European Commission

Horizon 2020
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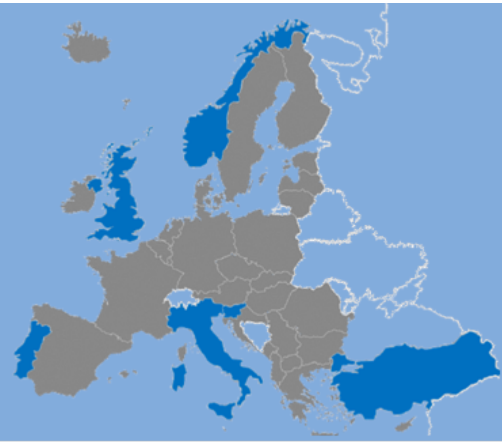
liquefACT

THESSALONIKI
16TH EUROPEAN CONFERENCE ON
EARTHQUAKE ENGINEERING
18 - 21 JUNE 2018
www.16ecee.org



EARTHQUAKE INDUCED LIQUEFACTION RISK:
HOLISTIC ASSESSMENT AND MITIGATION

Wednesday 20th June 2018 - 11:30-13:00

ROOM: CR2 (Building M2 - Thessaloniki Concert Hall/16ECEE Conference Venue)

ASSESSMENT OF LIQUEFACTION RISK AT DIFFERENT GEOGRAPHICAL SCALES

Carlo G. Lai, Francesca Bozzoni, Claudia Meisina & Daniele Conca

UNIVERSITÀ DI PAVIA

UNIVERSITY OF PAVIA - EUCENTRE

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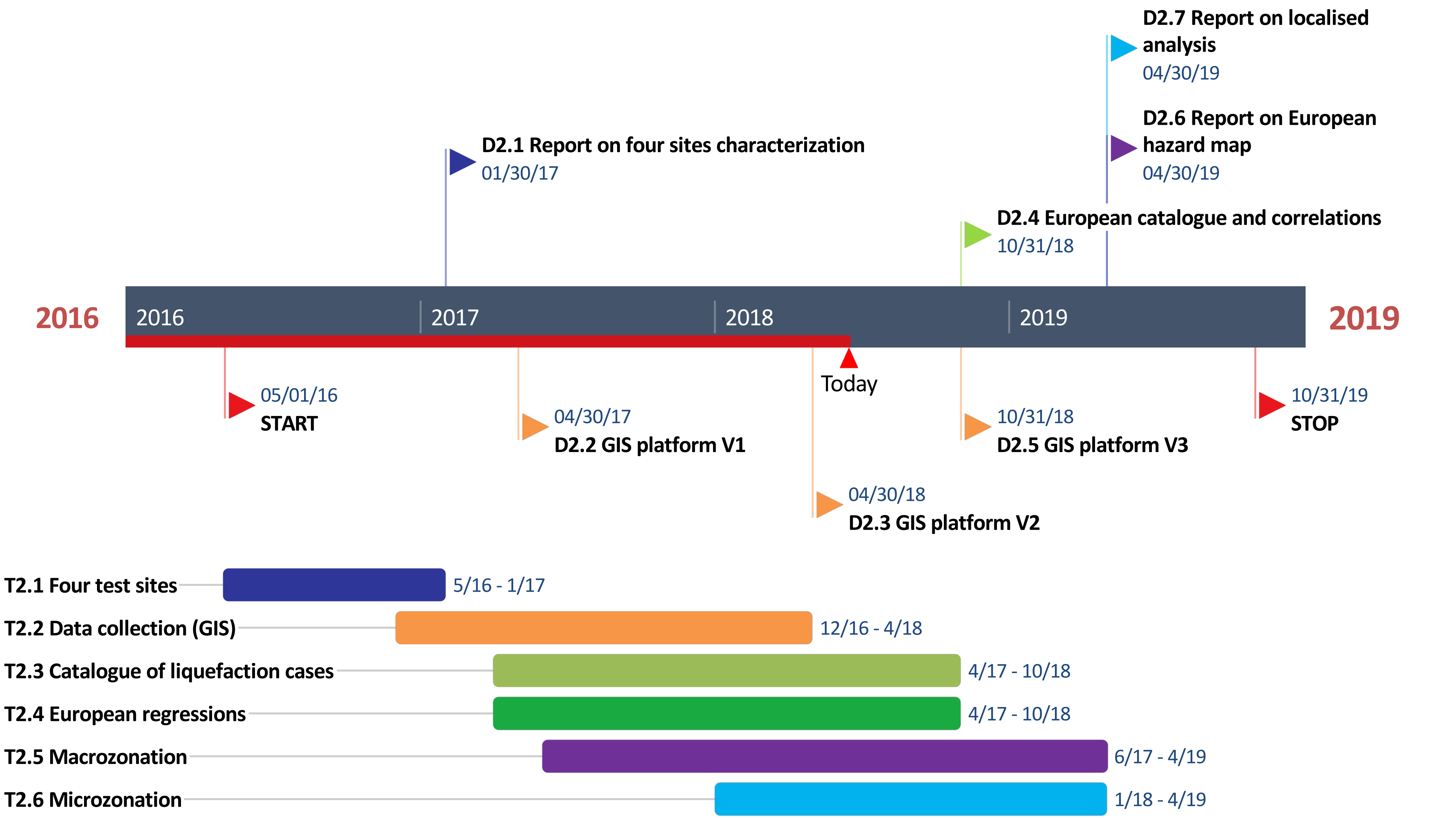
TASKS OF WP2

- **T2.1 Ground characterization at the four European testing sites**
  1. Emilia region in Italy
  2. Lisbon area in Portugal
  3. Ljubljana area in Slovenia (by the Lower Sava river)
  4. Marmara region in Turkey
- **T2.2 Collection of geological and seismological data for Europe within a GIS framework**
- **T2.3 Construction of a GIS-based catalogue of historical liquefaction occurrences in Europe**
- **T2.4 Calculation of European regressions to predict liquefaction occurrence starting from the main seismological information of an earthquake**
- **T2.5 Development of a European liquefaction hazard map - MACROZONATION**
- **T2.6 Validation of the European liquefaction hazard map by detailed analysis at the four testing areas - MICROZONATION**

TIMETABLE OF WP2



MACRO-ZONATION OF LIQUEFACTION RISK AT THE EUROPEAN SCALE

OVERVIEW

✓ BASIC IDEA: combination of ground parameters and hazard parameters (PGA)

GROUND PARAMETERS
Liquefaction susceptibility

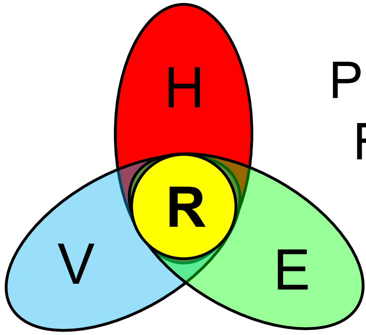
HAZARD PARAMETERS
Liquefaction triggering factors

LIQUEFACTION
RISK MAP

Definition of RISK from natural catastrophes

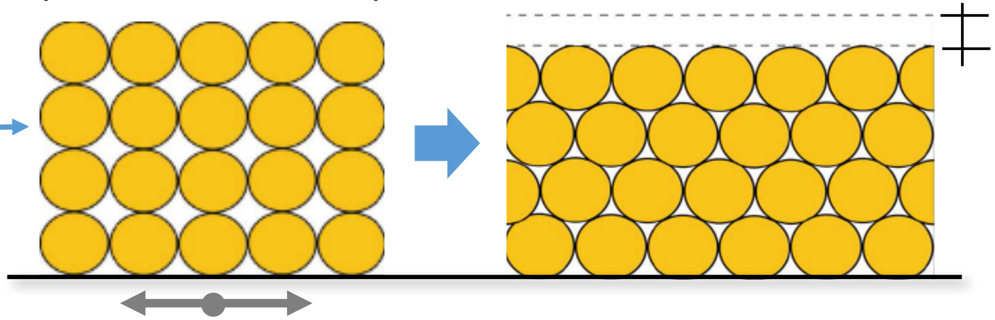
The most accredited *quantitative* definition of *RISK* from natural disasters is that proposed by UNESCO(*) in 1972 which establishes that the RISK of a "system" (e.g. structure, slope, etc.) is the <u>*convolution*</u> of 3 *independent* random variables:

- HAZARD
- VULNERABILITY
- *EXPOSURE*



PROBABILISTIC FRAMEWORK

saturated, loose sand (VULNERABILITY)



seismic shaking (HAZARD)

RISK of settlement (DAMAGE-GEO)

HAZARD

RISK of (DAMAGE-STRU)

(http://nisee.berkeley.edu/eqiis.html)

AIM OF THE MACROZONATION LIQUEFACTION HAZARD MAP

http://www.nationsonline.org/oneworld/europe_map.htm

Cell size of 900 × 900 m and should not be enlarged to greater scales

Cannot be used for detailed and local visualization!

The map shows a harmonized overview of European liquefaction hazard at the 1:5 Mil. scale

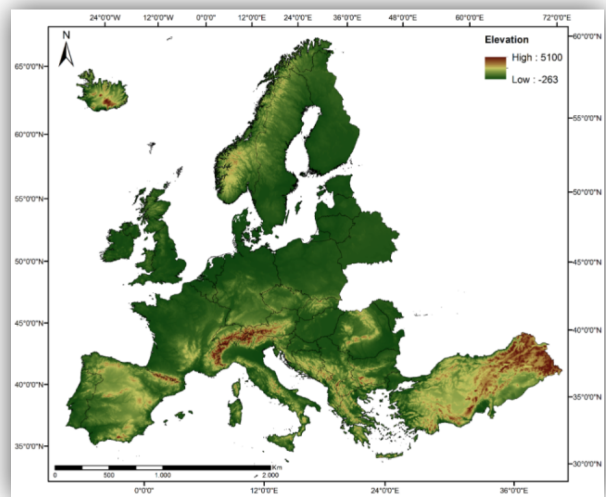
AVAILABLE AND DERIVED DATA

✓ Available geospatial and seismic data at European scale:

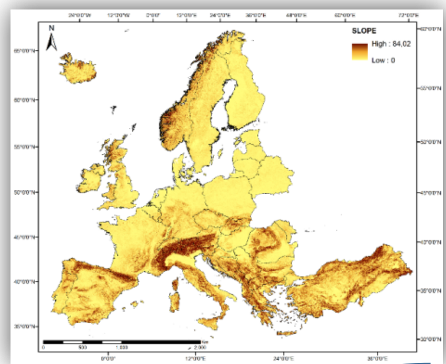
- Probabilistic seismic hazard maps EURO-MEDITERRANEAN region as proposed by the **SHARE project** for 6 return periods (i.e. 73, 102, 475, 975, 2475, 4975 years)
- Seismogenic zones for Europe
- European Database of Faults (EDSF)
- European vs30 model
- European LITHOLOGY map
- Quaternary geology map
- European DEM model → useful to extract terrain attributes especially morphological and hydrological parameters:
  - SLOPE
  - CTI (compound topographic index)
  - Hydro-graphic network
  - EUCLIDEAN DISTANCE from HYDRO-GRAPHIC NETWORK

DIGITAL ELEVATION MODEL AND DERIVED DATA

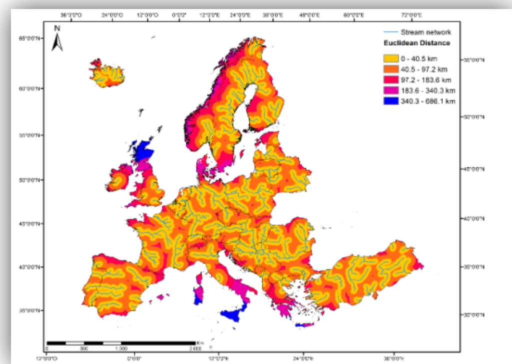
The lower spatial resolution of **Shuttle Radar Topography Mission** SRTM (90 m) requires lower computation capacity than the EU-DEM (30 m) for the processing of DEM-derived product of the entire European territory.



