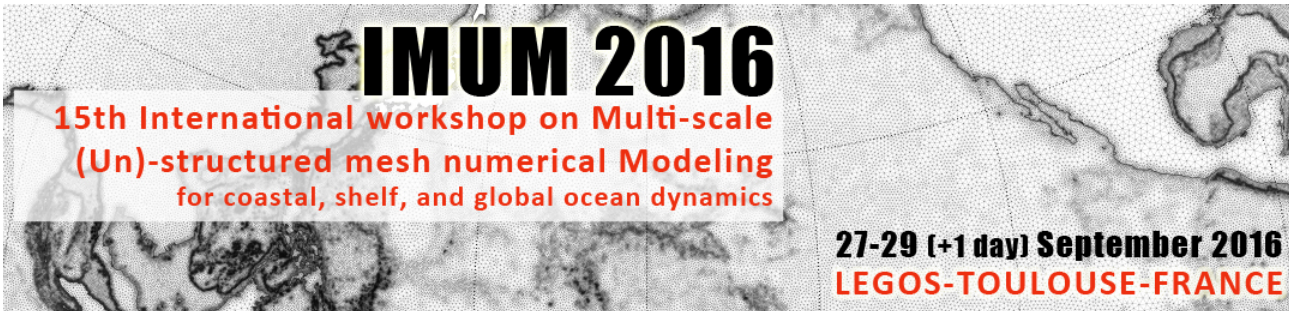

BOOK OF ABSTRACTS

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10:00 - 11:00

Mesoscale eddies on unstructured meshes

S. Danilov, Q. Wang, D. Sein, D.Sidorenko

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Mesoscale eddies contribute to the dynamics of ocean circulation in many important ways. Resolving them in the context of global ocean simulations still present a challenge because the Rossby radius of deformation is highly variable and can be as small as several km at high latitudes. Models formulated on unstructured meshes provide a possibility of locally eddy resolving approach. However, a question arises on how to select the resolution, and how mesh variability may affect the eddy dynamics. We discuss a set of questions related to this topic showing that (i) the observed variability and the information on the behavior of the Rossby radius can be one of the criteria helping in mesh design and that (ii) there might be a delayed turbulence development downstream into a high-resolution domain.

The latter means that the size of refined patches has to be sufficiently large to simulate the unbiased eddy dynamics.

As resolution is increasing, the resolved eddy dynamics may contain a substantial ageostrophic component which may lead to a noisy signal in the vertical velocity on the mesh patches where the resolution is varied. The appearance of this noise depends on the details of discretization. Variable resolution also leads to a question how to combine the locally resolved eddy dynamics with the parameterized one over the coarse part.

In a more broad context, even locally eddy-resolving global meshes are already large and approach in size the eddy-permitting and eddy-resolving meshes of global regular models (from 1/4 degree or finer, or 1M or more surface vertices), which implies massively parallel implementations. Our experience with FESOM1.4 shows that because of good parallel scalability the throughput (simulated model years/per day) reached on large meshes is very competitive to (not worse than) that shown by regular-mesh models, with only a moderately increased demand on computational resources. This in a way changes the message to the community on the numerical efficiency of unstructured-mesh models for global ocean applications: these models, especially the new finite-volume developments (MPAS, FESOM2, ICON), can be nearly as fast as the regular-mesh models in terms of their throughput.

Thetis: A versatile unstructured grid ocean model

Tuomas Kärnä[1] , Stephan Kramer[2], Lawrence Mitchell[2], David Ham[2] and Antonio Baptista[1]

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Simulating coastal ocean flows poses many practical challenges related to capturing complex coastal topography, retaining strong density gradients and dealing with long (seasonal to multi-annual) time scales at reasonable computational cost. Due to the wide range of relevant spatiotemporal scales, it is evident that a single choice of space/time discretization cannot fit all the applications, ranging from river simulations to estuaries, river plumes, and shelf sea processes.

In this presentation we introduce an unstructured grid ocean model Thetis. Our goal is to develop an accurate, efficient and flexible model that could be used across various applications.

Thetis is implemented on Firedrake[1] (Rathgeber et al., 2015; Lange et al., 2015), a generic finite element modeling framework. Firedrake combines high level abstractions (symbolic representation of weak forms, finite element function spaces, etc.) with sophisticated automated code generation. As such it provides an extremely flexible modeling environment where element types and equations can be easily modified without sacrificing computational efficiency.

Thetis solves the hydrostatic equations with Boussinesq approximation, using mode splitting and explicit or semi-implicit time integration. It also implements a Generic Length Scale turbulence closure model (Umlauf and Burchard, 2003). Biharmonic hyperviscosity is used to stabilize baroclinic processes. Currently supported spatial discretizations include P0-P0, P1DG-P1DG and Raviart–Thomas-P1DG elements. The model scales well in parallel, strong scaling performance being close to expected values.

We present a range of baroclinic benchmarks test cases and demonstrate that the model achieves expected accuracy and delivers good computational efficiency. In a standard lock exchange benchmark (Ilıcak et al., 2012) numerical mixing, as measured by reference potential energy, is comparable to existing models that use similar numerics. Using the benchmarks, we compare the different finite element families, time integration schemes and stabilization methods in terms of accuracy and computational cost. Finally we present a high-resolution river plume simulation that demonstrates the importance of low numerical diffusion.

References

- Ilıcak, M., Adcroft, A. J., Griffies, S. M., and Hallberg, R. W. (2012). Spurious dianeutral mixing and the role of momentum closure. *Ocean Modelling*, 45–46(0):37–58.
- Lange, M., Mitchell, L., Knepley, M. G., and Gorman, G. J. (2015). Efficient mesh management in Firedrake using PETSc-DMPlex. *SIAM Journal on Scientific Computing*.
- Rathgeber, F., Ham, D. A., Mitchell, L., Lange, M., Luporini, F., McRae, A. T. T., Bercea, G., Markall, G. R.,and Kelly, P. H. J. (2015). Firedrake: automating the finite element method by composing abstractions. *CoRR*, abs/1501.01809.
- Umlauf, L. and Burchard, H. (2003). A generic length-scale equation for geophysical turbulence models. *Journal of Marine Research*, 61:235–265(31).

