Assessing the impact of meteorological models in coastal and estuarine surface drift forecasting systems

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Abstract: The implementation of ocean and coastal operational systems is now relatively accessible to the scientific community. Although estuary modelling is more challenging than coastal processes in specific processes, operational and pre-operational implementations tend to integrate high resolution hydrodynamic models, but sometimes forced with sea surface boundary conditions from low resolution atmospheric models. This approach may result in biased forecasts, especially when modelling the transport of floating objects or substances. This work compares results obtained from the simulation of sea surface lagrangian trajectories under the combined forcing of the same hydrodynamic model data but with meteorological models of different spatial resolutions. The lagrangian modelling results are generated based on a user interface using MOHID model, and specifically designed to provide fast, easy-to-use and reliable lagrangian forecasts seamless integrated with metocean data. The obtained results for the Lisbon region indicate that simply passing from 9km to 3 km spatial atmospheric model resolution in nearshore areas or inside the estuary, can result in distinct trajectories from floating substances or objects, in more than 10 km in less than 48 hours. In offshore applications, there is no particular advantage in implementing high resolution atmospheric models, although using low resolution (e.g. GFS 27km) can generate differences of 5 km after 48 hours.

Keywords: MOHID, lagrangian, estuaries, meteorological models, hydrodynamics.

1. INTRODUCTION

The increasing operational computational and operational capacity for building and maintaining high resolution hydrodynamic models is a strong advancement for a better support on multiple activities, including management of beach water quality, prevention and response to marine accidental pollution, navigational aid, etc.

When implementing these kind of systems, particularly in forecasting systems, it is not uncommon to find a huge gap between the spatial resolutions of the hydrodynamic models and their atmospheric boundary conditions. Some cases take in consideration hydrodynamic models with 100m spatial step or even less, under atmospheric boundary conditions resulting from operational atmospheric models with 9-12km spatial resolution.

Thus some pertinent questions may arise: what is the relevance of the atmospheric forcing resolutions in these modelling systems? Is there any particular advantage of having a huge hydrodynamic horizontal (and vertical) spatial discretization when the ingested atmospheric models are not even able to differentiate a Port from an entire city, or an island from the open sea?

Action Modulers is presently involved in multiple activities and research projects (MARINER, MARPOCS) regarding national and transnational integrated metocean modelling implementation, and development of associated downstream services and decision support systems for Port operations and National Marine Pollution Response services (*Action Seaport*). Thus, finding concrete answers to some of these questions might be relevant in order to properly implement an efficient modelling framework.

In order to find answers to some of these questions, the work here presented tries to assess the influence of different atmospheric model resolutions in a hydrodynamic model, and particular on surface currents and on the transport / trajectory of floating objects or substances.

2. MATERIALS AND METHODS

2.1. Area of study

Since this work is mainly focussed on the impact of atmospheric models in coastal and estuarine drift forecasting systems, the Lisbon region + Tagus estuary was selected. This coastal area includes an important Port (Port of Lisbon) with intense maritime traffic (including tankers – see Fig. 1), surrounded by the most urbanized region in Portugal (more than 2.5 million people leave in both estuarine margins), with important bathing waters, touristic activities and the closeness of Sintra Mountains (about 16 km extension). Both urbanized areas and Sintra Mountains may influence the atmospheric regime in the coastal and estuarine waters, due to the effect on topography roughness. The main source of freshwater into the estuary is the Tagus River, with flow rates varying typically between 50 and 2000 m3 s -1.

Fig. 1. Tankers density in the Lisbon region (MarineTraffic).

2.1. Models used

The proper development of this study is supported by implemented metocean and lagrangian modelling applications in the area of study, making use of widely used open-source modelling software.

Different atmospheric models, with different resolutions, are used as surface boundary / forcing conditions for the same hydrodynamic and oil spill models. The expected differences in results, are only due to these atmospheric models, since all the other configurations are kept constant between simulations.

2.1.1 Atmospheric models

3 different model configurations, with different resolutions, were considered in the scope of this work. The coarser model considered is the widely used NOAA's Global Forecasting System (GFS), namely, the near-real time solution with a 0.25º spatial step (approx. 27 km at Lisbon latitude).

