Contribution of Heliborne Electro-Magnetic survey for landslide prediction: application to La Martinique (West Indies, France)

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1. Motivations

Since 4 years , the French Geological Survey owns a heliborne electromagnetic coverage for overseas departments (i.e. Mayotte, Guadeloupe, La Martinique and la Réunion).

- The main goal was to acquire new information about the lithology, the geological structure and the regolith.
- The survey was performed by SkyTEM under the supervision of the French Geological Survey *(support by EU-ERDF, DEAL Martinique, the Martinique Region and the Water Office)*

Base on these survey, the French Environmental Ministry has decided to use the data in the framework of natural hazard assessment especially for slope instabilities.

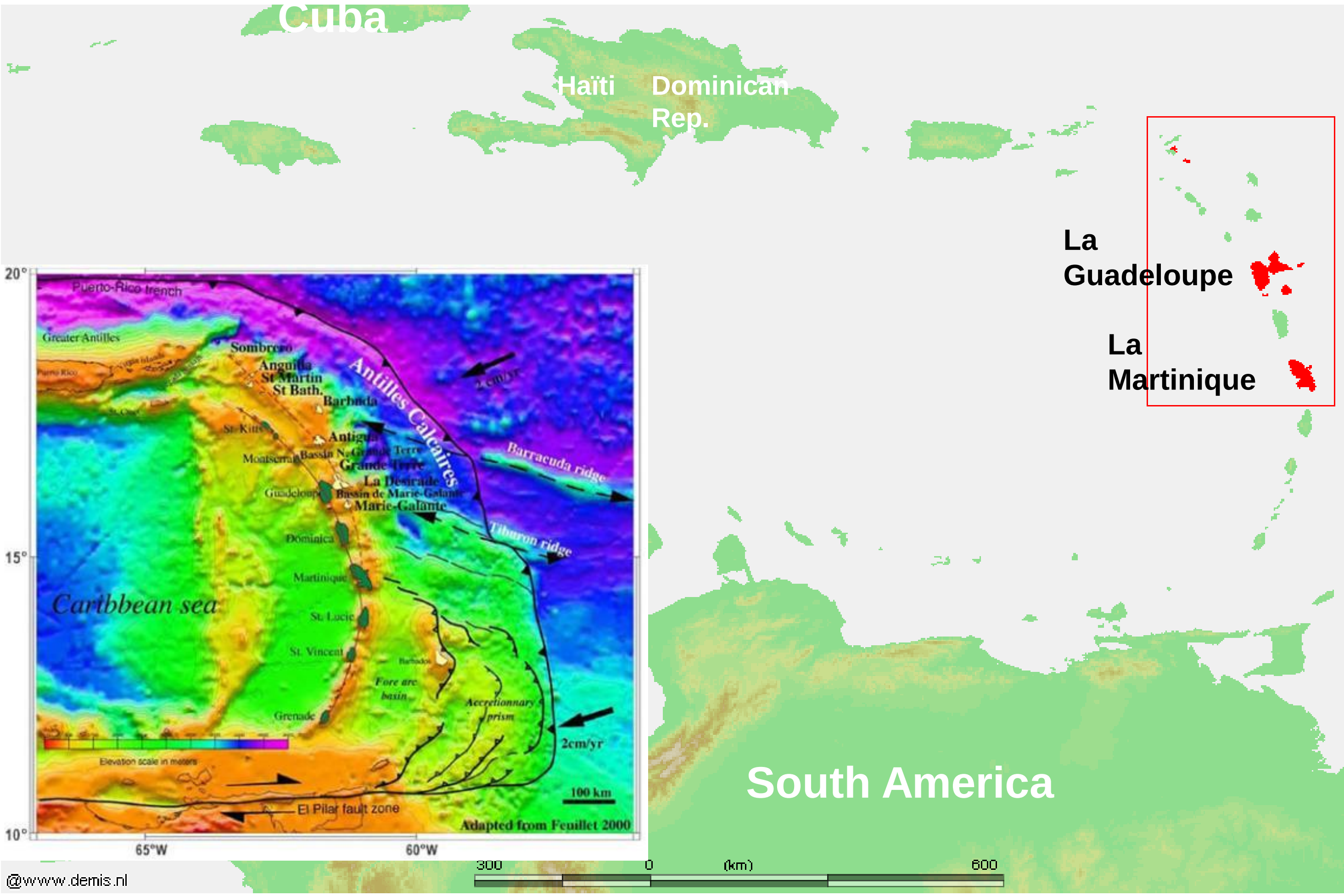
Thus the objectives of this study were:

- To assess the potentiality of the heliborne EM in the framework of landslide hazard analysis;
- To test an approach in order to help and improve the future revaluation of official PPR (legal documents) by coupling the derived 3D model with a physically based model computing the probability of failure (spatial model ALICE®).

2. Context

La Martinique:

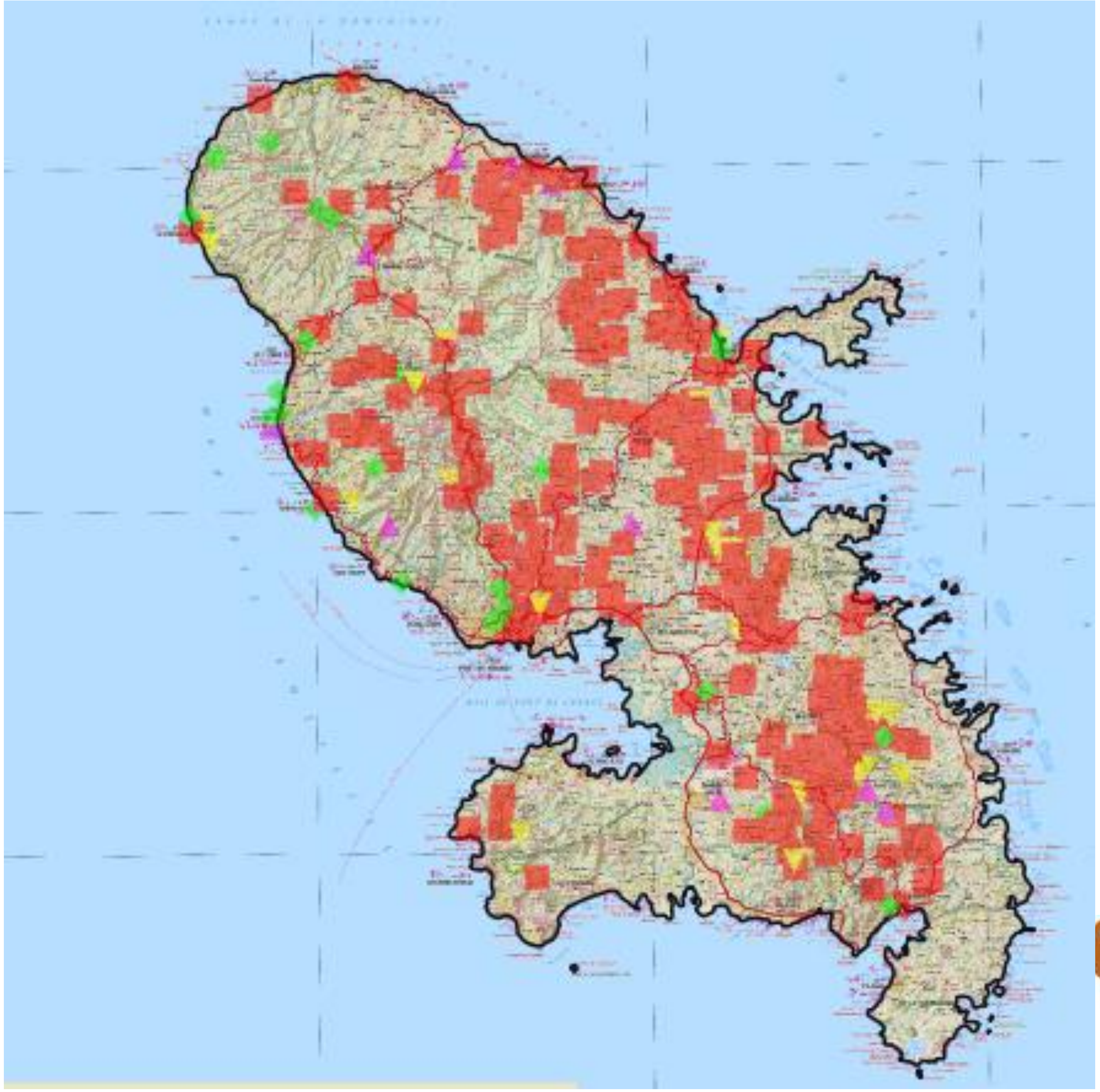
- Belongs to the French West Indies, composed of seven territories;
- Volcanic island resulting from the subduction of the Atlantic plate with the Caribbean plate;
- Territory subjected to slope instabilities.



