# SUB-MESOSCALE WAVE HEIGHT RETURN LEVELS ON THE BASIS OF HINDCAST DATA: THE NORTH TYRRHENIAN SEA

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A 32-years wave re-analysis has been employed in order to develop an extreme value analysis for the whole Ligurian Sea (North Tyrrhenian Sea). Wave hindcast data have been obtained through numerical modelling implemented at DICCA, University of Genoa, covering the whole Mediterranean Sea. Model outputs for wave characteristics (wave height, period and direction of propagation) have been extracted on 30 virtual buoys displaced in the area covering the whole temporal domain (32-years) at hourly frequency in order to develop an exhaustive wave climate analysis. A non stationary model is presented and applied in wave climate assessment with the purpose of taking account for the effects of seasonality in providing return level estimates. Time-varying model employed proved to be versatile in modeling different wave fields largely diversified in such kind of area and wave hincast data apply well in order to perform waves statistical downscaling.

*Keywords: statistical downscaling; non-stationary models; hindcast data*

## INTRODUCTION

Recent advances in extreme values theory applied to sea and ocean wave data have been focused on wave hindcast data employment (Stephens and Gorman, 2006; Golshani et al., 2007; Breivik et al., 2009; Silva and Mendes, 2013; Sartini et al., 2014). This approach arises directly from the necessity of building a hindcast waves series of sufficient length to properly estimate average and extremes of wave climate.

Models hindcast data also overcomes possible issues given by the not correct functioning of buoys systems, such as lacking maintenance operations, problems in sensors calibration, data acquisition suspensions or time frequency differences. Numerical modelling employment allows to overcome these criticalities for long-term wave hindcast database development and provides the scientific and the engineering communities with reliable wave data for extended time periods. Hence the use of wave generation and propagation models (such as the third generation spectral models) is largely getting foothold with both forecast and hindcast purposes. Their application also fully meets the stringent requirement given by offshore and coastal engineering in having available high and medium resolution wave hindcast data taking into account of coastal morphology and bathymetry which can affect wave parameters used for maritime structures design within local areas and offshore regions. As a consequence, extension of high-resolution wave model integration to generate a hindcast archive covering decades at medium-high spatial resolution allows to perform a complete statistical analysis for wave climate evaluation in coastal areas.

The present work is based on the application of a third generation spectral model (WaveWatchIII) for the developement of a long hindcast simulation (1979-2010) in the Mediterranean Sea in order to develop an extensive wave climate statistical analysis on a sub-regional scale. The statistical wave climate analysis has been developed employing either stationary and time varying model for wave extreme values estimation. The paper briefly describes the hindcast numerical model and the data otained at first. Then, statistical models are introduced and results obtained for a large set of virtual-buoys displaced in the Ligurian (North-Tyrrhenian) Sea are discussed. Finally, some consideration for future developments are debated.

## WAVE CLIMATE ANALYSIS - HINDCAST SERIES 1979-2010

The present work comes downline of a previous project existing between the University of Genoa and the meteorologic Center belonging to the Regione Liguria, based on the development of a metocean modelling chain for wave forecast and re-analysis in the Ligurian Sea. More precisely, the last project phase had the specific purpose of assessing the complete wave climate of the area by means of a wave hindcast database. To this aim, 32 years of wave simulation covering the whole Mediterranean Sea have been provided through an optimized and validated metocean modelling chain active at the University of Genoa (Mentaschi et al., 2013a,b).

### Model and data

The hindcast database has been obtained forcing the wave generation model with a meteorological model. The wind forcing employed in the simulations has been provided by 10-m wind fields obtained using the non-hydrostatic mesoscale model WRF-ARW version 3.3.1 (Skamarock et al., 2008). A single

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computational domain has been defined for the WRF model, covering the whole Mediterranean with an almost 10 km grid resolution in latitude and longitude on a Lambert conformal grid. For the wave generation and propagation numerical modeling the third generation wave model Wave-WatchIII, version 3.14 (Tolman, 2009), has been implemented for the description in the Mediterranean basin on a regular grid with a resolution of 0.1273×0.09 degrees, corresponding to almost 10 km at the latitude of 45°N, and ETOPO1 data has been used for the interpolation on the computational grid of the bathymetry. Wave time series, then, have been extracted on 30 virtual buoys uniformly displaced across the Ligurian Sea (see figure 1a where are reported just a limited number of the virtual buoys); nomenclature and geographic coordinates of a selection of buoys are listed in table 1. Virtual buoys displacement has been assessed along the entire ligurian coast in order to take account for wave features variations due to both different meteorologic forcing and coastal morphology. In the framework of the above mentioned project a study about wave climate of the area in terms of inter-annual and seasonal variability of the main wave parameters has been developed (Besio et al., 2014); a new step in performing extreme wave analysis is here given trying to incorporate the effect of seasonality in return levels estimates.

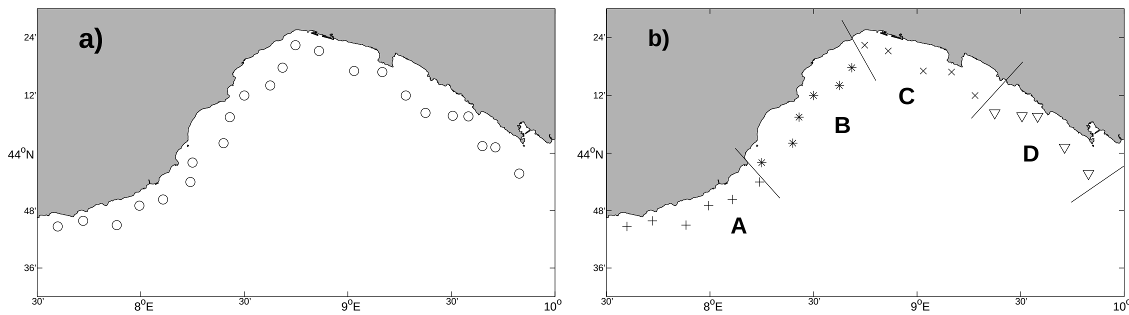


**Figure 1: a) spatial buoy-points distribution across the Ligurian Sea; b) definition of four main area along the Ligurian Sea.**