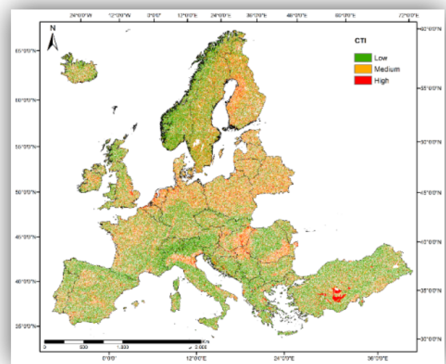
http://srtm.csi.cgiar.org



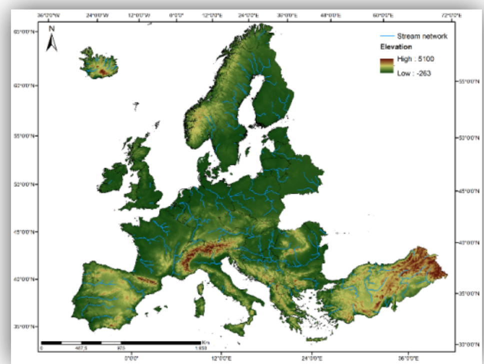
SLOPE



HYDRO-GRAPHIC NETWORK



CTI (COMPOUND TOPOGRAPHIC INDEX)



EUCLIDEAN DISTANCE FROM STREAM NETWORK

METHODS

Two different approaches have been identified:

1. DATA-DRIVEN METHODS

- ✓ Relation between **explanatory variables** (*i.e. factors that affect the occurrence of liquefaction*) and occurrence of liquefaction. Relation between **explanatory variables** and liquefaction occurrence is developed through a statistical/machine learning algorithm (Logistic Regression, ANN, SVM, Decision Trees, etc.)

- ✓ Calibrated (or *trained*) from **database** of past earthquakes where presence/absence of liquefaction has been mapped.

Data-driven method by Zhu et al. (2015) → logistic regression model

Logistic regression framework: a liquefaction occurrence probability (*P(X)*) is expressed in terms of **explanatory variables.**

Explanatory variables:

- PGA_M *
- Shear-wave velocity (Vs30)
- Compound topographic index (CTI)

*magnitude weighted peak ground acceleration

METHODS

Two different approaches have been identified:

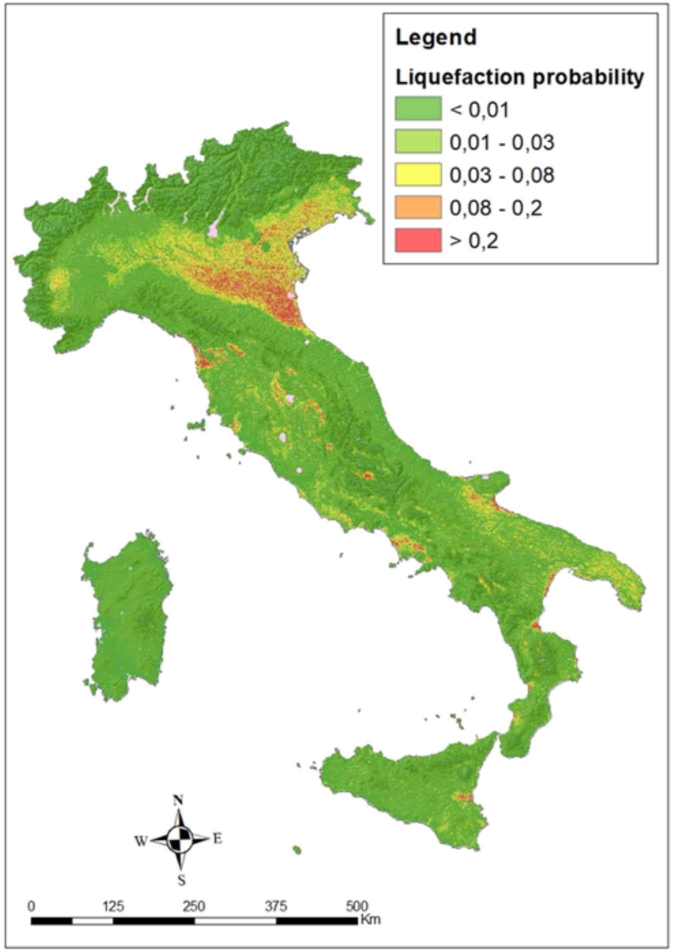
2. KNOWLEDGE-DRIVEN METHODS (based on experts' opinion)

- ✓ *Analytical Hierarchy Process* (**AHP**, introduced by T. Saaty, 1980), where the judgment of an **Expert** is applied in order to rank the **explanatory variables** (the highest the rank, the highest the contribution to the liquefaction hazard).
- ✓ A weight for each variable is computed
- ✓ Final map: integration of the variables via weighted sum and overlay operations.

Input data → Rank → Weight → Map

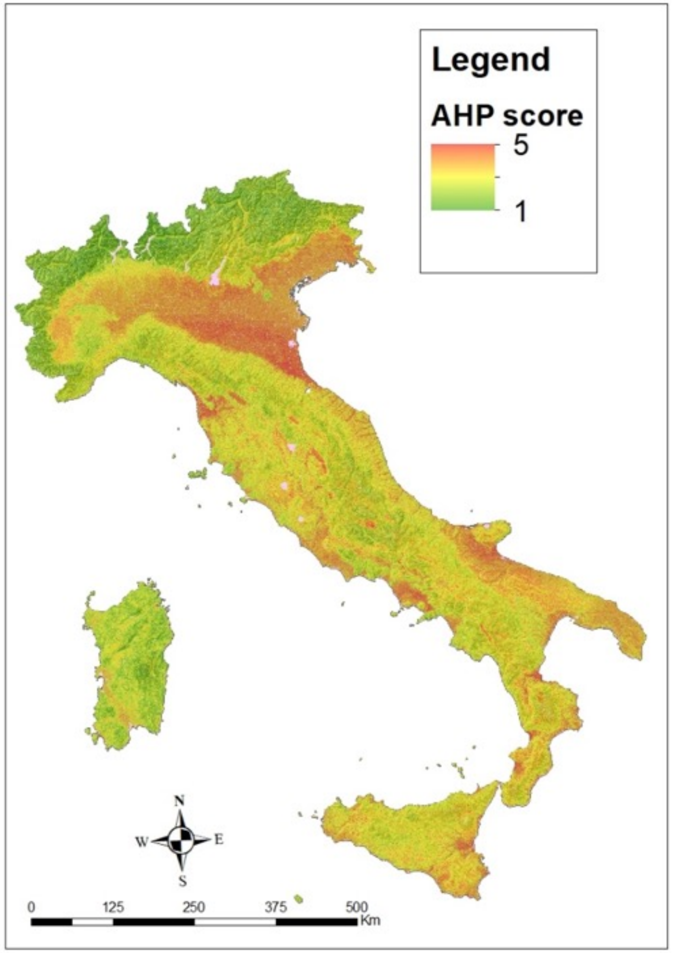
➢ Technique used successfully to map seismic hazard zonation (Mohanty and Walling 2008, Pal et al. 2008, Bathrellos et al. 2009, Erden and Karaman 2012, He et al. 2014, Karimzadeh et al. 2014, Panahi et al. 2014, Quadrio et al. 2015)

PRELIMINARY RESULTS



Logistic Regression (Zhu et al., 2015)

AHP



- Preliminary application to the Italian area of two methods in a GIS environment
- PGA refered to the 475 years return period (extracted from SHARE)

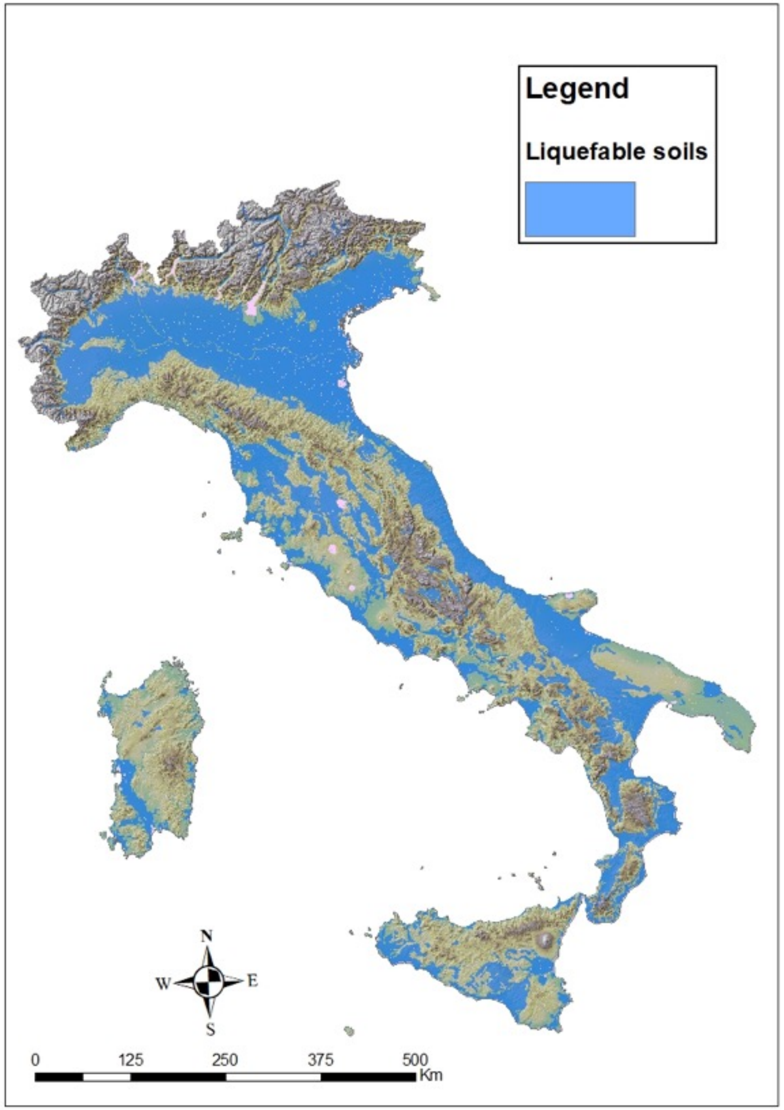
PRELIMINARY RESULTS

Some low seismicity zones and some non-susceptible zones may present a medium level for liquefaction hazard*.