Using a nested downscaling modelling approach, 2 different forecasting systems were recently implemented by Action Modulers, using WRF (http://www.wrf-model.org/) open-source modelling software. Both cover continental Portugal, with the first level having 9km spatial resolution, and the second one with 3 km. The first level uses GFS as lateral boundary conditions, while the second level (3km) is nested in the first one. Both have 30 vertical layers, and a time step of 60 seconds in WRF-9km and 20 seconds in WRF-3km.

The management, control and automatic operation of WRF models is fully integrated in Action Modulers's Action Server software solution. These model implementations are presently being used by Action Modulers to different direct and indirect purposes, including the support of flood early warning systems or boundary conditions to coastal models.

2.1.1 Hydrodynamic model

The hydrodynamic model solution considered for this study is the Tagus mouth operational model, implemented, validated and used by MARETEC-IST since 2005 (Fernandes, 2005; Campuzano et al, 2012; Ascione Kenov et al, 2014) in the scope of multiple projects (e.g. EASYCO, LENVIS, DRIFTER, ARCOPOL, etc.), exercises with authorities, and monitoring programs (SANEST). This model is running in a full 3D baroclinic mode with a variable horizontal resolution ranging from 2 km to 300 m around the estuary mouth. The vertical discretisation consists in 50 vertical levels with a resolution close to 1 m near the surface.

Since this assessment is only focused in the transport of floating substances, only the surface hydrodynamic vertical layer will be taken into account when analysing the results.

The numerical software used for this model application is MOHID modelling suite (www.mohid.com), which is a public-domain open-source system.

2.1.1 Lagrangian transport model / oil spill model

An oil spill trajectory model was used, in order to evaluate the distinct drift results when using different atmospheric model resolutions (and also different surface currents, which are also influenced by the atmosphere). The oil spill model used is integrated in lagrangian component of MOHID, and has been widely used and validated in oil spill applications, exercises and real situations across the world, allowing the simulation of all major oil transport and weathering processes at sea (Fernandes, et al., 2013). In this work, all the oil vertical processes and weathering processes are excluded, except the mechanical spreading, which has direct influence on the horizontal evolution of the floating pollutants. Wave-driven velocity (Stokes drift) and a wind-drag coefficient of 3% are also included. The simulated substance is a medium oil (*Carpinteria*), and 100 particles are instantly released in each origin.

3. RESULTS

3.1 Atmospheric models performance

Prior to the application and analysis of the influence of meteorological solutions in the hydrodynamic models and the transport of floating objects or substances, a brief comparison and statistical analysis of the meteorological models and different meteorological stations was conducted. These stations are publicly available through Weather Underground (www.wunderground.com). Nine stations covering the area of study were selected (see Fig. 2, left side), and 1 one-week time period (covering the days used for hydrodynamic and lagrangian model simulations used in this paper) was considered.

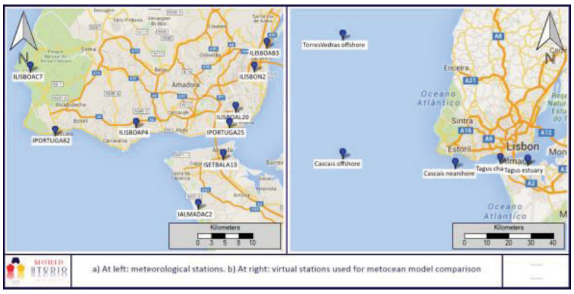

Fig. 2. Location of meteorological stations used for validation (left) and selected points for hydrodynamic analysis (right).

The statistical analysis for wind speed is presented in Table I. Air temperature and wind directions were also evaluated. As can be seen, WRF generally presents better results than the WRF 9km, and this one, better than GFS (27km). In some stations, model performances are clearly influence by important topographic accidents, like for instance, the station *ILISBOAC7*, located in Sintra Mountains. It can also be seen that meteorological models tend to overestimate the wind speed, especially when they have lower spatial resolution. This is the result of having smoother and lower detailed topographies.

Table I. Statistics of meteorological model performance for wind speed in multiple stations (25 April – 1 May 2016).

