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MULTI-PROXY SEDIMENT TREND ANALYSIS (MSTA): SEDIMENTARY DYNAMICS FROM SOURCE TO SINK

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Abstract: To study the surface sediment dynamics of the Cherbourg roadstead, the grain-size end-members of a set of 199 sediment samples are computed and integrated into a multi-proxy sediment trend analysis (MSTA). Cherbourg harbor is a sheltered area where the finest sediments mix with "fossil" sands, gravels from local erosion and shell debris from outside. Using the finest sediment of the data set, this new approach allows us to highlight marine or continental sources and sinks of this fraction.

Keywords: sedimentary dynamic, end-members, GSTA, Cherbourg roadstead

1 INTRODUCTION

Sediment is made up of a more or less complex mixture of particles, each of which is the result of a source and erosion, transport and deposition processes (Flemming, 1988). Grain size analysis is widely used to study sediment environments. The spatial variability of granulometric parameters (mean, sorting, skewness, kurtosis) can be used to estimate transport directions (STA®: Sediment Trend Analysis; McLaren, 1981; McLaren and Bowles, 1985) and GSTA (Gao and Collins, 1992). The "End-Members" (EMs) approach was developed by Weltje (1997) for this purpose. This model can determine the number and granulometric spectra of different populations in a granulometric data set of a study area. The analysis of the spatial organization of each EMs and their mixing percentage allows identifying the characteristics of sedimentary environments. The R package 0.9.6 of EMMAGEo (Dietze and Dietze, 2019), facilitates the application of this approach in the decomposition of a multimodal granulometric distribution into its different grain populations. The "End-Members" method is increasingly used and compared jointly with the STA®/GSTA method (Liu et al., 2012; Li and Li, 2018; Yu et al., 2019; Yuan et al., 2021; Chen et al., 2022; Paladino et al., 2022; Dong et al., 2023; Meng et al., 2023). For these authors, modeling of granulometric EMs used in addition to STA®/GSTA analysis allows a better understanding of sediment transport patterns and associated mechanisms, thus facilitating environmental interpretation. The approach proposed here is based on the integration of these two methods (EMs and STA®/GSTA) by replacing historical statistical parameters with EM characteristics. It is applied to the Cherbourg harbor (Fig. 1), a site whose complexity is reflected in the heterogeneity of the surface grain-size patterns, the currents and the anthropogenic morphology (Fig. **Erreur ! Source du renvoi introuvable.**) (Grégoire et al., 2019). The objective is to highlight the dynamics of the establishment of the relative concentrations of EMs recognized in the Cherbourg harbor and, consequently, of the related sedimentary processes.

2 MATERIALS AND METHODS

Sediment samples were taken using a Shipek grab and stored still wet at 5°C. The grain-size dataset has been obtained using a Horiba laser particle size analyzer with a measurement range from 0.01 µm to 2000 µm (logarithmically spaced). We used granulometric data (87 classes) in an end-member analysis (Weltje 1997) performed with the EMMAGEo package (Dietze and Dietze, 2019) of the R software. We obtained vector fields showing sediment dynamics based on End-Members through a Multi-proxy Sediment Trend Analysis (MSTA). MSTA is an internal numeric tool developed in Python under QGIS software based on a GSTA like approach as developed by Poizot et al. (2006) and Poizot and Méar (2010). Residual current vector fields were obtained through the MARS 2D (Model for Application at Regional Scale in 2D) numerical model. This model simulates the horizontal movement of oceanic water masses to study and predict the dynamics of coastal and estuarine waters (Lazure and Dumas, 2008).

3 RESULTS AND DISCUSSION

The End-Members (EM) analysis of the 199 surface sediment samples collected in 2018 in the Cherbourg roadstead (Fig. **Erreur ! Source du renvoi introuvable.**) recognized 4 typical grain-size distribution patterns, identified as EM1, EM2, EM3 and EM4 (Fig. 2). The 4 EMs explain about 90% of the total variance,

with respectively 39.3% for EM1, 5.6% for EM2, 37.8% EM3 and 17.3% for EM4. The figure 3 is composed of the spatial distribution maps of the normalized relative concentrations of these 4 EMs.

