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Analysis of the 29 October 2018 sea-storm in the Ligurian sea

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Abstract –During the last days of October 2018 a very deep low pressure system from the west Mediterranean, generated a very strong southerly pressure gradient resulted in the most intense phenomena at the last decades relating to Liguria coasts, causing unusual widespread damages. In this study were presented the analysis and the description of the sea-storm dynamic occurred on 29 October 2018. During the event, over Ligurian sea (North Western Mediterranean) were observed strong, organized and stationary thunderstorms, storm wind gusts and an intense sea-storm, hitting the entire Ligurian coast characterized by very rough to high sea state and a nearly oceanic peak wave period.

I. INTRODUCTION

The Hydrological and Weather Centre of Liguria Region (hereafter CMI) is the ARPAL (Regional Agency for Environmental Protection) office dealing with weather forecast, hydrology and climatology primarily aimed at the Civil Protection needs. The CMI is managed and coordinated by the regional Civil Protection structure and is placed under the organizational and functional direction of the Liguria Region.

Observed data and numerical weather interpretation products, constitute the base for weather and sea forecast elaboration and for warning and alert emission on the entire Region. The modeling chain used by the CMI is the result of research experience and specific studies conducted since 1994 by the University of Genoa and CNR (National Research Council) on behalf of the Liguria Region and has been consolidated thanks to years of operational application at the CMI.

The sea navigation safety and sea costal activities, depends strictly on accuracy and reliability of sea conditions forecast and on how this information is managed. For this reason CMI every day produce a sea weather forecast bulletin and issue a Weather Vigilance Bulletins or a Warning Bulletin depending on weather situations. The days before the 29 October 2018 event the CMI issued warning bulletins for intense sea-storm and strong gale winds up to storm intensity. In this study, were investigated the numerical weather prediction outputs coming from both atmospheric and wave models and comparing them with data coming from ondametric buoy and meteorological stations located in Ligurian Sea area. The main objective of this work is to analyse the interesting and unusual sea-storm configuration that occurred in the last days of October 2018 which produced numerous and extensive damages over Ligurian coastal region especially for the harbours at the eastern side. The next four sections are divided as followed: section 2 contains a short description of sea-storm with the support of several data collected by ondametric buoy of Capo Mele, owned by ARPAL (on the west part of Ligurian sea). Section 3 contains a brief description of the operational modeling chain in use by the CMI. Section 4 contains a discussion of the models performances and a general discussion about the CMI procedures for issuing sea-storm warnings. Finally, in Section 5, some conclusions and suggestion are drawn.

II. DESCRIPTION OF THE EVENT

The synoptic scenario, some days before the event, was characterized by an extended Upper Level Through (hereafter ULT) over the west Europe, between Iberica Peninsula and France, in slow movement to Mediterranean sea (Fig. 1). This configuration has initially led to an intense and persistent hot and wet Libeccio flow (south-westerly) that has crossed the west and central Mediterranean from Africa and reached the Ligurian Gulf in a remarkable thermal contrast with respect to the preexisting, colder and drier air mass (Pedemonte et al 2018 [1]). Since 27th October this situation supported an intense and continuous cyclogenetic activity between Balearic islands and Sardinia island. During the first hours of 29 October the ULT moved decisively toward the west Mediterranean and north Italy significantly increased the growth rate of the baroclinic instability. The effect was the formation of a deep low pressure system between Baleari islands and west Sardinia moving north-eastward, further deepening, with an unusual trajectory. Since early afternoon, following the ascent of the deep low system towards the Ligurian Sea, the low levels winds came first from south-east and later from south causing a strong reinforcement of both medium winds and gusts: different stations recorded average wind values and gusts between violent storm and hurricane (according to the Beaufort scale classification) until the early hours of the night. The maximum recorded value from ARPAL ground stations network, correspond to the maximum value recordable by the instruments but probably, the gusts have reached higher values. It is also important to point out that the