**Table 1: Buoy-points nomenclature and coordinates. Listed buoys are the ones subject to analysis in the present paper.**

| Virtual Buoy | Longitude [°E] | Latitude [°N] |
|---|---|---|
| Ventimiglia | 7.599118 | 43.745062 |
| Imperia | 7.993233 | 43.817641 |
| Laigueglia | 8.250000 | 43.967525 |
| Alassio | 8.246939 | 43.997583 |
| Savona | 8.625000 | 44.235000 |
| Varazze | 8.685000 | 44.296500 |
| Arenzano | 8.746762 | 44.374164 |
| Genova | 8.860727 | 44.354073 |
| Tigullio | 9.280000 | 44.200000 |
| Riva Trigoso | 9.375000 | 44.140000 |
| La Spezia | 9.877817 | 43.899734 |

Significant wave heights monthly maxima are here employed in a time-dependent version of a GEV model (Menéndez et al., 2009; Mínguez et al., 2010). Seasonal behavior is introduced using harmonics in order to model GEV parameters within a year:

$$\mu(t) = \beta_0 + \sum_{i=1}^{P_\mu} \left[\beta_{2i-1}\cos(i\omega t) + \beta_{2i}\sin(i\omega t)\right], \tag{1}$$

$$\psi(t) = \alpha_0 + \sum_{i=1}^{P_\psi} \left[\alpha_{2i-1}\cos(i\omega t) + \alpha_{2i}\sin(i\omega t)\right], \tag{2}$$

$$\xi(t) = \gamma_0 + \sum_{i=1}^{P_\xi} \left[ \gamma_{2i-1} \cos(i\omega t) + \gamma_{2i} \sin(i\omega t) \right], \tag{3}$$

where $\mu(t)$, $\psi(t)$ and $\xi(t)$ are respectively location, scale and shape parameters of GEV distribution, $\beta_0$, $\alpha_0$ and $\gamma_0$ are the coefficients relative to the stationary part while $\beta_i$, $\alpha_i$ and $\gamma_i$ are the perturbations amplitudes, $\omega = 2\pi T^{-1}$ is the angular frequency where $T$ represents the years number, $P_\mu$, $P_\psi$ and $P_\xi$ represent the number of sinusoidal harmonics in a year and $t$ is given in years. Harmonics are introduced up to the third order to model, respectively, the annual, the semi-annual and the quarterly cycle within a year of scale and location parameters, while cycles are arrested to the second order for shape parameters. Secular terms have been neglected, even if long-term significant wave height trends have been calculated using a linear regression applied on significant wave heights annual maxima (Figure 2) for each virtual buoys, so they can be easily incorporated into the model.

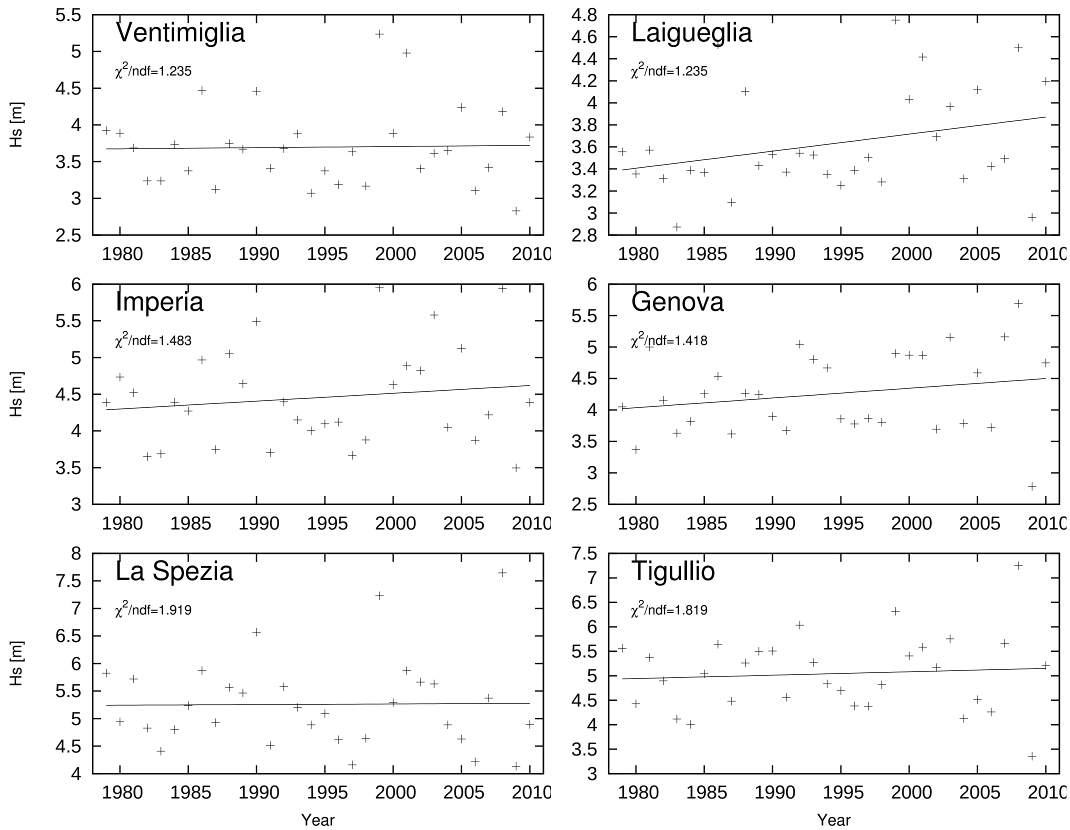


**Figure 2: Significant wave height trends for the buoy-points selected. The $\chi^2/ndf$ represents the $\chi^2$ per degrees of freedom ratio.**

For each monthly maxima observation sample occurring at a specific instant $t$, the maximum likelihood method is employed to estimate model parameters. Clearly, as a consequence, a large variety of models with different degrees of freedom, ranging from the simplest one corresponding to a homogeneous Gumbel distribution to the largest parameterization with five overall harmonics ($P_\mu = 3$, $P_\psi = 3$ and $P_\xi = 2$ ), is available in order to represent as best involved dataset.

The importance in introducing harmonics in order to model seasonal behavior could be synthetically appreciated in Figure 3, where the stepwise algorithm introduces one by one harmonics for the sample buoy Tigullio for a 20 years return period. Model selection has been performed using a step-wise algorithm minimizing the Akaike information criterion (Akaike, 1973).

