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Using a GIS to enhance grain size trend analysis

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ABSTRACT

This paper introduces GisedTrend, a plugin of the QGIS geographical information system that implements the Grain Sized Trend Analysis (GSTA) method. It is advantageous to incorporate the GSTA method in a GIS since it can directly access: (i) environmental information such as bathymetry, coastline, etc., (ii) spatial analysis tools available in such working environments, (iii) input/output data management; all these features are provided by standard GIS software. The paper also presents two case studies: the first case is based on an artificial dataset to focus on effects of obstacles on GSTA computed vector fields. The second case is based on a dataset acquired in the western part of the NW Mediterranean sea (Gulf of Lions, France). In this area, rocky formations, more or less continuous, outcrop directly on the seafloor, modifying the local hydrographic context and thus the sedimentary dynamic.

Software availability

Name of software: GiSedTrend (Gis based sediment trend analysis)
Developer: Emmanuel Poizot
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Year first available: 2008, then named eCSedTrend
Hardware required: GNU/Linux distribution (RedHat, Debian, Ubuntu, etc.)
Software required: QGIS stable version (1.0.2), PostGreSQL, PostGIS, pqxx library, QT library (TrollTech)
Program language: C++
Availability and cost: Contact via e-mail, no cost
Maintenance: The software will be periodically updated with the new research advances

1. Introduction

In a number of coastal management studies, it is essential to have a reasonable estimate of sediment transport. Numerous researches have built models for predicting bed material transport. The transport mechanism is complex and the transport models are based on simplifying assumptions that often lead to large prediction errors (Bhattacharya et al., 2005; Winter, 2007). For Bagnold (1980), it is difficult or even impossible to use a deterministic mathematical framework to obtain an accurate expression of the transport processes. The use of data-driven modelling is an alternative approach. It is especially suitable in the case of sediment transport modelling, when knowledge of the physics is limited. There are numerous successful applications of data-driven methods (see for example: Govindaraju, 2000; Dibike and Solomatine, 2001; Bhattacharya and Buraimo, 2003; Bhattacharya et al., 2005; Liu and Huang, 2009; Wilkinson et al., 2009). In this paper, we present a GIS based data-driven model to determine sediment transport using Grain Size Trend Analysis (GSTA) method.

Mc Laren (1981) first defined the fundamentals of Sediment Trend Analysis (STA®), a method that aims to determine the net sediment transport pathways on the seabed. The STA® method is based on the comparison of statistical parameters, i.e., mean, sorting and skewness, associated with the grain-size distributions of sediment samples. Mc Laren (1981) demonstrated that relative changes in these parameters are the result of transport processes, which makes it possible to infer the directions of sediment transport. Using the three statistical parameters, two types of trend can be identified out of eight possible combinations. These two cases have the highest probability of occurring between two sediment samples: the grain-size distribution can either become Finer (F),

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Better sorted (B) and more negatively (−) skewed, or, alternatively, Coarser (C), Better sorted (B) and more positively (+) skewed. These two trend types are respectively denoted as FB− and CB+.

According to Wheater et al. (1993), Mc Laren's model can be considered as a mixture between an empirical and a conceptual approach. The model is empirical because it is based primarily on the analysis of observations and seeks to characterize the response to the input data. The model is also conceptual, since it tends to include a general description of sedimentation processes without considering the specific details of interactions between processes (Sorooshian, 1991).

Mc Laren (1993), Mc Laren and Bowles (1985) and Mc Laren and Little (1987) used the STA® method in a one-dimensional context with relatively good success. Gao and Collins (1991) modified Mc Laren's initial STA® approach to allow a two-dimensional (2D) study. The main add-on is the definition of a characteristic distance (noted D_{cr}) representing the spatial scale on which samples are considered as neighbours. In this way, statistical parameters are compared between a central station and samples within the characteristic distance. Enhancements of Gao and Collins (1991) method have also been proposed. Le Roux (1994a) modified the way in which vectors are computed and proposed a method based on weighting the grain-size parameters to define the final vectors. Asselman (1999) followed the different steps of Gao and Collins method, but adopted a raster-based approach after interpolation of the statistical parameters by kriging. Using geostatistical concepts and tools, Poizot et al. (2006) studied the semi-variogram of the statistical parameters to define the characteristic distance denoted as D_g. Applying this approach to the results of Asselman (1999), they used a regular grid of sample points obtained after geostatistical interpolation of the initial irregular grid parameters.

