# PROBABILISTIC IDENTIFICATION OF ROCKFALL SOURCE AREAS: AN EXAMPLE FROM EL HIERRO (CANARY ISLANDS, SPAIN)


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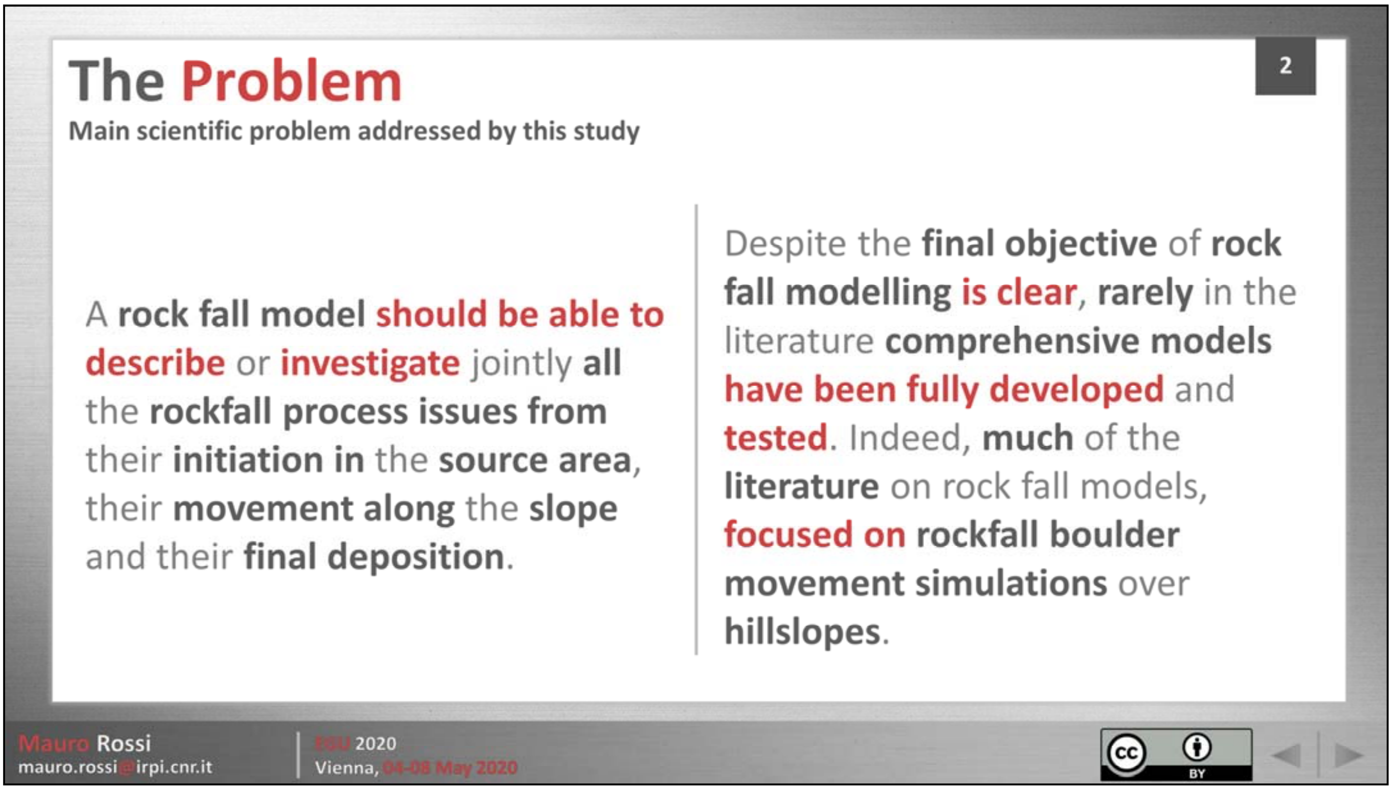
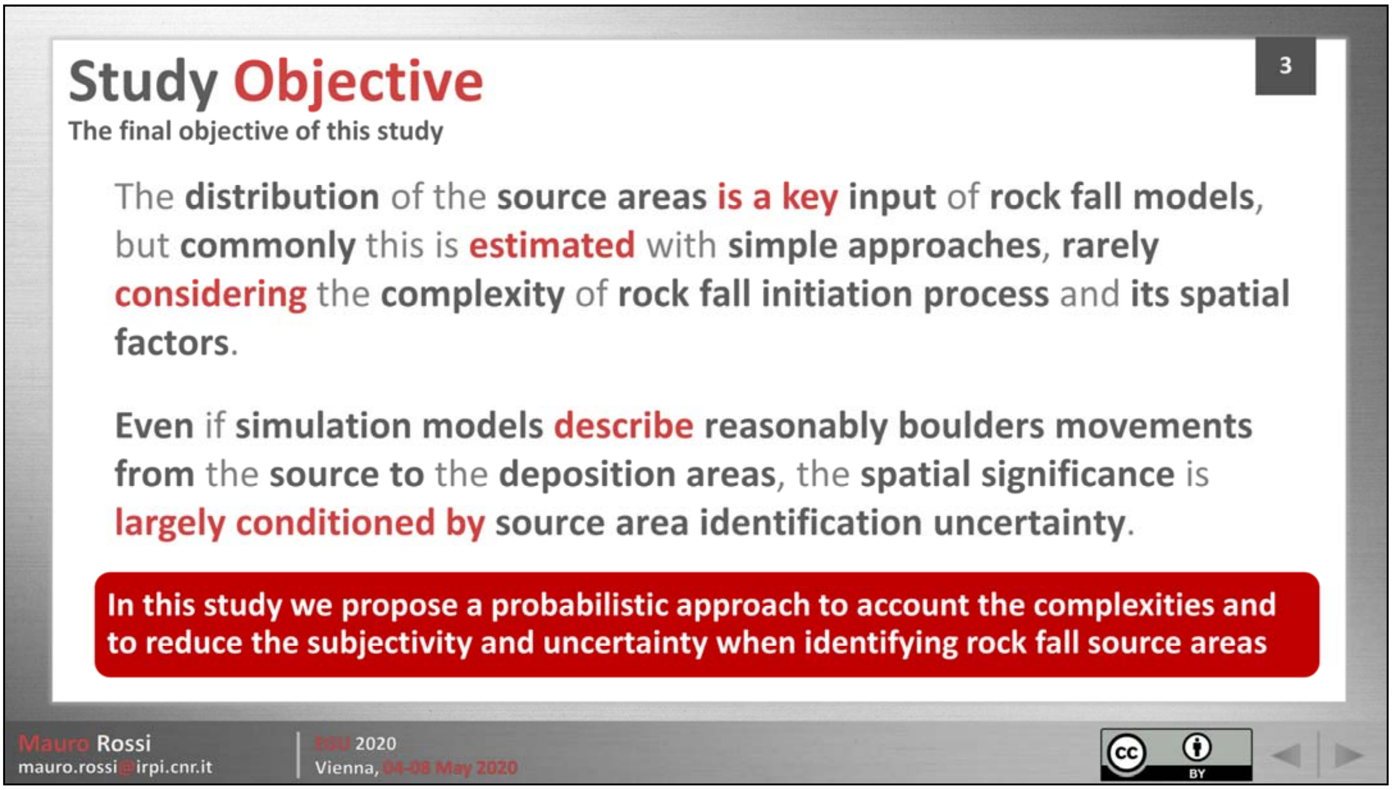


