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SHORT TERM CHANGE OF SEA CLIMATE AND INFLUENCE ON THE LITTORAL OF BELVEDERE MARITTIMO (COSENZA - ITALY)

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EXTENDED ABSTRACT

Le aree costiere rappresentano delle entità fisiche in continua e rapida evoluzione e sono il prodotto della combinazione di pressoché tutti i processi morfogenetici. Inoltre i litorali sono da sempre stati considerati dall'uomo zone di particolare interesse economico - sociale e conseguentemente sfruttati per la costruzione di infrastrutture abitative, per il trasporto e per il turismo. Ciò ha portato spesso ad una eccessiva pressione sui paesaggi costieri, con gravi conseguenze sul territorio.

È noto come, a livello mondiale, circa il 70% delle coste mobili sia soggetto a intensi fenomeni erosivi che, a partire dagli anni '50-'60, hanno reso necessaria la costruzione di opere di difesa. Queste ultime spesso non hanno prodotto pascimenti sufficienti a ripristinare le ampiezze antecedenti la crisi erosiva. Sebbene tra i principali fattori dei processi erosivi siano da imputare sicuramente la diminuzione delle precipitazioni e l'impatto antropico, con la costruzione di porti, moli e di dighe sui fiumi che limitano la fonte principale di sedimento per le spiagge, è anche possibile che un cambiamento nel regime del vento possa aver comportato una variazione nell'idrodinamica delle aree costiere, che a sua volta potrebbe avere influenzato il trasporto dei sedimenti lungo la costa. Secondo studi effettuati sul Mediterraneo il regime del vento ha infatti subito alcuni mutamenti dovuti a cause su scala globale come il *global warming*, che ha portato a una deviazione delle perturbazioni cicloniche verso l'Europa Centrale e dunque a una diminuzione degli eventi estremi nel bacino del Mediterraneo. Tuttavia il fenomeno sembra avere differenti tendenze se si aumenta il dettaglio della scala delle aree in esame, situazione riscontrata ad esempio nel Golfo del Leone come in alcune stazioni meteorologiche in Italia, che hanno registrato un aumento della ventosità generale e delle velocità a partire dagli anni '70.

In Italia l'arretramento delle spiagge ha riguardato oltre il 50% dei litorali sabbiosi e specie negli ultimi decenni le spiagge sono andate incontro a un intensificarsi dei fenomeni erosivi, con un conseguente arretramento della linea di riva che ha reso necessari urgenti e costosi interventi ingegneristici con la costruzione di opere di difesa, al fine di proteggere la costa dall'azione erosiva del moto ondoso, non più bilanciata dall'apporto sedimentario dall'entroterra. In particolar modo, la Calabria ha subito un incremento erosivo a partire dalla seconda metà del XX secolo ed è stata oggetto di numerosi piani e progetti atti a contrastare l'erosione costiera. Nello specifico, nel presente lavoro, è stato esaminato il paraggio tirrenico compreso fra Diamante e Capo Bonifati (CS), che presenta i più cospicui fenomeni di erosione della Calabria e che risulta listato da diverse tipologie di opere di difesa costruite a partire dagli anni '70. Tali opere sono state spesso danneggiate dalle violente mareggiate invernali, rendendo necessaria la riprogettazione e il ripristino delle stesse e che ad oggi non sembrano aver prodotto i risultati attesi. Il paraggio in esame ha molto prossima la boa di Cetraro della Rete Ondametrica Nazionale (R.O.N.), ma soprattutto la stazione anemometrica di Bonifati (che presenta registrazioni a partire dal 1961, con più di 50 anni di dati), che hanno consentito la ricostruzione del clima meteomarino. Data la scarsità di dati ondametrici a disposizione (poco meno di 10 anni), l'analisi di quelli anemometrici ha permesso di individuare i cambiamenti in termini di ventosità e regime dei venti, responsabili del moto ondoso, a sua volta principale agente morfogenetico e morfodinamico del litorale. Da queste valutazioni sono quindi state eseguite delle simulazioni con modelli numerici che, paragonandone i risultati con l'andamento della linea di riva nel corso del periodo studiato, hanno permesso di stabilire gli effetti di tali variazioni su quest'ultima.

Il presente lavoro si prefigge lo scopo di indagare la presenza di eventuali cambiamenti nel regime del vento, secondo un approccio statistico, e di valutarne i possibili effetti sulla zona costiera del comune di Belvedere Marittimo, attraverso l'utilizzo di modelli numerici in grado di simulare l'idrodinamica del luogo. Tale metodologia, in un ambiente microtidale dove domina l'energia del moto ondoso, è facilmente esportabile su qualunque tipo di costa mobile che abbia in prossimità una stazione anemometrica, in grado di fornire serie storiche di dati, sopperendo così all'assenza o carenza di dati ondametrici.

Un analisi di questo tipo permetterebbe quindi di:

1) valutare le oscillazioni decennali del clima ondoso (un intervallo di tempo generalmente coincidente con la durata media di un'opera di difesa); 2) valutare i cambiamenti nel verso della corrente lungoriva, in particolare nel semestre invernale, responsabile dello spostamento dei materiali lungo costa (*drift*); 3) di indicare possibili correttivi alle opere di difesa qualora non risultino efficaci ai fini del pascimento dell'arenile.

ABSTRACT

In Italy, during the last decades, the coasts have undergone an intensification of erosive processes. This has led to many problems due to the proximity of communication routes (like roads and railways) and inhabited areas to the coast. One of the most affected areas is the coast of Belvedere Marittimo, located on the Tyrrhenian side of Calabria, South Italy. The erosional crisis of the beaches is certainly due to the increasingly urbanization of the territory, both coastal and inland, which prevents normal sediment influx that feed the beaches. However, it is equally true that there are well-known global scale changes of climate, which it is possible that are causing an increase storm intensity of tropical hurricanes and extra tropical storms. The Mediterranean Region has showed different behaviors related to local factors, with some exceptions to the general trend showing an increase of extreme events, related to wind speed and direction and therefore with effects on sea climate. In this scenario, the coast of Belvedere Marittimo will be the area of interest of the project, as previous works on the location has showed a correlation to the shoreline retreat with the increase of wind extreme events, especially in the 2001-2010 period. The decision to focus the research on wind data allows overcoming one of the most common problems of this type of studies in Italy, which is the shortage of wave data. This area has already been object of different sea defenses during the decades, but the breakwaters and groins, built for more than thirty years, did not produce significant progradation of the beaches. The proposed methodology is applicable in a microtidal regime where dominates the wave climate, and is easily exportable on the beach near an anemometric station, capable of providing historical data series thus fill the data gap on the waves. Moreover, the evaluation of changes in speed and direction of the winds / waves will allow a rethinking of the types of defenses along the beaches.

Keywords: *Tyrrhenian coast, wind regime, beach erosion, statistical analyses*

INTRODUCTION

Coasts are landscape features that undergo deep and fast changes; the present high intensity of coastal changes is a problem of worldwide importance that becomes crucial along densely inhabited coastal belts.

Storms and storm surges represent a permanent threat to, for instance, structures, energy supply facilities, forests and coastal defense systems. Coastal zones are exposed to wind force, surges and waves that can destroy sea defenses. Quite a number of studies focused on surges in Venice -Adriatic Sea (e.g. Camuffo *et alii*, 2000; Camuffo, 1993; Pirazzoli & Tomasin, 2002; Mancinelli *et alii*, 2017). However, many of them are related to local scale events (like surges), whereas the other researchers have focused on a larger region like (Lionello *et alii, 2003;* Robinson *et alii,* 1973). Changes of near-surface winds from wind observations in the Central Mediterranean and Adriatic Sea have been investigated by Tomasin & Pirazzoli (2003) for example.

A robust assessment of changes in the regional storm climate needs to be based on many decades of homogeneous data, which are hardly ever available when regarding direct wind measurements. The homogeneity of data is another main issue (see e.g. Böhm *et alii*, 2001; Aguilar *et alii*, 2003; Auer *et alii*, 2003; Auer *et alii*, 2007) and has to be addressed carefully. Inomogeneities typically occur when the data are affected by changes in observation practices – such as station - relocations, changes of the gauge or in the environment surrounding the gauge, or others.

The erosion of beaches and shorefront properties can be partly related to the sediment yield deficit due to the multiple processes and environmental factors acting together. Of importance are the climate controls on the erosion processes, as the strong reduction in rainfall amount (D'Alessandro *et alii*, 2002; Bramati *et alii*, 2014). The foremost is the global warming, responsible for increased rates of sea-level rise that began as early as the late nineteenth century, with global mean ocean levels having risen some 0.15-0.20 m during the twentieth century. The global warming (Wang *et alii*, 2006) and increased ocean-water temperatures appear to be the primary cause of increased storm intensities of tropical hurricanes and extratropical storms (Komar, 2011). The prospect is that the erosion and flooding of shores will be substantially enhanced during the twenty-first century, compared with that experienced in the past. For example in Italy, all the beaches of Calabria Region recently underwent a strong erosional crisis; the investigations carried out have shown the influence of wind climate (D'Alessandro *et alii*, 2002).

Coastal erosion can also be the result of more local human modifications of the environment, particularly those that decrease the volumes of sand and gravel that reach the beaches. Specifically, the construction of dams on rivers can cut off what had been the primary source of sediment to the beaches (Tarragoni *et alii*, 2011; Tarragoni *et alii*, 2014; Tarragoni *et alii*, 2015a; Tarragoni *et alii*, 2015b). Also significant as a cause of erosion is the construction of jetties and breakwaters along the coast, which prevent the longshore movement of the beach sand so it can no longer reach and nourish distant beaches.

Coastal scientists and engineers presented reviewed models to evaluate the erosion impacts that result from those marine processes and environmental modifications, dealing also with management applications that include the range of potential responses to problems related with beach and property erosion.

This paper is about a statistical analysis of historical series of winds that blew along Tyrrhenian Calabria coast and a joint analysis of different shorelines covering the same period. The aim of this paper is:

1) to test for the presence of trends in the anemometric regime;
2) to estimate the return levels of extreme winds for various re-

turn periods;
3) to reconstruct the wave climate;
4) to check the link with the erosional crisis of the beaches in the last decades.

The paper is organized as follows: Section 2 briefly recalls the main physiographic features of the area under study, Section 3 contains the description of data used and the statistical methodology, Section 4 reports the main results of the analysis, in Section 5 a result discussion and in Section 6 the main conclusions.

GEOMORPHOLOGICAL FEATURES

The coastal stretch, in the Belvedere Marittimo (Cosenza) municipality, is part of the Tyrrhenian boundary of the Catena Costiera, north of the tectonic line of Sangineto. The analyzed coastline extends for approximately 4 km between the stream mouth of Vallecupo, in the north, and Soleo, in the south (Fig. 1). The shoreline has the characters of a N-S trending beach interrupted by the Punta di S. Litterata and Capo Tirone juts.

