Multi Hazard Assessment: The Azores Archipelagos (PT) case

Dorothea Aifantopoulou[1], Giorgio Boni[2], Luca Cenci[2], Maria Kaskara[3], Haris Kontoes[3], Ioannis Papoutsis[3], Sideris Paralikidis[1], Christina Psichogyiou[3], Stavros Solomos[3], Giuseppe Squicciarino[2], Alexia Tsouni[3], Themos Xerekakis[3]

[1]GEOAPIKONISIS S.A.P.GE., [2]CIMA FOUNDATION, [3]NOA

The COPERNICUS EMS - Risk & Recovery Mapping (RRM) activity offers services to support efficient design and implementation of mitigation measures and recovery planning based on EO data exploitation. The Azores Archipelagos case was realized in the context of the FWC 259811 (EMS – RRM), and provides Risk Management relevant information for a number of natural disasters

CONTACT

Establishment of the Geo-spatial Data Base

Risk Modelling

- Hazard
- Vulnerability
- Exposure
- Risk level assessment
  - Population
  - Assets
    - Buildings
    - Industries, etc
    - Transport Network
    - Environment
- Mitigation Measures

Earthquake

Flash Floods

Lava Flow

Landslides

Soil Erosion

Coastal Erosion

Tsunamis & Storm Surges

Spatial Modelling

First Response Infrastructure

Risk and Recovery Maps & Tables

To obtain more information you are kindly invited to **click** the

Risks' or Processes'

specific subjects

SUMMARY

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GEOAPIKONISIS S.A.

IAASARS

cima

CHALLENGES | SOLUTIONS

FIRST SLIDE

Multi – Risk Assessment

Challenges		Solutions	
Modelling Dimensions/ parameters	Varying Concepts/ Assumptions	Risks Specific Expertise/ Tools	Convergence Intensive Management

Data Variability

Challenges		Solutions	
Source/ Quality/ Scale - Status	Risks Geospatial	Validation Consistency Harmonization	Aggreg/ Disagr Georeferencing Update/ Integr

Area of Interest

Challenges		Solutions	
Large Nine islands	Variable Remote	Parallel Common Processes	Com RDBMS In depth sources search

Products Specifications

Challenges		Solutions	
Relevance Accuracy	Integrity Fine Scale	Quality Man Rules & Tolerances	Customized Tools Development

Copernicus

- Earthquake
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System / Service Design was based upon four pillars:

- Flexibility (modeling, information content)
- Efficiency (data availability, data model)
- Excellence
- Fit to purpose/ specifications inclusive production

Implementation accounted for:

- Models data, parameters and processes
- Update / Refinement/ Generation/ Completion needs
- Existing platforms/ tools & State of the Art Approaches
- Specified level of detail and thematic accuracy standards

Production was based upon :

- Commercial and open SW solutions
- Existing Tools Customization & Tools development
- GIS, RDBMS, EO, Engineering/ Disasters Expertise
- Landscape and/ or structural characteristics

Results comply with:

- COPERNICUS mapping guidelines
- INSPIRE, OGC standards
- Quality Specifications
- Area specificity

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Risk & Recovery Products Information

FIRST SLIDE

Background Information:

- Physiography (contours, hydrography, height spots, etc)
- Transportation Network, Industry and Utilities
- Public Services
- Land Use/ Land Cover

Risk Information (5 risk levels):

- Population at Risk- *per disaster*
- Assets (Buildings, Environmental, Road Network, Bridges, critical infrastructure, etc) – *per disaster*

Mitigation:

- Top Level proposal on adequate (risk level/ asset basis) measures
- Presentation of alternatives

Risk Management and Response:

- Safe Shelters, Hospitals, etc and access to them
- Information on assets and population that may (potentially) be affected

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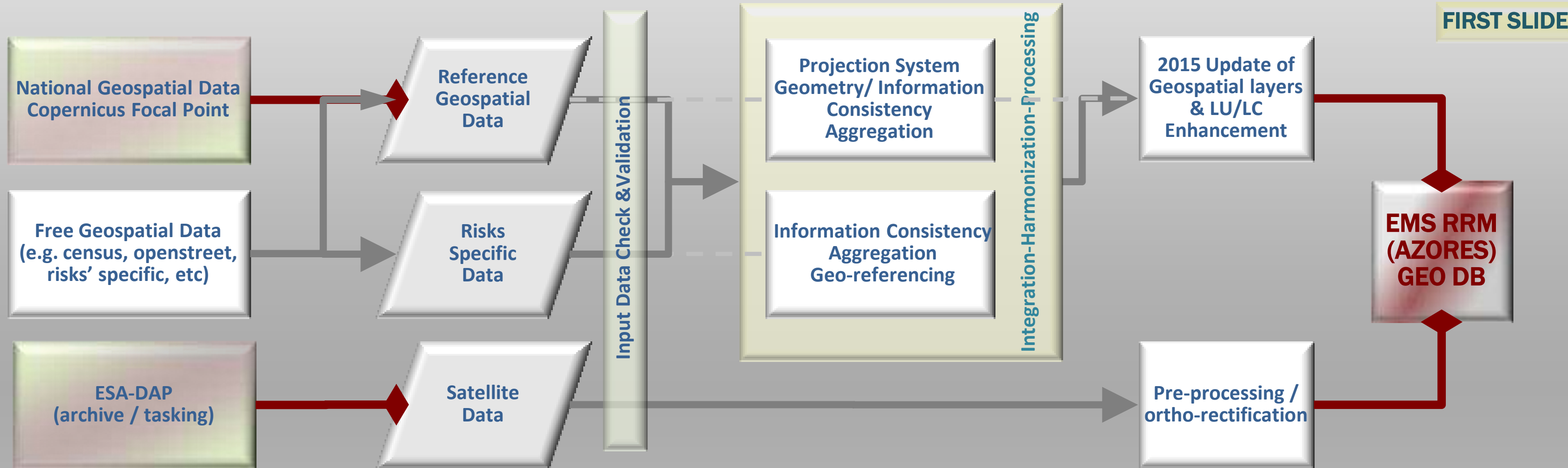
FIRST SLIDE



- **Data validation;** gaps & quality assessment ➤ Integration/ Update approach
- **Data Integration**
  - Re-projections/ Geo - referencing
  - Input data harmonization; format, scale, attribute information content, Thematic information nomenclature, reference years, etc)
  - Geometry – Topology match
  - Spatial & attribute conformance to products' specifications
  - Additional layers design & production
- **Update Content**
  - Enrichment
  - Spatial adjustments – corrections
- **EO data ortho-rectification**

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Reference EO data

DATA	Processing

DATA

- **Reference National data**
  - **Ortho-imagery**/ 0,5 m
    - Aqc. Dates: 2006-2009
    - Scale: 1/10.000
    - EPSG codes: 5014 & 5015
  - **Digital Elevation Models (DEM)**
    - National DEM layer / 5 m
    - National DEM layer / 10 m
- **Satellite imagery**
  - **Pleiades** pan-sharpen 4-bands
  - **WorldView** pan-sharpen 4-bands

Processing

Ascii to raster (DEM)

Re – Projection

Mosaics

Satellite

Ortho-rectification - Bundle Adjustment/ 4-bands

Sub-pixel level Accuracy; tie & check points

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LULC layer

FIRST SLIDE

Input data

LAYER	SCALE	COVERAGE
CLC 2006	1:100k	Full coverage
Limites e Ocupação do Solo (Detailed Land Use Map)	1:5k	Partial (5 from 9 islands)
Urban Atlas	1:10k	Partial, part of Sao Miguel only
Road Network	1:10k	Full coverage
OSM LULC polygons	Varies	Partial - scattered

Methodology

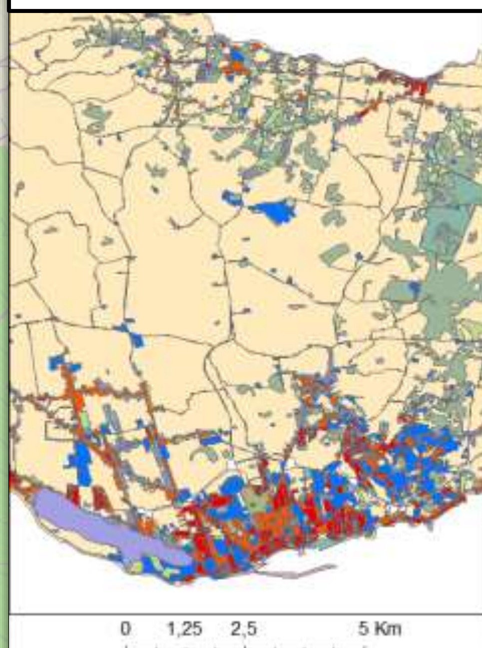
- GIS procedures
  - Re-projections
  - Input data information hierarchy
  - Input data aggregation – harmonisation
- Image interpretation
  - Filling-up gaps
  - Updates to ref. year (2015)

Specifications

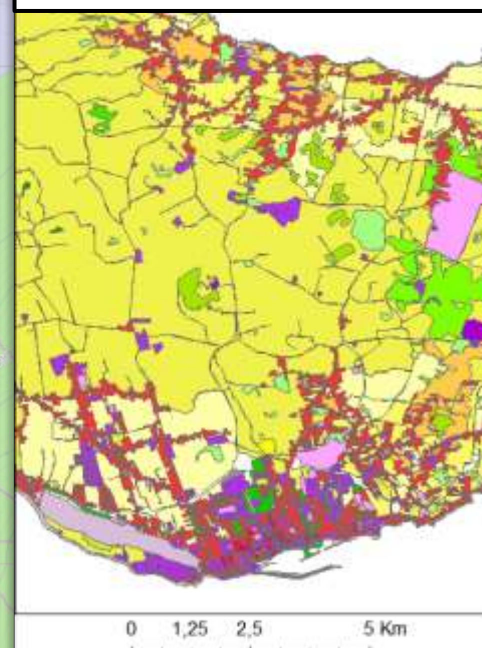
- Scale: 1:10k/ MMU: 1ha
- Class level: Up to CLC level 4

CLC06

Urban Atlas



Product



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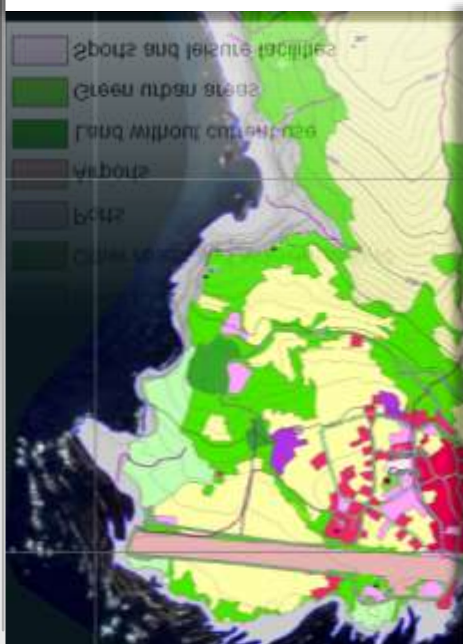
Thematic Layers / nomenclature

FIRST SLIDE

Land Use - Land Cover

- Continuous Urban Fabric (P.B.F. > 80%)
- Isolated Structures
- Commercial, Public & Private Services
- Industry & Utilities
- Main roads and associated land
- Local roads and associated land
- Other roads and associated land
- Ports
- Airports
- Land without current use
- Green urban areas
- Sports and leisure facilities
- Arable land
- Pastures
- Broad-leaved forest
- Coniferous forest
- Shrubs and/or herbaceous vegetation
- Natural grassland
- Bare rock
- Beaches, dunes and sand planes
- Sparsely vegetated areas
- Inland wetlands
- Lakes
- Water reservoirs