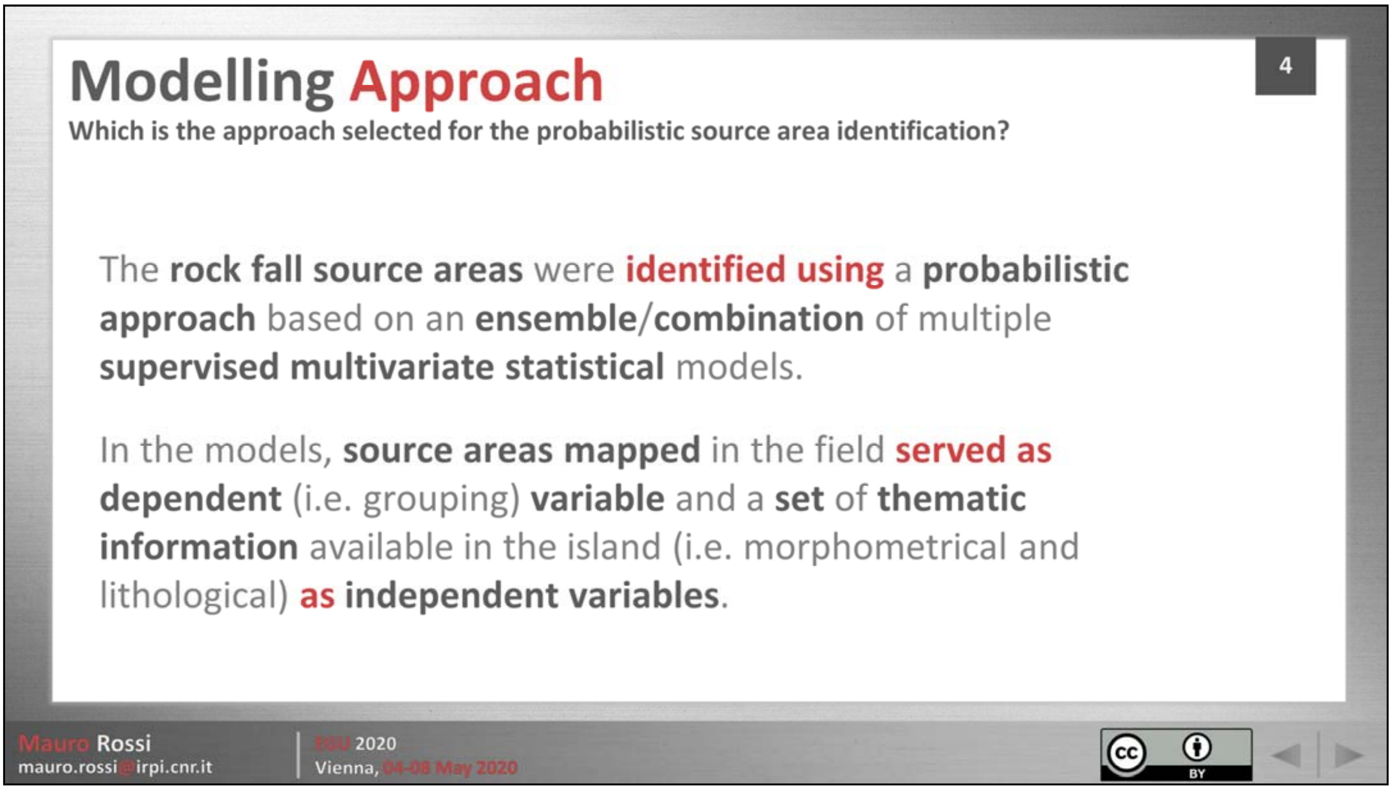

A rock fall model should be able to describe or investigate jointly all the rockfall process issues from their initiation in the source area, their movement along the slope and their final deposition. Despite the final objective of rock fall modelling is clear, rarely in the literature comprehensive models have been fully developed and tested. Indeed, much of the literature on rock fall models, focused on rockfall boulder movement simulations over hillslopes.