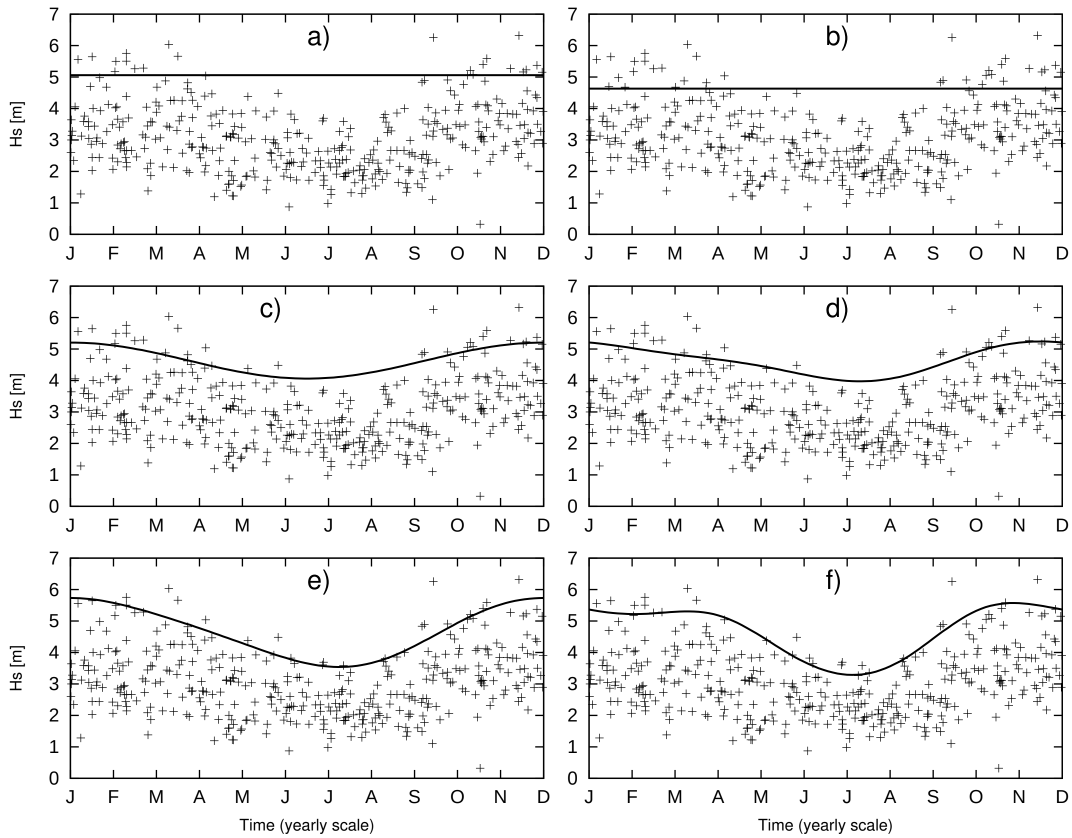


**Figure 3: Stepwise return levels for Tigullio buoy, omnidirectional seas. a) null shape parameter, number of total parameters: 2; b) non-null shape parameter, number of total parameters: 3; c) the annual cycle for location parameter, number of total parameters: 5; d) the semi-annual cycle for location parameter, number of total parameters: 7; e) the annual cycle for scale parameter, number of total parameters: 9; f) the semiannual cycle for scale parameter, number of total parameters: 11.**

## Results

The whole study has been focused on the complete statistical characterization of the area. More precisely, before performing the non-stationary extreme waves analysis, the following topics have been investigated for first:

- application of Rayleigh statistics in order to study annual and seasonal variability of the wave integrated parameters ($H_s$, $T_m$, $\theta_m$,...);
- study of probability density functions of the main wave parameters in function of both mean and peak direction;
- study of joined probability of occurrence for the pairs significant wave height/peak period and significant wave height/mean direction.

Analysis of results reveals a marked tendency of the wave fields to pattern aggregation (Figure 1b). A first overview points out to four different wave patterns whose features mainly depend on both the different local meteorological perturbation regimes pertaining to the area and, thus, on the offshore wave exposure conditions, and the available wind fetch. More precisely, a first area identified by the western virtual buoys up to Laigueglia location reveals a good exposure to South-West long-fetch winds while the short-fetch ones have a limited effect (area A). A good opening to the South and South-East winds is also shown. The second neighboring area includes points up to Savona buoy and comes to be the meanly less exposed to offshore waves generated both from the South-West, South and South-East winds (area B). This feature is probably due to both the coastal positioning, particularly sheltered from the South-West and South winds, and the limited wind fetches extension, even though the South-East sector should be the most exposed in the area. Third sector limited by Arenzano and Tigullio buoys is the northerest of the Ligurian coast and shows a significant exposure to the South-West events, corresponding to the dominant and prevalent sector, and also a good contribution given by the South (with fetch shorter than the South-West ones) and South-East (with fetches such enough extended but with limited effects due to the coastal morphology) seas (area C). Finally, the last eastern area is characterized by a large exposure to both the long and short-fetch South-West winds, with marked seasonal variability (area D). South-East events are practically negligible due to the coastal morphology and the very limited fetches.

A marked seasonality is observed for all the integrate wave quantities; in particular the intra-annual assessment of monthly significant wave heights can be appreciated in Figure 4 for a selection of buoy-points displaced on the whole area.