The coastal mountsides to the north of Capo Tirone, formed of marly - clayey lithotypes, are incised by sizeable terraces; those located at a height of 30 m are wider and better preserved with surfaces dissected by deep fluvial cuts, and widespread solifluction processes influence them. The shores located at the bottom of these slopes record modest sizes, with a maximum extension of 20 m. To the south of Capo Tirone the coastal plain of Belvedere Marittimo opens up and stretches up to the mouth of the Torrente Sangineto. The coastal belt is characterized by the presence, just south of Capo Tirone, of a terraced surface (“i Monti”) located between 50 and

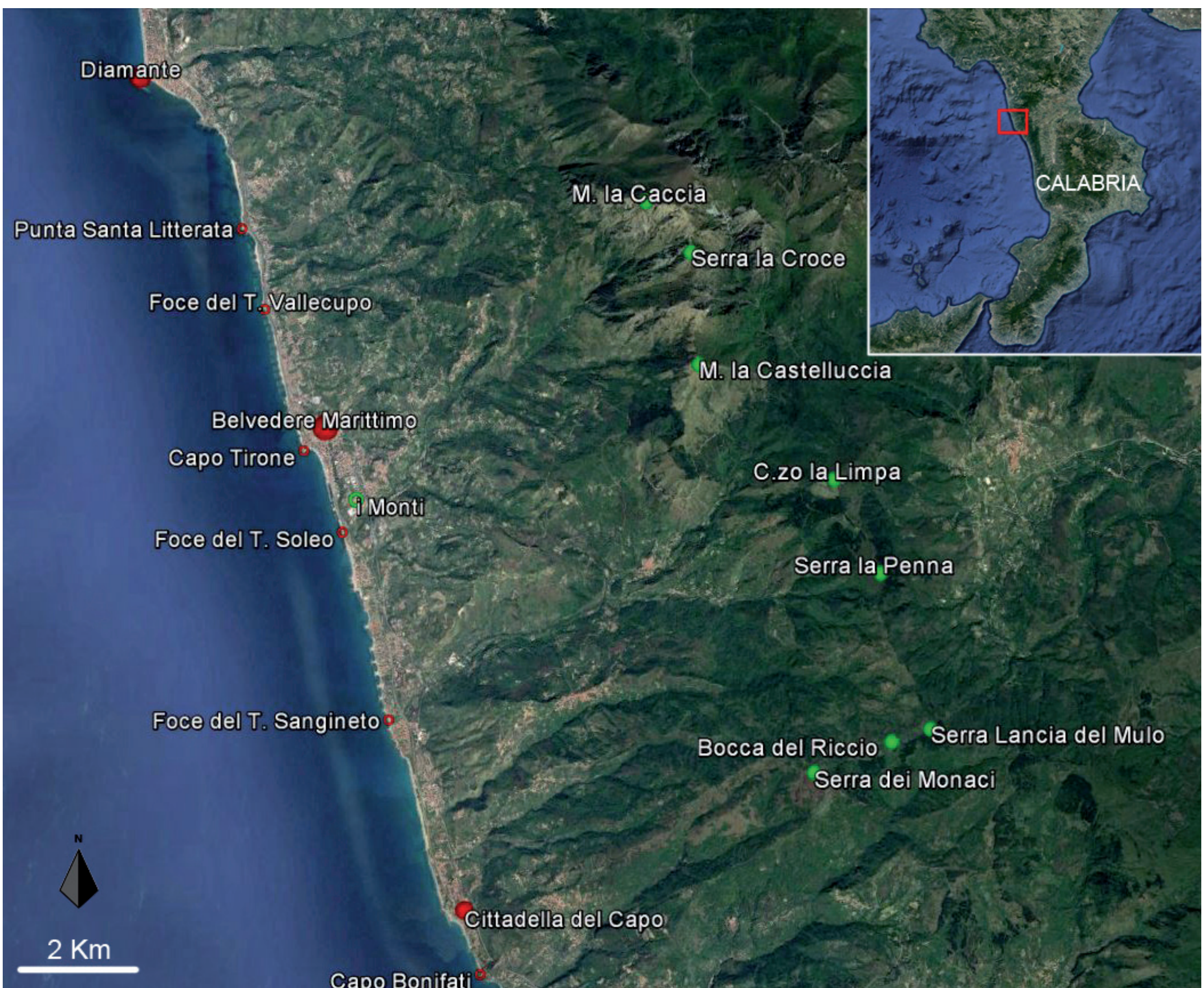

Fig. 1 - The area of Belvedere Marittimo, in Calabria (South Italy)(Google Earth, 4/16/2016)

60 m; the slope delimitating the terrace is deeply and extensively incised by a series of gullies; the material produced by the progressive retreat of the cliff, masks the terrace below which is found at 20 m. To the south of this terrace the coastal plain slightly extends because of the more evident supplies of the Soleo and Sangineto streams; the shores record variable width comprised between 15 and 50 m. In particular, the Torrente Soleo dismembers and dissects the "i Monti" terrace, and deposits a sizeable alluvial fan just before flowing into the sea. The Torrente Sangineto is the only watercourse of the studied area with a fair catchement basin and an alluvial plain 200-300 m wide (Bellotti *et alii*, 2009).

Therefore, the coastal area is overall characterized by terraces cut by small streams that feed the beach. Terraces did not show morphological modifications during the last decades.

The beaches bordering the slopes, on the contrary, show an evolution, which implies that such important modifications occurred during the last century. In particular, the shoreline comprised between Punta di S. Litterata and the Torrente Sangineto mouth recorded a general stability between 1873 and 1955 (D'Alessandro *et alii*, 2002). A more widespread erosional process characterized the period between 1955 and 2002. Along an area close to the North of Capo Tirone, where the maximum retreat occurred, the beach disappeared and the road around the promontory was destroyed by the waves. The stretch between the Soleo and the Sangineto streams, which is the southernmost part of the examined shore has registered, over the last 50 years, a linear retreat (on average more than 1,5 m/y). It is remarkable that along this stretch of coastline there are numerous habitations and tourist structures, that at the present time, are by now close to the shoreline, and therefore, in danger. The maximum erosional crisis has registered between 1955 and 1978; afterward, during the 80's, it followed a progradational process that, only partially, restored the extent of the shore. In the last few years, a renewal of the retreating processes has been taking place. These have almost cancelled the progradational processes

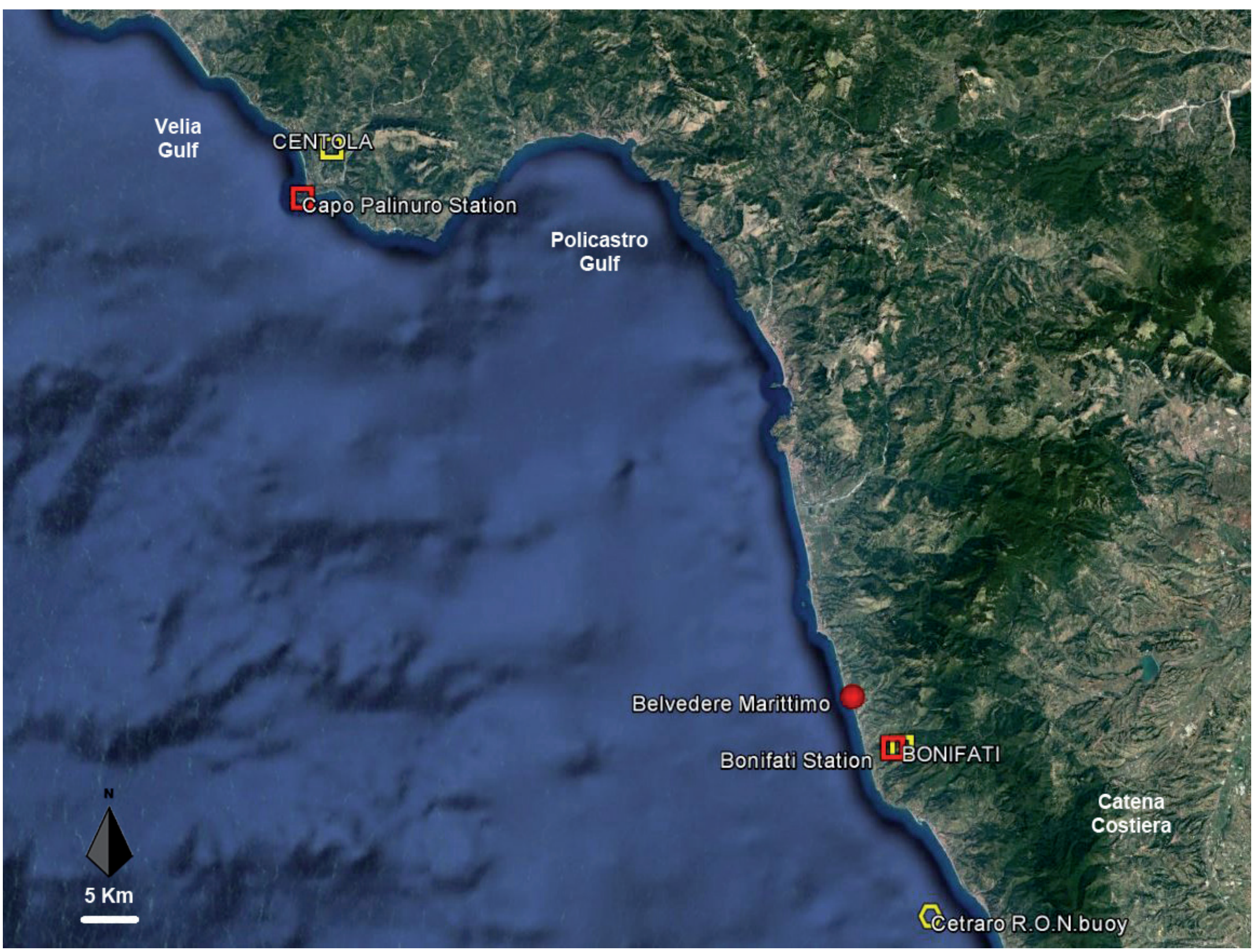

Fig. 2 - Location of the meteorological stations and buoy (Google Earth 12/14/2015)

recorded before (Bellotti *et alii*, 2009).

The seafloor is characterized by a quite regular morphology, except for local articulations in the zone near Capo Tirone. Moreover, in the zone in front of the structures and for lower depths, because of the jagged pattern of the isobaths, the evident influence of the coastal engineering structures along the entire coastal strecht extending between the Torrente Vallecupo and Capo Tirone can be observed. The morphological changes of the sea floor, occurred between 1980 and 2002, show a widespread erosion phenomenon in the more northern part of the area has been noticed; moreover, a partial spill of inert materials was observed in correspondence with the openings of the structures, this is also confirmed by the grain size analysis of the sediments at the seafloor. This phenomenon mostly occurs during the storm, in fact the wave motion, over the breakwaters, causes rip currents (in the openings between the structures) that are responsible for transport of sediments towards the open sea. In the majority of the seawalls, the central area is characterized, on the open seaside, by a shallower depth with respect to the extremities.

DATA AND METHODOLOGY

Data collection

For this paper we used wind data from bulletin provided by the National Center of Aeronautical Meteorology and Climatology (C.N.M.C.A.) of the Italian Air Force, recorded by two meteorological stations: Capo Palinuro and Bonifati stations. These two stations were selected considering the length of their time series and for their proximity to the studied site.

Capo Palinuro station (Fig. 2) is in the town of Centola in the province of Salerno, South Italy (15°16'50.71"E Gw – 40°01'31.06"N). The station is located on a rocky cape that goes for two kilometers in the Tyrrhenian Sea, between the Velia gulf and the Policastro gulf. It is at an altitude of 185 meters above sea level and is bordered to the East by mountains with a NW-SE direction. It is possible that the local orography influences the recorded direction of the wind (D'Alessandro *et alii*, 1981). Even if the station is located at 60 km of distance, this station was chosen as it is the nearest to Belvedere Marittimo (except for Bonifati station) with a time series of 60 years that may be useful in terms of comparison.

Bonifati station (Fig. 2) is in the town of Bonifati in the province of Cosenza, South Italy (15°53'29.34"E Gw – 39°35'4.89"N), at an altitude of 484 meters above sea level and at almost two kilometers and a half from the coast. On the East of the station there is the Catena Costiera, with peaks above 1000 meters especially in the East and North.

The data recorded by Capo Palinuro station cover a period from 1951 to 2010, for a total of 161,979 data, while those recorded by Bonifati station range from 1961 to 2010, with 108,140 data. The type of the bulletin is the SYNOP, with daily records every three hours for the station of Palinuro (3, 6, 9, 12, 15, 18, 21, 00) and every three hour starting from 06 to 18 for Bonifati. The SYNOP type provides data of the wind to the ground level with date, time, wind direction (in degrees on a discrete scale with 36 distinct values, with 360° indicating the North and 0° used as the value for missing data) and speed in knots (with an error of 1 knot). The anemometer is placed away from obstacles and at a height of 10 meters above the ground.

