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Evidences of atmospheric pressure drop and sea level alteration in the Ligurian Sea

Diana Di Luccio[1], Guido Benassai[2], Massimo De Stefano[1], Raffaele Montella[1]

[1] *University of Naples "Parthenope", Science and Technologies Department, Napoli, Italy*
[2] *University of Naples "Parthenope", Engineering Department, Napoli, Italy*

***Abstract* – Extreme weather events have significant impacts on coastal human activities and related economy. In this scenario, the forecast of sea storms and sea level alteration in order to mitigate the effects of waves on shores, piers and coastal structures, is a challenging goal. To this end, we investigated the atmospheric pressure drop and sea level increase as a result of 29-30 October 2018 storm event. The dataset used to analyze these phenomena consists of wind-wave numerical modelling and in-situ measurements, validated with National Mareograph Network (RMN) and Tuscan regional wave network. The results of the numerical model give severe wave heights and a pressure drop at the peak of the storm, which produced many coastal damages with coastal defences collapses, loss of property and infrastructure.**

I. INTRODUCTION

The evolution of winds, wave and wind-driven sea circulation is of great applicative relevance for the observation of oceanographic phenomena [1]. Forecasting and hindcasting the action of sea storm and sea level increase on piers, coastal structures and beaches is of paramount importance in order to understand the relative mechanism, such as beach erosion and accretion, sea level alteration etc., and suggest mitigation measures.

In this paper we characterized the storm event of 29-30 October 2018 that occurred in the Ligurian Sea through the analysis of high resolution numerical simulations. These simulations were carried out on both atmospheric and marine domain, the first one through the configuration of Weather Research and Forecasting (WRF) model [2], the second with WaveWatch III (WW3) model [3]. The wind-wave numerical models already supported some studies on coastal dynamics [4, 5], the assessment of coastal vulnerability [6] and the coastal management [7], also in combination with SAR-derived field observations [8, 9]. In this context, we validated the atmospheric and wave data with some weather stations and buoy measurements in order to obtain realistic scenarios useful to compute the coastal response to the wind-wave storm. These storms are characterized by wind generated waves and storm surge, which is a rise of sea level associated with a moving low pressure system for an amount of one centimetre for each mbar decrease in pressure. High sea levels and strong forces exerted by accompanying waves impact on sea defences, property and habitats, causing loss of life, damage (through inundation and waves) loss of property and infrastructure [6].

The rest of this paper is as follows. Section ii. describes the numerical approach and the dataset, Section iii. presents the experimental results and Section iv. concludes.

II. METHODS AND DATA

In this study a met-ocean high resolution model chain is used to simulate the media-storm event pattern which interested, among other areas, the Northern Italian peninsula.

The used models are operational at the University of Naples "Parthenope" meteo-marine forecasting center (Meteo@Uniparthenope - `www.meteo.uniparthenope.it`) since 2009 [10, 11, 12]. The National Mareograph Network (RMN) stations provided by the Italian Institute of Environmental Protection and Research (ISPRA - `www.mareografico.it`) were used to validate the meteorological model and to describe the mechanisms underlying the sea level conditions in the study area from 23 to 31 October 2018. The wave data provided by Toscana Region hydrologic/hydraulic service (`www.cfr.toscana.it`) were used to validate the offshore wave model in the same time interval.

A. *Numerical model components*

The spatial and temporal reconstruction of storm event has been done making use of a high spatial resolution weather-sea off-line coupled forecasting system configured using High Performance Computing (HPC) infrastructure to manage and run the open-source model components WRF and WW3 running in cascade. The operational system is based on complex data pre-processing, simulation, post-processing and inter-comparison dataflow, provided by the DagOnStar workflow engine [13].

The first workflow component is the atmospheric model WRF-ARW which computes the 10m wind fields and other atmospheric parameters needed to drive the WW3 offshore wave model.

