Characterization of Bed Morphodynamics Using Multibeam Echo Sounding (MBES) and Wavelet Transform (WT) Analysis

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LONG-TERM GOALS

The overall objectives of this project are as follows:

Application of the Wavelet Transform (WT) technique in the spatial domain to characterize the spatial distribution of co-existing bedforms of multiple dimensions generated under different flow field scenarios (waves, unidirectional flows and combined flows).

Demonstrate the applicability of WT analysis for the description of bedforms frequently found in coastal and river environments. An improved description of bed features and their interactions will certainly contribute to a more complete understanding of theories describing bedform formation and evolution.

Improve overall understanding of small and large scale features, which is especially important because of their strong implications for the associated patterns of bed roughness characteristics, flow resistance and sediment transport.

Describe the hydrodynamic interaction of multiple sized bedforms and, conversely, the bed morphology given averaged hydrodynamic parameters; this approach could be used to develop and validate numerical approaches that will allow detailed examination of associated hydrodynamic and morphological conditions at inlets and river mouths.

OBJECTIVES

To extend the WT analysis technique developed by Cataño-Lopera *et al.* (2009) with laboratory observations, to the case of bed morphodynamics under field conditions at rivers and estuaries. For this purpose, the WT technique will be applied in the spatial domain rather than in the temporal domain, as conventionally used.

To apply the WT technique in the spatial domain to field measurements of bedforms in the Missouri River near St. Louis (MO) and the St. Clair River near Port Huron (USA-Canada). The bathymetric surveys employed a Multibeam Echo Sounding (MBES) system.

APPROACH

1- Starting from the 1D WT technique by Cataño-Lopera *et al.* (2009), we developed a 2D whole-field technique based on the continuous wavelet transform method to analyze the bedform scales present in a particular bathymetry using the 2D Morlet wavelet function (Fig. 1).

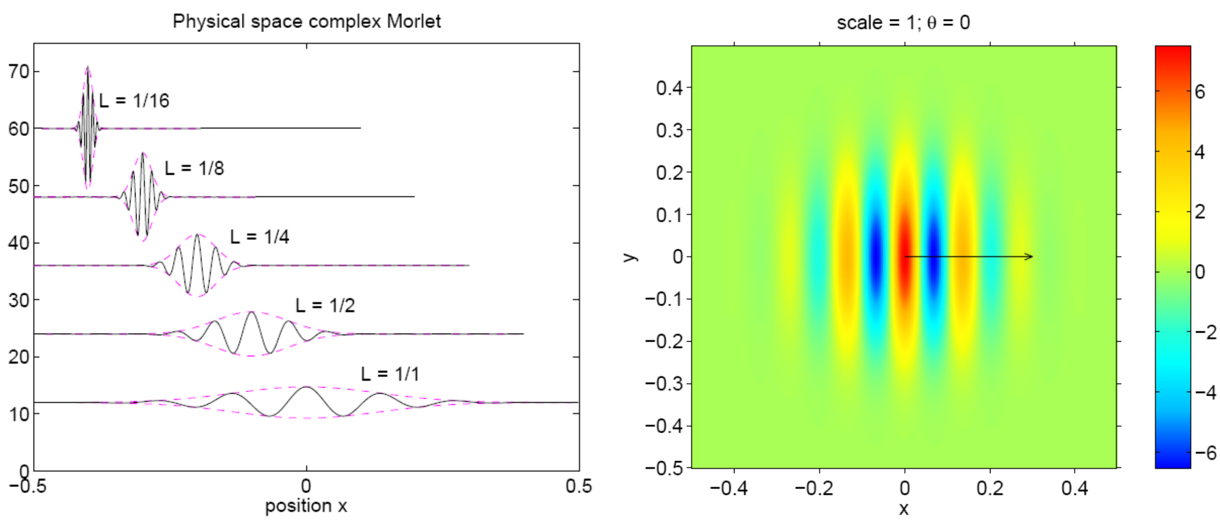

Fig. 1. Morlet wavelet function for 1D space (left) and 2D space (right).

2- Calibration of the 2D WT tool using synthetic bathymetries generated numerically for simple bedform configurations.

3- Validation of the 2D WT tool using laboratory bathymetries from bedforms generated under standing waves.

4- Application of the 2D WT tool to bathymetric surveys from MBES swaths of two field sites: the Missouri River near St. Louis (MO) and the St. Clair River near Port Huron (USA-Canada).

