On the Development of an Operational SWAN Model for the Black Sea

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Purpose

- This poster describes the results of some studies performed on the development of an efficient and operational SWAN model for the Black Sea. This model will be used to study the wind-wave climate and wave energy potential in the region and will provide boundary conditions for coastal engineering and nautical activities. The present model development is a continuation of previous modelling exercises by e.g., Akpinar et al. (2012). Final results will be published elsewhere (Van Vledder and Akpinar, 2014). In the former study wave model performance was satisfactory for the lower sea states but lacking good results for the more severe sea states. Here, we aim to further improve model performance by developing an optimal unstructured grid, selection and calibration of input winds against wind measurements and wave model verification against buoy data. Our development plan consists of four major steps using the latest developments in wave modelling techniques.

Development plan

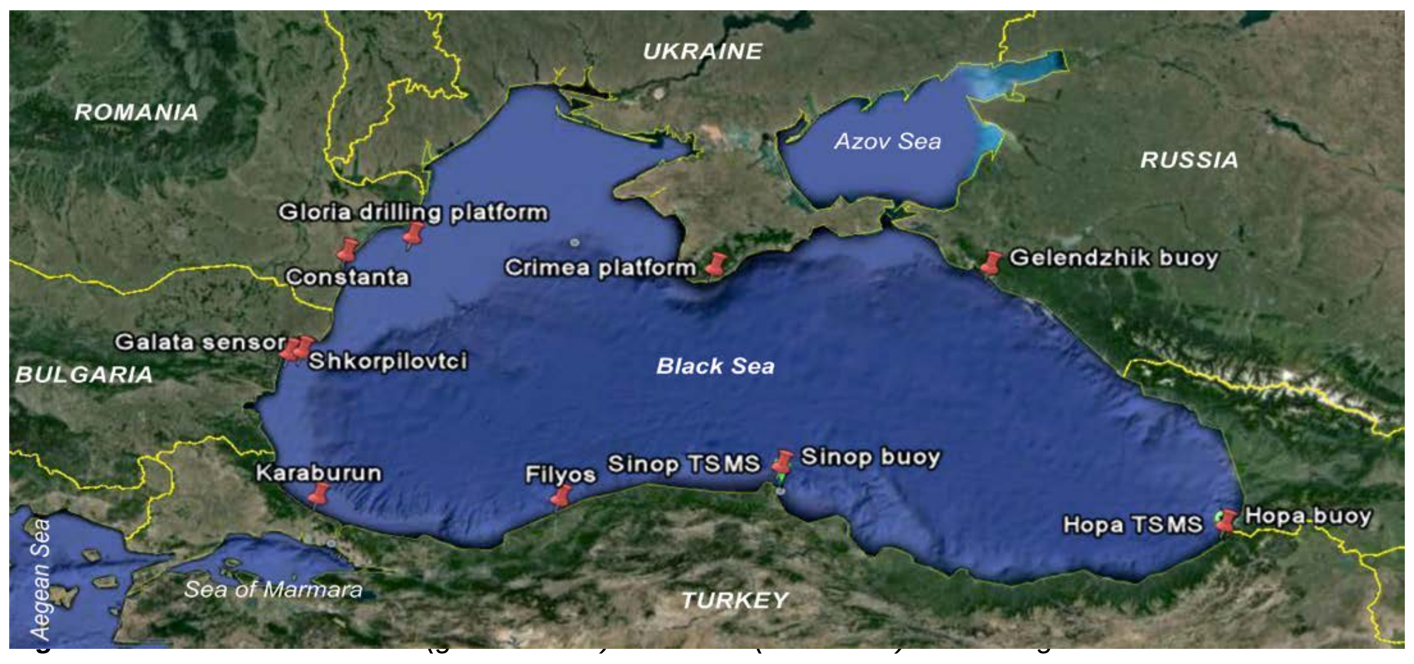
- The first step towards an efficient operation prediction model for the Black Sea is to develop an optimal unstructured grid with the aim to have a fine resolution where needed. Zijlema (2009) showed that unstructured computational grids offer immense modelling flexibility for complicated areas. Although the Black Sea has a relative simple geometry we still see benefits of applying an unstructured mesh. In generating an unstructured mesh we apply a size function to steer the grid generator. Relatively fine grid resolutions are needed in areas where relative large gradients in the wave field occur. For the Black Sea this happens along its land-sea boundary where initial wave growth occurs, in the shallow areas in the northwest and in various bays. We will show the results of sensitivity studies with the SWAN model to illustrate the process of developing an optimal grid.