Risk Level

- Very Low
- Low
- Medium
- High
- Very High

First Aid Areas

- First Aid Areas
- Camp location
- Shelter
- Field hospital
- Helicopter landing spot
- Gasoline tank

Mitigation Measures

- Breakwaters, seawalls, groynes
- Structural reinforcement of assets

Administrative boundaries

- Municipality

Populated places

- City
- Town
- Village

Buildings

- Airport
- Port
- Commercial, Public & Private Services
- Industry & Utilities
- Place of worship
- Other
- Unclassified

Transportation

- Airport
- Port
- Bridge & overpass
- Tunnel
- Highway
- Primary Road
- Secondary Road
- Local Road
- Other

Physiography

- 300 - Primary
- Secondary
- Spot heights

Hydrography

- Rivers & streams
- Coastline

Points of Interest

- Hospital
- Fire station
- Police
- Education
- Sports
- Government Facilities
- Industrial facilities
- Water infrastructure
- Electricity infrastructure
- Wave power infrastructure
- Power stations
- Wind turbines
- Oil
- Marina
- Military

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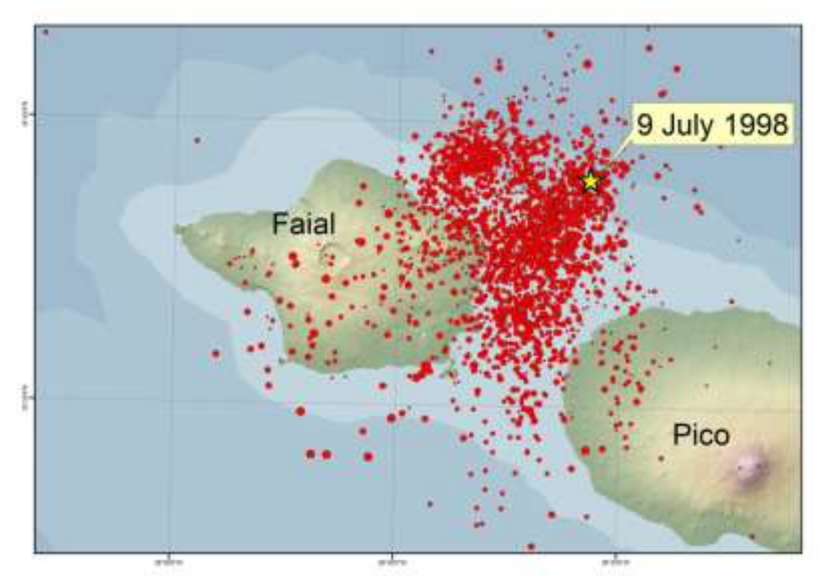
FIRST SLIDE

The Azores Archipelago is located at the triple junction of the Mid-Atlantic Rift, where the Eurasian, Nubian, and American Plates meet. It includes the Western Group (the Flores and Corvo Islands), the Central Group (the Terceira, Graciosa, Sao Jorge, Pico and Faial Islands) and the Eastern Group (the Sao Miguel and Santa Maria Islands and the Formigas Islets). All the Azores islands are of volcanic nature and emerge from an anomalously shallow and rough topographic zone. The tectonic of the islands is constrained by the deformation of the internal structures of the Azores Plateau. Geodetic data depicts that Graciosa Island follows the average movement of the Eurasian plate, the Santa Maria Island express the same vector as the Nubian plate while the other islands show a behavior of inter plate deformation.

The most recent devastating events are:

- The **January 1st, 1980**, 7.2 magnitude earthquake (Hirn et al., 1980) which affected Terceira, São Jorge and Graciosa islands causing the death of nearly 60 people, and
- The **July 9th, 1998**, 5.8 magnitude earthquake (Senos et al., 1999) that hit Faial and Pico islands resulting in 8 casualties, while 1,700 people were left homeless.



Epicentres of the July 9th, 1998 Faial earthquake & aftershocks

Risk Modelling

Hazard
Vulnerability
Exposure
Risk level
- Population
- Assets
  - Buildings
  - Industries, etc
  - Transport Network
  - Environment

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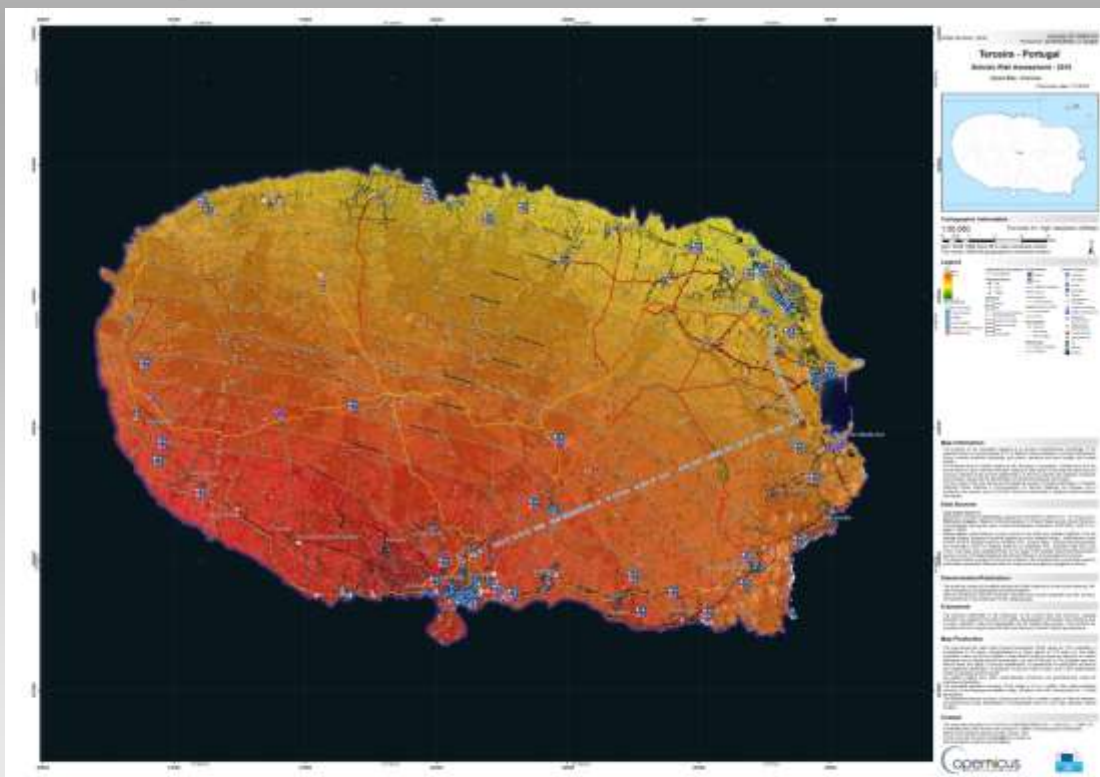
FIRST SLIDE

Probabilistic seismic hazards maps in terms of PGA have been prepared. These were obtained by applying the Cornell (1968) methodology as implemented in CRISIS2007 (Ordaz et al. 2007). The adopted approach follows four steps: i) sources identification, ii) assessment of earthquake recurrence and magnitude distribution, iii) selection of ground motion model, and iv) the mathematical model to calculate seismic hazard.
The state of the practice is to represent the temporal occurrence of earthquakes as well as the occurrence of ground motion at a particular site in excess of a specified level by a Poisson process. It is also assumed that: i) earthquakes are spatially and temporally independent, and ii) the probability that two seismic events will take place at the same location and at the same time is zero.



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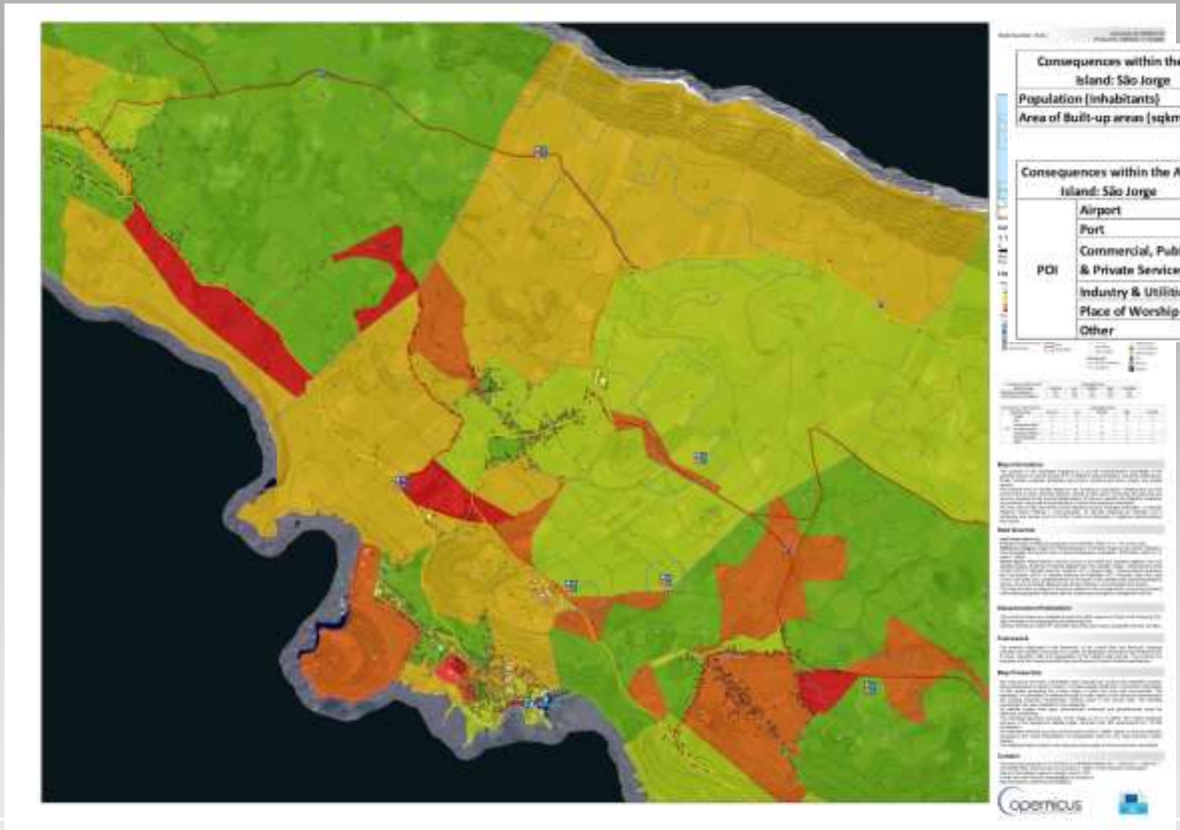
FIRST SLIDE

The macro seismic method or empirical vulnerability approach was adopted. It is the Level 1 (LM1 method) of RISK-UE program (Milutinovic and Trendafiloski, 2003), originally proposed by Giovinazzi and Lagomarsino (2004) according to the European Macro seismic Scale (EMS-98, Grünthal, 1998).
Risk-UE-LM1 is suitable for vulnerability, damage and loss assessment in urban environments with adequate estimates on seismic intensity and portfolios large enough, so that any uncertainties associated with standardized indexes can be balanced out. RISK-UE program was launched after the disastrous earthquakes of Izmit and Athens in 1999, and adapted the US methodologies (ATC13, 1985; HAZUS, 1999) into the European structural typologies.