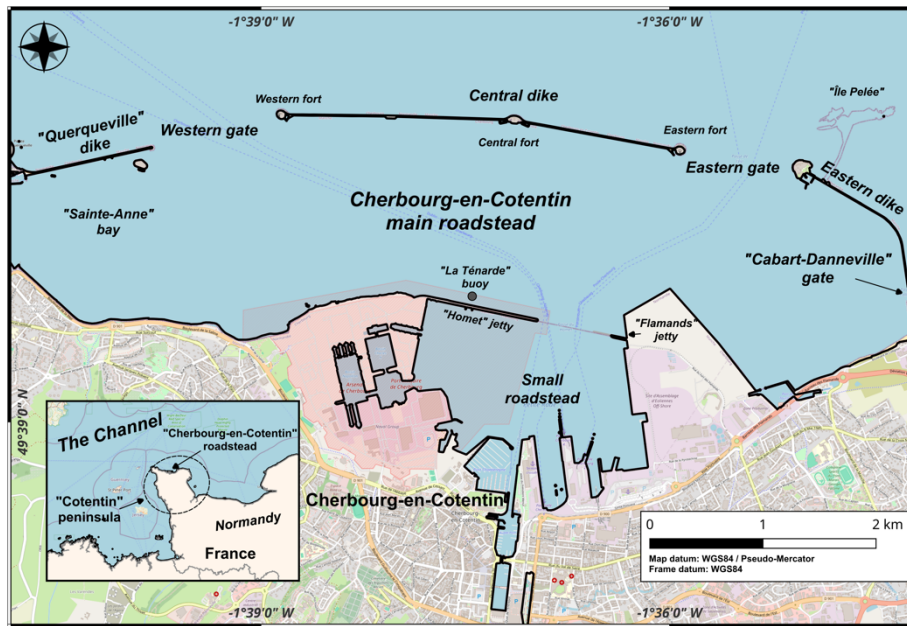


Figure 1: The Cherbourg roadstead.

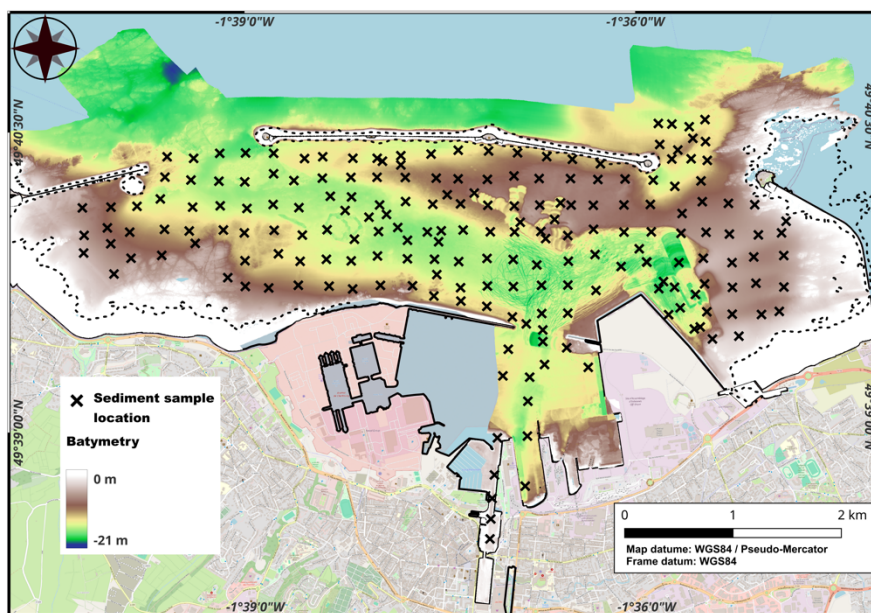


Figure 2. Sediment sample location (2018) and bathymetry of Cherbourg roadstead

The particle size curve of EM3 is characterized by a single mode at 200 μm (Fig. 2). Spatially, EM3 is present in significant concentrations, where the other EMs are not. In other words, EM3 corresponds to the sedimentary bottom in the study area.

EM4 is characteristic of the coarsest sediments, with two almost identical modes at 287 μm and 1 mm (Fig. 2). It is present only in the axis of the West Pass, the area of the strongest hydro-dynamics in Cherbourg roadstead, under the joint action of tidal currents and swells. All grain sizes lower than EM4 are leached in this area.

