arctic Archipelago including Baffin Bay, Hudson Strait and Hudson Strait and Hudson Bay was developed, calibrated and validated against available data. Although, the modeled and observed water level and current are in reasonable agreement, the comparison shows many strange features which are difficult to interpret. It is likely that some of the model-data mismatch is due to important seasonal changes in the tidal constants.

A potential damping mechanism that dissipates tidal energy, modifies the tidal phase, is the friction produced at the interface between the ice and the ocean. Frictional effects of the ice cover were represented in the model through a quadratic stress on the ice-ocean interface with a drag coefficient computed based on the fractional sea ice coverage. We used the same parameterization as in Collins et al. (2011), however, allowed the sea ice coverage to vary with time. Comparison with a number of tide gauge records showed that the seasonal cycle reproduced by the model reasonably well on the west of the Archipelago, however not in the Labrador Sea and Hudson Bay.

Recent studies show the potential of the seasonal tidal variability not only in the Subarctic ocean (Fok et al. (2013)), but also globally (Muller et al. (2014)). Therefore, the range of seasonal variations of the tidal constants at the open boundary and its importance for the correct reproduction of the tidal dynamics in the whole Archipelago was assessed.

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Citation: Kleptsova, O. and J. Pietrzak, 2017, High resolution tidal model of the Canadian Arctic Archipelago, The 16th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, Stanford, CA, USA, Aug 29-Sep 1.

Kopera, Michal A. et al.: Towards a non-hydrostatic fjord circulation model using high-order continuous/discontinuous Galerkin method and non-conforming unstructured mesh

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Ice-sheet/ocean interaction in Greenland is one of the key outstanding challenges in climate modeling, yet present-day climate models are not able to resolve fine-scale processes in the fjords. This is due to orders of magnitude difference in spatial scales between the open ocean (~1000km) and fjord (<1km) as well as complex bathymetry and coastline.
I will be presenting the progress of the NUMO project (Non-hydrostatic Unified Model of the Ocean), which goal is to develop a non-hydrostatic ocean model able to resolve ice-sheet / ocean interactions, circulation within the fjord and exchanges with the ocean. As a proof-of-concept, we focus on Sermilik Fjord and Helheim glacier system. An unstructured mesh is used to realistically represent the geometry of the fjord, while in the areas of particular importance (i.e. glacier front) the resolution is increased by non-conforming mesh refinement. NUMO models the ocean using the incompressible Navier-Stokes equation discretized with unified continuous/discontinuous Galerkin method. The long-term goal is to simulate all Greenland"s fjords and adjacent coastal ocean and couple this simulation to regional or global Earth System Models.

Citation: Kopera, M. A., Maslowski, W. and F. X. Giralda, 2017, Towards a non-hydrostatic fjord circulation model using high-order continuous/discontinuous Galerkin method and non-conforming unstructured mesh, The 16th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, Stanford, CA, USA, Aug 29-Sep 1.

Korn, Peter: The unstructured grid ocean model ICON-O

Peter Korn

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We describe the ocean model ICON-O, the ocean component of the newly developed Earth System Model MPI-ESM-2 of the Max Planck Institute for Meteorology and the ocean model of the ICON modelling system. ICON-O is a global general circulation model, formulated on an icosahedral grid with triangular cells and an Arakawa C-staggering. The models dynamical core as well as its oceanic parameterizations use a coherent structure-preserving discretization that is an amalgam of finite-element, finite volume and mimetic discretization methods. We present a numerical analysis of the models and present results from numerical experiments that range from global ocean simulation to first coupled simulations involving atmosphere, sea-ice and land models.

Citation: Korn, P., 2017, The unstructured grid ocean model ICON-O, The 16th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, Stanford, CA, USA, Aug 29-Sep 1.

Kramer, Stephan C. et al.: Modelling the coastal zone using Thetis

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[2]Center for Coastal Margin Observation & Prediction, Oregon Health & Science University, Portland, OR, USA

The coastal zone around the British Isles provides a number of challenges for numerical models: there are regions with very high tidal currents and places with a large tidal range including extensive wetting and drying. The high energy tidal flow is also what makes this area of great interest to tidal renewable energy schemes. More generally, there are many other engineering activities that require reliable modelling of the flow, the prediction of changes in the flow due to human activities, and the impact of those on the environment. The interaction of small-scale engineering structures and the larger scale flow is a multi-scale problem that benefits from the use of unstructured mesh methods.

Thetis is an unstructured-mesh, finite-element model that solves both the depth-averaged, as well as the three-dimensional equations with applications in the coastal zone and estuaries. It is based on Firedrake which is a finite element framework, that automatically derives highly optimized code from a high-level-abstraction description of the finite element equations. This allows for flexibility with respect to the exact choice of discretization without compromising the efficiency of the model. In this talk we will present progress on the development of Thetis through a number of case studies situated in the UK coastal zone.

The Severn estuary has one of the world's highest tidal ranges, and therefore has huge potential for tidal elevation based renewable energy schemes. Plans for a tidal lagoon in Swansea Bay are in an advanced stage of approval. The estuary includes large tidal flats which require a robust wetting and drying scheme. We will present the ability of Thetis to represent the current flow patterns, as well as the impacts of an operating tidal lagoon. We will also show some preliminary results from a model of the Solent, the strait that separates the Isle of Wight from the mainland.

One of the key advantages of a hydrodynamic model based on the Firedrake framework is that it allows for a straightforward and completely automated derivation of its adjoint. The gradient information this provides can be used in highly efficient gradient-based optimization algorithms that optimize a chosen outcome of the model with respect to its input parameters. We will present the results of the optimization of the power output of tidal energy extraction in the Alderney Race between the Alderney channel island and the mainland of France. This poses an interesting optimization problem where energy extraction in UK and French territorial waters are potentially competing.