The distribution of the source areas is a key input of rock fall models, but commonly this is estimated with simple approaches, rarely considering the complexity of rock fall initiation process and its spatial factors.

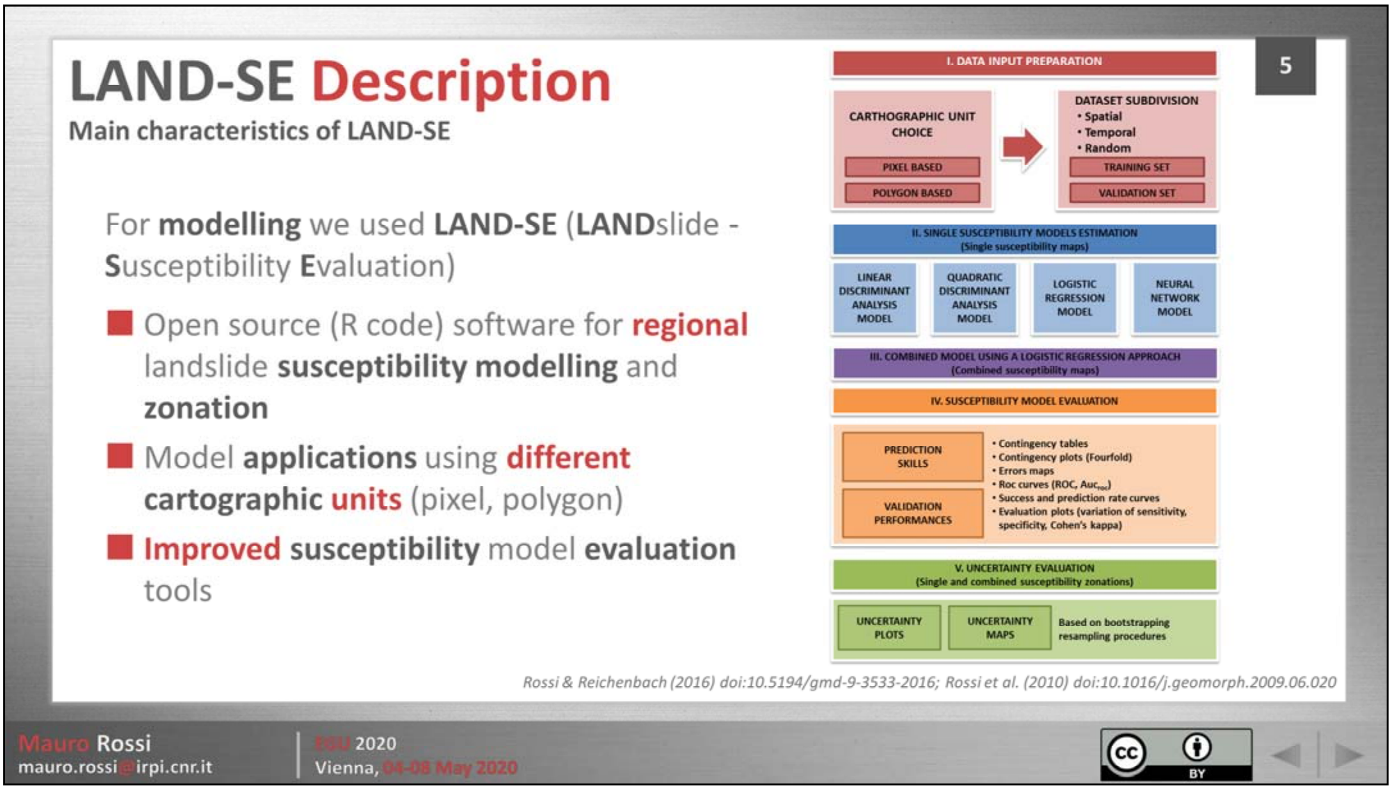
Even if simulation models describe reasonably boulders movements from the source to the deposition areas, the spatial significance is largely conditioned by source area identification uncertainty.

In this study we propose a probabilistic approach to account the complexities and to reduce the subjectivity and uncertainty when identifying rock fall source areas




The rock fall source areas were identified using a probabilistic approach based on an ensemble/combination of multiple supervised multivariate statistical models.

In the models, source areas mapped in the field served as dependent (i.e. grouping) variable and a set of thematic information available in the island (i.e. morphometrical and lithological) as independent variables.



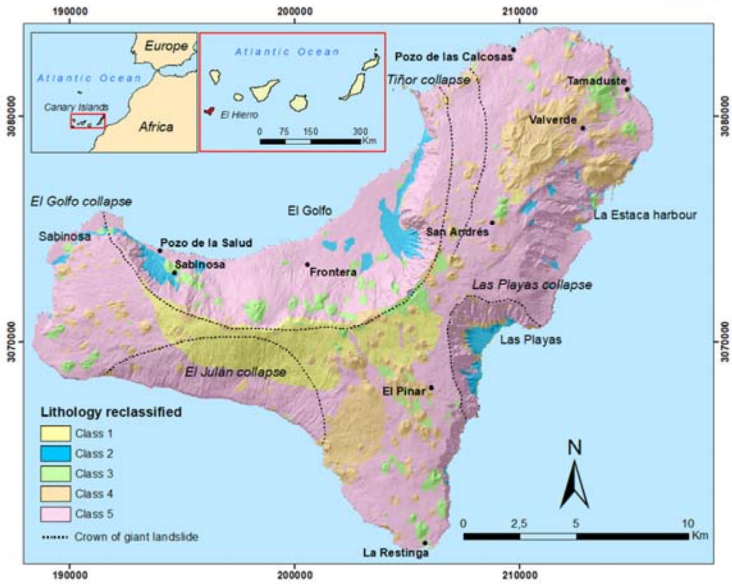

LAND-SE (LANDslide - Susceptibility Evaluation) is an Open source (R code) software for regional landslide susceptibility modelling and zonation, it can be used for modeling applications using different cartographic units (pixel, polygon), and it includes improved susceptibility model evaluation tools