[1]http://www.firedrakeproject.org/

12:00 – 12:30

Direct simulation of mesoscale and submesoscale eddy influences in the Antarctic Circumpolar Current using MPAS-Ocean

Luke Van Roekel,Todd Ringler, Milena Veneziani, Juan Saenz, Phillip Wolfram

The impacts of submesoscale and mesoscale eddies on ocean circulation has been extensively studied. However, these studies often consider the impact of these eddies on the large-scale ocean separately. Simulating the interaction of these eddies is fairly challenging, as it requires resolution of disparate scales (O(1km) and O(10km) respectively). Here we utilize the Model for Prediction Across Scales-Ocean (MPAS-Ocean)to address this issue.MPAS-Ocean utilizes a horizontally unstructured mesh based on spherical centroidal voronoi tessellations, which allows for variability of horizontal resolution within a domain. MPAS-Ocean is applied to a zonally symmetric domain that captures the climatology of the Antarctic Circumpolar Current (ACC).Two simulations are conducted, in both the model resolves the first Rossby radius of deformation everywhere in the domain and only one contains a region of high resolution in the ACC that resolves submesoscale eddies. The results are presented utilizing the Eliassen Palm Flux Tensor (EPFT)framework to elucidate the influence of each scale of eddy on the mean flow and possible interactions. Further, the EPFT framework allows for a diagnosis of the diffusivity of PV due to submesoscale and mesoscale eddies. Uncertainties in the results due to the choice of sub-grid parameterizations (in particular vertical mixing) are also discussed.

14:00 – 14:30

Modelling from basin- to community-scales on large unstructured grids

Joseph Zhang, Xavier Bertin

Recent development of community model SCHISM paved way for large-scale modelling on unstructured grids by effectively leveraging new numerical algorithms for multi-scale processes and emerging massively parallel HPC facility. Our ultimate goal is to enable a seamless model that traverses ocean basin, shelf, nearshore, estuary, and upstream rivers without resorting to grid nesting. In this talk we will present some recent developments that enabled this type of capability including: benchmarking of the model at large scale and associated issues on flexible horizontal and vertical grids (with no bathymetry smoothing), and hybrid openMP (shared memory) and MPI paradigm for massively parallel computing. As demonstration, we will show model applications for western Pacific circulation, influence of bridge pilings in Chesapeake Bay, surge and flooding associated with Xynthia (a winter storm that severely impacted the Bay of Biscay in 2010) and recent developments of the sediment transport model that allowed multi-decadal fully coupled morphodynamic and stratigraphic simulations. A commonality of all these applications is the use of vastly different horizontal and vertical resolutions from open ocean to community scale (from ~6km with 40+ vertical layers to ~2m with a few vertical layers) in a single 3D grid.
While implicit time stepping is used at all scales for efficiency, we also discuss different grid requirements between large and small scales; in particular, grid size transition needs to be smooth for large-scale processes to introduce appropriate amount of dissipation in the eddying regime, but very skew elements are tolerated by the model at other scales.

14:30 – 15:00

Unstructured Ocean Loading Atlas

Damien Allain, Pascal Gégout, Jean-Paul Boy and Florent Lyard

September 5, 2016

The ocean loading atlas of the solid Earth deformation by the ocean tides from FES2014 has been produced. The FES2014 unstructured grid has been extended onto the continents. The mesh generation and assembly functions of the TUGOm Tools library have been used. The density calculation algorithm has been adapted to produce uniform meshes on large continents. The deformation has been computed for each point of application by summing the contribution of the complex masses of all the elements, which makes a total of 1.5 · 1012 contributions to calculate. The calculation of the contribution has been strongly optimized and paralleled to make the calculation in 1 ks on a 12-core PC. The atlases have been compared with an ocean loading atlas computed from a structured grid. The results show very good agreement, but on the coasts where differences due to interpolation errors (in the output and the input) can reach 5 mm.

15:00 – 15:30

A baroclinic model of the Columbia river-to-ocean continuum

V. Vallaeys *, T. Kärnä, A. M. Baptista, E. Deleersnijder, E. Hanert
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The Columbia River estuary is characterized by high river discharges and strong tides which generates generating high velocity flows and sharp density gradients. Its dynamics strongly affect the coastal ocean circulation. Numerically modelling this region requires the model to be multiscale, but also not too diffusive to correctly represent the plume propagation and the salinity intrusion in the estuary.

To model this ROFI, we use and develop SLIM 3D, a finite element model that solves the Boussinesq hydrostatic equations on unstructured grids with a P1DG scheme. The grid is vertically extruded on a constant number of "sigma-z" levels, where the resolution is focused in the near-surface region.

The bathymetry of the estuary alternates between deep narrow channels and shallow areas. In order to keep its relevant features, we developed an iterative smoothing procedure to satisfy the Haney criterion elementwise, and hence limiting the diffusion to an unresolved scale.

In this work, we analyze the ability of SLIM 3D to reproduce the main features of the Columbia River-to-ocean continuum. In particular, we emphasize on the tidal variations of the salinity intrusion, as well as on the plume characteristics, the latter being strongly impacted by the wind stress. We compare the results with in-situ data on the shelf and at multiple locations in the estuary.

A fair comparison is also performed with another unstructured grid model, SELFE, that has been extensively used in that region. Both models are compared on idealized testcases and on the Columbia River ROFI benchmark. Our simulations confirm the tendency of SELFE to be quite diffusive, resulting in overly smoothed density gradients when compared to observations, where SLIM 3D seems to reproduce sharper fronts.

16:00 – 16:30

Hydrodynamic modeling of Gironde estuary

Florent LYARD

16:30- 17:00

Pine Island Glacier ice shelf melt distribution modelled at basal channel scales, enabled by unstructured mesh approaches

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Matthew D. Piggott

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Paul R. Holland, Satoshi Kimura and Adrian Jenkins

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Recent observational studies (Jenkins et al. 2010 [1] and Dutrieux et al. 2013 [2]) have helped to constrain estimates of the melt behaviour underneath Pine Island Glacier (PIG) ice shelf, in western Antarctica. Generally however, observations are limited, due to the relatively inaccessible and inhospitable environment. A solid ice cover, up to many kilometres thick, bars access to the water column, so that observational data can only be obtained by inference from above, drilling holes through, or launching autonomous vehicles beneath the ice. This is further exacerbated by the fact that results of these recent studies have implied a significant proportion of the melting (~80%) occurs in networks of sub-kilometre scale basal channels close to the grounding line, some of the most inaccessible parts of sub-ice shelf ocean cavities.