Citation: Kramer, S. C., Kärnä, T., Coles, D., Angeloudis, A., Avdis, A. and M. D. Piggott, 2017, Modelling the coastal zone using Thetis, The 16th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, Stanford, CA, USA, Aug 29-Sep 1.

Kubatko, Ethan (Invited): Discontinuous Galerkin methods and supporting computational tools for shallow water modeling

Ethan Kubatko

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Discontinuous Galerkin (DG) finite element methods exhibit a number of favorable properties for modeling shallow water (and related) flows — properties that include their ability to handle advection-dominated flows, their extremely high parallel efficiency and the relative ease with which both h (mesh) and p (polynomial) refinement can be implemented. This talk will highlight the development and application of a suite of DG models for one-, two- and three-dimensional shallow water flow, overland flow due to rainfall and spectral wave modeling. Supporting computational tools that are used within the context of these models will also be discussed, which include an advanced unstructured mesh generator that we have developed, called AdMesh+, that seeks to simplify and streamline the mesh generation process. A number of applications that demonstrate the accuracy, efficiency and robustness of the developed modeling framework will be presented, including the investigation of wind-driven waves on the Great Lakes, the modeling of hurricane storm surge in the Gulf of Mexico region and the simulation of coupled overland flow and channel routing in watersheds.

Citation: Kubatko, E., 2017, Discontinuous Galerkin methods and supporting computational tools for shallow water modeling (Invited), The 16th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, Stanford, CA, USA, Aug 29-Sep 1.

Lee, Dave: Mixed mimetic spectral elements for geophysical flows

Dave Lee

Los Alamos National Laboratory, Santa Fe, NM, USA

This talk will discuss the potential application of mixed mimetic spectral element methods to geophysical flows. These recently developed discretization schemes preserve the generalized Stokes theorem and identities of vector calculus in the discrete form (Kreeft, J. and Gerritsma, M., 2013), and in doing so are able to conserve higher moments such as energy and potential enstrophy which control the turbulent cascades in geophysical fluids, while also providing higher order accuracy. Through the use of spectral element edge functions (Gerritsma, M., 2011) the fundamental theorem of calculus is satisfied in 1D, and tensor product combinations of standard nodal and edge basis functions allow for the exact preservation of the Kelvin-Stokes and divergence theorems in higher dimensions. With differentiation representing a mapping between manifolds these properties are satisfied pointwise for differential mappings to higher dimensional manifolds, and in the weak form for differential mapping to lower dimensional manifolds.

Using this method of mixed mimetic spectral elements a solver for the rotating shallow water equations will be presented (Lee, D. et al., 2017). The continuity equation is solved in the strong form and so conserves mass pointwise. The rotational form of the momentum equation is solved in the weak form and allows for the global conservation of vorticity, with no spurious projection of energy onto the vorticity space, since the curl operator exactly annihilates the gradient operator in the discrete form. Quadratic moments (energy and potential enstrophy) are conserved to truncation error in time, while potential enstrophy conservation is contingent upon exact spatial integration. These results are demonstrated through both formal proofs and numerical experiments.

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Masunaga, Eiji et al.: Nonlinear internal wave dynamics and sediment transport processes investigated with the SUNTANS model

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Internal tides are ubiquitous phenomena in the ocean and are key to understanding mixing and mass transport processes. When they propagate onto continental shelves, internal tides become nonlinear and are accompanied by strong currents and mixing as they propagate into shallow regions. Recent observational studies indicate strong mixing and sediment resuspension events caused by breaking of internal tides in coastal oceans. In this presentation we will present results of the unstructured grid SUNTANS model applied to study nonlinear internal wave processes in the vicinity of islands located on the Izu-Ogasawara Ridge, off the Japan mainland. Barotropic tides propagate over this ridge and generate strong barotropic tidal flows which result in strong internal tide generation. We show that internal tides with the diurnal K1 frequency are trapped and resonate around the islands, which results in highly nonlinear internal wave motions and a strong diurnal internal wave energy flux. Resonance and nonlinear processes like shoaling and lee-wave generation produce higher-frequency waves that, unlike the diurnal waves that are evanescent, can radiate from the island because they are superinertial. In addition, the internal tides enhance bottom stress and mixing resulting in offshore transport of sediments.

Citation: Masunaga, E., Fringer, O. B. and H. Yamazaki, 2017, Nonlinear internal wave dynamics and sediment transport processes investigated with the SUNTANS model, The 16th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, Stanford, CA, USA, Aug 29-Sep 1.

Nugraha, Adi et al.: On 3-D thermal simulation in a fast moving reservoir

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One of the important hydrodynamic characteristics of a reservoir is thermal stratification. It can largely govern the fate and transport of contaminants, water quality, and fish migration pathways in the reservoir. Reproducing strong thermal stratification a in a complex 3D environment in the vicinity of a hydropower dam is challenging. While short duration simulation of hydrodynamics near hydropower structures may be conducted using conventional CFD solvers, thermal stratification develops over several months requiring year-long simulation with atmospheric heat exchange through the free surface. Maintaining stratified environment in a fast flowing turbulent environment poses a particular challenge for typical 3D circulation models. This study evaluates thermal structure during the summer month from June through September under different flow condition using a well-known Navier Stokes coastal and ocean 3D hydrodynamics model, SUNTANS, in the fast moving Hell Canyon Reservoir. While this model has been used extensively for stratified flows in estuaries, its ability to maintain stratified conditions in deep narrow reservoirs under high flow conditions has not been tested. The model was calibrated and validated using flow and temperature data from years 2013 and 2014, respectively. The results show good agreement between model results and observed data for both years 2013 and 2014; values of absolute mean error and root mean squared error values were less than 1^{o}C at most stations. A qualitative comparison of observed velocities with simulated values was generally matched the observed data well. By comparing two hydrographic years, we found that the thermal stratification is not only controlled by the net atmospheric heat flux but also by the relative temperature difference of the inflow inducing density flows. This study demonstrated that SUNTANS is capable to examine the thermal stratification processes at high level of satisfactory in the reservoir.