FILTERS

PGA Threshold (0.1g, 475y)

Liquefable Soils



*more evident for the AHP method

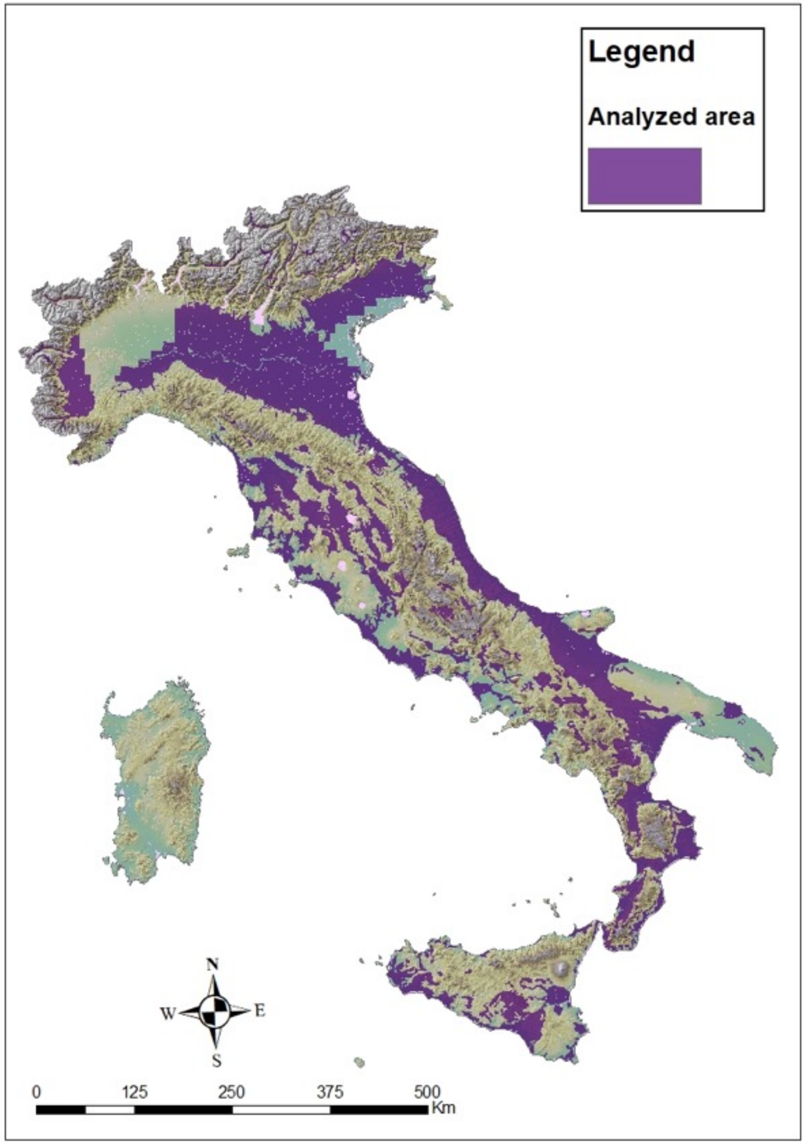
PRELIMINARY RESULTS

Analyzed area

PGA Threshold

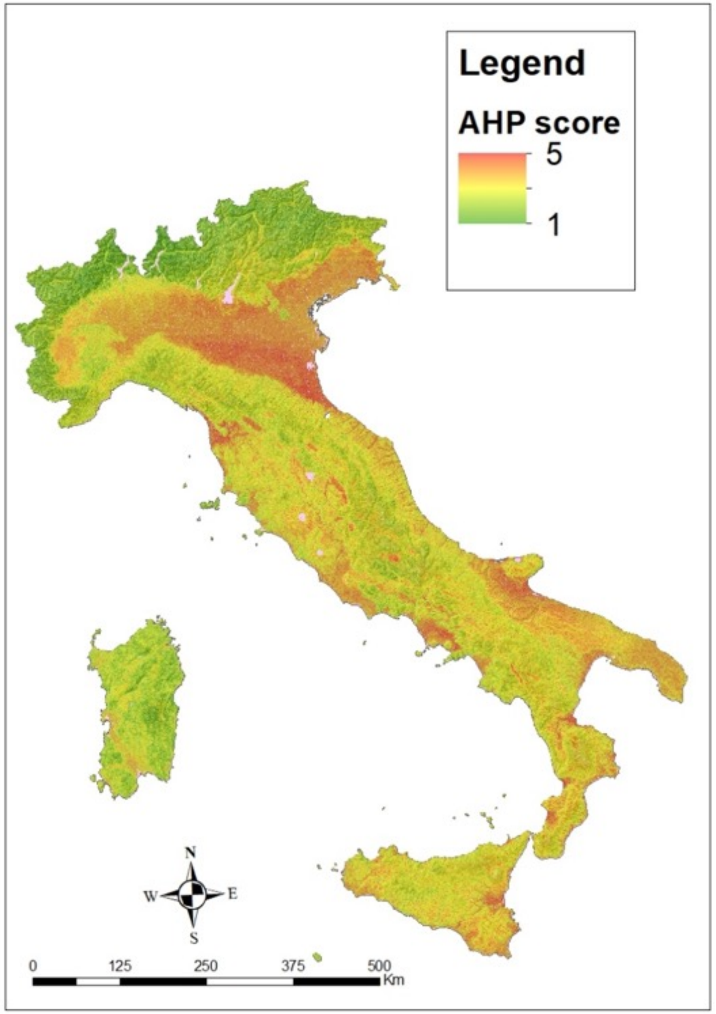
+

Liquefable Soils

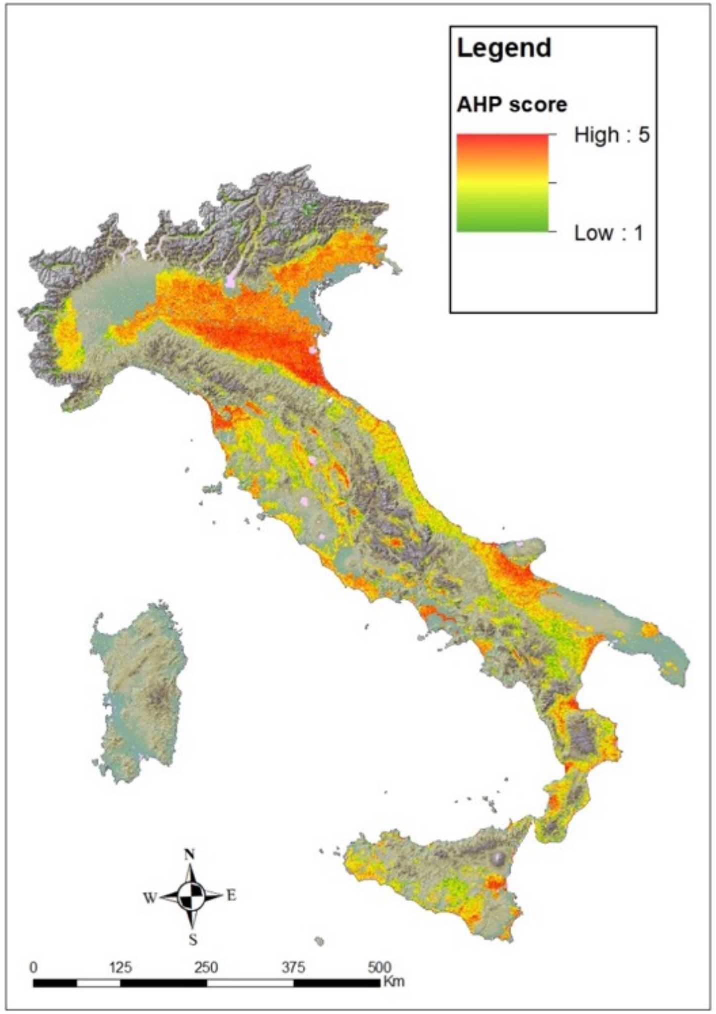


PRELIMINARY RESULTS

FILTERS OFF



FILTERS ON

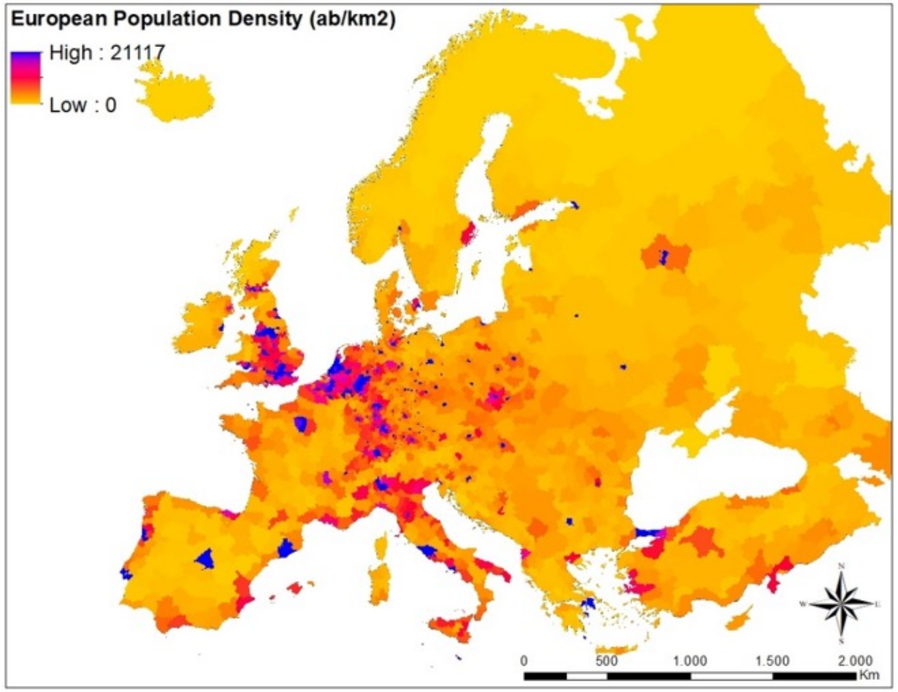


ONGOING ACTIVITIES TO COMPUTE LIQUEFACTION RISK MAP

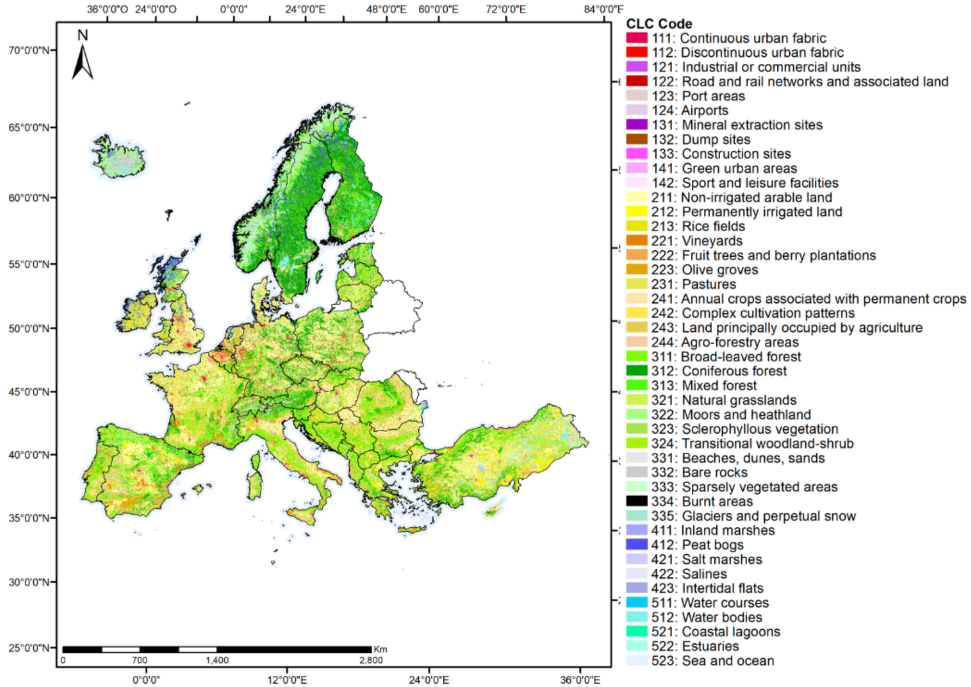
Liquefaction Risk: convolution of hazard, vulnerability and **exposure**

Seismic input   Soil Susceptibility

POPULATION DENSITY



CORINE LAND USE COVERAGE MAP 2012



CATALOGUE OF EUROPEAN LIQUEFACTION OCCURRENCES AND REGRESSIONS

CONSTRUCTION OF A GIS-BASED CATALOGUE OF LIQUEFACTION OCCURRENCES IN EUROPE

FINAL AIM => **GIS-based catalogue containing historical information regarding the liquefaction-related phenomena occurred in Europe** (sand ejects and boils, soil settlements and lateral spreading, ground and structural failures).