Accurately representing these small-scale processes in conventional ocean models is a huge challenge even in focused regional studies, and will not be possible in global coupled climate simulations in the near future. I will present the development of a new model of PIG that is capable of resolving the range of scales necessary to evaluate the melt distribution and forming processes that dominate. This is built on the Fluidity model (Piggott et al. 2008 [8]) that simulates non-hydrostatic dynamics on meshes that, like the FESOM model of Timmermann et al. 2012 [4], can be unstructured. In this case, the grid can be unstructured in all three dimensions and use an anisotropic adaptive-in-time resolution to optimise the mesh and calculation in response to evolving solution dynamics. The parameterisation of melting in this model has been validated in idealised cavity domains (Kimura et al. 2013 [5]) and a validation is underway for the dynamic treatment of the ice-ocean interface (Candy et al. 2016 [7]). Additionally, the model is not limited to a specific vertical coordinate system and can capture purely vertical features, which enables it to accurately represent ice fronts, and small shallow features.

I will discuss the development of this model of PIG; including the cavity domain, conforming to appropriately filtered boundaries generated from data collected during the British Antarctic Survey Autosub 2009 expedition, and the simulation of non-hydrostatic dynamics to date (see Figure 1). This will include validation to observations and MITgcm model results in a Circumpolar Deep Water forcing scenario from measurements in 2012, as recently presented in Science (Dutrieux et al. 2014 [3]). The unstructured nature of the developed model (Candy et al. 2016 [6]) captures the high spatial variation seen in melt rates in the small-scale channels, that its difficult to resolve in other fixed-mesh state-of-the-art models.

As a result this new model has the potential to provide further valuable insights into the physical processes driving the observed large melting and modulation of ice-ocean interactions at subkilometre scales, that are not possible with structured-mesh approaches.

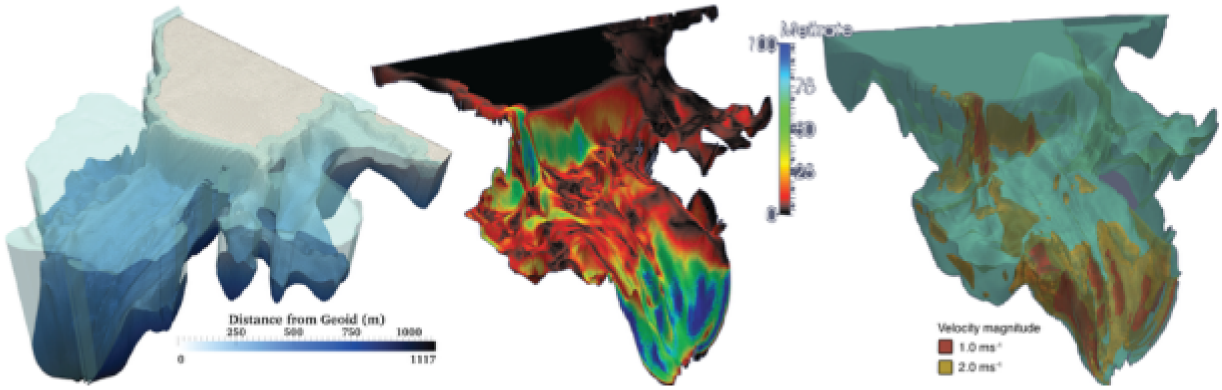

Figure 1. The discretised domain of the PIG ice shelf ocean cavity is shown on the left, with simulated melt rates under the ice sheet presented in the middle, and velocity contours on the left.

References

1. Jenkins A., Dutrieux P., Jacobs S.S., Mc Phail S.D., Perrett J.R., Webb A.T. and White D. Observations beneath Pine Island Glacier in West Antarctica and implications for its retreat. Nat. Geosci. 3, 468–472 (2010) dx.doi.org/10.1038/ngeo890.
2. Dutrieux P., Vaughan D.G., Corr H.F.J., Jenkins A., Holland P.R., Joughin I. and Fleming A. Pine Island Glacier ice shelf melt distributed at kilometre scales. Cryosphere, 7, 1543–1555 (2013) dx.doi.org/10.5194/tc-7-1543-2013.
3. Dutrieux P., De Rydt J., Jenkins A., Holland P.R., Ha H.K., Lee S.H., Steig E.J., Ding Q., Abrahamsen E.P. and Schröder M. Strong Sensitivity of Pine Island Ice-Shelf Melting to Climatic Variability. Science 343 (6167), 174-178 (2013) dx.doi.org/10.1126/science.1244341.
4. Timmermann R., Wang Q. and Hellmer H. Ice shelf basal melting in a global finite-element sea ice/ice shelf/ocean model. Annals of Glaciology, 53 (60) (2012) dx.doi.org/10.3189/2012AoG60A156.
5. Kimura S., Candy A.S., Holland P.R., Piggott M.D. and Jenkins A., Adaptation of an unstructured-mesh, finite-element ocean model to the simulation of ocean circulation beneath ice shelves. Ocean Modelling, 67 39-51, dx.doi.org/10.1016/j.ocemod.2013.03.004 (2013).
6. Candy A.S., Holland P.R., Kimura S., Piggott M.D. and Jenkins A. Pine Island Glacier ice shelf melt distribution modelled at basal channel scales. In prep. (2016).
7. Candy A.S., Holland P.R., Piggott M.D. and Jenkins A. Dynamic treatment of the ice-ocean interface at the base of an ice shelf. In prep (2016).
8. Piggott, M.D., Gorman, G.J., Pain, C.C., Allison, P.A., Candy, A.S., Martin, B.T. and Wells, M.R.: A new computational framework for multi-scale ocean modelling based on adapting unstructured meshes, International Journal for Numerical Methods in Fluids, 56, 1003–1015 (2008) dx.doi.org/10.1002/fld. 1663.