Citation: Nugraha, A., Khangaonkar, T. and S. Brink, 2017, On 3-D thermal simulation in a fast moving reservoir, The 16th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, Stanford, CA, USA, Aug 29-Sep 1.

Ortleb, Sigrun (invited): Discontinuous Galerkin schemes on un-structured meshes for shallow water flows with wetting and drying: insights into positivity preserving implicit time integration

Sigrun Ortleb

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Advancing and receding water fronts are an important aspect of coastal ocean flows demanding a robust and efficient numerical simulation. In this talk, the flow is modelled by the 2D shallow water equations and discretized by the discontinuous Galerkin method on fixed unstructured grids. The challenge is to obtain a mass conservative scheme which is well-balanced, i.e. preserves stationary flows, and robustly extends to the dry areas of the computational domain. For explicit time integrators, a suitably small time step and certain limiting procedures usually guarantee the non-negativity of the water height. Nonetheless, in case of very small cells in nearly dry regions, explicit time integration can be limiting. Hence, implicit schemes are considered which preserve the non-negativity of the water height for arbitrarily large time steps. From a theoretical point of view, the positivity preserving properties of the implicit Euler method are a key concept to the non-negativity of the water height, hence the corresponding mathematical theory will be highlighted. Furthermore, higher order unconditionally positive time integrations schemes which are based on the so-called Patankar approach will be presented. The implementation of implicit time integration usually employs Newton-type nonlinear solvers incorporating Krylov subspace techniques to solve the resulting linear systems. In this context, numerical evidence shows that precisely the limiting procedures which generate the success of explicit wetting and drying procedures have to be carefully reformulated in case of implicit schemes. Appropriate approaches will be provided preserving non-negativity of the water height combined with fast convergence of the nonlinear and linear solvers employed to solve the resulting nonlinear systems of equations.

Citation: Ortleb, S., 2017, Discontinuous Galerkin schemes on un-structured meshes for shallow water flows with wetting and drying: insights into positivity preserving implicit time integration, The 16th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics (invited), Stanford, CA, USA, Aug 29-Sep 1.

Petersen, Mark et al.: Ocean-ice shelf interactions in Antarctic ice shelf cavities

Mark R. Petersen[1], Xylar Asay-Davis[2], Jeremy Fyke[1], Jon Wolfe[1], Matthew J. Hoffman[1], Stephen F. Price[1], Todd Ringler[1], Adrian Turner[1] and Luke Van Roekel[9]

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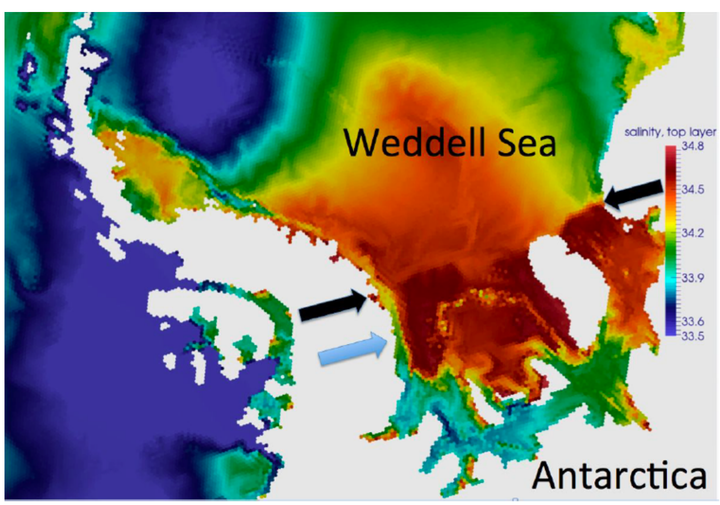
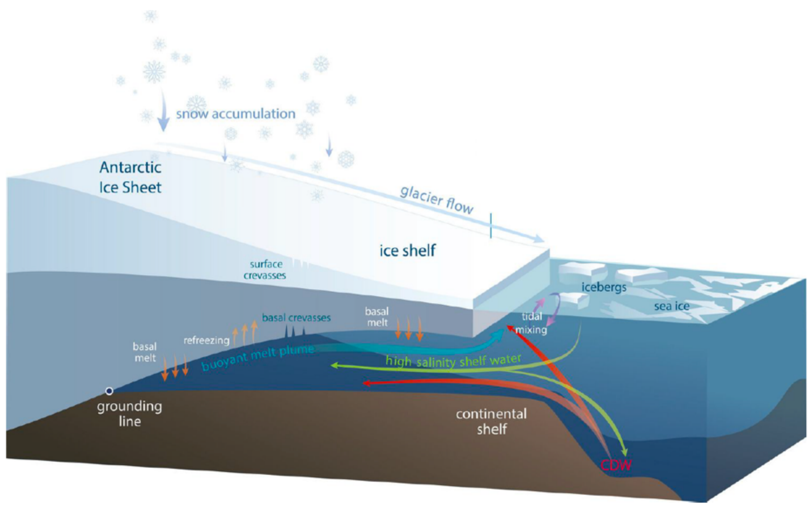
The U.S Department of Energy's Accelerated Climate Model for Energy (ACME) includes new ocean, land-ice, and, sea-ice components using the Model for Prediction Across Scales (MPAS) framework MPAS provides an unstructured variable-resolution capability for each of these components allowing for global, coupled, high-resolution ACME simulations to be run efficiently on large, high-performance computers. Recently, the ability to simulate ocean circulation in ice shelf cavities has been added to ACME. This new science capability is critical for projecting Antarctica's potential future contributions to global sea level, which is one of ACME's primary science drivers. Here, we discuss results of initial simulations using this new capability. These simulations range from idealized, benchmark experiments primarily meant for model verification, to global, CORE-forced and fully-coupled simulations using a range of model configurations (down to and including eddy-resolving grid resolutions). Analysis of global simulations are currently focused on validation, using observed sub-marine melt rates and other relevant oceanographic features, and the identification and minimization of coupled model biases. We also discuss preliminary results from perturbation experiments in the spirit of Spence et al. (GRL, 41, 2014), which aim to examine the impacts of anticipated future changes to Southern Ocean winds on submarine melt rates, Antarctic ice sheet dynamics, and ultimately Antarctic-sourced sea level rise.