# Study **Area**

El Hierro, Canary archipelago

| Class | Lithology | Type |
|---|---|---|
| 1 | Sand and Lapilli | Soft soils |
| 2 | Sedimentary deposit | Hard soils |
| 3 | Pyroclastic material | Soft rocks |
| 4 | Basalt flows and Trachyte | Hard rocks |
| 5 | Breccia and massive basalt | Very hard rocks |

Adapted from Hernández-Gutierrez (2014)

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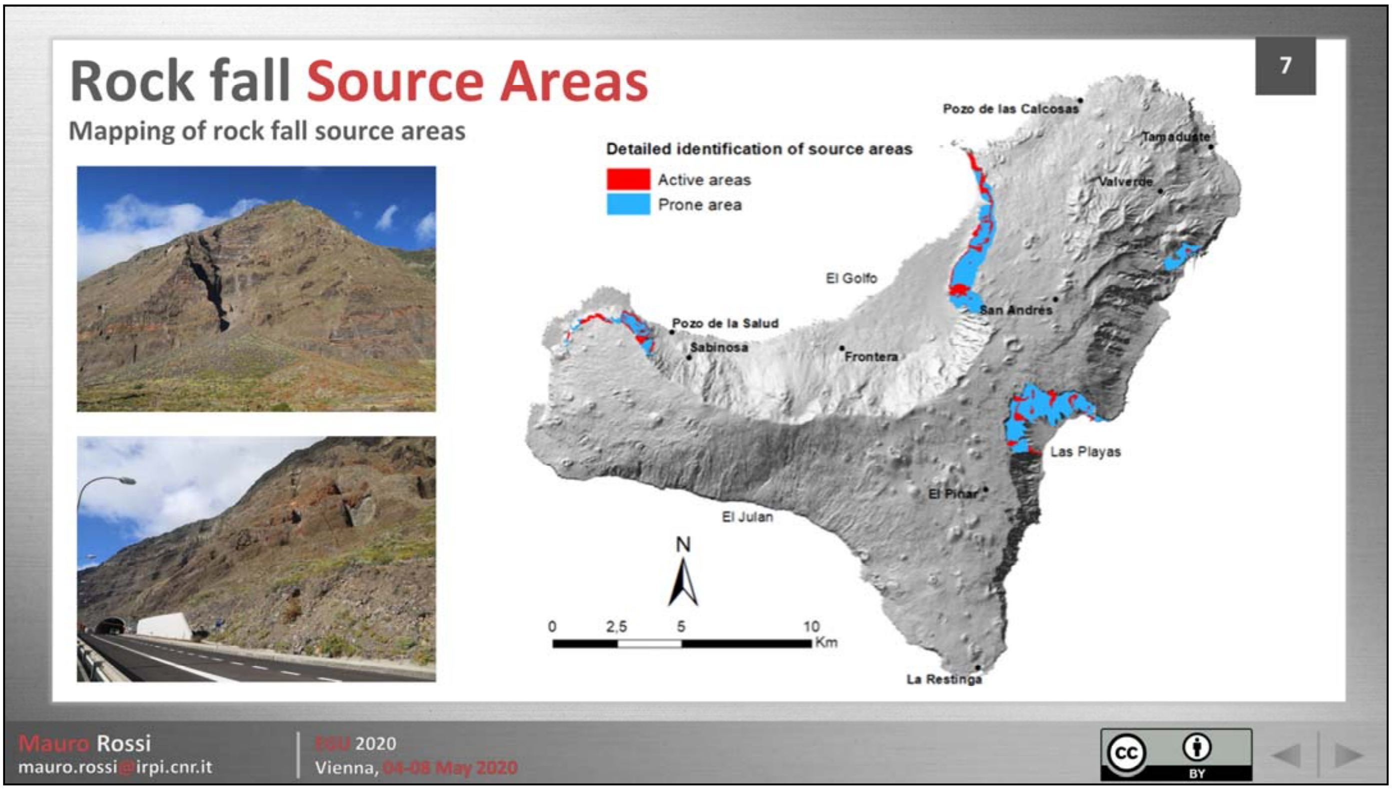
El Hierro, located in the south-western edge of the Canary Islands. The island has an extension of 268.71 km2 and a population of 11.166 inhabitants distributed in three municipalities: Frontera, El Pinar and Valverde. The island is located in a transitional zone between temperate and tropical climate where the temperature is controlled mainly by three factors: the trade-winds that affect the island most of the year, the abrupt relief and the contrast between the northern and the southern slopes. The higher rainfall levels are recorded during the autumn and winter, mainly in December when heavy storms are frequent, associated with intense rainfall and strong winds. The island has a peculiar truncated trihedral shape, with three convergent ridges of volcanic cones, separated by wide horseshoe-shaped embayment.

