Implementation of WWIII wave model for the study of risk inundation on the coastlines of Campania, Italy

G. Benassai[1] & I. Ascione[2]
[1]*Department of Environmental Sciences, DSA, Parthenope University, Naples, Italy*
[2]*Department of Applied Sciences, Parthenope University, Naples, Italy*

Abstract

The spectral third-generation wind-wave model WAVEWATCH III, operational since January 2005 at the Department of Applied Sciences of the Parthenope University, was adopted for simulating wave propagation and risk evaluation in the Gulf of Naples. The model was coupled with PSU/NCAR mesoscale model (MM5), which gives wind forcing at 1-h intervals. The model was implemented using a four-nested grid configuration covering the Mediterranean Sea toward the Gulf of Naples. Simulated results were compared with data recorded in 2000 offshore of the Gulf of Naples and with wind and wave data collected by APAT offshore of the mouth of river Sele in the Gulf of Salerno. Maps of coastal vulnerability, damage and risk were obtained taking into account the wave vulnerability and the potential damage to people and structures in case of coastal inundation. The obtained results are also used to classify the coastal zones of the Naples Province on the basis of the risk evaluation.
Keywords: wave model, validation, risk evaluation, coastal inundation.

1 Introduction

The coastlines of Naples Province extends more than 150 km from the Northern bound at the mouth of Lake Patria to the Southern bound at the end of Sorrento peninsula, including also the isles of Capri, Ischia and Procida.

The provincial Civil Protection had as objective the evaluation of the potential risk of flooding on the beaches and the establishment of a database of beaches vulnerable to wave storms. In this manner, a priority scale of the

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possible shore protection measures can be established and consequently, individual projects can be managed within a single framework that accounts for benefits as well as adverse impacts. A regional modelling system run by University Parthenope encompassing winds, waves and evaluation of risk of beach flooding is the backbone of the planned Civil Protection shoreline management system.

This paper describes the wave component of the comprehensive regional modelling system, which was developed by University Parthenope together with the monitoring program of winds, waves and currents. The present paper, focusing on the wave modelling, substantiates the model implementation on the coastlines of the Naples Province and the model validation through a statistical comparison with wind and wave data collected on the Northern and Southern boundaries of the Gulf of Naples.

2 The wave model

WaveWatch III is a third generation wave model developed at NOAA/NCEP as a further development of WaveWatch I, (Delft University of Technology) and WaveWatch II (NASA, Goddard Space Flight Center). The governing physical equations, the physical parametrizations and the numerical methods reflect some modifications of previous models. The solution of the governing equations is based on a first and a third order accurate numerical scheme. The breaking waves physics are not modeled, hence the applicability of this model is outside of the surf zone and on large scale. Outputs from the model include significant wave height on gridded fields with the associated wave directions and periods, spectral information about wave energy at the different wavelengths.

Table 1: Spatial information about the four domains (Latitude and longitude in deg.).

	Latitude range	Longitude range	Latitude Increments	Longitude Increments
DOM 1	30.02 47.84	-5.53 41.83.	0.24	0.24
DOM 2	36.11 48.31	3.76 22.41	0.08	0.08
DOM 3	39.80 41.67	12.50 16.47	0.03	0.03
DOM 4	40.41 41.08	13.72 14.69	0.01	0.01

Input to WW3 can consist of wind, current, water level, temperature and ice concentration fields on the spatial wave model grid. In this study, input data used include bathymetry, wind field data and a number of input parameters required by the model. The WW3 model was coupled with the MM5 model, which gives the wind fields to force the wave model. The model system MM5/WW3 was implemented to cover four nested areas (from regional ocean to small scale):

- DOMAIN 1 (Mediterranean sea)
- DOMAIN 2 (Seas around Italy)
- DOMAIN 3 (Tyrrhenian sea)

- DOMAIN 4 (Gulf of Naples)

Information about the spatial dimension of four domains is summarized in Tab.1.

An example of the nested grids is reported in figure 1 (domains 3 and 4).