The main mode of EM2 is at 134 μm (Fig. 2), with two other minor modes at 1 mm and 12 μm . In the Cherbourg roadstead, EM3 is mainly located east of the central dike, gradational between the high

percentages of EM1 to the west and those of EM3 to the east. EM2 represents a transitional sedimentary cover between two other well-marked ones.

The particle size curve of EM1, whose main mode is at 12 μm (Fig. 2), nevertheless shows a significant asymmetry with 3 other weaker modes in relation to the main modes of the other EMs. This feature indicates that EM1 overlaps the other 3 EMs. This is reinforced with regard to the spatial distribution map, which shows that the concentrations of EM1 (> 30%) cover a large part of the sampled area.

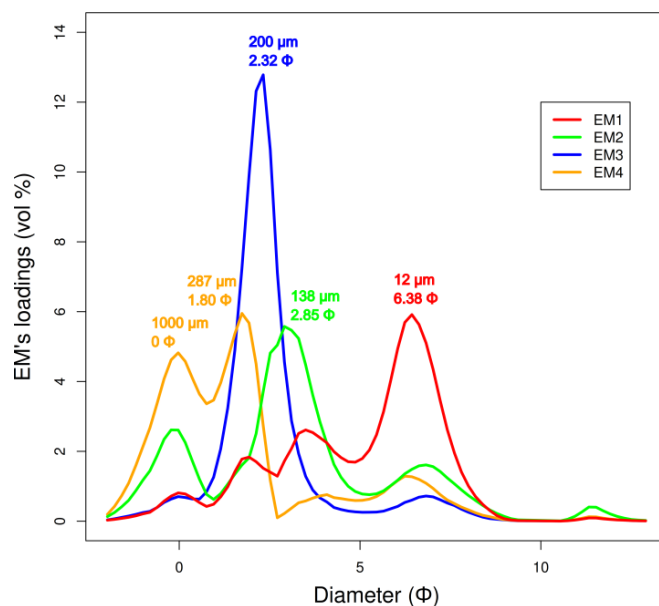


Figure 2: The four EMs identified in the sedimentological dataset of the 2018 campaign.