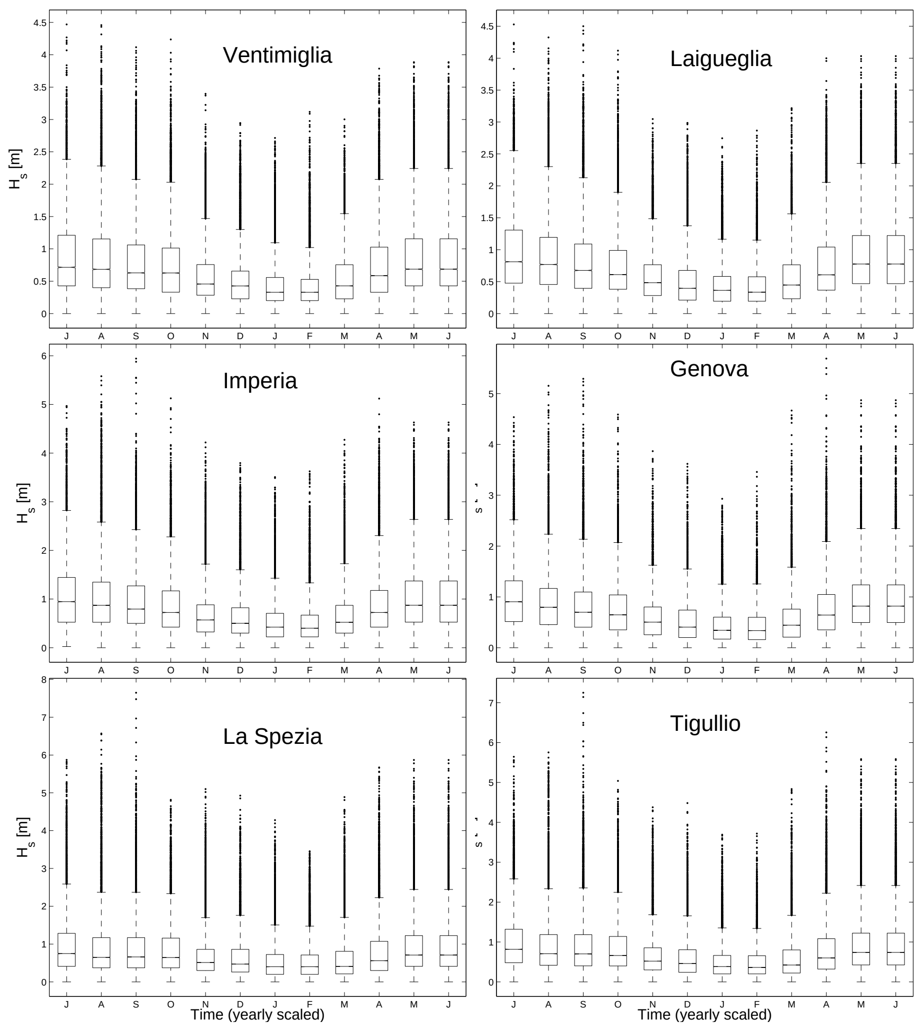


**Figure 4: Box plots of month-type significant wave heights for Ventimiglia, Laigueglia, Imperia, Genova, La Spezia and Tigullio buoys. Box limits represent respectively first and third quartile, while the line identifies the median. Dashed lines represent values smaller and greater respectively than the first and third quartile; exceeding points represent outliers.**

| | Ventimiglia | Laigueglia | Imperia | Genova | La Spezia | Tigullio |
|---|---|---|---|---|---|---|
| $\beta_0[m]$ | 2.34 | 2.26 | 2.67 | 2.21 | 2.79 | 2.66 |
| | (0.02) | (0.02) | (0.03) | (0.03) | (0.05) | (0.04) |
| $\beta_1$ | 0.49 | 0.53 | – | 0.42 | 0.49 | 0.57 |
| | (0.03) | (0.03) | | (0.04) | (0.06) | (0.06) |
| $\beta_2$ | 0.18 | 0.12 | – | 0.08 | 0.10 | 0.08 |
| | (0.03) | (0.04) | | (0.04) | (0.07) | (0.06) |
| $\beta_3$ | – | – | – | – | – | 0.01 |
| | | | | (–) | | (0.0) |
| $\beta_4$ | – | – | – | – | – | −0.14 |
| | | | | (–) | | (0.06) |
| $\beta_5$ | – | – | – | – | – | – |
| $\beta_6$ | – | – | – | – | – | – |
| $\alpha_0[m]$ | 0.74 | 0.74 | 0.41 | 0.52 | 0.10 | 0.21 |
| | (0.05) | (0.04) | (0.05) | (0.03) | (0.05) | (0.04) |
| $\alpha_1$ | 0.22 | 0.17 | 0.12 | – | 0.26 | 0.23 |
| | (0.05) | (0.05) | (0.05) | | (0.05) | (0.05) |
| $\alpha_2$ | −0.03 | −0.01 | −0.01 | – | 0.10 | 0.08 |
| | (0.03) | (0.05) | (−0.05) | | (0.05) | (0.05) |
| $\alpha_3$ | – | −0.09 | – | – | −0.07 | −0.15 |
| | | (0.05) | | | (0.05) | (0.05) |
| $\alpha_4$ | – | −0.04 | – | – | −0.06 | −0.09 |
| | | (0.05) | | | (0.03) | (0.05) |
| $\alpha_5$ | – | −0.12 | – | – | – | – |
| | | (0.05 | | | | |
| $\alpha_6$ | – | −0.01 | – | – | – | – |
| | | (0.05 | | | | |
| $\gamma_0[m]$ | −0.17 | −0.16 | −0.02 | −0.01 | −0.18 | −0.13 |
| | (0.03) | (0.03) | (0.03) | (0.04) | (0.03) | (0.03) |
| $\gamma_1$ | – | – | – | – | – | – |
| $\gamma_2$ | – | – | – | – | – | – |
| $\gamma_3$ | – | – | – | – | – | – |
| $\gamma_4$ | – | – | – | – | – | – |
| $l$ | −282.50 | −281.88 | −407.54 | −412.56 | −526.16 | −497.52 |
| $p$ | 7 | 11 | 5 | 5 | 9 | 11 |
| $AIC$ | 535.0 | 519.7 | 785.1 | 801.1 | 250.7 | 1.022 |

**Table 2: Summary of harmonics parameter estimates and models AIC criterion for all the virtual buoy-points, omnidirectional seas.**

Extreme waves analysis performed on both the omnidirectional and dominant seas, defined as the most energetic sector on the basis of a 22.5° angle-bin, well retrace previous considerations, adding also further evaluations about the seasonality behavior shown by the different virtual buoys by means of the non-stationary GEV model employment. More precisely, the effect of seasonality in providing return levels estimates partly validates waves patterns arrangement observed; virtual buoys show different seasonal levels, expressed in term of involved model parameters, in function of pertaining area. In figure 5 significant wave heights return levels in function of defined return periods for such selection of points (Ventimiglia and Laigueglia represent the two far ends of the first sector, Imperia belongs to the second one, Genova to the third and Tigullio and La Spezia lie into the fourth one) displaced across the whole area are provided. Control parameters of each model selected are reported in table 2. Results reveal upper middle seasonal level, expressed in terms of number of involved parameters equal or higher than 6, on the 0÷11 observed scale, for both the far ends points of the area, especially for the eastern ones, while lower values are reached for points belonging to the second area. It is not possible to appreciate seasonality effects as well for Genova location probably since cycles found by means of best model chosen affect only the location parameter, while the scale one keeps constant (figure 6, panel a and b). It's also due to underline that non-stationary GEV model seems to be unable to represent at best seasonal level observed for La Spezia buoy (which reaches up to 9 parameters, table 2); underestimated return levels with respect to the expected one (Sartini et al., 2014) are here provided.

