Operational Oceanographic Forecasts in the Thermaikos Gulf: The WaveForUs Project

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Abstract

Sea state (wave, circulation, storm surge) modelling and forecasting in Greece, are notions well understood, investigated and implemented but only within the scientific community and mainly for research purposes. When it comes to practical implementations, there is poor distribution of the available information to every-day Greek users. Especially for Thermaikos Gulf (NW Aegean Sea), an area of high environmental significance and where a broad spectrum of sea-based activities (tourism, aquacultures, marine transportations, sea-related recreational and nautathletic activities etc) takes place, the availability of high-resolution, gridded sea state prognoses is very low. Under this reasoning, a state-of-the-art forecasting system (WaveForUs: **Wave** climate and coastal circulation **For**ecasts for public **Us**e) is implemented that will deliver 3-day forecasts of wave, circulation and storm surges for the Thermaikos Gulf; the forecasts will be disseminated to the public via television broadcasts and internet applications. The WaveForUs platform will soon be fully functional and aspires to provide Greek users with an invaluable tool for their sea-based activities. The present paper focuses on presenting the calibration/validation of the sea-state models of the system. The validation and calibration of the models is still ongoing, however the results of hindcasting simulations and of preliminary products are satisfactory and compare well with in-situ and satellite/modelling data.

Keywords: waves, storm surges, circulation, modelling, sea state forecasts

1. INTRODUCTION

WaveForUs (**Wave** climate and coastal circulation **For**ecasts for public **Us**e) is a newly implemented forecasting system that uses state-of-the-art weather, wave, hydrodynamic circulation and storm surge modelling in order to produce daily, user-friendly 3-day sea state forecasts in the Thermaikos Gulf (NW Aegean Sea) and deliver them to users through television, internet and GIS applications. The structure of the WaveForUs system is graphically depicted in Figure 1; it consists of the modelling platform, which essentially includes the various forecasting models, and of the forecast dissemination platform. The present work focuses on the presentation of the modelling system (Figure 1) that consists of the WRF-ARW atmospheric model [1,2], WaveWatch III wave propagation model [3], POM coastal circulation model [4] and HRSS storm surge model [5]. The meteorological outputs (wind and pressure fields, precipitation, surface radiation and heat fluxes, air temperature etc) are used by the sea-state models, which in turn, produce 3-day prognoses of wave fields (significant wave height and direction), circulation (currents) and thermohaline properties of seawater and Sea Level Heights (SLH). The application area extends southwards to the Cape of Kassandra (39.97˚N). It is noted that each of the model runs in a coupled manner within a coarser and broader field than the one of the study area, in order to obtain the necessary boundary conditions. Daily television broadcasts are planned and will soon deliver forecasts of wave and SLH fields to the public, as well as emergency bulletins in cases of high risk of coastal flooding. The forecast products will also be available to the public through the project webpage and the web-

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based GIS application, which will provide users with the option of visualising various kinds of modelling outputs, such as spatial distributions at the surface and at various depths (where applicable), timeseries of forecast results and temperature and salinity profiles at specific grid points, as well as cross-sections of three-dimensional parameters at selected locations. At present, the modelling platform is fully functional and selected parameters are made public through the project webpage (http://wave4us.web.auth.gr/). The forecasting products are also planned to be incorporated in other European operational oceanography platforms. Taking into account the particularities and importance of the domain of application, the products of the forecasting platform will, on one hand, find interest from various groups of end-users and, on the other hand, be exploitable by other applications, like environmental modelling and coastal zone management projects.