- The second step is to choose the proper wind forcing. We have the availability of ECMWF ERA Interim wind fields at different special and temporal resolutions. To find the best operational solution we performed simulations for the ECMWF ERA Interim wind fields with five different spatial resolutions (0.1x0.1, 0.25x0.25, 0.75x0.75, 1.875x1.875, 3.0x3.0) and we investigated whether or not wind source with the finer spatial resolution improves wave model performance. Besides, the performances of the different wind fields (ECMWF ERA Interim reanalysis, ECMWF ERA 40 reanalysis, ECMWF Operational datasets, NCEP CFSR reanalysis, NASA MERRA reanalysis, and JRA-25 reanalysis) were examined by using the wind measurements at the coastal land station (Hopa TSMS location in Figure 1).
- The third step comprises the choice of the proper model physics, i.e. the parametric representation of the physical processes of wind wave growth, white-capping dissipation, shallow water dissipation and nonlinear wave-wave interactions. The performance of various modelling approaches was assessed and the one providing the best model results was chosen.
- The fourth and last step involves the investigation of the optimal time step for the non-stationary wave model computations. Here we focused on the required time step in both the input wind fields and the non-stationary wave computations to properly catch at least the dynamic storm events which make the Black Sea notorious, for example the storm in February 8, 2012.

