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Exploring DELFT3D as an operational tool

Coastal Risk exploratory Project

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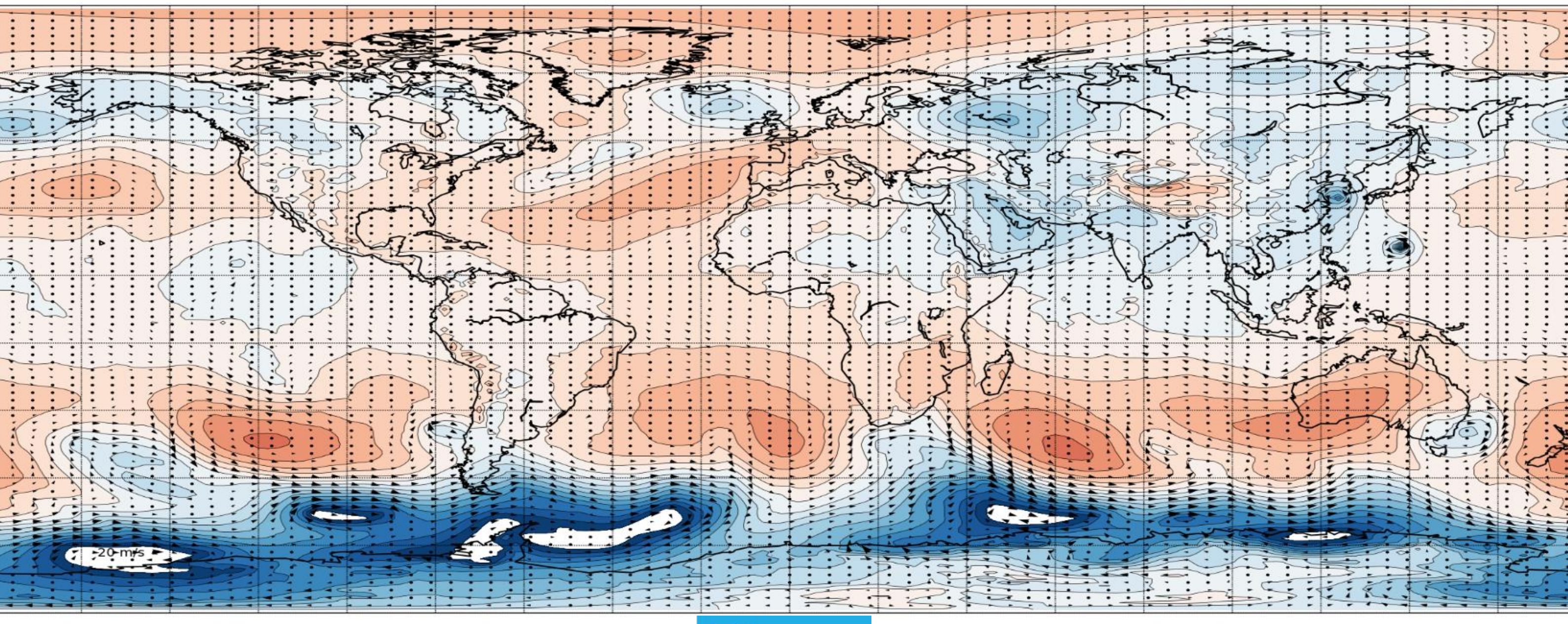

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Contents

Abstract

One of the deliverables foreseen within the Coastal Risk exploratory research project was a prototype of an operational system that can tackle the task of an early information and awareness platform.

The proposed prototype aimed to include an extensive range of physical processes including tides, waves and fluvial flows. One of the very few suites of codes that can handle the plethora of interactions considered and an open sourced one, is Delft3D (https://oss.deltares.nl/web/delft3d). Thus, the focus has been to develop a functional workflow based on this model and expand it to meet the requirements of the foreseen system.

The capabilities of DELFT3D have been validated and tested extensively (see corresponding document at http://oss.deltares.nl/web/delft3d/download). However, its basic usage is to be used through a GUI based on MATLAB and on a case by case basis. In order to make the tools versatile enough to be used within a script-based operational system with on-demand functionality, a wrapper needed to be developed. Thus, a number of Python scripts have been written that provide pre-processing setup of the simulations avoiding the dependency on MATLAB. These command line scripts could form the basis of the operating system.

The Mediterranean Sea was selected as a test case for validating and benchmarking the various components as well as testing the integration to an operational prototype. The outcome of this research suggest that a prototype system is feasible but there are still issues to be addressed. An overview and the status of development is presented below.