The research team is composed by Prof. Marcelo H. Garcia as PI, Prof. James L. Best as co-PI, and Jose M. Mier as Ph.D. student. Development of the 2D WT tool was performed by Marcelo H. Garcia and Jose M. Mier. Data for validation was provided by Dr. Blake J. Landry from laboratory experiments in the wave tank at the Ven Te Chow Hydrosystems Laboratory. The bathymetric surveys were performed by James L. Best who supplied the data for the field application of the technique.

WORK COMPLETED

1- The WT analysis tool for 2D bathymetry field has been developed. It is available as a MATLAB® code that can be applied to an input bathymetry given as a 'xyz' file. It applies the 2D continuous wavelet transform technique using the 2D Morlet wavelet function for different scales and directions to the whole bathymetry field. It returns an output image of the original bathymetry with the different bedform scales present indicated by superimposed shadowed areas (Fig. 2). Additionally, the principal direction of bedform orientation can be displayed by a superimposed arrow field.

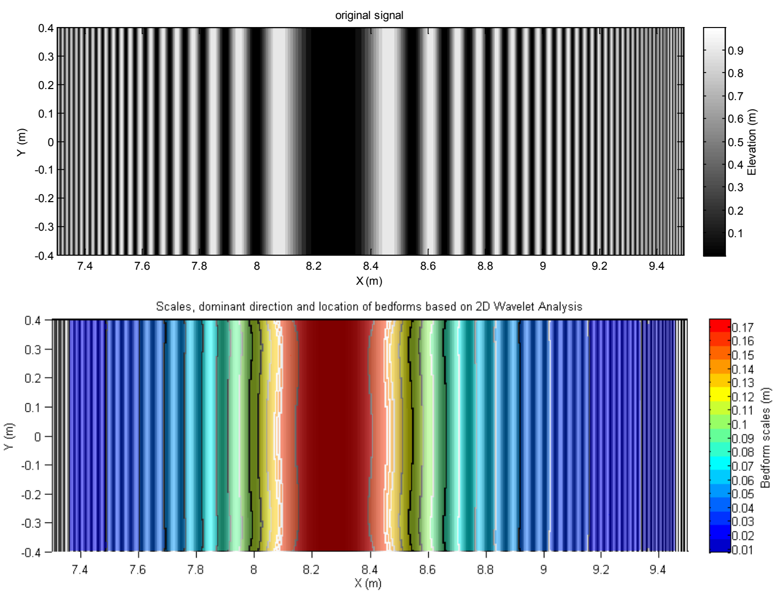

Fig. 2. Results of the 2D WT tool applied to a unidirectional synthetic bathymetry field. Original bed elevation map (top) and identified bedform scales map (bottom).

2- The 2D WT has been calibrated using synthetic bathymetries both for scale (Fig. 2) and direction (Fig. 3) of the bedforms present.

3- The 2D WT tool has been validated using the bathymetric data sets of Landry (2011) which were generated under standing waves conditions. They include small scale bedforms (ripples) ranging from 5 cm to about 20 cm superimposed on top of large scale bedforms (bars) of about 4 m. The 2D WT tool has been able to identify the different bedform scales present and their location (Fig. 4).

4- The 2D WT tool has been applied to bathymetry data obtained from field surveys at the Missouri River near St. Louis (MO) and the St. Clair River near Port Huron (USA-Canada). Data was collected using a MBES system, which provided unrivalled resolution of the entire bottom morphology, with lateral coverage of each swath extending to nearly 5 times the flow depth. The x,y grid spacing of the datasets was 0.25 m and 0.5 m, respectively.