In order to produce the numerical simulations presented in

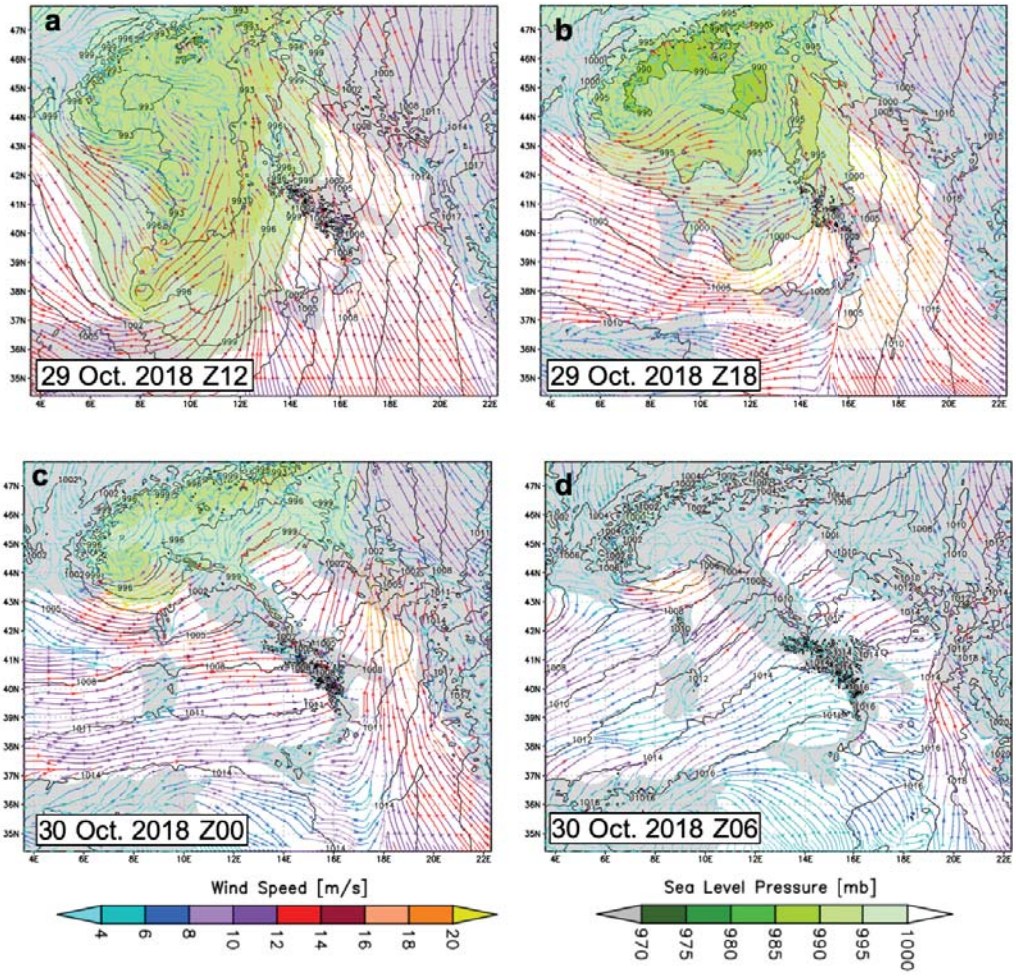

Fig. 1. Sea level pressure and wind fields WRF model simulation in 29 october 2018 (at 12:00 UTM (a), 18:00 UTM (b)) and 30 october 2018 (at 00:00 UTM (c), 06:00 UTM (d)).

this paper, we configured the WRF model, initialized with the Global Forecast System (GFS) produced by the National Center for Environmental Prediction (NCEP), with two-way nested computational domains: a coarse domain ($d01_{WRF}$) covering the whole Europe and a fine domain ($d02_{WRF}$) covering the Italian peninsula, with a 25 km and 5 km spatial resolution, respectively.

