The coupling system of ROMS and WWMII models

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Introduction

- The motivation of this work was to couple the 3rd generation spectral wave model WWMII (Wind Wave Model II), that works on unstructured meshes (Roland, 2009), with the well know ROMS model in order to account for the effect of currents on waves and vice versa. The benefit of such a coupling between the unstructured WWMII and ROMS is an improved computational performance due to the flexibility of the unstructured mesh. Here we show first results with respect to the validation of the numerical schemes and the coupling approach itself.

The ROMS and WWMII models

ROMS

- The ROMS model is a finite difference model that solves the Eulerian primitive equations in curvilinear coordinates.

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} = fv - \frac{1}{\rho}\frac{\partial p}{\partial x} + F_{m,x} + F_{w,x} + F_{surf,x} + F_{bottom,x}$$

- ROMS uses the hydrostatic and bousinesq approximations.
- ROMS uses σ-coordinates for the vertical discretization.
- ROMS uses the split-explicit method in order to resolve fast surface waves with a barotropic model.
- ROMS has a variety of high order schemes for momentum advection, tracer advection, horizontal pressure gradient, etc.
- ROMS has infrastructure for coupling with other models (SWAN, WRF, etc.). It is a generally well written program.
- ROMS has adjoint/tangent modules (not used here)
- ROMS has possibility access to some biology and sediment models.

WWMII

- The WWMII model solves the Wave Action Equation

$$\frac{\partial N}{\partial t} + \nabla_x((c_g + U_A)N) + \nabla_k(\dot{k}N) + \nabla_\theta(\dot{\theta}N) = S_{tot}$$

with

$$S_{tot} = S_{ds} + S_{in} + S_{nl3} + S_{nl4} + S_{bot} + S_{break}$$

- The model uses triangular unstructured meshes in geographical space, which gives the model great flexibility when complicated domains have to be resolved and it allows to optimize the distribution of the calculation points in order to save time.
- The model solves the Wave Action Equation using the fractional step method (Yannenko, 1971)
- The model uses ultimate quickest schemes according to (Leonard, 1982) as used in WWIII (Tolman, 2011).
- For the advection in spatial direction the WWMII uses numerical schemes from the family of Residual Distribution Schemes (e.g. Abgrall, 2006)
- Implicit and explicit schemes are available.

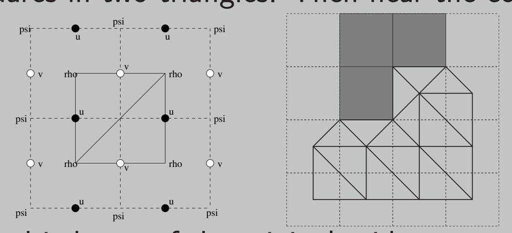
The coupling

Theory

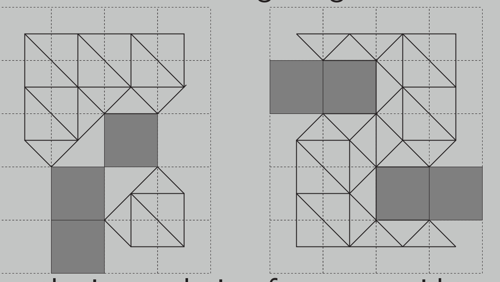
- Waves are inducing a current named *Stokes drift* which is a nonlinear effect of waves and explains many effects of waves. Waves also enters into the primitive equations by the radiation stress terms
- In Longuet-Higgins 1953, an explicit expression for the barotropic term of the radiation stress is found.
- But the full baroclinic equations are still under discussion. What we believe is the correct set of equations is the ones devised by Ardhuin:
  - It gives a wave condition at boundary open or closed.
  - It represents surface stress and dissipation of the oceanic model as integral of the corresponding term for waves, thereby allowing to use formulations for waves.
  - It uses pseudomomentum and Generalized Lagrangian Mean formalism
- Waves also enter into sediment modelling, turbulence modelling, etc.

Implementation

- The ROMS model uses finite difference while the WWMII model uses finite element meshes, so some interpolation is necessary.
- Our standard interpolation strategy is to subdivide the squares in two triangles. Then near the coast, we add some more triangles.



- Those additional triangles allow us to respect the straits and isthmus of the original grid.