2. Context

<u>Landslides</u>

- More than 500 phenomena inventoried (French official database –BDMvt)



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2. Context

Landslides are mainly due to :

- A complex lithology and soil:
  - Highly weathered volcanic lithology
  - Different type of soil with high clay content

- Hurricane seasons participating actively to land degradation

- Heavy land pressure (density ≈ 348 inh. per km^2, *5th French departement*) with anarchic development *(no drainage, no stabilization plan, etc…)*

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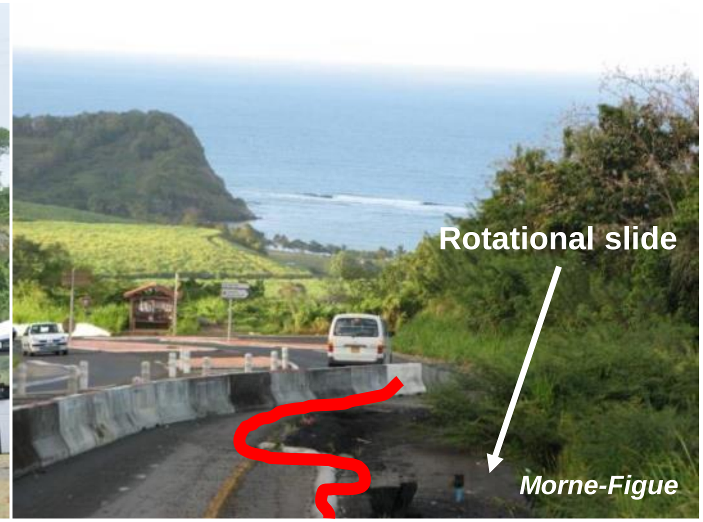
2. Context

Landslides

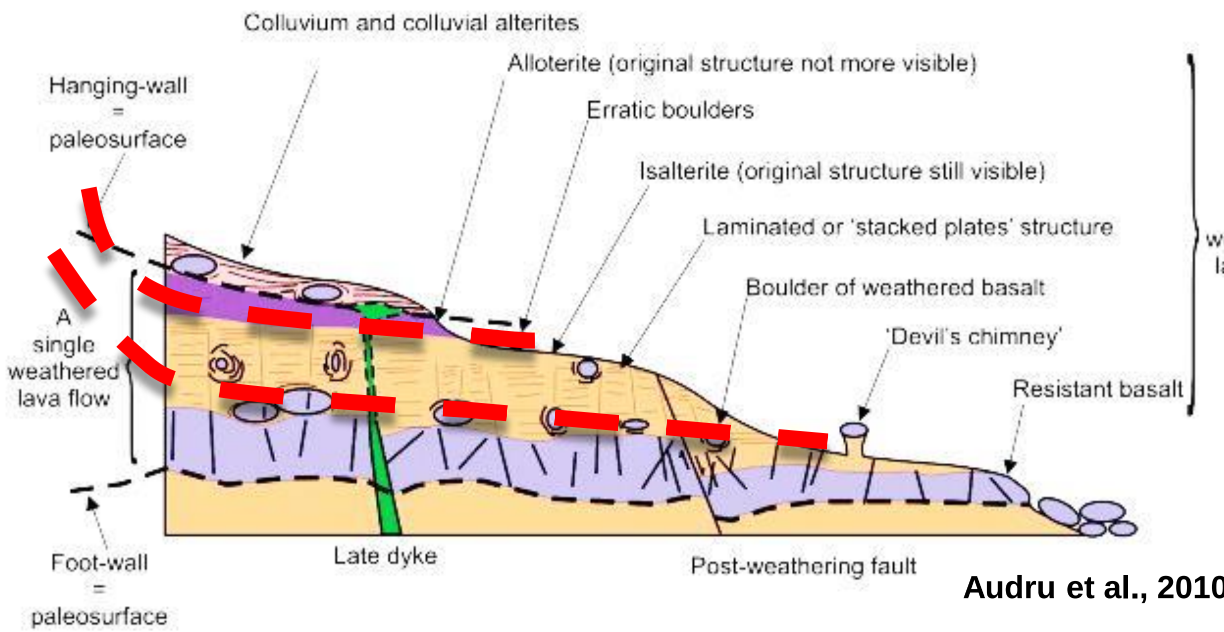
- Shallow and deep landslides;
- Translational, rotational, mudslide phenomena



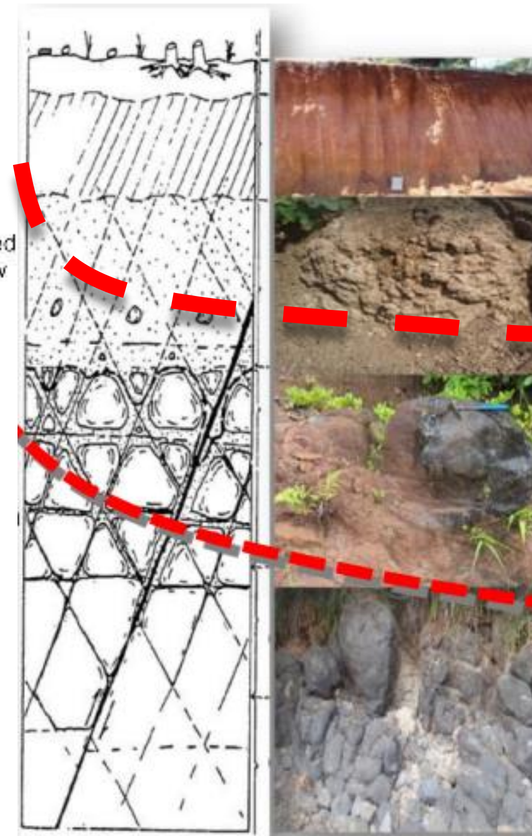
2. Context

Landslides

- shallow and moderate deep landslide (2-10 m) occurred in very weathered material (H4/H3);
- Deep landslide (> 10 m) occurred in weathered materials (H3) or at the interface between weathered materials (H3) and few weathered material (H2).