A two-way nesting approach was applied also to the WW3 model configuration with a 0.09° spatial resolution for the coarse domain ($d01_{WW3}$) on Mediterranean Sea and 0.03° for the fine domain ($d02_{WW3}$) covering the Italian seas. $d01_{WW3}$ is thus a closed domain forced only by the weather conditions provided by the WRF offline coupled data; no wave boundary conditions were therefore necessary for this domain.

B. Athmospheric and sea wave observations

We considered the available data, collected with a 1/6 h timestep, by the RMN stations of Genova (44°24'36.46"N, 08°55'31.86"E), Livorno (43°32'46.63"N, 10°17'57.62"E), and Marina di Campo (42°44'33.48", 10°14'18.00"), hereafter called P1, P2 and P3, respectively. All the stations measure sea level (SL) with millimetric precision since 2010 with a new microwave level sensor (radar), coupled with the historical ultrasonic hydrometer sensor present since 1998. They are also equipped with an anemometric sensor measuring wind speed (WS) and direction (WD) 10 meters above the ground, a barometric sensor recording the sea level pressure (SLP), an air and water temperature sensor, as well as a relative humidity sensor. In order to reduce the data spike in SL measures, we applied a third-order one-dimensional median filter to the timeseries, while the data gap were not removed in all cases.

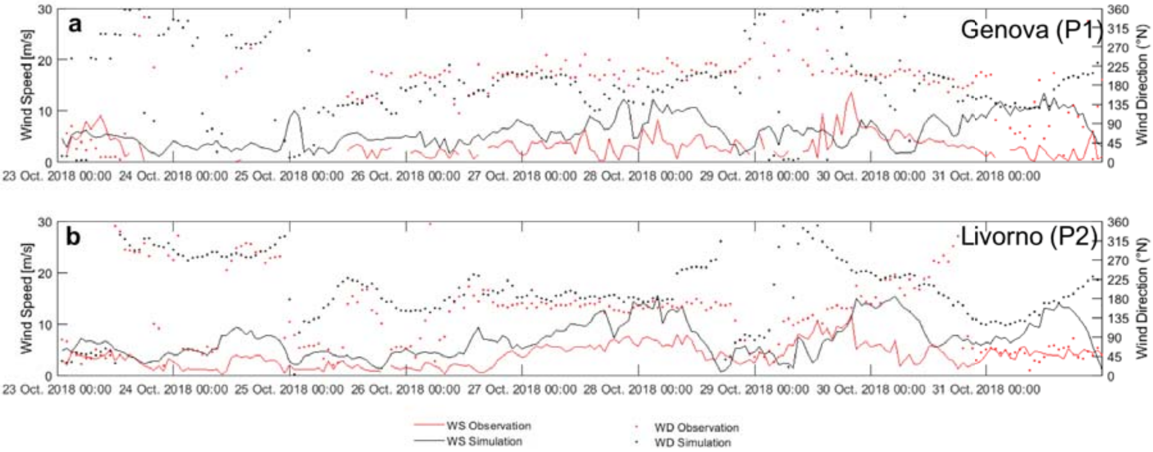

Fig. 2. Comparison between observed and simulated wind fields (WS and WD) during the period 23-31 October 2018 in P1 and P2 locations.

The sea wave height (H_s), peak period (T_p) and direction (D_p) were recorded in the sites of Giannutri (42.23°N, 11.04°E) and Gorgona (43.57°N, 09.95°E), hereafter called B1 and B2, respectively. These buoys, located on 140 m depth, are operating since 1 October 2008 and 6 December 2013, respectively.

III. RESULTS

A. *Wind and wave storm description*

Hereafter we give a short description of the results of WRF model on the Italian peninsula for the storm case study (Fig.s 1a,b,c,d). A low pressure vortex formed on the south west of Corsica (29 Oct. 2018 at 00:00 and 06:00 UTM), then moved north towards the french Alps and the Austria (29 Oct. 2018 at 12:00 UTM and 18:00 UTM). As a consequence of the rapid movement of the orographic low pressure system, strong (up to 20 m/s) winds released their force along the eastern part of the Ligurian coast (30 Oct. 2018 at 06:00 UTM) followed by equally intense winds in the western part (30 Oct. 2018 at 18:00 UTM, Fig. 2).

