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Nonlinear Analysis of Seafloor Topography

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Long-Term Goals:

Large- and small-scale tectonism and volcanism shape seafloor topography near Mid-Ocean Ridges (MOR) and produce a variety of both regular and irregular morphological features. Large consistent features such as the Mid-Atlantic Ridge (MAR), central valley, and crestal mountains, are superimposed by smaller and more irregular features such as ridge offsets, ridge-parallel faults, and volcanic constructions. Many of these features are observable on Sea Beam swath-collected bathymetry. Our long-term objective is to quantify regularities in seafloor morphology and determine which features are best described by purely stochastic processes, which are suitable for deterministic physical and predictive models, and which fall somewhere in between.

Scientific and Technological Objectives:

This research has focussed on finding and analyzing deterministic (regular, periodic or chaotic) and stochastic variations in seafloor faulting and volcanism by using and developing image processing and non-linear analysis techniques. Quantitative analysis of features requires a digital data base with the locations of only specific features, e.g. the locations of all ridge-parallel faults. To achieve this we developed 2-dimensional digital filters designed to decompose topographic images into data bases containing, for example, fault locations. The filters were designed using wavelet transforms, event/scale decomposition techniques that can be adapted to screen for features of a given size and shape. The data bases containing the locations of specific features were then processed with nonlinear data analysis techniques that measure determinism vs. stochasticity and linearity vs. nonlinearity. Data sets for this study included a 1600 km Sea Beam bathymetric profile from the northeast Pacific and Hawaii.

Background:

In year one of this two-year project, we concentrated on developing the wavelet transform into a tool suited to identifying and isolating topographic features in bathymetric and side-scan sonar data. The wavelet transform gives a time/frequency (or equivalently, space/scale) decomposition of a signal. It can be thought of as a bank of linear filters which decompose a signal into a set of band-pass filtered time (or spatial) series. Each series contains information about events at a given scale. The actual shape of the filter, the wavelet, can be varied to select for events of different shapes, i.e. ridges, valleys, rough topography, transients signals, etc. Wavelet transforms can be applied to 1-dimensional data series or 2-dimensional data matrices (images or maps). In year two of this project we concentrated on studying nonlinear dynamics data analysis methods and adapting them to use on data series of fault locations obtained via the wavelet transform. These nonlinear methods are based on the principles of embedology, where a time series is transformed into a higher dimensional state-space representation of a system via time-delay embedding. For example, given data series X(t)=x(tl),x(t2),x(t3),x(t4)....x(tn), a three dimensional state vector V can be created using time delays such that V(t)=[(x(t1),x(t2),x(t3))1, (x(t2),x(t3),x(t4))2, (x(t3),x(t4),x(t5))3....(x(tn-2),x(tn-1),x(tn))n-2]. Analysis of the geometry of this new embedded vector yields information on the dimension of the dynamics of the underlying system, the amount of stochasticity vs. low dimensional dynamics, and the predictability of the time series.

Approach:

The approach we have taken in this study is to 1) identify quality one- and two-dimensional bathymetric and side-scan sonar data sets, 2) design one-dimensional wavelet transforms to isolate features in one-dimensional bathymetric profiles, 3) design two-dimensional digital filters based on wavelet theory to identify fault scarp locations in bathymetry and side-scan images, 4) apply nonlinear dynamics analysis to quantify stochasticity, low-dimensional dynamics and predictability in fault locations near Mid-Ocean Ridges.

Accomplishments and Results:

Three projects employing the wavelet transform to identify morphological features were completed in year one: analysis of a straight bathymetric profile from the Pacific, fault scarp identification in Sea Beam coverage of a 100 km x 70 km section of the MAR, and a comparison of fault and ridge identification in Sea Beam bathymetry with that in side-scan sonar images from the same area in the MAR. In year two we designed a wavelet filter for isolating faults in a section of the ONR Natural Laboratory. A series of nonlinear analysis techniques were studied, and then tested at a workshop (Nonlinear data analysis in marine ecology) held at WHOI under the ONR/URIP program. These techniques which were applied to the fault data series, include: local geometric projection, nonlinear prediction, local vs. global prediction and various measures of stochasticity.

Impact on Science and Relationship to Other Projects:

The nonlinear analysis of fault locations will identify regions of the seafloor which are more or less able to be described by deterministic models. Thus it will help researchers of seafloor generation processes identify areas which may have been crested by deterministic physical processes rather than uniform stochastic processes. These data analytical techniques can be used on time series generated by almost any processes and thus they can be used across many research disciplines. The wavelet image analysis usefully identifies features of the seafloor in bathymetric and side-scan sonar images. The techniques can easily be extended to use on other types of images, including those from shallow water sonar.

Paper Resulting from This Work:

Little, S.A. and Smith, D.K, 1996, Fault scarp identification in side-scan sonar and bathymetry images from the Mid-Atlantic Ridge using wavelet-based digital filters, in L.F. Pratson and M. Edwards (eds.), Advances in Seafloor Mapping using Sidescan Sonar and Multibeam Bathymetry Data, Mar. Geophys. Res., in press.

Little, S., S. Ellner, M. Pascual, M. Neubert, D. Kaplan, T. Sauer, H. Caswell, and A. Solow. 1996. Detecting nonlinear dynamics in spatio-temporal systems, examples from ecological models. Physica D 96:321-333.

Little, S.A., 1994, Wavelet analysis of seafloor bathymetry, an example, Wavelets in Geophysics, E. Foufoula-Georgiou and P. Kumar (Eds.), 365pp, Academic Press, 167-182.

Little, S.A., P.H.Carter and D.K. Smith, 1993, Wavelet analysis of a bathymetric profile reveals anomalous crust, Geophys. Res. Letts, 20, 18, 1915-1918.

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