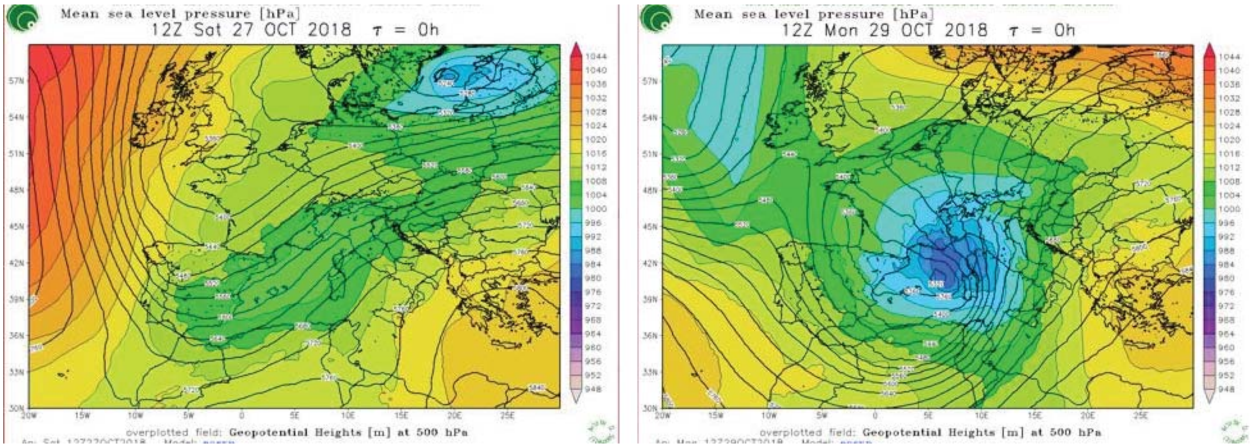

Fig. 1 Mean Sea Level Pressure (hPa) (bluish colors for low pressure values) with overplotted 500 hPa Geopotential Heights field (balck lines) from ECMWF analysis. Left panel: analysis from ECMWF run at 12 UTC on 27 October. It is visible a wide ULT between west and north Europe and a low pressure channel over west Mediterranean. Right panel: analysis from ECMWF run at 12 UTC on 29 October. A deep low pressure system is directed toward Liguria.

wind storm affected the whole region: in fact, in this phase, ground stations distributed over the entire Region exceeded the gale wind average threshold (range 34-40 kt) and some recorded storm average value (range 48-55 kt). Low pressure system reached 976 hPa (Valzemola station 19:00 UTC) thus rapidly increases the wave high, resulting in extended sea-storms since the evening. The pressure gradient at ground between Costa Azzurra and north Tuscany increased from 6 hPa up to 10 hPa with a mean sea level pressure loss of 9-13 hPa in 12h recorded by Capo Mele Buoy and other different ground stations. Because low pressure movement, a strong (up to 25m/s) south/south-easterly flow blowing along the eastern part of the Gulf of Genoa was almost immediately followed by an equally intense south-westerly flow in the western part. In these cases, the sea conditions are usually characterized by a complex crossed sea state, resulting from the superposition of wave components generated by different strong wind fetches. (Orlandi et al 2008 [2]). The very fast increase of wave high, more than 3.5m of significant wave high (hereafter SWH) and mean wave period (hereafter MWP) growth between 07.00pm (local hour) on 29th and 01:30am on 30 October 01:30am can be attributed to several factors: 1) a very large wind fetch that interested a big portion of Mediterranean sea and Ligurian coast (typical fetch extensions for Ligurian coast are: 400 M from SW, about 100 M from SSE and about 200 M from WSW);. 2) mean wind speed between strong gale and storm and wind gusts up to hurricane for a period longer than 12 hours; 3) likely storm surge effect associated with the deep low pressure transition over the Ligurian Gulf causing a sea level average increase of about 50-60 cm with grater wave penetration on the coasts; 4) finally, a moderate wave tide (30-40 cm).

Concerning the sea-storm characteristic, data trend between Capo Mele buoy (representative for the sea state on the west Ligurian coast) and Gorgona buoy

