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# New Approaches for Multi Source Data Sediment Characterisation, Thickness Assessment and Clean up Strategies

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The present article explain how potentially contaminated sediment thickness in Augusta harbour was estimated by using a multisource dataset characterized by a variable accuracy. Inequalities constrains on the sediment thickness are extracted from the sediment sampling stations and seismic profiles in which the hard irregular sub-bottom was out of detection range (soft data). It utilized the kriging-with-inequalities method that belongs to the data transformation group. The method considers the inequalities constraints as data themselves and, after a transformation, their use together with the exact hard data to estimate the thickness of the sediment layer. The results show the usefulness of an approach that permitted to extract the maximum information from multisource data, collected for different purposes, in order to assess the 3D spatial domain of recent contaminated sediment and reduce the cost of management.

## 1. Introduction

Remediation of contaminated sediments is a theme, increasingly addressed by the scientific community (Goovaerts, 1999 and references within), especially in harbour areas. The environmental characterization of marine sediments is very useful for the definition of proper remediation strategies (Guerra-Garcia and Garcia-Gomez, 2005). In environmentally polluted marine areas, like the Augusta Harbour (NE Sicily, Italy), the quantitative assessment of potentially contaminated sediment is becoming a challenging scientific issue (Cappucci et al., 2011). Different methodological approaches can be applied to investigate the sedimentary thickness and the geometry of different boundaries layers. They greatly differ in precision and productivity and no one can be considered exhaustive. In this context, the main goal in the environmental characterization of a polluted marine site is to obtain a good knowledge of the chemical and physical characteristics of sediments in three dimensions (Raspa et al., 2008; Langlais, 1990; Chilès and Delfiner, 1999). An important task arises with the aim of assessing the layer thickness in the domain boundaries, where a hard irregular sub-bottom is overlapped by a sediment layer (Emery, 2007). In environmental monitoring and management this layer is the main basis for sedimentary processes and pollutants concentration.

## 2. Study area

The Augusta Harbour is a natural bay that is 8 km long and 4 km wide. It is located in the Augusta Gulf on the eastern coast of Sicily Island in southern Italy (Figure 1). It is delimited in the northern sector by

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the town of Augusta and closed to the south and east by artificial dams that were built in the early ‘60s. The Cantera and Marcellino Rivers drain into the Harbour with seasonal and discontinuous freshwater inflow (Lisi et al., 2009). The Harbor is about 22,700,000 $m^2$, and the average water depth is about 15 m. Water exchange takes place mainly across the eastern and southern inlets. The first one is the main entrance, at about a 40 m depth. Within the Augusta Harbour, many dredging operations have been carried out from 50’s to 2000. The seafloor, characterized by silty-sandy sediments, is deepening offshore and does not present any sedimentary structure created by natural hydrodynamic forces. The Meso-Cenozoic substrate belongs to the Hyblean plateau outcrop in the mainland. Along the coast, the Pliocene clays and Quaternary biocalcarenites represent the main feeders for marine sand in the Augusta Harbour (Amore et al., 1992). This sequence determined an outcropping of rocky substrate in different sites of the Augusta Harbour area. The superficial sediments are mainly silt and poorly sorted. Extensive tectonic activity has faulted the Cretaceous carbonatic substratum, creating a semi-graben structure.

The harbour is strongly polluted, mainly due to past and/or active petrochemical activities in the area, and sediments have very high concentration, at varying depth, of mercury (Hg), Hydrocarbons, Hexachlorobenzene (HCB), Polychlorobyphenils (PCB), dioxins and furans (PCDD/F; ICRAM, 2008).