For the waves we used data collected from the buoy of Cetraro (15°55'.1"E Gw - 39°27'.2"N, Fig. 2) of the R.O.N. (Italian Wave Measurement Network), provided by I.S.P.R.A. (Italian Institute for Environmental Protection and Research). The buoy has worked for more than ten years, from 1999 to 2014. Data include the significant wave height in meters (Hs), peak period in seconds (Tp), average period in seconds (Tm) and the average direction of propagation in degrees from the North (Dm), with records every 3 hours up to 2002 and every 30 minutes in the following period.

We also collected shorelines (with appropriate georeferencing) from different sources. The first one (a shoreline of the 1873) was taken from a topographic map of the I.G.M.I. (Istituto Geografico Militare Italiano). The second one (1955) comes from the base flight 1954/1955 of the I.G.M.I. The third one (2002) derives from a previous work on the area (Bellotti *et alii*, 2009), through a GPS survey. The fourth one (2006) was provided from I.S.P.R.A. The last one, for the year 2015, was recorded in the April, 2015, through the use of GPS. The last one (2015) was recorded in the April 2015, through the use of two GPS Leyca Geosystems 12000. Two devices, a *rover* and a *reference*, connected by a radio contact, compose this model. The rover is moved across the shoreline for data acquisition and the reference is placed in a known point (as the geodetic points I.G.M. 95) to correct the position of the first. For this case, two geodetic points of the I.G.M. were used (available at http://www.igmi.org): 220901 for Diamante and 228601 for Capo Tirone. The reference system used for the data recording was the WGS 84.

Statistical analysis

In previous works (Pirazzoli & Tomasin, 2003; Bellotti *et alii*, 2011; Bramati *et alii*, 2014), the mid '70s appeared to be a period where changes in wind and precipitations were reported. For this reason, we decided to analyze the time series with different statistical tests and time frames to evaluate any mutation in wind trend, with particular attention to the extreme events.

Stations wind data correlation

We first tried to find a correlation between the two stations (since they are distant almost 72 km). After processing a match between the two different time series for years, days and hours of registration, we try to calculate the Pearson correlation coefficient:

$$\rho_{XY} = \frac{\sigma_{XY}}{\sigma_X \sigma_Y},$$

where X and Y are the two speed variables of the two stations, ρ_{XY} is the correlation index, σ_{XY} is the covariance and σ_X and σ_Y are the respective standard deviations.

A scatter plot for the two speed variables (in logarithmic scale) was elaborated to better understand the distribution for a further comparison.

A GAM (Generalized Additive Model) was also applied to the speed variables in logarithmic scale to further describe the relation between the two time series. The GAM is able to extend the linear regression model $y_i=\beta_0+\beta_1 x_{i1}+\beta_2 x_{i2}+...+\beta_p x_{ip}+\varepsilon_i$ with the replacement of the term $\beta_j x_{ij}$ with a generic non-linear function $f_j(x_{ij})$ thus obtaining $y_i=\beta_0+f_1(x_{i1}),+f_2(x_{i2}),+...+f_p(x_{pj}),+\varepsilon_i$, where p is the number of predictors. In this context, the present formula was used:

$$\{log(x1+1)\approx s[log(x2+1)]\}$$

where *x1* is the speed for Capo Palinuro and *x2* the speed for Bonifati. The *s* term is used to define the smooth in the GAM formula.

Proportionality test

We also made a proportionality test (for every time series) to observe the increase or decrease of class divided wind before and after the 1975. This year was chosen as a *break point*, a year where were noticed changes in wind speed/direction and precipitation, as mentioned before (Pirazzoli & Tomasin, 2003; Bellotti *et alii*, 2011; Bramati *et alii*, 2014). We divided the wind speeds by the limits of the Beaufort classes, to evaluate the frequency of each class before and after the 1975. The events sum of every Beaufort class was then compared with the total records for every period and station. The p-value has been set equal to 0.01 (0.99 confidence level). The null hypothesis (p-value > 0.01) is the case where more cases (or an equal proportional number) were recorded in the first period, before the 1975. The alternative hypothesis (p-value < 0.01) is where frequency for each class is higher after 1975.

GEV analysis

For the analysis of extreme events, we use the Generalized Extreme Values distribution (GEV) (Coles, 2001):

$$G(z) = exp\left\{-\left[1+\xi\left(\frac{z-\mu}{\sigma}\right)\right]^{-1/\xi}\right\}$$

To compare two different periods and to estimate any changes in trend that may have occurred we used again the two time series divided in two periods, before and after the 1975, for the same reason explained earlier. There were then elaborated two different models for the extreme events distribution for every time series (Capo Palinuro and Bonifati), before and after 1975, considering all the wind blowing direction. Subsequently the test was repeated considering only the blowing direction between 180 and 360 degrees, to evaluate the onshore winds, from the western quadrants, separately. The chosen time frame was set on monthly max speed values.

After the models for the distributions were elaborated, we compared the location (μ), scale (σ) and shape (ξ) parameters resulting before 1975 with the ones after 1975, to try to highlight any change in extreme events distribution. To determine the presence of a statistically significant change in the two periods, a 95% confidence interval (CI) was used.

From the GEV models we also obtained the return levels for the two stations, before and after 1975, applying the inverse of the GEV formula (Coles, 2001):

$$z_p = \begin{cases} \mu - \frac{\sigma}{\xi}\left[1-\{-log(1-p)\}^{-\xi}\right], & for\ \xi \neq 0 \\ \mu - \sigma \log\{-log(1-p)\}, & for\ \xi = 0 \end{cases}$$

where z_p is the *return level* associated with the *return period 1/p*.

This process too was repeated for all the wind directions and then only for the onshore winds. The return times considered were 5, 10, 25, 50 and 100 years. We used a 95% CI to determine any statistically significant difference.

Hidden Markov Model

The hidden Markov model (HMM) is a class of mixture model for time series data that assumes that the generative process is expressed as a mixture, where the temporal evolution of the latent states follows a First order Markov process (Mastrantonio & Calise, 2016). From an interpretation point of view, the latent regimes can be considered as latent wind state, such as calm or storm and each state has its own distribution that generates the data, with, for example, different mean direction and speed. We model the evolution of the latent states using a transition matrix that tells us, for a given time, which is the probability to move from the current state to a different one.

We test the model on 3 time windows: T1 (1961-1969), T2 (1979-1988) and T3 (2001-2010). The HMM model used for each time frame was the one proposed in Mastrantonio & Calise, 2016. We calculated then the wind speed (λ_y), direction (μ_θ) and concentration (c_θ) mean values for each station, as the relatives transition matrices for the wind regimes resulted from the model. A confidence interval of 95% was used. In addition we elaborated a tab to evaluate the possibility of a missing record for the direction in case of low speed wind. With this approach we want to show that the specific distributions of the states changes between them.

Reconstruction of the wave climate to the coast

After the statistical ana lysis, we proceeded with the reconstruction of the wave climate. In this phase we used the wave data recorded by the buoy of Cetraro (15°55'.1''E Gw - 39°27'.2''N) of the R.O.N., provided by I.S.P.R.A. The buoy has worked for almost ten years, from 1999 to 2008.

Depth of Closure

To update the depth of closure we used the Hallermeier formula (1981):

$$h_{in} = 2.28\ H_s - 68.5\ (H_s^2/gT^2)$$

where h_{in} is the depth of closure, H_s is the local significant wave height, T is the wave period associated to H_s and g is the gravitational acceleration. The calculation of the annual depth of closure is based on the H_s reached for no more than 12 hours per year.

S.WA.N.

Wave data were opportunely formatted, to obtain a data set with records every three hours, to eliminate record errors and a script was used to fill the missing data in case of short gaps (shorter than 3 hours) through linear interpolation. The data were classified according to double entry tables: Hm0-Dm (significant wave height and average direction) and Hm0-Tp (significant wave height and average period), with classes of height of 0.5 m, classes of direction of 10° and classes of period of 0.5 s. We classified data with a height less than 0.25 m as calm and they were not incorporated in the tables and in the following run of S.WA.N. For each class of the table Hm0-Dm with at least one representative we chose the central element of the class and we associate the peak period class most populated for that height range in the table Hm0-Tp, selecting then as representative the central peak period of the class. Then, we propagate to the shoreline every sea state so selected, using the model S.WA.N in stationary mode. We intend as sea state a statistical summary of the parameters Hm0, Dm and Tp of the waves present in a fixed time interval. Chosen a point in the middle of the shoreline selected (15° 50'51.83" EGw - 39 ° 36'17.94 "N) we reconstructed the wave climate at the bathymetric -10 meters and -5 meters. From these reconstructions, we selected the peak wave height (in open water) with its direction and mean period, which we used to simulate its propagation from offshore to shore.

Shoreline analysis

It was reconstructed the evolution of the shoreline over the last 140 years relative to 1873, 1955, 2002, 2006 and 2015. After the acquisition of the shorelines was completed, they were georeferenced and overlapped using the open source QGis software. Subsequently, the shorelines were divided in two sections. The first and northernmost one between the points A (15°49'56.76 EGw – 39°40'00.56" N) and B (15°50'50.33" EGw – 39°37'17.86"N), and the second and southernmost section between the points B and C (15°51'39.04" E Gw - 39°35'33.55 N).

After the overlapping of the different shorelines, we calculated (for every time interval between the lines) the eroded and the accumulation areas with the parallelogram rule, multiplying the areas by the depth of closure value proposed in Bellotti *et alii* (2009), that is 6,39 meters, to obtain the volumes. For this purpose the Bruun rule was used (Walkden & Dickson, 2008), according to the formula:

$$B = h \, \Delta x$$

where B is the sedimentary budget, h is the depth of closure and Δx is the horizontal translation distance.

RESULTS

Correlation between the two stations and proportionality test

The first step to analyze the wind data was to try to find a correlation between the two different time series. We proceeded with the creation of a junction variable between the two series to be able to compare them, due to the presence of different time intervals in the records and for the presence of some missing data. Then we made a correlation test for the two time series that showed a very low correlation coefficient (-0.003985476). The value very close to zero proves that the two series are not correlated.

Then we try to elaborate a dispersion plot in a logarithmic scale with a bisecting line for both the time series (Fig. 3). The plot shows a sort of symmetrical distribution of the data, even if there is an evident confused distribution for the extreme speeds, probably for the presence of noise in data, due to the high number of missing data. For a clear reading of these data we tried to use a GAM (Generalized Additive Model), in Fig. 4, with a confidence interval (the dotted lines) and a red line indicating the value of zero. All the values that are above the zero and in the middle of the confidence intervals are assumed to have a significant relation. As we can see in the GAM plot there is a significant relation for the highest values of speed in logarithmic scale, from 3.6 and above that corresponds at a speed of 36 knots and above (the values over the zero and inside the confidence intervals). This can show an obvious situation where there is a dominant wind blowing in the area that is recorded by the two stations.