1 Introduction

Sea level rise due to extreme weather events are perilous to coastal communities. Current trends in climate change research suggest that these events will likely increase in the future. There is a need for models that can provide awareness and insight. These systems can be used as a test bed for risk mitigation studies and crisis management tools. Tides, storm surge and waves contribute to coastal conditions. Tides are the result of gravitational forces, while storm surge and wave height are produced by meteorological conditions (wind, pressure). Their combined effect determines the inundation risk for coastal areas. Currently there is a model that estimates the storm surge due to data received by weather numerical simulations (Annunziato, A & Probst, P. 2016). In an effort to extent this configuration to include the tidal and wave components, a feasibility study was performed within the Coastal Risk exploratory project to assess whether the DELFT3D suit of codes can provide an acceptable solution. The Delft3D suite has many modules that can be run independently or in coupled mode. The FLOW module can be used to evaluate the hydrodynamic response of a mass of water to various forcing components such as tides and winds. It can run on a rectilinear or curvilinear, boundary fitted grid in 2D or 3D mode. The 2D mode solves the depth-averaged hydrodynamic equations most applicable to storm surge computations while the 3D mode is required in dealing with transport processes.

The model solves the Navier Stokes equations for an incompressible fluid, under the shallow water and Boussinesq assumptions. This is coupled with a hydrostatic equation for pressure. The grid is staggered with the velocity computed on the vertices and the height of the water (pressure points) in the center of the grid cell. The numerical method is based on finite differences. The time integration is fully implicit, utilizing a variation of the ADI-method providing 2nd order accuracy both in space and time. The code is written in Fortran90 and is using MPI (*mpich*) to run in parallel mode.

The WAVE component uses a variation of the SWAN model (Simulating WAves Nearshore) to simulate the evolution of random, short-crested, wind-generating waves. It is a fully implicit and fully spectral code that can handle all wave directions.

More information is available within the extensive collection of manuals provided by Deltares (http://oss.deltares.nl/web/delft3d/manuals).

2 Implementation

Deltares software is usually managed through a GUI that facilitates the creation of the grid and setting up the boundary conditions. Visualization of the results is provided through additional tools. This platform is based on the proprietary MATLAB environment. Some aspects of the platform might also be Windows OS restricted.

The above described setup poses a number of issues. The aim of the project is to provide an operational module that can handle daily or on demand a simulation of arbitrary attributes such as location, time frame, resolution, etc. Our computational environment consists of Linux Virtual Machines.

The code itself is written in Fortran90 and utilizes MPI (mpich) for parallelization. Therefore, the execution of the code is straightforward. However, the pre/post processing needs to be done in a way that provides transparency, portability and flexibility. More so, it has to be amenable to a high degree of automation.

The open source version of DELFT3D has a number of community based tools and scripts that are provided through the publicly available repository dubbed OpenEarthTools (https://publicwiki.deltares.nl/display/OET/OpenEarth). Based on the python scripts available there and developing additional scripts to mimic the GUI functionality the pre/post processing needs are addressed.

The code has been compiled (version tag 5740) on 2 Linux flavoured operational systems, namely UBUNTU 16.04 and CENTOS 7. The setup procedure including all required dependencies has been documented and can be easily reproduced.

A number of python scripts are available that comprise the workflow for setting up, executing and post-processing the simulations. The workflow setup is presented below.

Step 1. The required input variables are the time frame, the Lat-Lon window and the grid resolution. Using these information, a setup script provides wind velocity and pressure based on ECMWF HR data to be used as quasi-stationary forcing terms (i.e. constant for every hour, which is the forecast interval). The corresponding bathymetry is also computed through interpolation on GEBCO (http://www.gebco.net) data.

Step 2. The evaluated data (Lat, Lon, u, v, p, bathymetry) are written to the corresponding files (meteo, bathymetry, grid) consistent with DELFT3D requirements. In addition, the main preference file can be edited accordingly.

Step 3. The code can now be launched.

As this stage the code is run in parallel mode on multiple cores. A more systematic scalability study is presented below. The output is in NetCDF format in order to facilitate easy analysis. However, the restart files are written in Deltares's own binary format (Nefis). The code output is controlled by corresponding flags in the main configuration file. The output includes a number of attributes for the whole computational grid and also a time series of data for specific observation points that were pre-described. Note that the pre-processing tools include this capability.

Time frame of the execution on 700x260 grid for 72 hours of forecasting is around 30 minutes on 4 cores.

Visualization and analysis is done by python scripts but since the output format is in NetCDF there is no imposed restriction. In fact, through a post-processing modification of the output files the results can be imported into the in-house developed visualization tool Tsunami Analysis Tool (TAT) as well.