At least four giant landslides (El Golfo, El Julan, San Andres, and Las Playas) have modified the island during the last 200–300 thousand years.

The northern part of the island (El Golfo) is characterized by a flat area shaped by large volcanic debris-avalanche and by gravitative deposits bounding the long north facing escarpment with more than 1000 meters relief. The area is the result of giant landslide occurred in the Pleistocene. The South western side (El Julán) has a diversified morphology with an extremely high roughness, which is the results of an east facing slope with an average terrain gradient close to 50% shaped by numerous channels covered with recent eruptive materials that formed slag deserts and malpais.

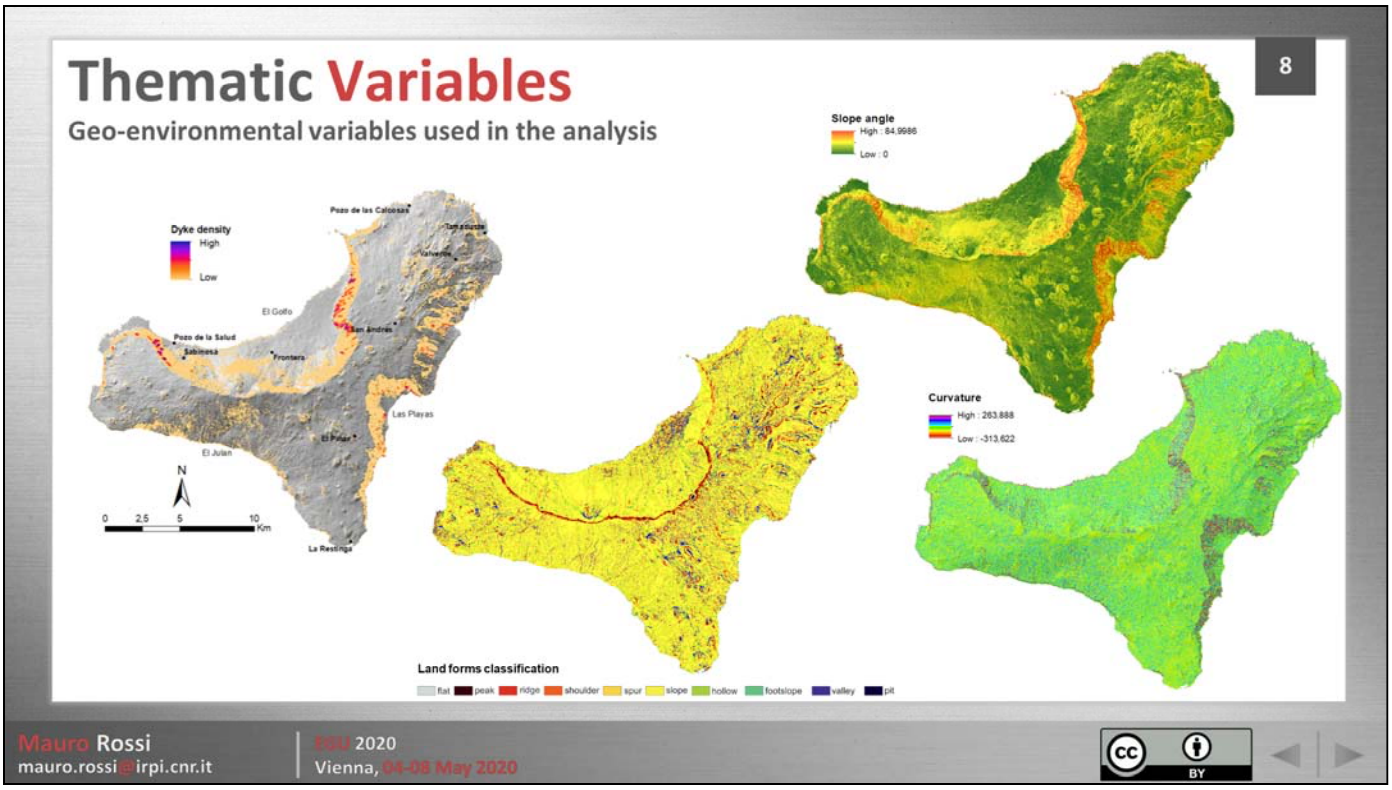
Rockfall is a widespread natural process in the island, occurring generally along the steepest rock cliffs and forming evident talus deposits with a conical shape. The impact of rockfalls is relevant as highlighted by the numerous interactions with urban structures and infrastructures.

The map show a simplified lithological map of El Hierro reclassified from the geological map. The classification mostly reflects the mechanical behavior of rocks cropping out in the island and was used as one of the main thematic parameter in the analysis.




The identification of rockfall source areas is a crucial step when modelling rockfall. In this analysis, we have used a combination of different techniques to identify source areas. We have preliminary selected 4 test-sites which are well recognized as prone to rockfalls: Las Playas, Sabinosa, El Golfo and La Estaca and then we mapped source areas through: (i) orthophotos interpretation; (ii) analysis of digital elevation model; (iii) analysis of geological and geomorphological features and (iv) field surveys.