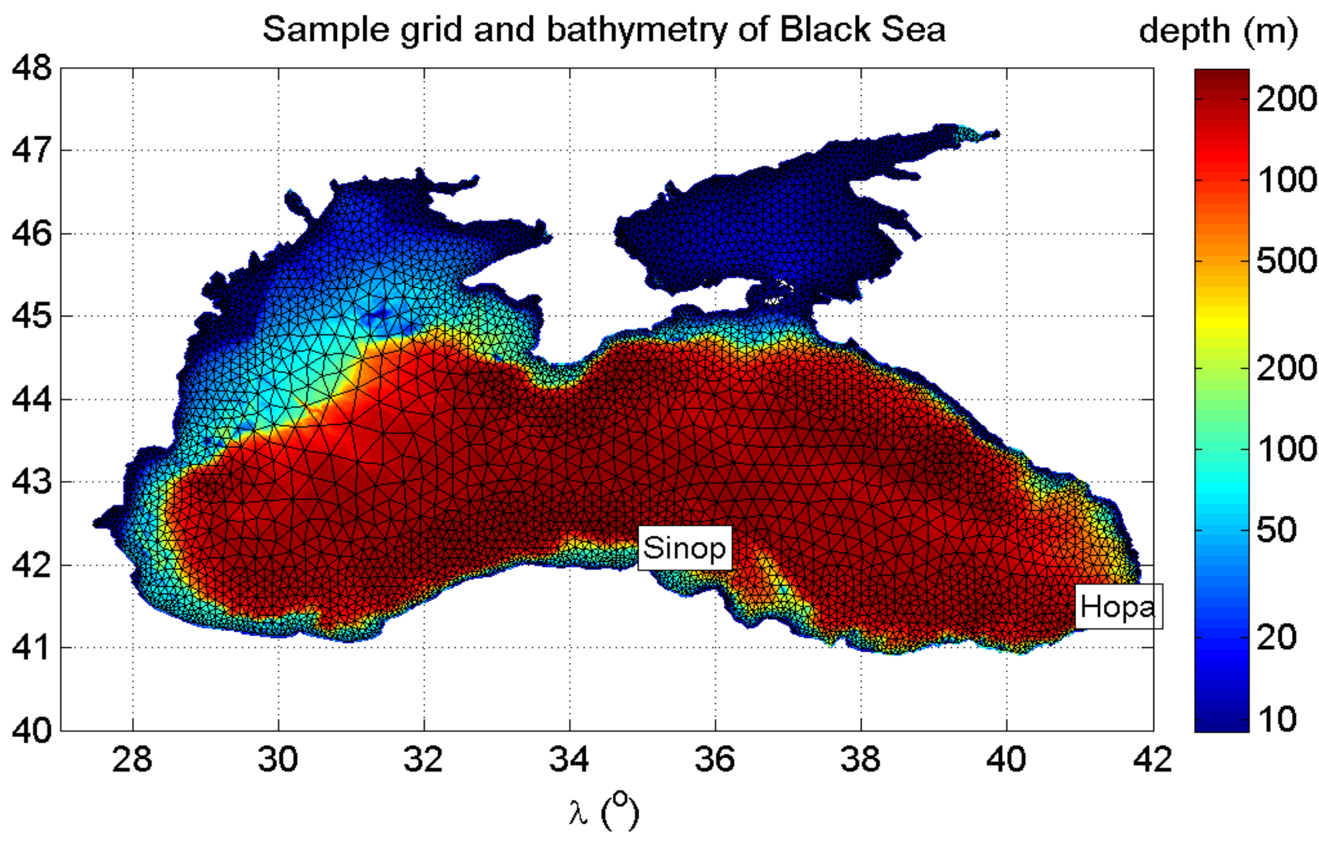
Generation of unstructured grid

- To develop an efficient operation prediction model for the Black Sea we investigated different unstructured grids and compared their performances with that of regular grids (Table 1). We determined that **unswan_2** model whose numbers of vertices, internal cells, boundary cells, internal faces, and boundary faces are 17855, 32838, 1417, 50656, and 1453, respectively, had the best performance. Structure of this model is seen in Figure 2. Model performances were validated at two buoy stations (Figure 1).

***Table 1**. Error statistics of models with different regular and unstructured grids*

	Sinop station						Hopa station					
	H_{m0}			T_{m-02}			H_{m0}			T_{m-02}		
Spatial resolution	RMSE	SI	R	RMSE	SI	R	RMSE	SI	R	RMSE	SI	R
0.08º x 0.08º	0.56	0.55	0.81	1.36	0.33	0.66	0.40	0.69	0.66	1.65	0.42	0.59
0.067º x 0.067º	0.54	0.53	0.82	1.34	0.33	0.66	0.39	0.67	0.68	1.65	0.42	0.65
0.02º x 0.02º	0.52	0.52	0.83	1.48	0.36	0.64	0.37	0.64	0.67	1.75	0.45	0.62
Unswan_1	1.56	1.53	0.21	4.84	1.17	0.02	0.79	1.36	0.35	2.25	0.58	0.05
Unswan_2	**0.47**	**0.46**	**0.65**	**1.31**	**0.32**	**0.42**	**0.34**	**0.58**	**0.59**	**1.28**	**0.33**	**0.56**
Unswan_3	1.65	1.62	0.06	4.11	1.00	0.12	0.35	0.61	0.54	1.11	0.28	0.40
Unswan_4	0.67	0.66	0.43	1.47	0.36	0.29	0.48	0.83	0.51	1.15	0.29	0.21





