REVEALING MACHINE LEARNING'S POTENTIAL FOR MORPHOTECTONIC ANALYSIS OF MARINE FAULTS: APPLICATION TO THE NORTH-SOUTH FAULTS IN THE ALBORAN SEA (WESTERNMOST MEDITERRANEAN)

Canari, A.(1,2),**Pousse-Beltran, L.**(3), **Giffard-Roisin, S.**(3), **Perea, H.**(1) and **Martínez-Loriente, S.**(1)

(1) Institute of Marine Sciences - CSIC, Marine Geosciences, Barcelona, Spain ; (2) Faculty of Earth Sciences, University of Barcelona, Barcelona, Spain;
(3) Institute of Earth Sciences, University of Grenoble-Alpes, Grenoble, France

Contact author: acanari@icm.csic.es

QR to abstract

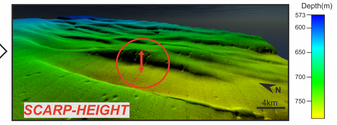
INTRODUCTION

MOTIVATION

- **Earthquakes** and **tsunamis** can be **geological hazards** of great **social impact**.
- Analyzing **faults' morphotectonic parameters** (e.g., Scarp-Height) **enhances knowledge** of their earthquake-generating potential, thereby **improving seismic hazard assessment**.

Surface-rupturing normal faulting photography from Norcia Earthquake in Italy's Apennine Mountains (Marsan,D.et al. 2017)

RV Sarmiento de Gamboa (Spain-CSIC)



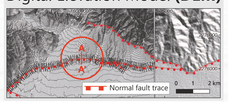
3D Marine surface-rupturing normal faulting from the Alboran Sea.

PROBLEMATIC

Traditional methods for morphotectonic estimations often rely on **empirical or semi-automatic approaches** (e.g., Hodge et al., 2019; Wolfe et al., 2020) that **require** substantial **expert-time.**

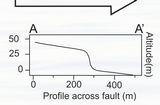
NEW METHOD BUT NOT DEVELOP FOR MARINE ENVIORNMENTS

Digital Elevation Model **(DEM)**



DEM of Ameca fault in Mexico with topographic profiles across active normal fault (Pousse,L et al. 2022 PATA)

Topographic profiles

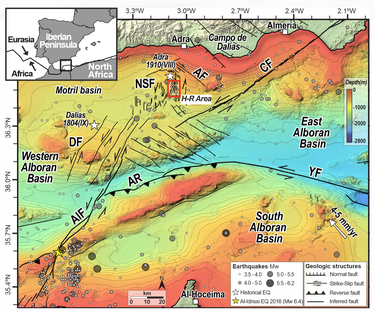


ScarpLearn algorithm
(Pousse,L et al. 2022 PATA)

?

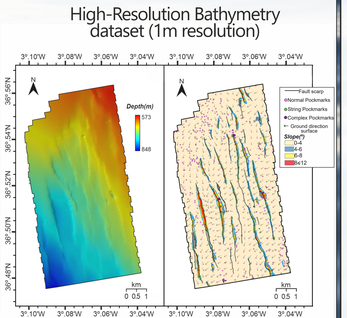
Applying Machine Learning for an advanced **quantification analysis** data at **marine environments**.

OUR STUDY AREA AND DATA



Tectonic map of the Alboran Sea. The Red box is the high-resolution bathymetric data of the North-South fault system.

High-Resolution Bathymetry dataset (1m resolution)



High-Resolution bathymetry area Geomorphologic map

CONVOLUTIONAL NEURONAL NETWORK (CNN) FOR OCEANIC PROCESS

SIMULATED MARINE FAULT SCARPS

Creatre simulated dataset of bathymetric profiles with random parameters.

DEEP LEARNING METHOD BASED ON CNN MODEL

Scarp Learn for Bathymetry datasets

Training the CNN on the synthetic data catalogue and create a model.

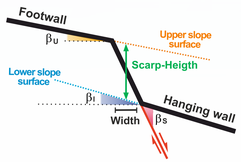
APPLY MODEL TO REAL DATA

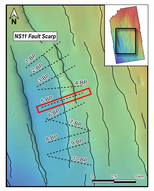
Run the model to real data to obtain the scarp height and uncertainties of each profile.