The subsequent elaboration of lag plots did not show a significant correlation between the time series, so we decided to investigate the proportionality of the wind speeds recorded. We divided the two time series in two periods, before and after the

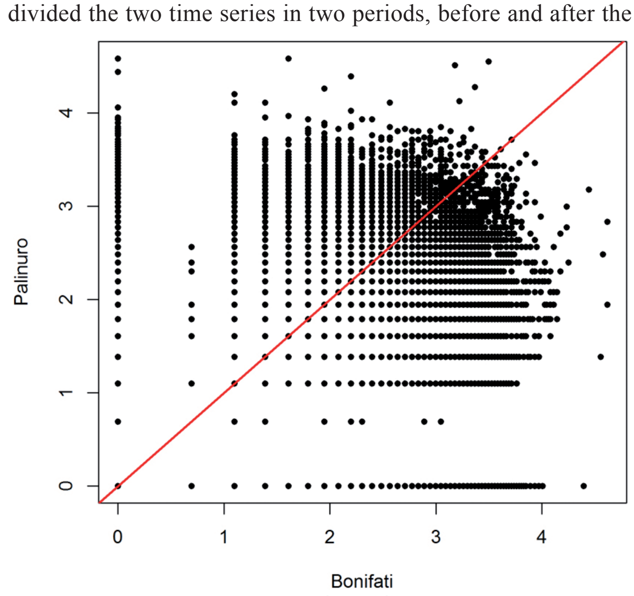

Fig. 3 - Dispersion plot in log scale for the speed data of Palinuto and Bonifati station

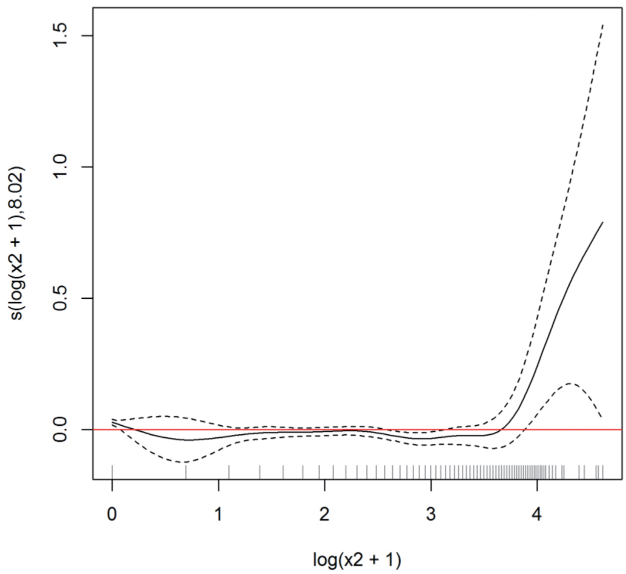

Fig. 4 - GAM plot for the speed data of Palinuro and Bonifati stations. Red line represent the zero value and the dotted lines represent the confidence intervals

1975, as this year is recognized by the literature as a breakpoint for wind trends, with changes in wind speed and direction (Pirazzoli & Tomasin, 2003; Bellotti *et alii*, 2011). Then we calculate with different speed thresholds the proportionality before and after the 1975 to detect any possible increment. We selected the speed thresholds to match the Beaufort classes and we made a sum of the events of a determined speed range then compared with the total cases recorded in the relative period to make a proportion between the recorded cases, for every speed class, before and after 1975. We used a p-value of 0.05 and as H0 the case where we have the same or a greater number of cases for a specific wind speed class in the period before 1975 (p-value >0.05). The H1 (p-value <0.05) is the case where we have less cases (always in proportion) in the first period for a specific speed class.

As showed in the Tab. 1, Bonifati station presents in all the wind speed classes an increase of frequency in the second period (p-value <0.05), even if we can trust only the results until the threshold >=47 knots, as in the next two classes we have only one record for the first period. In those cases, the approximation

BONIFATI	H1:less cases in the first period		
Period	**Threshold >3 knots**	**Total cases**	**p-value**
1961-1975	25304	44743	6.598e-15
1975-2010	38409	65221	
Period	**Threshold >6 knots**	**Total cases**	**p-value**
1961-1975	16885	44743	2.603e-06
1975-2010	25502	65221	
Period	**Threshold >10 knots**	**Total cases**	**p-value**
1961-1975	10106	44743	0.001441
1975-2010	15235	65221	
Period	**Threshold >16 knots**	**Total cases**	**p-value**
1961-1975	4672	44743	1.036e-11
1975-2010	7658	65221	
Period	**Threshold >21 knots**	**Total cases**	**p-value**
1961-1975	2125	44743	< 2.2e-16
1975-2010	4189	65221	
Period	**Threshold >27 knots**	**Total cases**	**p-value**
1961-1975	749	44743	< 2.2e-16
1975-2010	2000	65221	
Period	**Threshold >33 knots**	**Total cases**	**p-value**
1961-1975	228	44743	< 2.2e-16
1975-2010	809	65221	
Period	**Threshold >40 knots**	**Total cases**	**p-value**
1961-1975	54	44743	9.534e-10
1975-2010	194	65221	
Period	**Threshold >47 knots**	**Total cases**	**p-value**
1961-1975	15	44743	1.661e-05
1975-2010	69	65221	
Period	**Threshold >55 knots**	**Total cases**	**p-value**
1961-1975	1	44743	7.056e-05
1975-2010	27	65221	
Period	**Threshold >63 knots**	**Total cases**	**p-value**
1961-1975	1	44743	0.02341
1975-2010	11	65221	

PALINURO	H1:less cases in the first period		
Period	**Threshold >3 knots**	**Total cases**	**p-value**
1951-1975	45481	72735	< 2.2e-16
1975-2010	64075	89244	
Period	**Threshold >6 knots**	**Total cases**	**p-value**
1951-1975	27546	72735	< 2.2e-16
1975-2010	38645	89244	
Period	**Threshold >10 knots**	**Total cases**	**p-value**
1951-1975	13501	72735	< 2.2e-16
1975-2010	18181	89244	
Period	**Threshold >16 knots**	**Total cases**	**p-value**
1951-1975	5094	72735	0.1867
1975-2010	6353	89244	
Period	**Threshold >21 knots**	**Total cases**	**p-value**
1951-1975	2271	72735	0.3573
1975-2010	2816	89244	
Period	**Threshold >27 knots**	**Total cases**	**p-value**
1951-1975	746	72735	0.2232
1975-2010	951	89244	
Period	**Threshold >33 knots**	**Total cases**	**p-value**
1961-1975	225	72735	0.02131
1975-2010	330	89244	
Period	**Threshold >40 knots**	**Total cases**	**p-value**
1951-1975	51	72735	0.02268
1975-2010	90	89244	
Period	**Threshold >47 knots**	**Total cases**	**p-value**
1951-1975	23	72735	0.1338
1975-2010	39	89244	
Period	**Threshold >55 knots**	**Total cases**	**p-value**
1951-1975	13	72735	0.1225
1975-2010	25	89244	
Period	**Threshold >63 knots**	**Total cases**	**p-value**
1951-1975	9	72735	0.07245
1975-2010	21	89244	

Tab. 1 - Proportion test results for Bonifati and Palinuro stations to the Chi-square might be incorrect. For Palinuro we have a different situation, with more cases recorded in the second period only for the wind speeds <10 knots and between 34 and 47 knots. All the other speed classes show the same proportion (or more cases) in the period before 1975.

GEV and return levels

To study the behavior of the tails of the distribution for wind speed (in knots) we used the GEV (Generalized Extreme Values) that is a model to analyze the extremes of time series with independent data. The advantage to use the GEV is the possibility to unify the three families of distribution for extreme events (the Gumbel, Frechét and Weibull classes) into a single distribution family that greatly simplifies statistical implementation. Through inference one, the data themselves determine the most appropriate type of tail behavior, and there is no necessity to make subjective a priori judgments about which individual extreme value family to adopt (Coles, 2001). We then divided the two time series in two parts each, before and after 1975 and to render the time series independent we decide to block data for one month, in order to obtain a time series with month maxima for the wind speed. The autocorrelation test showed an acceptable result (Fig. 5), with the second term under the 0.5 value. The monthly time frame was also enough to maintain a good number of data for the wind speed variable. A conversion of data in logarithmic scale gave back a better quantile diagnostic plot. The GEV was then applied first on the two periods of the different time series (Bonifati and Palinuro) for all the wind directions and then it was applied only considering the onshore winds, from South to North (clockwise), due to the direction of

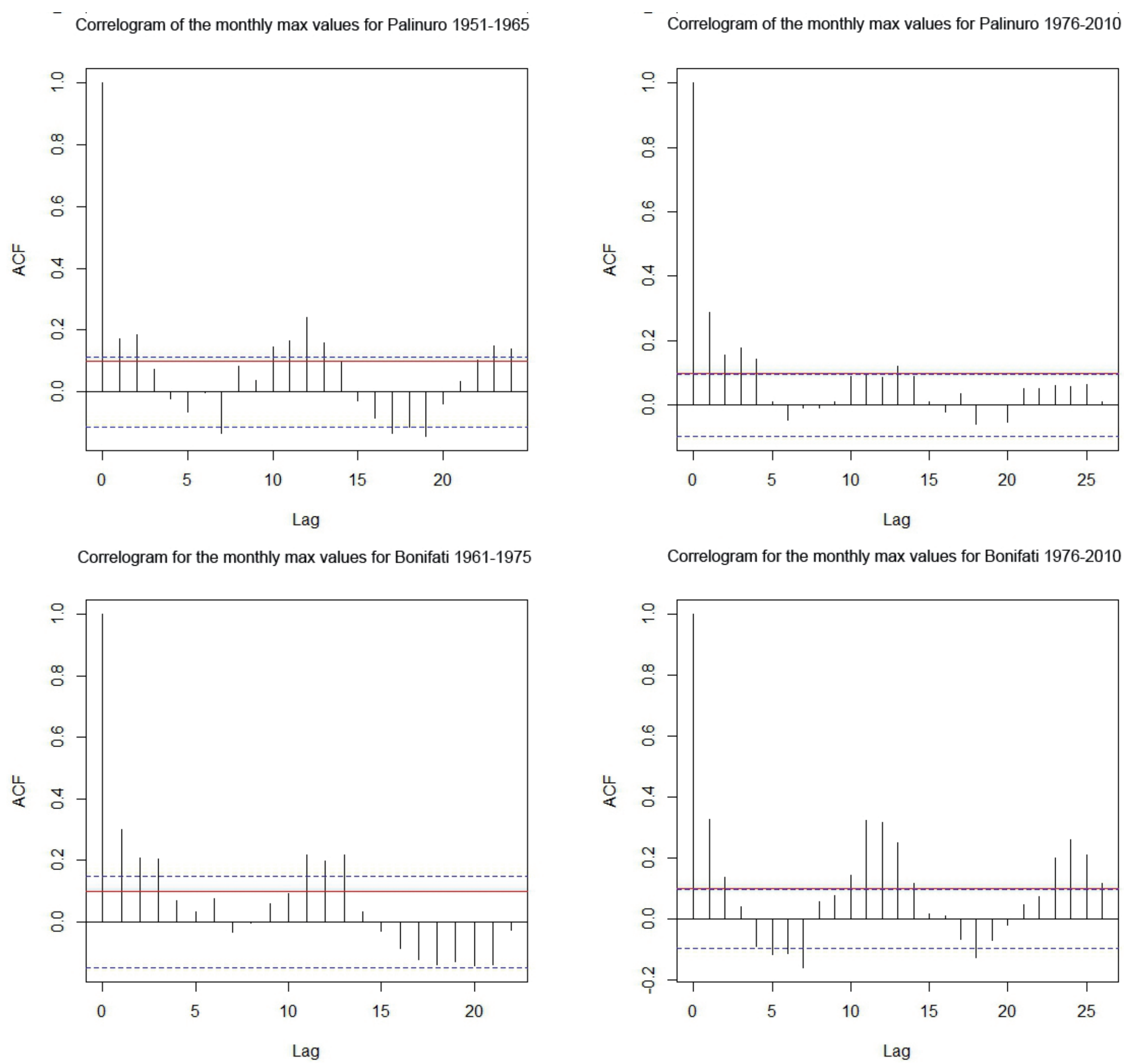

Fig. 5 - Autocorrelation test plots for the two stations in the two different periods, before and after 1975. The red line is the value of 0.1

CAPO PALINURO - GEV DISTRIBUTION OF WIND SPEED MONTHLY MAX IN KNOTS (LOGARITHMIC TRANSFORMATION) (CI 95%)						
PERIOD	μ (mu)	σ (sigma)	ξ (xi)	se μ	se σ	se ξ
1951-2010	3.296 (3.272 3.320)	0.296 (0.280 0.312)	-0.123 (-0.160 -0.086)	0.012	0.008	0.019
1951-1975	3.301 (3.264 3.337)	0.300 (0.275 0.324)	-0.164 (-0.217 -0.112)	0.019	0.013	0.027
1976-2010	3.293 (3.262 3.323)	0.293 (0.272 0.314)	-0.095 (-0.147 -0.044)	0.016	0.011	0.026

Tab. 2 - GEV parameters for Palinuro station for the wind speed in log transformation. All the wind direction are considered