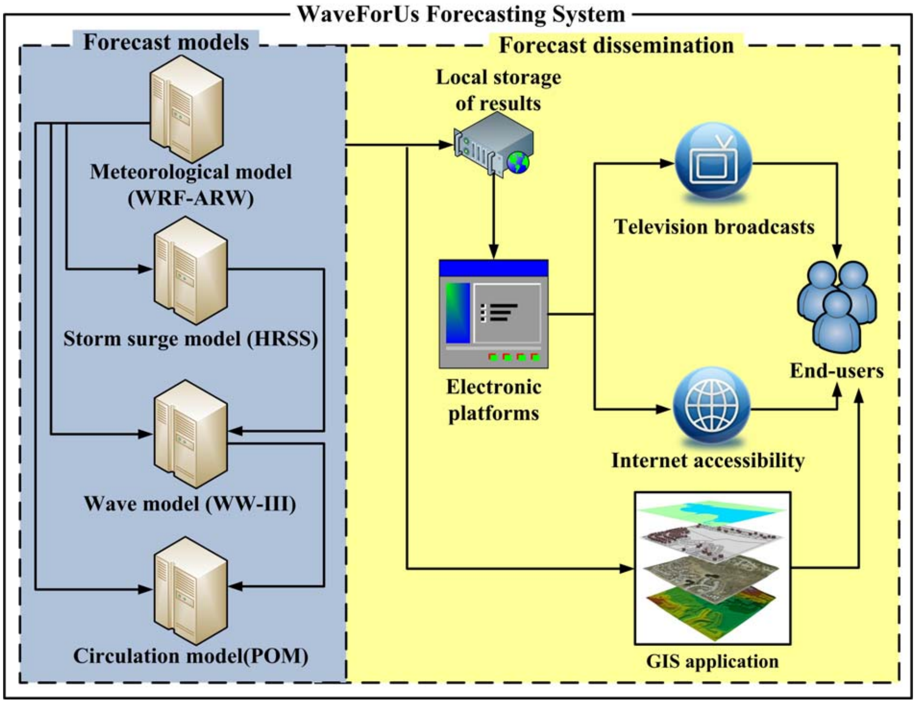

Figure 1. The WaveForUs forecasting system in its operational phase

In the following parts of the paper, we present the basic aspects of the modelling platform and results from hindcasting simulations for the period of 2012 by the three sea-state forecasting models and their comparison with corresponding in-situ or satellite data.

2. MATERIALS AND METHODS

The WaveForUs modelling platform consists of the following four mathematical models (1 atmospheric and 3 sea-state models):

- Meteorological model: Weather Research and Forecasting model with the Advanced Research dynamic solver (WRF-ARW, version 3.2.0) [1,2]
- Wave model: WaveWatch-III (WW-III, version 3.14) [3]
- Coastal circulation model: Princeton Ocean Model (POM, version 2008) [4]
- Storm surge model: High Resolution Storm Surge model (HRSS) [5]

The models are applied in three domains of gradually increasing discretisation (Figure 2): **a)** Mediterranean Sea (Domain 1) with a step of 0.15°x0.15° (~15km), **b)** Aegean Sea (Domain 2) with a step of 0.05°x0.05° (~5km) and **c)** Thermaikos Gulf (Domain 3) with a step of 0.016°x0.016° (~1.7km). Initial and boundary conditions are transferred from the coarser to the finer domain, while atmospheric input parameters for the sea-state models are obtained by the application of

WRF-ARW in each domain (Figure 2). It is noted that WW-III is not applied in Domain 1, since preliminary applications of the model showed that an inclusion of the Mediterranean Sea has practically no effect to the wave forecasts in the Thermaikos domain. POM is only applied in Domain 3 and receives boundary conditions (temperature, salinity and horizontal velocity fields) from the myOcean system (http://www.myocean.eu). The coupling of the modelling platform is currently underway and includes the provision of SLH from HRSS to WW-III and the addition of Stokes drift velocities calculated by WW-III to POM. Following indicative results from hindcasting simulations are presented and discussed.