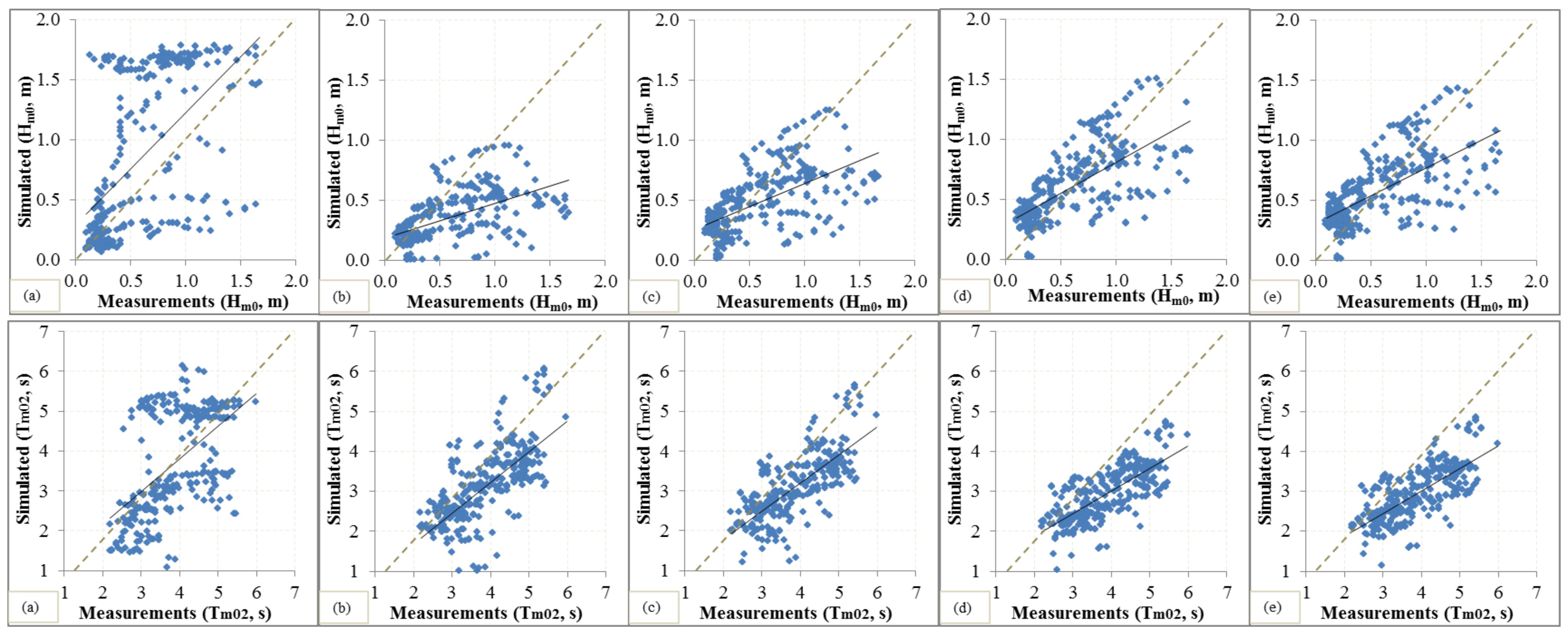


***Figure 3**. Scatter plots of simulated wave parameters H_{m0} (upper panel) and T_{m02} (bottom panel) by using the wind fields with the spatial resolution of 3.0º (a), 1.875º (b), 0.75º (c), 0.25º (d), and 0.1º (e) at Hopa buoy station*

Effect of the spatial resolution of the wind fields on the wave model

- We had the wind fields with different spatial resolution from the ERA Interim dataset of the ECMWF to assess the sensitivity of wave fields to the effect of spatial resolution of the wind fields. Thus, wave hindcasts with the same model physics settings were carried out by forcing the wind fields with the 5-different spatial resolution (0.1º, 0.25º, 0.75º, 1.875º, 3.0º) for March 1996. The results, which are illustrated in Figure 3, showed that using the wind fields with the spatial resolution of 0.25º enhances the model validation (RMSE=0.31 m, 0.29 m, 0.34 m, 0.41 m, and 0.60 m for H_{m0} for 0.1º, 0.25º, 0.75º, 1.875º, and 3.0º, respectively).