The 2D approach have been used by many workers in a wide range of different environments such as sandbanks (Gao et al., 1994; Mallet et al., 2000b; Vanwesenbeeck and Lanckneus, 2000), rivers (Asselman, 1999), beaches (Delgado et al., 2002; Pedreros et al., 1996; Van Lancker et al., 2004), estuaries (Mallet et al., 2000a), harbours (Gao and Collins, 1994) and continental shelves (Duman et al., 2006). Nowadays, Grain Size Trend Analysis (GSTA) is used to qualify methods which define trend vectors (directions and patterns) based on the analysis of particular spatial relationships (trends) between the mean size, sorting and skewness of seabed sediment (Gao and Collins, 1992; Mc Laren and Bowles, 1985).

Most recent papers on GSTA are reviews (Le Roux and Rojas, 2007; Mc Laren et al., 2007; Poizot et al., 2008) which aim to establish the state of the art of the method and focus on the remaining problems. Some of these difficulties do not depend on the GSTA method, and can arise, for example, from the sediment sampling method, the sampling strategy or the grain-size analysis (Plomaritis et al., 2008). These problems are identified as input uncertainties (Poizot et al., 2008). Other problems discussed in the literature are related to the GSTA method itself: trend types, definition of characteristic distance, smoothing of vectors, tests to determine significance of results, etc. These pitfalls are identified as model uncertainties (Poizot et al., 2008). While minimizing input uncertainties remains under the control of operators, model uncertainties can be reduced by methods that offer a greater flexibility in applying the GSTA approach.

With the growing use of computers, different software has been used to implement the GSTA method during the course of its development (Chang et al., 2001; Gao, 1996; Le Roux, 1994c; Pedreros et al., 1996; Poizot and Méar, 2008). These different implementations of GSTA focused on the method itself, while the trends were determined only on the basis of comparisons of statistical parameters.

Natural processes leading to modifications of the grain-size parameters show changes and interactions with boundaries (natural and/or artifial). In most GSTA studies, the transport pathways analysed are modelled without taking into account the environmental limits (coastline, breakwaters, rocky outcrop, etc.) in which they develop. In some cases, such simplifications can be unrealistic and this could explain the discrepancies noted by authors between GSTA results and other information on a particular area (Mallet et al., 2000a, b; Poizot et al., 2008; Van Lancker et al., 2004; Vanwesenbeeck and Lanckneus, 2000).

Even if samples are not separated by artificial structures, they can be affected by natural obstacles such as a headland, a complex area with highly irregular borders or rocky outcrops. In most studies presenting GSTA results, the maps show information such as coastlines, bathymetry or harbour limits. These data are simply intended to produce a more realistic map and do not influence the vector computation even if direct interactions are evident. However, Plomaritis et al. (2008) took breakwaters limits into account during the creation of regular sampling grids, but they did not consider these limits during the GSTA vector field computation step.

To provide a flexible tool and take into account additional environmental information for GSTA computation, we decided to develop GisedTrend, a plugin application of the opensource QGIS software. This new tool offers capabilities in the field of Geographical Information Systems (GIS), so the GSTA approach can then benefit from the advantages of a GIS environment:

- the import/export management of data in different formats;
- geodetic dataset management;
- the mixing of vector and raster datasets;
- access to geographical analysis tools;
- etc.

Written in C++, GisedTrend plugin allows us to perform a two-dimensional Grain Size Trend Analysis. Moreover, implementing GisedTrend plugin in a GIS study environment also presents an opportunity to improve the application of the GSTA approach:

- full choice of trend types;
- taking into account geographical or anthropogenic boundaries;
- upgrading the interpretation by providing maps displaying the spatial pattern of a theme or series of attributes (thematic maps);
- new methods for vector computation;
- upgrading the presentation of results.

After presenting QGIS and GisedTrend plugin, we make use of two examples based on GSTA studies to demonstrate the new capabilities offered by the GisedTrend plugin implemented under QGIS. The first example is a theoretical case that aims to demonstrate the impact of a dyke on the vector field. The second study is based on real data acquired on the continental shelf off the Roussillon coast (France, Gulf of Lions, Western Mediterranean).

2. GisedTrend: a GSTA plugin of QGIS

2.1. QGIS: an opensource GIS software

A Geographical Information System (GIS) is a framework for storage, representation, analysis and restitution of georeferenced data on a particular topic and area. GIS are created with the aim of decision/management support. Among the tools used, software represents a key component of the data management facilities, i.e., storage, treatment and display.