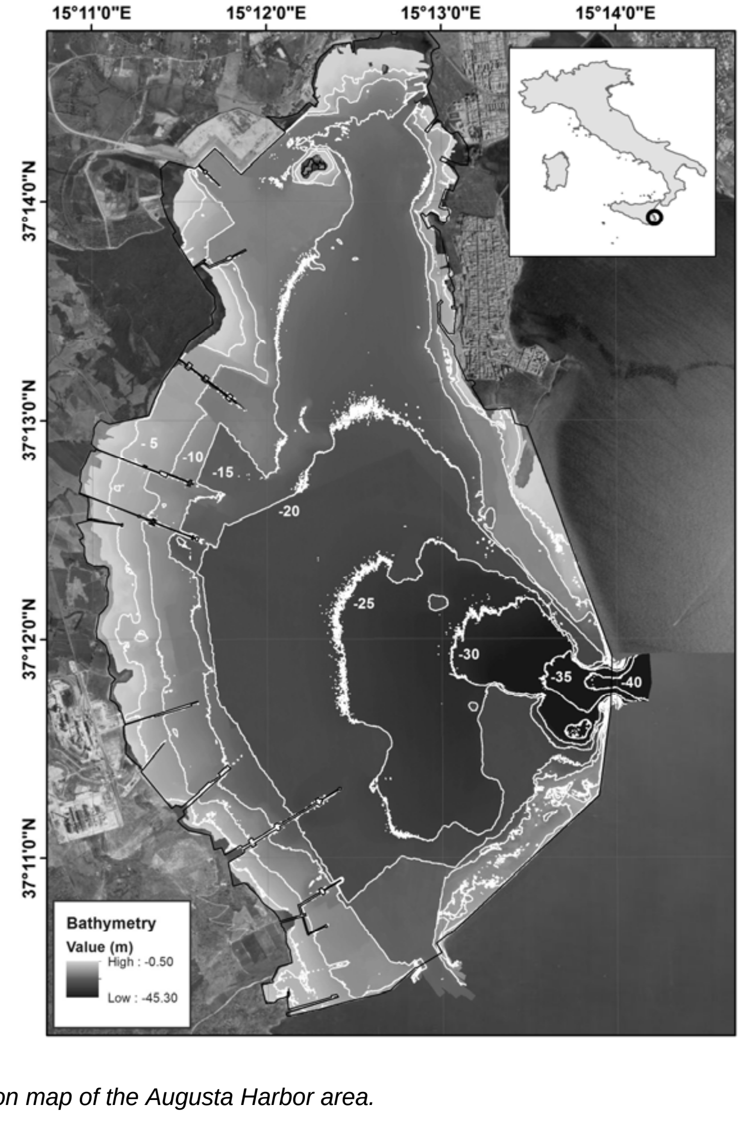


*Figure 1: Location map of the Augusta Harbor area.*

## 3. Methods & Materials

Stratigraphy derived from 480 sediment cores, 90 km of Sub Bottom Profiler (SBP) images and 76.5 $km^2$ of the Side Scan Sonar (SSS) mosaic were used to assess the thickness of the sediment layer over the rock substrate (Figure 2). The seismic profiles, available as jpg images, were geo-referenced and inserted into a Geographical Information System (GIS). Then, based on the sampling locations and the routes followed during the geophysical survey, the sediment sampling stations nearest to the routes were selected and associated to the corresponding positions on the stratigraphic rendering of the SBP's images). Some areas are characterized by bare rock extensions that are interspersed with small depocentres or small sediment pools (few meters in diameter and few cm thickness). Due to the aim of the chemical-physical characterization, during the field campaign activities, sampling stations were moved within the sediment pools. The thickness of recent sediments was derived by estimating the distance (m) between the seafloor and the underlined formations (Figure 3).

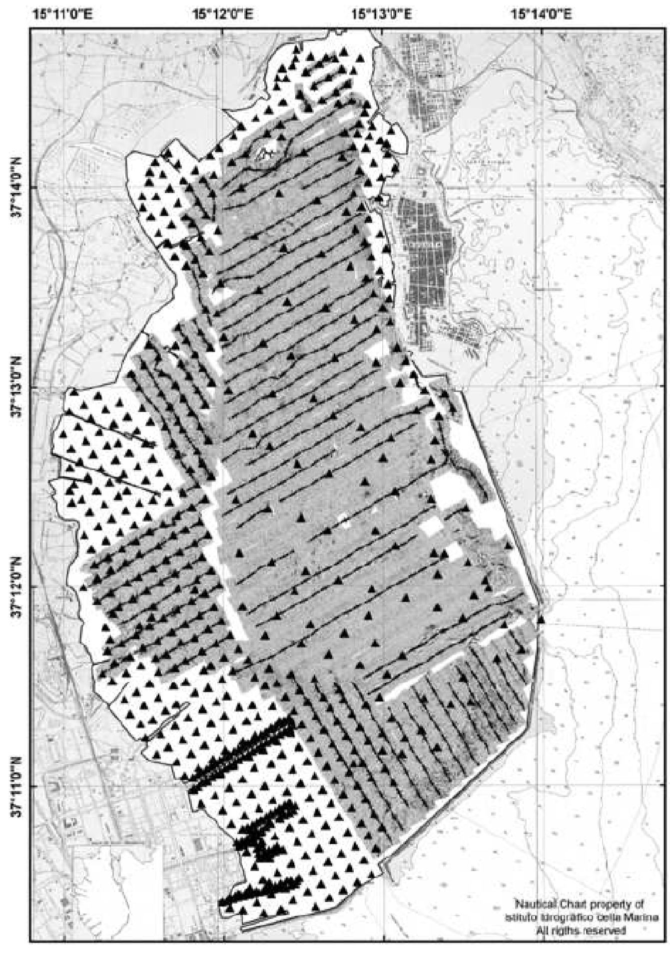


*Figure 2: Location map of the different data used within the Augusta Harbor (dotted lines: navigation tracks of the SBP survey; triangles: core's location and; grey area: SSS mosaic).*

