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Revealing Machine Learning's potential for morphotectonic analysis of marine faults: Application to the North-South faults in the Alboran Sea (Westernmost Mediterranean)

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Seismic hazard assessment requires a detailed understanding of the evolution of fault systems, rupture processes, and linkage between segments. Identifying and characterizing Quaternary surface faulting features, such as fault scarps, provide valuable morphotectonic data on cumulative displacement over time, especially in regions with moderate to low seismic activity. Although fault cumulative vertical surface offsets have been traditionally measured using topographic profiles, these profiles are unevenly spread along the faults and may not reflect all the morphological changes along them. To address this situation, expanding the analysis to encompass a larger number of profiles is a viable option; nevertheless, manually executing this task would prove significantly time-consuming. Machine Learning (ML) has shown unprecedented capacities to evaluate large datasets in reduced time and provide a wealth valuable information with their related uncertainties. With this in mind, we propose a ML algorithm called ScarpLearn based on Convolutional Neural Networks (CNN) to compute the vertical cumulative displacement and its uncertainty for normal fault scarps. Despite ScarpLearn being initially developed to characterize simple scarps in onshore areas, we have enhanced its capabilities so that it can also be used in offshore areas subject to oceanic processes. This includes, among others, more intense diffusion, or the presence of seabed features such as pockmarks. Additionally, we have improved the code's versatility by providing a method modification that allows it to better characterization of scarps in more complex areas where multiple faults offset the seafloor. To this, we have trained the algorithm using a large database of realistic synthetic bathymetric profiles, including different parameters such as fault dip, slip velocity, scarp spread, scarp diffusion coefficient, and variable resolutions to ensure adaptability to all datasets. These modifications have resulted in the improvement of the ScarpLearn algorithm’s adaptability, elevating its accuracy and reliability in capturing the complexity of marine fault systems, but also applicable to terrestrial systems. We have applied the new ScarpLearn version to the North-South faults of the northern Alboran Sea, contributing to the accurate analysis of this Plio-Quaternary transtensional system and its complex geological structures. This innovative approach has allowed us to refine the morphotectonic analysis of the area and to understand better the geodynamics of the North-South faults system.

In this research, we have explored the advances of the CNN method achieved in oceanic environments, considering intensive data compilation, computational time, accuracy, uncertainties, and current limitations. Our advances demonstrate the ScarpLearn ML potential, specifically tailored to analyze marine environments and multiple fault segments both onshore and offshore. Our research results contribute to the progress of marine geosciences by improving morphotectonic analysis using ML algorithms.

Keywords: Convolutional Neural Networks (CNN), Oceanic processes, Normal faults, Multiple scarps.