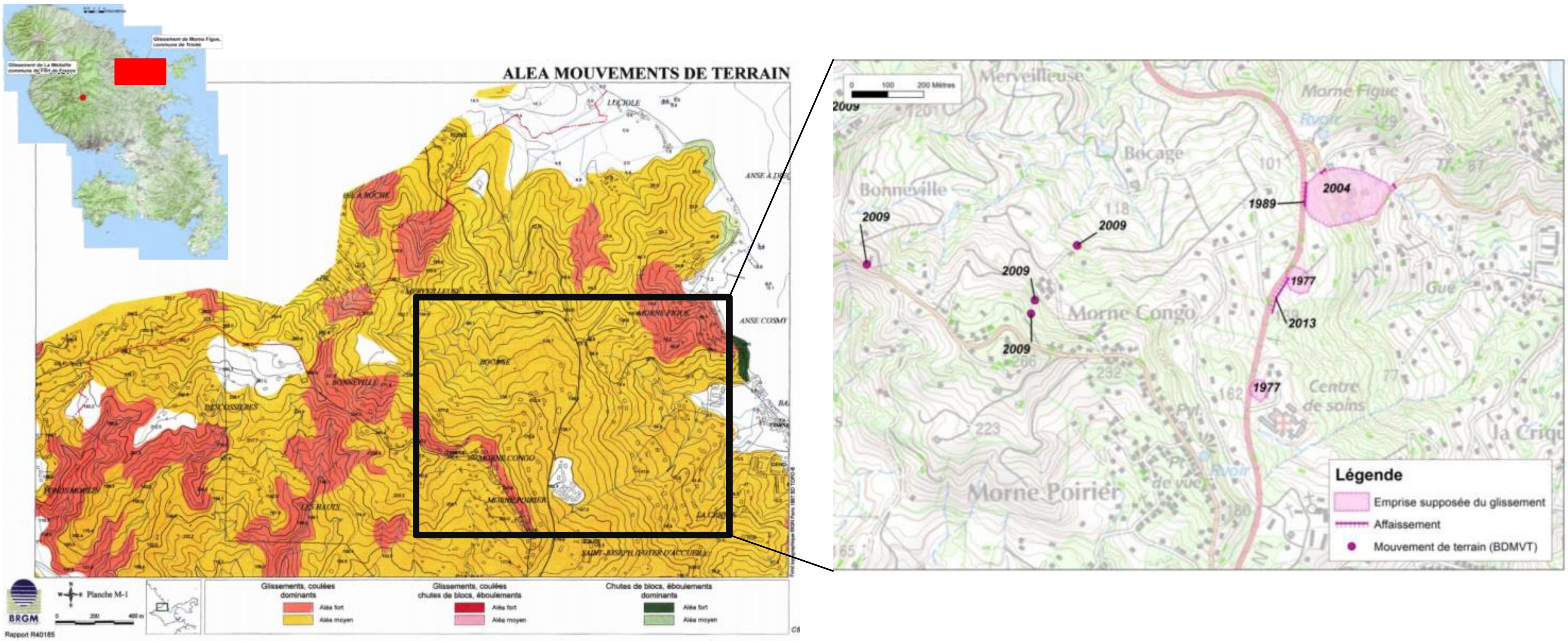
Audru et al., 2010



Nehlig et al., 2012

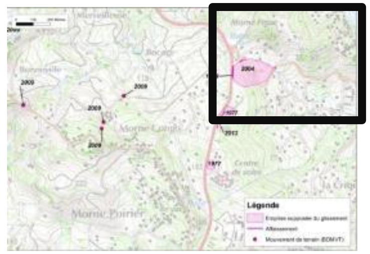
2. Context

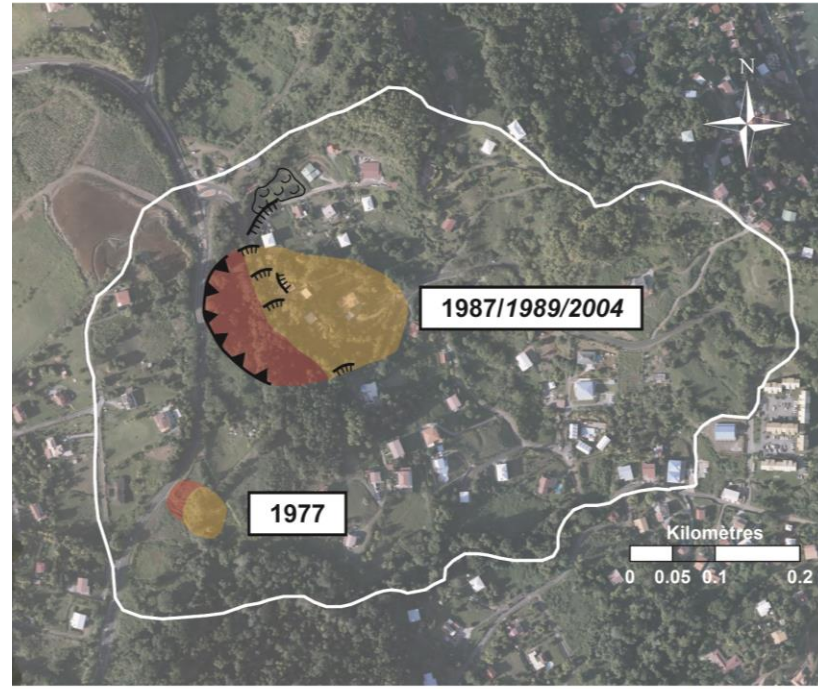
To assess this instabilities some documents have been elaborated *(e.g. PPR –landslide hazard map- by french legal procedure)* but they oversimplify the different factors *(as weathered lithology)* and neglect triggering factors.



Understand slope instabilities mechanics and anticipate them is becoming a challenge and a major aim of legal institutions.

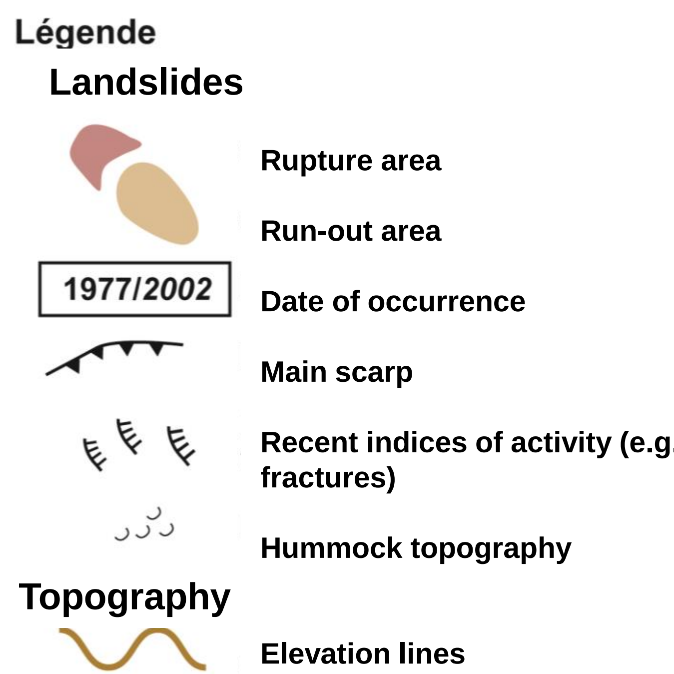
3. Study site





<u>Morne-Figue</u>

- Rotational landslide;
- Length: 150 m;
- Width:110 m
- Depth ≈ 10 m
- Date of occurrence: 1987
- Activity: active by intermittence *(especially during the humid season)*