This behavior remark a critical issue largely discussed in literature (Coles, 2001; Castillo et al., 2004; Méndez et al., 2006; Holthuijsen, 2007; Thompson et al., 2009; Mazas and Hamm, 2011) in using identical-distributed maxima in extreme values analysis; in this specific case the model is not versatile enough to

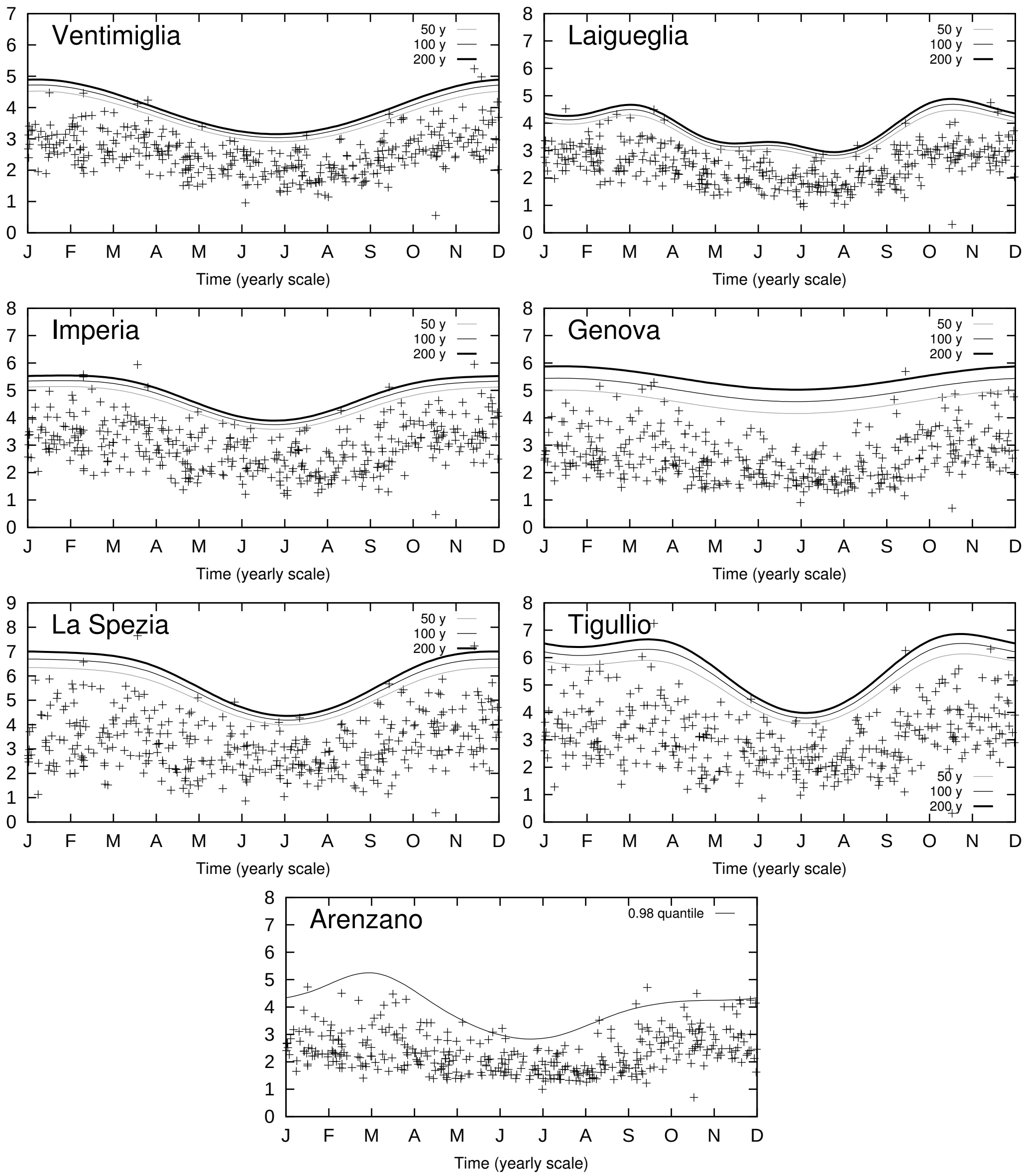


**Figure 5: 50, 100 and 200 years return levels for Ventimiglia, Laigueglia, Imperia, Genova, La Spezia and Tigullio buoys, omidirectional seas. + symbols indicate significant wave heights monthly maxima.**

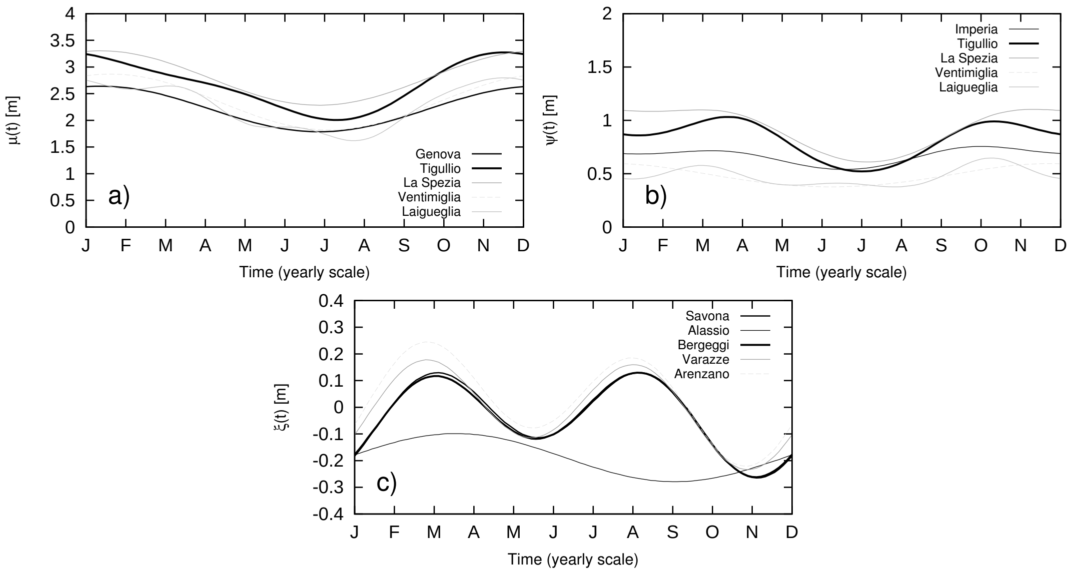


**Figure 6: Intra-annual variability of models parameters ((a) location parameter, b) scale parameter and c) shape parameter).**

model higher sea waves and the adoption of significant wave heights monthly maxima causes remarkable changes in significant wave heights cumulative distribution. The adoption of a Peak Over Threshold (POT) model could overcome the flaw given by identical-distributed maxima models in modelling higher sea storms.