09:30- 10:30

Subgrid hydrodynamics and sediment transport modeling on unstructured grids

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In many applications of unstructured-grid models to study hydrodynamics and sediment transport, particularly in estuarine and coastal environments, model accuracy is often limited by a lack of knowledge of sediment properties and observations needed for initialization and forcing such as winds, waves, river inflows, and tides, and bathymetry and vegetation coverage. Therefore, use of higher resolution does not always lead to more accurate results, and in many cases it may be justified to employ lower grid resolutions that allow improved model efficiency while still achieving acceptable model accuracy. Under such circumstances, the bathymetric resolution may be higher than the model grid resolution. When this occurs, the effects of high-resolution bathymetric variability on the solution can be retained on the coarse grid without sacrificing model efficiency by implementing the subgrid bathymetry method of Casulli and Stelling (2009, 2011). In this method, high-resolution bathymetry is used to compute cross-sectional areas and volumes of the coarse-grid cells, thereby ensuring accurate flow conveyance and water levels. Because the subgrid bathymetry ensures accurate water volumes and cross-sectional areas regardless of the computational grid resolution, an advantage of the method is that it alleviates the need to generate unstructured grids that exactly follow the coastline.

In this presentation I will discuss application of the subgrid bathymetry method to study hydrodynamics and sediment transport in a saltwater marsh in San Francisco Bay, USA, using the unstructured-grid SUNTANS model. The model domain is characterized by broad, shallow, and vegetated marshes that are incised by narrow channels, some of which are engineered to restrict seaward sediment transport with culverts. While the subgrid method accounts for the effects of high-resolution bathymetry on the flow and stage with a coarse computational grid, this coarse grid leads to inaccurate predictions of sediment transport. I will present a method that accounts for subgrid effects on the sediment transport by reconstructing the subgrid bottom stress in a way that improves predictions of erosion and deposition. Results will be presented for the hydrodynamics and sediment transport on an unstructured, hybrid grid composed of triangles and quadrilaterals. A high-resolution, three-dimensional simulation that resolves the bathymetry and vegetation coverage on the computational grid without subgrid bathymetry will serve as the base case. A coarse-grid model that employs the proposed subgrid parameterizations will then be presented that reproduces the base case results at a fraction of the computational cost.

11:00 – 11:30

Inter-comparison of finite-element and discontinuous Galerkin methods in ocean modelling

Daniel Le Roux

The shallow-water system is extensively used in environmental studies to simulate the propagation of typical waves (e.g. Kelvin, inertia-gravity, Rossby). For a number of discretization methods, non physical solutions and dispersion/dissipation problems appear in the representation of the waves.

The aim of this talk is first to compare finite-element and discontinuous Galerkin results for the propagation of equatorial waves on structured and unstructured meshes. Secondly, a 2-D Fourier analysis is performed using discontinous Galerkin methods and the choice of the numerical flux is discussed. Numerical simulations are presented and they confirm the theoretical results.

11:30 – 12:30

Fractally homogeneous air-sea turbulence

with Frequency-integrated, wind-driven gravity waves

Colton J. Conroy and Kyle Mandli

Department of Applied Physics and Applied Mathematics

Columbia University in the City of New York, USA

In this talk, we present the development of an accurate, yet efficient, multiscale short-crested gravity wave model. A key component of the investigation involves an exploration into atmospheric turbulence along with the wind-waves it generates. In particular, we examine the local distribution of turbulence along space-time paths rather than that of traditional spatial distributions. These temporal distributions are unique functions of a set of so-called characteristic variables, which represent the large scale dynamics of the local neighborhood under consideration, expressed in terms of a reference velocity and the maximum turbulent pulsation of a given space-time volume.

Through a number of logical conjectures we unearth a (local) self-similar structure of the atmospheric turbulence that we use to “pave” large scale averages to construct a wind curve whose fractal dimension is consistent with theory and observation. The local kernel provides exact perturbation relations for the characteristic frequency and energy density of the wind-sea, and immediately gives rise to an expression for the local pressure in terms of the kinetic energy of the atmosphere, which serves as the initiator of the air-sea energy transfer. We cement this energy transfer mechanism in terms of the dispersion relation and group velocity of the wind-waves providing unambiguous local source terms for a system of frequency-integrated balance equations—equations that preserve the moments of the short-crested gravity waves—in which the solution is more tractable than that of traditional frequency-resolving spectral methods.

The model is discretized using unstructured Runge-Kutta discontinuous Galerkin (RKDG) methods, where all the primary variables including the integrated direction of the moment field are discretized using discontinuous polynomial spaces of arbitrary order. Numerical results illustrate the generation and propagation of the waves while hindcasts over Lake Erie evaluate the wind-sea assumptions inherent to the model.

14:00 – 14:30

Tidal downscaling in a 3D (structured) circulation model: a new approach based on tailored 2D (unstructured) simulations

F. Toublanc[1] , N. Ayoub[2] , F.Lyard[2] , P. Marsaleix[3] , T. Duhaut[3] , D. Allain[4]

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[4] *Celad – LEGOS, Toulouse*

Modeling the 3D ocean circulation in coastal areas requires an accurate representation of the tidal dynamics. This is particularly true in the Bay of Biscay, where tides are highly energetic over the shelf, with tidal ranges reaching 6m at the coast. Although tidal dynamics are dominated by semi-diurnal constituents, nonlinear interactions occurring between these constituents and the topography result in the generation of overtides such as M4. Downscaling the tidal dynamics in a coastal model from a larger scale solution raises several methodological issues, especially in terms of currents. In particular, the choice of the large scale solution is crucial; the impact of likely inconsistencies in bathymetry and grid resolutions between the large scale model and the coastal one should be evaluated.

In this study, we propose a new approach to tidal downscaling for coastal modelling by using two numerical models, T-UGO and SYMPHONIE, on the same rectangular mesh and bathymetry at the nodes. The unstructured grid model T-UGO 2D spectral model is adapted to perform these simulations, and provide tidal boundary conditions to the 3D circulation model SYMPHONIE. The latter is set-up on a variable mesh grid that allows us to represent the different physical processes, including tides, that influence the dynamics of the bay, from the deep plain scale to the estuarine scale. The horizontal grid resolution varies between approximately 3km at the oceanic open boundary and less than 300m in the Gironde estuary and the Pertuis Charentais. Three types of tidal boundary conditions are tested for the SYMPHONIE model: the FES2012 atlas, T-UGO 2D spectral simulations, and SYMPHONIE 2D clamped simulations. Complex errors, taking into account both the amplitude and the phase of the M2 tidal constituent, are reduced by more than 75% with a regional forcing (SYMPHONIE or T-UGO 2D), compared to a global forcing (FES2012).