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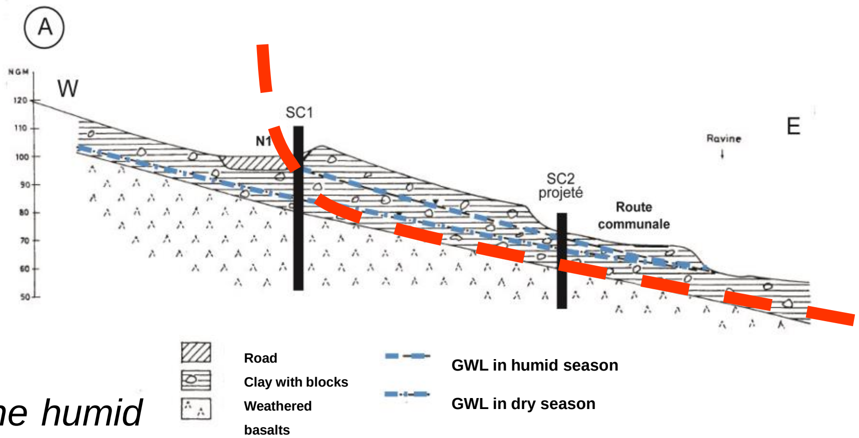
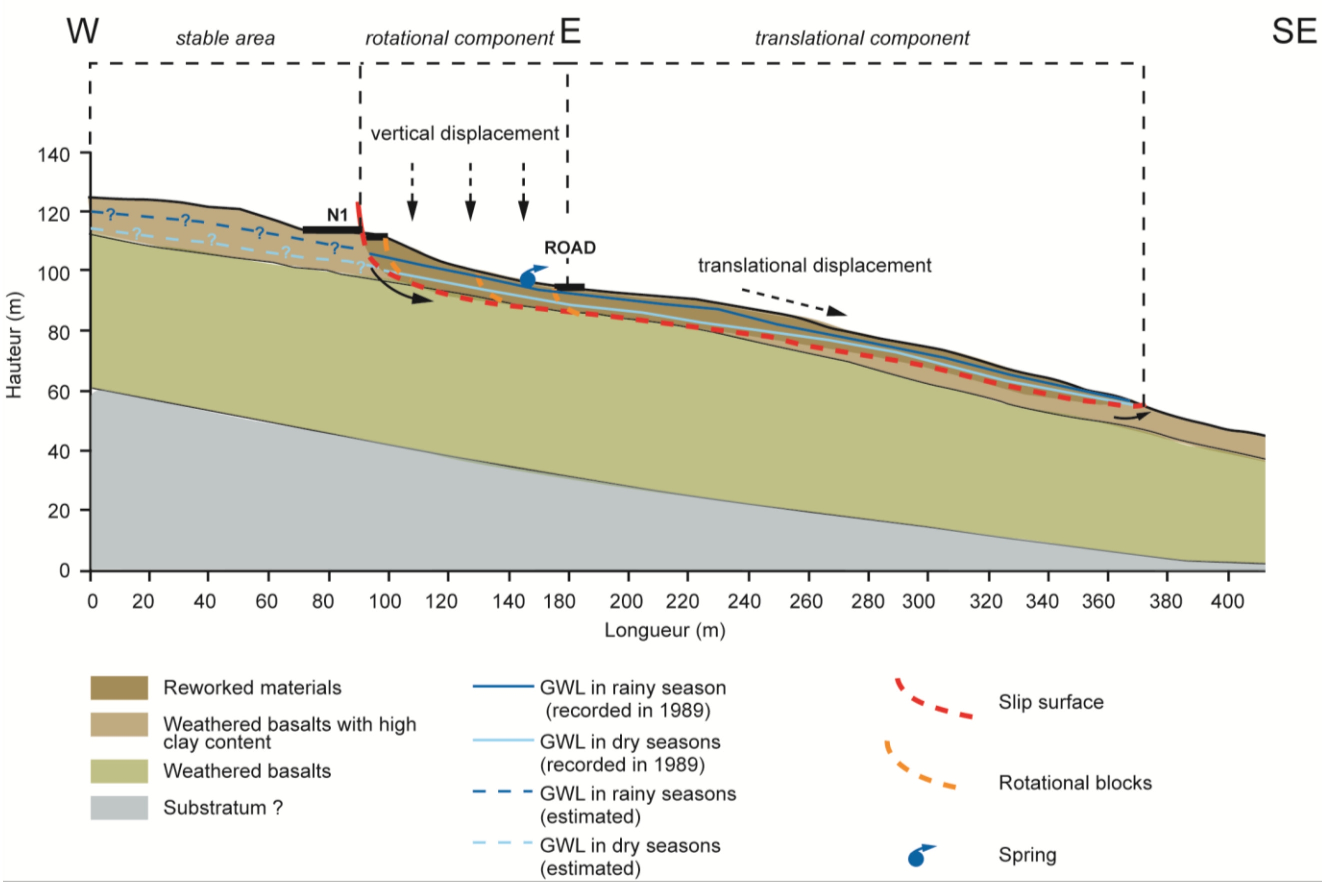




4. Methodology

In 3 steps

1. EM data: acquisition & data processing

- Data acquisition (2013)
- Processing (2014)

2. Elaboration of the 3D model

- Analysis and first interpretations of logs
- Definition of materials (surficial deposits, lithology) and their depths following the resistivity
- Comparison with existing data (boreholes, reports, geotechnical surveys, …)
- Interpolation of different layers and elaboration of the 3D model

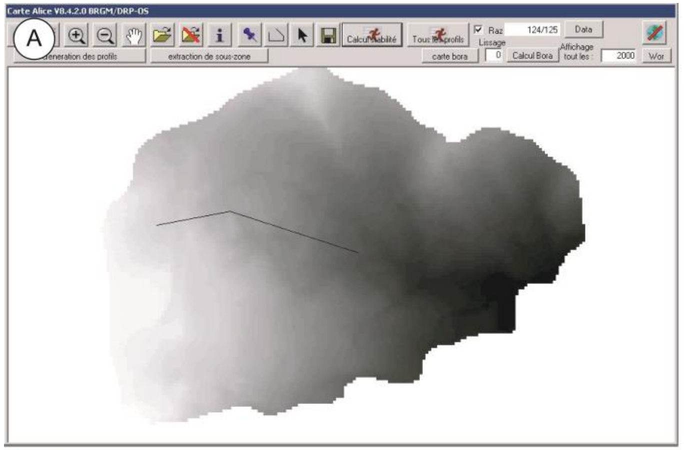
3. Calibration of the PBM computing the probability of failure

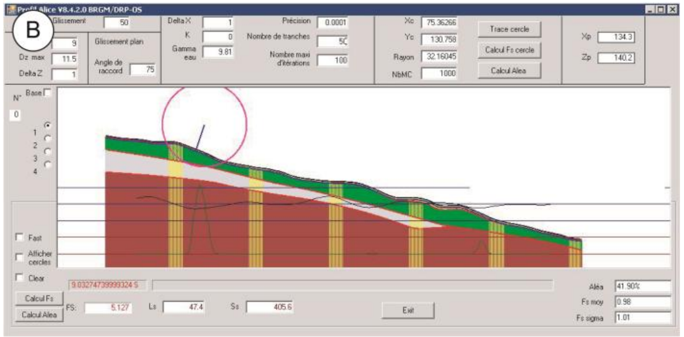
- Model: ALICE®
- Integration of the 3D model (layer by layer)
- Integration of geotechnical values
- Sensitivity analysis (on cell size and on geotechnical values)
- Computation of several scenarri following the GWL

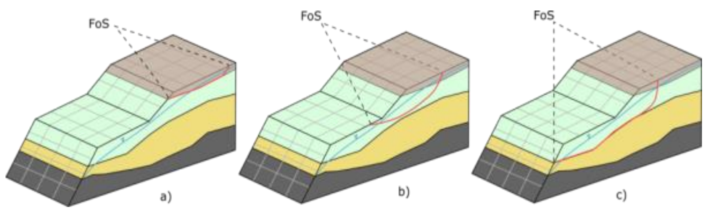
4. Model: presentation

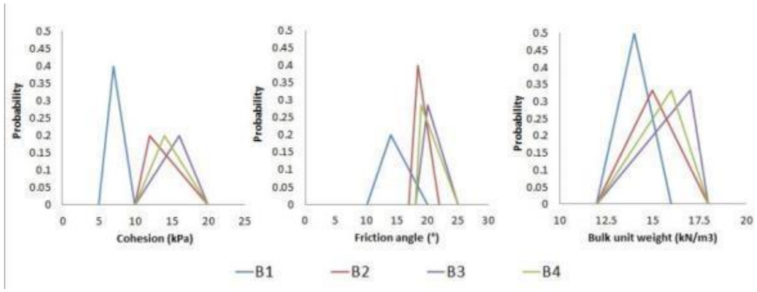
<u>ALICE®</u>

- Spatial Physically Based Model computing factor of safety (FoS) and probability of failure (FoS < 1, i.e. geomechanic parameters - cohesion, frictional angle and volumetric weight- are given through possibility distributions);
- 2.5D approach along the steepest profiles;
- Based on Morgenstern and Price (1967) equations;
- Able to take into account different size and depth of failure (expert parametrization);
- Tested in different environments, especially in French West Indies (between 2005 and 2010), in Tahiti and in Pyrenean areas.