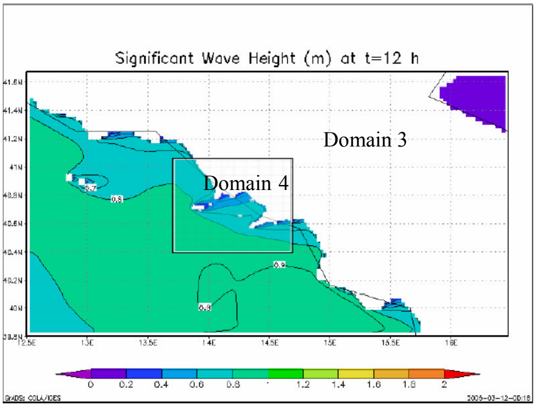

Figure 1: Example of Significant wave height for domain 3 and domain 4.

3 Model validation with wind and wave data

Data used to validate the model are the following:

- Wave data collected in years 1999 and 2004 from the APAT stations of Ponza and Capo Linaro located offshore the Gulf of Naples, in activity since 1989 and 2001, respectively;
- Wind data collected in year 2000 at the University Parthenope station of Licola, in activity since 1990.
- Wind and wave data collected in year 2000 at the Sele river mouth station, in activity from 1998.

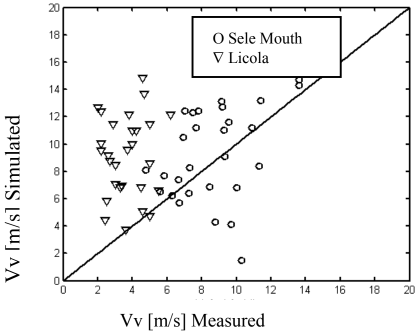

Figure 2: Comparison between measured and simulated wind data – Licola and Sele mouth stations.

The comparison between the numerical simulations and the wind data recorded in Licola and offshore the mouth of river Sele is given in fig. 2 and 3 for the storms of November - December 2000. The examination of the results shows that the model underestimates the wind measurements when data are recorded on land: the points corresponding to Licola (recorded on land) are located in the higher part of the figure (showing simulated wind velocity in excess with respect to the data), while the points corresponding to Sele river mouth exhibit a good agreement between wind simulations and data; on the other hand, a good agreement is observed for the wind direction, for both Licola and Sele river mouth.

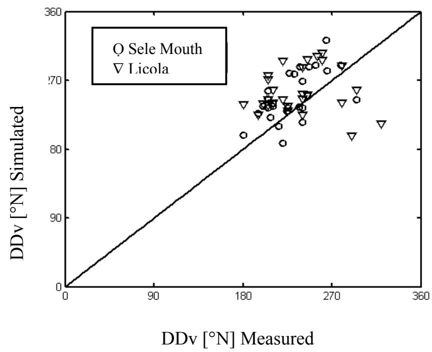

Figure 3: Comparison between measured and simulated wave direction data – Licola and Sele mouth stations.

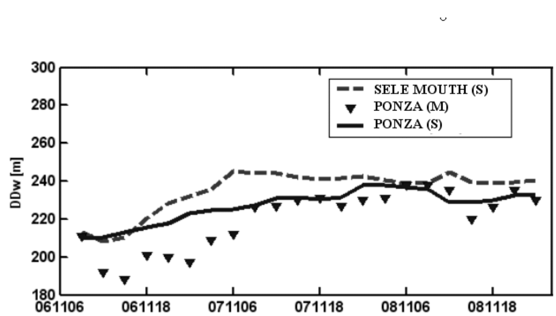

Figure 4: Comparison between measured and simulated wave direction data – S=simulated Ponza and Sele mouth stations – November 2000. M=measured.

In fig. 4 and 5 the time histories of the simulated and recorded waves are given for the November 2000 storm and in fig. 6 and 7 for the December 2000 storm, respectively. The examination of fig. 6 shows that the agreement between simulated and observed waves is more acceptable than the wind speeds, for both the deep water (Ponza) and intermediate depth conditions (Sele mouth).