Consequences within the AOI Island: São Jorge	Vulnerability Level				
	Very Low	Low	Medium	High	Very High
Population (inhabitants)	847	1153	983	1059	463
Area of Built-up areas (sqkm)	0,176	0,339	0,341	0,335	0,304

Consequences within the AOI Island: São Jorge		Vulnerability Level				
		Very Low	Low	Medium	High	Very High
POI	Airport	0	0	0	0	1
	Port	0	1	1	0	0
	Commercial, Public & Private Services	11	19	12	11	6
	Industry & Utilities	11	0	26	1	0
	Place of Worship	1	2	3	3	2
	Other	1	0	1	1	1

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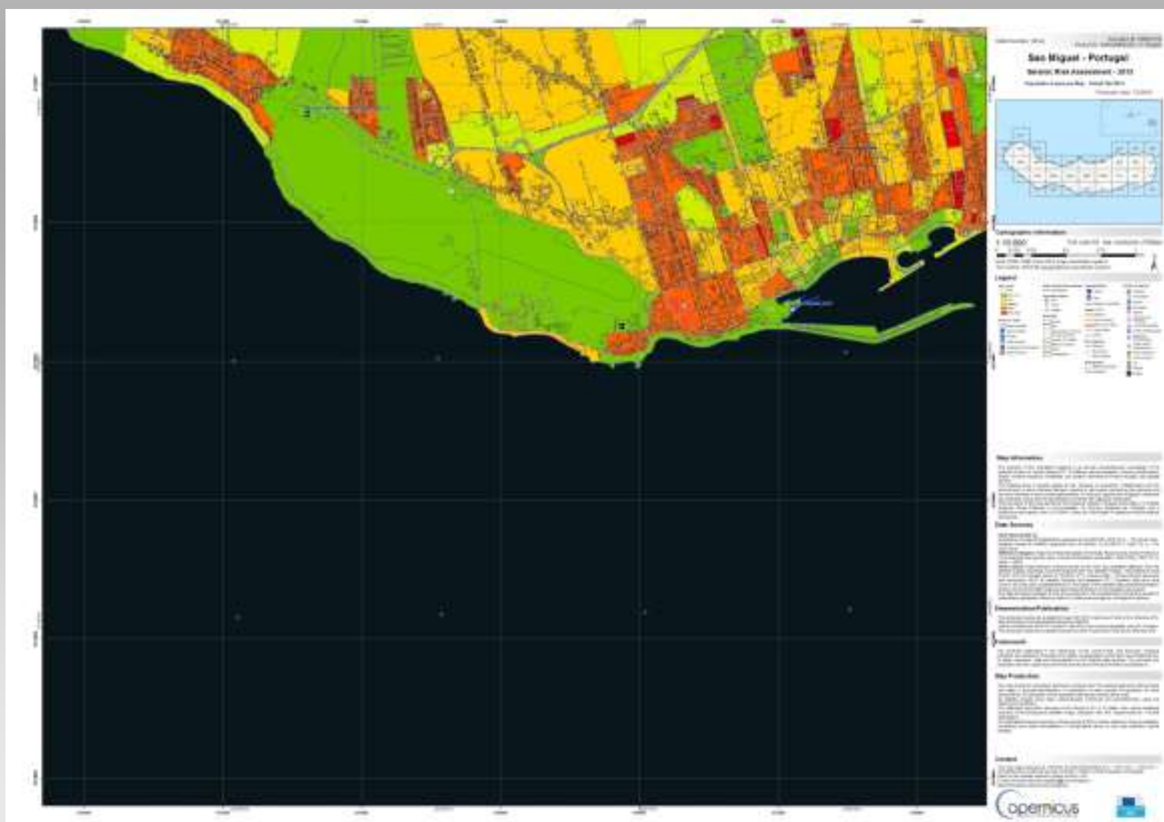
Population exposure mapping was realized at census block scale, accounting also for the individual buildings (on the basis of the digitized buildings footprints). Population exposure is thematically graded according to the population density in inhabited areas and **categorized** in **five** different classes (Very Low, Low, Medium, High, and Very High).

A step wise approach was adopted : i) sources identification, ii) calculation of total number of population for each census block, iii) calculation of the population density per census block area.



Population exposure (seismic) levels

Risk Modelling

Hazard

Vulnerability

Exposure

Risk level

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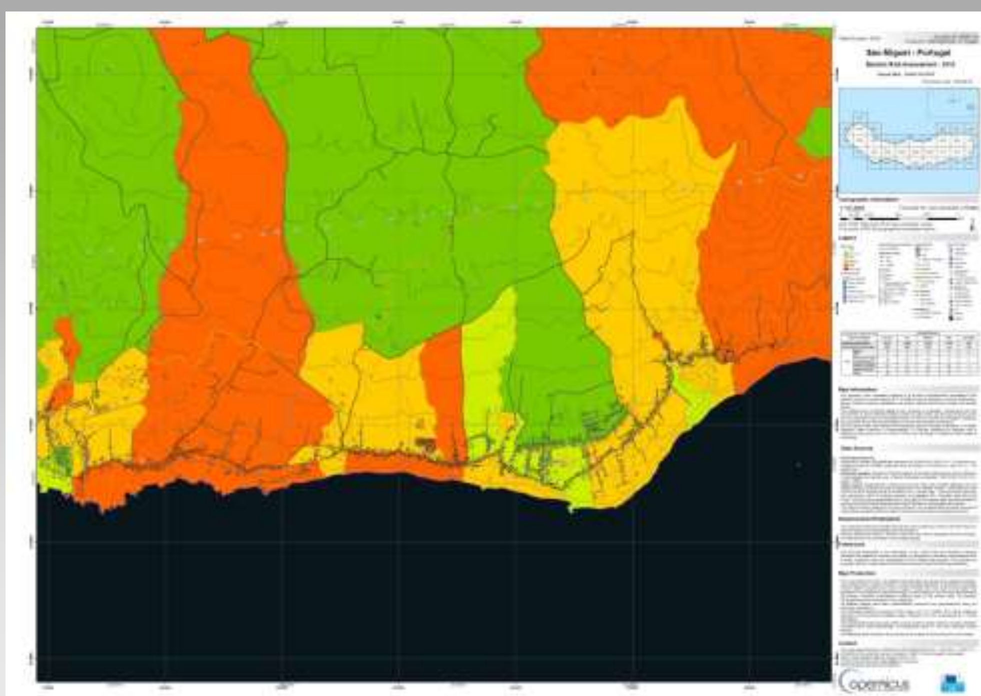
FIRST SLIDE

Risk is defined as: **Risk** = Hazard x Exposure x Vulnerability. Hazard takes values from a continuous range, exposure is either 1 or 0 whether it is exposed to an earthquake or not and vulnerability is also a continuous variable, ranging from 0 to 1. Damage scenarios are composed in terms of discrete damage probability distribution. The calculation of the mean damage grade (μD) (No damage, Slight damage, Moderate damage, Substantial to heavy damage, Very heavy damage, Destruction) has been computed per block, without any weighted factor and is the average value of the individual buildings' damage grade.

The **final damage grade** is defined as the one that **corresponds to the highest probability of occurrence of the average μD per block**.



Mitigation measures: General structural, general enclosure, wood, steel and reinforced concrete frame structures, masonry structures, etc.

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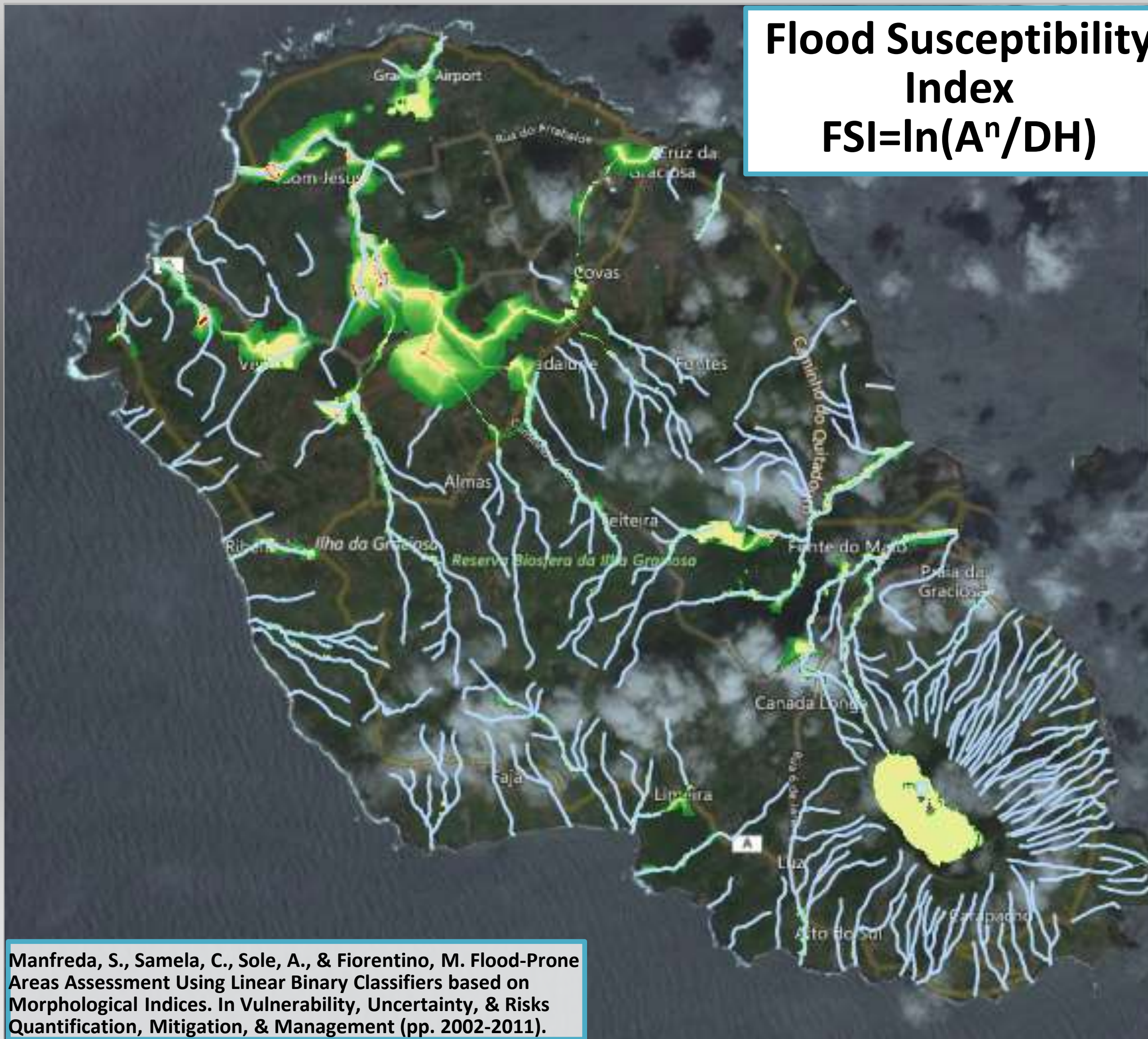
Flood Susceptibility Index

$$FSI=\ln(A^n/DH)$$



Manfreda, S., Samela, C., Sole, A., & Fiorentino, M. Flood-Prone Areas Assessment Using Linear Binary Classifiers based on Morphological Indices. In Vulnerability, Uncertainty, & Risks Quantification, Mitigation, & Management (pp. 2002-2011).