BONIFATI - GEV DISTRIBUTION OF WIND SPEED MONTHLY MAX IN KNOTS (LOGARITHMIC TRANSFORMATION) (CI 95%)						
PERIOD	μ (mu)	σ (sigma)	ξ (xi)	se μ	se σ	se ξ
1961-2010	3.276 (3.244 3.308)	0.375 (0.354 0.396)	-0.248 (-0.277 -0.219)	0.016	0.011	0.015
1961-1975	3.255 (3.207 3.304)	0.309 (0.276 0.342)	-0.188 (-0.240 -0.135)	0.025	0.017	0.027
1976-2010	3.286 (3.246 3.327)	0.398 (0.371 0.425)	-0.271 (-0.306 -0.235)	0.021	0.014	0.018

Tab. 3 - GEV parameters for Bonifati station for the wind speed in log transformation. All the wind direction are considered

CAPO PALINURO - GEV DISTRIBUTION OF WIND SPEED MONTHLY MAX IN KNOTS (LOGARITHMIC TRANSFORMATION) - ONSHORE WINDS (CI 95%)						
PERIOD	μ (mu)	σ (sigma)	ξ (xi)	se μ	se σ	se ξ
1951-2010	3.188 (3.162 3.214)	0.329 (0.312 0.346)	-0.180 (-0.207 -0.153)	0.013	0.009	0.014
1951-1975	3.164 (3.122 3.206)	0.346 (0.319 0.373)	-0.199 (-0.239 -0.160)	0.021	0.014	0.020
1976-2010	3.205 (3.173 3.237)	0.311 (0.290 0.333)	-0.155 (-0.196 -0.115)	0.016	0.011	0.021

Tab. 4 - GEV parameters for Palinuro station for the wind speed in log transformation. Only the wind from the West is considered

BONIFATI - GEV DISTRIBUTION OF WIND SPEED MONTHLY MAX IN KNOTS (LOGARITHMIC TRANSFORMATION) – ONSHORE WINDS (CI 95%)						
PERIOD	μ (mu)	σ (sigma)	+ξ (xi)	se μ	se σ	se ξ
1961-2010	2.991 (2.958 3.025)	0.392 (0.369 0.415)	-0.298 (-0.327 -0.268)	0.017	0.012	0.015
1961-1975	3.008 (2.948 3.067)	0.374 (0.330 0.418)	-0.451 (-0.539 -0.363)	0.031	0.022	0.045
1976-2010	2.998 (2.956 3.039)	0.402 (0.374 0.431)	-0.299 (-0.339 -0.258)	0.021	0.015	0.021

Tab. 5 - GEV parameters for Bonifati station for the wind speed in log transformation. Only the wind from the West is considered

the coastline considered, almost North-South.

To analyze the results of the GEV models we considered the *location* (μ), *scale* (σ) and *shape* (ξ) parameters for every station and period. First, we took into consideration the results for all the wind blowing directions. The models shown in Tab. 2 and Tab. 3 indicate point estimations different for the two periods but there are partial overlaps if we consider the CI (confidence intervals) at 95%. There are no significant differences between the two models of the two periods for each station. But if we see the results for the onshore winds (Tab. 4 and Tab. 5), we can see a significant difference for the shape parameter (ξ) for Bonifati station, implying that the models before and after 1975 are significantly different.

This difference is also evident if we analyze the return levels for these return times: 5, 10, 25, 50 and 100 years. Using a CI of 95% and the wind speeds in a logarithmic scale, if we take into account all the wind directions, there is no significant difference for the return levels before and after 1975 for both Palinuro and Bonifati (Fig. 6). But if we consider only the onshore winds we can see a very different pattern in the return levels only for Bonifati station (Fig. 7), showing a large increase even in the first return time of five years (from a speed of 40.5 knots to 52 knots).

Hidden Markov Model (HMM)

The model has detected three regimes (or states) for the wind in both stations. The three intervals examined are defined as T1 (01/01/1960 - 31/12/1969), T2 (01/01/1979 - 31/12/1988) and T3 (01/01/2001 - 31/12/2010). For simplicity, we can define the regimes as the low, medium and high-speed states. A 10 years gap between the intervals was used to maintain independent the time series. The results are based on daily max.

For Palinuro station, in Fig. 8 and Fig. 9 there are respectively the mean speed and mean directions of the three regimes (columns) in the different intervals (rows).

To better understand the differences between the regimes, it is possible to consult: Tab. 6 for the wind speed linear variable (λ); Tab. 7 for the mean direction estimate in radians (μ); **Tab. 8** for the circular concentration (*c*) or precision, where the highest the value the highest the concentration (with a max value of 1). All the tabs shows the point estimates and the confidence interval of 95%.

The mean speed variable shows an increase of the value in T2, to return to the initial condition in T3, for all the three periods. The mean direction of the wind shows variations for the first regime between T1 and T2, changing from N 157° to N 145°. In the second regime the direction changes from a value between N 6°-12° (in T1 and T2) to N 352° (in T3). In the third regime (the high-speed one) in T1 and T2 the prevalent direction is from N 12° and it changes to N 101° in T3. Considering the circular concentration the first regime is more turbulent in T2 and T3. The second regime is more turbulent in T1 and T3 and more concentrated in T2. The third regime is very turbulent in all the periods.

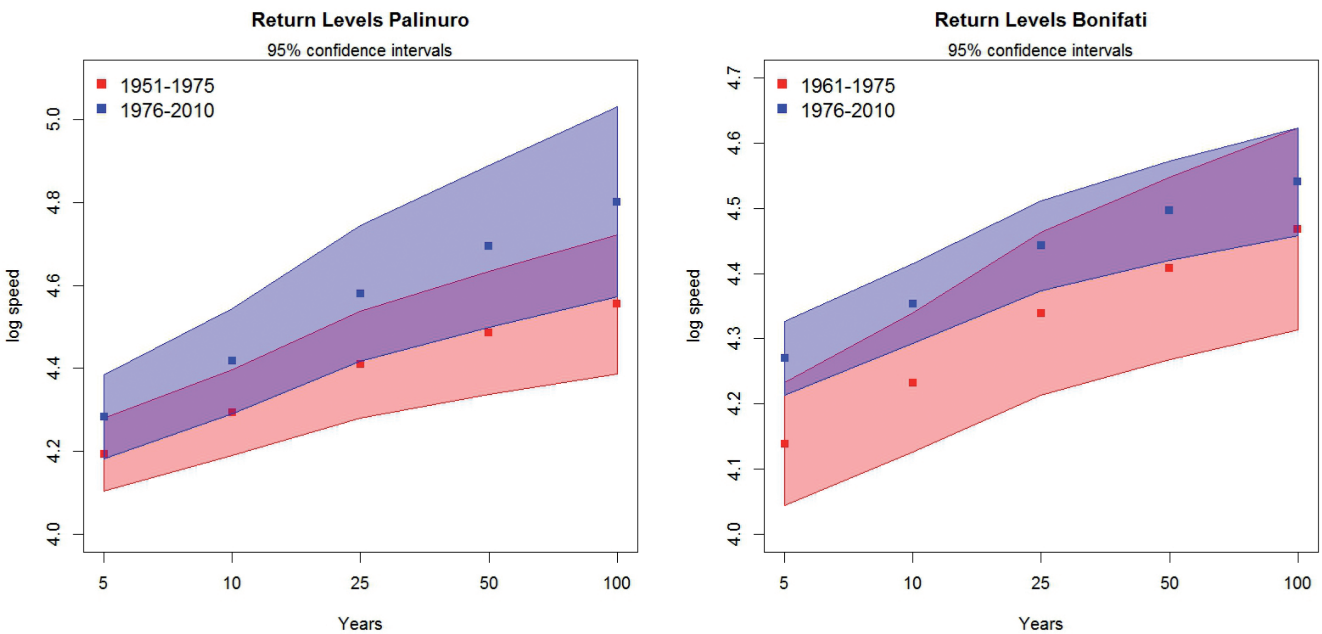

Fig. 6 - Permanent displacement maps: a) dry soil conditions; b) wet soil conditions

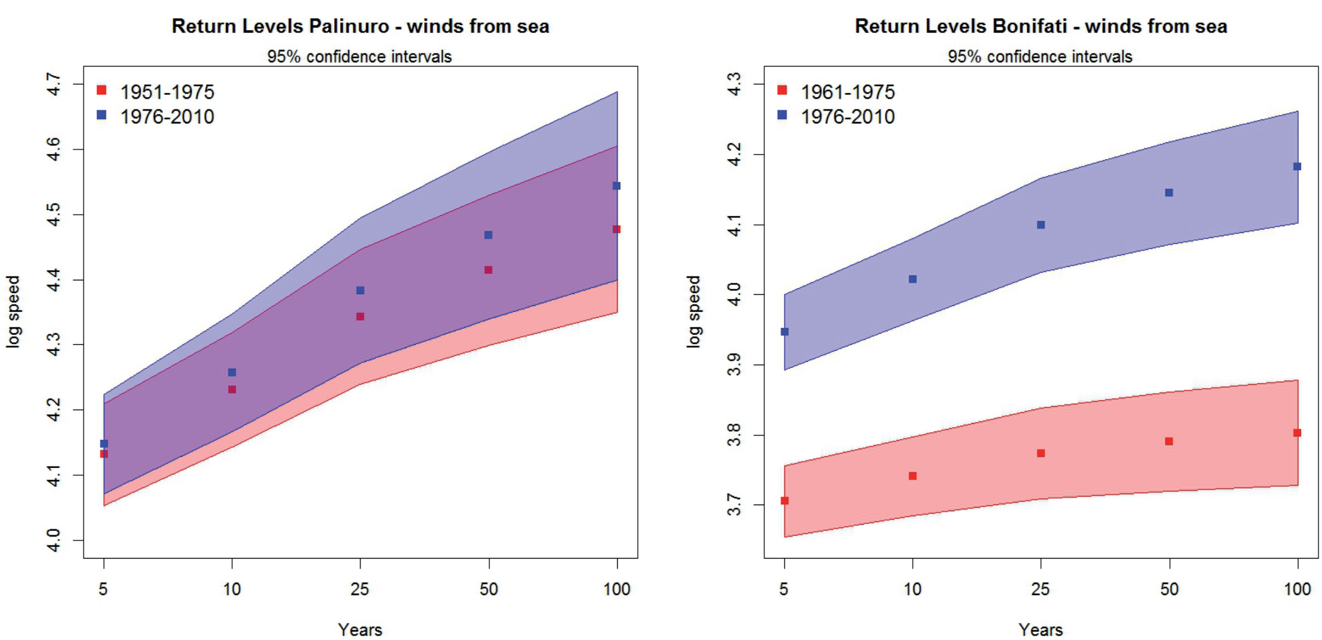

Fig. 7 - Return levels for the wind speed in logarithmic scale after 1975. The blue and red area are the confidence intervals for Palinuro and Bonifati respectively (95%)

In Tab. 9 and Tab. 10 it is possible to consult respectively the possibility to not have a circular value for a weak wind speed (ν) and the transition matrix. The Tab. 9 shows very low values and there is no need to comment further. In the transition matrix (Tab. 10), the first regime does not change its possibility to remain in its state in all the three periods, as for the possibility to pass in the second regime. On the contrary, the chance to pass from the first to the third regime increases in T2, to return on initial values in T3. The second regime shows a lower autotransition value in T2 and it increases again in T3. The probability to pass from the second to the third regime does not change in all the time intervals. The third regimes does not show any change in all the T.