The time histories of the simulated and recorded wave storms gives more insight into the physical aspects of the simulation: in fact, the wave simulations of the November 2000 storm (characterized by quite uniform directions spread from 200°N to 230°N) are in good agreement with the data (figs. 4 and 5), while the simulations of December 2000 storm present higher differences (figs. 6 and 7). These differences are due to a first stage of the storm (wave directions coming from South) in which the significant wave heights are correctly simulated, and a second stage (associated with the superposition of swell and sea waves) in which the model probably underestimates the swell waves.

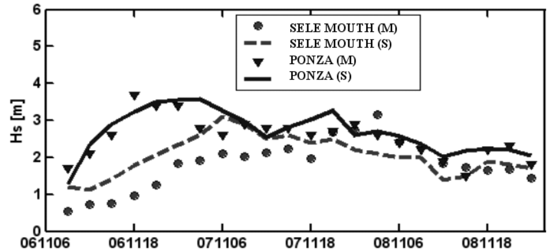

Figure 5: Comparison between measured and simulated significant wave height – Ponza and Sele mouth stations – November 2000. M=measured S=simulated.

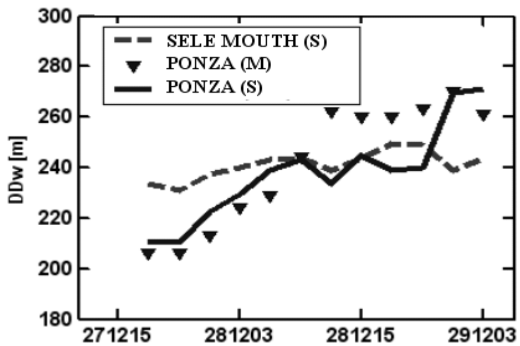

Figure 6: Comparison between measured and simulated wave direction data – Ponza and Sele mouth stations – December 2000 M=measured; S=simulated.

The global results of the statistical comparison are given in table 2, which reports the parameters of the linear regression (intercept A, slope B and regression coefficient *r*), together with the standard deviation.

The examination of table 2 confirms the previous considerations about the differences between the land and offshore wind measurements. In fact, the regression coefficient of the wind velocities at Licola is the lowest of all the parameters considered.

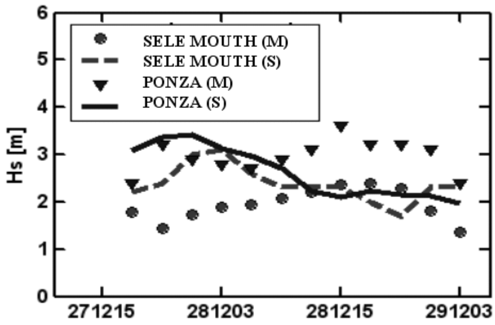

Figure 7: Comparison between measured and simulated significant wave height – Ponza and Sele mouth stations – December 2000 M=measured S=simulated.

Besides, the comparison between the statistical parameters relative to the significant wave heights at Ponza (offshore) and Sele mouth (inshore) shows that the agreement is better for the offshore conditions, with regards to the regression coefficient and the standard deviation. This result suggests that some physical effects (like bottom friction) should be better simulated.

Table 2: Global results of the statistical comparison.

	A	B	r	std
DDv Licola	133.21	0.47	0.73	24.51
Vv Licola	5.84	1.03	0.38	2.67
DDw Ponza	126.61	0.45	0.92	9.15
Hs Ponza	0.83	0.74	0.81	0.32
Vv Sele	2.87	0.77	0.55	3.16
Hs Sele	1.23	0.45	0.55	0.54

4 Wave simulations in the gulf of Naples

The implementation of the wave model on the coastlines of the Gulf of Naples was exemplified for the coastal locations shown in fig.8, with reference to the simulations of the recent wave storm of December 2004.