FIRST SLIDE

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- **Hazard**
- **Vulnerability**
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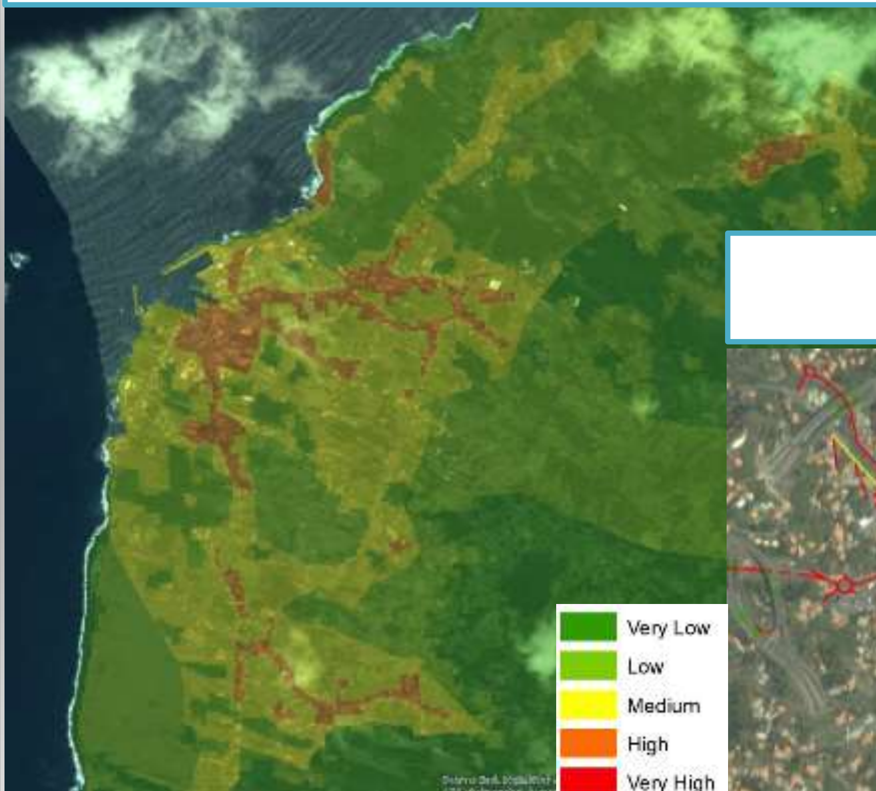
Population vulnerability:
F (Pop. density, social charac, build. density & typology, LULC)



floors

floors/total number of buildings)*0.7+(Number buildings 3-4 floors/Total number of buildings)*0.5+(Number buildings > 5 floors/Total number of buildings)*0.3

calculation were reclassified in numeric vulnerability class

POI	Vulnerability Class
Airport	0.7
Commercial, Public & Private Services	0.5
Education	0.9
Fire station	0.9
Government Facilities	0.7
Hospital	0.9
Military	0.7

Road Type	Vulnerability Class
Other	0.9
Local Road	0.7
Secondary Road	0.5
Primary Road	0.3
Highway	0.1

POI and Road Network:
F (destination and road category)

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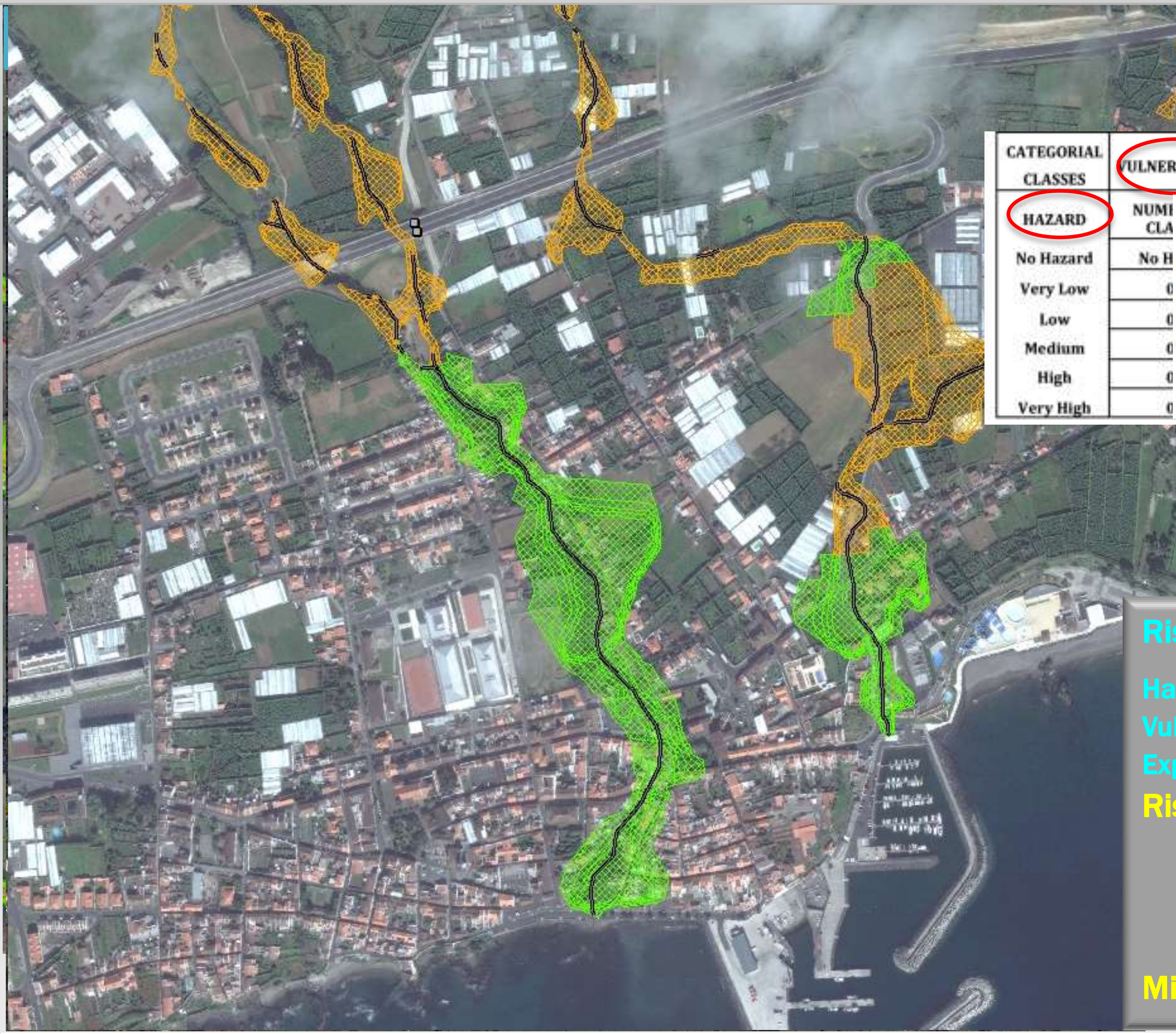
[1]GEOAPIKONISIS S.A.P.GE., [2]CIMA FOUNDATION, [3]NOA



FIRST SLIDE

Risk Modelling

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Exposure

Risk level assess

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  - Buildings
  - Industries, etc
  - Transport Network
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Lava Flow
Landslides
Soil Erosion
Coastal Erosion
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The geodynamic framework of the Azores is dominated by an active triple junction between three of the world's large tectonic plates (the North American Plate, the Eurasian Plate and the African Plate) a condition that has translated into the existence of many faults and fractures in this region of the Atlantic. All the islands have volcanic origins, although some, such as Santa Maria, have had no recorded activity since the islands were settled.

In the Azores there are

26 active volcanic systems

8 are submarines

From the beginning of the island's settlement, around the 15th century, there have been 28 registered volcanic eruptions (15 terrestrial and 13 submarine). The last significant volcanic eruption, the Capelinhos volcano (Vulcão dos Capelinhos), occurred off the coast of the island of Faial in 1957; the most recent volcanic activity occurred in the seamounts and submarine volcanoes off the coast of Serreta and in the Pico-São Jorge Channel.

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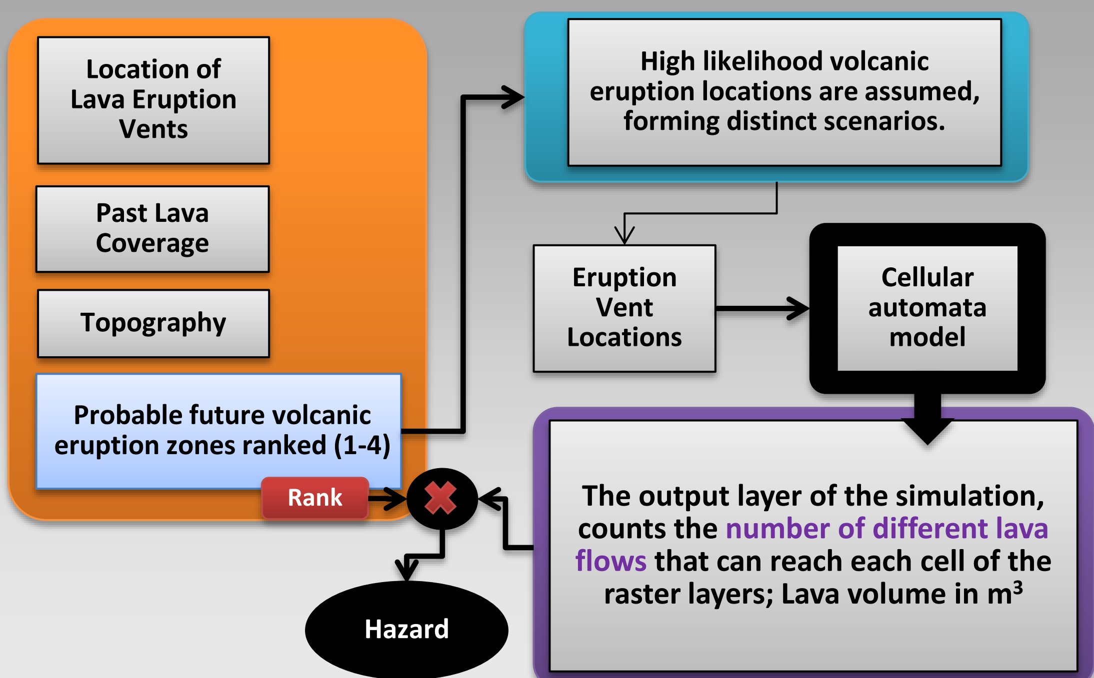
The Lava Flow Hazard assessment has been determined through

- Studying the historical volcanic activity of the area.
- Defining the possible lava eruption areas.
- Estimating the lava flow paths and their convergence by applying a **cellular automata** (Gíslason[1]) based **Lava Flow Hazard numerical model.**

Creation and Activation of dense **lava eruption vent spots** over the areas, considered as lava eruption areas. Topographical characteristics (critical driving factor) of the high volcano slopes do not allow the simulated lava flow streams to converge, early, near their sources (ignition spots); For this reason and in order to assess the risk within, otherwise, "no-data" areas, a complementary risk layer, depicting the risk over such eruption zones appears at the Lava Flow Risk Assessment product. The aforementioned complementary risk layer encodes five classes of risk (very low, low, medium, high, very high) which resulted from the study of the historical volcanic activity (eruption intensity and eruption frequency) for each eruption source and further attribute the associated lava eruption areas.

[1] Gestur Leó Gíslason, Department of Development and Planning, Aalborg University, Denmark, Final Thesis, June 2013



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Example maps; (A) Population at Risk and (B) Transportation Networks at Risk for Sao Miguel Island. Population Risk map includes tables for Population, Built-up areas & Assets at Risk, which in conjunction with the Transportation Network at Risk table show the qualitative results of Lava Flow risk analysis.

Statistics for lava flow for Azores islands, Portugal

Road Network (km.)