Main **seismological features** of seismic events (date, geographic coordinates, magnitude, focal mechanism if known, etc.)

Liquefaction site parameters (geographic coordinates, epicentral distance, type of failure, etc.)

GIS-BASED CATALOGUE OF EARTHQUAKE-INDUCED LIQUEFACTION OCCURRENCES IN EUROPE V1.0

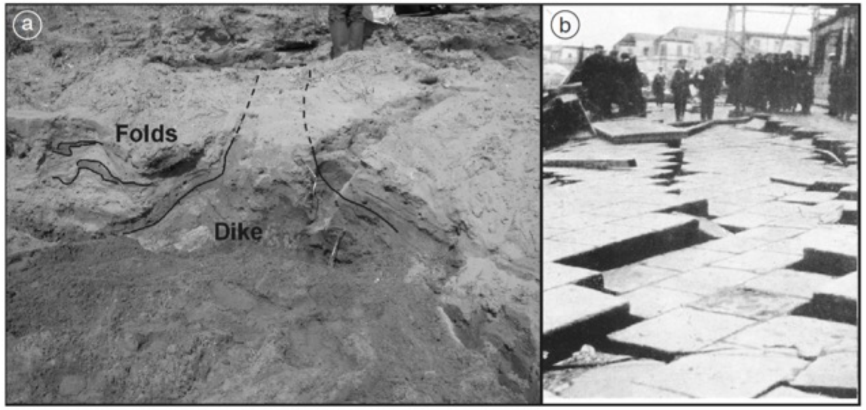
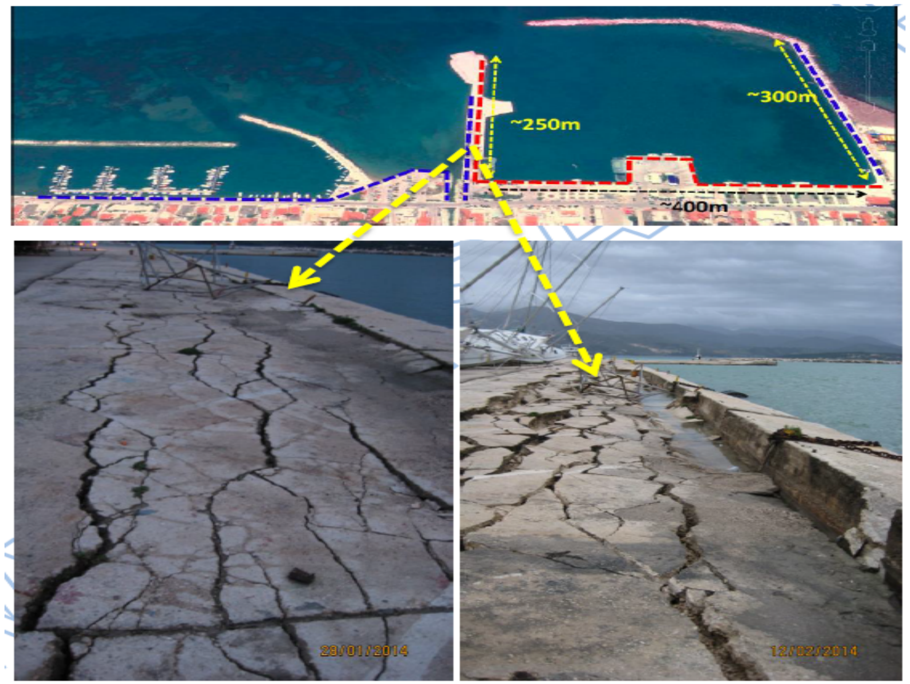


Fig. 2a,b. Examples of liquefaction features in Eastern Sicily: a) surveyed by means of paleo-seismological analysis in the Catania plain (after Guarnieri *et al.*, 2008); b) from historical reports, liquefaction in the Messina harbour after the 1908 earthquakes (after Baratta, 1910).

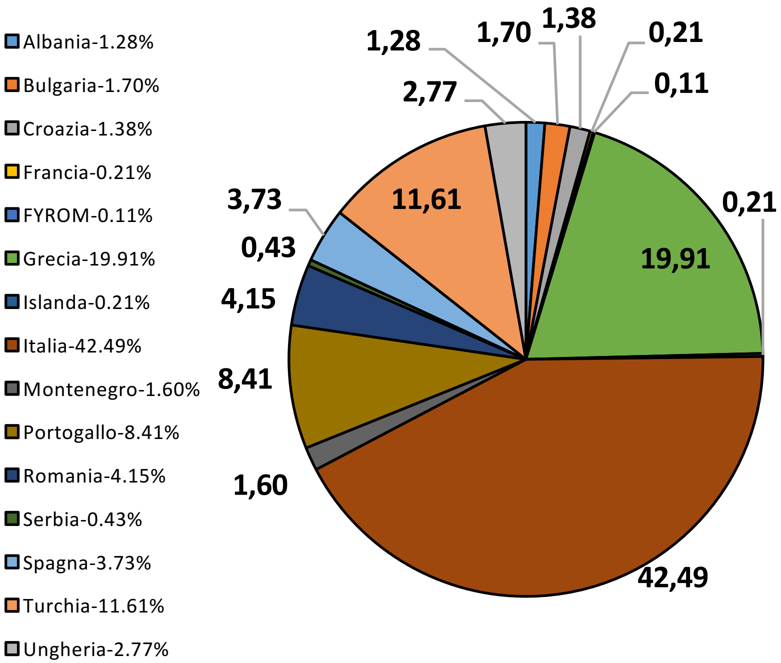
Sand volcano, 1911 earthquake [Gyori et al. 2014]

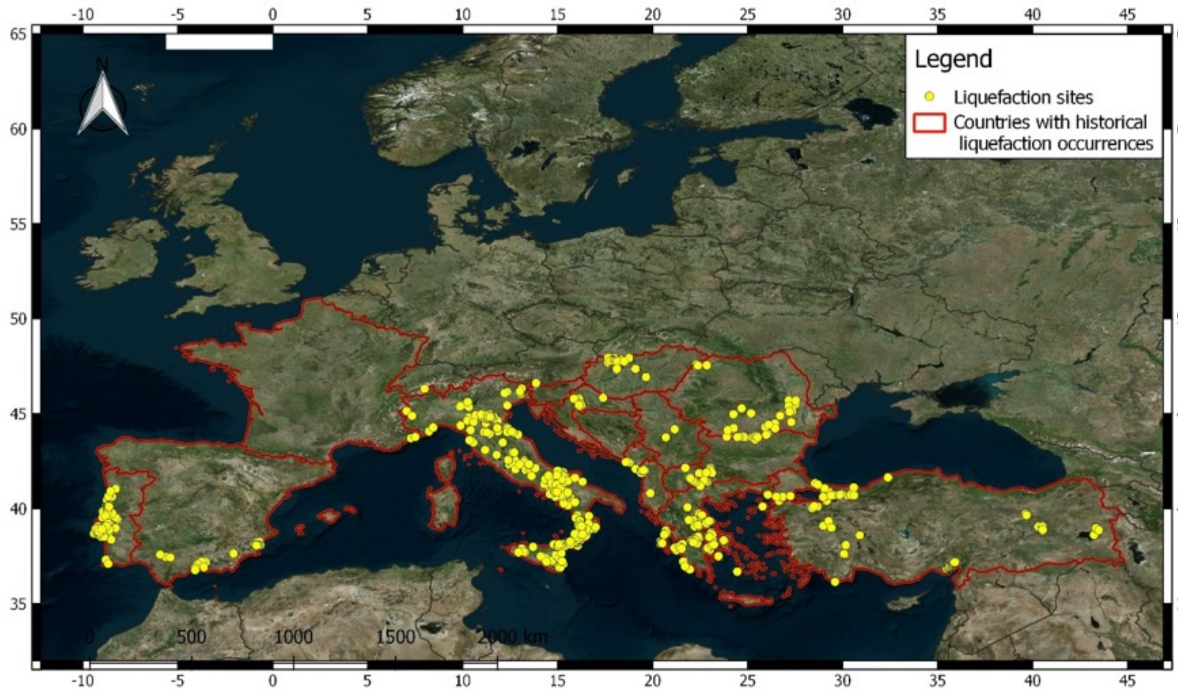


Liquefaction at Kefalonia port [Earthquakes report 2014]