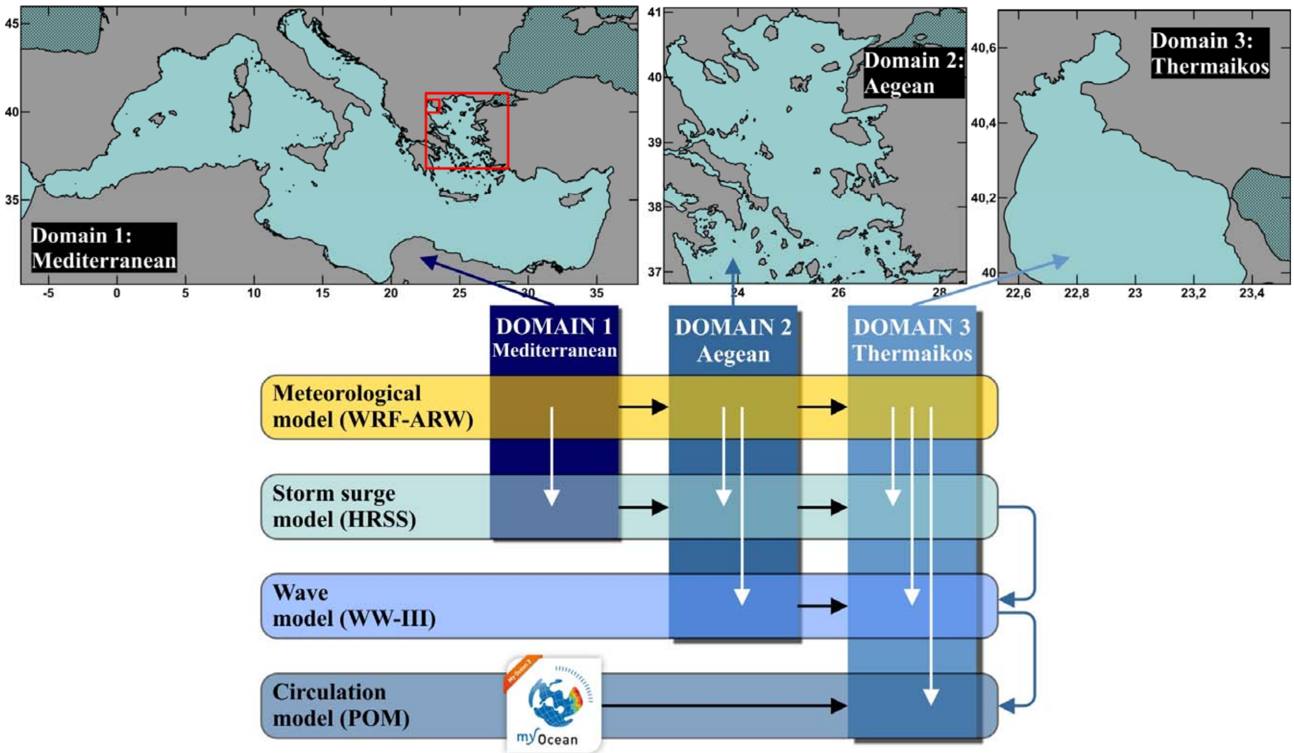

Figure 2. Representation of the forecasting models and the corresponding application domains; black arrows (bottom panel) denote transfer of initial and boundary conditions, white ones the introduction of input data and blue arrows coupling between the models.

3. RESULTS AND DISCUSSION

3.1 Wave modelling results

The calibration/validation of the WW-III model is performed in Domain 2, due to the lack of satellite altimetry data for Domain 1. Using the Jason-2/Phase-A satellite data for the period of 13/01/2012 to 17/04/2012, after appropriate time and space collocation so that satellite recordings and model outputs coincide both temporally and spatially, we obtained acceptable correlation between simulation and measurement for the significant wave heights (Hs) (Figure 3); given that using algorithms to determine Hs values from satellite altimetry measurements involves significant errors, the correlation of the two datasets is considered satisfactory (the linear fit is close to a 1:1 relation). It is also noted that comparing the corresponding values of wind velocities, we obtained a self-similar scatter pattern, which indicates that the differences in Hs values are most likely related to differences in input wind fields used by the model and the satellite measured wind fields. Furthermore, the strongest scattering (Figure 3) appears in relatively low significant wave heights (Hs<2m) and, therefore, the model predicts energetic wave conditions in the field effectively.