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Citation: Petersen, M. R., Asay-Davis, X., Fyke, J., Wolfe, J., Hoffman, M. J., Price, S. F., Ringler, T., Turner, A., and L. Van Roekel, 2017, Ocean-ice shelf interactions in Antarctic ice shelf cavities, The 16th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, Stanford, CA, USA, Aug 29-Sep 1.

Pieper, Konstantin et al.: Exponential time differencing for large time stepping in variable resolution ocean modeling

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MPAS-Ocean utilizes a multi-resolution mesh that resolves sensitive scales with a locally refined mesh. This allows for a reduction in computation time in the coarse regions. However, due to the CFL-condition, the global time-step of explicit methods is restricted by the smallest grid cell. To address this, we explore the use of exponential time differencing (ETD). ETD methods allow for large time-steps, while still retaining key properties of explicit integrators. We investigate a modified ETD-Rosenbrock scheme applied to the rotating shallow water equations, discretized by the TRiSK scheme. We prove conservation of mass up to machine precision and demonstrate stability for large time-steps (orders of magnitude above the CFL-compliant ones), and conservation of energy up to a time-truncation error. The main difficulty in the implementation arises in the computation of the phi-functions of the ETD-method, which are usually resolved by Krylov-subspace methods. Here, we exploit the energy conserving properties of the underlying spatial scheme and replace the Arnoldi process by a skew-Lanczos process with respect to a care-fully chosen inner product, which significantly reduces computation time. Additionally, we describe the extension towards a multi-layered model and the efficient parallel implementation in the context of the MPAS framework. Computational results are shown for double gyre and Gaussian pulse test cases.

Citation: Pieper, K., Sockwell, K. C., Leng, W., and M. Gunzburger, 2017, Exponential time differencing for large time stepping in variable resolution ocean modeling, The 16th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, Stanford, CA, USA, Aug 29-Sep 1.

Pietrzak, Julie et al.: The stability of Caribbean coastal ecosystems under future extreme sea level changes: towards biogeomorphicdynamic modelling of Caribbean reefs under climate change

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We present SCENES project (PI: Henk Dijkstra, co-PI's: Pietrzak, Bouma); the overarching objective is to provide future scenarios of the long-term biogeomorphic development of calcifying algae under abiotic drivers, primarily sea-level rise. We give an overview of SCENES, and then focus on Project B, in which we investigate the impact of changing wave climate on the biogeomorphdynamic evolution of Caribbean bays. With climate projections warning of sea level rise and increased frequency and severity of storms, it is important to understand the potential consequences of climate change on these fragile ecosystems. To do this we adopt a multi-scale, multi-model approach. Downscaling from the POP climate model, to a regional ADCIRC-SWAN model, to a bay model for which we are developing a biogeomorphodynamic model for Delft3D. The POP model provides information on changing sea-level due to eddies, seasonal and long term changes. To simulate tides and storm surge, we refine the validated, regional Gulf of Mexico and Caribbean ADCIRC-SWAN model developed by Gonzalez-Lopez, https://curate.nd.edu/show/3n203x8345f. Furthermore, recent developments of Shingle https://github.com/adamcandy/Shingle have allowed for high quality grids with resolutions suitable for basin scale to bay scale modelling. To simulate the biogeomorphodynamic response we use the advanced sediment modules available in Delft3d, and further develop these to allow for calcifying sediments. Here we discuss our first results carried out with the available model and progress in refining the grids down to bay scales, as well as our plans to further validate the refined model before carrying out multi-decade scale hindcast and forecast runs.

Citation: Pietrzak, J. D., Candy, A. S., Zijlema, M., and SCENES team, 2017, The stability of Caribbean coastal ecosystems under future extreme sea level changes: towards biogeomorphicdynamic modelling of Caribbean reefs under climate change, The 16th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, Stanford, CA, USA, Aug 29-Sep 1.

Proft, Jennifer and Dawson, Clint: Influence of storm characteristics on hurricane flood surge

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Significant advances have recently been made in physics-based hurricane storm surge modeling with high performance computing simulations. The highly accurate and robust SWAN+ADCIRC wave and circulation numerical model is efficient, operates on a single computational unstructured mesh, and seamlessly integrates both the pertinent physics and numerics of such a complicated physical system. Our research employs this model on a high-resolution mesh incorporating the Western Atlantic, Gulf of Mexico and Texas coastlines. All high-performance computing simulations are performed on the Texas Advanced Computing Center's supercomputers.

The severity of hurricanes in the United States has traditionally been measured by the Saffir-Simpson scale, a simple model based solely on wind speed, resulting in a category 1-5 rating. However, reliance on this scale as an indicator of storm surge, the primary destructive force during a hurricane, leads to misconceptions of the impending danger by the public, emergency planners, and scientific community alike. As a potential impact measure, it inadequately provides accurate and reliable estimations of flood hazard and wind damage. The primary failure of the scale is its inability to account for important factors characterizing the generation of hydrodynamic surge other than solely wind.