PROJECT STEPS

1- Implement the deep learning algorithm for offshore applications.

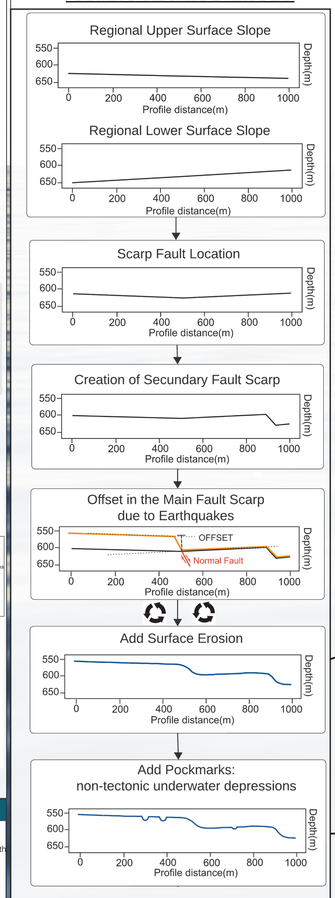
2-Validate the algorithm using ScarpLearn Bathymetry in the designated study area against manually estimated results.





WORKFLOW

DATASET SIMULATION



Synthetic Bathymetric-Profiles

Within study:

1000 train — 50% — **Trainning catalogue**

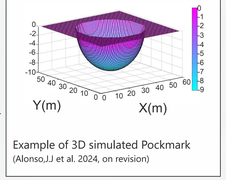
1000 validation — 50% — **Validation catalogue**

Development of diverse simulated marine profiles based on geomorphological expertise

Diffusivity (m²/kyr):
Higher values are observed offshore compared to onshore areas.

Onshore: 0.5-10 m²/kyr (Hodge et al., 2019)
Offshore: 0.5-20 m²/kyr (understudy in our research)

Fluid outflow seafloor depression

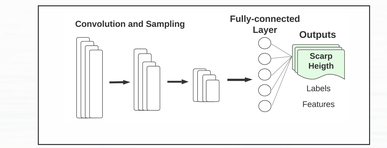


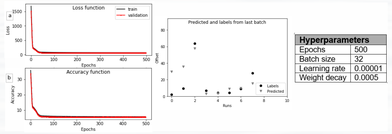
Example of 3D simulated Pockmark (Alonso,J.J et al. 2024, on revision)

MODEL TRAINNING

2 CNN Models employed

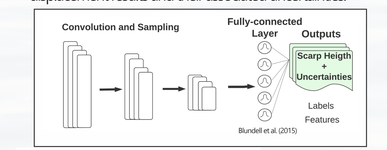
1) Non-Bayesian model: Exclusively for tests and validations, owing to its shorter computational time.

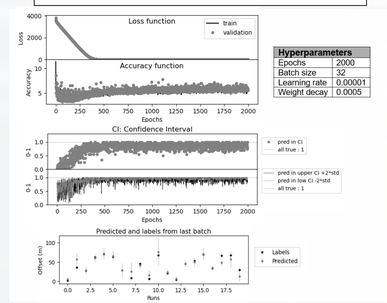




Hyperparameters	
Epochs	500
Batch size	32
Learning rate	0.00001
Weight decay	0.0005

2) Bayesian inference model: to derive final fault displacement results and their associated uncertainties.

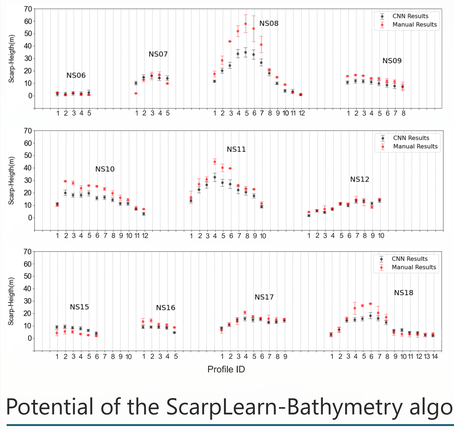


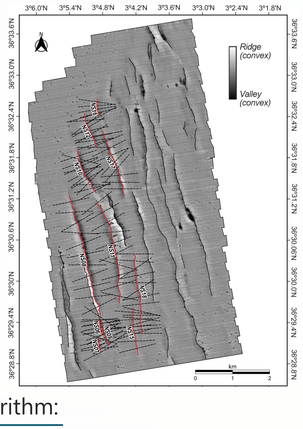


Hyperparameters	
Epochs	2000
Batch size	32
Learning rate	0.00001
Weight decay	0.0005