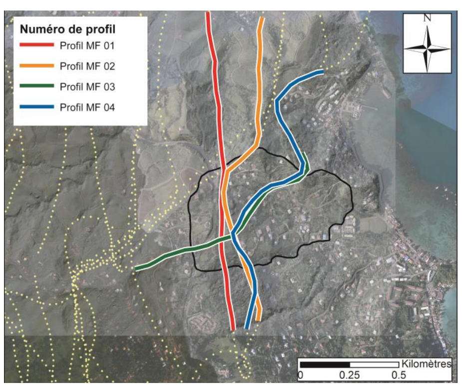


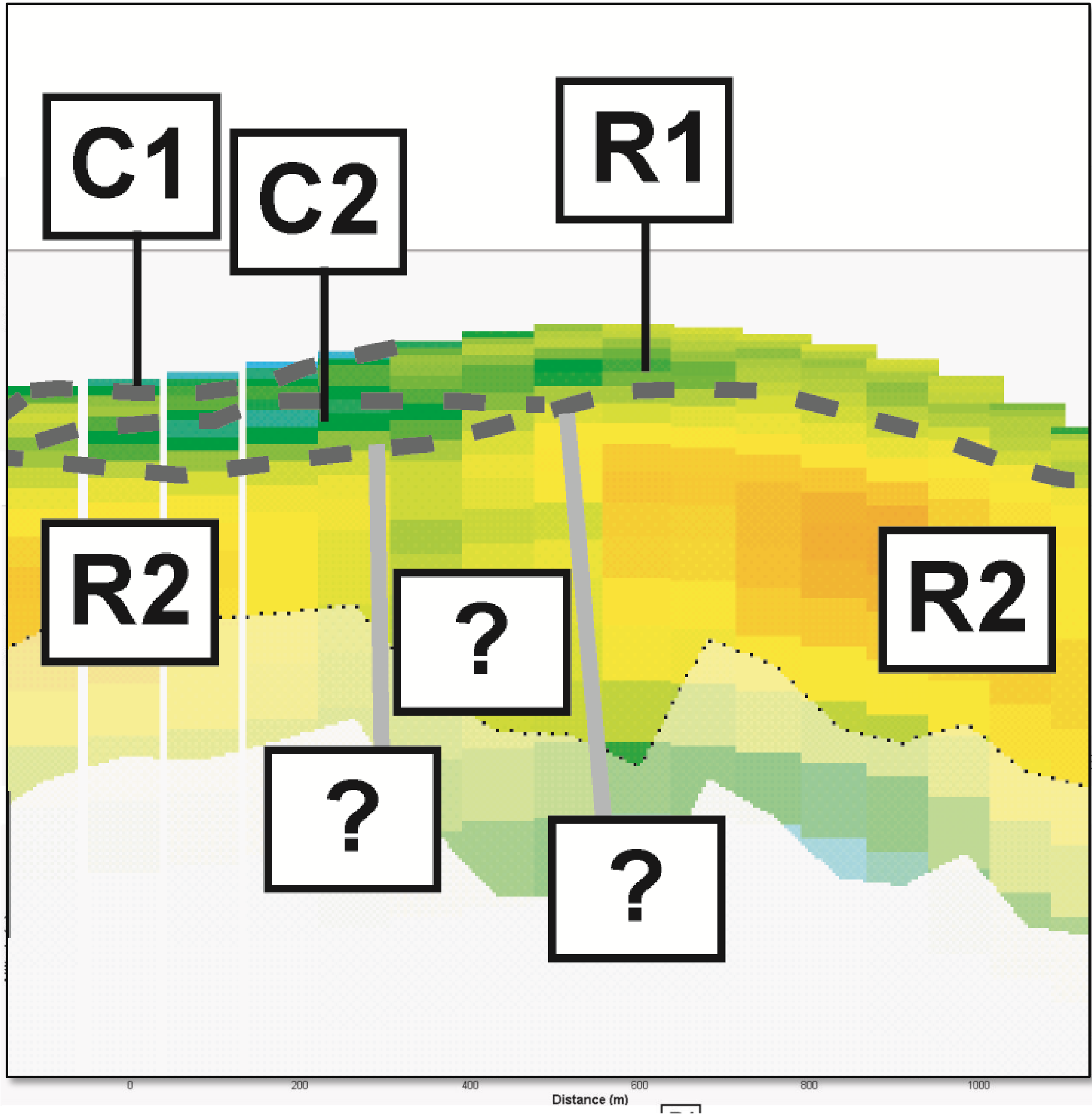




5. Results: EM data

- Five profiles;
- One log every 30 meters;
- Vertical accuracy: 2-5 meters;
- Different resistivity contrasts were observed corresponding to different type of materials observed in the field and with boreholes.



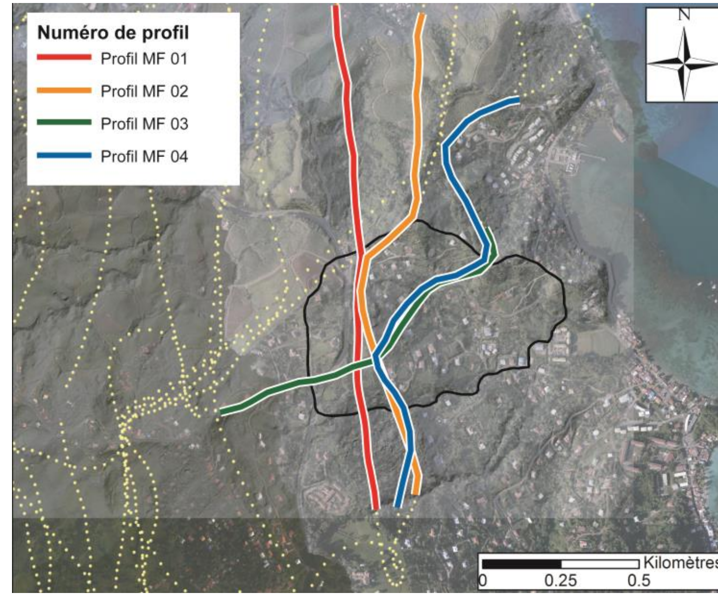


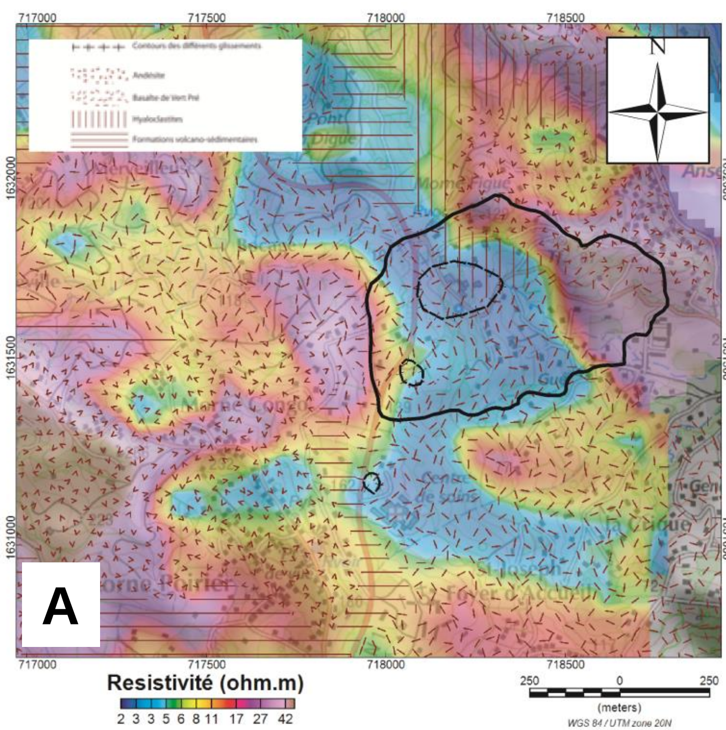
5. Results: EM data

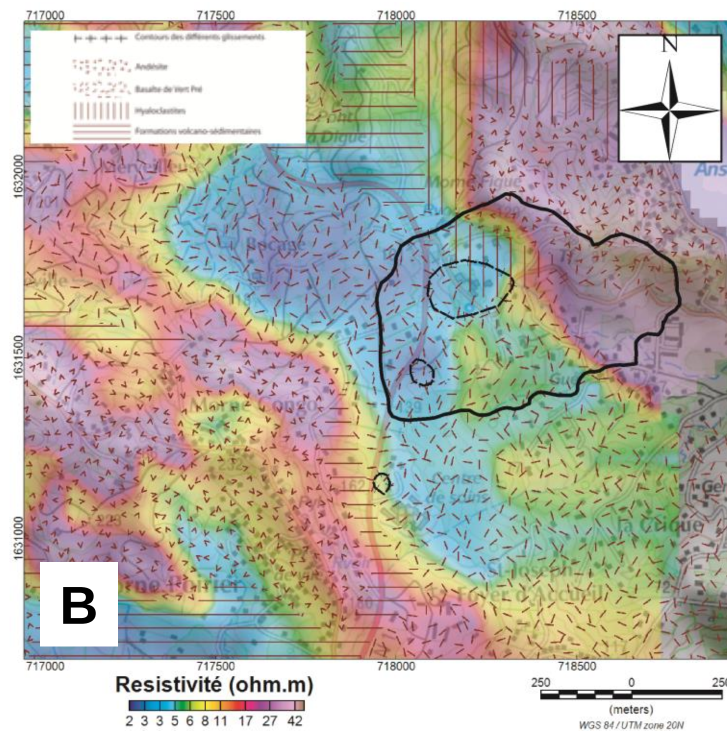
Examples of resistivity maps obtained after interpolation