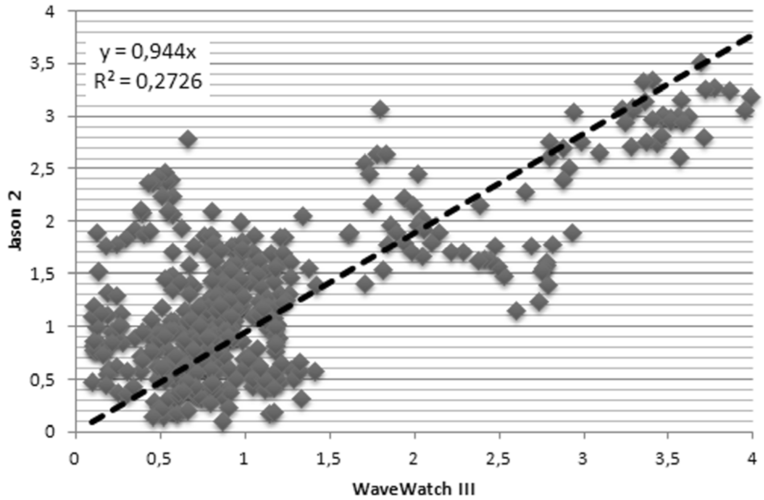

Figure 3. Correlation of satellite data (Jason 2) and WW-III outputs for the significant wave heights (Hs) for the period of 13/01-17/04/2012. The dashed line is a linear fir to the data.

3.2 Coastal circulation modelling results

Figure 4 presents the correlation of simulated Sea Surface Temperatures (SST) and corresponding satellite measurements for the period of 2012 for 4 locations in the application domain. In lack of initial and boundary conditions for the period, the simulation took into account uniform initial conditions in the field (temperature 13°C, salinity 35psu and zero velocities) and free radiation at the southern open boundary. It is noted that the model grid (1/60º) is significantly smaller than the cell of the satellite measurements (1/16º).