GIS-BASED CATALOGUE OF EARTHQUAKE-INDUCED LIQUEFACTION OCCURRENCES IN EUROPE V1.0

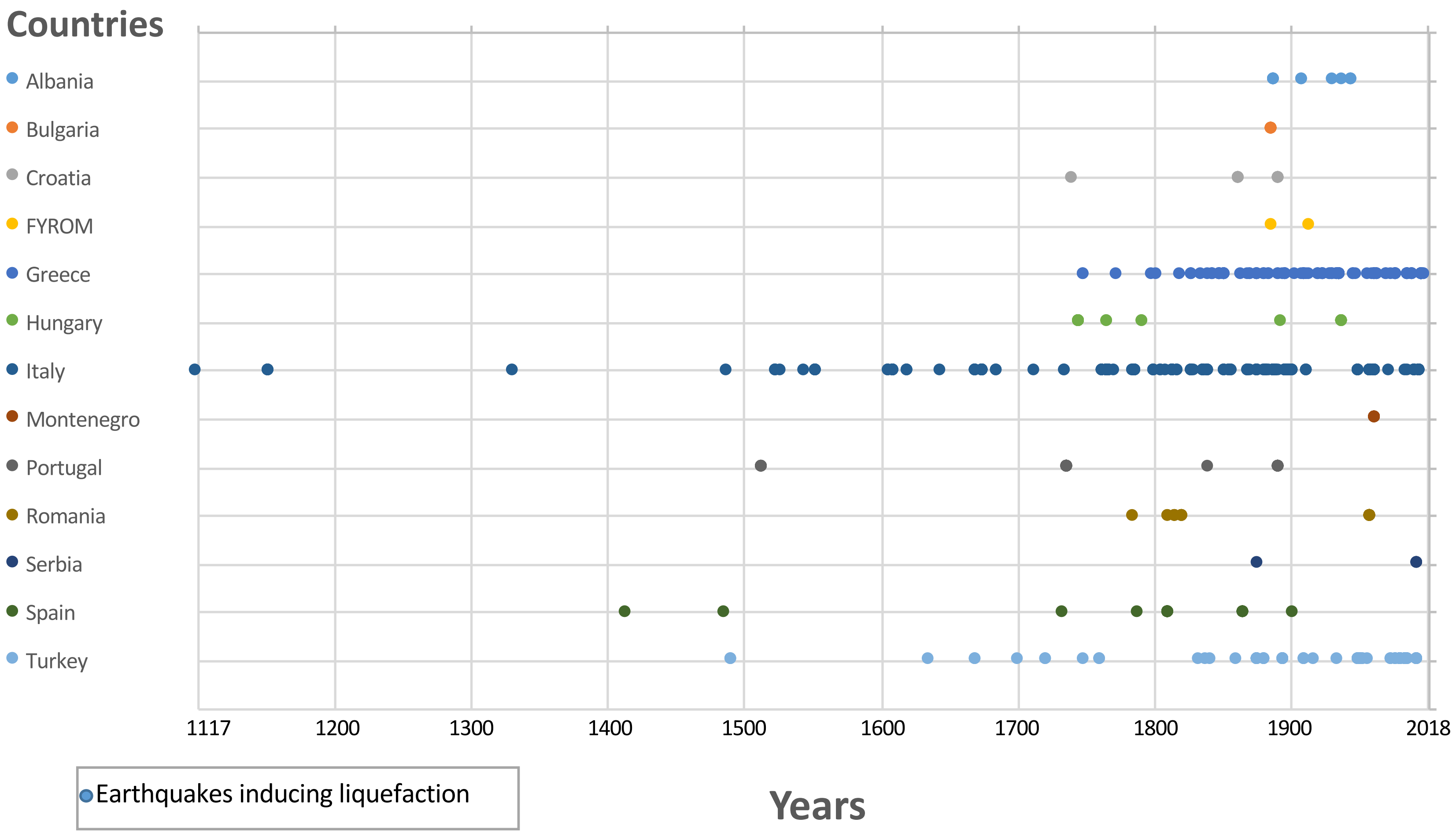
939 liquefaction cases in Europe induced by **188** earthquakes
(main source for earthquake: SHARE catalogue; national catalogues, such as CPTI15 for Italy)





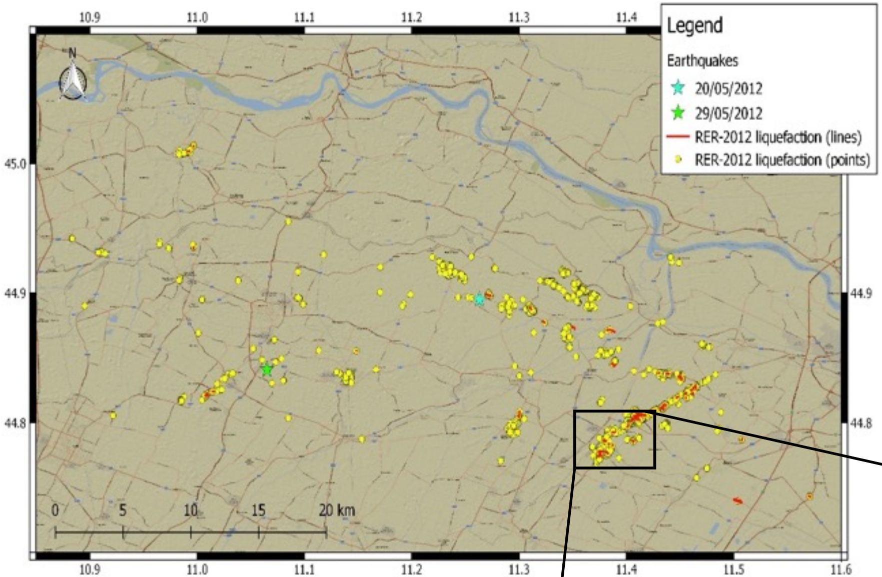
GIS-BASED CATALOGUE OF EARTHQUAKE-INDUCED LIQUEFACTION OCCURRENCES IN EUROPE V1.0

What about the completeness of the catalogue?

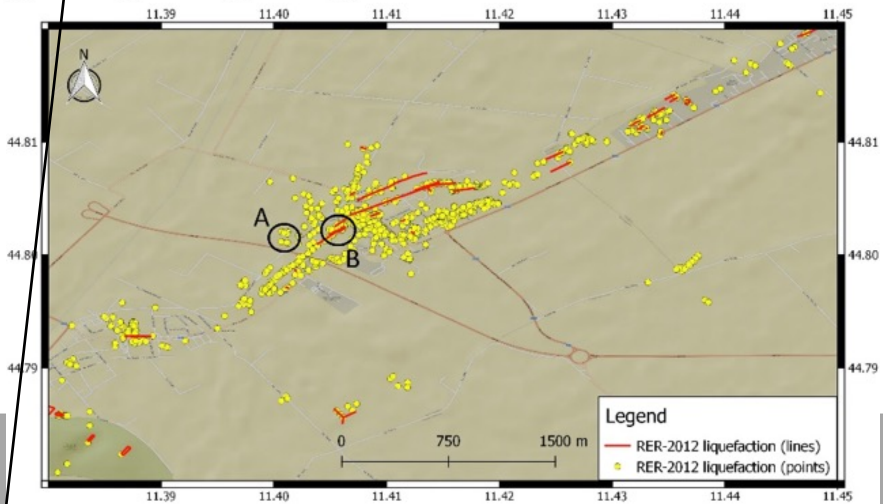


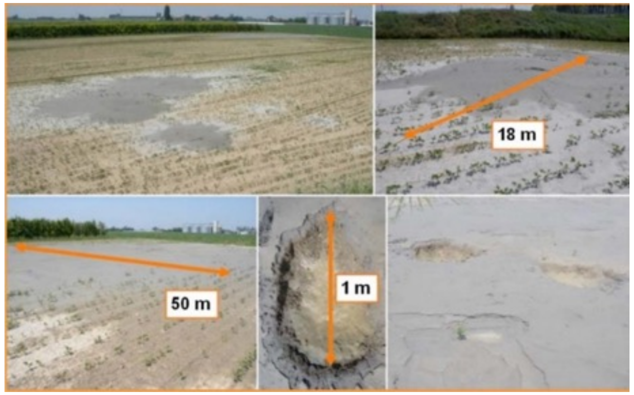
GIS-BASED CATALOGUE OF EARTHQUAKE-INDUCED LIQUEFACTION OCCURRENCES IN EUROPE V1.0

How to define a single case of liquefaction in the catalogue?



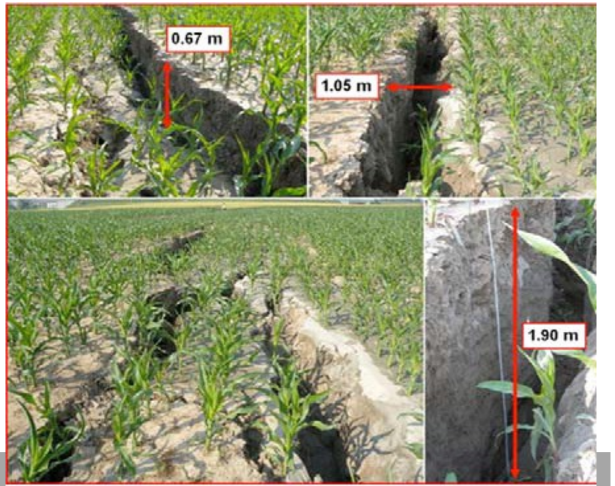
Liquefaction during the 2012 Emilia earthquakes





Liquefaction in site A
San Carlo
[Bozzoni et al., 2012]