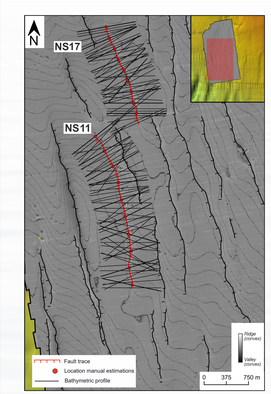
APPLICATION TO THE NORTH-SOUTH FAULTS

Validation of our CNN model with manual estimations:

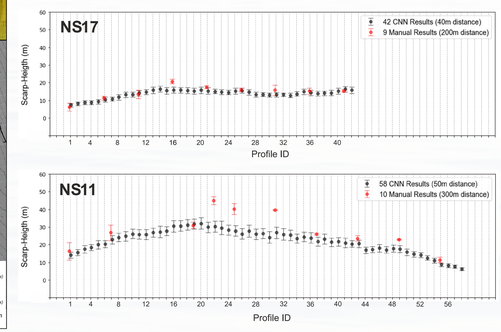




Potential of the ScarpLearn-Bathymetry algorithm:



Manual estimation	Scarp Learn Bathymetry
> several weeks	< 1 minute



KEY MESSAGE / FUTURE RESEARCH

- **ScarpLearn's Bathymetry** models have been **validated** for offshore datasets by **manual estimations** of the **high-resolution dataset** (1m resolution) of our study area.
- **Diffusivity** related to the bottom currents and non-cohesive materials in the seafloor and the complexity of the area due to the **multiscarps probably produce misfit** in the **validation**.
- Our **quantitative approach** provides a significantly **larger database** of **results** than traditional methods, enabling a more **comprehensive analysis** of **offshore fault systems' growth and evolution**.
- Integration of **Deep Learning** techniques offers **potential** for
  1-Improved characterization of fault scarps.
  2-Reduced time and effort requirements.
  3-Enhanced uncertainty quantification.

UPCOMING RESEARCH → Extend the application of our model to bathymetric data of lower resolution, encompassing the entirety of the North-South fault system.

References

[1] Alonso del Rosario,J.J.,Canari,A.,Blázquez-Gómez,E., and Martínez-Loriente,S., Posit: An Automated Tool for Pockmark Signature Detection and Other Applications (on revision).
[2] Blundell,C.,J.Cornebise,K.Kavukcuoglu, and Wierstra,D. 2015. « Weight uncertainty in neural network ». In International conference on machine learning, 1613-22. PMLR.
[3] Hodge, M., J., Biggs, Fagereng, A., Elliott,A., Mdala, H., and Mpheso. F., 2019. « A Semi-Automated Algorithm to Quantify Scarp Morphology (SPARTA): Application to Normal Faults in Southern Malawi » Solid Earth 10(1):27-57.
[4] Nash, D. B. 1980. Morphologic dating of degraded normal fault scarps. The Journal of Geology, 88(3), 353–360.
[5] Marsan,D, Beroza,G.C., and Gomberg,J. 2017. «How Earthquakes Start and Stop». Earthquakes: Nucleation, Triggering, Rupture, and Relationships to Aseismic Processes; Cargèse, Corsica, France.
[6] Pousse,L., Giffard-Roisin,S., Audin,L., Lacan,P., Lallemand,T., Cougoulat,G., and Nuñez Meneses,A. 2022. Active Tectonics and Archeoseismology (PATA) Extended Abstract.
[7] Wolfe, F. D., T. A. Stahl, P. Villamor, and B. Lukovic. 2020. « Short Communication: A Semiautomated Method for Bulk Fault Slip Analysis from Topographic Scarp Profiles ». Earth Surface Dynamics 8 (1): 211-19.

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