Several recent studies have attempted to quantify the factors that affect storm surge behavior via computational. In this talk, it is shown that the size of a hurricane wind field, the intensity, and a newly proposed potential kinetic energy are much more indicative of resulting storm surge and related flooding. We present results of a suite of synthetic storms impacting the Galveston Bay, Texas area that demonstrates this phenomenon.

Citation: Proft, J., and C. Dawson, 2017, Influence of storm characteristics on hurricane flood surge, The 16th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, Stanford, CA, USA, Aug 29-Sep 1.

Rakowsky, Natalja et al. (invited): The FESOM model family – recent applications

Natalja Rakowsky, Sven Harig, Antonia Immerz, Sergey Danilov and Dmitry Sidorenko

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This contribution focuses on two applications of the FESOM model family. On the one hand, recent runs with the finite volume code FESOM2 on large global meshes with regional focus are presented.

FESOM's shallow water branch TsunAWI is the subject of the second part. TsunAWI, still based on finite elements, is used as an operational model in the Indonesia Tsunami EarlyWarning System (InaTEWS). InaTEWS derives tsunami forecasts in two different ways: from scenarios in a pre-computed database or from an on-the-fly simulation. The pre-computed scenarios are based on TsunAWI simulations with inundation on a triangular mesh with a resolution ranging from 20km in the deep ocean to 300m - 50m in coastal areas. The on-the-fly propagation model EasyWave (Andrey Babeyko, GFZ) solves the linear shallow water equations on a regular finite-difference grid with a resolution of about 1 km and the coast line as a vertical wall. EasyWave is used after a tsunami has been generated in an area not covered by the database or after seismic measurements show an earthquake mechanism not present in the database. As the numerical settings of both models are quite different, variations in the outputs are to be expected; nevertheless, the differences in the warning levels should not be too large for identical sources. In the current study, we systematically compare the warning products like estimated wave height and estimated time of arrival by the two approaches.

Citation: Rakowsky, N., Harig, S., Immerz, A., Danilov, S., D. Sidorenko, 2017, The FESOM model family – recent applications, The 16th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics (invited), Stanford, CA, USA, Aug 29-Sep 1.

Stelling, Guus (invited): On the integration of rainfall, free surface flow and ground water with detailed DEMs

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This contribution will be about modelling heavy rainstorms, drainage, ponding, flooding, infiltration and exfiltration of groundwater. For practical applications two aspects are important: (i) the bathymetry and (ii) the flow.

Ad(i): Due to advanced remote sensing techniques very detailed DEM's (digital elevation models) are nowadays available. For instance of the Netherlands height data is publicly available with a grid spacing of 0.5 m. Often there are more data points than can be handled by a numerical flooding simulation of a large area. The sub-grid method,(Casulli,2009), however allows the use of very detailed bathymetric data without the need for flow variables at every pixel. In urban areas not only the surface area is important but also the underground systems for sewage, drainage and even public transportation may be relevant for accurate flooding simulations. In rural areas the infiltration capacity of the soil plays a role as well. In our contribution we will show how the bathymetry is an integrated whole of the surface, the subsurface and underground network systems.

Ad (ii): To simulate surface flows due to dam breaks, or other causes such as rain storms and storm surges, two types play an important role: rapidly varied flow and overland flow. Rapidly varied flows, such as bores and hydraulic jumps, are dominated by conservation laws. Overland flow is dominated by friction. In our contribution we will describe what kind of additions (Stelling, 2012) to the sub-grid method are required to get accurate results for both flow types. In the subsurface there is groundwater flow and pipe flow. For ground water we use a simple Dupuit assumption. Pipe flow may be pressurized. Non-linearities due to for instance the transition from free surface flow to pressurized flow are solved by the Nested-Newton Method, (Casulli and Stelling, 2013). We also show how the interaction between surface water and groundwater, such as infiltration and exfiltration or seepage, is modelled.

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Citation: Stelling, G.S., 2017, On the integration of rainfall, free surface flow and ground water with detailed DEMs, The 16th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics (invited), Stanford, CA, USA, Aug 29-Sep 1.

Suckale, Jenny et al. (invited): Linking a shallow water model and large-eddy simulations to understand tsunami runup through coastal mitigation parks

Jenny Suckale[1], Simone Marras[2], Brent Lunghino[3], Beatriz Eguzkitza[4], Guillaume Houzeaux[4], Anne-Cecile Lesage[4], Francis X. Giraldo[5], Emil Constantinescu[6] and Michal Kopera[7]