Nevertheless virtual buoys belonging to the west-middle area exhibit lower seasonal levels as expected on the basis of previous areas clustering, an interesting feature is given by the shape parameter behavior; while it is not common in the Mediterranean Sea to find cycle for shape parameters (Montagna, 2011), and this is the reason why in the present work two harmonics have been considered enough in representing annual variability, shape cycles are here strikingly present for a limited number of virtual buoys mainly belonging to the less-exposed area (figure 6, panel c). In particular, it is clear a range from different types of tail distribution, expressed by the shape parameter turning from negative to positive and conversely, for all the location, with the exception of Savona buoy where a net Weibull tail is detected ($\xi < 0$ for Weibull distribution). Even if buoys belonging to this coastal area have shown minor seasonal levels expressed in terms of number of involved parameters detected, effects induced by shape parameter harmonics are marked in providing return level estimates (see for example levels for Arenzano buoy, figure 5, for a 20 year return level). For sake of completeness, traditional annual return level estimates are provided in order to evaluate the total envelope given by intra-annual contributions (Figure 7). 95% confidence levels are estimated through the delta method (Rice, 1994).

Analysis has been also extended to the dominant sea; the main sector of incoming offshore waves is automatically detected by the algorithm, opening a 45° angle fixed on. In table 3 all the parameters related to the best models selected in the case of dominant seas are reported; direct comparison with omnidirectional results reveals higher seasonal levels, expressed in terms of number of involved parameters, for La Spezia location (11 parameters), with a little peer trade-off in reduced level for Tigullio buoy (9 parameters). This specific pattern seems to be more realistic, in line with East coast assessment and with the assumption of increasing seasonal values moving toward the eastern far end. Clearly, the effects of seasonality induced by short and long fetches south-west meteorological forcing is better detected incorporating directional seas in the time-varying model. Even though central sector of the area should provide intermediate levels, extension of analysis to the directional seas seems to be able to gather the specific assessment of both full-regime South-West and South-East seas which sometimes occur in the area during the year. This is the specific case of La Spezia location, whose intra-annual return level distribution (figure 8) better reflects

| | Ventimiglia | Laigueglia | Imperia | Genova | La Spezia | Tigullio |
|---|---|---|---|---|---|---|
| Sector | 175.5 ÷ 220.5 | 175.5 ÷ 220.5 | 175.5 ÷ 220.5 | 157.5 ÷ 202.5 | 210.7 ÷ 255.7 | 211.5 ÷ 256.5 |
| $\beta_0[m]$ | 1.83 | 1.18 | 2.61 | 2.65 | 2.70 | 2.97 |
| | (0.03) | (0.04) | (0.04) | (0.03) | (0.06) | (0.05) |
| $\beta_1$ | 0.28 | 0.27 | – | 0.30 | 0.48 | 0.47 |
| | (0.05) | (0.05) | | (0.04) | (0.07) | (0.07) |
| $\beta_2$ | −0.05 | −0.25 | – | −0.11 | 0.15 | 0.13 |
| | (0.04) | (0.05) | | (0.04) | (0.08) | (0.07) |
| $\beta_3$ | – | – | – | −0.05 | – | – |
| | | | | (0.04) | | |
| $\beta_4$ | – | – | – | −0.06 | – | – |
| | | | | (0.04) | | |
| $\beta_5$ | – | – | – | – | – | – |
| $\beta_6$ | – | – | – | – | – | – |
| $\alpha_0[m]$ | 0.41 | 0.38 | 0.29 | 0.62 | 0.77 | 1.21 |
| | (0.03) | (0.05) | (0.03) | (0.05) | (0.04) | (0.05) |
| $\alpha_1$ | – | 0.15 | 0.14 | 0.17 | 0.25 | 0.27 |
| | | (0.05) | (0.05) | (0.05) | (0.04) | (0.04) |
| $\alpha_2$ | – | −0.14 | −0.01 | −0.14 | 0.07 | 0.09 |
| | | (0.04) | (−0.03) | (0.05) | (0.05) | (0.04) |
| $\alpha_3$ | – | −0.02 | – | −0.19 | −0.14 | −0.13 |
| | | (0.05) | | (0.05) | (0.05) | (0.05) |
| $\alpha_4$ | – | 0.13 | – | 0.01 | −0.07 | −0.09 |
| | | (0.05) | | (0.04) | (0.04) | (0.05) |
| $\alpha_5$ | – | – | – | – | 0.06 | – |
| | | () | | | (0.03) | |
| $\alpha_6$ | – | – | – | – | 0.07 | – |
| | | () | | | (0.03) | |
| $\gamma_0[m]$ | −0.27 | −0.21 | −0.02 | −0.07 | −0.19 | −0.18 |
| | (0.03) | (0.04) | (0.03) | (0.03) | (0.03) | (0.03) |
| $\gamma_1$ | – | – | – | – | – | – |
| $\gamma_2$ | – | – | – | – | – | – |
| $\gamma_3$ | – | – | – | – | – | – |
| $\gamma_4$ | – | – | – | – | – | – |
| $l$ | −382.45 | −413.14 | −435.62 | −349.583 | −558.48 | −549.27 |
| $p$ | 5 | 9 | 5 | 11 | 11 | 9 |
| $AIC$ | 750.91 | 800.28 | 843.2 | 675.16 | 1.089 | 1.074 |

**Table 3: Summary of harmonics parameter estimates and models AIC criterion for all the virtual buoy-points, directional seas.**