The final dataset has two sources of hard data and two sources of soft data:

- 480 sediment cores (most are up to 2 m in length), out of which 226 locations are referred to as hard data and 254 to soft data and;

- 924 locations derived from 90 km of SBP seismic profiles, out of which 531 locations are referred to hard data and 393 to soft data.

Data log and stratigraphy of the sediment cores has been joined with the SBP data, producing one dataset of 1,404 points: 757 of hard data and 647 of soft data. First using the conditional Expectation with Inequalities the soft data were replaced by a new set of hard data. The conditional expectations of the normalized hard data were calculated at each inequalities location by using the Gibbs sampler technique (Casella and George, 1992). This interactive algorithm simulates, for each instance of soft data, a given number of realizations of the transformed thickness variable according to its variogram model and conditioned by the inequalities and the exact data. After the simulation, the mean value of the realizations was calculated at each soft data point. After the back transformation, these values represent the most probable boundary layer position within the soft data locations. The new set of data was joined to the previous hard data, and a variogram was calculated in order to model the spatial variability of the sediment thickness within the harbour area. Then the SSS images showing the bedrock outcrops were considered in order to improve the assessment of the sediment thickness. If the bedrock was observed on the seafloor, the zero thickness value was imposed to every cell within that area.

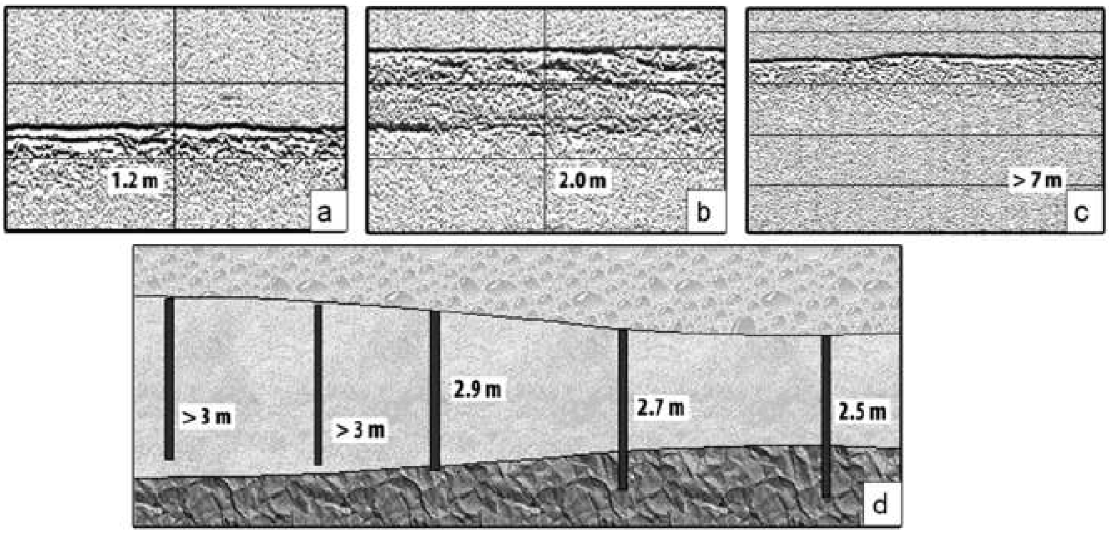


*Figure 3: Examples of hard and soft data from the present study that were extracted from the SBP cross section (a - plano-parallel stratified sand; b - sediment thickness of 2 m above the seismic horizon; c - homogeneous sand with uncertain thickness >7 m) and from the cores (d). The horizontal lines of the SBP images indicate a distance of 2 m.*