The numerical wind fields (Fig. 2), validated with observations at Livorno and Genova ISPRA weather stations, show wind speeds higher than 15m/s coming from SW and W, which are consistent with the weather maps of Fig. 1.
The numerical sea level pressure field, validated with observations at Marina di Campo, Livorno and Genova stations, show a pressure drop during 29 and 30 October 2018 which reached the value of 990 mb (Fig. 3).
The statistical comparison between the simulated and observed sea level pressure in the three locations is reported in Table 2. It is noted that the reliability of the simulations is quite homogeneous in the investigated area with very low bias and scatter index, with significant values of regression coefficients and an SPS (Summary Performance Score) [14] close to 1. A similar statistical comparison has been made between the simulated and observed wind fields, reported in Table 1. The numerical wave fields during the storm show significant wave heights higher than 5 m hitting the Ligurian Sea, which are consistent with the observed significant wave heights at Gorgona and Giannutri buoys (Fig.s 4a and b, respectively), which exhibit a maximum value higher than 5.0 m and 6.0 m, respectively. The statistical comparison between the simulated and observed wave height in the two locations is reported in Table 3.

Table 1. Statistical comparison between observed and simulated wind speed (WS) in P1 and P2 locations.

		RMSE	BI	SI	R	SPS
P1 Genova	WS	4.2673	0.9930	0.9613	-0.0872	-0.0672
P2 Livorno	WS	4.4835	0.8528	0.7181	0.4774	0.1336

Table 2. Statistical comparison between observed and simulated sea level pressure (SLP) parameter in P1, P2 and P3 locations.

	RMSE	BI	SI	R	SPS
P1 Genova	3.7898	7.7408e-04	0.0037	0.9275	0.9973
P2 Livorno	3.1602	7.4446e-04	0.0030	0.9425	0.9977
P3 Marina di Campo	3.0812	0.0013	0.0029	0.9396	0.9976

B. *Sea level analysis in time and frequency domain*

The sea level (SL) observations at Marina di Campo, Livorno and Genova ISPRA tidal stations during the period 23-31 October 2018, reported in Fig. 5 showed the

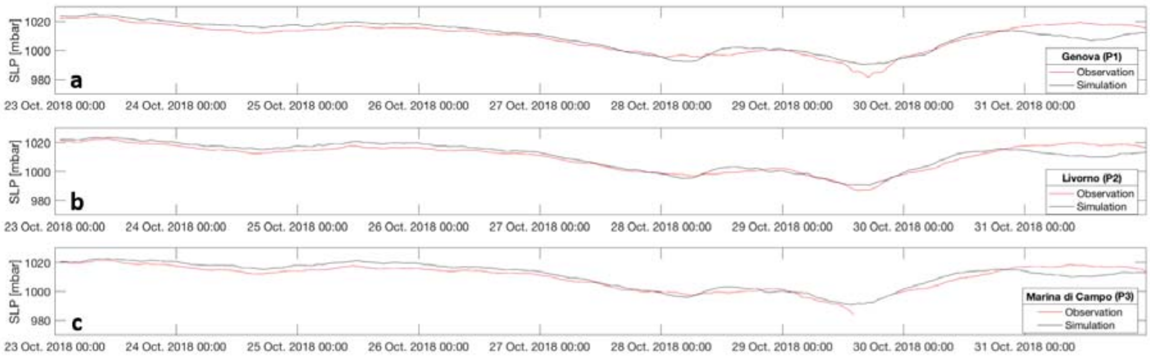

Fig. 3. Comparison between observed and simulated sea level pressure (SLP) during the period 23-31 October 2018 in P1, P2 and P3 locations.