A master script that can set up a new run based on the ECMWF input (every 12 hours) and the restart files of the run of the previous time stamp was developed.

2.1 Performance

The ability of the model to meet the required operational constrains and the overall efficiency is measured through scaling experiments within our computational resources. The model run in parallel mode utilizing MPI with fixed grid and an ever increasing number of computational cores. Also tested was the compiler depended performance and the added benefit of running the simulation on RAMDISK thus avoiding IO delays. It turned out that the latter was not important for the case considered, although this could change for other cases. We opted to use the RAMDISK approach and perform the scaling experiment for both INTEL and GNU compilers. The results are presented below.

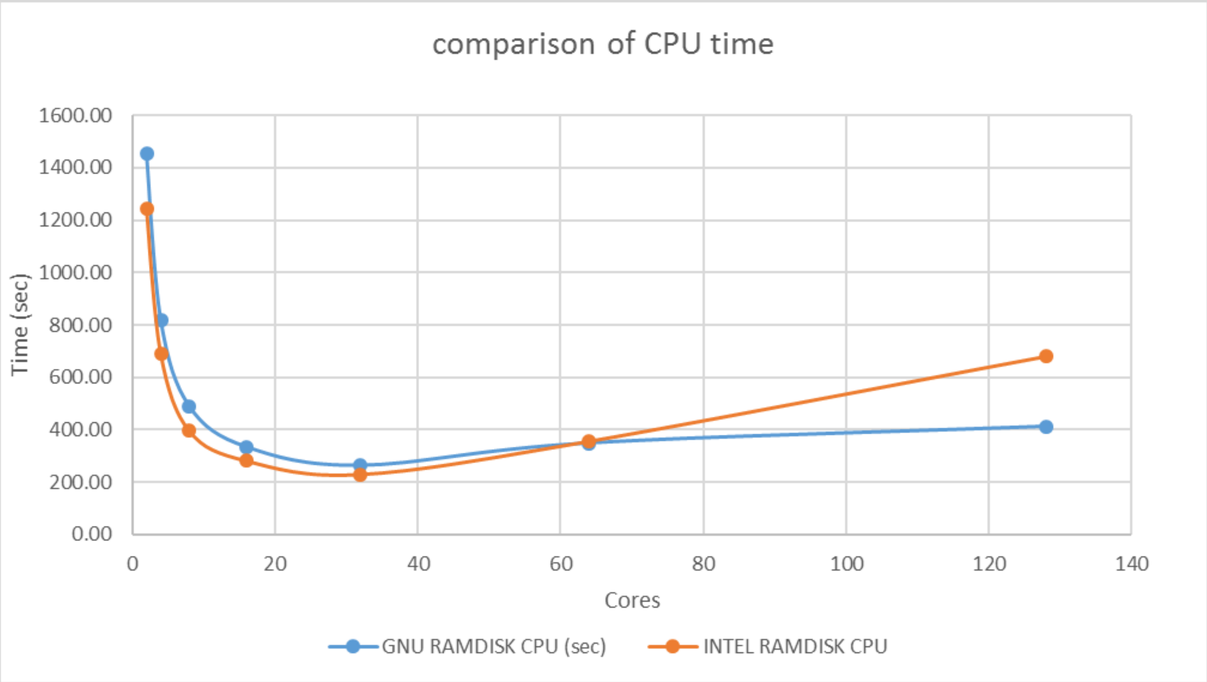


Figure 1 - Execution time vs. number of core of DELFT3D-FLOW.

It is seen that the performance of the INTEL based executable is better for modest number of cores but deteriorates for large number. However, for the current setup (hardware, software, simulated case, etc.) there seem to be an optimum number of cores (~32) for both versions. Thus, the configuration which includes the INTEL compiled version and 32 cores was adopted for the operational runs.

3 Assessment

The different components of the proposed system are tested utilizing the DELFT3D suite.

3.1 Storm Surge

A first comparison of the storm surge calculations can be made with the results of the operational HyFlux code for the test case of the Mediterranean Sea.