Coupling of an unstructured wave model with a curvilinear hydrodynamic model : the storm surge of March 2013 in the Gulf of Lion, France

Fabien Rétif[1], Guillaume Mikolajczak[1] , Léo Seyfried[1], Patrick Marsaleix[1], Claude Estournel[1] and Thomas Duhaut[1]

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Keywords : water level, coupled wave-current model, wind, atmospheric pressure, storm

During storms, the water level rises to several meters above its usual mean level, causing considerable damages to natural and artificial structures. The nearshore water level is governed by the astronomical tides, meteorological conditions (pressure, wind), geostrophic currents, waves, rivers and local bathymetry (Chelton and Enfield, 1986). Water level is modelled during the storm of March 2013 in the Gulf of Lion, France (Figure 1A). The simulation is based on SYMPHONIE (Marsaleix et al., 2006, 2008), a robust 3D circulation model dealing with most of the oceanographical forcings and on the wave model WAVEWATCH III (v5.08)(Tolman and Hendrik, 2015). To avoid interpolations, we use the same computational points for these two models. We build first the curvilinear mesh then we split each rectangular cell into two triangles to build the unstructured mesh (Figure 1A). To better take into account the important feedbacks between waves and currents in the nearshore zone, models are coupled by the coupler OASIS3/MCT-3 (Valcke et al., 2015).

The figure 1B shows water level computed by SYMPHONIE and water level observations during the storm at the tide gauge of Port-Vendres. We properly reproduce the observations with an maximum error of 0.29 m. Future works will focus on comparisons of currents and on the transport of suspended particulate matter.

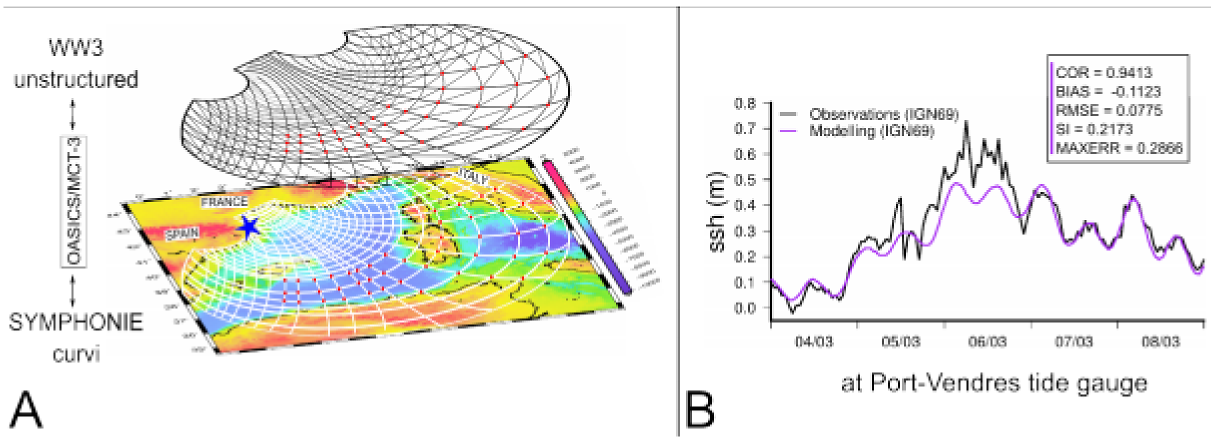

Figure 1: A) Bathymetry of the Gulf of Lion and the computational grid. The WW3 mesh is built from the SYMPHONIE mesh where each cell is splitted into two triangles. The blue star is the location of Port-Vendres; B) Water level (m) comparison between observations and modelled at Port-Vendres.

References

- Chelton, D. B. and Enfield, D. B. (1986). Ocean signals in tide gauge records. *Journal of Geophysical Research*, 91:9081–9098.
- Marsaleix, P., Auclair, F., and Estournel, C. (2006). Considerations on open boundary conditions for regional and coastal ocean models. *Journal of Atmospheric and Oceanic Technology*, 23:1604–1613.
- Marsaleix, P., Auclair, F., Floor, J. W., Herrmann, M. J., Estournel, C., Pairaud, I., and Ulses, C. (2008). Energy conservation issues in sigma-coordinate free-surface ocean models. *Ocean Modelling*, 20:61–89.
- Tolman and Hendrik, L. (2015). User manual and system documentation of WAVEWATCH III R version 5.08. Technical report, MMAB Contribution n 316.
- Valcke, S., Craig, T., and Coquart, L. (2015). Oasis3-mct user guide, oasis3-mct 3.0, technical report, tr/cmgc/15/38. Technical report, CERFACS/CNRS SUC URA No 1875, Toulouse, France.

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15:00 – 15:30

Coupling of Unstructured (ADCIRC) and Structured (XBeach) Models by Perl Script

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Coastal erosion associated with the storm events sometimes changes the coastal environment extensively. For coastal management related analyses, numerical simulations have been used by several researchers. For example, to simulate erosion in a storm event, Vousdoukas et al. (2011) applied XBeach to reproduce storm-induced morphological changes on the beach. McCall et al. (2010) simulated the coastal erosion induced by Hurricane Ivan in 2008. Most of these approaches have focused on a precise reproduction of erosion or sedimentation under severe conditions. While such hindcasting efforts can provide a better understanding of the coastal hydrodynamics, they cannot provide an effective countermeasure in case of a forthcoming storm. To overcome such shortcomings, we propose a short-term simulation using near real-time coastal erosion forecasting based on time-varying typhoon advisories,as suggested by Suh et al. (2015).

Among the several morphological models available, XBeach (Roelvink et al., 2009) is considered to effectively represent extreme storm-induced beach erosion. However, during the periods when typhoons attack, the characteristics of waves is the most important factor that affects the extent of erosion. Storm-induced waves and current interactions in surge simulations were profoundly investigated (Dietrich et al., 2010) by using the coupled ADCIRC+SWAN model. Recently, this coupled model has been applied for near real-time storm surge forecasting (Suh et al., 2015). However, because of the different discretization schemes for the two models, they are not directly coupled. Thus, we employed rapidly varying wave characteristics from this coupled model as a driving force in beach erosion of XBeach. This feature was used in XBeach to find the corresponding response in terms of the morphological change. In this work, we also developed an automated coupling procedure using a Perl script. Thus, the wave heights, periods, and incident angles at every 10 minutes from SWAN and sea level by ADCIRC, transferred automatically to open boundary of XBeach simulation. However, to maintain computational efficiency, we implemented a threshold for the pressure-response relationship, i.e., if the external force in terms of wave height could not reach the critical driving force value, computation of erosion was not performed in Xbeach.

