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Wave-current interactions in the Black Sea and Mediterranean sea: tests with two operational models

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Abstract. The influence of the wave-current interactions on the operational wave forecasting in the Black Sea and Mediterranean Sea was tested. We used two operational wave models: the SWAN wave model implemented operationally at NIMH-BAS and MFWAM (the operational implementation of the WAM wave model of METEO-FRANCE). The model outputs for the runs with and without wave-current interactions are compared with satellite altimetry data. The comparison shows that the overall influence of the wave-current interactions in these two semi enclosed seas is very limited and their implementation in the operational wave models may be justified only for some specific areas in the Mediterranean Sea.

Keywords: wave current interaction, Black Sea, SWAN, WAM, Mediterranean sea

1. INTRODUCTION

The operational spectral wave models take into account the processes of wave generation by wind, wave dissipation due to wave breaking (whitecapping), nonlinear wave-wave interactions, processes in shallow water such as depth induced wave breaking, bottom friction and sometimes other processes such as wave damping due to vegetation, refraction, diffraction etc. A process that is currently not taken into account by the operational wave models of NIMH (National Institute of Meteorology and Hydrology) is the interaction between waves and surface currents. The currents depending on their velocity and direction in relation with the wave direction may lead potentially to significant changes in the wave parameters. For instance strong currents opposite to the waves may reshape the wave spectra and also increase the wave steepness and the significant wave height. The steeper waves are more dangerous for the ships and

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especially boats. This is one of the reasons to study the effects of inclusion of the wave-current interactions in the operational model of NIMH for the Black sea and the operational model of METEO FRANCE for the Mediterranean Sea. The wave-current interactions for the Black Sea have been studied by Rusu (2010) and Ivan et al (2012). Their conclusions are that there are conditions for strong influence of opposite currents on waves close to the Danube Delta and entrance of the Sulina Chanel due to existing strong currents that may lead to generation of unusually high steep waves. The goal of the present article, however is to test the inclusion of such interactions in operational context and to evaluate the influence on the wave simulation quality in larger context.

2. METHODS AND DATA

The wave models used in the study are the operational wave model of METEO FRANCE MFWAM based on the WAM wave model (WAMDI Group, 1988) with wave breaking parameterization that is not the default for WAM cycle 4- the parameterisation of Ardhuin (Ardhuin et al, 2008) and also the SWAN wave model (Booij et al, 1999) that is operational at NIMH. The setup of the Bulgarian implementation of SWAN is presented in Galabov et al (2015). The wind data is from ARPEGE model for the Mediterranean Sea and ALADIN for the Black Sea (Bubnova et al, 1995; Bogatchev, 2008). The currents are obtained from the MERCATOR OCEAN system with a spatial resolution of 0.1°. We compare the modelled significant wave heights using satellite altimetry data from JASON2 and SARAL/ ALTIKA satellite.

3. RESULTS

The wave model runs are with and without included wave- current. For the coast of France the runs are for October and November 2014- the currents are stronger during these months and that is the reason for the selection of months. We found that there is an area close to Nice (eastern part of the French Mediterranean coast) where there are conditions for wave propagation opposite to the surface currents and with significant difference between the runs with and without wave-current interaction. Fig.1. shows a case with interaction between waves and opposite currents for the coast of France and Fig.2 shows the influence on the wave steepness- there is a relatively small area were the wave steepness increases but it is close to the coast. Different definitions of warning criteria for the shipping include the steepness and therefore inclusion of wave-current interactions may be important for such specific areas. The simulation of the same case with MFWAM leads to qualitatively the same result.

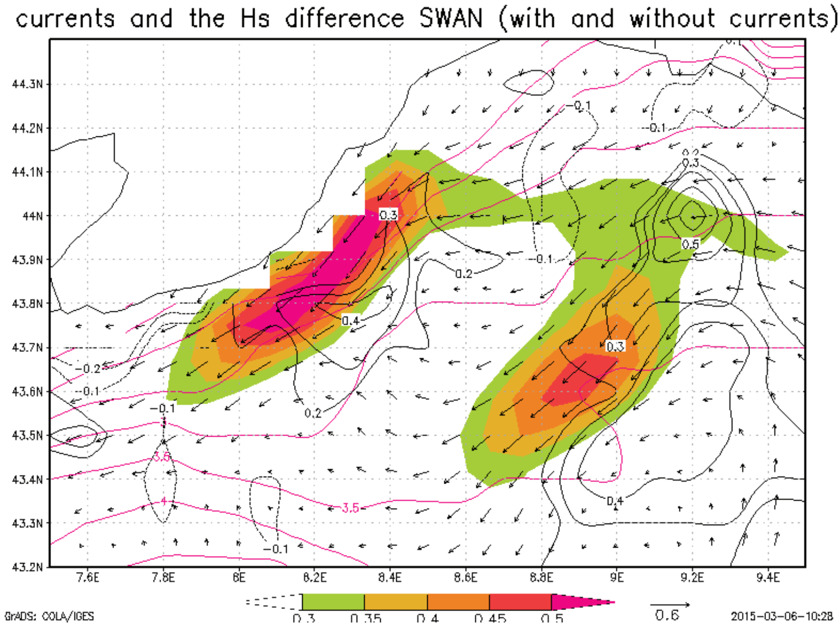

Fig.1. Surface currents (vectors), currents speed (black contours), significant wave height without wave-current interaction (purple contours), the difference in significant wave heights with and without wave-current interaction (colour range). Simulation with SWAN for a case in October 2014**.**