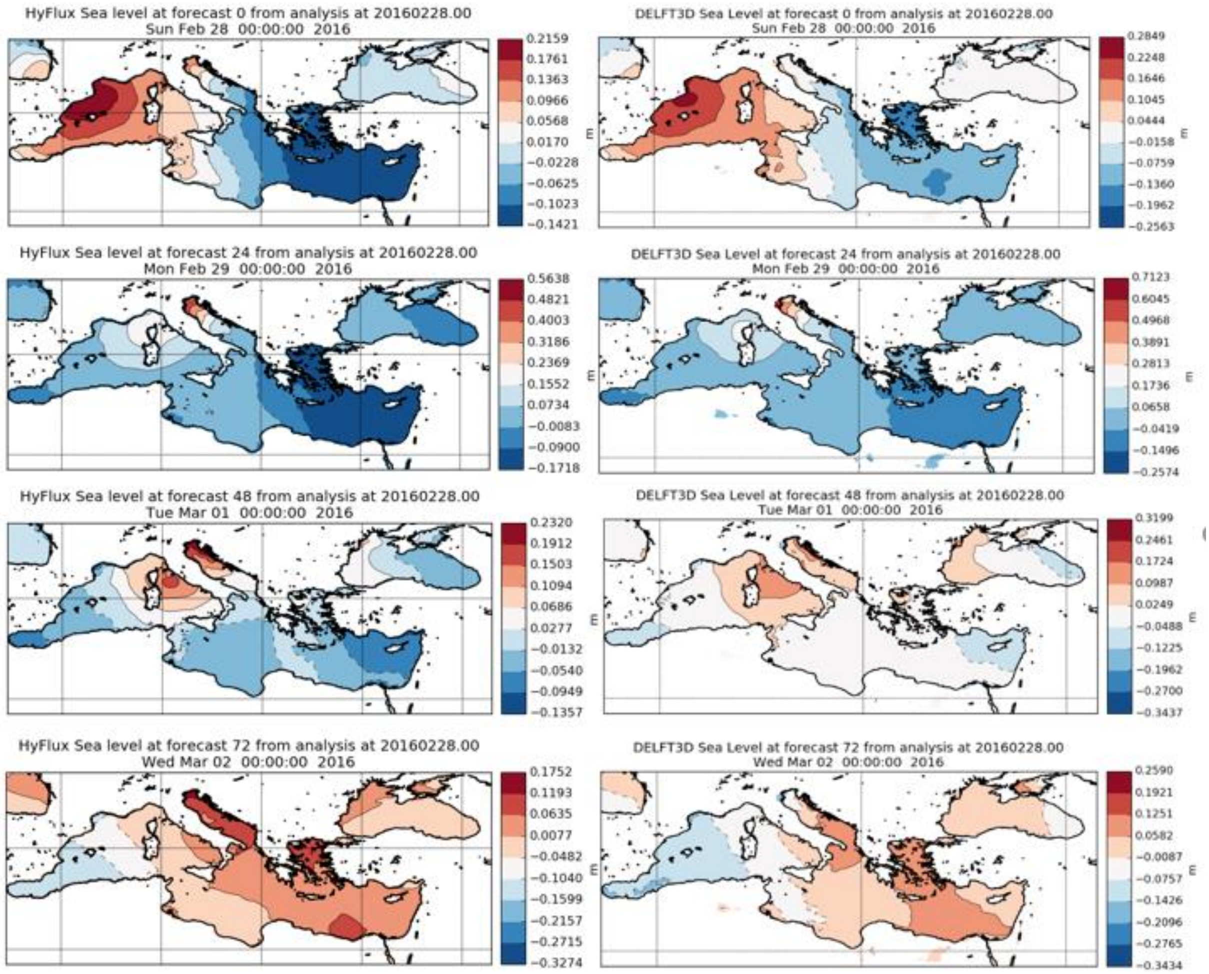


Figure 2 - Comparison between HyFlux and DELFT3D for storm surge forecasting.

Such a comparison is presented in Figure 2 for the forecast of 28 Feb 2016 00:00. Note that the Delft3D-Flow has started on the 18th of Feb with a cold start (all hydrodynamic variables set to zero). Differences can be attributed to a number of issues including grid, bathymetry and forcing. A more detailed quantitative analysis is in progress.

Comparison with measured data is presented below for a specific case of an extreme event in Venice. The first figure depicts the forecasting and the markers indicate the combined line consisting of the 12-hour forecasting of each result based on analysis wind data. The range of the colored lines is indicative of the uncertainty of the extreme event. The second figure shows the comparison of the combined result with the measured storm surge. Note that the last part of the combined curve is the full forecast based on the analysis of 28/2/2016.