Wind speed (m/s)		Stations									
		IALMADAC2	ILISBOAB3	ILISBOAC7	ILISBOAL20	ILISBOAP4	ILISBON2	IPORTUGA25	IPORTUGA82	ISETBALA13	All data
Measured data	Mean	3.08	1.45	1.11	2.08	5.49	3.65	3.63	2.25	2.12	**2.77**
	Sddev	2.07	0.95	0.90	0.87	2.51	1.79	1.76	2.45	1.46	**2.16**
WRF 3km	Mean	3.81	3.95	5.02	3.72	4.53	3.65	3.50	5.47	3.72	**4.13**
	Sddev	2.25	1.97	1.74	2.14	2.29	1.57	1.85	2.44	2.14	**2.15**
	MAE	1.23	2.67	4.06	1.81	1.48	1.17	1.08	3.22	1.82	**2.02**
	RMSE	1.58	3.18	4.30	2.43	1.90	1.49	1.40	3.54	2.50	**2.69**
	MB	-0.73	-2.49	-3.92	-1.64	0.96	-0.01	0.13	-3.22	-1.60	**-1.37**
WRF 9km	Mean	5.11	3.98	4.65	3.72	4.61	3.95	3.72	4.95	3.72	**4.25**
	Sddev	2.00	1.76	1.61	1.93	2.00	1.77	1.93	1.85	1.93	**1.94**
	MAE	2.37	2.70	3.68	1.79	1.32	1.31	1.44	2.71	1.98	**2.11**
	RMSE	2.10	3.70	6.16	2.61	2.74	1.17	2.86	2.98	2.51	**2.69**
	MB	-2.03	-2.53	-3.54	-1.64	0.88	-0.31	-0.09	-2.70	-1.60	**-1.49**
GFS	Mean	5.65	4.06	6.48	3.90	3.90	4.06	3.90	6.43	3.90	**4.70**
	Sddev	2.02	1.79	2.31	1.64	1.64	1.77	1.64	2.40	1.64	**2.17**
	MAE	2.69	2.72	5.52	1.90	1.73	1.45	1.00	4.16	1.89	**2.54**
	RMSE	3.15	3.04	5.84	2.19	2.10	1.77	1.28	4.38	2.17	**3.25**
	MB	-2.57	-2.61	-5.37	-1.83	1.58	-0.41	-0.27	-4.18	-1.79	**-1.93**

3.1 Impact on surface currents: integrated hodograph

In order to assess the influence of the different meteorological models in the surface hydrodynamics, 5 different virtual stations were defined, and time series were extracted from those points, with the hourly modelled surface current velocities for a 72-hour period between 28-4-2016 00:00 and 1-5-2016 00:00. These velocities were then integrated under integrated hodographs, and the results for 4 of those points are presented in Fig. 3.

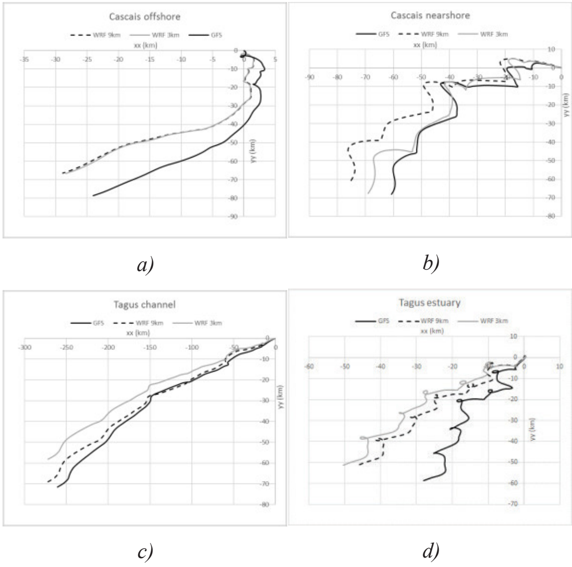

Fig. 3. Integrated hodographs under different meteorological forcing and different locations: a) Cascais offshore; b) Cascais nearshore; c) Tagus channel; d) Tagus estuary.