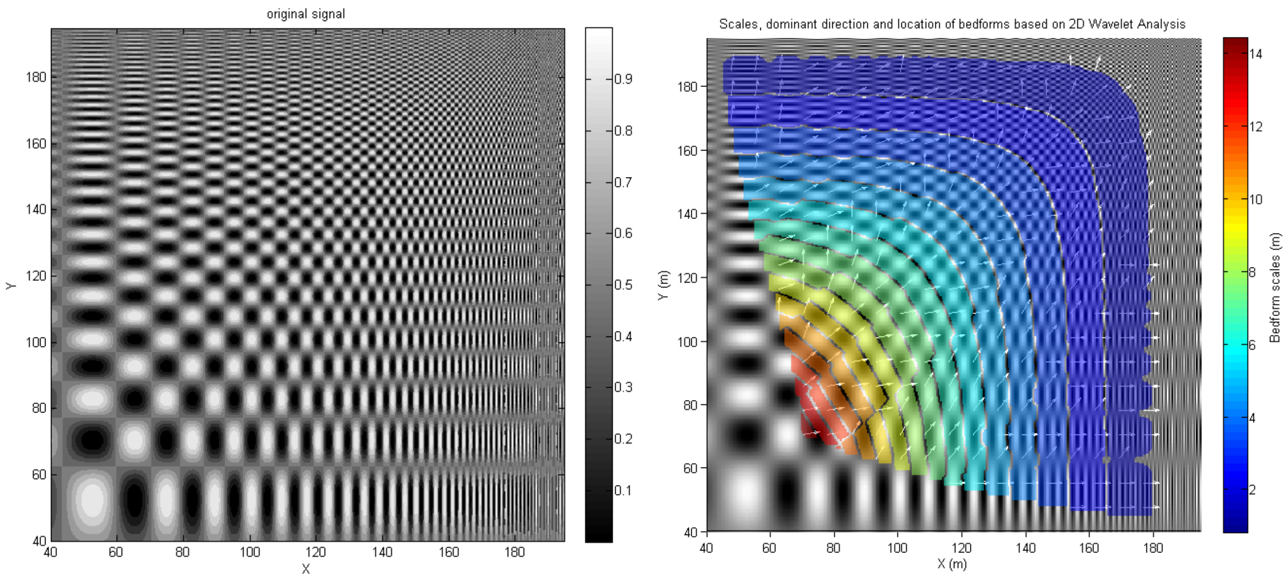

Fig. 3. Results of the 2D WT tool applied to a synthetic bathymetry field with different bedform scales and directions used during the calibration process. Original bed elevation map (left) and identified bedform scales and directions map (right).

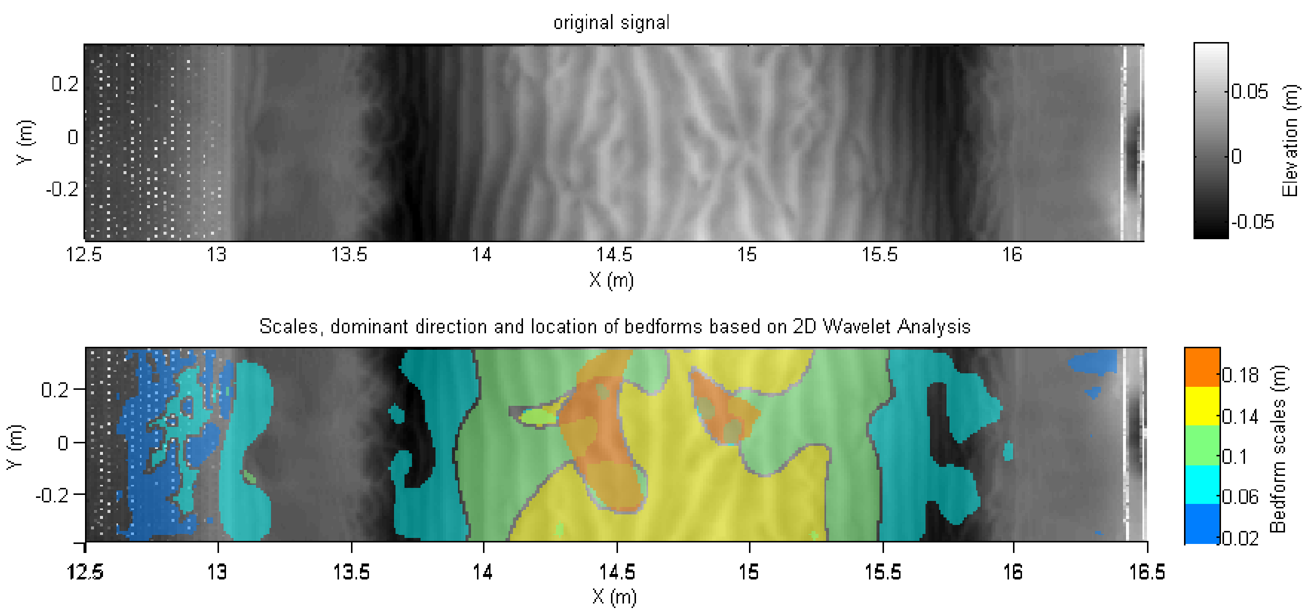

Fig. 4. Results of the 2D WT tool applied to the laboratory bathymetry of Landry (2011) used for validation. Original bed elevation map (top) and identified bedform scales map (bottom).