A = map for resistivity at 4 meters below topography

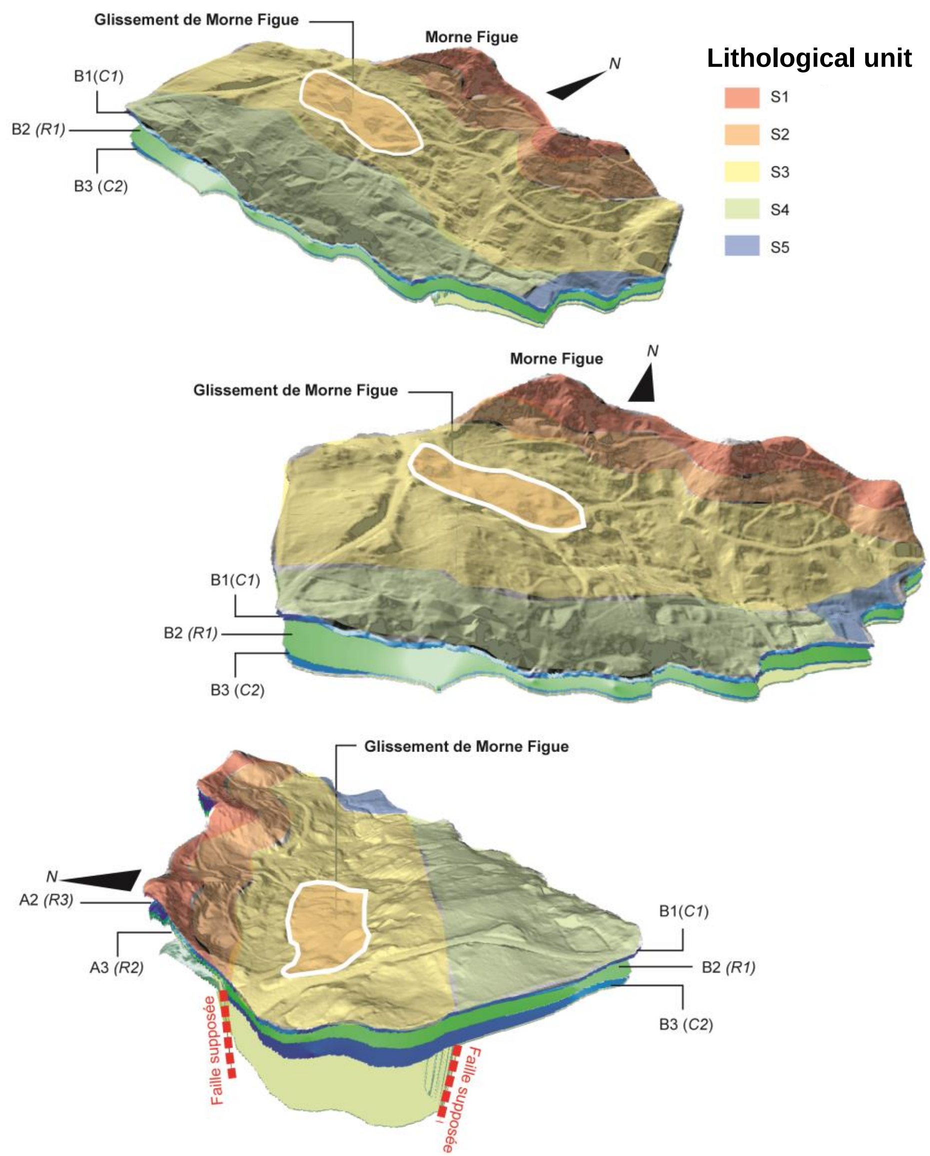
B = map for resistivity at 20 meters below topography