The map shows the location of the source areas in the different test sites. In particular, we have identified 2 type of source areas, namely “Active” and “Prone” areas. With prone areas we identify those areas characterized by geological and geomorphological potentially prone to the rockfalls occurrence, but where recent evidences of detachments are not observed. Prone areas were identified heuristically analyzing orthophotos in the areas where the slope angle is larges of 45º. Active areas were mapped where recent evidences of detachments are visible in the field. Due to the difficult and dangerous site accessibility, UAVs were used for the recognition of the active areas.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Thematic Variables
Geo-environmental variables used in the analysis
Dyke density
High
Low
Pozo de las Calcosas
Tamaduste
Valverde
El Golfo
San Andrés
Pozo de la Salud
Sabinosa
Frontera
Las Playas
El Pinar
El Julan
N
0 2,5 5 10 Km
La Restinga
Slope angle
High : 84,9986
Low : 0
Curvature
High : 263,888
Low : -313,622
Land forms classification
flat peak ridge shoulder spur slope hollow footslope valley pit
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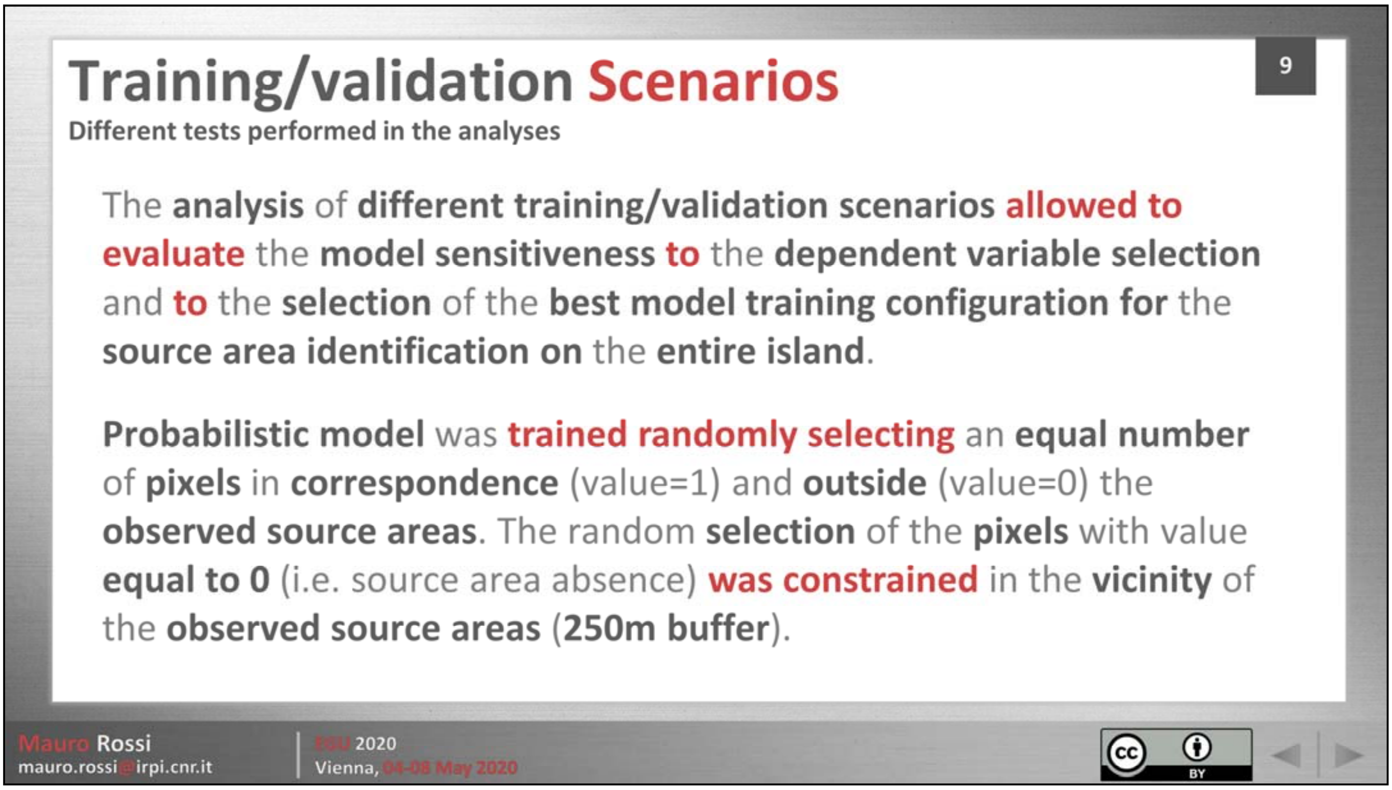


The analysis of different training/validation scenarios allowed to evaluate the model sensitiveness to the dependent variable selection and to the selection of the best model training configuration for the source area identification on the entire island.

Probabilistic model was trained randomly selecting an equal number of pixels in correspondence (value=1) and outside (value=0) the observed source areas. The random selection of the pixels with value equal to 0 (i.e. source area absence) was constrained in the vicinity of the observed source areas (250m buffer).

# Training/validation Scenarios

**Different tests performed in the analyses**

**List** of the **test sites** and **type** of **mapped source areas** (**active**, **prone**, **buffer**) **selected as training** and **validation sets in** the **different scenarios**.