From the analysis of the datasets, shadowed area maps were obtained showing the location, scale and direction of the dominant bedforms present. These results were overlaid on the original bathymetries to allow for easy identification of the features and their spatial distribution. In the Missouri River bathymetry (Fig. 5), two main scales were identified: the features on the bottom-right side of the image correspond to medium scale bedforms of 5 to 10 m in wavelength, while on the top-left of the image 20 to 40 m large scale bedforms were found. In the case of the St. Clair River (Fig. 6), the tongueshaped sandy formation analyzed presented a defined bedform scale around 10 m in wavelength, decreasing to about 5 m near the edges. Also, arrows on the image help identify the direction of the bedforms, which most likely correspond to the direction of the dominant flow that contributed to generate each particular feature at that scale. Areas of superimposed bedforms were observed at other locations where multiple scales had been identified. In these cases, the directions of the bedforms superimposing were rarely the same, suggesting the presence of different dominant flows for each scale.

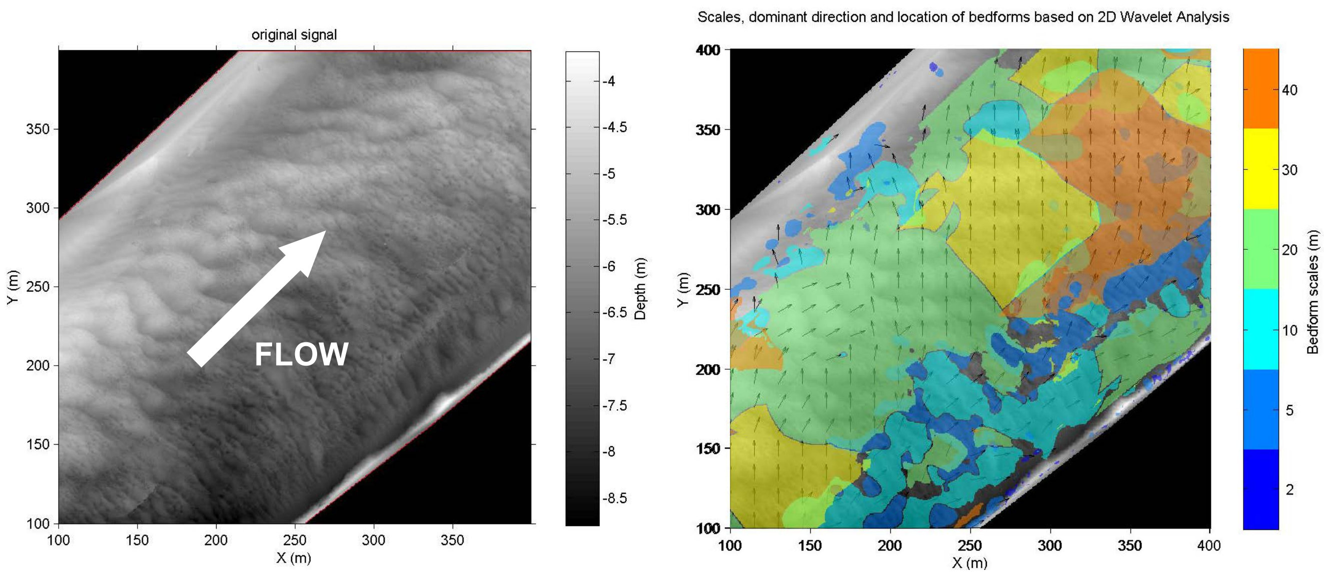

Fig. 5. Results of the 2D WT tool applied to the Missouri River bathymetry data. Original bed elevation map (left) and identified bedform scales map (right).