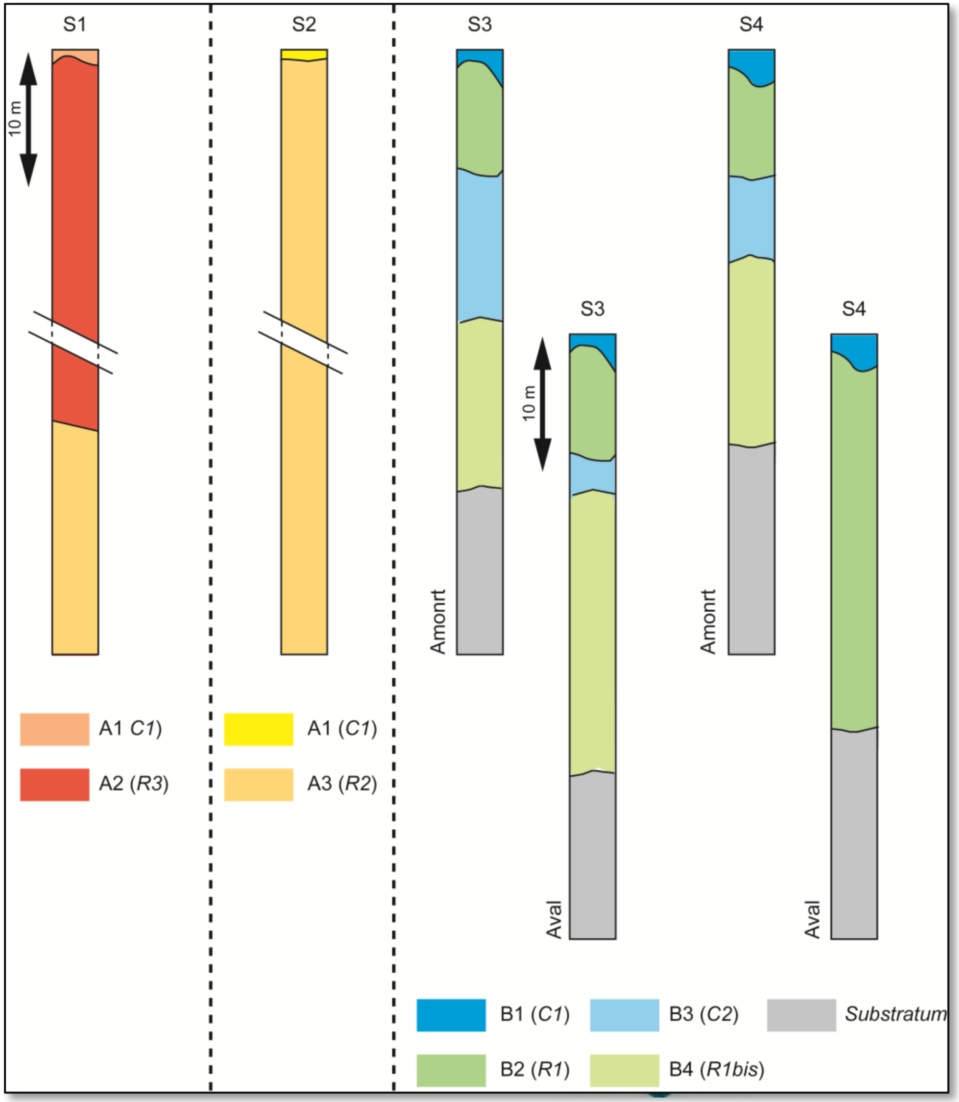




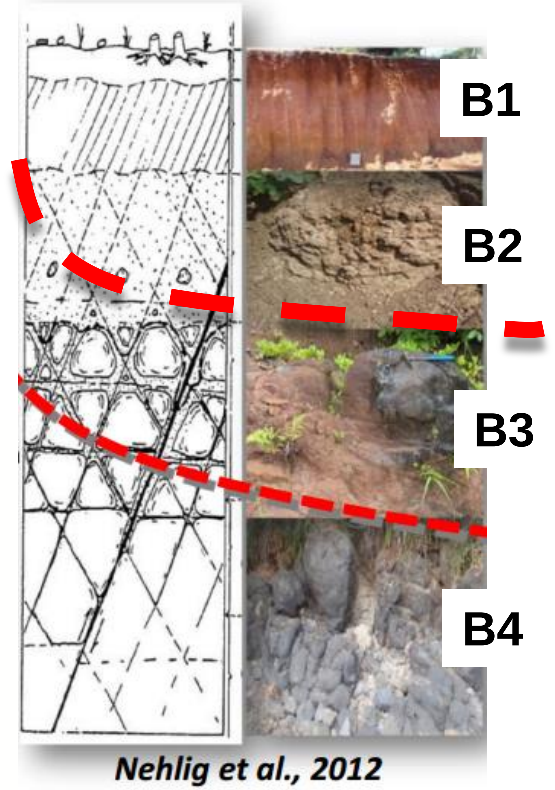


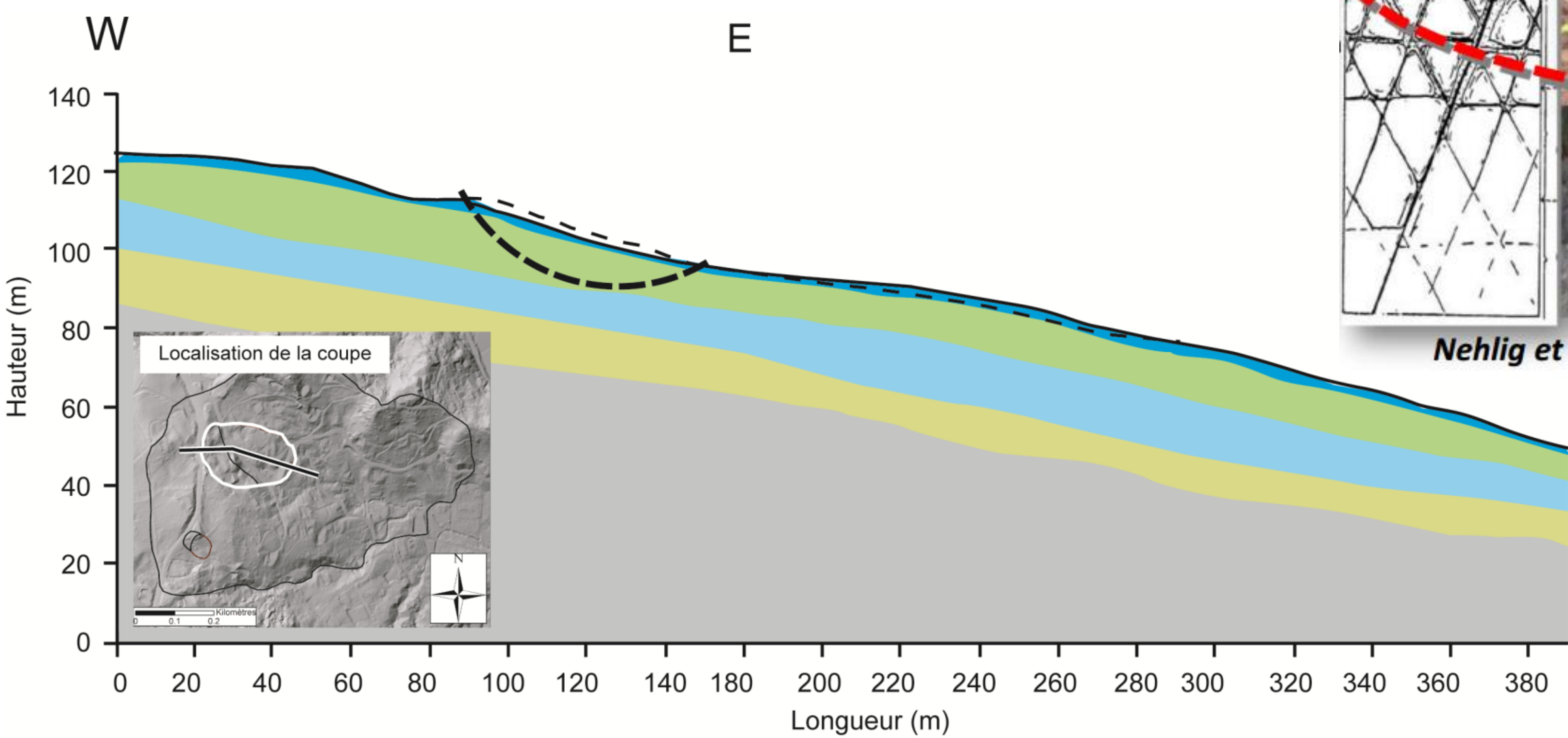
5. Results: 3D model





5. Results : interpretations





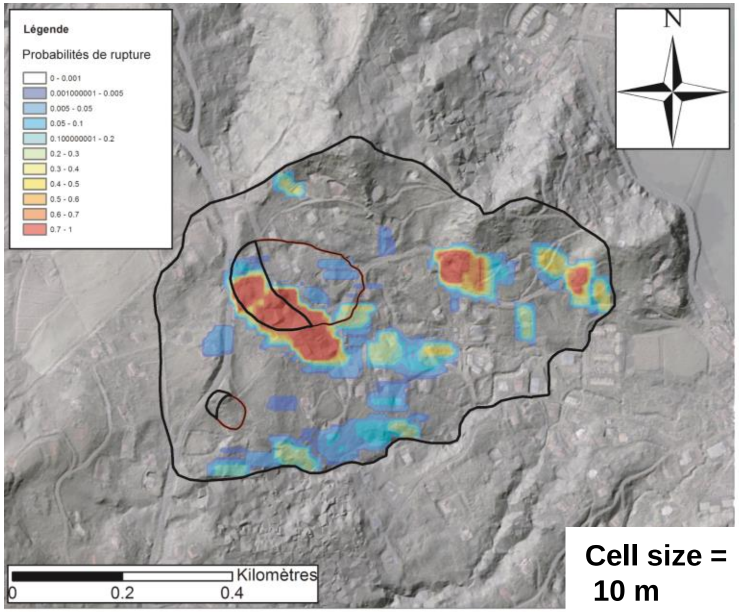
B1 (*C1*)
B3 (*C2*)
Substratum
Topography before failure rupture
B2 (*R1*)
B4 (*R1bis*)
Modeled failure (= failure of Morne-Figue landslide)

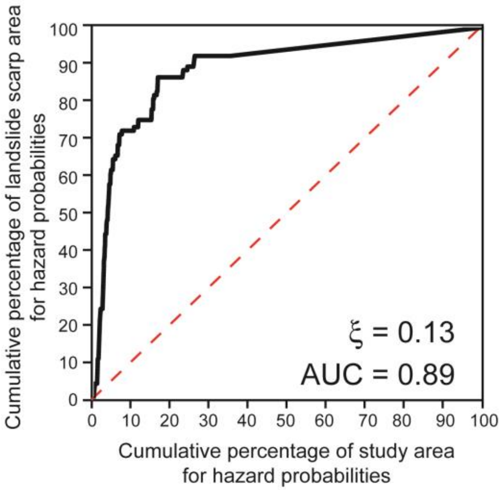
5. Results: geotechnical values

Lithological unit	Layer	Thickness	γ (kN.m^{-3})		c (KPa)		φ(°)	
			Public report (geotechnical studies)	Value retained after sensitivity analysis	Public report (geotechnical studies)	Value retained after sensitivity analysis	Public report (geotechnical studies)	Value retained after sensitivity analysis
S1	A1 – weathered andesite (H4/H3)	Up to 10 m	10-30	10-30	10-15	10-15	5-15	10-15
	A2 - weathered andesite (H2/H1)	Up to 20 m	10-30	10-30	8-16	8-16	6-40	30-40
	Substratum (andesite)	infinite	26-30	30	40	40	40	40
S2	A1 – weathered hyaloclastites	Up to 3 m	05-29	10-15	5-20	5-10	1-35	10-18
	A3 - Substratum (hyaloclastite	infinite	29-30	29	31-35	35	31-35	35
S3 or S4	B1 – very weathered basalt (H4)	1-3 m	12-17	12-17	5-15	5-10	10-22	10-20
	B2 – weathered basalt (H3)	5-9 m	10-18	12-18	1-20	10-20	16-25	17-22
	B3 - weathered basalt with very low resistivity (H3)	7-12 m	10-18	12-18	5-25	10-20	18-25	18-25
	B4 - weathered basalt (H2)	6-10 m	10-18	12-18	5-25	10-20	18-25	18-25
	Substratum (basalte	infinite	29-30	29	50-66	66	30-38	38