| | Case | Training areas | Validation areas |
|---|---|---|---|
| **Scenario 1** | Case 1 | El Golfo and Las Playas | Sabinosa and La Estaca |
| | Case 2 | Sabinosa and La Estaca | El Golfo and Las Playas |
| | Case 3 | El Golfo, Las Playas, Sabinosa and La Estaca | El Hierro island |
| **Scenario 2** | Case 1 | El Golfo and Las Playas | Sabinosa and La Estaca |
| | Case 2 | Sabinosa and La Estaca | El Golfo and Las Playas |
| | Case 3 | El Golfo, Las Playas, Sabinosa and La Estaca | El Hierro island |
| **Scenario 3** | Case 1 | El Golfo and Las Playas | Sabinosa and La Estaca |
| **Scenario 4** | Case 3 | El Golfo, Las Playas, Sabinosa and La Estaca | El Hierro island |

| | Case | Source areas training | | | Source areas validation | | |
|---|---|---|---|---|---|---|---|
| | | Active | Prone | Buffer | Active | Prone | Buffer |
| **Scenario 1** | Case 1 | 1 | No Data | 0 | 1 | No Data | 0 |
| | Case 2 | 1 | No Data | 0 | 1 | No Data | 0 |
| | Case 3 | 1 | No Data | 0 | 1 | No Data | 0 |
| **Scenario 2** | Case 1 | 1 | 1 | 0 | 1 | 1 | 0 |
| | Case 2 | 1 | 1 | 0 | 1 | 1 | 0 |
| | Case 3 | 1 | 1 | 0 | 1 | 1 | 0 |
| **Scenario 3** | Case 1 | 1 | No Data | 0 | 1 | 1 | 0 |
| **Scenario 4** | Case 3 | 1 | No Data | 0 | 1 | 1 | 0 |

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List of the test sites and type of mapped source areas (active, prone, buffer) selected as training and validation sets in the different scenarios.

# Scenarios Results

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Synthesis of the training/validation performances in terms of Accuracy and Area Under ROC curve

| | Case | ACC (Accuracy) | | | $AUC_{ROC}$ (Area under Roc Curve) | | |
|---|---|---|---|---|---|---|---|
| | | Training | Validation | Difference | Training | Validation | Difference |
| Scenario 1 | Case 1 | 91.24 | 90.83 | 0.41 | 0.957 | 0.966 | - 0.009 |
| | Case 2 | 91.02 | 89.93 | 1.09 | 0.969 | 0.956 | 0.013 |
| | Case 3 | 91.26 | 90.6* | 0.66* | 0.961 | 0.966* | -0.005* |
| Scenario 2 | Case 1 | 90.28 | 86.14 | 4.14 | 0.944 | 0.932 | 0.012 |
| | Case 2 | 86.28 | 90.68 | - 4.40 | 0.933 | 0.943 | - 0.01 |
| | Case 3 | 89.47 | 88.61* | 0.86* | 0.945 | 0.951 | -0.006* |
| Scenario 3 | Case 1 | 91.24 | 86.43 | 4.81 | 0.957 | 0.932 | 0.025 |
| Scenario 4 | Case 3 | 91.24 | 88.61* | 2.63* | 0.962 | 0.955* | 0.007* |