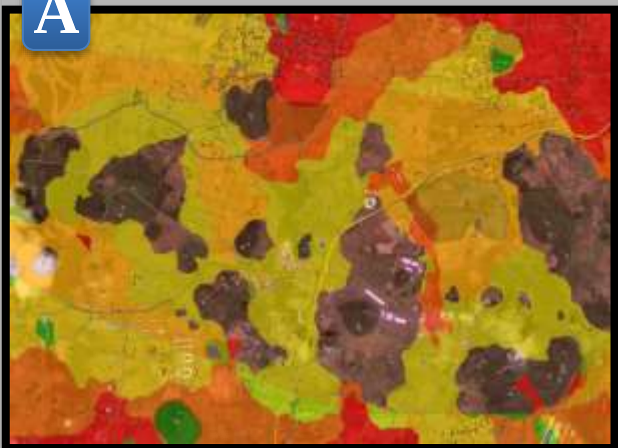
Built up areas (Ha.)

POIs

Population (Number of residents)

Lava flow Risk Level	Corvo	Flores	Faial	Pico	Sao Jorge	Graciosa	Terceira	Sao Miguel	Santa Maria	TOTAL
Very Low	9	538	3634	1	467	0	2993	6017	-	13659
Low	0	0	2073	138	82	1655	3551	12439	-	19938
Medium	0	0	3282	357	267	0	876	4003	-	8785
High	0	0	601	1964	140	0	1612	8126	-	12443
Very High	0	0	3850	6980	2	0	12395	73454	-	208242

A



B

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- Disruption of source or advancing front of lava flow by explosives.
- Cooling advancing front of lava with water.
- Diversion using earth banks and channels.
- Lava flow retention basins.
- Land-use planning.
- Volcanoes monitoring: monitor seismic activity, monitor gas emissions, monitor ground deformation using GPS, theodolites, electrical distance measurements and remote sensing, monitor pressure changes in the underground using strain measurements.

A - Lava flow retention basin;
B - Lava diversion / ditch;

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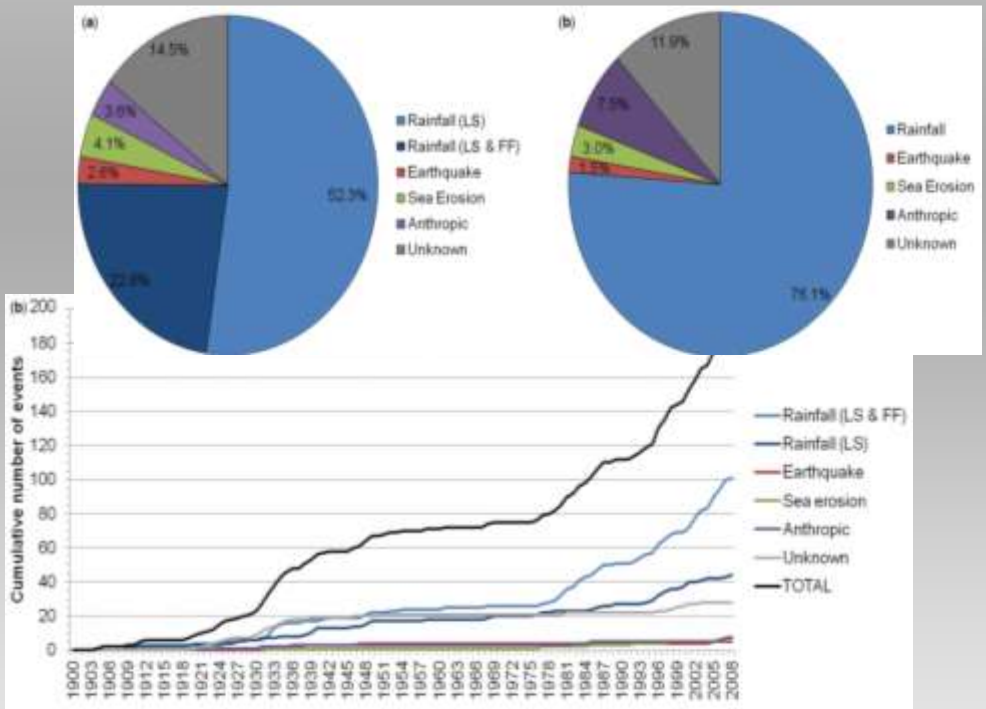
The Azores island complex is a region particularly vulnerable to slope instability due to geological, geomorphologic and meteorological factors.

The volcanic nature and morphology of the islands, namely the existence of steep slopes developed on incoherent volcanic materials, condition the occurrence of landslides, which are typically triggered by earthquakes, volcanic eruptions or more often by extreme precipitation events (75.1% in S. Miguel island).



The rainfall triggered landslides present increasing rates the last 20 years and, in S. Miguel island, some 76% of the casualties were also caused by rainfall-triggered landslide events.

FIRST SLIDE

[Environmental Setting]

Marques, R., Amaral, P., Araujo, I, Jaspar, J.L. & Zezere, J.L. 2015. Landslides on Sao Miguel Island (Azores): susceptibility analysis and validation of rupture zones using a bivariate GIS-based statistical approach. Geological Society, London, Memoirs, 44:16784, doi:10.1144/M44.13.

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The *Norwegian Geotechnical Institute* methodology was used towards **Landslide Hazard assessment** for the triggering factors of 100-year extreme monthly rainfall (Tp) and 475-year return period PGA (Ts). Slope inclination (Sr). Lithology (Sl), soil moisture (Sh) and land use (Sv) were also taken into account as conditioning factors assigned with a severity-based index.

NGI Landslide Hazard Index

$(S_r \times S_l \times S_h \times S_v) \times T_p$ or T_s

The **Exposure** of Assets depends on their distance with reference to :

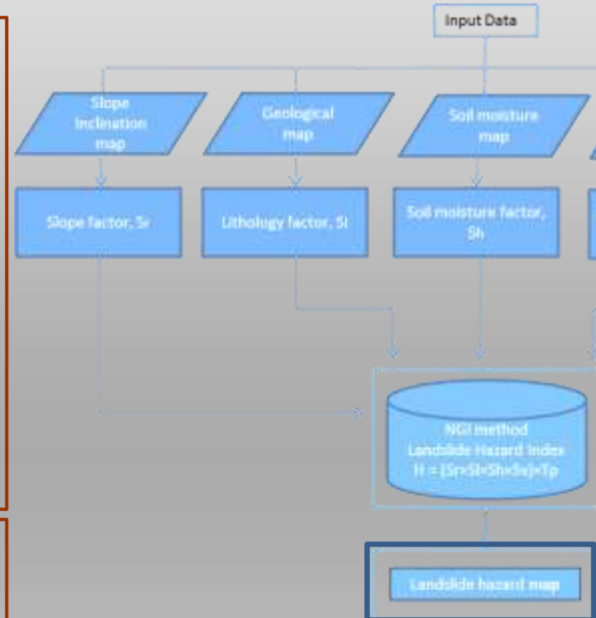
- the Landslide Hazard zone and
- the topography

Vulnerability accounts for specific parameters with respect to the assets' type:

Buildings:
- Construction material
- Building age

Transportation Network:
- Road hierarchy
- Bridge existence

FIRST SLIDE



The **Landslide Risk** assessment and the recognition of the elements at risk account for the Landslide *Hazard* assessment, and the *Exposure* & *Vulnerability* of the assets.

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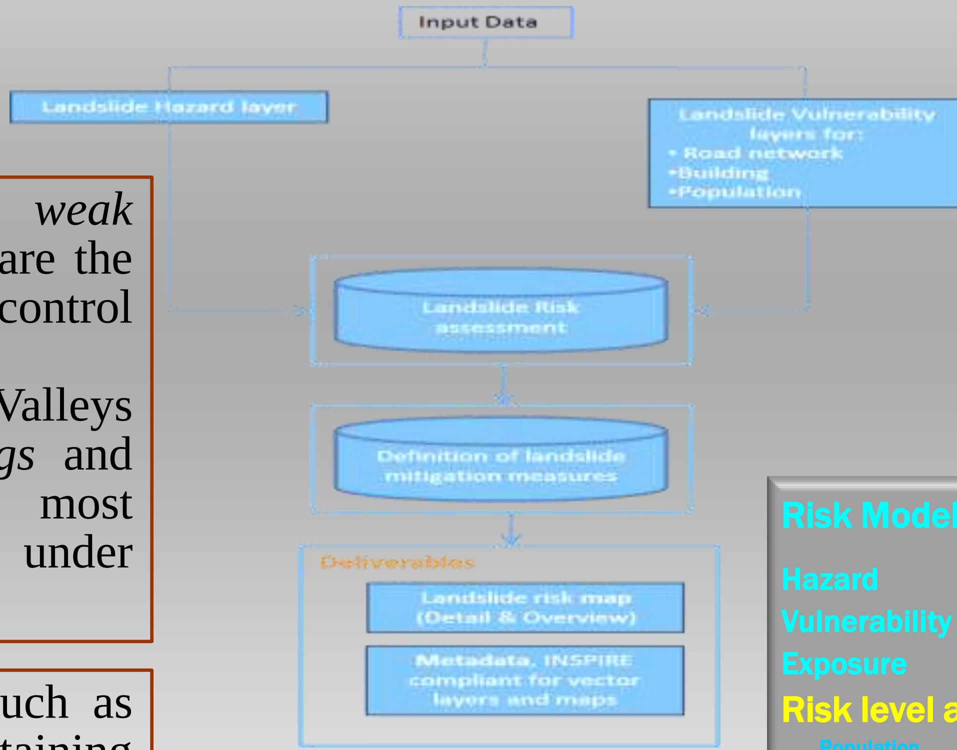
The **Landslide Risk** for Buildings and Transportation Network is the outcome of Landslide *Hazard* and *Vulnerability* of the exposed assets convolution.



Steep slopes and *weak geological* formations are the main factors which control landslide hazard.
Built up areas in V-Valleys with *masonry buildings* and *local roads* are the most vulnerable and thus under higher risk.

Mitigation measures such as fences, barriers, retaining walls, vegetation coverage and geomembranes are suggested in relation to the landslide hazard & risk level.