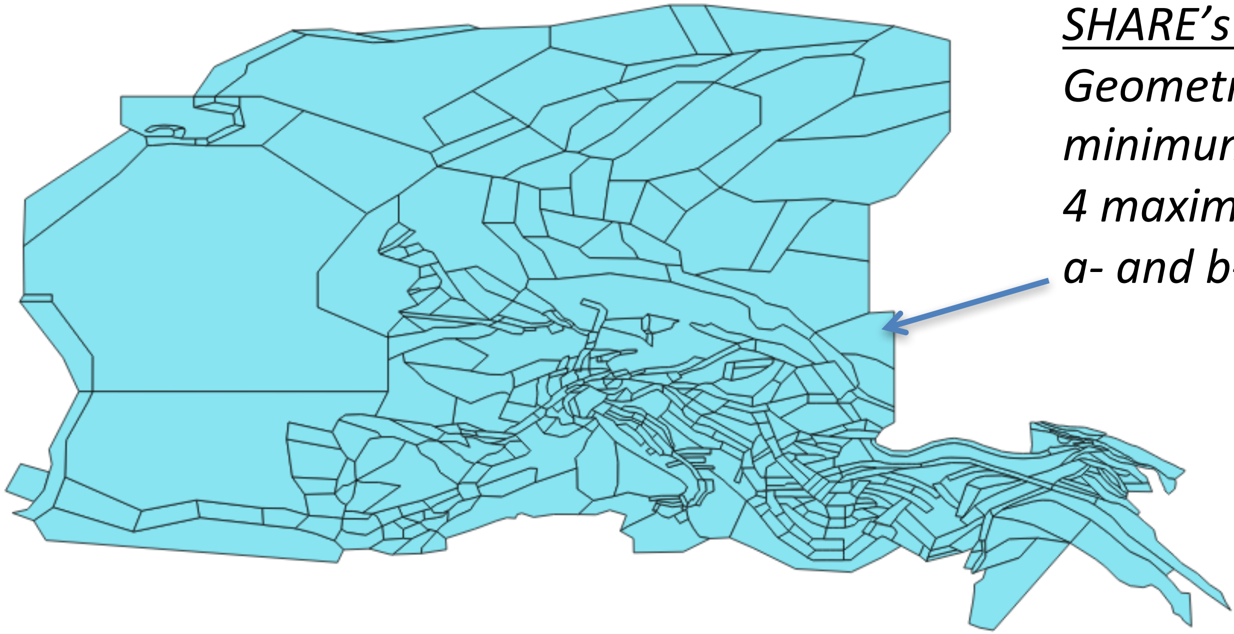
Ground cracks in site B
San Carlo
[Bozzoni et al., 2012]



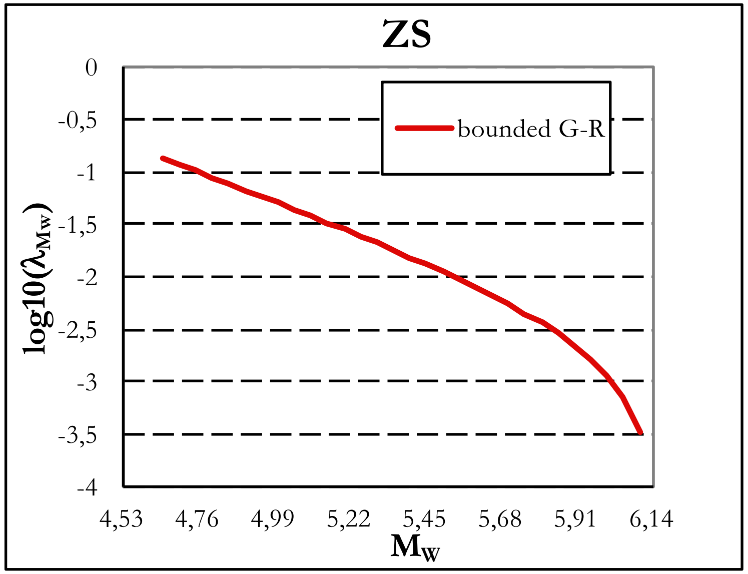
GIS-BASED CATALOGUE OF EARTHQUAKE-INDUCED LIQUEFACTION OCCURRENCES IN EUROPE V1.0

What is the return period for each event of the catalogue?

1) Identification of the seismic sequences through the Gardner and Knopoff (1974) algorithm
2) Computation of the return period for each mainshock based on SHARE's seismogenic zones



SHARE's products:
Geometries of the SZ,
minimum and maximum seismogenic depth,
4 maximum magnitudes with weights,
a- and b- parameters of the GR relationship



Return period for each mainshock
$T_R = 1/\lambda_{Mw\_mainshock}$

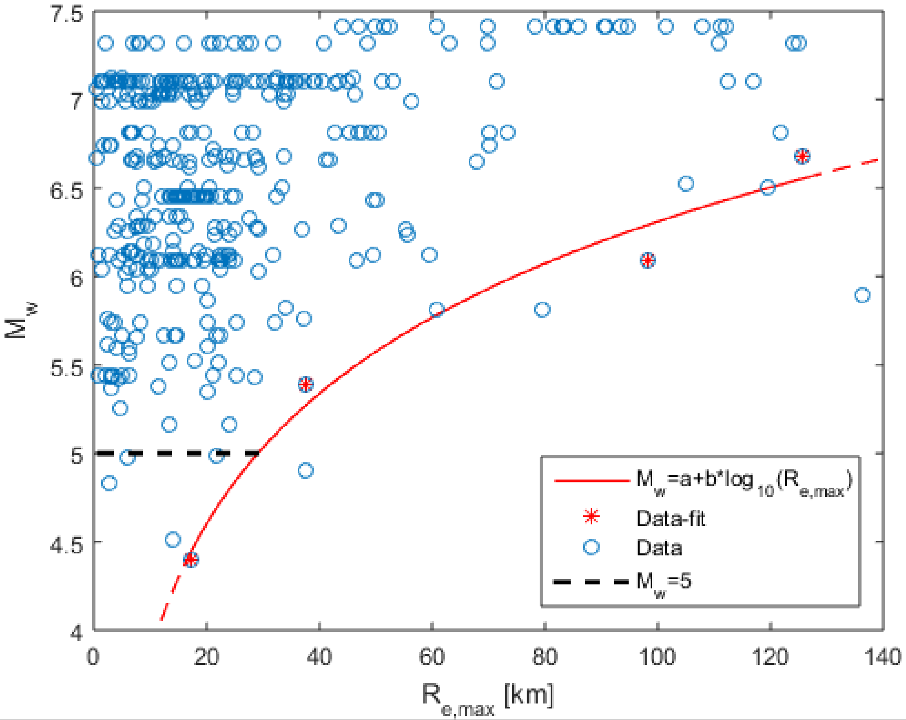
3) Association of the return period of the mainshock to the entire seismic sequence

CALCULATION OF ITALIAN RELATIONSHIPS BETWEEN MAGNITUDE AND DISTANCE FOR LIQUEFACTION

By adopting a general model from literature and a nonlinear least-squares solver

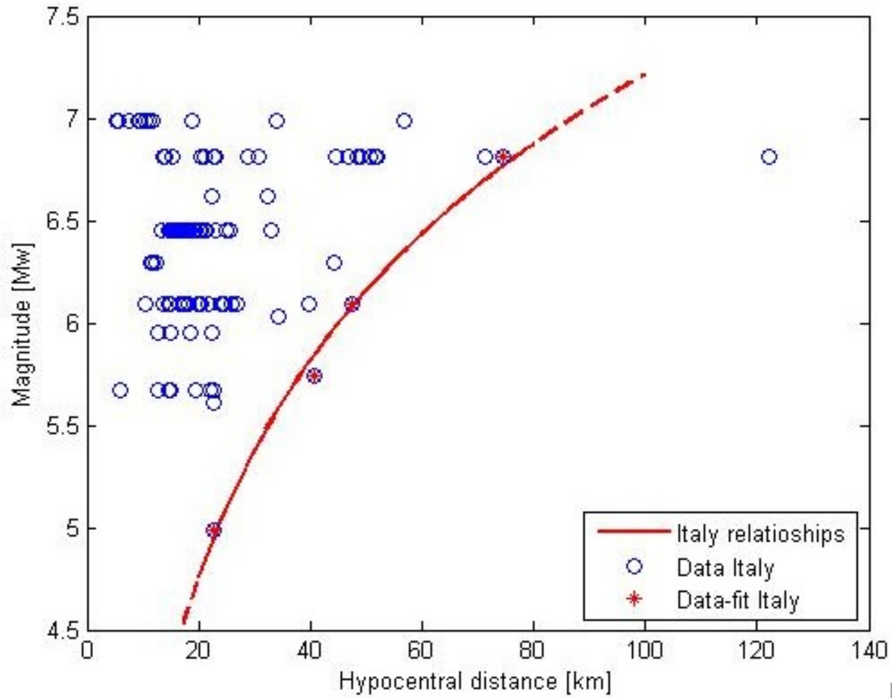
Relationship in epicentral distance:
393 data

$$M_w = 1{,}42 + 2{,}44\log(R_e)$$



Relationship in hypocentral distance:
113 data

$$M_w = 0{,}184 + 3{,}514\log(R_{hypo})$$



MICROZONATION OF LIQUEFACTION POTENTIAL AT THE MUNICIPALITY SCALE

EMILIA REGION, ITALY CAVEZZO MUNICIPALITY

EMILIA REGION, ITALY CAVEZZO MUNICIPALITY

INTER-INSTITUTIONAL AGREEMENT
FOR MICROZONATION STUDY AT CAVEZZO

A voti unanimi e palesi

D E L I B E R A

- di approvare l'accordo di collaborazione inter-istituzionale con l'Università di Pavia - Dipartimento di Ingegneria Civile e Architettura ed Eucentre, l'Amministrazione Provinciale di Modena e l'Amministrazione Comunale di Cavezzo finalizzato alla microzonazione sismica per lo scuotimento del suolo e per il rischio liquefazione del Comune di Cavezzo;
- di dare atto che il Responsabile del Servizio Geologico, sismico e dei suoli provvederà alla sottoscrizione dell'accordo di collaborazione inter-istituzionale ai sensi della Deliberazione n. 2416/2008, e che lo stesso avrà la durata di mesi dodici con decorrenza dalla data di stipula;
- di dare atto che il presente accordo non comporta impegni finanziari di ciascun Ente nei confronti dell'altro e che la Regione Emilia-Romagna, l'Università di Pavia - Dipartimento di Ingegneria Civile e Architettura ed Eucentre, l'Amministrazione Provinciale di Modena e l'Amministrazione Comunale di Cavezzo contribuiranno allo svolgimento delle attività previste mettendo a disposizione ognuno le proprie competenze, i dati in proprio possesso e il proprio personale.