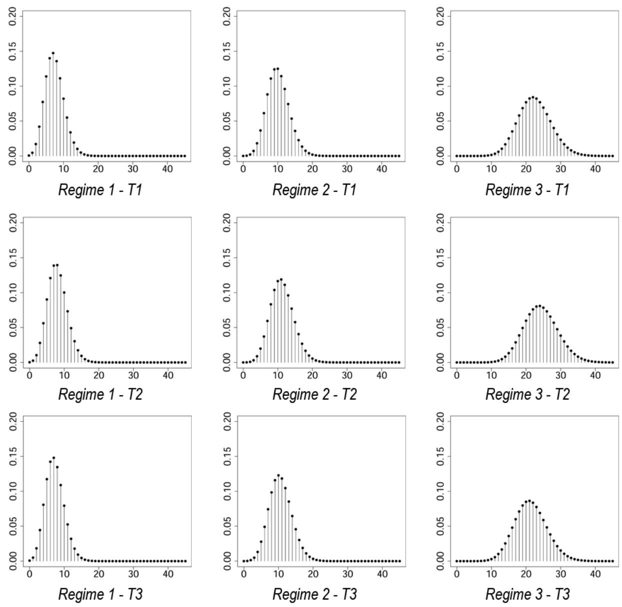

Fig. 8 - Capo Palinuro: mean wind speed density in the three periods T (rows) for the three regimes (columns)

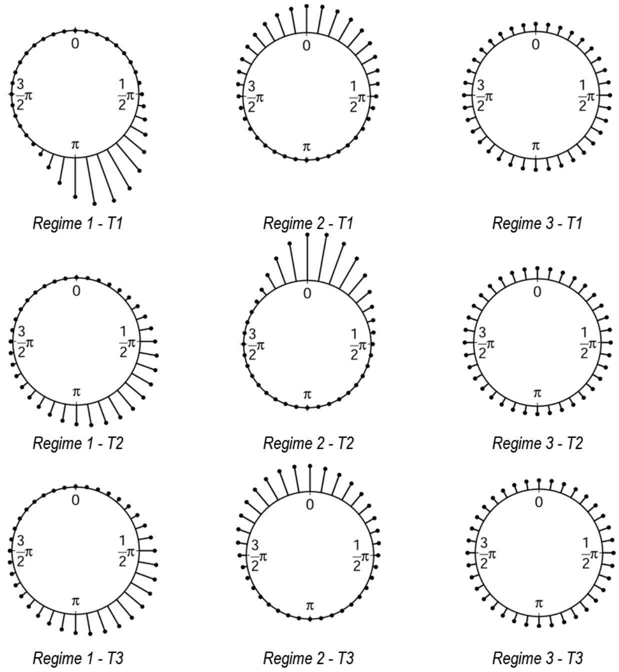

Fig. 9 - Capo Palinuro: mean wind direction density in the three periods T (rows) for the three regimes (columns)

CAPO PALINURO WIND SPEED MEAN VALUE			
	T1	**T2**	**T3**
$\hat{\lambda}_{y,1}$	1.998	2.084	1.985
CI	(1.967 2.027)	(2.056 2.111)	(1.945 2.023)
$\hat{\lambda}_{y,2}$	2.310	2.418	2.361
CI	(2.282 2.336)	(2.385 2.453)	(2.335 2.384)
$\hat{\lambda}_{y,3}$	3.112	3.188	3.059
CI	(3.090 3.136)	(3.166 3.211)	(3.033 3.087)

Tab. 6 - Capo Palinuro: estimate of the wind speed mean value with a confidence interval of 95%. Columns represent the different periods and rows the different regimes

CAPO PALINURO WIND DIRECTION MEAN VALUE			
	T1	**T2**	**T3**
$\hat{\mu}_{\theta,1}$	2.748	2.540	2.506
CI	(2.689 2.809)	(2.408 2.676)	(2.229 2.737)
$\hat{\mu}_{\theta,2}$	0.107	0.210	6.160
CI	(0.026 0.193)	(0.154 0.265)	(6.017 0.023)
$\hat{\mu}_{\theta,3}$	0.212	0.218	1.765
CI	(1.686 3.444)	(5.128 1.337)	(0.731 3.278)

Tab. 7 - Capo Palinuro: estimate of the wind direction mean value with a confidence interval of 95%. Columns represent the different periods and rows the different regimes

CAPO PALINURO CIRCULAR CONCENTRATION MEAN VALUE			
	T1	**T2**	**T3**
$\hat{c}_{\theta,1}$	0.896	0.637	0.629
CI	(0.878 0.912)	(0.629 0.644)	(0.616 0.641)
$\hat{c}_{\theta,2}$	0.699	0.886	0.680
CI	(0.686 0.704)	(0.867 0.903)	(0.671 0.688)
$\hat{c}_{\theta,3}$	0.137	0.090	0.082
CI	(0.042 0.243)	(0.014 0.162)	(0.014 0.144)

Tab. 8 - Capo Palinuro: estimate of the circular concentration mean value with a confidence interval of 95%. Columns represent the different periods and rows the different regimes

The same methodology was then used to analyze the time series of Bonifati station. As for the first case, the resulting regimes are three. In Fig. 10 and Fig. 11 are represented the mean wind speeds and the mean wind direction respectively. It is possible to spot an intensity increase for the third regime in T3, the opposite of what we observed for Capo Palinuro. In the direction plots it is possible to notice a clockwise rotation for first regime, from T1 to T3, changing its prevalent direction from South-West to West. Other changes are present in the second regime (from North-East to South-East) and the third one (from South-East to North East),

CAPO PALINURO ESTIMATE OF THE MEAN VALUE			
	T1	T2	T3
$\hat{\nu}_{\theta,1}$ CI	0.006 (0.002 0.011)	0.001 (0.000 0.003)	0.001 (0.000 0.004)
$\hat{\nu}_{\theta,2}$ CI	0.007 (0.004 0.012)	0.001 (0.000 0.003)	0.001 (0.000 0.005)
$\hat{\nu}_{\theta,3}$ CI	0.002 (0.000 0.006)	0.000 (0.000 0.002)	0.001 (0.000 0.005)

Tab. 9 - Capo Palinuro: estimate of the mean values and confidence intervals (95%) for the parameter

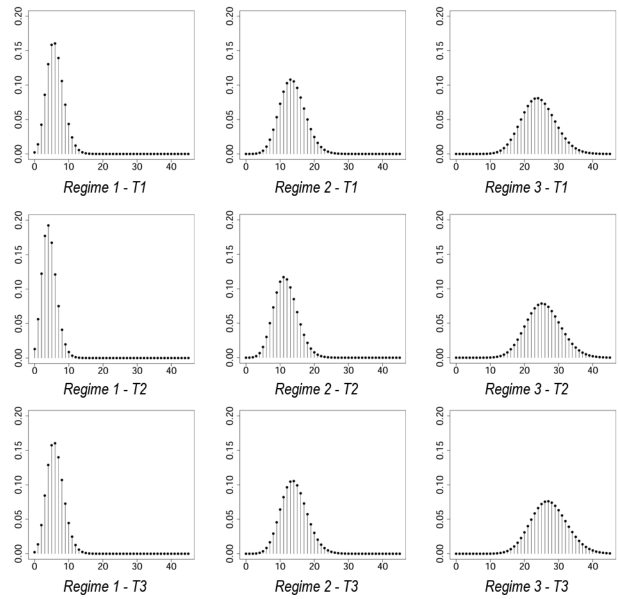

Fig. 10 - Bonifati: mean wind speed density in the three periods T (rows) for the three regimes (columns)

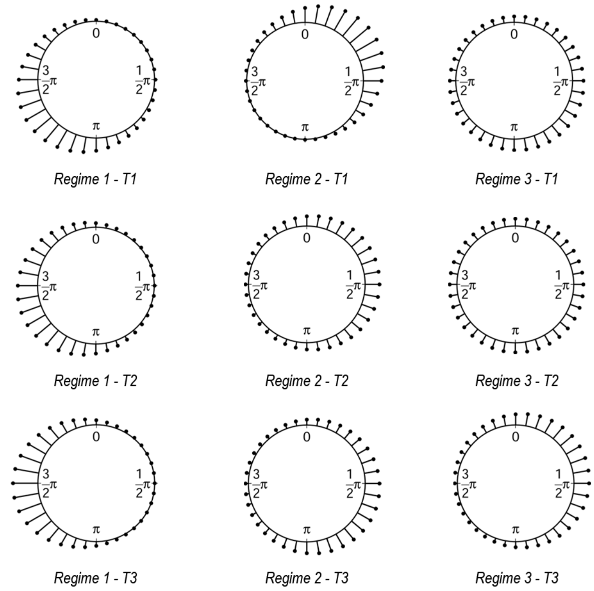

Fig. 11 - Bonifati: mean wind speed density in the three periods T (rows) for the three regimes (columns)

even if less noticeable.

To prove these changes, a confidence interval of 95% was used also in this case, as shown in Tab. 11, for mean speeds, and Tab. 12, for mean directions. The mean wind speeds of first and second regimes decreases in T2, to increase again (even further) in T3. The third regime shows a continuous increase from T1 to T3. Examining the mean directions, the first regime rotates for more than 30° from T1 to T3, changing its prevalent direction from N 236° to N 269°. The second regime rotates from N 45° to N 75° in T2. The third regime rotates from N 132° to N 66° between T1 and T3. In Tab. 13, the direction concentration does not show changes for the first regime. The second one increases its turbulence in T2. The third regime has a very low concentration in T1 and T2, with a value just a little higher in T3.

Even in this case, the possibility to not have a circular value for a weak wind speed (Tab. 14) shows no values and there is no need to comment.

In the transition matrix (Tab. 15), the first regime increase its autotransition in T2 and T3. In addition, the probability increases at the third regime increases, from T1 to T2, to return at the starting values in T3. The second regime decreases the autotransition from T1 to T2, but it increases a lot in T3. It also increases the probability to pass at the first regime in T2, to decrease again in T3. For the third regime, in T3, there is a decrease of the probability to pass at the first regime.

CAPO PALINURO TRANSITION MATRIX T1				CAPO PALINURO TRANSITION MATRIX T2				CAPO PALINURO TRANSITION MATRIX T3			
	1	2	3		1	2	3		1	2	3
1	0.639 (0.593 0.684)	0.313 (0.267 0.364)	0.047 (0.028 0.070)	1	0.579 (0.530 0.627)	0.327 (0.280 0.377)	0.094 (0.071 0.121)	1	0.730 (0.679 0.775)	0.236 (0.186 0.287)	0.034 (0.011 0.062)
2	0.209 (0.178 0.245)	0.626 (0.582 0.661)	0.166 (0.143 0.191)	2	0.333 (0.289 0.382)	0.508 (0.454 0.554)	0.159 (0.132 0.187)	2	0.134 (0.104 0.167)	0.712 (0.671 0.748)	0.153 (0.131 0.177)
3	0.062 (0.038 0.093)	0.369 (0.325 0.415)	0.568 (0.528 0.609)	3	0.096 (0.063 0.135)	0.365 (0.316 0.415)	0.538 (0.497 0.580)	3	0.021 (0.004 0.046)	0.405 (0.356 0.454)	0.573 (0.527 0.619)

Tab. 10 - Capo Palinuro: transition matrix with the estimate of the mean values and confidence intervals (95%) for the probability transition in the three different periods

BONIFATI WIND SPEED MEAN VALUE			
	T1	T2	T3
$\hat{\lambda}_{y,1}$ CI	1.805 (1.775 1.833)	1.470 (1.432 1.504)	1.810 (1.777 1.842)
$\hat{\lambda}_{y,2}$ CI	2.615 (2.577 2.650)	2.457 (2.422 2.489)	2.649 (2.594 2.696)
$\hat{\lambda}_{y,3}$ CI	3.185 (3.162 3.209)	3.245 (3.215 3.275)	3.305 (3.269 3.340)

Tab. 11 - Bonifati: estimate of the wind speed mean value with a confidence interval of 95%. Columns represent the different periods and rows the different regimes

BONIFATI WIND DIRECTION MEAN VALUE			
	T1	T2	T3
$\hat{\mu}_{\theta,1}$ CI	4.122 (3.967 4.279)	4.426 (4.264 4.590)	4.700 (4.537 4.848)
$\hat{\mu}_{\theta,2}$ CI	0.845 (0.680 1.018)	1.312 (1.096 1.542)	2.080 (0.962 2.607)
$\hat{\mu}_{\theta,3}$ CI	2.303 (1.928 2.749)	2.276 (0.224 4.130)	1.147 (0.744 1.818)

Tab. 12 - Bonifati: estimate of the wind direction mean value with a confidence interval of 95%. Columns represent the different periods and rows the different regimes

BONIFATI CIRCULAR CONCENTRATION MEAN VALUE			
	T1	T2	T3
$\hat{c}_{\theta,1}$ CI	0.638 (0.630 0.647)	0.601 (0.592 0.609)	0.698 (0.686 0.725)
$\hat{c}_{\theta,2}$ CI	0.692 (0.682 0.702)	0.351 (0.344 0.358)	0.410 (0.371 0.433)
$\hat{c}_{\theta,3}$ CI	0.235 (0.079 0.249)	0.094 (0.012 0.255)	0.416 (0.389 0.454)

Tab. 13 - Bonifati: estimate of the circular concentration mean value with a confidence interval of 95%. Columns represent the different periods and rows the different regimes

BONIFATI ESTIMATE OF THE MEAN VALUE			
	T1	T2	T3
$\hat{\nu}_{\theta,1}$ CI	0.051 (0.040 0.063)	0.168 (0.148 0.188)	0.021 (0.014 0.031)
$\hat{\nu}_{\theta,2}$ CI	0.001 (0.000 0.004)	0.001 (0.000 0.004)	0.002 (0.000 0.006)
$\hat{\nu}_{\theta,3}$ CI	0.001 (0.000 0.004)	0.001 (0.000 0.007)	0.002 (0.000 0.008)

Tab. 14 - Bonifati: estimate of the mean values and confidence intervals (95%) for the ν parameter

Wave Data analysis results

Depth of closure

From the calculations made on the wave data from the buoy of Cetraro (1999-2014, a period that almost coincides with the last decade examined), the significant wave height H_s is equal to 4.44 meters, with a significant period associated of 8 s. This is the H_s reached for no more than 12 hours per year. The depth of closure calculated is then 7.92 meters.