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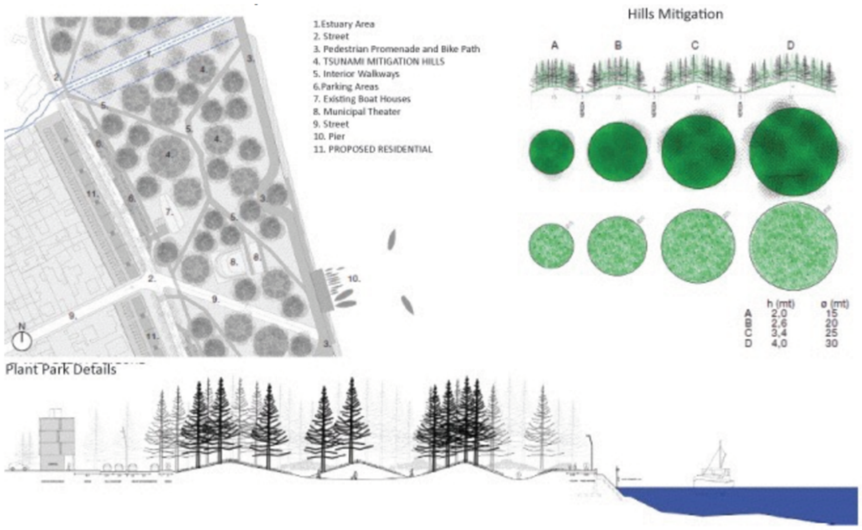
Coastal communities around the world are increasingly considering nature-based approaches to reduce tsunami risk. A common setup for these projects is to develop a coastal mitigation park – an ensemble of hills along the shoreline that are intended to dissipate some of the energy transported by the tsunami prior to impact with the build environment behind the park (see figure below). In this study, we attempt to inform the design of coastal mitigation parks through insights into the fluid-dynamical interactions of a tsunami with mitigation hills. We pursue two interconnected goals. As a first step, we simulate the three-dimensional flow of a bore around a single hill to better understand how the interaction of the turbulent flow with the hill affect the energy balance of the incoming tsunami. We solve the three-dimensional Navier-Stokes equations for incompressible flow with a free surface, discretized via linear finite elements with a fully implicit time integration, a variational multiscale method for stabilization and a dynamically adaptive Smagorinsky eddy viscosity. In the second step, we explore different park configurations and a variety of different incoming waveforms using the nonlinear shallow-water equation. We adopt the numerical model (NUMA2D), a 2D version of the NUMA model [Giraldo et al., 2002] and [Abdi and Giraldo, 2016].



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Citation: Suckale, J., Marras, S., Lunghino, B., Eguzkita, B., Houzeaux, G., Lesage, A., Giraldo, F. X., Constantinescu, E., and M. Kopera, 2017, Linking a shallow water model and large-eddy simulations to understand tsunami runup through coastal mitigation parks, The 16th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics (invited), Stanford, CA, USA, Aug 29-Sep 1.

Suh, Seung-Won et al.: Simulation of tidal asymmetry change induced by anthropogenic developments on the west coast of Korea in the Yellow Sea

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Multiple anthropogenic alterations performed for several decades in the Yellow Sea (YS) on the west coast of Korea (WCK) have changed the natural shorelines and yielded diverse unexpected results. Remarkable coastal hydrodynamic alterations can be found in tidal asymmetry, energy flux, dissipation, and far-field tidal distortion on the east coast of China. Thus, to mitigate unexpected consequences, profound examinations should be precisely conducted by considering the sea-level rise (SLR). To understand the alteration in tidal asymmetry due to SLR, gamma parameters were evaluated in this study by using the ADvanced CIRCulation (ADCIRC) model under finely resolved complex coastal geometry of the WCK. The shrinking of the tidal flat area because of multiple coastal developments has directly caused abrupt changes in near-field tidal hydrodynamics. Moreover, the completion of the Siwha dike in the Gyeonggi Bay (GGB) triggered a switch from ebb dominance to flood dominance based on the gamma and energy flux analyses. The Saemangeum dike construction led to near-field de-amplification of M2 but amplification on the opposite part of the YS in the Shandong area of China. Thus, the land reclamation effects propagate to both the near- and far-field areas in YS from Korea to China and vice versa. In GGB, the incorporation of future SLR through IPCC RCP scenarios of 4.5 and 8.5 showed an increase in their mean SLR by 0.64 and 0.82 m by 2100. In addition, hypothetical SLR scenarios of 1.0 and 2.0 m were simulated to assess further possible rise, and a nodal factor of 18.6 years was included in the analyses. Moreover, hypothetical cases involving the removal of the Siwha dike were tested to assess the potential for its restoration with or without the consideration of potential SLR. As a result of SLR, the tidal asymmetry could spatial change while gamma parameter intensity attenuated. M2 and M4 tidal energy fluxes would be lessened by the SLR. Considering energy dissipation, the lessening of the tidal flat area directly affected the reduction in M4; however, a slight change was observed in M2 based on the SLR scenarios. As a small change in tidal asymmetry could yield long-term morphological changes in the macrotidal environment, these alterations should be treated with importance. In addition, the removal of the Siwha dike, which was a tipping point on tidal asymmetry, cannot be undone even with an SLR scenario based on a numerical restoration test.

Citation: Suh, S., Kim, H., and J. Seok, 2017, Simulation of tidal asymmetry change induced by anthropogenic developments on the west coast of Korea in the Yellow Sea, The 16th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, Stanford, CA, USA, Aug 29-Sep 1.

Van Roekel, Luke: An assessment of the applicability of vertical mixing parameterizations to high resolution ocean and coastal models

Luke Van Roekel

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Many coastal and ocean models utilize vertical mixing parameterizations based on first order turbulence closure, where the vertical turbulent tracer flux is proportional to a diffusivity times a local gradient of tracer. The diffusivity can be determined in a number of ways: from a simple empirical function to a predicted sub-grid scale turbulence kinetic energy. Independent of how a vertical mixing parameterization determines diffusivity is an implicit averaging in space and time. This implies that within a model element, turbulence must be stationary and further that there are a sufficient number of turbulent structures for accurate statistics. As the spatial resolution of models decreases and the temporal resolution of forcing increases, these assumptions become tenuous. Yet, vertical mixing parameterizations developed for coarse resolutions and long time steps continue to be used. Here we evaluate two ubiquitous ocean vertical mixing parameterizations (K-Profile Parameterization and Mellor and Yamada Level 2.5) in a suite of oceanographically and coastally relevant forcing scenarios against Large Eddy Simulations. These tests reveal important considerations for the continued use of each of these common vertical mixing parameterizations and a few critical pathologies in certain scenarios. Further, sensitivity tests are conducted across a range of resolutions and forcing frequencies to determine the robustness and appropriateness of these schemes at very high spatial and temporal model resolutions.