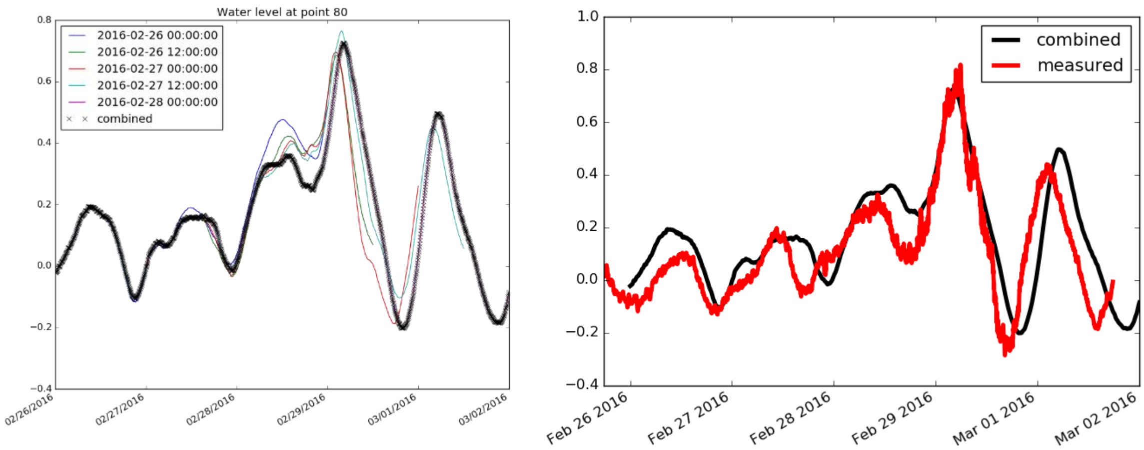


Figure 3 - Analysis and comparison with observations.

It is seen that the specific event is well captured. A more systematic analysis of a 3 year hindcast is under way for verification purposes that could provide a more comprehensive overview of the model's capabilities.

3.2 Tides

The tidal component can be introduced in 2 ways. Either by assigning an astronomical boundary condition on the boundaries and/or activating the tidal component within the code. In general terms, when a relative small area is considered, assigning a boundary time series should produce the proper tidal response due to the relative small mass of water considered. For larger basins or areas with deep oceans, one has to consider also the direct contribution of the gravitational forces on the water motion. Thus, activation of the tidal component might be required to achieve the desired behaviour. A number of tests were performed in accessing the applicability of the tidal component. Preliminary tests indicate that also the value of the bottom friction is important in optimizing the simulation.

In the case below an astronomical boundary condition is imposed at Gibraltar. This condition is extracted from a tidal solution provided by Deltares for the Mediterranean Sea.

The results produced after 20 days of simulation should approach the expected one from the given solution matrix. No other process is considered (no wind forcing, etc.).

Fig. 4 shows that for the case of Ravenna (IT):

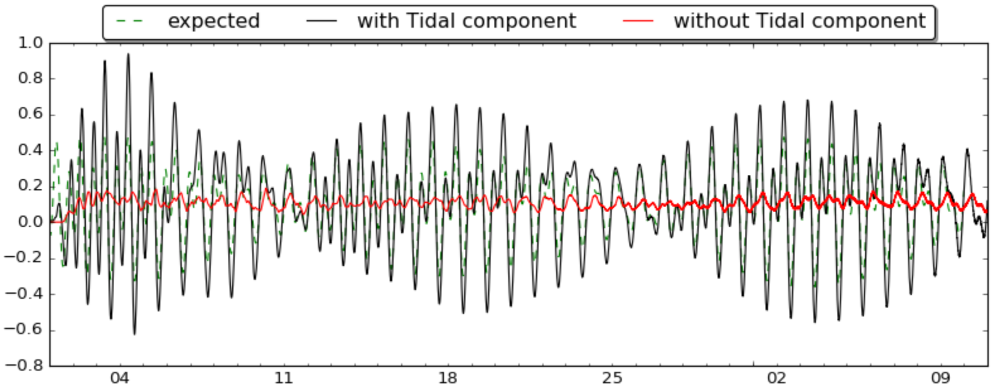
- When only the boundary forcing at Gibraltar is imposed, the tide does not propagate correctly into the Adriatic sea and the curve (red in the plot) shows too low amplitude.

- the inclusion of the tidal component in the calculation (gravity force applied to the whole calculation domain, black full curve) produces an amplitude that is closer to the expected solution by Deltares (dotted curve). Thus the tidal component is necessary in order to achieve the expected result.