S.WA.N.

As shown in the Tab. 16, relative to offshore, the most frequent wave direction (17.5%) is from N 260°, with a peak in height of 8 meters. The tabs relative to the bathymetrics of -10 and -5 meters show a lower number of cases, because waves of more than 0.25 meters coming from offshore decrease their height near the coast, as a result of energy dissipation for interaction with the bottom and breaking. The waves that reach the coast with height less than 0.25 meters are recognized as calm cases and not considered by the model. Tab. 16 is relative to offshore from the selected point, using the wave data of Cetraro buoy. Tab. 17 and Tab. 18 are relative to the bathymetric of -10 and -5 meters respectively. In Tab. 18 the

BONIFATI TRANSITION MATRIX T1				BONIFATI TRANSITION MATRIX T2				BONIFATI TRANSITION MATRIX T3			
	1	2	3		1	2	3		1	2	3
1	0.712 (0.682 0.740)	0.225 (0.195 0.256)	0.063 (0.047 0.083)	1	0.756 (0.729 0.781)	0.220 (0.195 0.247)	0.024 (0.015 0.035)	1	0.793 (0.765 0.820)	0.167 (0.139 0.194)	0.040 (0.025 0.057)
2	0.281 (0.247 0.314)	0.572 (0.529 0.616)	0.147 (0.116 0.180)	2	0.232 (0.206 0.260)	0.618 (0.585 0.651)	0.149 (0.128 0.174)	2	0.230 (0.190 0.273)	0.567 (0.519 0.616)	0.202 (0.165 0.242)
3	0.085 (0.060 0.112)	0.231 (0.192 0.273)	0.685 (0.646 0.721)	3	0.051 (0.029 0.082)	0.488 (0.430 0.545)	0.460 (0.406 0.513)	3	0.105 (0.066 0.150)	0.424 (0.352 0.494)	0.469 (0.401 0.533)

Tab. 15 - Bonifati: transition matrix with the estimate of the mean values and confidence intervals (95%) for the probability transition in the three different periods

total %		0.7	1.0	0.9	1.0	1.3	2.0	1.6	0.8	0.6	0.6	0.4	0.4	0.7	0.3	0.4	0.4	0.4	0.9	1.7	2.5	2.5	1.7	2.0	2.8	5.5	13.1	17.5	13.0	9.2	5.6	3.4	2.2	0.9	0.8	1.0	0.2	100.0	
total		160	218	187	224	293	437	342	166	141	129	89	81	144	69	95	78	98	207	376	542	558	373	434	616	1210	2879	3846	2844	2016	1223	756	482	202	175	214	50	21954	100.0
Classes Hm0 (m)	8.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	1	0.0
	7.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1	0.0
	7.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0.0
	6.5	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-	1	-	4	0.0
	6.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1	0.0
	5.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	2	2	-	-	1	1	1	-	-	9	0.0
	5.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	3	-	-	-	-	-	-	1	-	-	7	0.0
	4.5	-	1	-	-	-	-	1	-	-	-	-	-	-	-	-	-	1	1	-	-	1	-	-	-	-	6	1	-	2	-	-	-	-	1	-	-	15	0.1
	4.0	2	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	2	-	1	-	1	3	6	13	8	6	3	4	2	-	2	-	-	-	54	0.2
	3.5	-	1	-	-	-	-	-	2	1	-	-	-	-	-	-	-	-	-	2	-	-	2	3	2	6	19	13	13	6	1	3	1	-	-	5	-	80	0.4
	3.0	1	-	1	-	1	-	-	1	1	1	1	-	-	-	-	-	-	1	3	3	4	8	6	7	21	37	22	23	9	6	2	3	-	1	10	-	173	0.8
	2.5	3	3	3	1	2	2	5	-	3	5	3	-	1	3	2	3	5	2	3	1	5	5	9	16	44	67	70	31	27	8	6	10	1	1	1	2	353	1.6
	2.0	3	6	1	2	4	-	3	2	-	3	3	1	1	2	2	1	3	2	4	4	6	9	21	26	78	144	172	91	62	20	15	10	5	3	5	2	716	3.3
	1.5	4	6	2	7	10	5	11	6	12	15	8	10	6	3	4	7	5	9	16	21	20	14	23	42	136	343	382	223	129	49	18	2	4	9	9	2	1572	7.2
	1.0	24	17	21	29	56	79	53	34	19	20	19	23	20	6	16	21	21	26	69	119	114	72	70	93	241	637	733	511	369	131	56	29	25	20	33	8	3834	17.5
	0.5	123	183	159	185	220	351	269	121	105	85	55	47	116	55	70	46	63	166	277	394	407	263	301	427	678	1608	2439	1944	1407	1002	654	426	164	138	150	36	15134	68.9
		0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350	total	total %
		Mean Direction Classes (deg N)																																					

Tab. 16 - Double entry dataset, with mean significant wave height (Hm0) and relative mean direction, representative of the sea state offshore of the selected point of the Belvedere Marittimo coast

total %		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	1.1	2.0	2.8	2.9	2.0	2.3	3.2	6.7	14.7	30.5	11.9	9.5	4.0	2.5	1.1	0.9	1.1	0.1	0.1	100.0	
total		0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	11	98	207	376	542	558	373	434	616	1288	2801	5821	2283	1825	756	482	202	175	214	17	23	19110	100.0
Classes Hm0 (m)	8.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0.0
	7.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0.0
	7.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0.0
	6.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	1	0.0
	6.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	-	-	-	-	-	-	2	0.0
	5.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-	-	-	-	2	0.0
	5.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	1	4	4	-	-	-	-	-	-	-	-	12	0.1
	4.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	-	1	-	-	-	-	-	-	-	-	-	7	0.0
	4.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	19	-	8	8	-	-	1	1	-	-	-	-	40	0.2
	3.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	2	25	-	13	3	4	-	-	-	1	1	-	-	51	0.3
	3.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	2	3	7	58	-	22	36	7	5	-	2	1	-	-	-	144	0.8
	2.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	4	-	4	8	6	16	44	67	101	-	15	2	4	-	1	-	-	-	273	1.4
	2.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	3	4	5	5	30	26	78	144	172	91	97	6	10	-	1	-	-	-	673	3.5
	1.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	7	4	6	23	23	42	136	343	382	223	198	15	10	6	1	15	-	1	1438	7.5
	1.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	8	11	16	140	134	72	70	93	241	637	733	511	500	74	31	4	12	6	5	1	3300	17.3
	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	11	89	192	346	394	407	263	301	427	678	1608	4383	1407	1002	654	426	189	158	192	12	21	13167	68.9
		0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350	total	total %
		Mean Direction Classes (deg N)																																					

Tab. 17 - Double entry dataset, with mean significantwave height (Hm0) and relative mean direction, representative of the sea state in the selected point of Belvedere Marittimo coast at the bathymetric of 10 meters

total %		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	1.0	2.0	2.2	2.9	2.0	2.3	3.3	6.8	14.8	30.7	12.0	9.6	4.0	2.4	1.1	0.9	1.1	0.1	0.1	100.0	
total		0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	11	95	198	376	423	558	373	434	616	1288	2801	5821	2283	1825	756	453	202	175	214	15	23	18948	100.0
Classes Hm0 (m)	8.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0.0
	7.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0.0
	7.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0.0
	6.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0.0
	6.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0.0
	5.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0.0
	5.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0.0
	4.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0.0
	4.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	1	-	-	-	-	-	-	-	3	0.0
	3.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	1	6	4	1	-	-	-	-	-	-	-	21	0.1
	3.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	4	5	44	-	21	24	4	2	1	1	2	1	-	-	111	0.6
	2.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	2	-	4	10	6	23	102	67	123	23	22	5	4	2	1	-	-	-	395	2.1
	2.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	5	4	5	14	30	26	78	144	172	91	117	6	10	-	-	-	-	1	704	3.7
	1.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	7	4	26	14	23	42	136	343	382	223	178	15	10	6	2	15	-	-	1427	7.5
	1.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	5	4	16	21	114	72	70	93	241	637	733	511	500	74	2	4	12	6	3	1	3120	16.5
	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	11	89	192	346	394	407	263	301	427	678	1608	4383	1407	1002	654	426	189	158	192	12	21	13167	69.5
		0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350	total	total %
		Mean Direction Classes (deg N)																																					

Tab. 18 - Double entry dataset, with mean significant wave height (Hm0) and relative mean direction, representative of the sea state in the selected point of Belvedere Marittimo coast at the bathymetric of 5 meters resulted prevalent direction offshore (West) increases is frequency, reaching 30.7% at N 260°, with a maximum height of 4 meters. Generally, the sea – defenses of the area were built with a height of 2 meters a.s.l. or less, and 6.4% of the waves reaching the coast are equal or above this limit. In Fig. 12 there is the propagation of the highest wave of the dataset (Hm0 = 8 meters with prevalent direction of N 260° and period of 13.5 s). It shows an area between Diamante and Capo Tirone with a wave height of almost 5 meters near the coast and with a height of more than 8 meters offshore, resulting in an increase of the height proceeding to the coast. This area is one of the most affected by erosional phenomena and presents defenses damaged by the violent winter storms.

Shoreline dynamics

A-B section

In A-B (Fig. 13) is present a strong erosion process from 1873 to 1955 for all the section, with an exception for the mouth of the Torrente Vallecupo, much wider to the end of the XIX century. This erosion crisis continued from 1955 to 2002 and the first breakwaters and groins were built in the southern portion to block the sediment transport longshore. In 2002-2006 interval, even with wide use of breakwaters, groins and seawalls the erosion was not stopped, although there are some points where there is stability and with little portion with sediment accumulation. In 2006-2015 interval, the retreat of the shoreline is less evident. Despite this, between the defenses are still present erosional phenomena. The breakwaters are nowadays badly damaged and there are no deposition forms (like "*tomboli*") between the breakwaters and the shoreline. The only exception are two spots with little beach cusps. In the southern portion of the A-B section, between the breakwaters, is present a small progradation of the beach.