Citation: Van Roekel, L., 2017, An assessment of the applicability of vertical mixing parameterizations to high resolution ocean and coastal models, The 16th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, Stanford, CA, USA, Aug 29-Sep 1.

Wan, Di et al.: Wind-driven response and mixing scheme studies in a narrow deep-silled fjord using ROMS

Di Wan, Charles Hannah, Mike Foreman, Patrick Cummins and Pramod Thupaki

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Douglas Channel is a narrow (4 – 5 km wide) and deep (400 m) fjord with a deep sill at 200 m depth located off the coast of northern British Columbia, Canada. Observations of the currents measured using ADCPs (Acoustic Doppler Current Profiler) show strong wind driven currents at the surface and counter-wind currents at mid-depth. We use an idealized model using ROMS (Regional Oceanographic Modeling System) to study the wind-driven mixing and circulation at the surface and at depth. Sensitivity tests are conducted to explore how the surface currents and mixed layer depth respond to different vertical mixing scheme, stratification, and vertical grid configuration. Comparisons with observations made are used to suggest optimum values for similar systems.

Citation: Wan, D., Hannahm, C., Foreman, M., Cummins, P., and P. Thupaki, 2017, Wind-driven response and mixing scheme studies in a narrow deep-silled fjord using ROMS, The 16th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, Stanford, CA, USA, Aug 29-Sep 1.

Wang, Bing et al.: Model study of the effects of intensive aquaculture on residence time and nutrient transport in a coastal embayment

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In this talk we will present results from the SUNTANS model applied to study the impacts of aquaculture farming and the associated drag on residence times and nutrient cycling in a semi-closed coastal embayment. The focus is on Sanggou Bay, a 10 km bay in the Yellow Sea and one of the largest aquaculture sites in Northern China where large quantities of kelp and bivalves are cultivated on suspended raft networks. Drag from the aquaculture is parameterized for surface infrastructure, kelp canopies, and bivalve cages. A model for dissolved inorganic Nitrogen (DIN) includes transport, vertical turbulent mixing, and sediment and bivalve sources, and a kelp sink, with the primary source of DIN derived from the background concentration in the Yellow Sea. Test cases show that, due to drag by the dense aquaculture and a reduction of flushing, DIN from the Yellow Sea is consumed on the edges of the kelp farms before reaching their interior, where low DIN concentrations limit kelp production rates. Aquaculture drag also causes the residence time in the mid bay to increase from an average of 4 days without aquaculture to roughly 8 days with aquaculture. In parts of the bay along the inner shoal with lower than average flushing rates, the residence time increases from 25 to 40 days. Low flushing and a lack of a DIN sink by kelp farms in these regions make them susceptible to phytoplankton blooms due to high nutrient retention.

Citation: Wang, B., Cao, L., Fringer, O.B., Micheli, F., and R. Naylor, 2017, Model study of the effects of intensive aquaculture on residence time and nutrient transport in a coastal embayment, The 16th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, Stanford, CA, USA, Aug 29-Sep 1.

Westerink, Joannes et al.: High resolution unstructured grid hydrodynamic circulation model of the Indian Ocean, Western Pacific Ocean and adjacent marginal seas

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We have developed a comprehensive high resolution circulation model driven by tides and winds in the Indian Ocean, Southern Ocean, Western Pacific, and the connected marginal seas. Marginal seas such as the Yellow sea, the East and South China through the Arafura Seas, the Bay of Bengal, and the Arabian Sea. The tidal and wind driven circulation patterns are particularly complex in the marginal seas due to the shallow depths and the resulting standing waves. The circulation model ADCIRC is used to look at barotropic tides and seasonal and tropical wind driven events for the purpose of understanding the general dynamics of these regions, of specific interest are baroclinically driven dissipation along the shelf break and ridges, shelf dissipation, tide-wind driven eddy structures through island chains, and the interaction o these processes.

Towards this end we have developed a single un-structured grid to encompass the entire region providing adequate resolution over submarine ridges, shelf breaks, and shallow reef systems, in addition to highly resolved bays, ports and harbors important to the region. The method directly ties ocean scale dynamics to long term water levels available within intricate harbor complexes. The model system is driven by in-situ data, smart process-based coupling paradigms, and other models to achieve hydrodynamic consistency and accuracy. The understanding of the dissipation processes within the ocean basins, shallow seas, over reefs, shelf breaks and ridges, shelves, estuaries and bays is critical to the hydrodynamic performance of the model

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Wolfram, Phillip (invited): Shedding LIGHT on eddy-induced mixing via in-situ analysis in MPAS-Ocean

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The Model for Prediction Across Scales Ocean (MPAS-Ocean) [Ringer et al. 2013, Petersen et al. 2015] is an unstructured-mesh global ocean model designed to simulate decadal Earth System changes, e.g., sea level rise. It is a component of the Accelerated Climate Model for Energy (ACME), a high-performance Earth System Model sponsored by the Department of Energy. MPAS-Ocean provides the opportunity to do in-situ analysis in preparation for upcoming exascale high-performance computing architectures [Woodring et al. 2016]. Analyses like the Eliassen-Flux Palm Tensor [Ringerl et al. 2017] are only computationally tractable with this type of approach because they require native dynamical spatial and temporal fidelity for their computation. Another key MPAS-O capability is Lagrangian In-situ Global High-performance Particle Tracking (LIGHT) [Wolfram et al. 2015, Sebille et al. 2017], which provides a Lagrangian description of the ow that is comparable to the MPAS-Ocean Eulerian dynamical core.