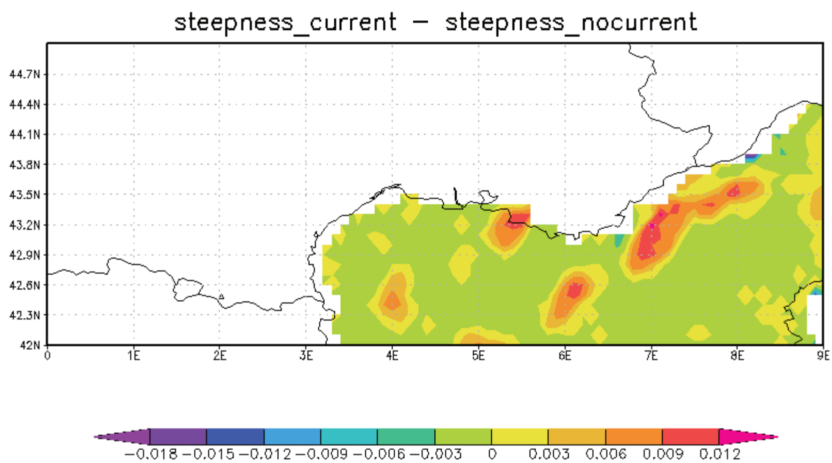

Fig. 2. Wave steepness difference between simulations with and without wave-current interactions**.**

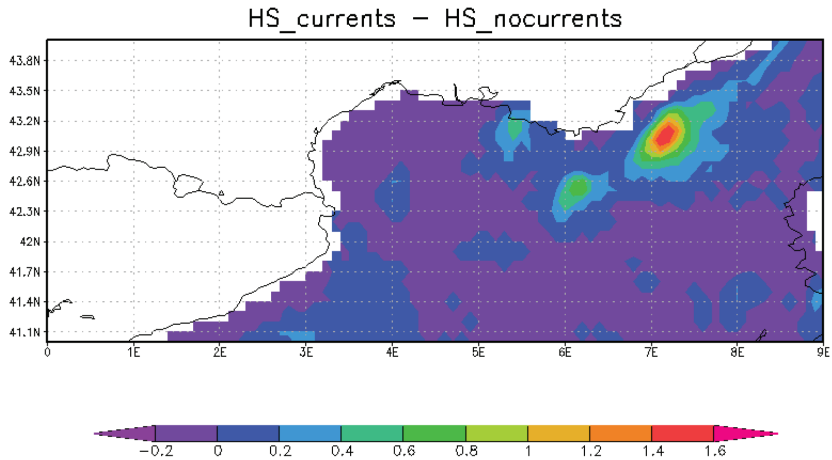

Fig. 3. Significant wave height [m] difference between simulations with and without wave-current interactions**.**

Fig.3. shows the difference for the significant wave height for the same case- there is an increase of the significant wave height by more than 1m in a small area with strong opposite currents. The problem is the lack of wave measurements in such small areas and lack of possibility to compare with actual measurements in this area. The area is too small to rely on satellite data- the probability to have a satellite track during such case in this area is practically zero.

Next we evaluate the wave-current interactions on a larger scale (the entire Mediterranean Sea). Fig.4. shows the maximal differences between the significant wave heights with and without the influence of currents. The areas with significant differences are the coast of France, Algerian coast, Adriatic Sea and the area south of Greece. Table 1 shows comparison with satellite measurements for October 2014 of the wave simulations with WAM and SWAN wave model with and without wave-current interaction. The statistical indicators are the bias, the scatter index and the root mean square error (RMSE). Generally WAM performs slightly better than SWAN, however the differences between the simulations with and without currents are small and the improvement is marginal. The results for November 2014 are without any significant difference- they are qualitatively the same.

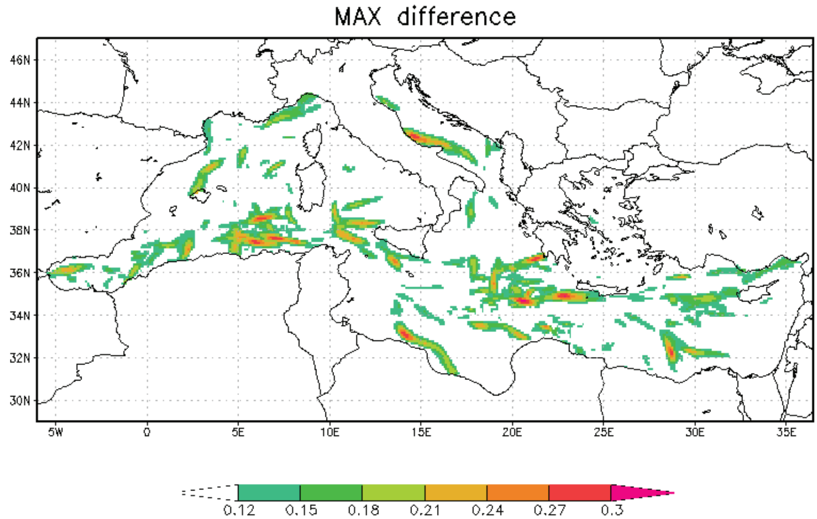

Fig. 4. The highest positive differences for the entire October 2014 (MFWAM simulation)- the difference for each 3 hours is taken and then the highest for each grid cell is extracted and plotted.