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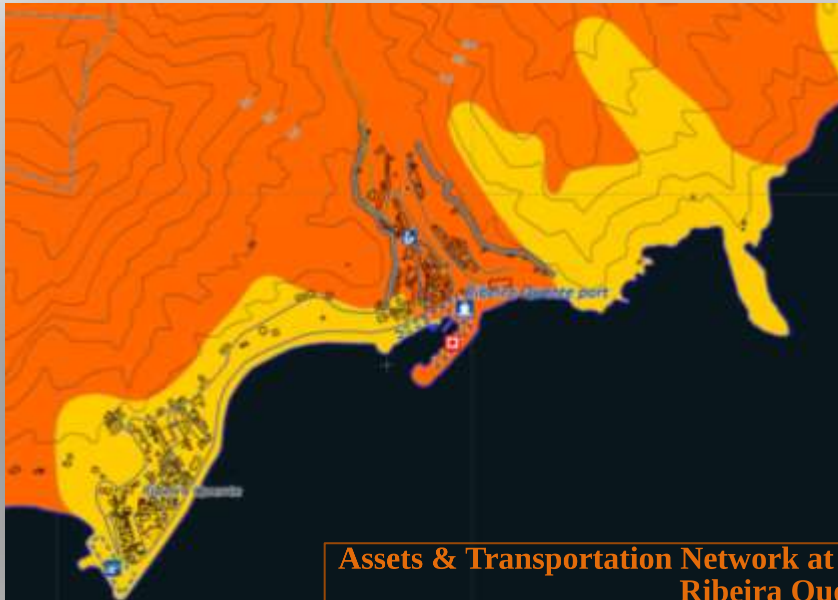
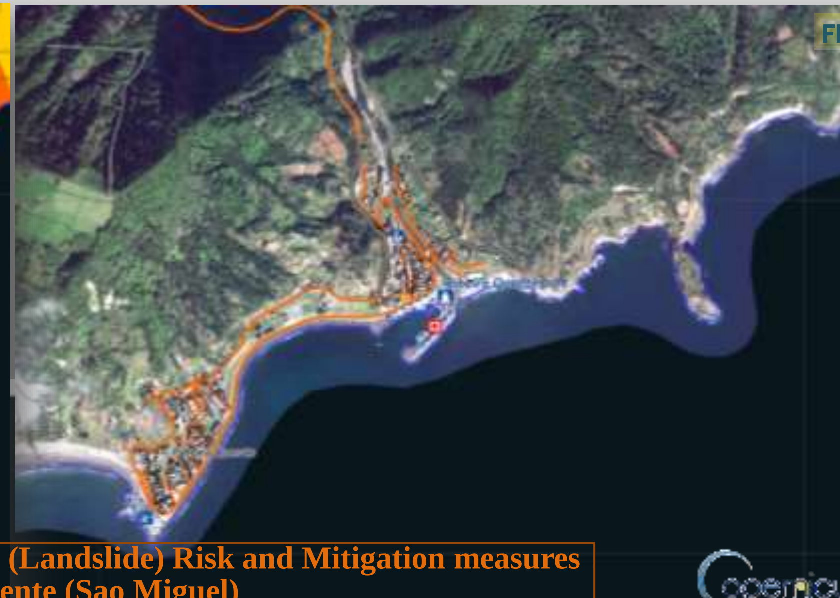
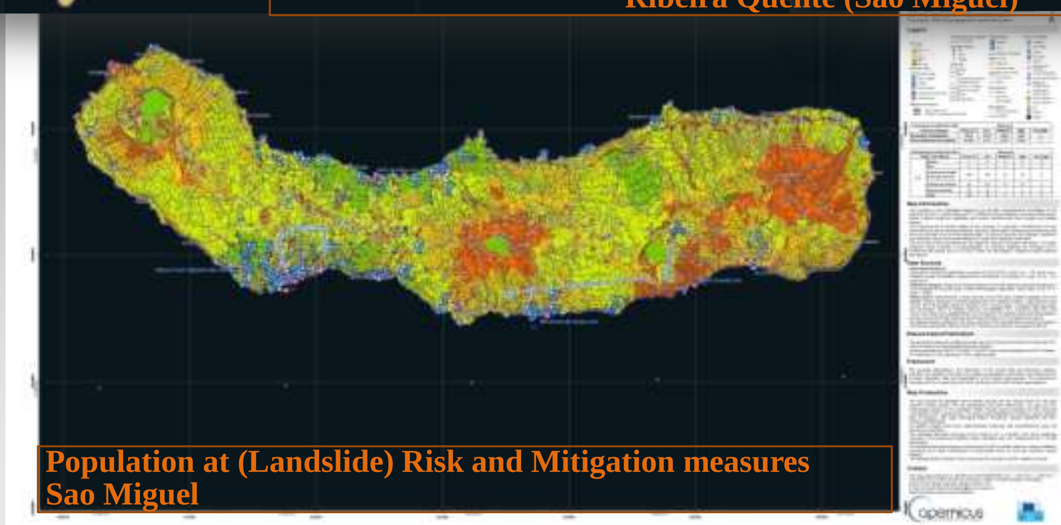




Assets & Transportation Network at (Landslide) Risk and Mitigation measures
Ribeira Quente (Sao Miguel)



Population at (Landslide) Risk and Mitigation measures
Sao Miguel

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[Environmental Setting]

The soil erosion hazard in Azores is closely related to the recent volcanic origin soils, the unusual hydraulic characteristics related to the presence of allophane (Fontes et al., 2004), the land use and cultivation techniques management.

Topsoil characteristics are dominated by high plasticity and weak aggregate stability when the soil is wet.

Rapid erosion may also be attributed to the low clay content and to organic matter mineralization during and immediately after cultivation.

The steepness of the slopes and the slope length constitute important factors to soil erosion process.

Unprotected and bare areas along steep volcanic flanks or coast slopes present the most unfavorable conditions towards soil erosion hazard.

Fontes, J.C., Pereira, L.S. & R.E. Smith (2004). Runoff and erosion in volcanic soils of Azores: simulation with OPUS. Catena 56 (2004)199-112.

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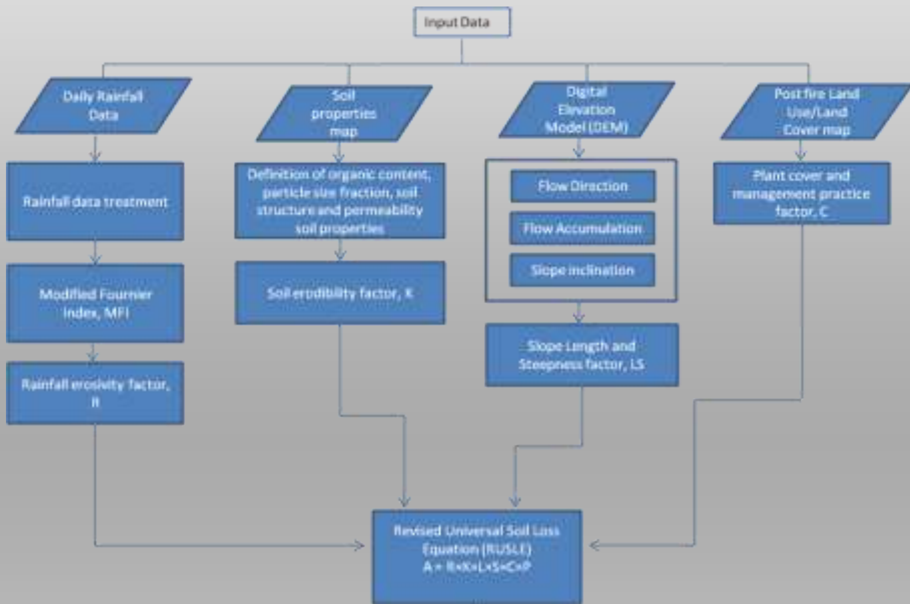

Soil Erosion Hazard due to water assessed through the empirical model Revised Universal Soil Loss Equation (RUSLE)

Five major factors are used to compute the expected average annual erosion

- Rainfall pattern - R
- Soil type - K
- Topography – L, S
- Land use / cover - C
- Management practices - P

Estimated average soil loss in tons per hectare per year

$$A = R \times K \times L \times S \times C \times P$$

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Overview Statistics Table

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Soil Erosion Risk Level	Land Cover/Use (Ha.)									
	Corvo	Flores	Faial	Pico	Sao Jorge	Graciosa	Terceira	Sao Miguel	Santa Maria	TOTAL
Very Low	45	3694.4	6482.6	0	3819.1	2169.6	22650.9	39600	4359.7	82821.3
Low	306.4	2325.7	4876	21787.6	6064.2	1715.8	8710	49600	1680.4	97066.1
Medium	1045.9	4126.1	215.2	19279.5	12223.8	1671.5	4701.4	56800	2598.2	102661.6
High	100.1	300.3	0	1994.4	1383.5	159.9	6.6	9700	282.1	13926.9
Very High	0	0	0	70.3	0	0	0	0	8.3	8.3

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The estimation of the coastal erosion risk follows a number or criteria, which are based on seven empirical indicators. Indicator-based approaches express the susceptibility of the coast by a set of independent signs. This indicator-based approach is followed at European level, including the Eurosion & Deduce projects.

Radius of influence of coastal erosion is meant to provide a proxy of the terrestrial areas, which may potentially be susceptible to coastal erosion in the coming period of 100 years.

Taking Sea Level Rise, local effects of land subsidence and other relevant parameters into account the coastal areas lying below 15 meter, above sea level, are considered to belong to the radius of influence of coastal erosion. For the purpose of the project, the radius of influence of coastal erosion has been defined at 500 meters.

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Table of Ratings of Azores in terms of coastal erosion hazard

	1 point	2 point	3 points		1 point	2 point	3 points
Relative sea level rise (best estimate for next 100 years)	< 0 mm/y	Between 0 and 0,40mm/y	>0,40 Mm/Y	**Digital Elevation Model**	< 5% of the region area lies below 5 meters	Between 5 and 10% of the region area lies below 5 meters	> 10% of the region area lies below 5 meters
Shoreline evolution trend Status	Less than 20% of the shoreline is in erosion	Between 20% and 60% of the shoreline is in erosion	More than 60% of the shoreline is in erosion	**Engineered frontage**	< 5% of engineered frontage along the regional coastline	Between 5% and 35% of engineered frontage along the regional coastline	> 35% of engineered frontage along the regional coastline
Highest water level	Less than 1,5 meters	Between 1,5 and 3 meters	More than 3 meters	**Near shore currents**	Distance >100m	Distance 50-100 m	Distance <50 m
Geological coastal type	> 70% of "likely non erodible segments"	"likely non erodable segments" between 40% and 70%	< 40% of "likely non erodable segments"				

Each one of the seven (7) sensitivity indicators is evaluated according to a semi-quantitative score that represents low, medium and high level of concern about the expected future risk or impact erosion.

The Sensitivity indicators, are then aggregated in grid scale and normalized, to respectively derive a sensitivity score, which actually defines the "**hazard** estimation of **coastal erosion**".

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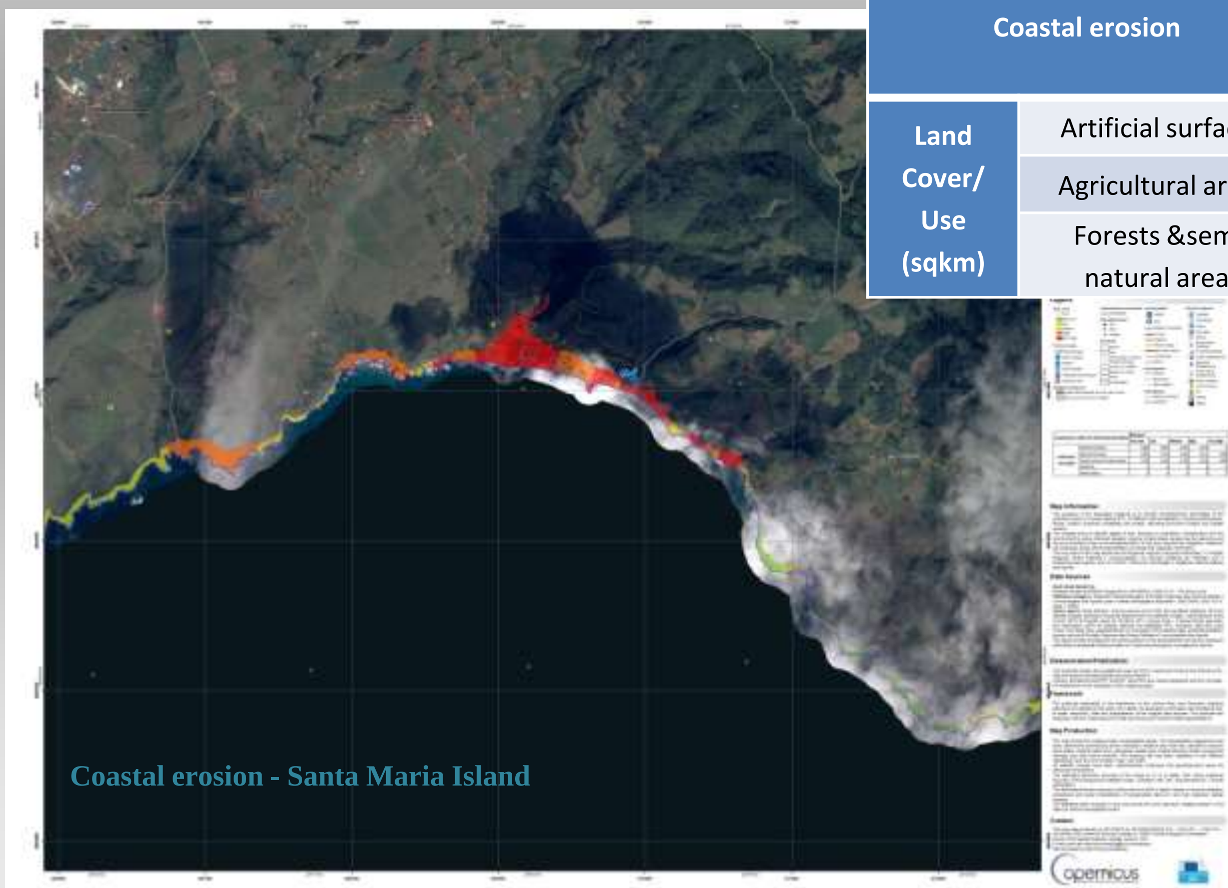
Coastal erosion Hazard for Santa Maria Island. Every map includes one table, which shows the qualitative results of the coastal erosion. Low & very low risk is observed at ports, at areas with implemented mitigation measures as well as at high basaltic hard cliffs, which are not affected by coastal erosion.