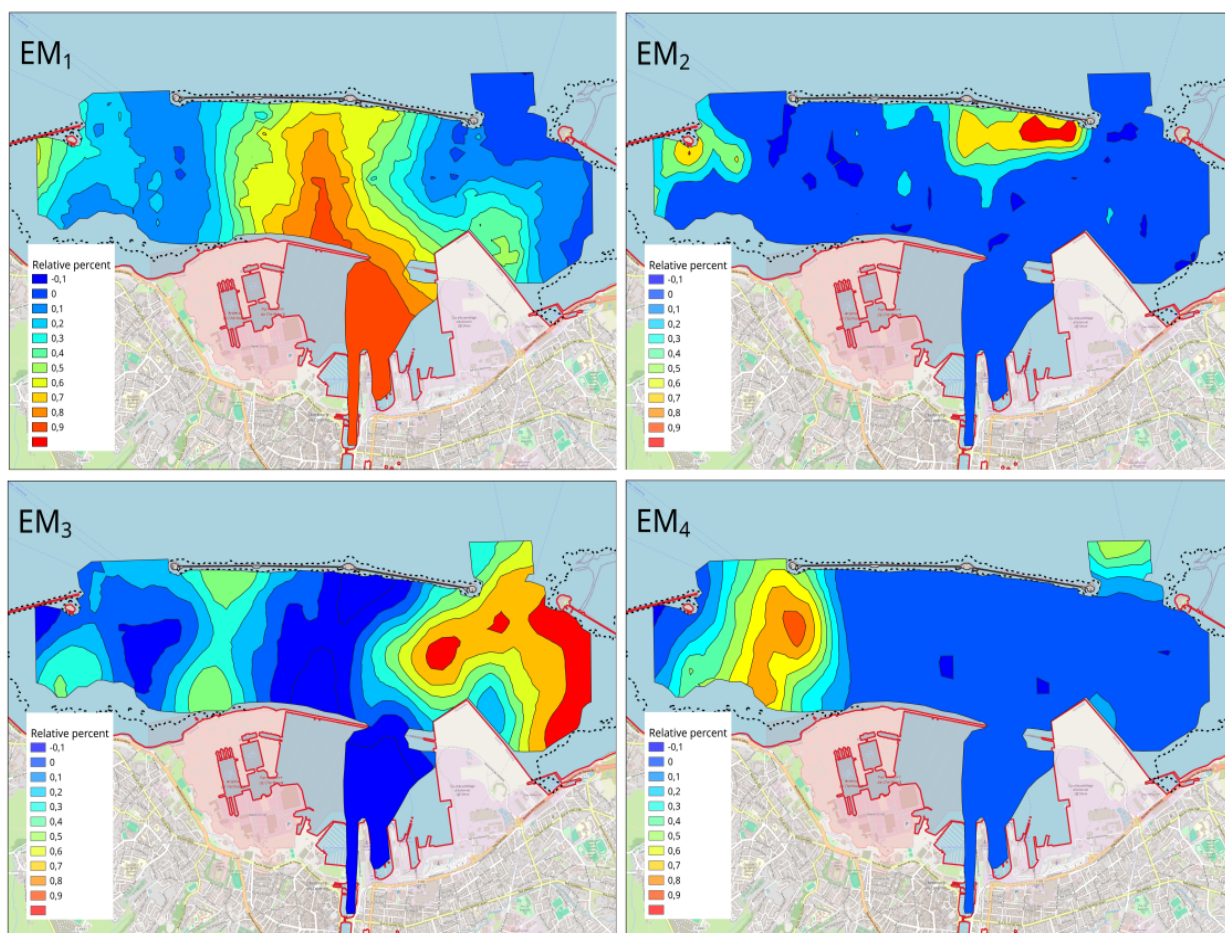


Figure 3: Relative percentage of the four EMs in the Cherbourg roadstead.

To highlight the sedimentary dynamics in the Cherbourg roadstead, the MSTA approach is implemented. Taking the example of EM1, MSTA should allow to identify the dynamics of the establishment of the highest concentrations of fine sediments. The evolution case studied corresponds to that highlighting the concentration gradients of EM1 (noted EM1+). Figure 4 shows the vector field of the EM1+ evolution case.

The fine sediments of the Cherbourg harbor come mainly from the outside, passing through the West and East passes. To the west, these sediments are trapped in the Sainte-Anne cove (Fig. 4, zone A). At this location, the resulting currents (Fig. 4, bottom left) form a dextral gyre that participates in the entry of sediment into the cove. The very weak currents inside the cove, favor the sedimentation of the finest particles (EM1). To the east of the roadstead (Fig. 4, zone C), the weak resulting currents allow their sedimentation. The convergence of the EM1+ vectors towards a point close to the new EMR embankments ("Flamands jetty", Fig. 1) here highlights a concentration of fine sediments under the action of a bathymetric control linked to the presence of a dredging trench at the center of the roadstead (Fig. **Erreur ! Source du renvoi introuvable.**).

Zone B of the figure 4 contains a vector field that converges, in its northern part, towards the center and in its southern part, towards the south (Ténarde buoy, Fig. 1). This organization is the result of two superimposed mechanisms. First, the resulting currents forms two gyres to the east (sinistral) and west (dextral) of this zone B. At the height of the dividing line between these gyres, the currents are weaker and thus allow the fall of fine particles. This has favored the installation of a population of benthic filter organisms *Crepidula fornicata* in high density. As the population has grown (mainly towards the south of zone B), these organisms have promoted, on the one hand, with their feces, the sedimentation and fixation of fine sediments and on the other hand, by their presence, the increase of the seabed apparent roughness and thus further reduced the current speed close to the seabed.

The fine sediments from the main Cherbourg roadstead enter the small one via the pass that makes them communicate (Fig. 4, zone D). The marine influence of this contribution extends to the marina entrance. Thanks to a bathymetric step that goes from -11 m to -3 m at the entrance to the port, the external marine fine sediments are stopped. This configuration leaves the possibility for fine continental sediments, contributions of the Divette (a small coastal river that flows into the port of Cherbourg), to be able to be deposited up to the edge of this step.