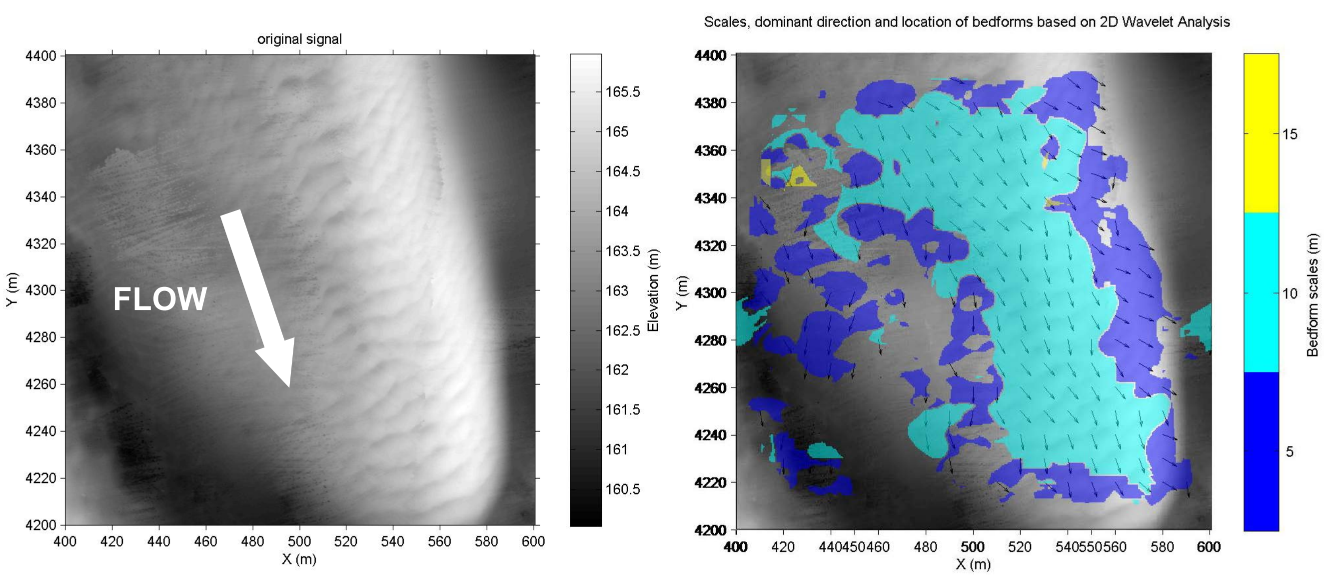

Fig. 6. Results of the 2D WT tool applied to the St. Clair River bathymetry data. Original bed elevation map (left) and identified bedform scales map (right).

RESULTS

The 2D WT tool allows the analysis of bathymetric data sets to obtain dominant bedform scales, their location and migration direction for the whole field based on the continuous wavelet transform and the Morlet wavelet. This provides a significant improvement with respect the existing techniques which were only capable of 1D bedform scale analysis (Cataño-Lopera *et al.*, 2009).

The results are obtained as a shadowed area map showing the location, scale and direction of the dominant bedforms present superimposed on the original bathymetry. This allows scientists to easily identify the relevant bed features and their location, as well as their possible relations with the hydrodynamic conditions present.

Particularly interesting is the fact that the 2D WT tool is able to identify the existence of different bedform scales superimposed in the same region of the bathymetry field. The direction feature can be very useful in these cases to identify the dominant flows that led to the development of each one of the bedform scales.

IMPACT/APPLICATIONS

Wavelet analysis has been used in numerous studies in areas such as geophysics (Farge, 1992; Meyers et al., 1993; Weng and Lau, 1994; Liu, 1994; Gu and Philander, 1995; Massel, 2001), biology and medicine (Dettori and Semler, 2007), and acoustics (Lardies, 2007). However, this technique had not been extensively applied to the analysis of bedforms generated either under unidirectional currents, oscillatory flows or a combination of both, until now.

The interesting results obtained through this work under laboratory and field conditions suggest that the 2D WT tool has great potential for deployment in the field and could yield extremely useful information for naval operations.

RELATED PROJECTS

None

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HONORS/AWARDS/PRIZES

IAGLR Chandler-Misener Award for most notable paper published in Journal of Great Lakes Research in 2011, International Great Lakes Association (2012)
Hunter Rouse Hydraulic Engineering Lecture Award, American Society of Civil Engineers, 2012
National Award for Scientific Contributions to Science and Technology from SENCYT, Government of Panama, Panama Canal Authority (2012)
Elected Fellow Environmental Water Resources Institute (2013)
Elected Distinguished Member, American Society of Civil Engineers, ASCE (2013).