Sensitivity tests were done on a simplified beach to verify the capability of the model in terms of variable external wave forcing. After verifying the parameters, hindcasting simulations were conducted for a real case; for Haeundae Beach in Busan, Korea to reproduce the erosion reaction with respect to a super typhoon, Maemi in 2003. Simulated results showed a good agreement in terms of the qualitative aspects for the entire beach area.A lack of precise verification of the observed data necessitates further refining of the model as a part of future research efforts. Nevertheless, since the overall computation could be accomplished automatically by using a Perl script on a parallel computer with 88 cores within 50 minutes for 1 day simulation, it can be concluded that this proposed erosion model could be satisfactorily employed for real-time forecasting of storm events.

REFERENCE

- Dietrich,J.C., Zijlema,M., Westerink,J.J., Holthuijsen,L.H., Dawson, C., Luettich, R.A., Jensen, R.E., Smith, J.M., Stelling, G.S. and Stone, G.W. (2011). Modeling hurricane waves and storm surge using integrally-coupled, scalable computations. Coastal Engineering. 58(1), pp 45-65.
- McCall, R.T., Van Thiel de Vries, J.S.M., Plant, N.G., Van Dongeren, A.R.,Roelvink J.A., Thompson, D.M. and Reniers, A.J.H.M. (2010). Two-dimensional time dependent Hurricane overwash and erosional modeling at Santa Rosa Island. Coastal Engineering 57, pp 668-683.
- Roelvink, D., Reniers, A., Dongeren, A., Thiel de Vries, J., McCall, R. and Lescinski, J. (2009). Modeling storm impacts on beachs, dunes and barrier islands. Coastal Engineering 56, pp 1133-1152.
- Suh, S.W., Lee, H.Y., Kim, H.J and Fleming, J.G. (2015). An efficient early warning system for typhoon storm surge based on time varying advisories by coupled ADCIRC and SWAN. Ocean Dynamics, DOI 10.1007/s10236-015-0820-3
- Vousdoukas, M.I., Almeida, L.P. and Ferreira, Ó. (2011). Modelling storm-induced beach morphological change in a mesotidal, reflective beach using XBeach. Journal of Coastal Research, SI 64 (Proceedings of the 11th International Coastal Symposium), 1916 – 1920. Szczecin, Poland, ISSN 0749-0208

The development of a new simulation and optimisation framework for marine technology

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Several technological developments in the coastal zone, such as the deployment of tidal stream turbines for marine renewable energy extraction, and the installation of multiport diffusers for the disposal of heat or degradable waste water, ask for sophisticated modelling tools that are capable of dealing with the multi-scale interaction between sub-metre scale installations and coastal ocean flows over hundreds of kilometres. Unstructured mesh models are a natural candidate for dealing with this. In order to increase the economic viability and minimise ecological impacts, design optimisation is needed. As shown in Funke et al. 2013 and Funke et al. 2016, PDE-constrained optimisation problems with many design parameters, such as the optimal positioning of turbines within an array, can be solved efficiently through gradient based optimisation algorithms in combination with the computation of sensitivity information via the adjoint method.

Although the derivation of the adjoint equations for existing models typically involves a lot of work in practical terms, in Farrell et al. 2013 it was shown that for finite element models developed in the Dolfin/FEniCS framework the derivation of the adjoint equations can be fully automated using the high level abstraction of the finite element equations that is available within this framework. This approach was followed in Funke et al. 2013 and 2016, and implemented in OpenTidalFarm, which demonstrate tidal farm optimisations coupled with a hydrodynamic model with a high level of detail and many degrees of freedom. Nonetheless, the numerics used in these papers were relatively simple (the Taylor-Hood finite element pair) and the underlying equations, the depth-averaged shallow water equations are not necessarily sufficiently realistic for the problem at hand.

Thetis is a new coastal ocean model, based on Firedrake, a finite element framework similar to FEniCS but with additional functionality that makes it well suited for large scale environmental fluid flows. In particular, Firedrake supports layered meshes an essential capability for modelling the coastal zone. In addition, it offers slope limiting functionality necessary for robust discontinuous methods. In this presentation we will demonstrate the functionality of Thetis for the modelling of tidal flows in the coastal zone. The model already supports a range of element pairs: mimetic mixed element pairs, equal order DG, and the $P_{n,DG}$-P_{n+1} family. We will investigate its performance and compare with existing models, such as OpenTidalFarm, Fluidity and Telemac. Furthermore, we will demonstrate its adjoint capabilities to compute sensitivity information and an example optimisation.

References

- S.W. Funke, P.E. Farrell, M.D. Piggott, *Tidal turbine array optimisation using the adjoint approach,* Renewable Energy, Vol. 63, 2013.

- S.W. Funke, S.C. Kramer, M.D. Piggott, *Design optimisation and resource assessment for tidal-stream renewable energy farms using a new continuous turbine approac*, Renewable Energy, accepted 2016.
- P.E. Farrell, D.A. Ham, S.W. Funke, M.E. Rognes, *Automated derivation of the adjoint of high-level transient finite element programs*, SIAM J. Sci. Comput. 35(4) 2013.

16:30 – 17:00

A gentle introduction to the Oceanographic Multipurpose Software Environment

Inti Pelupessy[1,2] Ben van Werkhoven[3] , Arjen van Elteren[2] , Jan Viebahn[1] , Adam Candy[4] , Simon Portegies Zwart[2] , and Henk Dijkstra[1]

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Abstract

We introduce the Oceanographic Multipurpose Software Environment (OMUSE): an open source framework for oceanographic simulation codes developed at the IMAU (Utrecht) using coupling technology developed at Leiden Observatory (Leiden). OMUSE aims to provide a homogeneous environment for numerical ocean simulation codes, simplifying their use and deployment. Using OMUSE numerical experiments that combine ocean models representing different physics or spanning different ranges of physical scales can be easily designed. Here, we present the design of OMUSE as well as the modules and model components currently included, which range from a simple conceptual models to to full global circulation models such as POP. We discuss the types of the couplings that can be implemented using OMUSE and present examples of OMUSE applications, that demonstrate the efficient and relatively straightforward model initialisation and coupling possible with OMUSE.