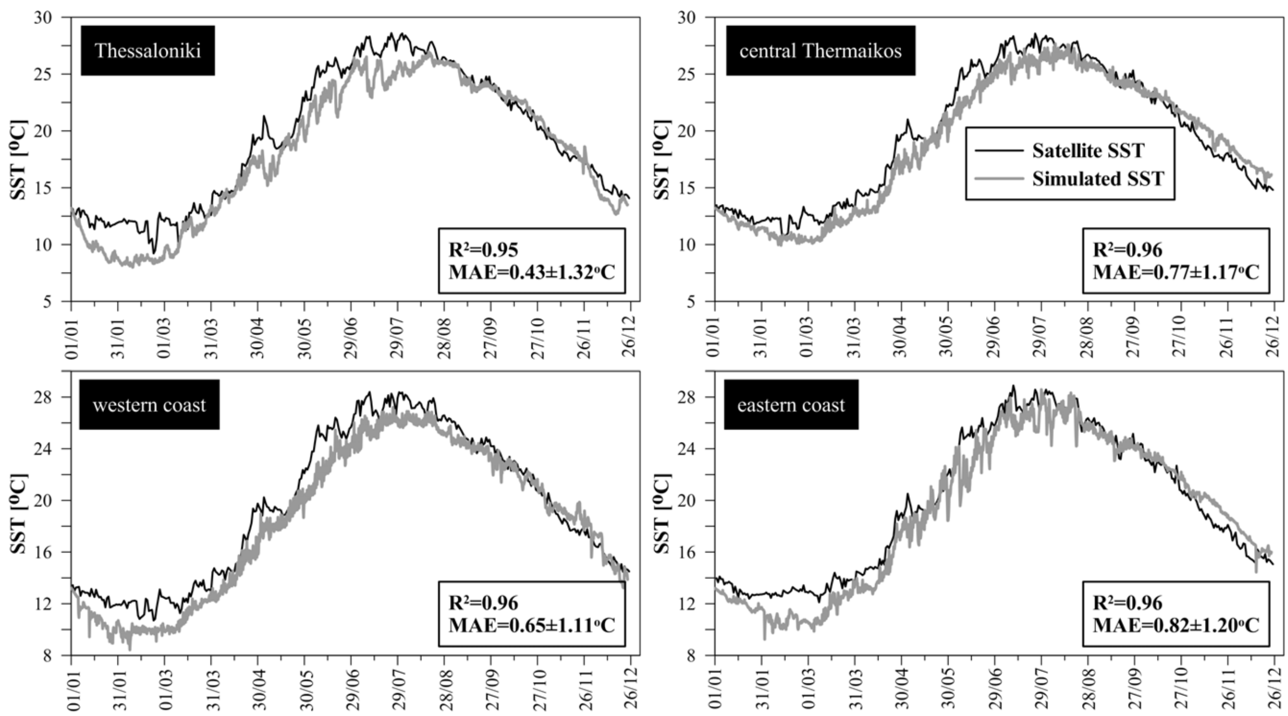

Figure 4. Comparison of satellite (black curve) and simulated (grey curve) SST values for the 2012 period. Correlation coefficients (R^2) and Mean Absolute Error (MAE) are noted on the graphs.

The model generally reproduces the annual cycle of temperatures adequately and the correlation of simulation and measurement is generally good (R^2~0.96), with low Mean Absolute Error (MAE) values. The model appears to underestimate SST for the first 2 months of the simulation, which is most likely due to the homogenous initial conditions considered. Differences in the accuracy of the model can be observed between the different areas of the gulf, with the area if the inner Thermaikos (Thessaloniki) to show the strongest depreciation of SST during the warming period. At the same time, simulated SST values for the eastern and central parts of the gulf are slightly higher than the measured ones near the end of the simulation period, while for the western part the coincidence of measurement and simulation is very good. The overestimation of SST in the eastern part is attributed to the lack of boundary conditions for this simulation and thus to the non-inclusion of the effects of the North Aegean waters (more saline and cooler waters that nominally enter from the eastern part and move cyclonically). Regarding other forecast parameters of the circulation model (not shown) it is noted that they are in accordance with corresponding measurements and the known circulation patterns in the domain.

3.3 Storm surge modeling results

Figure 5 shows the comparison of simulated and measured SLH (daily averages), obtained from a tidal gauge in the port of Thessaloniki. It can be noted the model generally describes the evolution of the SLH successfully, especially regarding the reproduction of local maxima; these peak SLH values are the most significant ones for the purposes of the forecasting system, since they can indicate inundation problems in coastal areas of low altitude. Especially for the periods of April to June and November to December the simulated SLH values follow closely the corresponding field data. However, there are periods of significant deviations, such as the period of July to October, where the model seems to conservatively underestimate the SLH. A likely source of divergence between simulation and measurements is the location of the tidal gauge inside the port basin of the Thessaloniki harbor, which can cause local phenomena (reflections, oscillations, etc) that cannot be reproduced by the scale of the model (~1.7km). Nonetheless, HRSS is clearly effective in describing the evolution of the SLH, given that it follows the temporal variability of the measurements. The further calibration of the model is currently underway, aiming at even more reliable results.