First of all, the surface currents obtained with GFS are significantly different from the other WRF model results (can reach 20 km after 3 days), except for the Tagus channel, where the tidal currents are very strong and dominant over the other forces. Second: somehow, even off the coast (Cascais offshore, and Torres Vedras offshore – hodograph not presented here, but similar to Cascais offshore virtual station), the WRF models results can differ from GFS – although velocities are quite similar between the two WRF model resolutions. Third, in Cascais nearshore virtual station, results from WRF 9km and WRF 3km can be significantly different (more than 10 km), due to the influence of the Sintra Mountains, better discretized in WRF 3km meteorological model. Just a last note to the directions obtained in Tagus channel – there is no movement towards east (even in high tides), mainly because the analysed time period is during low tide (low barotropic tidal velocities) and high downstream velocities induced by a strong Tagus river flow.

3.2 Impact of surface transport of floating objects or substances: lagrangian trajectories

Different lagrangian surface drift / oil spill model simulations (with weathering processes and vertical movements turned off) were conducted in different locations, and for a simulation period of 48 hours, between 28-4-2016 00:00 and 28-4-2016 00:00.

Centre-of-mass integrated trajectories from the released 100 lagrangian particles are computed, and presented in Fig. 4. These results were visualized and partially generated with MOHID Studio's Lagrangian Spill wizard plugin, allowing to easily generate and visualize on-demand lagrangian simulations.

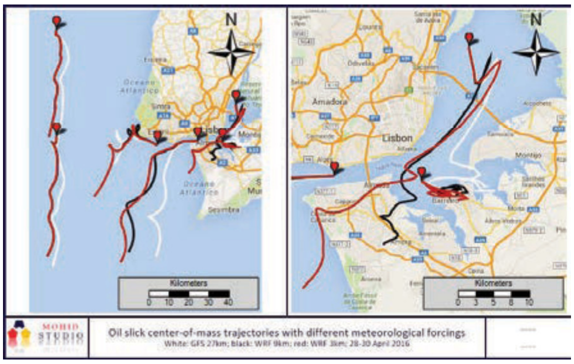

Fig. 4. Oil slick centre of mass trajectories at different release points (red placemarks), under different meteorological forcing: GFS – white; WRF 9km – black; WRF 3km – red.

The centre of mass can indeed be quite different under distinct meteorological model resolutions, particularly in the Tagus Mouth, Tagus estuary, and close to the coast. In these cases, differences greater than 10km in centre of mass trajectories can be found, in only 48 hours. In the other hand, the particle trajectories obtained from WRF-9km and WRF-3km forcing are quite similar in the offshore (by the Figure, the trajectories are almost overlapped), and thus, in these offshore areas, the results obtained seem to reduce the relevance of having high resolution offshore models; nevertheless, a low resolution model (GFS – 27km) presents a different trajectory (equal or less than 5 km of difference), meaning that even in these cases, GFS (or other low resolution models) should only be used as a last resource solution.

4. FINAL REMARKS

The work presented here fully integrates the Action Modulers strategy of improving metocean and marine pollution forecasting systems through the implementation of holistic modelling systems and novel decision support systems in multiple areas of application, and in the case of this work, particularly in coastal and estuarine areas. However, the development of high resolution metocean models must be properly analysed and adequately defined, in order to respond to the actual needs, and to find a good compromise between what is expected in terms of reliability and quality of results, and the computational time and human resources required. Having high resolution hydrodynamic models in some coastal and estuarine areas without a proper high resolution atmospheric forcing can represent an increase the costs without a specific benefit for the certain end users.

The quantitative relevance of wave modelling in the hydrodynamic and lagrangian transport in the studied coastal areas was not considered in this study, and should be pursued in the future.

Further meteorological validation will be conducted in the future for different areas and different parameters, as well as the implementation of higher resolution models, when needed (e.g. flash flood events require very high spatial and time resolution models in order to properly represent precipitation), in parallel with the development of operational services for disseminating meteorological forecasts (*Action Weather*).

Acknowledgements

This work is developed under project MARPOCS (co-funded by European Union; ECHO/SUB/2015/713854/PREP08) and MARINER (co-funded by European Union; ECHO/SUB/2015/713785/PREP10).

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