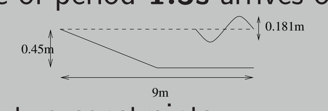


- The coupling is done by using FORTRAN programs that does the interpolation from one grid to another. Pipes are used to make the exchange explicit and minimize the need for code rewriting.

Idealized test cases and periodic grid

Shoaling test case

- For the shoaling idealized test case, a wave of period **1.5s** arrives on a beach and breaks



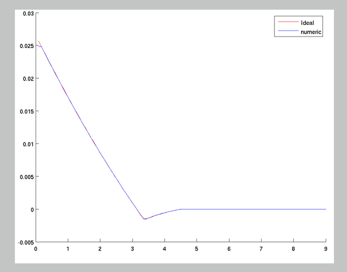
- The significant wave height satisfies to the two constraints:

$$H_S^2 c_g = Cst \text{ if no wave energy dissipation}$$
$$H_S \leq c_B(h+z) \text{ with } c_B = 0.415$$

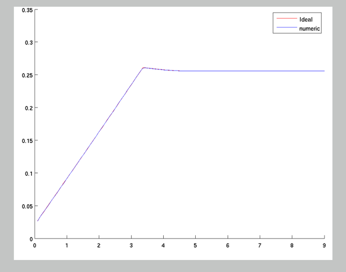
- The stress balance equation is

$$\frac{\partial S_{xx}}{\partial x} = -\frac{1}{h+z}\frac{\partial h}{\partial x}$$

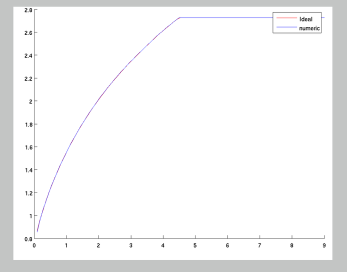
with S_{xx} the Longuet-Higgins potential, h the depth and z the free surface.
- The free surface and significant wave height can be computed with very high precision by iterating the above equations.
- The coupled system gives results very near to the "analytical" solution.



Free surface



Significant wave height

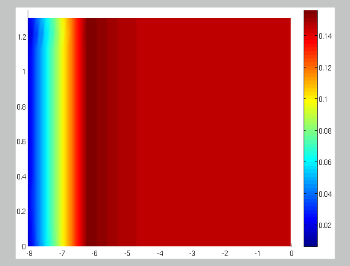


Wave length

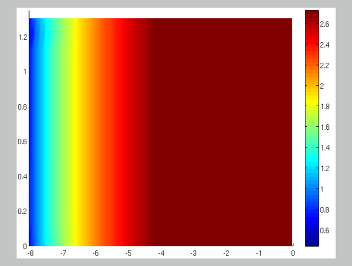
Visser's idealized test case

- Another important test case is the Visser test case where the waves are arriving obliquely on the beach.
- In order to adequately model such situations, we introduce ideal grid, that is grids where the model does not see the whole coordinate system:
  - Input contains triangle area, list of nodes and node depth.
  - Differences of coordinates between nodes of each triangles

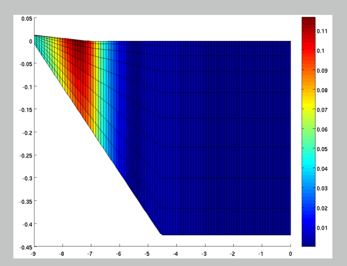
  Everything (angle masks, differentials, ...) can be computed from this grid data.
- This allows to build periodic grids for coupled wave models and so to simulate academic test cases with the coupled system.
- When the model is in steady state a longshore current is induced by the waves and this current is balanced by dissipation in the model. See below results for Longuet-Higgins formulation:



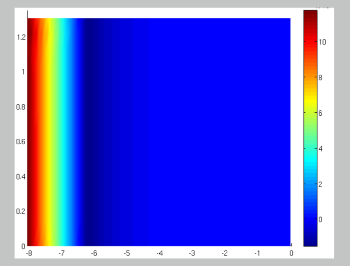
Significant wave height



Wave length



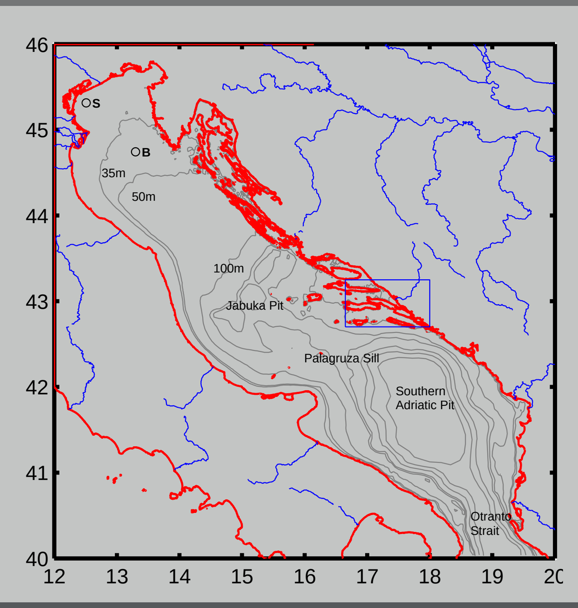
Longshore current

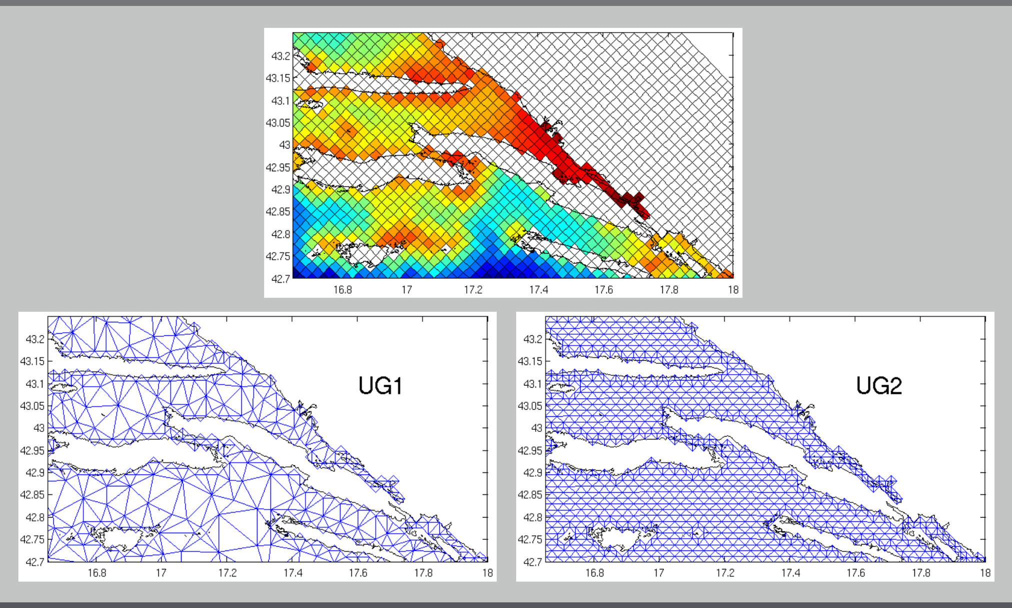


Free surface

Modelling of the Adriatic

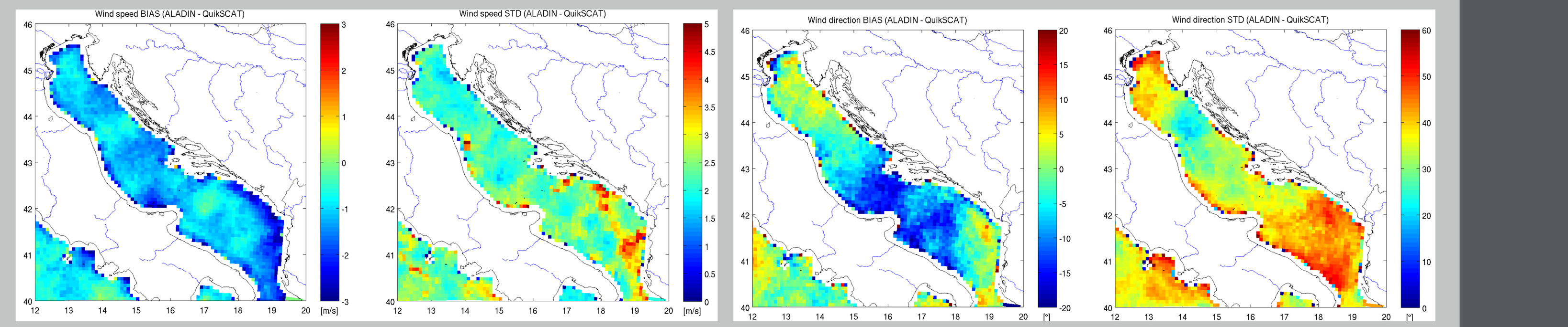
- We used the results of the ALADIN model as forcing for the coupled system applied in the Adriatic Sea. ALADIN is a spectral model using **8km** grid to provide variables for bulk flux calculation and wind.
- ROMS model was previously validated in the region giving RMSE on T/S for CTD: **0.92°C/0.44PSU**, RMSE on T for Medspiration L4 SST product: **0.82°C**
- For wave comparison we have **2** wave stations, Acqua Alta (S) and wave buoy (B)