Performances of the different atmospheric wind fields

- Accuracy of the wind fields data of the ECMWF ERA40, ECMWF ERA Interim, ECMWF Operational, JRA-25, NASA MERRA, and NCEP CFSR atmospheric models was discussed against the wind measurements during 1996 year at Hopa TSMS station. Scatter plot and time series comparison of this assessment were presented in Figure 4 and 5, respectively. As statistical indicators, for example scatter index (SI), the best atmospheric model is the ERA 40 (SI=0.93) but as bias, the ECMWF Operational dataset (bias=0.25) is better than others. However, it is interesting that the CFSR and NASA MERRA wind data follows quite well the temporal observed data, even peak data.

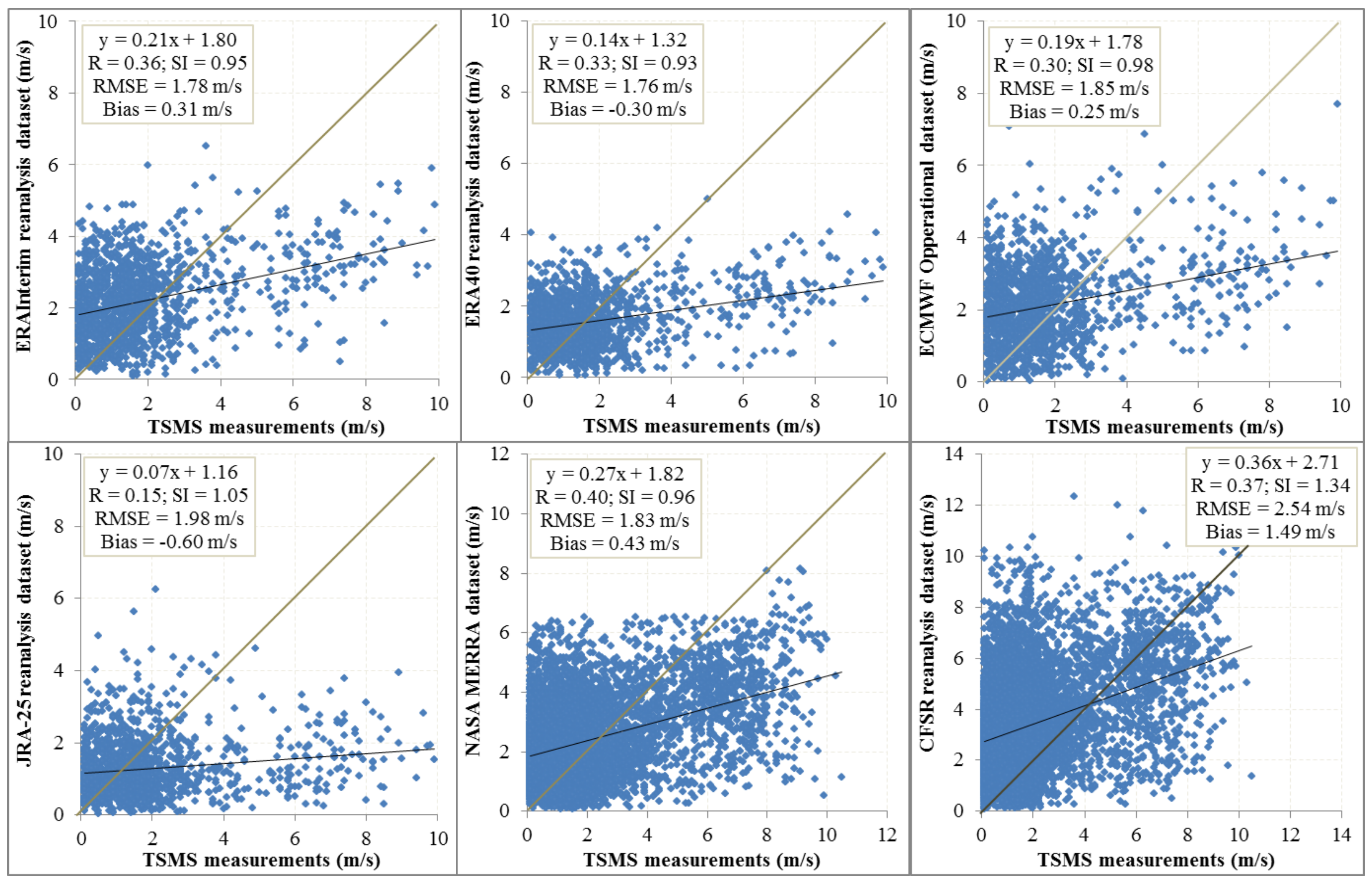


***Figure 4**. Scatter diagrams of wind speed fields of different atmospheric models against wind measurements at Hopa TSMS measurement location and basic statistical parameters.*