A fundamental ocean property that determines oceanic heat sequestration is isopycnal diffusivity. We compute diffusivity using LIGHT in a zonally-periodic Idealized Circumpolar Current, shown in Figure 1, to better understand meridional mixing, i.e., heat transport to and from ice shelves. Eddy mixing resolved by MPAS-Ocean is subsequently quantified. Results using a temporal diffusivity decomposition indicate the joint role of the eddy and mean ow in production of meridional mixing and suggest parameterization approaches [Wolfram and Ringler 2017a]. Novel Lagrangian scalar transport is used to compute effective diffusivity, which quantifies the time-varying evolution of irreversible mixing within the system [Wolfram and Ringler 2017b]. These applications demonstrate the capabilities of in-situ analysis to increase fundamental knowledge of the ocean and its role in the Earth System.

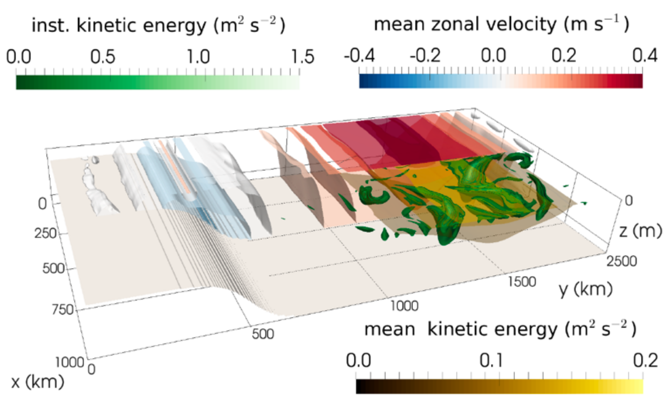

Figure 1: Time-averaged and instantaneous isometric view of the zonally-periodic Idealized Circumpolar Current (ICC) flow [7]. Eulerian instantaneous (green) and time-mean (gold) kinetic energy ($m^2\ s^{-2}$) are shown for $500 < x < 1000$ km. The Eulerian time-mean zonal velocity ($m\ s^{-1}$ red, white, blue) is shown for $0 < x < 500$ km.

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Ye, Fei et al.: Cross-scale baroclinic modeling from river tributaries to coastal ocean

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We apply newly developed techniques under the framework of "Semi-implicit Cross-scale Hydro-science Integrated System Model" (SCHISM) in simulating the baroclinic processes of tributary-bay-ocean systems. The goal is to improve model skills and efficiency while maintaining robustness, particularly on unstructured meshes with extreme element size transitions and large bathymetry gradients. To achieve good model skills, a faithful representation of underlying bathymetry and high order schemes are indispensable. The former is achieved with a flexible vertical grid system, which excels at reducing pressure gradient error and un-physical mixing at large bathymetry gradients. The later includes a 3rd-order WENO scheme for horizontal transport in the ocean part of the domain (eddying regime). To improve efficiency, a higher-order, monotone and implicit solver are applied for vertical transport to relax CFL condition. We highlight: (1) through results from sensitivity tests, the central role played by bathymetry in estuarine systems and the detrimental effects on volumetric and tracer fluxes as well as the channel-shoal contrast from a common class of bathymetry smoothing; (2) the performance of high order schemes in eddying regimes.

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Zhang, Yinglong et al.: Simulating the effects of vegetation on flows on unstructured grids

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Prevalence of vegetation (either submerged or emergent) in shallow water environment significantly affects the flow and turbulence structure. In this talk we develop a new 3D unstructured-grid model that accounts for the effects of vegetation. The model uses semi-implicit time stepping method and treats the new vegetation-related terms implicitly to enhance numerical stability, and thus the stability is independent of the vegetation parameters. This is demonstrated to be important as strong shears are commonly observed near the top of canopy. We benchmark the model using lab data and then apply it to a field study to illustrate the large influence of the vegetation on the flow.

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Zhang, Yun, et al.: A hybrid vertical coordinate for unstructured-grid, nonhydrostatic ocean modeling

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In numerical modeling of internal waves in the ocean, horizontally-unstructured grids can be used to resolve their multiscale nature, particularly when considering the evolution of long internal tides to short, nonlinear internal solitary waves. In the vertical, internal waves are best suited to isopycnal coordinates because they eliminate spurious vertical mixing as there is no need to compute advection across the isopycnal layers. Another advantage is that fewer vertical layers can be used to resolve the vertical structure in internal wave motions, thus providing cost savings particularly when computing the nonhydrostatic pressure. The disadvantage to nonhydrostatic isopycnal modeling, however, is that isopycnal coordinates cannot compute overturning or unstable convection. Furthermore, mixed layers are much better suited to z-levels, and bottom boundary-following flows are better suited to sigma coordinates. To accommodate the variety of vertical coordinates that are needed, we present the implementation of a generalized, or hybrid, vertical coordinate in the unstructured-grid, nonhydrostatic SUNTANS model. The governing equations are transformed into an arbitrary moving vertical coordinate that can be specified to follow the behavior of z, sigma, or isopycnal coordinates, while also having the capability to adapt in the vertical based on the vorticity or the vertical density gradients following methods employed in adaptive mesh refinement. We discuss the properties of the method and demonstrates its effectiveness with several test cases, including internal tide and solitary wave generation over a ridge, a nonhydrostatic lock exchange, and nonlinear internal wave diffraction and refraction around a model island.

Citation: Zhang, Y., Vitousek, S., and O. B. Fringer, 2017, A hybrid vertical coordinate for unstructured-grid, nonhydrostatic ocean modeling, The 16th International workshop on Multi-scale (Un)-structured mesh numerical Modeling for coastal, shelf, and global ocean dynamics, Stanford, CA, USA, Aug 29-Sep 1.

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