09:30 – 10:30

Unstructured Mesh Modeling in the Coastal Waters of British Columbia, Canada

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With a complex coastline comprised of narrow inlets, fjords, islands, and headlands; and a continental shelf sprinkled with canyons, shallow banks, and inland seas; the coastal waters of British Columbia provide a perfect setting for unstructured grid modeling. In this presentation, we will describe results from several regional ocean models that were primarily developed to better understand the environmental impact of aquaculture facilities and resource development. Most of the modeling has been done with FVCOM, the Finite Volume Community Ocean Model, but other approaches likeRiCOM, TIDE3D, SELFE and ELCIRC have also been explored. Simulation results showing for example, the dispersion of disease and parasites among salmon farms and to the native wild fish population will be described. Comparisons between observations and model fields will also be shown to illustrate the successes and short-comings of the modeling techniques and hopefully to engage the audience in further discussion.

11:00 – 11:30

Modelling marine connectivity in the Great Barrier Reef with SLIM

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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 Great Barrier Reef (GBR). Using such a high-resolution model allows us to simulate the classical cascade from large-scale to small-scales, but also a feedback from the small-scale to the large-scale. By coupling SLIM with a biophysical model of larval dispersal we can track the position of virtual larvae or propagules 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. Useful information can be extracted from these large matrices by using graph theory tools such as community detection, page rank and influence rank algorithms. These methods are illustrated for different applications including connectivity between submerged and near-sea-surface coral reefs, dispersion of seagrass propagules and crown-of-thorns starfish outbreaks. Our study suggests that combining a high-resolution multi-scale ocean model with novel graph theory algorithms is a powerful tool for studying physical connectivity between marine ecosystems and informing management decisions.

11:30 – 12:00

Simulation of surface oil slick transport using the 3D baroclinic ADCIRC on high-resolution unstructured finite element grids

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Accurate simulation of ocean currents near coastal regions can be used for the prediction of oil spill transport in such areas. Information from these predictions can help emergency responders make informed decisions regarding the clean-up process. In coastal regions, due to the considerable variation of bathymetry, and also discharge of fresh water from the rivers, the character of the fluid flow is three-dimensional.

During this presentation, we will discuss the application of the three-dimensional baroclinic ADCIRC model for the prediction of surface oil-slick transport, due to the Deepwater Horizon oil spill event. ADCIRC utilizes an unstructured grid that allows it to accurately capture high-resolution bathymetry. For stability, this high-resolution bathymetry needs to be smoothed in regions where it varies drastically, which, typically, is the shelf break region. These regions are identified by computing two different grid-roughness indicators, and are locally smoothed until certain conditions are satisfied.

We will also discuss recent improvements made in ADCIRC for computing the baroclinic pressure gradients, and, also, biharmonic horizontal diffusion/viscosity operators when the unstructured grid encompasses a wide range of spatial scales. We will show simulation results of the northern Gulf of Mexico during the Deepwater Horizon oil-spill event and compare them with observations at buoys. To investigate the influence of baroclinicity and vertical mixing, we compare these results against a two-dimensional barotropic simulation. Next, by representing surface oil slicks due to the oil-spill event as Lagrangian particles, we compute their transport due to ocean currents, and compare them with satellite observations.

14:00 – 14:30

High resolution tidal model of the Canadian Arctic Archipelago.

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A new high resolution tidal model of the Canadian Arctic archipelago is developed.The simulation is performed using ADCIRC and driven solely by the tidal elevation at the open boundaries. We used tidal spectrum for 8 major tidal constituents extracted from the FES global tide model. Frictional effects of the ice coverare represented through a quadratic stress exerted at the ice-ocean interface. The ice-ocean drag coefficient is computed based on the fractional sea ice coverage using the same parameterization as in Collins et al. (2011), however, it varies with time.

The model results are compared to the tide gauge data.The prediction errors vary from region to region, reflecting the regional tidal range. The largest regional errors are for the M2 tide, which has the largest amplitude. Errors for the diurnal tide constituents are dominated by the errors in the Arctic South Central and Southeast regions. These regions are difficult to model accurately since the diurnal tide in Boothia Bay in the Arctic Southeast region is nearly resonant.The *rms* error of the tidal constituents averaged over the entire model domain is about 14 cm for M2 and (7, 3, 5, 6, 8, 1 and 4) cm for (S2, N2, K2, O1, K1, Q1 and P1). These error levels are comparable to the existing models.The simulated velocity field is used to evaluate the tidal mixing factor, a useful metrics to identify areas where tidal currents can potentially make important contributions to polynya formation.

References:

- Collins, A. K., Hannah, C. G., Greenberg, D., 2011. "Validation of a High Resolution Modelling System for Tides in the Canadian Arctic Archipelago."*Canadian Technical Report of Hydrography and Ocean Sciences,* 273:vii+72pp.

14:30 – 15:00

A new high resolution tidal model in the Arctic Ocean

M. Cancet, O. Andersen, F. Lyard, D. Cotton, J. Benveniste

The Arctic Ocean is a challenging region for tidal modeling, because of its complex and not well-documented bathymetry, together combined with the intermittent presence of sea ice and the fact that the in situ tidal observations are rather scarce at such high latitudes. As a consequence, the accuracy of the global tidal models decreases by several centimeters in the Polar Regions. In particular, it has a large impact on the quality of the satellite altimeter sea surface heights in these regions (ERS1/2, Envisat, CryoSat-2, SARAL/AltiKa and the future Sentinel-3 mission).

Better knowledge of the tides improves the quality of the high latitudes altimeter sea surface heights and of all derived products, such as the altimetry-derived geostrophic currents, the mean sea surface and the mean dynamic topography. In addition, accurate tidal models are highly strategic information for ever-growing maritime and industrial activities in this region.

NOVELTIS and DTU Space, with the expertise support of LEGOS,have developed a regional, highresolution tidal atlas in the Arctic Ocean, in the framework of the CryoSat Plus for Ocean (CP4O) ESA project. In particular, this atlas benefits from the assimilation of the most complete satellite altimetry dataset ever used in this region, including Envisat data up to 82°N and the CryoSat-2 reprocessed data between 82°N and 88°N. The combination of all these satellites gives the best possible coverage of altimetry-derived tidal constituents. The available tide gauge data were also used for assimilation and validation.

