Geophysical Research Abstracts,
Vol. 11, EGU2009-1984, 2009
EGU General Assembly 2009

Characterization of Fault Roughness at Various Scales: Implications of Three-Dimensional High Resolution Topography Measurements

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Accurate description of the topography of active faults surfaces represents an important geophysical issue because this topography is strongly related to the stress distribution along fault planes, and therefore to processes involved in earthquake nucleation, propagation, and arrest.

In the present study, we investigate the scaling properties, including possible anisotropy properties of several outcrops of two fault surfaces (Vuache strike-slip fault, France, and Magnola normal fault, Italy) in limestones. At the field scale, recent Light Detection And Ranging (LIDAR) apparatus are used to acquire digital elevation models of the fault roughness over surfaces of 0.25 m^2 to 600 m^2 with a height resolution ranging from 0.5 mm to 20 mm. At the laboratory scale, the 3D geometry is obtained on two slip planes, using a laser profilometer with a spatial resolution of 20 μm and a height resolution less than 1 μm.

The scaling properties of these surfaces are measured using six different signal processing techniques. To investigate quantitatively the reliability and accuracy of the different methods, we generated synthetic self-affine surfaces with azimuthal variation of the scaling exponent, similar to what is observed for natural fault surfaces. The accuracy of the signal processing techniques is assessed in terms of the difference between an "input" self-affine exponent used for the synthetic construction and an "output" exponent recovered by those different methods. Two kinds of biases are identified: artifacts inherent to data acquisition and intrinsic errors of the methods themselves. In the latter case, the statistical results of our parametric study provide a quantitative estimate of the dependence of the accuracy with system size and directional morphological anisotropy.

Finally, using the most reliable techniques, we characterized the topography perpendicular to the slip direction that displays a similar scaling exponent $H_\perp = 0.8$ at all scales. However, our analysis indicates that for the Magnola fault surface the scaling roughness exponent parallel to the mechanical striation is identical at large and small scales $H_{//} = 0.6 - 0.7$ whereas for the Vuache fault surface it is characterized by two different self-affine regimes at laboratory and field scales. We interpret this cross-over length scale as a witness of different mechanical processes responsible for the creation of fault topography at different spatial scales.