The coastal locations were chosen in ascending order of wave vulnerability: the location 1 (Gulf of Pozzuoli) is the most sheltered; the location 2 (Torre del Greco) is in the center of the Gulf and so it is characterized by an intermediate wave vulnerability, while Massa Lubrense (location 3) presents a quite opened coastline and so it is subjected to the highest waves.

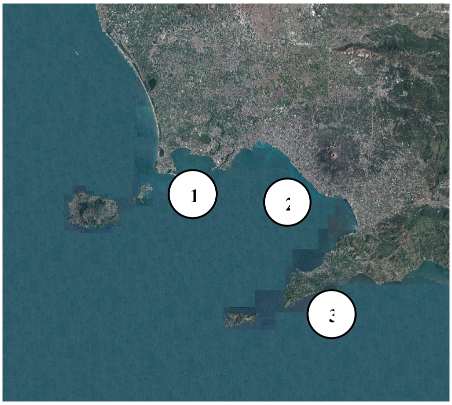

Figure 8: Location of coastal areas of interest in the Gulf of Naples.

Figs. 9 and 10 show the time history of the December 2004 storm referred to the model simulation in the three different coastal areas considered.

In the same figure the recorded waves at the APAT station of Capo Linaro, in the Central Thyrrenian Sea are given (the closer wave station of Ponza, did not work in that circumstance). The comparison between the wave directions simulated in the different coastal zones for the December 2004 storm is given in fig. 9. The results show that even in case of a storm of uniform direction (coming from South and South-West 180-230°N) the simulated wave directions are quite different in space: in locations 2 and 3, the simulated directions follow the offshore measurements more closely, while in the sheltered location 1 the waves are more forced to follow the coastal configuration which is opened only to Southern waves.

The comparison between the significant wave heights simulated in the different coastal zones, given in fig. 10, shows a good agreement with the measurements in the location 1, while in the locations 2 and 3 (more exposed) the simulations of the peak of the storm are in excess of almost 2 meters with the measurements. The local great storm severity was confirmed by the occurrence of a lot of damages to the harbours and to the beaches recorded in the Naples and Salerno Provinces.

It is evident from the results that the wave measurements, although very useful, cannot cover all the possible situations of wave occurrence in a complex coastal area like the Gulf of Naples, and that a regional wave hindcasting service is needed.

5 Analysis of wave vulnerability and risk inundation

The vulnerability, potential damage and risk were evaluated as reported in the following. For each exposed area an effective risk level was associated through the relationship between wave vulnerability and potential damage. Maps of coastal vulnerability, damage and risk were obtained taking into account the wave vulnerability and the potential damage to people and structures in case of coastal inundation. The evaluation of the storm severity was done through the analysis of the storm wave persistence of significant wave height H_s

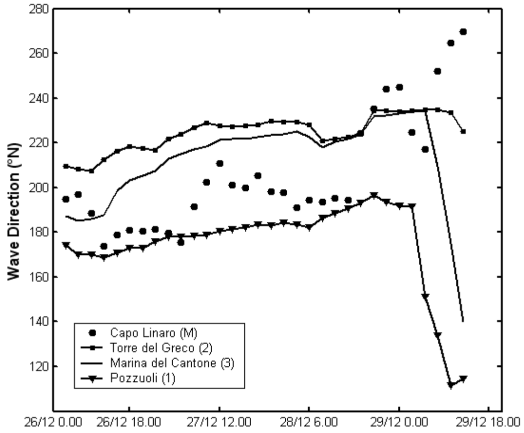

Figure 9: Time history of the December 2004 storm – wave direction.

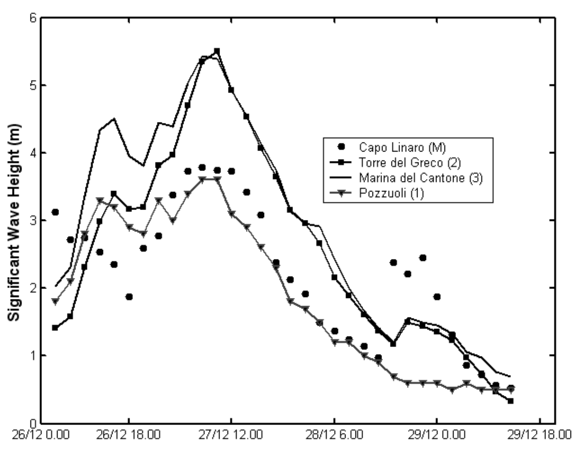

Figure 10: Time history of the December 2004 storm – significant wave height.