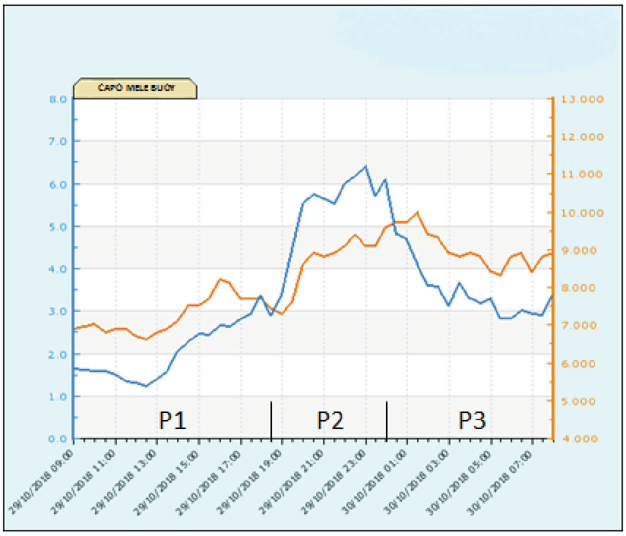

Fig. 2 A time-serie included between 29th and 30 October 2018 from Capo Mele Buoy. Blue line indicates SWH (m), orange line MWP (sec.). P1 to P3 refers to the sea-storm different phases.

(positioned offshore in northern part of Tuscany Region but representative for sea state description on east Ligurian coast) show the different sea-storm evolution among the two sectors of the Ligurian sea. Data from Capo Mele buoy allow the individuation of three different phases (Fig. 2) (Pasi et al, 2011 [3]). The first phase that goes from 12:30 (11:30 UTC) on 29 October to 18:30 was characterized by an increase in both SWH and MWP (from 1.21 to 2.89 m and from 6.6 to 7.4 sec.). The second phase (from 3.36 to 6.09 m of SWH and from 7.3 to 9.6 sec. of MWP), the more intense with regard to SWH, goes from 19:00 on 29 October to 00:00 on 30 October and has recorded a SWH peak of 6.41 m at 23:00 with a maximum wave high of 10.31 m at 20:30. The last

phase which goes from 00:30 to 07:00 on 30 October show a MWP peak (up to 10 sec. in the first hours) followd by an irregular decrease in both SWH and MWP.
With regard to coastal damages all along the coast from Finale Ligure to the Gulf of La Spezia, there have been serious damages. It has been reported that “hundreds” of yachts have been destroyed especially at Porto Carlo Riva in Rapallo, a marina which can host yachts up to 164 feet, was hit hard by 10-metre-plus waves. The severe damage have been partly due to the destruction of the breakwater, reinforced in 2000 after a similarly strong storm, which was supposed to protect the tourist port. This let violent seas into the main marina and damaged or destroyed dozens of vessels. Further west the marina in Portofino was relatively untouched but the main road connecting Portofino and Santa Margherita was badly damaged and remains closed for repair for more than 5 months.

III. THE OPERATIONAL CHAIN

The Ligurian sea is located in one of the most cyclogenetic area of the Mediterranean basin, where the interaction of the synoptic flow with the complex alpine topography cause the development of deep orographic lows (Trigo et al., 2002 [4]). The Region is frequently affected by severe flash floods over its very small basins, and sometimes by strong sea-storm. These conditions led the CMI in the past years to pay particular attention to the use and development of high-resolution model chains. Several deterministic high-resolution models, running every 6 or 12 h, are regularly used at the CMI to elaborate weather forecasts at short to medium range. The BOLAM and MOLOCH models have been developed at the Institute of Atmospheric and Climate Sciences of the Italian National Research Council in Bologna and run at ARPAL CMI using the ECMWF operational model (IFS) for initial and boundary conditions (Corazza et al., 2018 [5]). Bolam is a hydrostatic limited area model running on a hybrid vertical coordinate system with a split-explicit integration scheme. Moloch is a nonhydrostatic fully compressible model, nested in Bolam, using an implicit time scheme for the vertical propagation of sound waves, and explicit time-split schemes for the integration of the other terms of the equation of motion. Runs are updated every 6 h using the most recent simulations available from ECMWF. Initial and boundary conditions are available to ARPAL roughly 6 h after the nominal initialization hour. The BOLAM and MOLOCH wind fields are used to drive the WAVEWATCH III wave models implemented at different resolution thanks to a collaboration with the University of Genoa. One model is integrated over the whole Mediterranean sea with 10 km horizontal resolution driven by BOLAM and IFS ECMWF wind fields (domain 337x180 points). Over Ligurian sea is nested a second WWIII model with 2.5 km horizontal resolution with a two-way nesting scheme (domain 153x112). Both models allow to perform a 72 h forecast. WWIII is a third generation model (Komen et al., 1994, Tolman, 2009 [6]), which computes the directional wave spectrum integrating the wave action balance equation. The nonlinear part of wave evolution is described by the source term, which, for deep-water waves, is conventionally subdivided into three components: a wave-wave interaction source term, a growth term and a dissipation term. What differentiates third generation models from the first and second generation ones, is a punctual, even though approximate, representation of wave-wave nonlinear interactions through Discrete Interaction Approximation (DIA) (Hasselmann et al., 1985 [7]). Since nonlinear wave-wave interaction is responsible for the energy cascade from high frequency to low frequency modes, the adoption of DIA approximation, represents an important improvement in numerical simulations of wave dynamics (Mentaschi et al., 2013 [8]). The CMI available forecast fields for each model are: 10 m wind magnitude, Mean Wave Length, Mean Wave Period, Significant Wave Height, Mean Wave Height (empirical), Mean Wave Direction, Peak Period of 1D Spectra and Wave Danger.