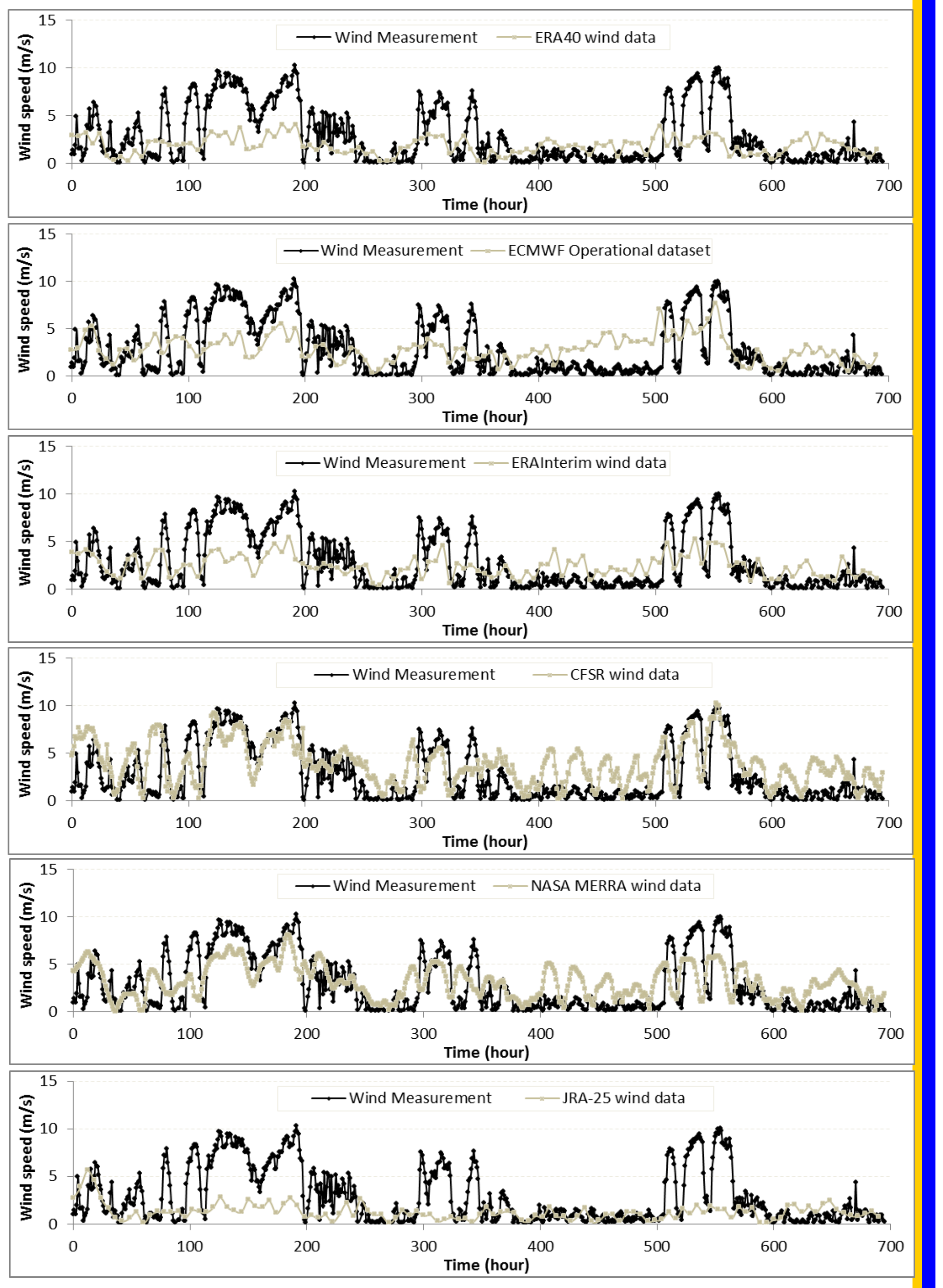


***Figure 5**. Time series comparison of observed wind speeds (the TSMS data) and different atmospheric models' wind speeds at Hopa TSMS measurement location. Period: February 1996 (696 hours).*

Choice of the proper model physics

- We investigated the best proper model physics for SWAN model for the Black Sea wave conditions. The effects of default formulations of the physical processes of wind wave growth, white-capping dissipation, the depth induced wave breaking, shallow water dissipation and nonlinear wave-wave interactions and different values of their tuneable parameters on the wave field were investigated. Finally, we found that the best proper model physics for the Black Sea wave conditions are as follow:

```
GEN3 KOMEN cds2=0.5e-5
WCAPping Janssen cds1=0.5 delta=1
QUADrupl iquad=8 Cnl4=5e7
BREaking constant alpha=1.0 gamma=0.73
FRICTION JONSWAP 0.038
TRIAD trfac=0.10 cutfr=2.5
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Investigation of the optimal time step

- The time step should be small enough to catch the effect of relatively fast temporal changes in wind speed and direction on the wave field but large enough to make the computation practically feasible. We focused on this topic in Akpinar et al .(2012). In this paper, we have carried out a more comprehensive analysis to decide which time step is required. The computations were performed for four different finer temporal resolutions and output results as can be seen from Table 2 were obtained for Hopa and Sinop buoy stations. Performances for 30-min, 20-min, and 10-min time step are close to each other. An improvement in 10-min time step analysis is observed, but only marginally. Therefore, we think that a 30-min time step is suitable for our simulations in the Black Sea.