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Regione Emilia-Romagna

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Provincia di Modena

EMILIA REGION, ITALY CAVEZZO MUNICIPALITY

ACTIVITIES CARRIED OUT BY UNIPV-EUCENTRE TEAM

✓ GROUND CHARACTERIZATION IN CAVEZZO

✓ GIS DATABASE INCLUDING GEOTECHNICAL AND GEOPHYSICAL TESTS IN CAVEZZO

✓ CONSTRUCTION OF A SEISMO-STRATIGRAPHIC MODEL USING GEOPHYSICAL TESTS IN CAVEZZO

✓ DEVELOPMENT OF A GEOLOGICAL MODEL USING BOREHOLES AND CPT

✓PROCEDURE FOR LIQUEFACTION POTENTIAL ASSESSMENT - *FIRST VERSION (V1).* PRELIMINARY APPLICATION FOR CAVEZZO

GROUND CHARACTERIZATION IN CAVEZZO

Starting point - Database Regione Emilia Romagna (RER) – **Jun. 2016**

LIQUEFACT investigation campaigns - Phase 1
Geostudi Astier – **Dec. 2016**
Geotecnica Veneta and UNIPV- DSTA (prove Lab.) – **Jan. 2017**

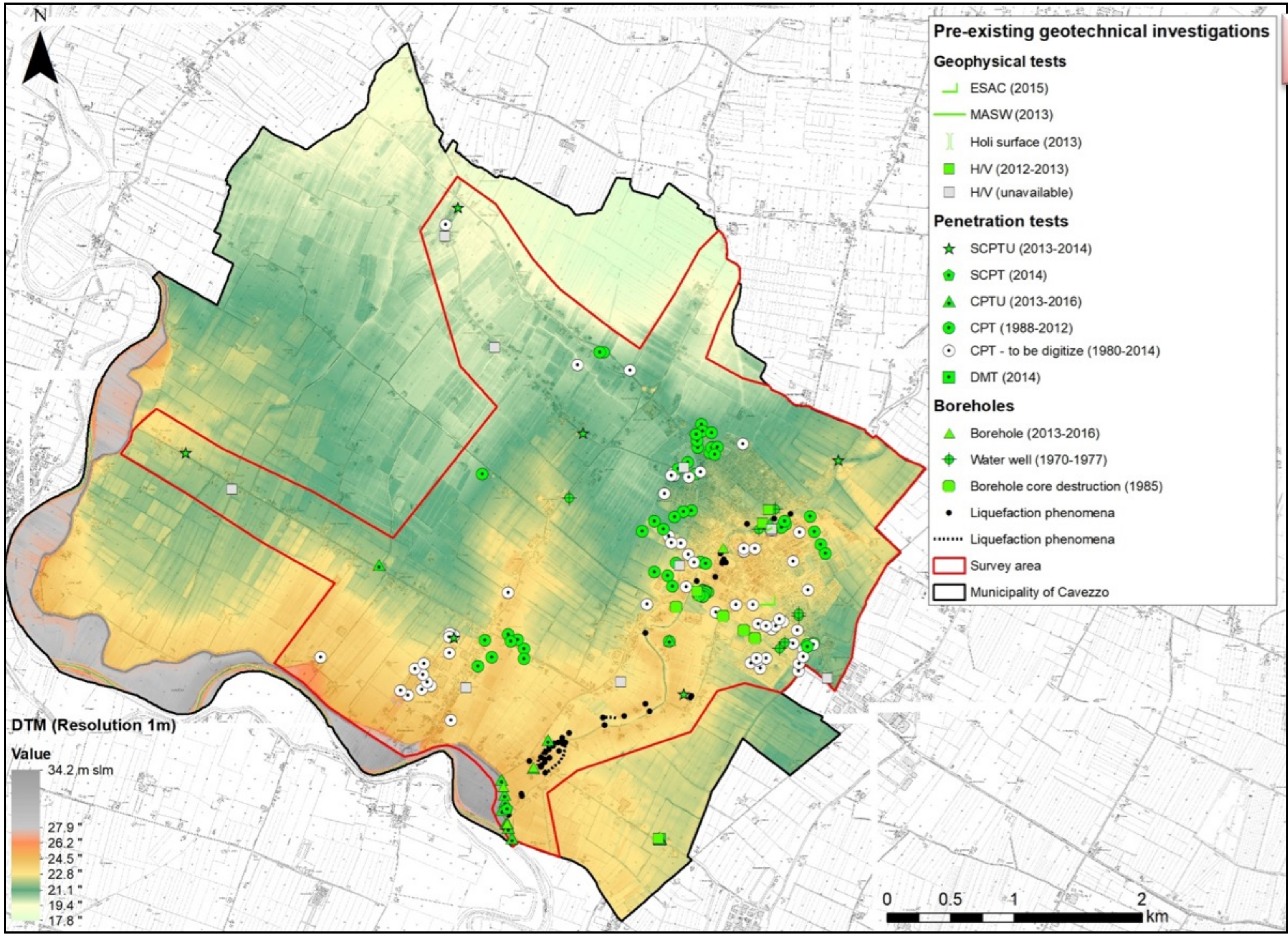
Collection and digitization of post-2012 earthquakes data (MUDE) – **Jul. 2017**

LIQUEFACT investigation campaigns – Phase 2
INGV – **Oct./Nov. 2017**
OGS – **Jan./Feb. 2018**

Investigation campaigns funded by Comune di Cavezzo and RER
Tecnoin Geosolution and Elletipi (prove Lab.) – **Dec. 2017/Jan. 2018**