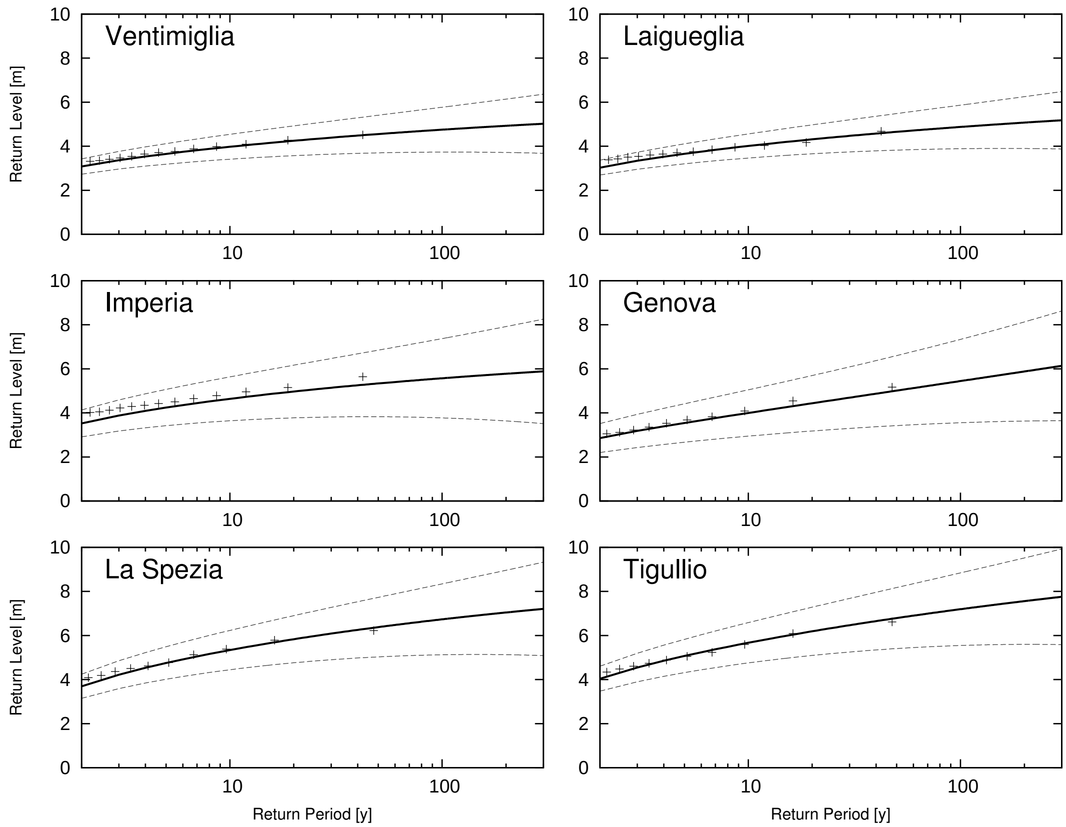


**Figure 7: Return levels for Ventimiglia, Laigueglia, Imperia, Genova, La Spezia and Tigullio buoys, omidirectional seas.**

higher seasonal levels pertaining of the area than omnidirectional results provided. None enough marked different swing is registered instead for Tigullio buoys, since model selected provides scale harmonic cycles set-up very close to the omnidirectional ones. Opening sector is wide enough to collect both the effects; time-dependent model such configured provides higher seasonal level for Genova location (11 parameters), while on average intermediate levels (5-7 parameters) are registered during the yearly average assessment. Clearly, this tendency reflects upon the intra-annual return levels distribution, which comply with maxima aggregation (figure 8, Genova ).

The opposite behavior, instead, is observed in the western side of the coast; time-varying model extended to the directional seas reveals minor levels for the western location Ventimiglia (5 parameters) while higher ones are found for Laigueglia buoy (9 parameters), which is located at the joining of the first western area and the less energetic stable second one. This behavior can be explained with a not enough wide sector on the dominant direction for Ventimiglia buoy, which includes partially southern events; joint action of South-East and South winds probably plays a key role for locations sited in this part of the area. These effects translate in similar but more platicurtic intra-annual distribution (Figure 8, Ventimiglia). In the specific case of Laigueglia buoy, instead, coastal morphology probably induces significant effects of wave field; as a consequence of buoys positioning near a cape, wave field feels the zonal effects raising from the encountering of South-West and South-East winds strengthen by shading and refraction phenomena induced by the coastal assessment, with upper middle seasonal behavior. As a consequence, intra-annual return levels exhibit a completely different trend with respect to the omnidirectional one (figure 8, Laigueglia), since analysis is led on a South-West centered sector, while, as supposed, South-East winds plays a key role as well. Results remark similar trend for Imperia location (figure 8), and, more in general, for locations sited in the second area, strengthening thus zonal stabilizing effects played by this tract of west coastline.