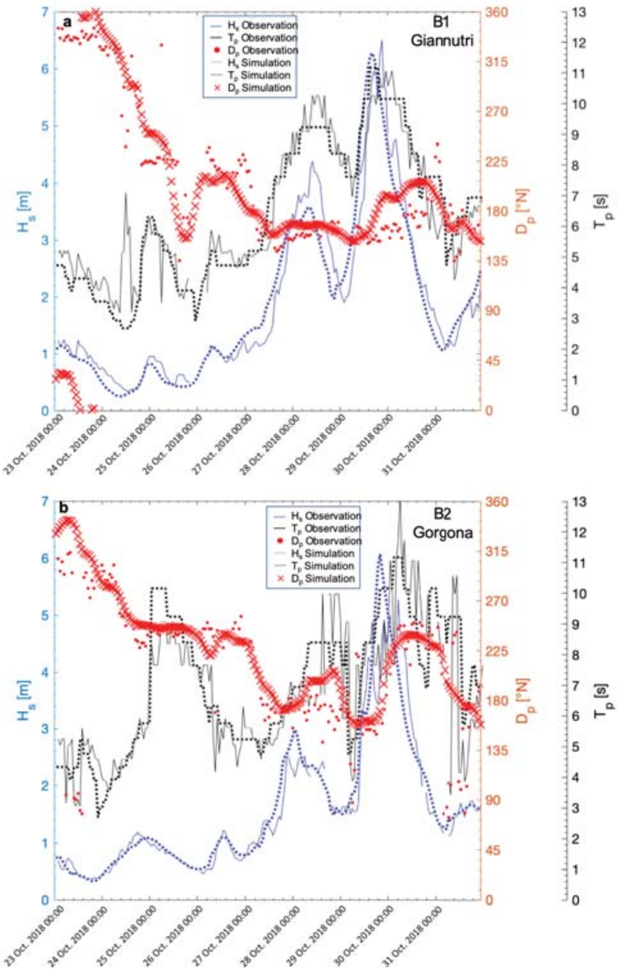

Fig. 4. Wave condition (H_s, T_p and D_p), recorded by Giannutri and Gorgona buoys and simulated in the same location points, during the period 23-31 October 2018.

sea level increase corresponding to the pressure drop. In particular, the SL time history given in Fig. 5a shows the

Table 3. Statistical comparison between observed and simulated wave fields (H_s and T_p) in B1 and B2 locations.

		RMSE	BI	SI	R	SPS
B1	H_s	0.4064	-0.0180	0.1715	0.9593	0.8800
Giannutri	T_p	0.8361	-0.0120	0.1245	0.9281	0.9132
B2	H_s	0.3822	0.0326	0.2005	0.9480	0.8549
Gorgona	T_p	1.4109	0.0356	0.2011	0.7766	0.8532

astronomic tide (moon component) superposed to the meteorological tide due to the wave storm. The joint action of the two components give a maximum sea level increase higher than 0.6m This is due to the inverse barometric effect, that is an increase of approx. 0.01m corresponding to a decrease of 1hPa in barometric pressure [15]. The SL spectral analysis, reported in Fig.s 5a, b and c, shows the two distinct signals of the astronomical and meteorological tide. The first exhibits a frequency of 2.2×10^{-5} Hz, corresponding to 12.4 hours (period of the dominant tidal component, lunar tide M2), the second exhibits a much lower frequency, corresponding to the period of the pressure drop wave. Both time and frequency domain analysis give evidence of the meteotsunamis [16, 17] produced by the resonant superposition of the strong atmospheric disturbance interacting with the astronomic tide.

IV. DISCUSSION AND CONCLUSIONS

During the last five days of October 2018 a strong cyclogenesis interested the western Mediterranean, especially Italy where intense thunderstorms leaded to flash floods and landslides.