Coastal erosion Statistics for Azores islands

Coastal erosion		Risk Level				
		Very Low	Low	Med	High	Very High
Land Cover/ Use (sqkm)	Artificial surfaces	3,55	5,07	3,47	0,45	0,02
	Agricultural areas	2,57	9,79	7,57	3,32	1,07
	Forests &semi-natural areas	1,49	4,46	3,72	2,38	0,19



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- Landslides
- Soil Erosion
- Coastal Erosion
- Tsunamis & Storm Surges

Multi Hazard Assessment: The Azores Archipelagos (PT) case

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FIRST SLIDE

The problem for Azores is critical, as they are particularly vulnerable to the effects of climate variability in the form of sea level rise, which could significantly impact the way of life. To minimize the impact of coastal erosion and maximize the protection of human life, nature and assets, mitigation measures should be designed and implemented after the estimation of risk of coastal erosion at each region of Azores.

Fig. Ribeira Grande: a) coastal engineering work at Ribeira Grande; b) pocket beach; c) exposed rocks and left-side wall (arrows) and d) exposed rocks and right-side wall (arrows)

Mitigation measures:

- Hardening the Shoreline
- Submerges Breakwaters
- Detached breakwaters
- Groins
- Sand Replenishment
- Wave Damping

Risk Modelling

Hazard
Vulnerability
Exposure
Risk level assessmen
- Population
- Assets
  - Buildings
  - Industries, etc
  - Transport Network
  - Environment

Mitigation Measu

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FIRST SLIDE

Almost all inhabited areas in Azores are located close to the coast and the exposure to **storm surge** hazard is significantly high. Population density is crucial for determining the sensitive zones and census data are used for generating the exposure layers. Specific assets such as industry, power and water infrastructure and religious assets were also identified.

Tsunami waves propagation:
The expected maximum **tsunami wave** heights in a number of forecast points along the coastlines of the islands were estimated for a specific earthquake scenario, selected based on historical data. The deformation at the source has been calculated by utilizing the Okada code (Okada, 1985). The generation and propagation of the tsunami waves was based on the SWAN model modified by JRC/IPSC. The estimation of the wave height at the designated forecast points has been made by using the Green's Law function tool that has been also incorporated in the JRC Tsunami Analysis Tool.

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FIRST SLIDE

Storm surges propagation

Analysis of the historical data of storm tracks over the Azores Archipelagos indicates a return period of 17 years and a return period of 41 years for H1 and H2 hurricane categories respectively. The maximum significant wave height (wind and swell) is derived along the island's coastline for two major storms based on the NOAA WAVEWATCH III model hind cast reanalysis and the associated storm-surge risk is estimated taking also into account the coastline morphology.

Inland wave propagation

The inland water propagation characteristics were determined by applying the appropriate hydraulic models for the tsunami & Storm surge hazards considering the maximum wave height, the geomorphology and the hydraulic roughness, in order to estimate the affected inland areas and calculate the local water depth.

Tsunami Hazard Severity	Local Water Depth (m)
Very Low	<2
Low	2-4
Medium	4-6
High	6-8
Very High	>8

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FIRST SLIDE

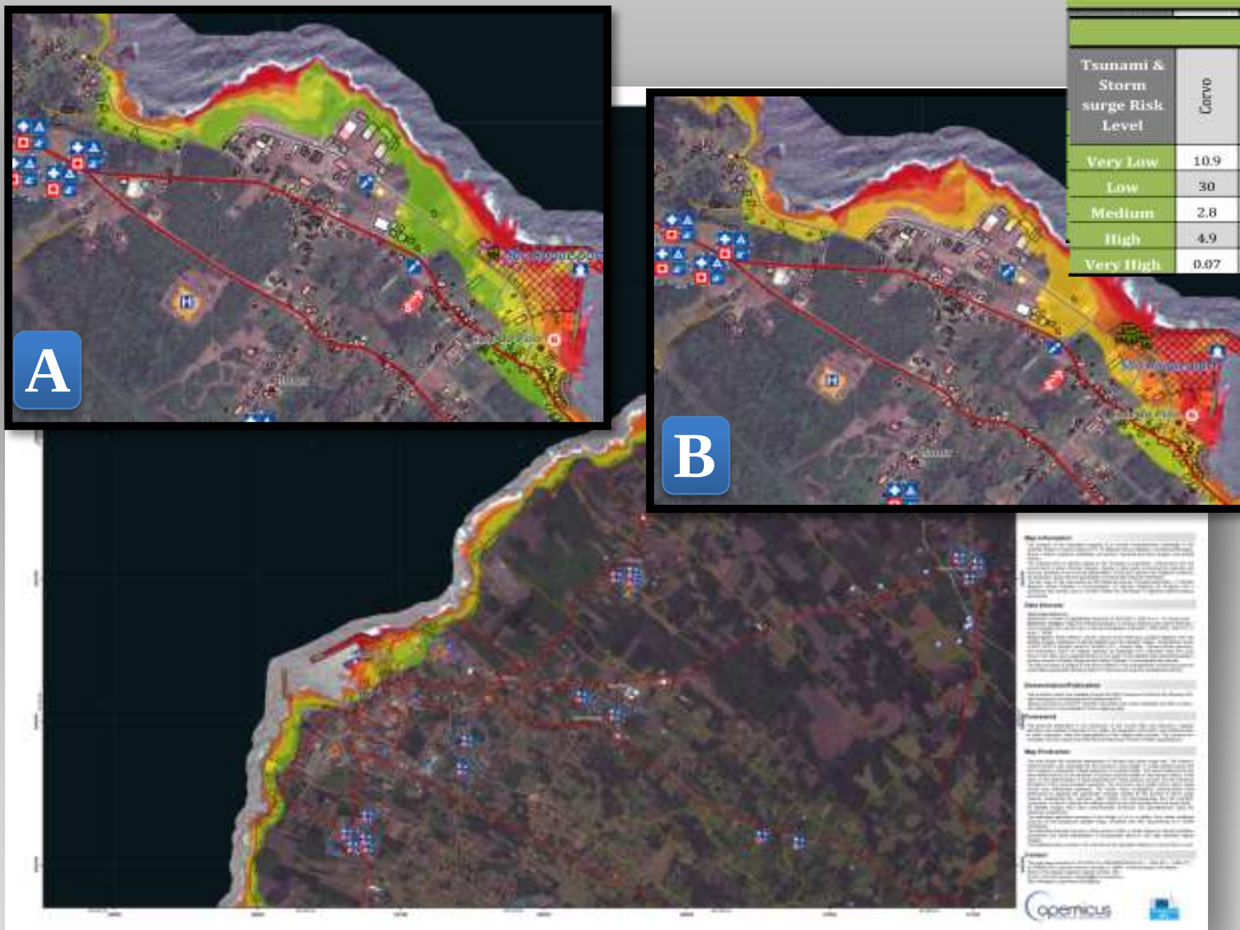
Example maps; (A) Population at Risk and (B) Environmental Risk over the various LU/LC classes for Pico Island. Population Risk map includes Population & Built-up areas tables which in conjunction with the Environmental Risk map table show the qualitative results of the risk analysis.

Built up areas (Ha.)

Population (Number of residents)

Land Cover/Use (Ha.)

Tsunami & Storm surge Risk Level	Corvo	Flores	Faial	Pico	Sao Jorge	Graciosa	Terceira	Sao Miguel	Santa Maria	TOTAL
Very Low	10.9	17.13	20.88	25.77	65.63	10.80	25.85	61.70	20.62	259.28
Low	30	59.46	75.68	148.82	155.38	58.00	156.04	211.58	57.17	952.13
Medium	2.8	46.97	42.80	166.14	84.07	45.40	98.61	174.94	21.52	683.25
High	4.9	23.39	35.84	97.45	39.04	18.40	111.25	153.85	13.67	497.43
Very High	0.07	0.75	0	24.00	1.38	0.04	9.85	107.63	0	143.72



Risk Modelling

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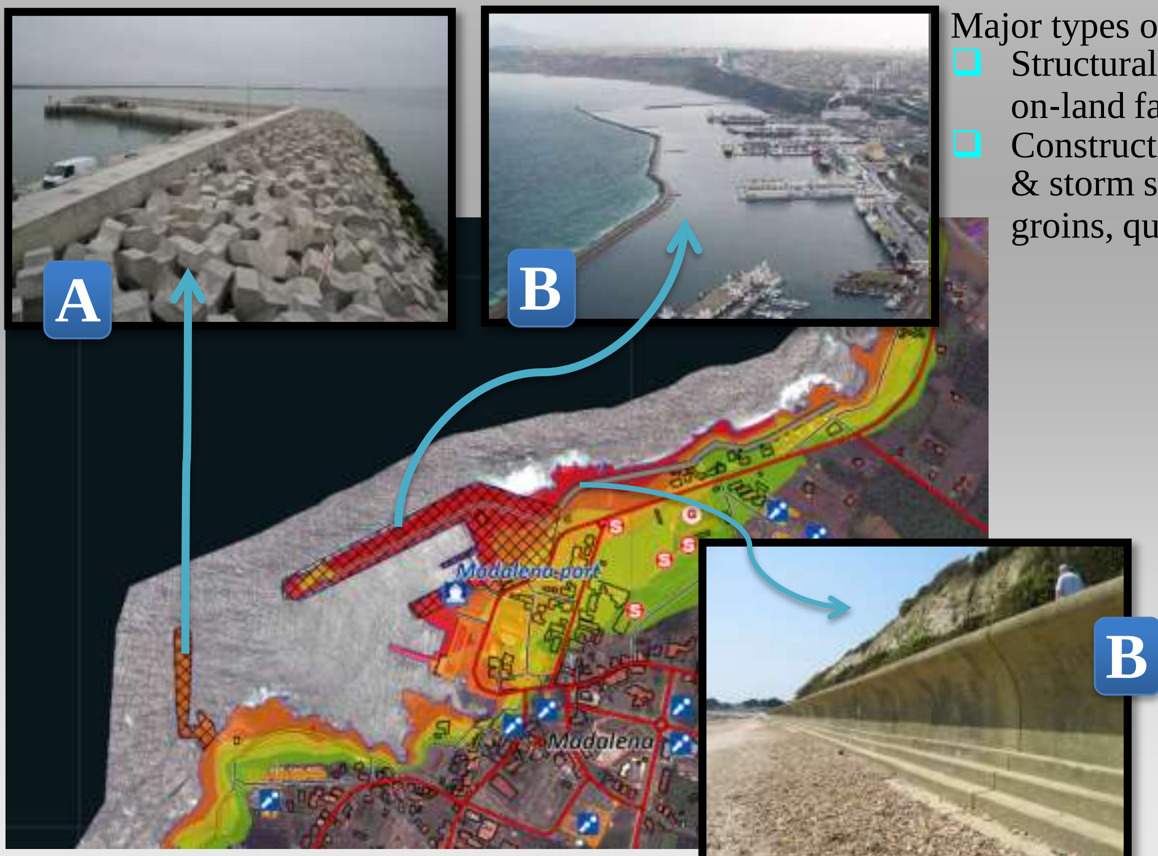
FIRST SLIDE

Mitigation measures include both construction (coastal defence) and site planning strategies. Structural countermeasures are especially necessary in ports to reduce intrusion into ports, but also onto the land.