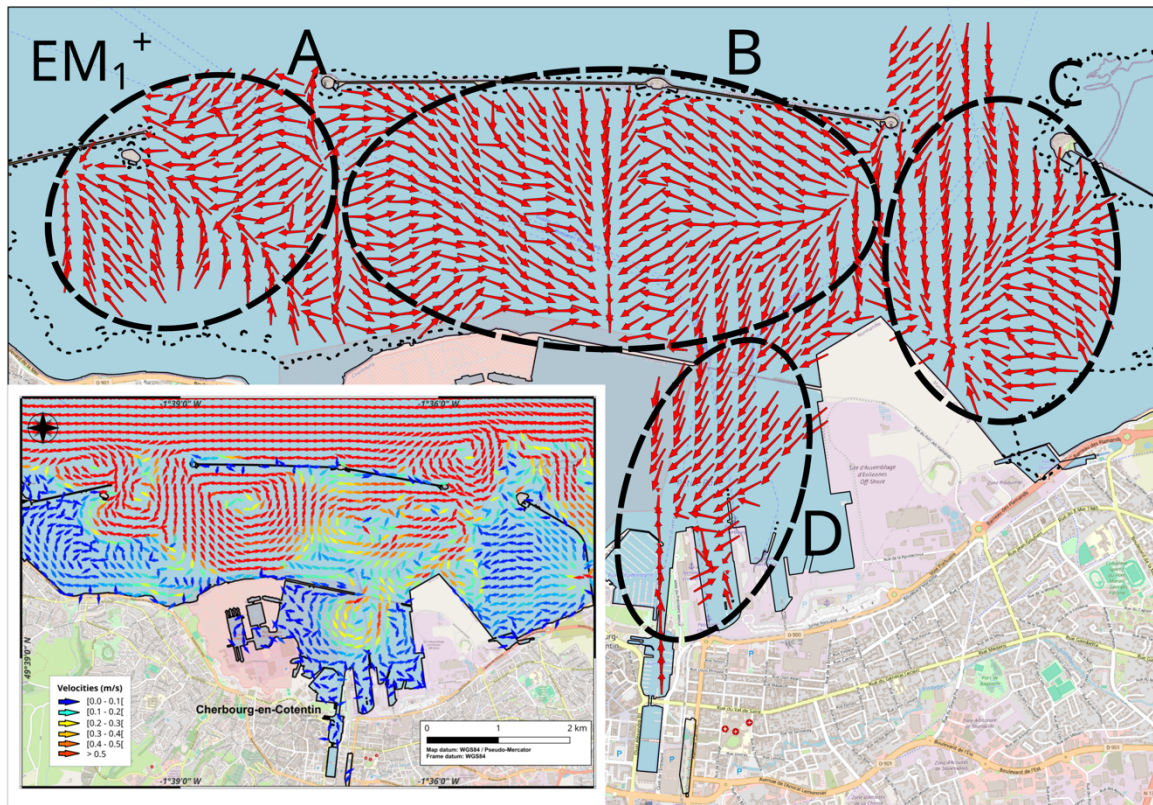


Figure 4: Vector field corresponding to the concentration gradient of EM1 (EM1+). Bottom left corner: the resultant speed and direction vector field of currents in the Cherbourg roadstead computed by MARS2D.

4 CONCLUSION

In this study, we propose a new method called MSTA which integrate various environmental parameters into a GSTA-like approach. As an example, we use results from an End-Members analysis to highlight fine sediment dynamics of the Cherbourg roadstead. We show that fine sediment fraction is mainly of marine origin. Continental sediment deposit is restricted to the inner part of the marina. The main accumulation areas have a dual origin. Anthropogenic action is linked to the construction of dykes and the digging of dredging pits. In both cases, these developments modify the circulation of water masses, facilitating the deposition of fine sediments transported in suspension. The setting up of invasive species of benthic filter-feeders has been facilitated by the existence in the center of the roadstead of an area of weak currents, allowing the sedimentation of fine sediments. Since then, this population has maintained this silted-up area. The results of this study demonstrate that in complex coastal areas, analyzing sediment dynamics based solely on grain-size analysis might provide a partial reconstruction. The MSTA approach allows integrating other environmental proxies that are more specific to the study area.

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