This paper presents the performances of this new regional tidal model in the Arctic Ocean.

15:00 – 15:30

Getting Ready for SWOT: Tidal Model Assessments off the Coast of British Columbia, Canada

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The waters off British Columbia, Canada are bounded by a complex coastline and have a continental slope and inland seas with complex bathymetry. They thus provide an ideal test bed for unstructured mesh models. In this presentation we will describe the evaluation of both global tidal models (e.g. FES2012, FES2014, GOT4.8) and local regional FVCOM models with tide gauge and satellite altimetry observations of tides. Baroclinic influence, a relatively large component off the coast of BC, on the surface signature of tides will be quantified. Approaches for improving the de-tided sea surface height accuracy so that it will be as close to the SWOT (Surface Water and Ocean Topography) satellite goal of 0.8 cm (when averaged over 2x2 km squares within each swath) will be discussed.

16:00 – 16:30

Integration of Geographic Information System frameworks into domain discretisation and meshing processes for geophysical models

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Computational simulations of physical phenomena rely on an accurate discretisation of model domains. Numerical models have increased in sophistication to a level where it is possible to support terrain-following boundaries that conform accurately to real physical interfaces, and resolve a multi-scale of spatial resolutions. Whilst simulation codes are maturing in this area, pre-processing tools have not developed significantly enough to competently initialise these problems in a rigorous, efficient and recomputable manner. In the relatively disjoint field of Geographic Information Systems (GIS) however, techniques and tools for mapping and analysis of geographical data have matured significantly.

In order to ensure model simulations are reproducible and the provenance of the data required is recorded, the manipulation and agglomeration of initialisation data needs to be standardised and automated. With the typical constraints on simulation domains for geophysical models consisting of bounding paths and surface scalar fields in a two dimensional plane, GIS frameworks potentially offer exactly what is required to formalise this processing. A new approach to the discretisation of geophysical domains is presented (Candy et al. [1], and [2] — [3]), and introduced with verified implementations. A complex domain example with a multi scale discretisation will be presented with scales ranging from 2000 km down to 5m details of the manmade structures of Portland harbour (Figure 1) and lagoon flats behind Chesil beach on the south coast (Figure 2). This brings together the fields of geospatial analysis, meshing and
numerical simulation models. This platform enables us to combine and built up features, quickly drafting and updating mesh descriptions with the rigour that established GIS tools provide. This, combined with the systematic workflow, supports a strong provenance for model initialisation and encourages the convergence of standards.

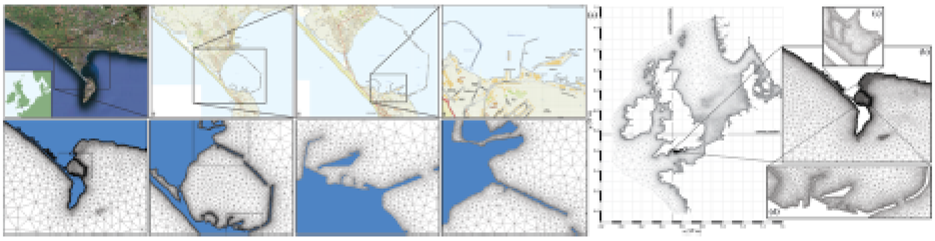

Figure 1. New tools to accurately define boundary representations from map data within GIS, here for Portland Harbour on the south coast of the UK. Domain discretisation: Meshing algorithms generate a metric-driven triangulation on the surface geoid domain from raster maps within GIS.

Figure 2. Left: A portion of an Ordinance Survey Street View product centred around the East Fleet region behind Chesil Beach, identified in Figure 1. Centre: The same region overlaid with vector polygon layers containing GIS generated contours of the beach and flat regions. Right: The meshed flats region accurately constrained by a metric calculated from several raster maps and polygon layers within GIS.

References

1. Candy A.S., Avdis A., Hill J., Gorman G.J., Piggott M.D. Integration of Geographic Information System frameworks into domain discretisation and meshing processes for geophysical models, Geosci. Model Dev. Discuss., 2014. http://www.geosci-model-dev-discuss.net/7/5993/2014/.
2. QGIS-Meshing project pages: http://gismeshing.org and code repository: https://github.com/adamcandy/QGIS-Meshing.
3. Shingle project pages: http://shingleproject.org and code repository: https://github.com/adamcandy/Shingle.

16:30 – 17:00

An unstructured grid model of the Scottish shelf waters to predict impacts of tidal energy extraction on hydrodynamics

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Renewable energy developments such as offshore wave, tidal and wind may occupy large areas and compete with other users of the maritime space. While large scale offshore energy farms have great promise as an alternative renewable energy source, their potential environmental impacts should not be underestimated. An unstructured grid coastal ocean model FVCOM (Finite-Volume Community Ocean Model) has been used to reproduce the present climate conditions in Scottish shelf waters, with a resolution refining from over 10 km at the open boundary down to approximately 1 km at the coast. Very large scale tidal stream energy scenario has been implemented in the FVCOM model using the momentum sink approach, in which a momentum sink term represents the loss of momentum due to tidal energy extraction. Near and far-field effects have been evaluated by comparing a set of ocean physical parameters describing the present ocean climate and the future state modified by energy-extraction.

9:30 – 10:30

Generalised Cartesian Grids

Stéphane Popinet

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Paris

I will present the key concepts behind the generalisation of Cartesian grids to allow for mesh adaptivity while preserving the conceptual simplicity and computational efficiency of standard Cartesian grids. The basic operations necessary to build efficient, parallel and adaptive solvers for hyperbolic and elliptic problems will be discussed, with an emphasis on the conceptual simplicity of multigrid solvers within this framework. Applications of the resulting system (implemented within the Basilisk library: http://basilisk.fr) to the adaptive solution of dispersive shallow-water equations (the Serre-Green-Naghdi equations) and the time-implicit solution of the Saint-Venant equations will demonstrate these concepts for realistic applications.

11:00 – 12:00

OMUSE demo

Inty PELUPESSY

13:00 – 14:00

Structured and unstructured mesh generation with POCViP

Damien ALLAIN

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We thank our supporting organizations without whom we would not have been able to host this workshop.