Wind comparison with QuikSCAT data

- QuikSCAT scatterometer provides sea surface (**10m**) wind field at a **12.5km** resolution
- Instrument specification gives zero bias and RMSE **2m/s** and **20°** for magnitude and direction. Validation studies with in situ data in coastal region (< **80km**) show increase in error both for magnitude (**0.93m/s ± 1.83m/s**) and for direction (**4.71° ± 31.15°**) (Tang et al., 2004)
- Validation of ALADIN data with QuikSCAT data shows good agreement and relatively small error:
  - wind speed: $-1.15 m/s \pm 2.50 m/s$
  - wind direction: $-4.16° \pm 38.14°$



Numerical results

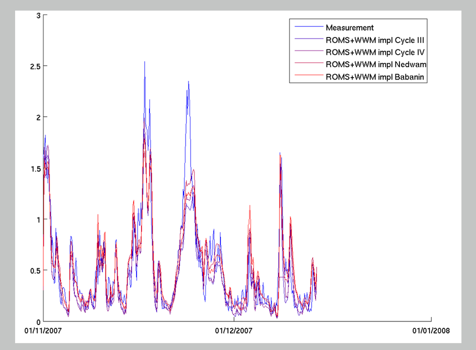
Comparison with station **S**

parameterization	Significant wave height			Mean wave length			Mean direction	
	RMSE	ME	Corr	RMSE	ME	Corr	ME	RMSE
Cycle III	0.26	0.09	0.87	24.55	20.55	0.68	-1.77	60.51
Cycle IV	0.27	0.10	0.86	19.43	15.83	0.72	4.29	56.45
Nedwam	0.23	0.01	0.88	20.17	14.54	0.73	7.83	55.74
Babanin	0.25	0.01	0.86	20.23	16.29	0.73	14.62	66.50

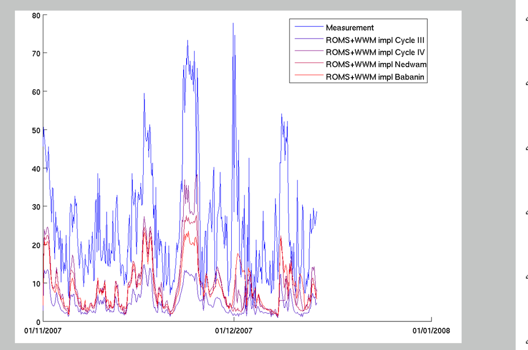
Comparison with buoy **B**

parameterization	Significant wave height			Mean wave length			Peak direction	
	RMSE	ME	Corr	RMSE	ME	Corr	ME	RMSE
Cycle III	0.24	0.10	0.90	17.17	15.30	0.70	-0.98	61.58
Cycle IV	0.23	0.09	0.90	10.60	8.73	0.79	3.94	64.09
Nedwam	0.20	-0.01	0.92	11.42	9.48	0.76	2.16	63.48
Babanin	0.23	-0.01	0.89	12.74	11.00	0.77	5.71	60.09

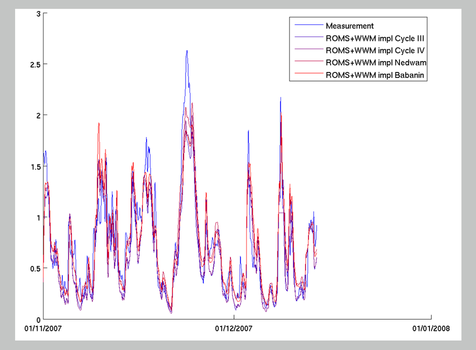
RMSE: Root Mean Square Error, ME: Mean Error, Corr: correlation. Those runs are done with the implicit scheme of WWMII and the finite difference grid (UG2, 32810 nodes) and not the FEM grid (UG1, 4896 nodes)