The analysed sea storm event was characterized by intense and persistent wind forcing responsible for the build up of the waves and sea levels, as showed in Fig.s 4 and 5, respectively. The northwest coast of Italy suffered the most from the high waves meeting coastal infrastructures and communities. The storm intensity produced many damages in the western part of Liguria. In particular, in the

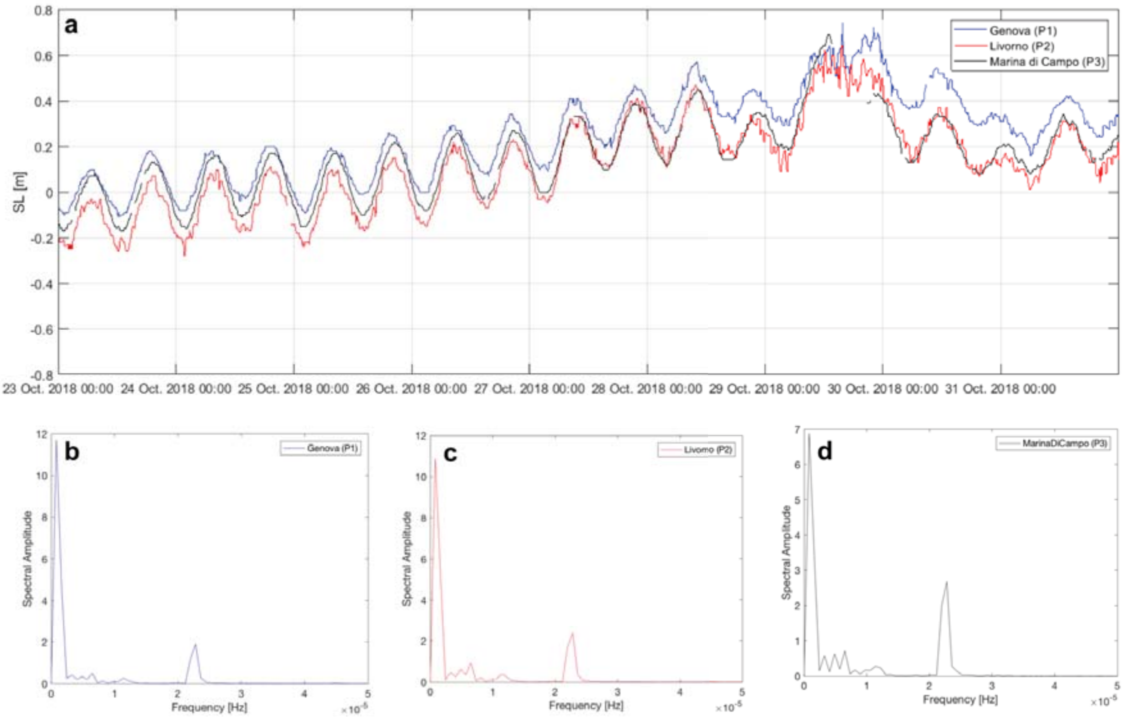

Fig. 5. Sea level (SL) observed during the period 23-31 October 2018 in P1, P2 and P3 locations (a) and relative spectrum amplitude in (b), (c) and (d), respectively.

Savona coastal area the storm caused the almost total destruction of the structures and piers of the bathing facilities and the cancellation of entire stretches of sandy and pebble beaches. An initial assessment of the damages estimated that out of 1300 equipped Ligurian touristic infrastructures almost 100 were completely destroyed and around 400 were seriously damaged, for a damage of at least 50 million euros. The action of the waves seriously damaged the port infrastructures: Santa Margherita Ligure and Rapallo harbours were particularly affected, with the collapse of the respective breakwaters. Towards Portofino, the fury of the sea caused the entire collapse of a section of provincial road near Paraggi. These damages demonstrated the importance of forecasting the action of sea storm and sea level increase on piers, coastal structures and beaches. In fact, the damages occurred to boats due to harbour collapse could be avoided with a proper alert system and the same could be have done with the beach damages.

V. ACKNOWLEDGMENTS

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