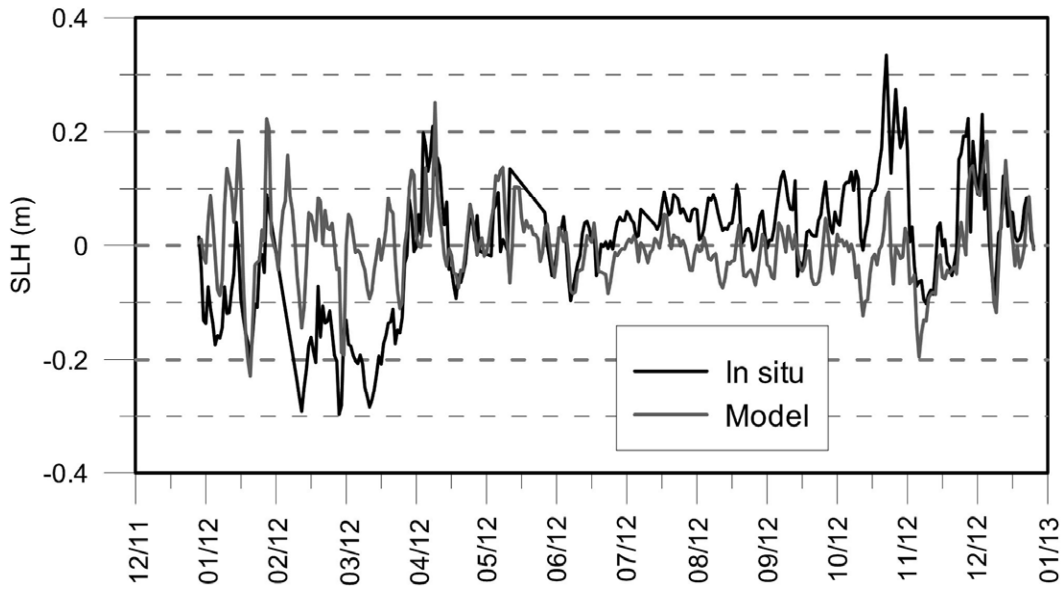

Figure 5. Comparison of measured (black curve) and simulated (grey curve) SLH for the 2012 period in the area of the Thessaloniki port

4. CONCLUSIONS

WaveForUs is an integrated sea-state forecasting system that will be able to provide high-resolution wave, circulation, seawater physical properties and sea level rise prognoses for the area of the Thermaikos Gulf (NW Aegean Sea). The system is already providing preliminary forecast results through the program webpage (http://wave4us.web.auth.gr/) and will soon enter its operational phase, in which the sea-state forecasts will also be delivered via television broadcasts and web-GIS applications, providing both general and more specialized information in a user-friendly manner.

Indicative results from the calibration/validation of the sea-state models of the forecasting system were presented in this work. These results show that the effectiveness of the models is quite satisfactory, with the simulated parameters to be close to corresponding in-situ/satellite data. More specifically, the WW-III model performs well, predicting significant wave heights close to satellite altimetry data, especially for strong wave conditions (Hs>2m). Results from the POM compare well with satellite SST measurements with generally low MAE values. The model reproduces the annual temperature cycle and known circulation patterns (cyclonic circulation in the outer gulf) effectively. The comparison of measured and simulated SLH for the inner Thermaikos show that the HRSS model performs well and successfully predicts the peak SLH values in the domain, values that are highly important for the purposes of the WaveForUs project. There are differences between recordings and model outputs in specific periods that are probably due to the location of the tidal gauge inside the Thessaloniki port that can induce small-scale phenomena that cannot be reproduced by HRSS. The calibration of the sea-state models is still ongoing, in an effort to produce even better forecast results; however, the preliminary results are quite satisfactory and indicate that, in its operational phase, the WaveForUs forecasting system will be a useful and reliable tool for users and their sea-based activities.

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REFERENCES

1. Skamarock W.C., J.B. Klemp, J. Dudhia, D.O. Gill, D.M. Barker, M.G. Duda, X.-Y. Huang, W. Wang, J.G. Powers, 2008. A description of the Advanced Research WRF Version 3, NCAR/TN-475.
2. Wang W., Bruyère C., Duda M., Dudhia J., Gill D., Lin H.-C., Michalakes J., Rizvi S., Zhang X., Beezley J., Coen J., Mandel J., 2010. ARW Version 3 Modeling System User's Guide, NCAR-MMM, pp. 354.
3. Tolman, H.L., 2009. User manual and system documentation of WAVEWATCH-III version 2.22, NOAA / NWS / NCEP / OMB, Technical Note, No. 276, pp. 194.
4. Blumberg A.F., Mellor G.L., 1987. A description of a three-dimensional coastal ocean circulation model, *Three-Dimensional Coastal Ocean Models*, (ed. N.S. Heaps), American Geophysical Union, Washington, DC, pp. 1-16.
5. Krestenitis Y.N., Androulidakis Y., Kontos Y., Georgakopoulos G., 2010. Coastal inundation in the north-eastern Mediterranean coastal zone due to storm surge events, *Journal of Coastal Conservation*, DOI: 10.1007/s11852-010-0090-7.