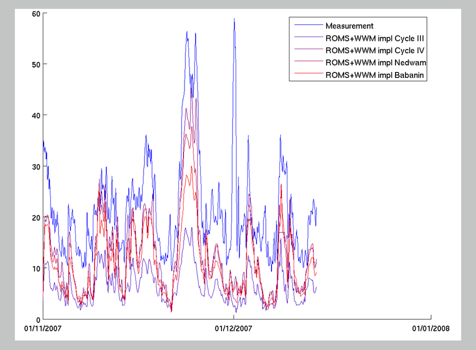
Significant wave height at **S**



Mean wave length at **S**

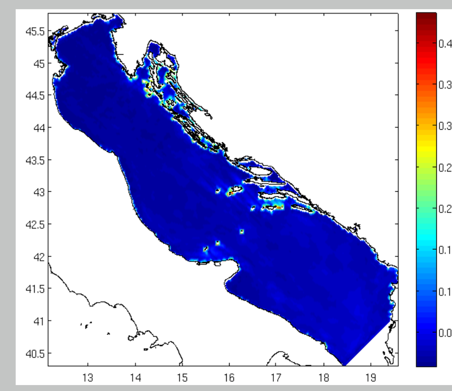


Significant wave height at **B**

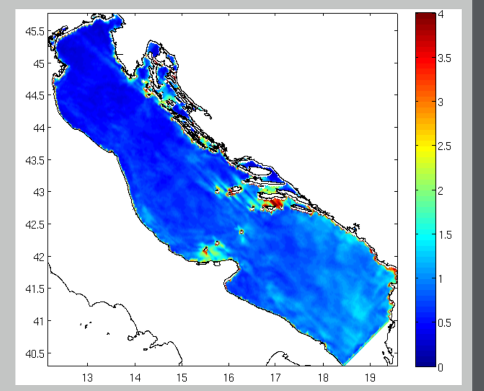


Mean wave length at **B**

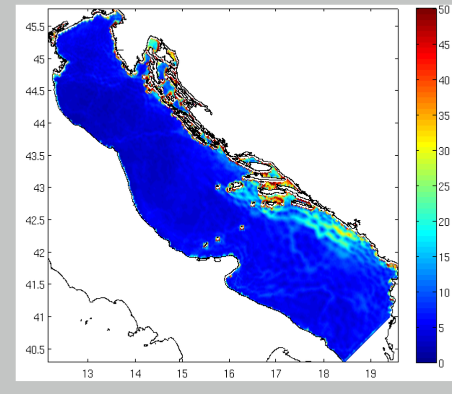
Mean absolute difference between run on UG1 and UG2



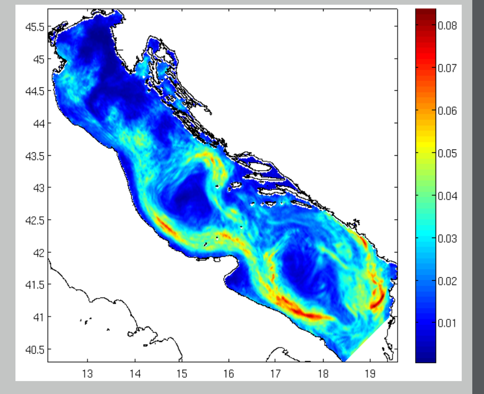
Significant wave height



Mean wave length



Mean direction



Surface current

Conclusions

Results

- A coupled system ROMS+WWMII has been created that provides forecast of current and waves.
- The grid of the wave model does not have to be the same as the grid of the oceanic model. A new subdivizion scheme for finite difference meshes has been introduced.
- A new simplified grid system has been implemented in the WWMII model.
- The coupled model has been validated with idealized test cases as well as with a realistic case of the Adriatic Sea **2km** setup.

Ongoing work

- Implement completely the Ardhuin approach (wave boundary condition, etc.)
- Unify the computation of surface stress by using the result of the wave model.
- Use integrals over the spectrum instead of mean wave length, direction, etc.
- Improve the computation of Lagrangian drifters in the ROMS model.
- Reduce error due to bathymetry gradients.

References

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