The following four damage levels were identified: D1 – moderate damage (marine parks, etc.); D2 – mean damage (recreational facilities); D3 – high damage (roads, railways, etc.); D4 – highest damage (populated areas).

For each area, the potential risk level was evaluated by the relationship between vulnerability and potential damage (see table 4).

Table 3: Global results of the statistical comparison.

P1 low	τ (H*s* =3m) =20 hours τ (H*s* =4m) =5 hours
P2 Mean	20<τ (H*s* =3m) =30 hours 5<τ (H*s* =4m) =15 hours
P3 Mean-high	30<τ (H*s* =3m) =40 hours 15<τ (H*s* =4m) =20 hours
P4 High	τ (H*s* =3m) >40 hours τ (H*s* =4m) >20 hours

Table 4: Relationship between vulnerability and potential damage.

	$\mathbf{P_4}$	$\mathbf{P_3}$	$\mathbf{P_2}$
$\mathbf{D_4}$	R_4	R_3	R_2
$\mathbf{D_3}$	R_3	R_2	R_1
$\mathbf{D_2}$	R_2	R_1	
$\mathbf{D_1}$	R_1		

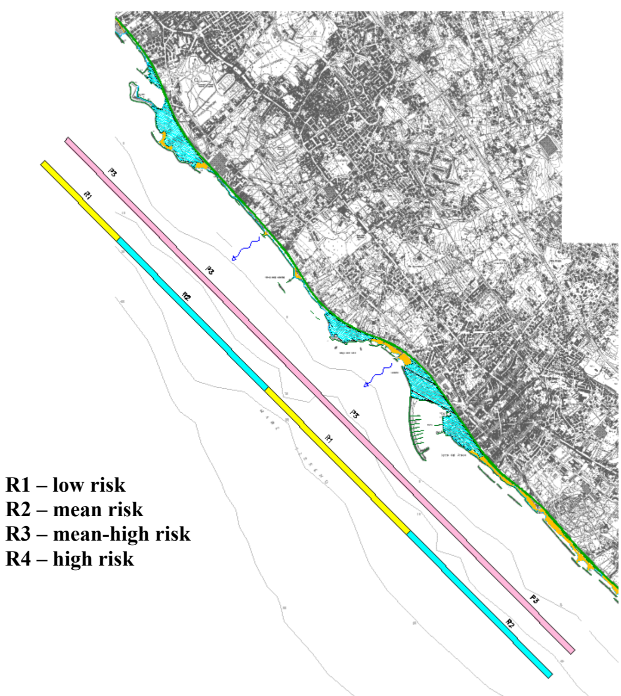

Figure 11: Risk evaluation for Torre del Greco coastline.

There are four risk levels (Table 4) in ascending order, as illustrated in the legend of figure 11.The obtained results are used to classify the coastal zones of the Naples Province on the basis of the risk evaluation. An example of risk evaluation is reported in figure 11 for Torre del Greco coastline.

6 Conclusions

The implementation and validation of a regional modelling system run by University Parthenope of Naples encompassing winds and waves for the wave simulation and propagation in the Gulf of Naples gave the following main results.

A good agreement was obtained between the simulations and the measurements for wind over the sea surface, while systematic errors were noted for wind measurements on land. A better agreement was obtained for the offshore wave simulations, especially for storms of uniform direction, as the simulations are more critical in case of swell and sea wave superposition.

A good agreement was also obtained for the inshore wave simulations, although a better tuning of the bottom friction effects should improve the results.

The results of the model implementation for the December 2004 storm gives evidence of the strong utility of a regional wind-wave model for a complex coastal area like the Gulf of Naples.

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