Table 1. Comparison of MFWAM and SWAN with and without currents with satellite altimetry data- October 2014.

Model	**Currents**	**Obs. Mean [m]**	**Model Mean [m]**	**Bias [m]**	**RMSE [m]**	**Scatter Index**
MFWAM	yes	1.242	1.127	-0.115	0.281	0.175
	no		1.123	-0.119	0.283	0.175
SWAN	yes	1.241	1.112	-0.129	0.308	0.191
	no		1.100	-0.141	0.322	0.197

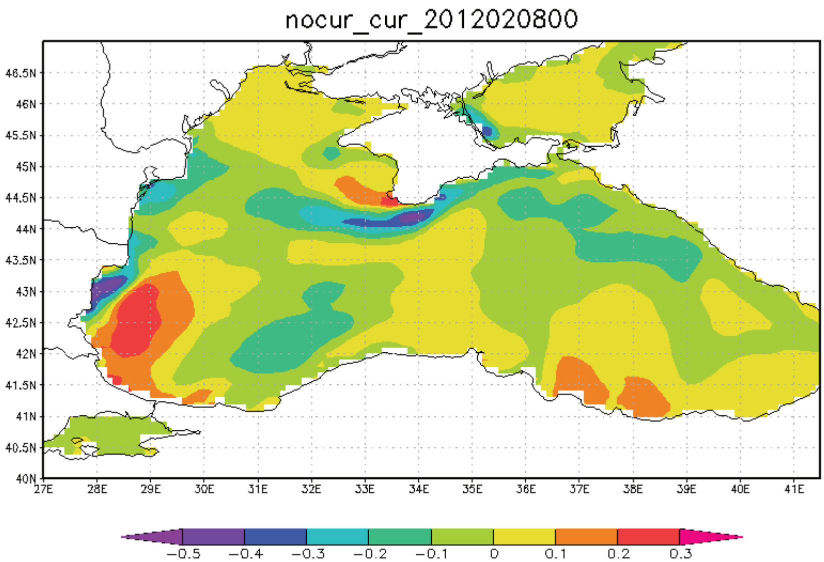

Fig. 5. Difference between the modelled significant wave heights for the Black Sea with and without wave-current interaction during the storm of February 2012. SWAN wave model with WAM cycle 4 physics.

Table 2. Comparison of MFWAM and SWAN with and without currents with satellite altimetry data- January-February 2012 for the Black Sea.

Model	Currents	Obs. Mean [m]	Model Mean [m]	Bias [m]	RMSE [m]	**Scatter Index**
MFWAM	yes	2.908	2.595	-0.313	0.552	0.141
	no		2.585	-0.323	0.558	0.141
SWAN-WAM cycle 4 physics	yes	2.910	2.53	-0.38	0.93	0.26
	no		2.47	-0.44	0.95	0.26
SWAN-WAM cycle 3 physics	yes		2.73	-0.18	0.82	0.27
	no		2.72	-0.19	0.90	0.27

The tests for the Black Sea are performed for the period January- February 2012 that includes many storms with an extreme one among them. Fig.5. shows the difference of the simulated significant wave heights for this storm. Taking into account that the waves in the open sea were above 6 m for the selected period that is visualized, the difference is in order of 5%. There is some increase of the wave heights when currents are included for the Southern Black Sea (the Turkish coast) however for the Bulgarian coast there are hardly any advantages of the simulation with wave-current interaction. The statistics of comparison with satellite data are shown on Table 2. As it may be seen the bias is lowest when we use WAM cycle 3 physics in SWAN (Komen parameterizations) however the scatter index is significantly lower when we use MFWAM wave model which shows the advantages of the whitecapping parameterization of Ardhuin over the parameterizations available in SWAN (the advantage of MFWAM is significant when we take into account the root mean square error and the scatter index). The wave-current interaction leads to only marginal improvement and in operational mode the inclusion of currents data into the wave model is not expected to improve the predictions.

4. CONCLUSIONS

The overall conclusion is that in the Black Sea and the Mediterranean Sea the inclusion of wave-current interactions in the operational wave models is not expected to lead to significant improvements. While it has some importance at some specific areas, it is presently impossible to verify the models for such small areas without measurements. Some improvement may be observed in smaller domains with very high resolutions but only if currents data with corresponding high resolutions are available which presently is not the case.

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