## 4. Results

The spatial variability of the sediment thickness is described by a well-structured variogram (Figure 4) that was calculated on 1,404 samples of the joined dataset constituted by the hard data and the most probable values of the soft data points. The nested variogram model is constituted by two structures: a nugget effect and a spherical model. The nugget effect takes into account the measurement errors and the variability occurring at distances shorter than the sampling lag. The spherical range, at nearly 1,100 m, represents the maximum distance of spatial correlation. In other words, it is possible to observe that the thickness values of two points further than 1,100 m apart are spatially independent. The cross-validation statistics (Table 1) show an estimation process that is characterized by a mean error of -0.00362 m and a standardized error of -0.00188 m. The mean error value can be considered negligible (0.14 %) compared to the value of the mean thickness of the sediment that was derived by using the 1,440 points of the dataset (2.53 m). Only in an exiguous number of locations (33 points) did the cross-validation standardized errors exceed the intervals [-2.5, 2.5], which define, in the case of a normal distribution, the 99 % confidence limit. By subtracting these outliers from the original dataset, a robust dataset was obtained. By comparing the statistical results of the latter subset with the original dataset, the sensitivity of the model to the outliers was tested. The statistics calculated on the robust data showed a mean error that is still very small (-0.03056 m). This result highlight that even if we remove the outliers, the model remains unbiased.

The definition of contaminated sediment thickness, up to 2 m of depth (maximum expected depth of pollutant through sediment column), was then used as a benchmark for the evaluation of the sedimentological and geophysical data (ICRAM, 2008). The thickness was, in fact, used as a first layer (Figure 5) for the volume estimation. Where the thickness is less than 2 m, the presence of a bedrock with an irregular trend allowed the threshold value that has been used for the final cut off. Basically the bedrock consists of a layer that only outcrops near the coastline and close to the rubble mound breakwaters. In some areas, the layer results in a complex series of ridges that are aligned along a SE-NW direction, which determine a strong variability in sedimentary cover thickness. Recent sediment are thinner and irregular in south-eastern part (up to the rock outcrops), and thicker in the central-western part where the rocky substrate is deeper.

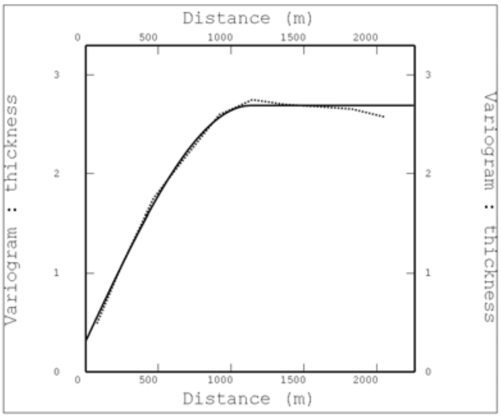


*Figure 4: Variogram of the sediment thickness. The dotted line represents the experimental variogram and the continuous line represents the theoretical variogram.*

| heading1 | Mean | Variance |
|---|---|---|
| Error | -0.00362 | 0.49992 |
| Stand. Err. | -0.00188 | 0.80581 |

*Table 1.: Cross Validation Statistics based on 1403 test data. Mean and variance calculated on error and standard error are reported.*

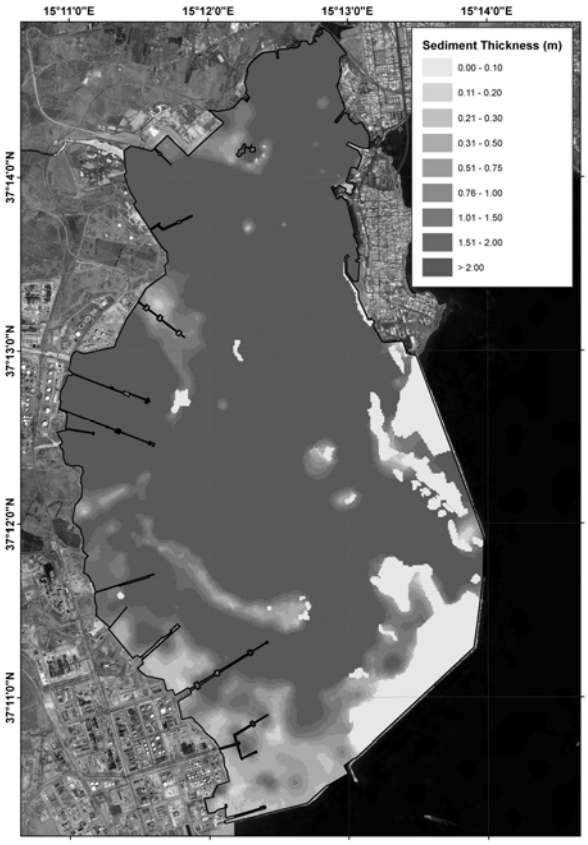


*Figure 5: Estimated superficial sediment thickness (from 0 to 2 m) within Augusta Harbour.*