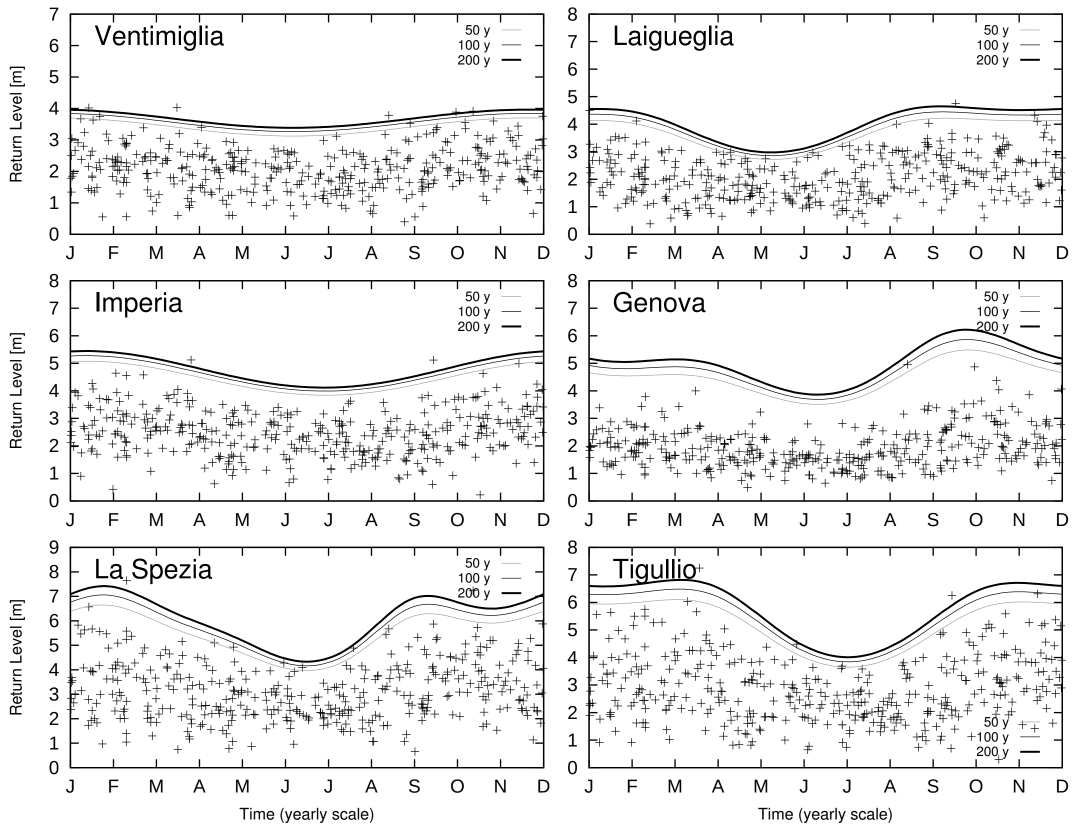


**Figure 8: 50, 100 and 200 years return levels for Ventimiglia, Laigueglia, Imperia, Genova, La Spezia and Tigullio buoys, directional seas. + symbols indicate significant wave heights monthly maxima.**

Annual results reveal also, as expected, on average higher values in the log-likelihood function; higher confidence levels in providing return levels estimates are particularly noticeable for the western and central buoys (figure 9). As expected, analysis extended to directional seas provides also higher return levels, with the exception of Ventimiglia buoy (figure 9), where the just supposed requirement in opening mainly sector to the south events finds here further proof.

## CONCLUSIONS

Wave climate in the Ligurian Sea has been defined by means of a non-stationary GEV model. To this aim, 32 year of hourly wave hindcast data representing 30 virtual buoys equally displaced in the study area have been employed. Analysis of results obtained in performing extreme wave analysis has revealed that wave features are affected by a significant seasonality mainly due to the weather perturbation regimes occurring in the area during different seasons. Furthermore, some virtual buoys experience less seasonal variability due to shading and refraction effects triggered by the morphology of the Western Ligurian coastline under South-West sea storms. Upper middle seasonal levels are reached in the central part of the gulf basically due to the higher storms induced by simultaneous conditions of live sea generated by both the events coming from the South-East and South-West waves. The highest seasonality behavior is noticed at both the far ends of the gulf, with major emphasis on eastern locations, probably due to the join effects given by the coastal morphology and the marked seasonality typical of the long-fetch and short-fetch South-West meteorological forcing standing on the areas. Thus, time-dependent GEV model proved to be quite versatile in modelling different wave conditions and the non-stationary configuration has been successful in representing different seasonality levels.

The present work open also the way to ongoing in-depth analysis, with the purpose of comparing results

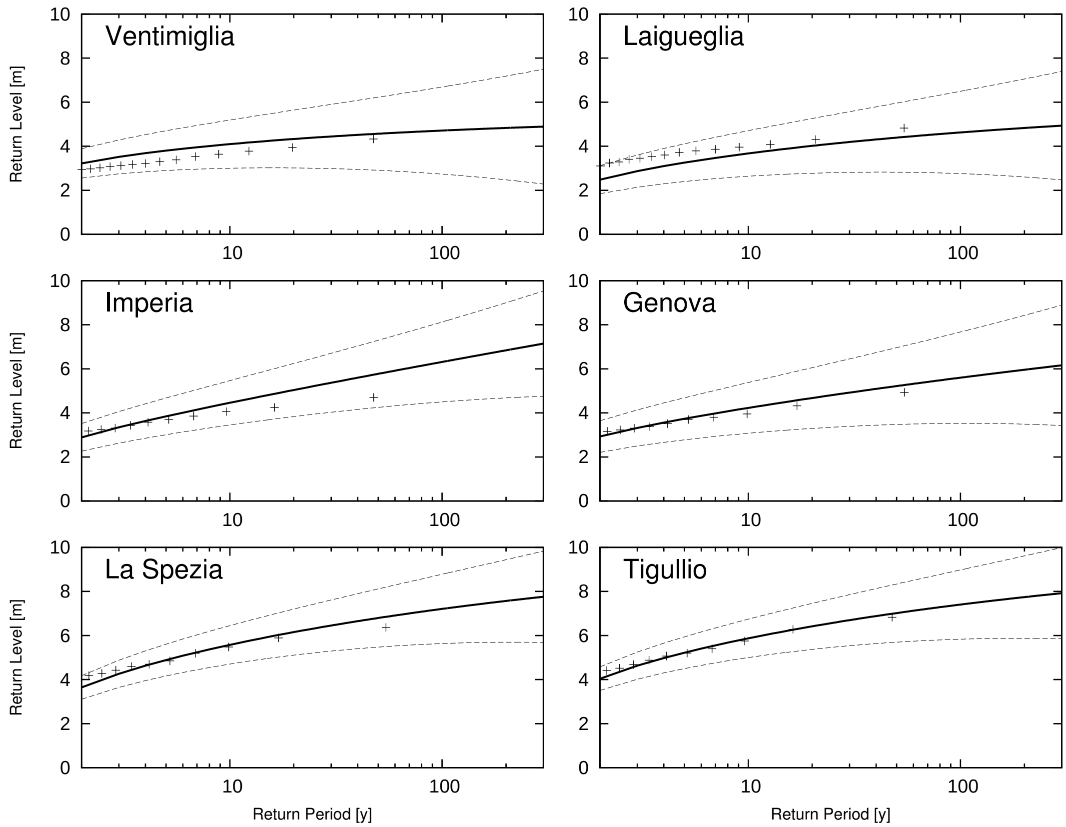


**Figure 9: Return levels for Ventimiglia, Laigueglia, Imperia, Genova, La Spezia and Tigullio buoys, directional seas.**

provided by statistical and dynamical downscaling performed by means of suitable numerical models able to detect as best coastal processes.

**ACKNOWLEDGEMENTS**

L. Sartini has been funded through European Project PO CROFSE 2007/13.

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