Fig. 5 shows instead the case of Palermo (IT) where:

- the option of imposing only the boundary condition shows a better response in respect to the case of Ravenna. However, there are oscillations developed at a later stage which suggest instability in both cases (with or without tidal component in the calculation domain). These can be ameliorated by modifying the bottom friction coefficient which however creates lagging and potential amplitude reduction. More analysis is required for addressing this issue.

a)



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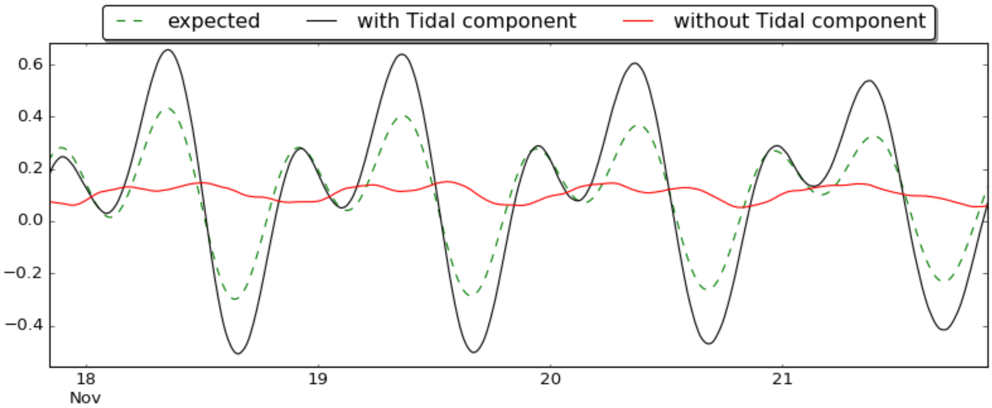
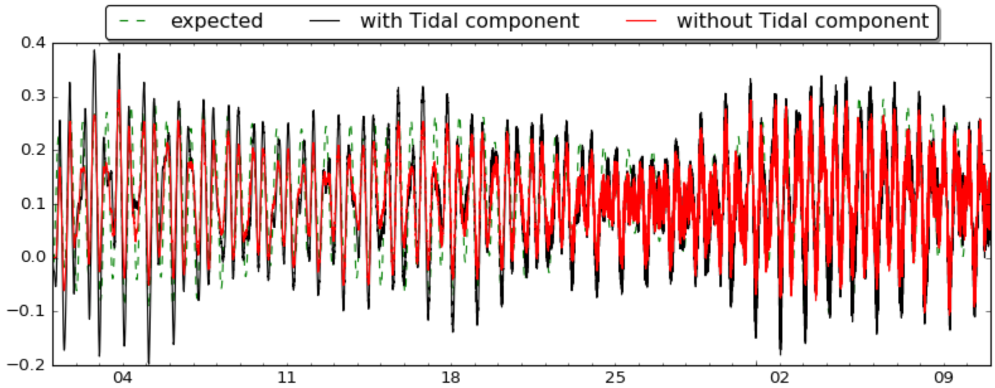


Figure 4 – a) Comparison between expected tide, and the computed value with/without the tidal component for Ravenna, IT. b) Close up detail.

a)



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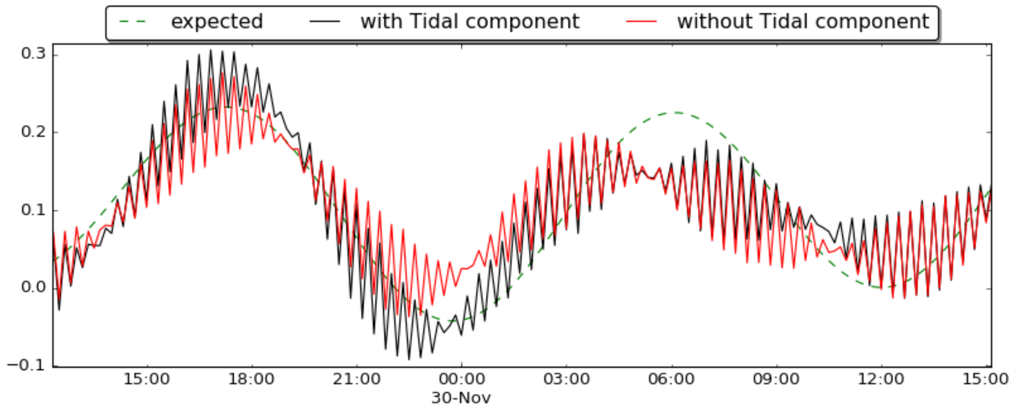


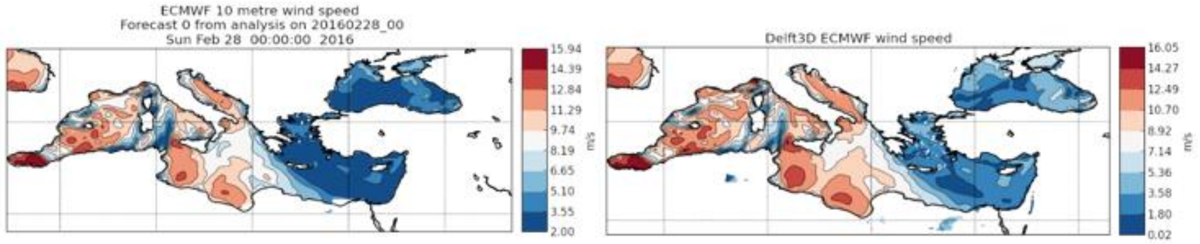
Figure 5 – a) Comparison between expected tide, and the computed value with/without the tidal component for Palermo, IT. b) Close up detail.