For both types of measures it is important :

- to estimate the incident profile (height and current with direction) and
- to plan in a cost-effective way.



Major types of structural countermeasures:

- Structural reinforcement of assets (ports & other on-land facilities) [A]
- Construction of defences in order to reduce tsunami & storm surges intrusion (Breakwaters, seawalls, groins, quays, dykes / levees) [B]

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Workflow

Data collection

Updated Geospatial layers
- DEM
- Census data
- Populated places
- Building footprints
- Buildings typology & use
- Road Network
- Hydrographic Network
- LULC layer
- Protected areas
- Water resources
- High voltage power lines

Produced layers
- Vulnerability
- Hazard
- Exposure
- Risk

→

Processes
- Spatial Analysis
- Network Analysis
- Visibility Analysis

→

Combination Information products
- Population density
- Secondary landslide prone areas in built-up areas
- Recovery planning
- Alternative roads
- Places for:
  - field hospitals
  - helicopter landing spots
  - camps locations
  - gasoline tank locations
- Safe shelters in the area
- Evacuation routes leading to safe shelters
- Location for emergency communication systems
- Storage places for food and water
- Secondary risks

FIRST SLIDE

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SPAT MOD

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DATA & RULES

FIELD HOSPITALS, HELICOPTER LANDING SPOTS, CAMPS & GASOLINE TANK LOCATIONS

Input layer	Condition/use
DEM - slope layer	Identification of flat areas: - Best areas: gentle slope (2-4%) - Accepted areas: threshold slope value < 10% - Flat sites (slope: 0-2%) rejected, due to presence of serious drainage problems of waste and storm water
Populated places	- Estimated capacity (area of the spot) - Distance from major towns
Water resources	Access to water reservoirs
Road network	Access to existing road network
Hydrographic network	Exclusion of internal water bodies Exclusion of streams & rivers (50 m buffering)
Electrical power grids (high voltage)	Access to high voltage network for power supply
Protected areas	Exclusion of protected areas
LU/LC layer	- Exclusion of highly dense vegetated areas - Inclusion of low dense vegetated areas (for shade, erosion/ dust reduction) - Fire prevention (buffer of 30m from highly dense vegetated areas)
Public services	Proximity to existing infrastructure (health, education, ports & airports)
Risk layer	Exclusion of high risk/vulnerability areas per risk case (e.g earthquake, tsunami, etc)

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DATA & RULES

SAFE SHELTERS (EXISTING BUILDINGS)

FIRST SLIDE

Input layer	Condition/use
Populated places	Estimated capacity: - per populated place & - per building (shelter)
Building s footprints	Area of the building
Buildings typology & use	Schools & universities, churches, indoor stadiums, commercial places like malls, hotels, military infrastructures etc
Risk layer	Exclusion of the affected buildings per case

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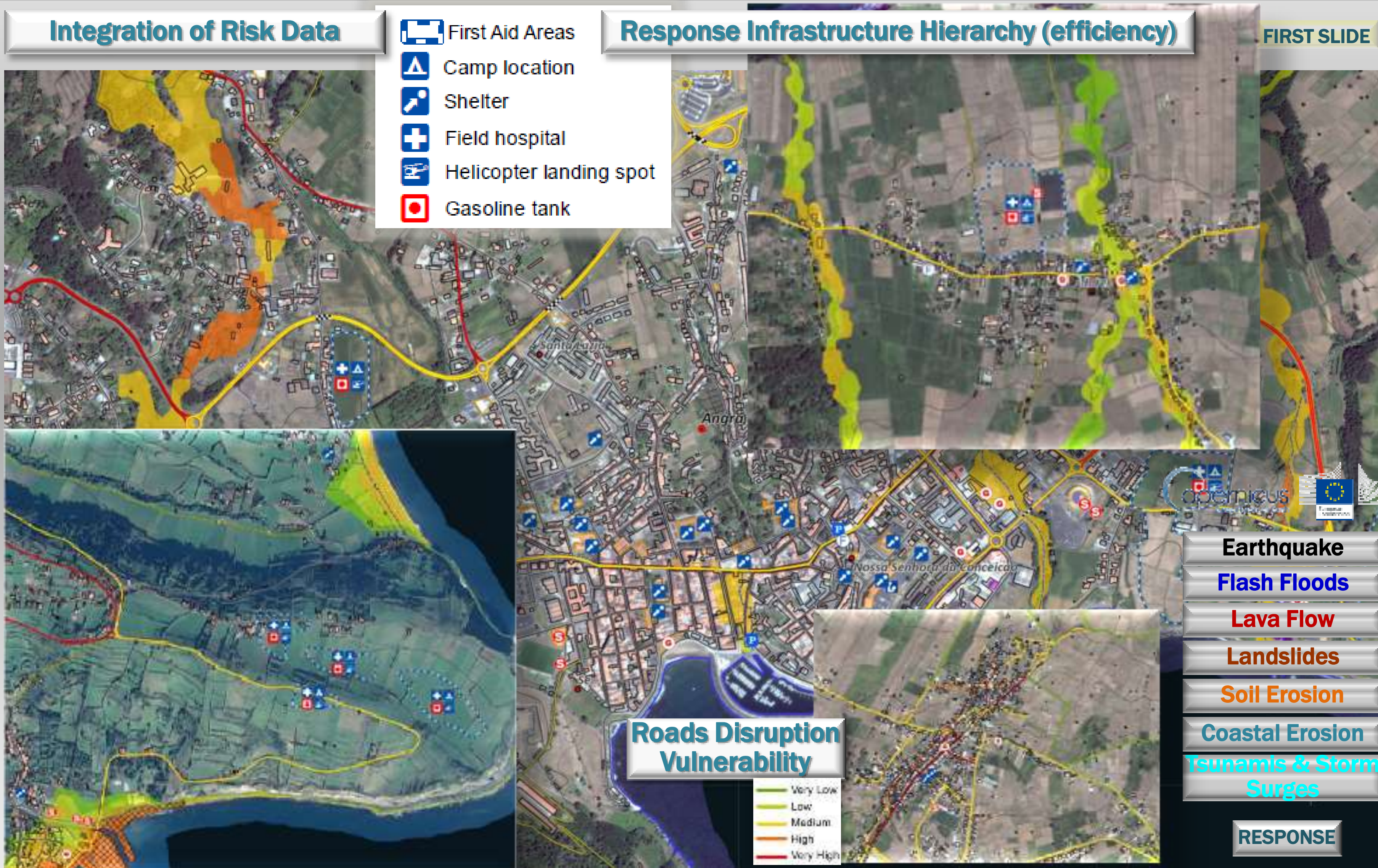
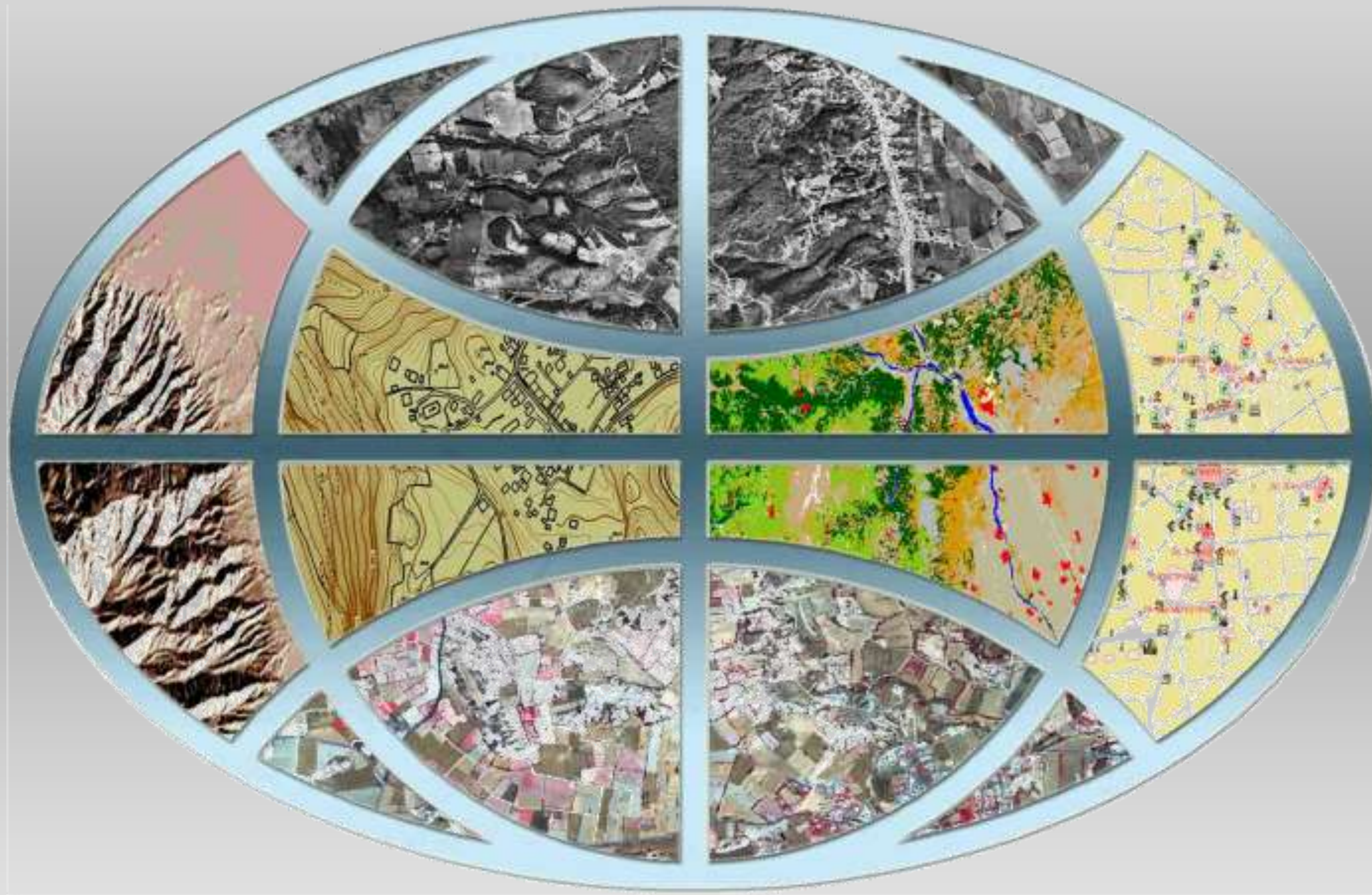


Thanking YOU…..



da@geoapikonisis.gr

www.geoapikonisis.gr

FIRST SLIDE