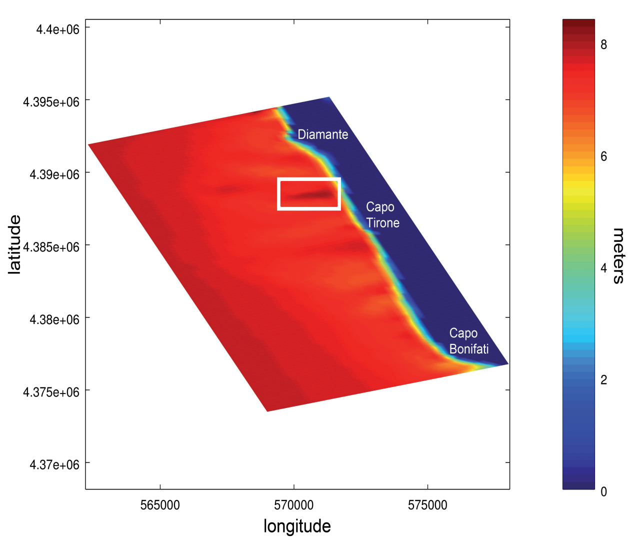

Fig. 12 - S.WA.N. simulation of the peak wave propagation (Hm0 = 8m; Dir = N 260°; Tp = 13.5) from open water to coast. The color gradient indicate the significant wave height in meters. In the ordinate and abscissa the metric coordinates (UTM). In the white box the area with higher wave energy

B-C section

In the section South to Capo Tirone, B-C (Fig. 14) the situation is different. In 1873-1955 interval there was strong erosion up to the mouth of Torrente Soleo. South to the mouth the beach was advancing. In the next interval, 1955-2002, along the northern portion where a port was built, the beach was advancing. The remaining portion of the section was interested by intense erosion phenomena, so that lots of breakwaters and seawalls were built. The next two intervals, 2002-2006 and 2006-2015, shows a more stable situation for all the B-C section. This is partly due to the wide use of sea defenses and strong urbanization of the area. There are only little spots of accumulation, but the erosion seems in part halted. However, this is not true for A-B section, where even if the erosion seems less intense, there are still eroded areas and absence of deposition forms despite the wide use of sea defenses.

Sedimentary budget

The results of the erosion and advancing areas for the entire section A-C with the Brunn rule (Walkden & Dickson, 2008) are presented in Tab. 19. In the first two intervals, that are 1873-1955 and 1955-2002 (for 129 years total), is present a strong erosional phenomenon with a total loss of material for 2 446 366.77 m^3. Only in the last two intervals (13 years) there is accumulation of sediment for 238 008.33 m^3, not sufficient to restore the initial conditions preceding 2002.

DISCUSSION

The coast of Belvedere Marittimo is by its very nature subject to erosion phenomena, as resulted from the reconstruction made with historical data and previous works (Bellotti *et alii*, 2009). The sea floor is steep due to the presence of coarse sand and gravel, classifying the beach as a reflective type, with plunging/surging breakers. In this case, the wave energy dissipate directly to the backshore. For all these reasons this type of coast is more vulnerable, with a wider run up that in the most violent winter storm was able to damage inland structures like roads, railways and inhabited areas.

The stations analyzed, Capo Palinuro and Bonifati, show a very low correlation between the two. A possible explanation could be the presence of a lag time between the records of the same wind event from one station to the other one, for the distance between the two stations (almost 72 km) and probably for the influence of the orographic conformation of the territory in such detailed scale. However, the symmetrical distribution of the wind speeds and the significant relation for higher speed suggest a relevant link. This could be explained with cases of intense cyclonic phenomena that affect the entire area. The proportionality test shows again a difference between the two stations. After the 1975, for Bonifati there is an increase of case numbers for all the speed classes, not the case of

Capo Palinuro. It is clear then how at this scale there are considerable differences even with few dozen km of distance, underlining the importance of local and more detailed studies.

The most important difference was noticed in the GEV analysis. Considering the wind from the fetch, for Bonifati station there is a substantial increase of the speed of the extreme events. The return level is in fact 10 knots higher in the first return period (5 years). This is very interesting, as the general trend in the Mediterranean shows a decrease, with some exceptions (Wang *et alii*, 2006; Benistom *et alii*,2007; Giorgi & Lionello, 2008; Lionello *et alii*, 2008).

The HMM model has made an important contribution, being able to analyze two different variables (circular and linear) and to manage the inflation of zeroes in time series, very frequent in this type of data (WASA Group, 1998; Matulla *et alii*, 2012, Calise, 2017). The results show again different trend changes for the two stations. For Capo Palinuro station, there are two period of less intense wind, in 1960-1969 and 2001-2010 decades. For Bonifati station there is a less intense period in the central decade, the 1979-1988. In addition, the last decade (2001-2010) shows an increase in wind speed, especially for the third regime (the fastest winds). Changes are visible also for directions, as in Capo Palinuro the second regime winds rotate to a NNW direction and in Bonifati the first regime winds (lesser speeds but more frequent) change the direction from SW to West, coming directly from offshore. The statistical analysis makes possible to state how there are statistically significant changes in wind trend, in particular for the last decade (2001-2010) of Bonifati station, the closest to the coastline studied.

With the few wave data at disposal (from 1999 to 2014) the depth of closure resulted equal to 7.92 m, a value that is greater of more than 1 m to the oldest value calculated in 2001 in a previous paper (Pranzini, 2004), equal to 6.39 m. This assumes that there is an increase of the significant wave height in 2001-2010, which coincides with what was observed for the winds.

Being the maximum height of the defense works on the coast equal to 2 m, it is important to note how, with the reconstruction made with S.WA.N., the 6.5% of waves reach and exceed that value (1234 cases on a total of 18948 cases). The most frequent direction is N 260°, the same of the maximum fetch of the area. The highest wave simulated at the 5 m bathymetric is equal to 4 m, almost the same of the calculated H_s (4.64 m). The simulation of the propagation of the highest wave of the set shows a particular area in the middle of the northern section, from Diamante to Capo Tirone, where there is an increase of the wave height proceeding to the coastline.

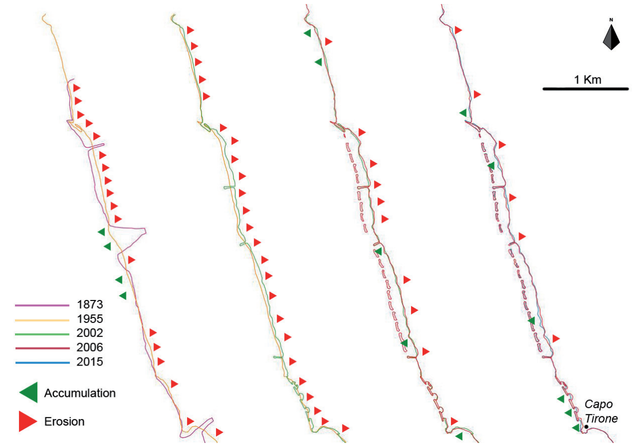

Fig. 13 - Shoreline of A-B section in years 1873, 1955, 2002, 2006 and 2015

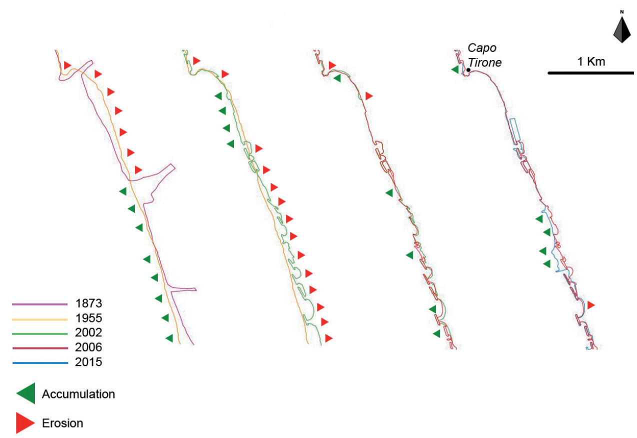

Fig. 14 - Shoreline of B-C section in years 1873, 1955, 2002, 2006 and 2015

From the shoreline analysis, it is clear how the area is subject to intense erosional crisis from the second half of 1800. This causes a considerable retreat of the beaches, especially in the northern section of the coast, from Diamante to Capo Tirone. The southern section seems stable, but this is due probably for the strong urbanization of the area (with also a port built in 2002), that transformed

YEAR INTERVALS	EROSION (in m^2)	ACCUMULATION (in m^2)	AREAS BALANCE (in m^2)	VOLUMES BALANCE (in m^3)
1873 -1955	210 149	65 308	144 841	925 533.99
1955 -2002	258 343	20 341	238 002	1 520 832.78
2002 -2006	29 163	31 455	2 292	146 45.88
2006 - 2015	28 414	63 369	34 955	223 362.45

Tab. 19 - Sedimentary budget tab. The values are in m^2 for areas and m^3 for volumes the beach in a beach-rock. The absence of accumulation forms like *tomboli* (despite the presence of the defenses for more than thirty years) shows of this structure are inadequate to protect the beaches and not able to contrast the winter storm waves.

From the calculation of the sediment budget, the values show an increment of sediment volumes after the 2002, even though with modest values. It is important to note also that sea defenses of any type almost completely cover this portion of the coast that was partially changed as a sort of rocky coast. The result of these interventions however is just a "freezing" of the situation, as the defense works resulted not able to guarantee a proper protection to the coast. It is also true that a natural accumulation of sediment near the breakwaters is completely absent, even after thirty years (in particular to the section North to Capo Tirone).

CONCLUSIONS

Erosion is a worldwide problem, affecting almost 70% of the beaches. In '50/60's lots of the sea defenses were built to try to prevent this phenomenon (Nordstrom, 2000). In Italy more than 50% of the beaches, in particular in Calabria, suffered a retreat of the shoreline. This region was object of lots of regional plans to try to counter this effect. In this paper, we decided to study a portion of the Tyrrhenian side of the Calabrian coast, between Diamante and Bonifati (CS), through the analysis of wind time series to find any relevant change in trend during the last fifty years. In fact, in this location many sea defenses were built since the '60s. However, these seem not to have produced a significant accumulation of sediments on the beaches.

The Cetraro buoy of R.O.N. and meteorological stations monitor this portion of shoreline, but for the lack of a sufficient long wave data time series (less than 10 years), we decided to focus the study on wind data (with more than 50 years of data) to try to correlate the erosional crisis with a possible change in the sea climate. Then we used wave data to confirm the results of previous tests.

It is very important in this study to consider the scale factor. Many works were made in the Mediterranean area, the Atlantic Ocean and the North Sea (Camuffo *et alii*, 2000; De Winter *et alii,* 2013; Giorgi & Lionello, 2008; Lionello *et alii*,2008; Matulla *et alii*, 2012; Pirazzoli & Tomasin, 2002; Pirazzoli & Tomasin, 2003; Pirazzoli *et alii*, 2009; Weisse *et alii*, 2012). However, there are very few of them dedicated to coast portions of a few tens of kilometers, as the case in this paper. We have shown, in fact, how in just a few dozen of km of distance there may be substantial differences in wind regimes, in some cases even the opposite for the two stations.

To underline this concept, it is interesting to note that for Bonifati station, the wind blowing from onshore resulted in countertendency with what observed in the Mediterranean in general, with a wind speed increase for the extreme events. The most relevant changes are concentrated in the last decade, 2001-2010. This is also confirmed in the analysis of the wave data, in the same decade, where is present an increment of the significant wave height and consequently of the depth of closure. This entails an expansion of the shoreface and the surf zone. In the northern portion of the area, between Diamante and Capo Tirone, the S.WA.N. simulation shows a spot with an increase of the wave height proceeding near the coast. The same area is the most affected by erosional processes, as resulted in the shoreline analysis.

It is then possible to state that there is a significant change in wind trend, especially in the last decade 2001-2010, that is also visible in wave data analysis. These changes seem to have an effect on the coast, with a retreat of the beaches only partially blocked by the defense works, unable to guarantee any form of sediment accumulation in more than 30 years.

The method used can be exported in case of:

1) a few miles of beach characterized by wave climate and microtidal regime;
2) absence or lack of wave data, but with anemometric data availability.

In conclusion, this analysis allows to reconstruct the possible fluctuation of the sea climate and, consequently, to give an indication of the best defense strategy for the coast.

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