***Table 2**. Test run results for investigation of the optimal time step*

	Sinop station					
	H_{m0}			T_{m-02}		
Time step	RMSE	SI	R	RMSE	SI	R
1 hour	0.54	0.55	0.78	1.41	0.34	0.64
30 min	**0.54**	**0.53**	**0.82**	**1.34**	**0.33**	**0.66**
20 min	0.53	0.52	0.84	1.32	0.32	0.68
10 min	0.53	0.52	0.84	1.30	0.32	0.69

	Hopa station					
	H_{m0}			T_{m-02}		
Time step	RMSE	SI	R	RMSE	SI	R
1 hour	0.40	0.68	0.67	1.74	0.45	0.64
30 min	**0.39**	**0.67**	**0.68**	**1.65**	**0.42**	**0.65**
20 min	0.39	0.67	0.68	1.63	0.42	0.64
10 min	0.39	0.67	0.68	1.63	0.42	0.64

Further investigations

- The present results are based on the first phase of our investigations. Hereafter we will continue our investigations as follows:
  - Further sensitivity tests will be carried out to choose the optimal unstructured grid.
  - The effect of spatial resolution of wind fields on the wave model will be analysed by comparing the effect of finer spatial resolutions. This will be also be discussed for more locations.
  - Comparisons on the accuracy of different wind sources will be extended for more locations , including an analysis of orographic effects. Comparison results will be checked by using satellite data. Calibration of the wind fields will be also carried out by using satellite data.
  - Effects of the wind field data of different atmospheric models on the wave model will be investigated.
  - Recent developments in deep water physics (cf., Ardhuin et al., 2010; Tolman et al., 2013) will be implemented in the SWAN model and its performance in the Black Sea will be assessed
  - Satellite data will be used to assess wave model performance of new model setups.

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