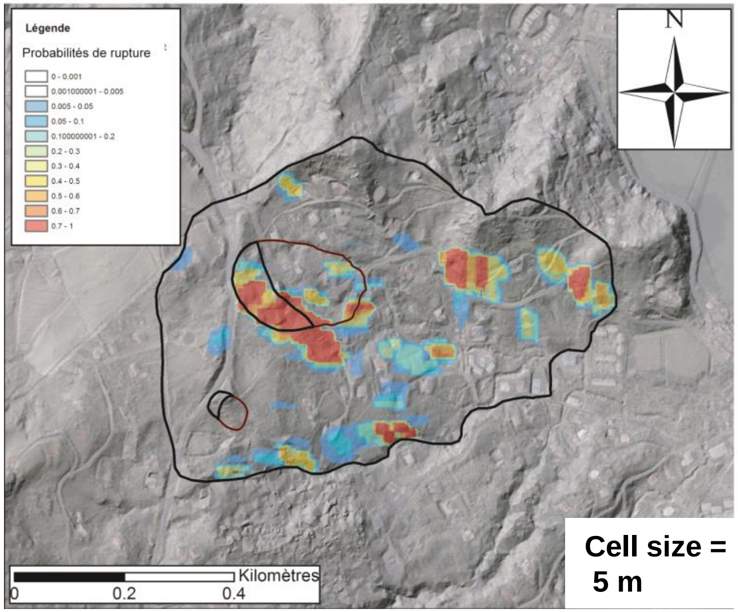
5. Results: slope instability model

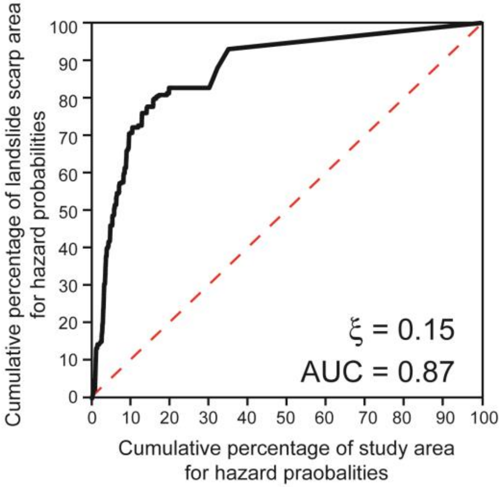
Simulation with a cell size of 10 m





Simulation with a cell size of 5 m



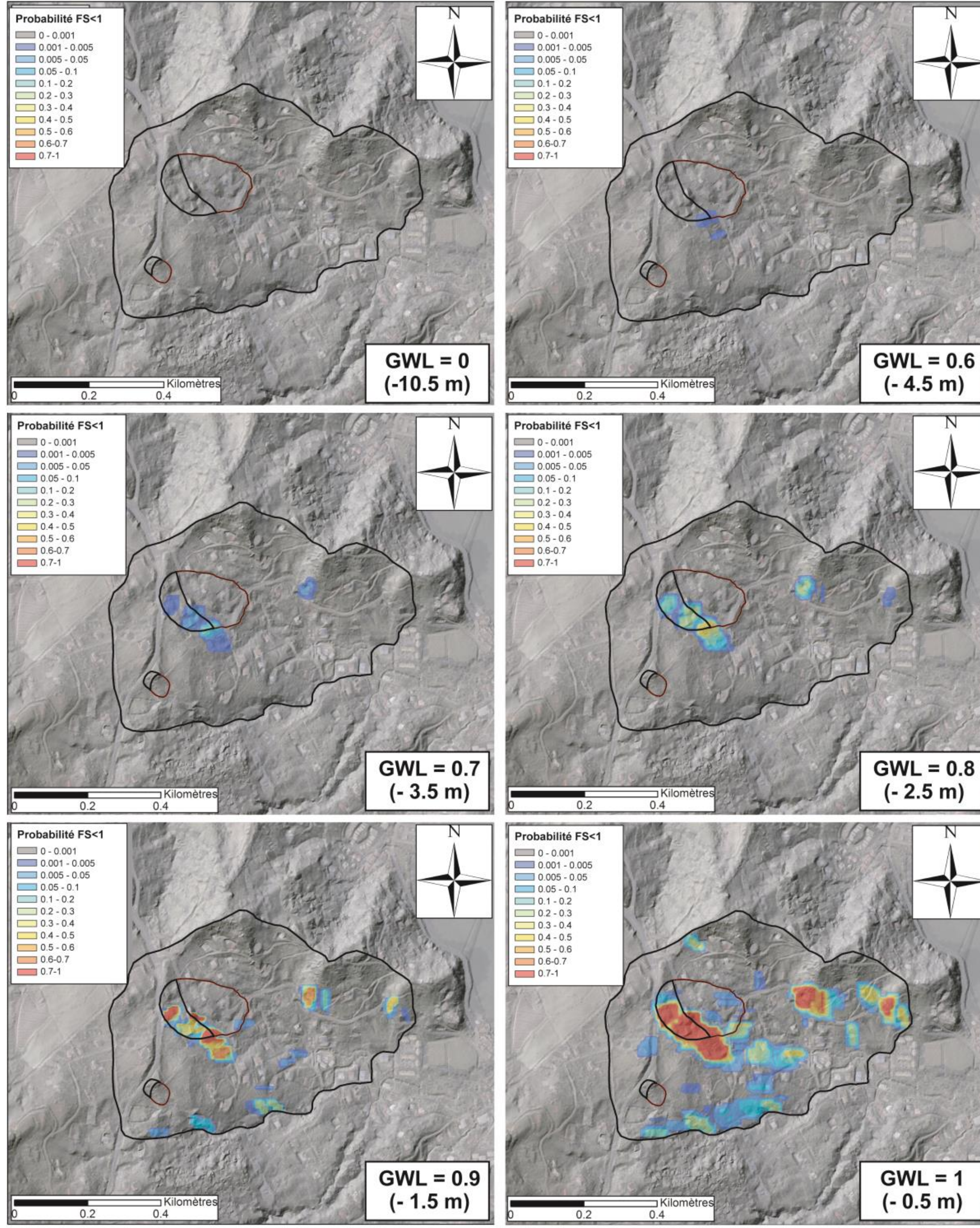


5. Results: slope instability model

Influence of the GWL: the conditions corresponds to the measurements realized in situ during 1.5 year (Allard, 1989).

0 = dry situation

1 = saturated situation



6. Conclusions

- Despite an unfavorable context (low resistivity of weathered lavas, complex lithology), the results of the heliborne EM obtained in this study have brought new information on mobilizable materials in complex volcanic environment such as:
  - Their extension;
  - Their thicknesses and depths;
  - The data allowed to build a new 3D model with new layers.

- The slope instability models performed with ALICE® taking into account the new information allowed:
  - To confirm this 3D model with a series of modeling taking into account the different materials, the simulated failure corresponds to the observations;
  - To develop scenarios of failure taking into account the GWL

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7. Perspectives

- For the slope instability model:
    - Reinforce the knowledge of the hydrogeology in this environment because we have simplify the flow water in the materials (*we suppose not one water table but different water table in different materials and relation between them*);
    - Attempt to correlate precipitation with activity of landslide and GWL;

- In the framework of French Legal procedure to landslide risk assessment (PPR):
    - A project is engaged to test the approach for largest area around Morne-Figue
    - Another project is engaged to test the approach for another territory with different materials in la Martinique.

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Thank you !