3.3 Waves

Benchmarking of the waves module within DELFT3D (swan) is done by comparing with the results of the global wave simulation provided by ECMWF. The comparison is presented in Fig. 6 for up to 48 hours forecast. The first line of graphs show the difference between the 2 models in term of wind forcing. The qualitative comparison is promising. The maximum values are comparable. The graphs in the second part of the figure provide a depiction of the variation between the results of the two models.

A systematic investigation in terms of grid dependency, applicable parameter space and coressponding comparison with observed data is needed for further validation.

a)



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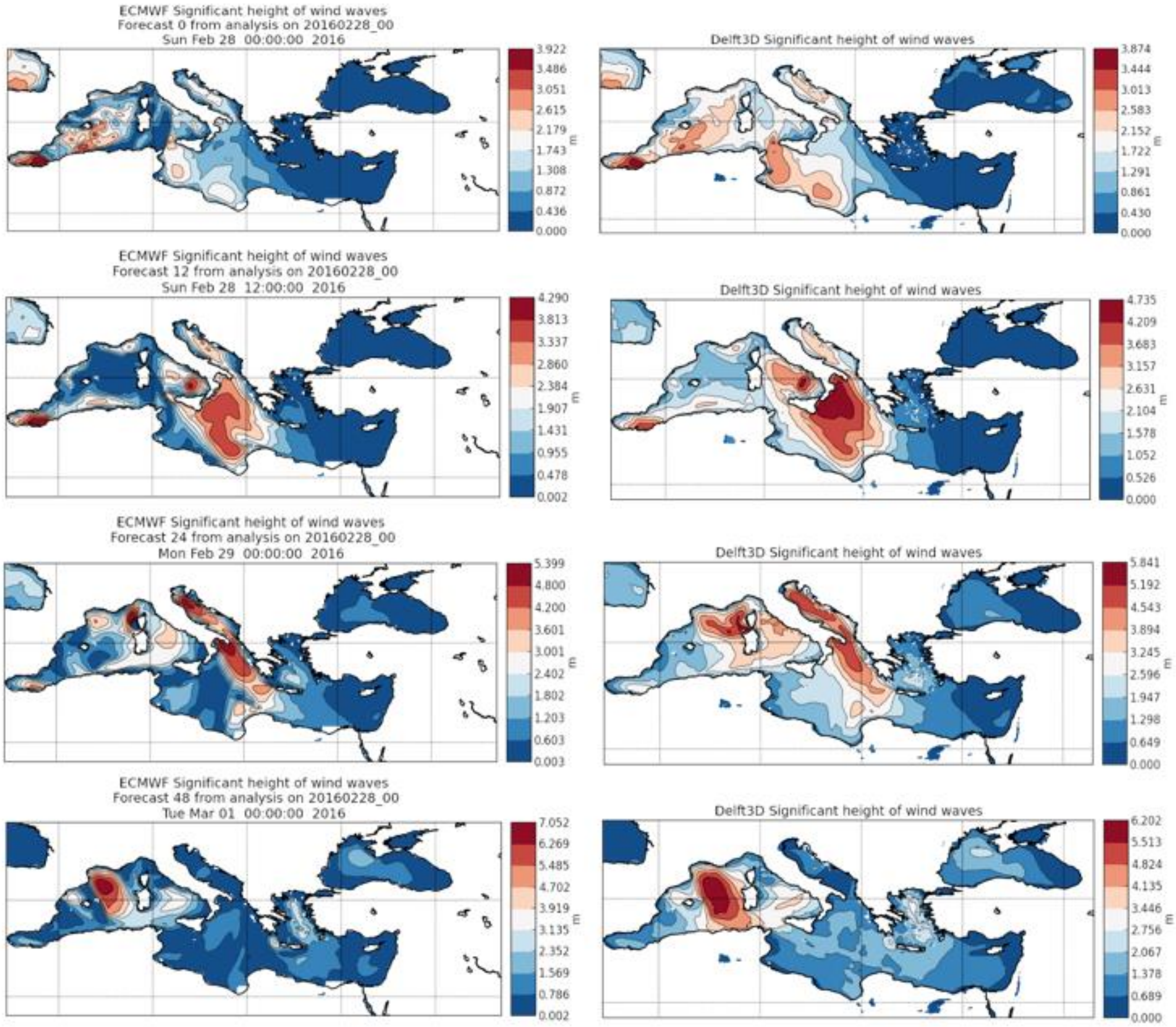

Figure 6 - a) Comparison of the wind forcing between local (right) and ECMWF (left) implementation. b) Wave height estimate of wind waves by DELFT3D-WAVE (right) and ECMWF (left).