IV. MODELS OUTPUT AND CMI PROCEDURES

Average quantities like SWH, MWP and Mean Wave Direction are the most commonly used by forecaster in the operational practice when elaborating sea state bulletins, emergency warnings for navigation (Niclasen et al., 2011 [9]) and coastal structures. In accordance with the CMI’s procedures, there are 3 sea coast state thresholds to warn Civil Protection office and final users. The first threshold, “moderate sea or locally rough”, is used when forecasted SWH is 2 m $\leq$ SWH $\leq$ 2,5 m and the pressure gradient configuration (intensity + position + isobars angle) is constant at least for 6 hours. During summer, season (May-September), if the event is longer than 6 hours it is possible to shift to the next threshold. The second threshold, “sea-storm conditions” is issued when 2,5 m $\leq$ SWH $\leq$ 4 m and the pressure gradient configuration is constant at least for 6-9 hours. Finally, the warning for “intense sea storm” is issued when the forecasted SWH is $\geq$ 4 m and the pressure gradient configuration at the sea level is constant at least for 9 hours. The gradient intensity magnitude and duration are very important parameters to correctly forecast the significant wave high and the mean wave direction. Another important field for more complete understanding and better predicting of the sea state structure, is the analysis of the directional wave spectrum (Bradbury et. al., 2007 [10]) but, due to a Capo Mele buoy wavemeter disruption, it was not possible to elaborate the spectrum data. The WWIII high resolution model on the Ligurian domain, correctly forecasted, for the period between 18UTC on 29 October and 00:00UTC on 30 October a sea state between high and very high first on the eastern part of Ligurian sea, interested by an intense south/south-easterly flow and later on the almost whole coastline (