## 5. Discussion and Conclusion

The results of the present study show the improvement of a standard methodology in order to assess the 3D spatial domain of recent sediment investigation extracted from multisource data collected for different purposes. The adopted methodology allowed the use of soft data in the estimation procedure (46% of entire dataset; 647 out of 1,404 data points) in order to improve the final sediment thickness estimation. The obtained results show the reliability of the methodology, which provided an almost zero mean error (-0.004 m), a low mean squared error (0.5 m), a good correlation coefficient between estimated and measured values ($\rho$ = 0.913), and standardized estimation errors that are almost independent of the estimated value ($\rho$ = 0.083). Therefore, the estimation of sediment thickness is particularly reliable within a range of 0–2 m covered by both hard and soft data. This created an important advantage in the final stratigraphy interpretation that lead to a calculation of the overall volume of contaminated sediments. The estimations of chemical and physical properties, with no information on the available sediment thickness, is always calculated on a theoretical thickness as the maximum depth reached by most of the cores (in this case 2 m) while using this improved standard methodology a better interpretation could be reached. In fact, if the entire Harbour extension is considered (22,700,000 $m^2$), this theoretical thickness corresponds to a 3D estimation domain of 45,400,000 $m^3$. As a major results, the application of our methodology allowed the reduction of the volume of available sediment (from 45,400,000 $m^3$ to 36,600,000 $m^3$ ; about 19% reduction in volume). Based on the fact that every instrument can produce responses with differing levels of confidence, this approach enhances the rendering of the different available data. In the case of this study, the geostatistical approach through the kriging-with-inequalities method permitted to estimate the thickness within the study area, even if there was a varying density distribution. As with other estimation processes, some limitations and approximations are to be expected, but the quality of the approach remains convincing, considering the amount of volume reduction. As a final remark, it is necessary to outline the fact that no numerical method can restore a lack of information that results from a suboptimal sampling strategy or, as in this case, due to a sampling strategy that was differently aimed.

## References


Amore C., D'alessandro L., Giuffrida E., Lo Giudice A. and Zanini A., 1992, Beach morphodynamic between Capo Peloro and Capo Passero (Eastern Sicily), (italian), Boll. Acc. Gioenia Sci. Nat., 25 (339), 69-114.

Cappucci S., Scarcella D., Rossi L. and Taramelli A., 2011, Integrated Coastal Zone Management at Marina di Carrara Harbor: sediment management and policy making, Journal of Ocean and Coastal Management, 54, 277-289.

Casella G. and George E.I., 1992, Explaining the Gibbs Sampler, The American Statistician, 46(3), 167-174.

Chilès J.P. and Delfiner P., 1999, Geostatistics modelling spatial uncertainty. Wiley and Sons Ltd., London.

Emery X., 2007, Simulation of geological domains using the plurigaussian model: new developments and computer programs, Computers & Geosciences, 33, 1189-1201.

Goovaerts P., 1999, Geostatistics in soil science: state-of-the-art and perspectives, Geoderma, 89, 1-45.

Guerra-Garcia J.M. and Garcia-Gomez, J.C., 2005, Assessing pollution level of sediments of a Harbour with two opposing entrances, Environmental implication. Journal of Environmental Management, 77, 1-11.

ICRAM, 2008, Clean up preliminary project of Rada di Augusta within the Priolo site of National Relevance (italian) - phase I and II – open file BoI-Pr-SI-PR-Rada di Augusta-03.22, Rome, Italy, 182 pp.

Langlais V., 1990, Estimation sous contraites d'inégalités. Thesis (PhD), E.N.S. des Mines de Paris. Available from http://cg.ensmp.fr/bibliotheque/public/LANGLAIS_Publication_00629.pdf.

Lisi I., Taramelli A., Di Risio M., Cappucci S. and Gabellini M., 2009, Flushing efficiency of the Augusta Harbor (Italy), Journal of Coastal Research, Special Issue 56, 841-845.

Raspa G., Innocenti C., Marconi F., Mumelter E. and Salmeri A., 2008, Evaluation of an Automatic Procedure Based on Geostatistical Methods for the Characterization of Contaminated Sediments. In: Soares A., Pereira M.J. and Dimitrakopoulos R., Eds., GeoENV VI-Geostatistics for Environmental Applications. Springer, New York, 421-441.