In addition to utilizing the wave component of DELFT3D suite (SWAN) there is the option of coupling the DELFT3D-FLOW results to the output of a standalone wave solver. For testing this option, a virtual machine was setup running Wave Watch III, a third generation

wave model from NOAA/NCEP based on previous iterations developed at Delft University of Technology and NASA Goddard Space Flight Center.
More info can be found at http://polar.ncep.noaa.gov/waves/wavewatch/. The model is currently being maintained by an extensive team of core developers spanning the world.

The use of such an advance wave model is likely to be more important away from the shore line and especially in the North Atlantic. A more systematic analysis is required in order to assess the capabilities and added benefits of this model.

4 Functionality

The prototype workflow based on python scripts can be used for setting up and performing simulations on demand. The pre-processing script create the input files for the simulation. The required input are lat/lon window, resolution, forecast range etc. The corresponding command looks like this

```
>python setup.py -100. -50 5 35 'med' '20160928.00' 72 .05 './MED/' 'True'
```

which refers to minlon, maxlon, minlat, maxlat, basename, date (YYYYMMDD.HH), number of forecasts, resolution (decimal degrees), path, compute uvp(T|F).

A folder is created on the defined path (in the above case './MED/' with name that of the time stamp specified (i.e '20160928.00'). Within this folder the required files for simulating the storm surge based on ECMWF data are stored. This script runs only once in order to setup the simulation and one can either create a composite script or execute the simulation manually from the corresponding folder. Note that a preference file is written on the top folder (in this case '/MED/') with the input variables.

After the first run has been concluded another script can handle the subsequent runs by copying the restart files from the previous run as well as the unmodified input files while modifing appropriately the preference file and creating the u,v,p files for the corresponding new time stamp. A complete date range simulation can be performed with a command line like the one below

```
>python rerun.py 20160928.12 20161011.12 './MED/'
```

which corresponds to start_time, end_time and path. The script looks for the previous time stamp folder in the defined path and carries on the simulation. In the above example, the 20160928.00 folder should be present in the '/MED/' location. Within the folder the restart files for every 12 hours are present after the initial first run. The new computation starts with the 20160928.12 time stamp and continues all the way to include also the 20161011.12 run. The attributes of these runs are read from the preference file created by the setup script. Further improvements can provide more functionality. The output is given in netCDF format and a number of post analysis tools can be used to visualize and manipulate them.

5 Outlook

The different components of the DELFT3D suit have been used in order to gain insight into coupled simulations in an automated fashion within a proposed large-scale coastal flood & inundation tool. The dependency on MATLAB has been overcome and a script based command line tool is available for launching the simulations. Validation and verification tests were performed that can serve as guideline for future development. There are however some open issues before the scope of the project can be achieved. The more challenging are

- The setup of a nesting computation. There are still issues with stability and automation but the development is ongoing.
- Coupled run with the DELFT3D FLOW – WAVE modules. Preliminary runs have been performed but the numerical resources requirements and/or applicability issues are still under investigation.
- Handling of fluvial flows, where present. Issues like grid and boundary conditions have not been addressed.

Further statistical analysis and expansion to a pan European model will provide a test bed for addressing the numerical problems described above drawing upon the experiences and competences developed through the Coastal Risk project.

References

- Annunziato, A and Probst, P. JRC storm surge system for Europe: JRC SSCS bulletins and the new GDACS system, EUR 2016.

Acknowledgements

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Authors

George Breyiannis, Thomas I. Petroliagkis, Alessandro Annunziato

List of abbreviations and definitions

ECMWF	European Centre for Medium Weather Forecast
GDACS	Global Disasters Alerts and Coordination System
JRC	Joint Research Centre
netCDF	Network Common Data Form
GEBCO	General Bathymetric Chart of the Oceans
TAT	Tsunami Analysis Tool
HR	High Resolution
NOAA	National Oceanic and Atmospheric Administration
NCEP	National Centers for Environmental Prediction
MPI	Message Passage Interface
SWAN	Simulating WAves Nearshore

List of figures

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