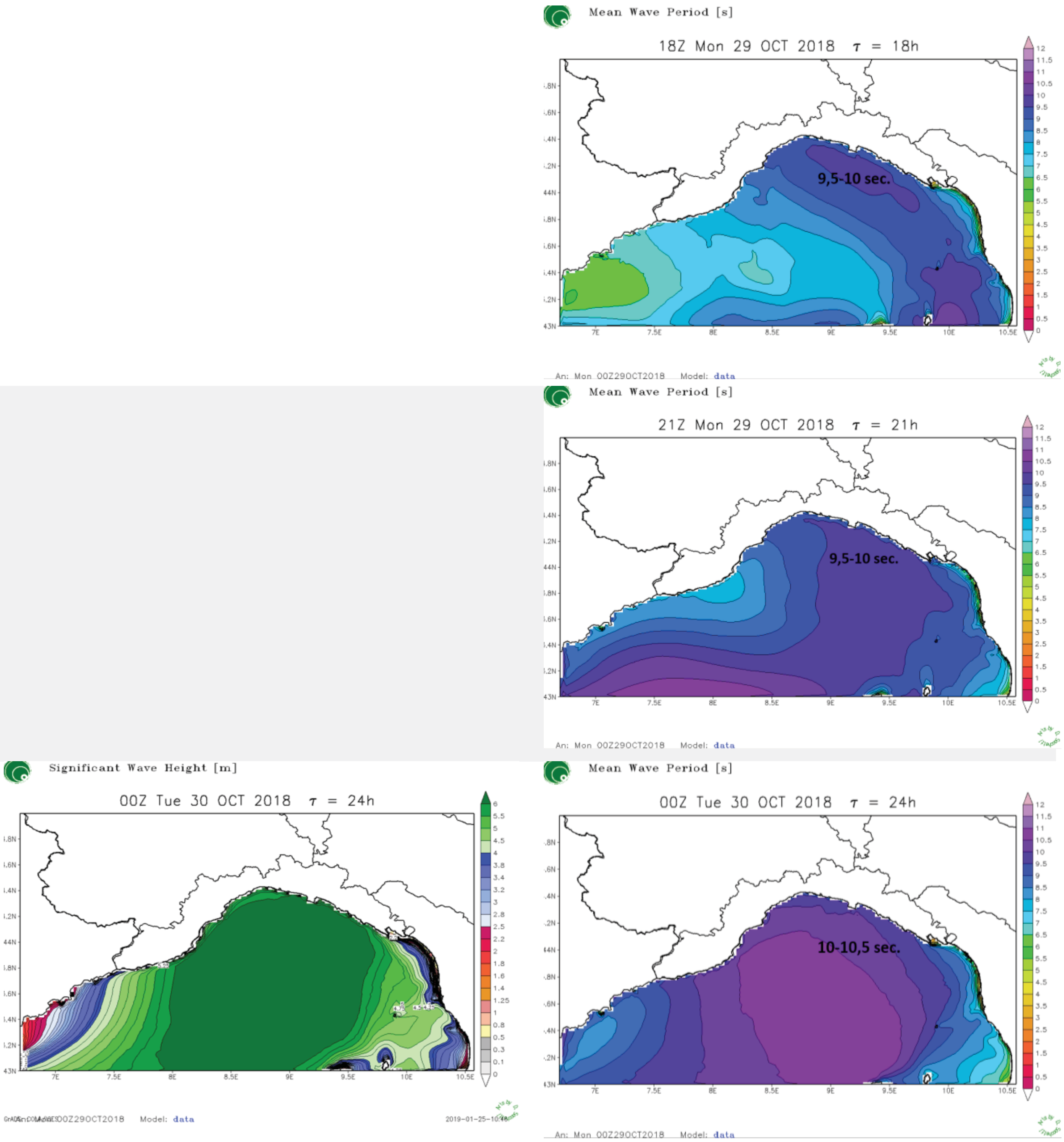

Fig. 3). Also the MWP is consistent with Capo Mele buoy and Gorgona Buoy record (not showed). The MWP starting from 21Z tend to rise from SW and later the MWP peak interested the central and east part of the Ligurian Gulf. The corresponding sea state can be ascribed to the arrival