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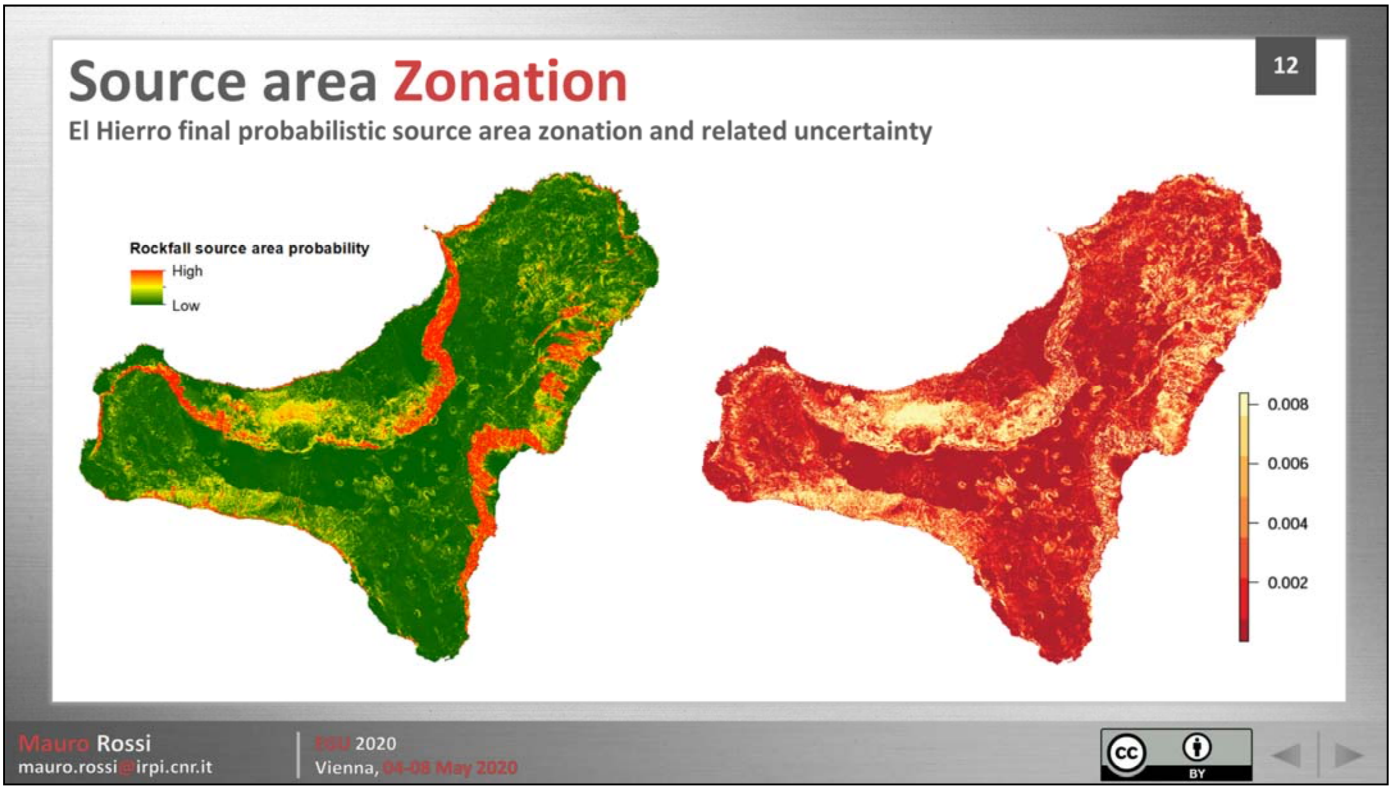
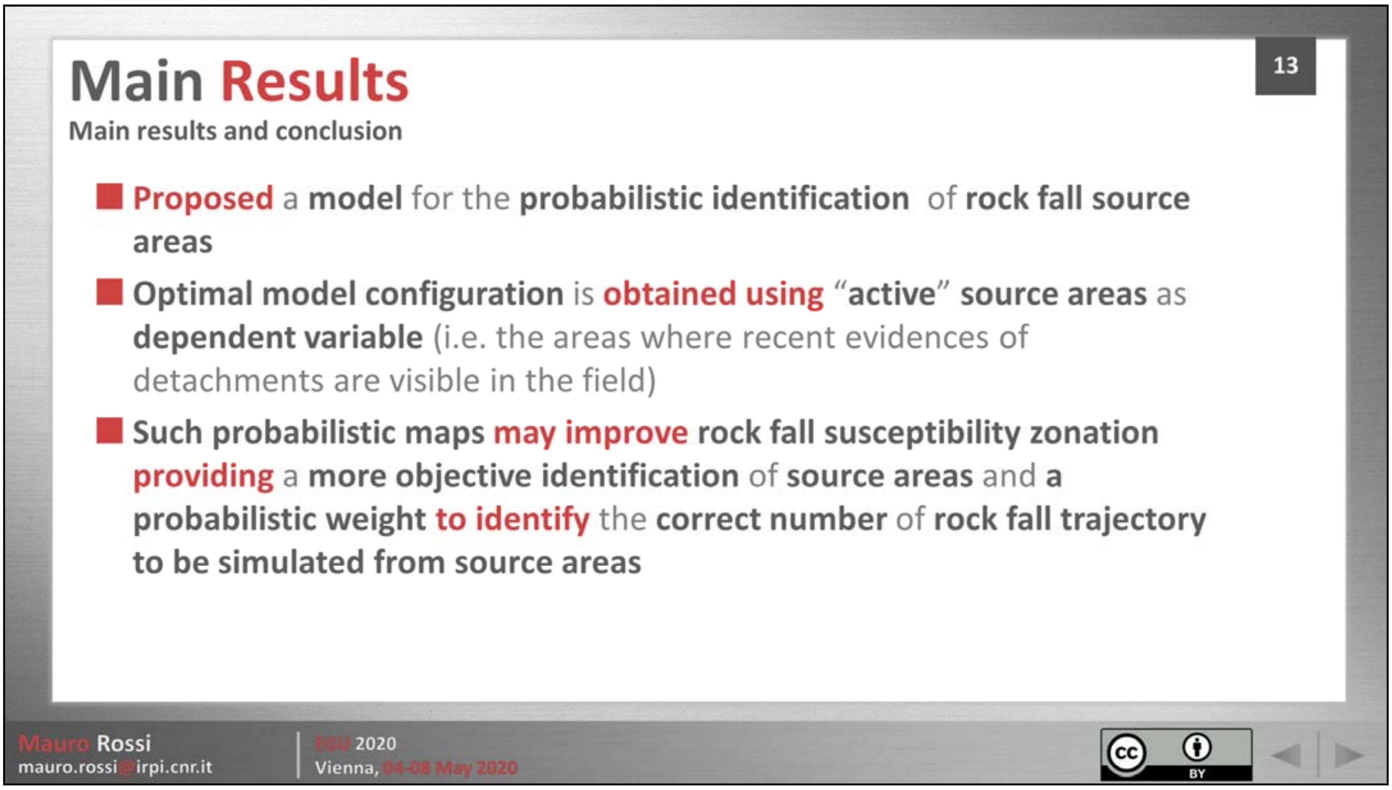
Table synthesizes for the different scenario the training/validation performances in terms of Accuracy and Area Under ROC curve. The asterisks in table, highlight the results of the model applications to the entire island (i.e. corresponding to validation of Case 3 for the different scenarios), which should be only considered as indicative of the real model performances.

The results show that the models are sensitive to the type of source area mapped in the field, with the best model performances obtained when using “active source areas” during training. Performances of models considering different test sites are close and do not indicate preferable training configurations. This indicates that accurate identification of active areas in the field even if limited to few study sites provide representative data to train the model. For these reasons the model for the entire study area was trained selecting all the test sites but considering only active source areas.




El Hierro final probabilistic source area zonation and related uncertainty. As expected, rock fall source areas are preferentially located in areas with high terrain gradient, but this factor itself is not sufficient to explain the spatial distribution of source area on the entire island, with the other information contributing significantly to the identification od area more prone to rock fall initiation.




Proposed a model for the probabilistic identification of rock fall source areas. Optimal model configuration is obtained using "active" source areas as dependent variable (i.e. the areas where recent evidences of detachments are visible in the field). Such probabilistic maps may improve rock fall susceptibility zonation providing a more objective identification of source areas and a probabilistic weight to identify the correct number of rock fall trajectory to be simulated from source areas