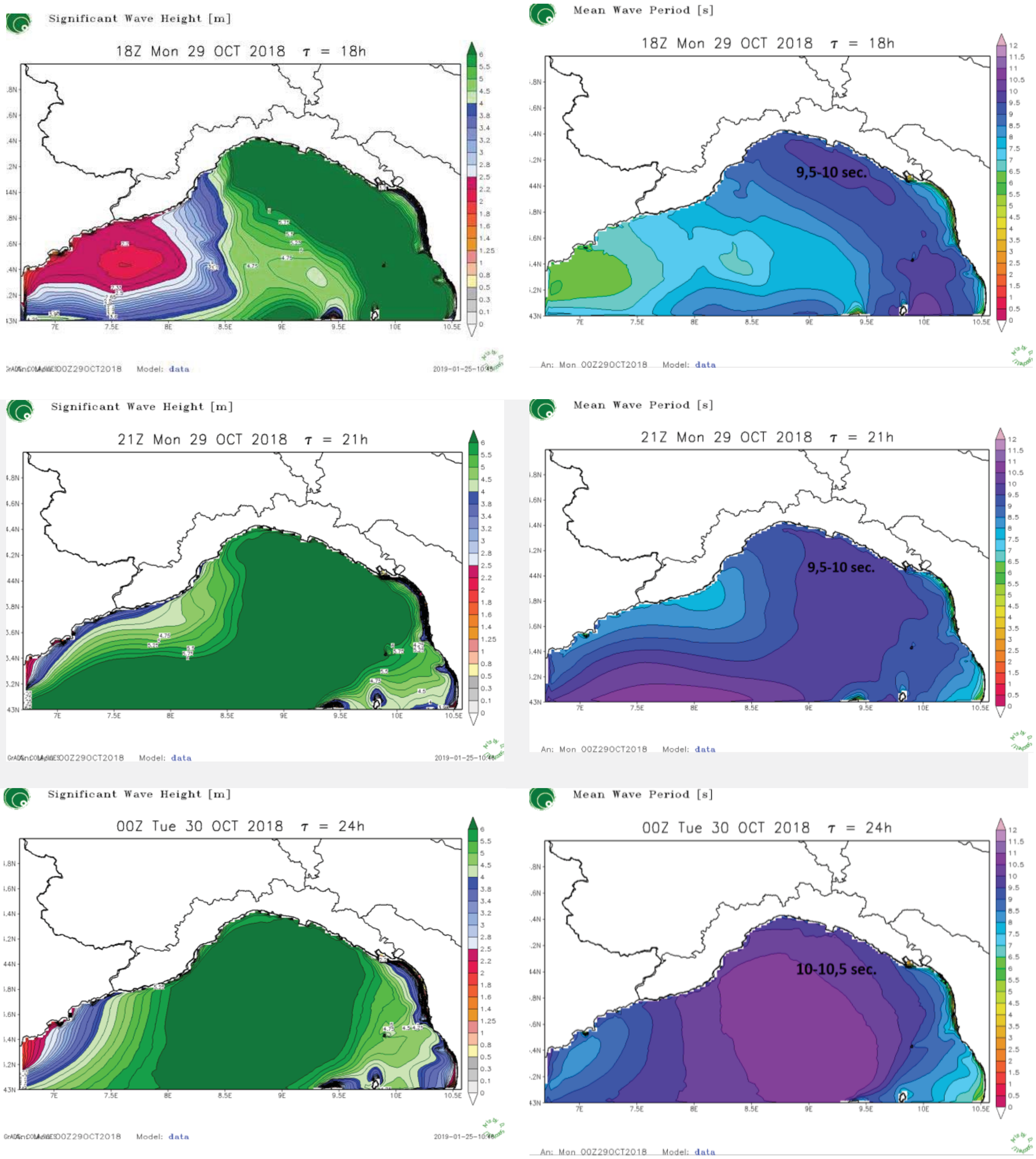

Fig. 3 From upper left corner: forecasted SWH (m) at +18h, +21h and +24h from WWIII high resolution (run 00UTC on 29 October), greenish colors for higher SWH values. From upper right corner: forecasted MWP (sec.) at +18h, +21h and +24h from the same run; purplish colors for higher MWP values.

of a swell coming from a very distant generating area located between Balearic Islands and Corsica Island.

V. CONCLUSIONS

The analysis of a sea storm event with damaging consequences all along Ligurian coast, in particular for harbour structures in the estern part, has been performed by using meteo-marine observations from coastal stations, off-shore buoys and a meteo-marine modelling chain. During the event, for the eastern part of Ligurian coast, only Gorgona buoy (north Tuscany) recorded data. Such a study showed an overall good agreement between observations and modelling results. Indeed, models'performaces correctly represented the overall evolution of a very rough to high sea state in the open sea

extending the intensity of swell to the Ligurian coasts (both for SWH and MWP). It was found that storm evolution could be divided into three different phases. The relevant coastal damages was produced stradding by Phase 1 and Phase 2. The influence of local bathymetry might have also played an important role in the waves'effectiveness to penetrate the coast (some news report up to 10 m height waves along eastern part coast).
The sea state of the second phase was characterized by an extreme (relatively to the Ligurian Gulf wave climate) peak wave period of 10 s, a nearly oceanic period. In accordance with the CMI's procedures, some days before the 29 October event, was issued the warning for "intense sea storm". Thanks to CMI operational model chain, forecasters in the operational practice provided a reliable sea state forecast and valuable informations for the sea navigation safety and sea costal activities. Nevertheless, a finer spatial grid models resolution would be required to better describe the waves propagation in coastal areas, in particular, for the last mile implementing an unstructured-grid for use in coastal ocean regions with complex irregular geometry such as in Liguria region. Since the atmosphere-ocean wave interactions are characterized by various spatiotemporal scales and nonlinear feedbacks, a further improvement could be the employment of a two-way coupled atmosphere-ocean wave model (Varlas, 2017 [11]). Finally, despite the development in spectral wave modeling research, no model is perfect, and research efforts in the growth, propagation, and transformation of random waves in both offshore and nearshore areas will continue in the future (Eldeberky, 2011 [12]).

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