EUCENTRE investigation campaign – **Mar. 2018**

GROUND CHARACTERIZATION IN CAVEZZO

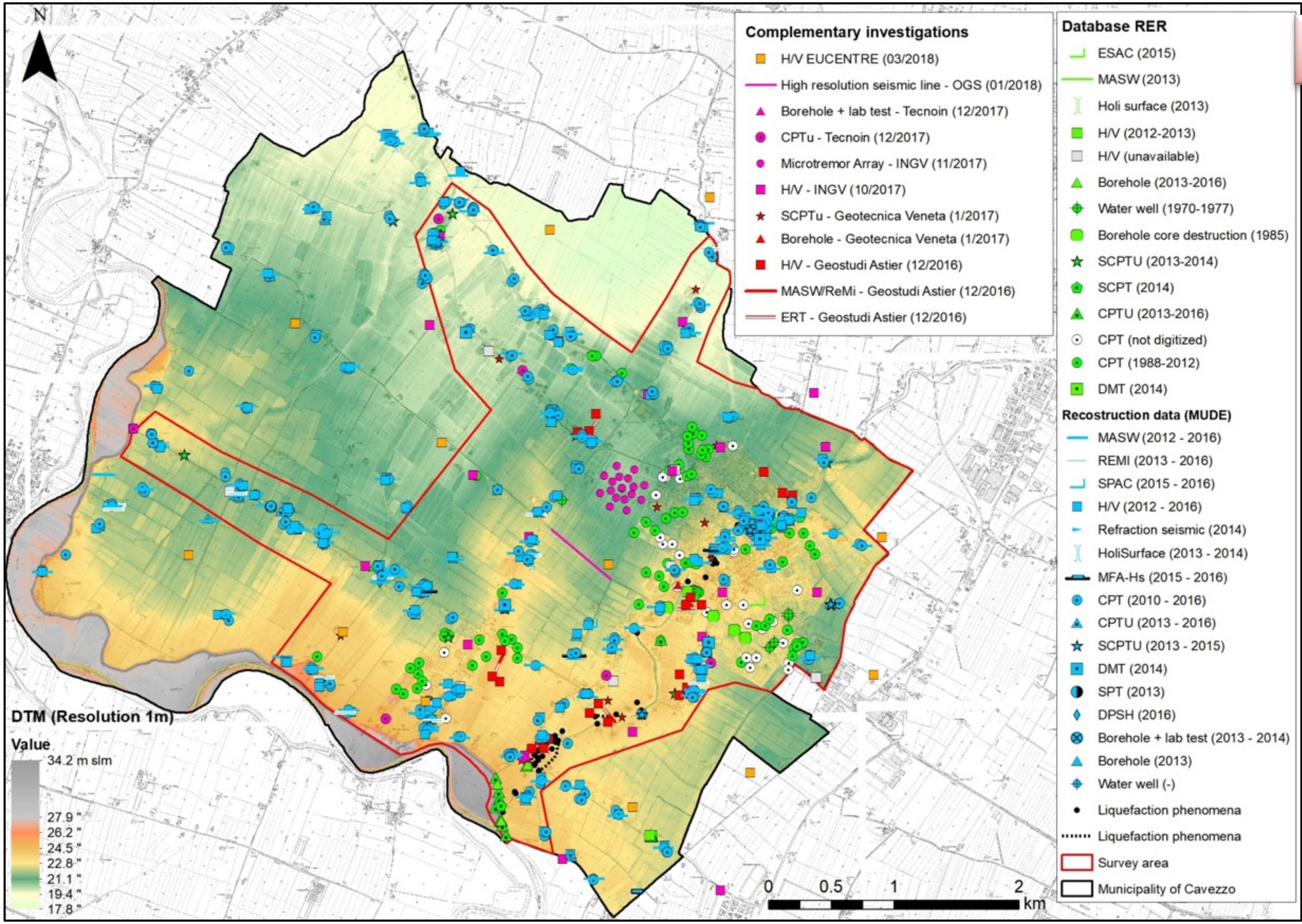


Jun. 2016

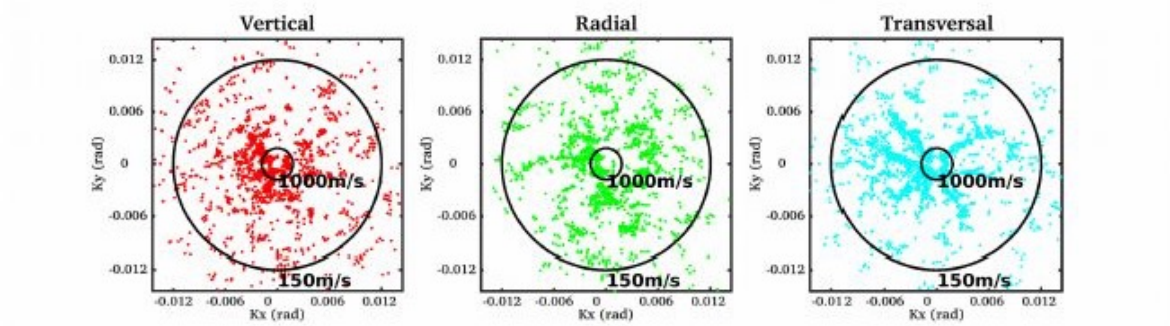
STARTING POINT

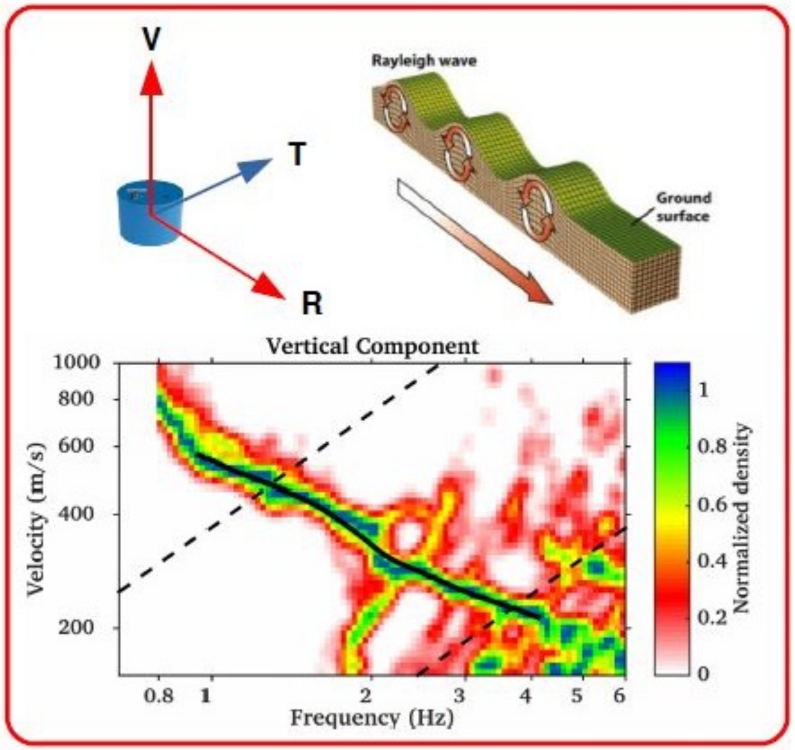
GIS DATABASE INCLUDING GEOTECHNICAL AND GEOPHYSICAL TESTS IN CAVEZZO

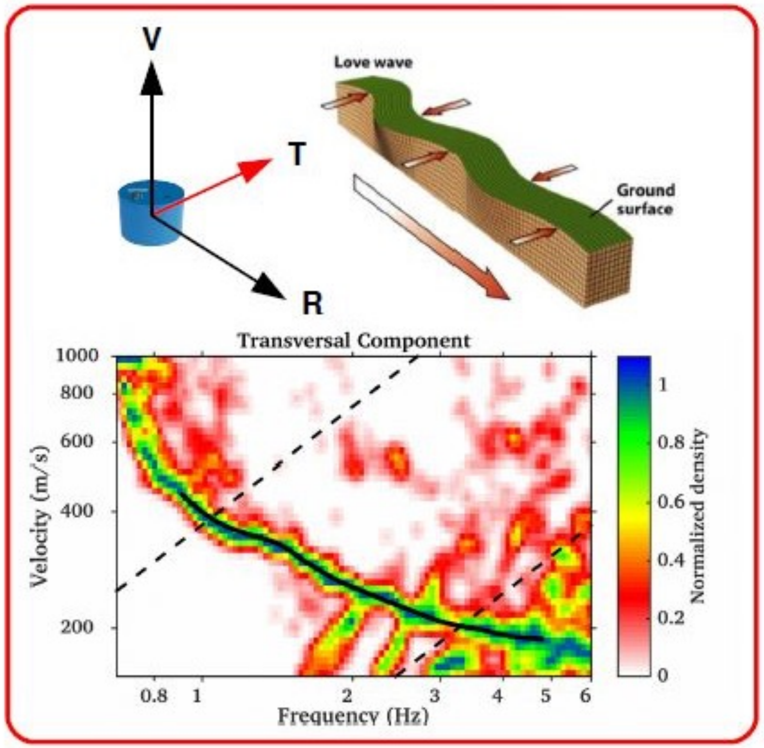
May. 2018



CONSTRUCTION OF A SEISMO-STRATIGRAPHIC MODEL USING GEOPHYSICAL TESTS IN CAVEZZO







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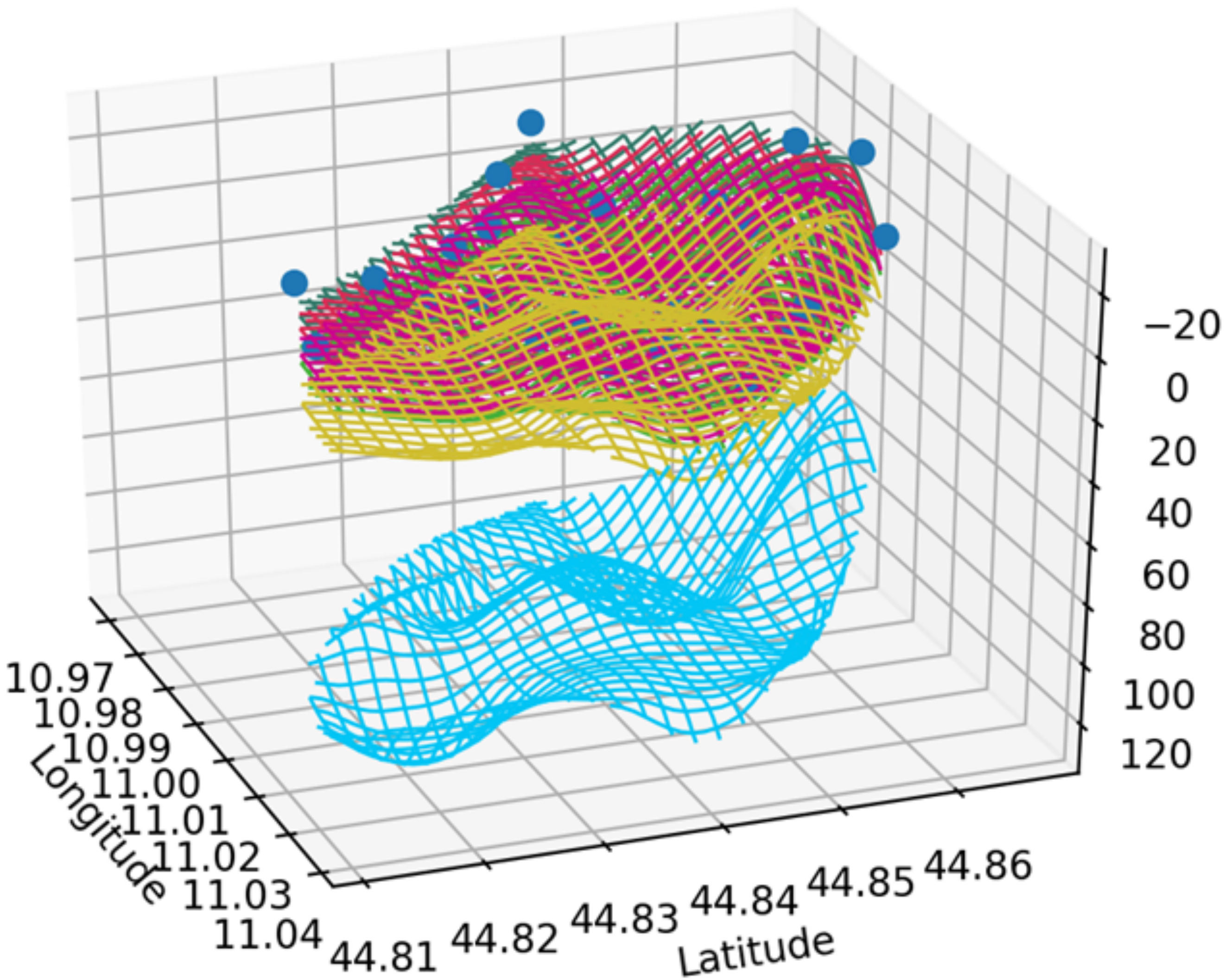
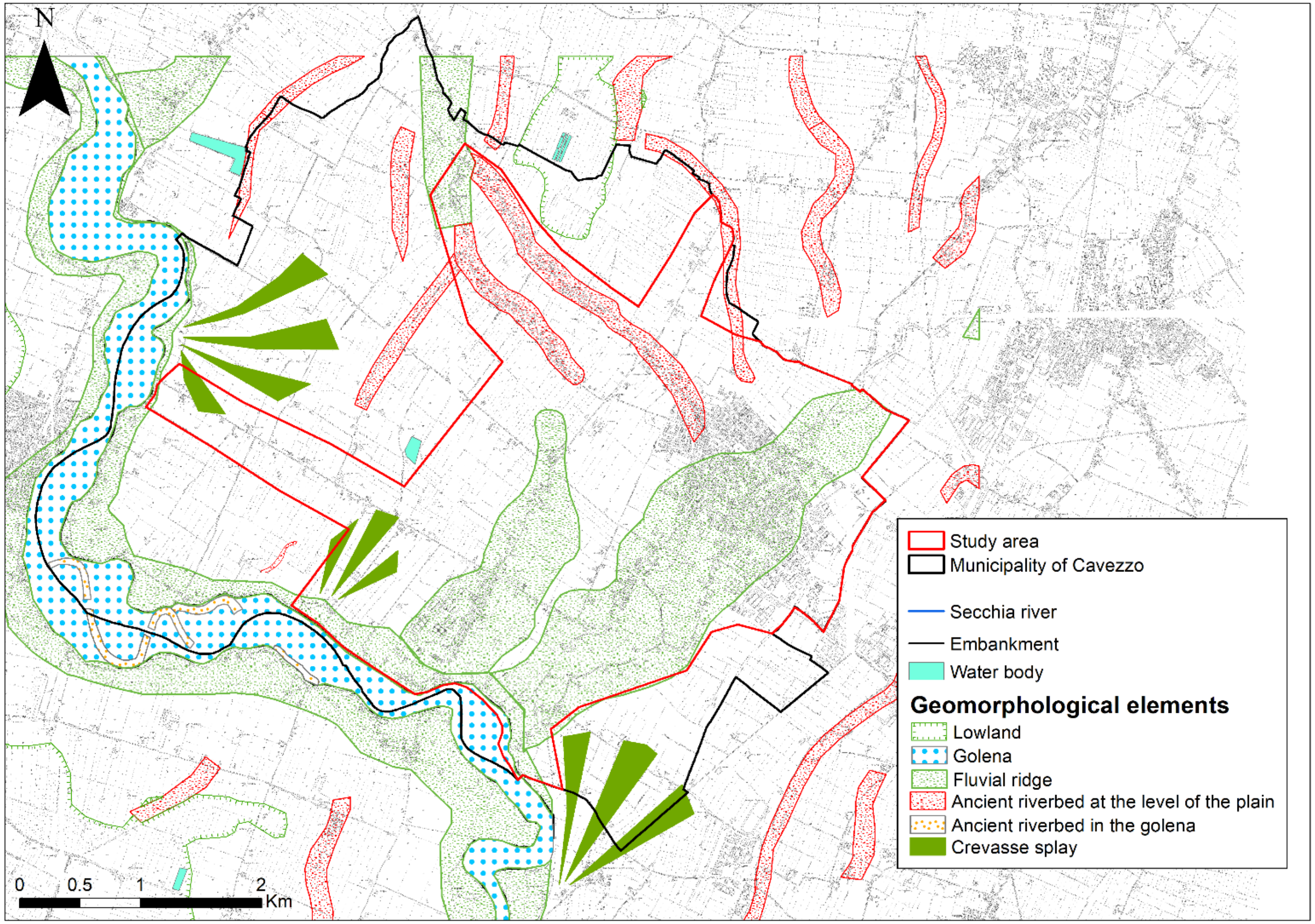


CONSTRUCTION OF GEOLOGICAL MODEL IN CAVEZZO

• Geomorphological map

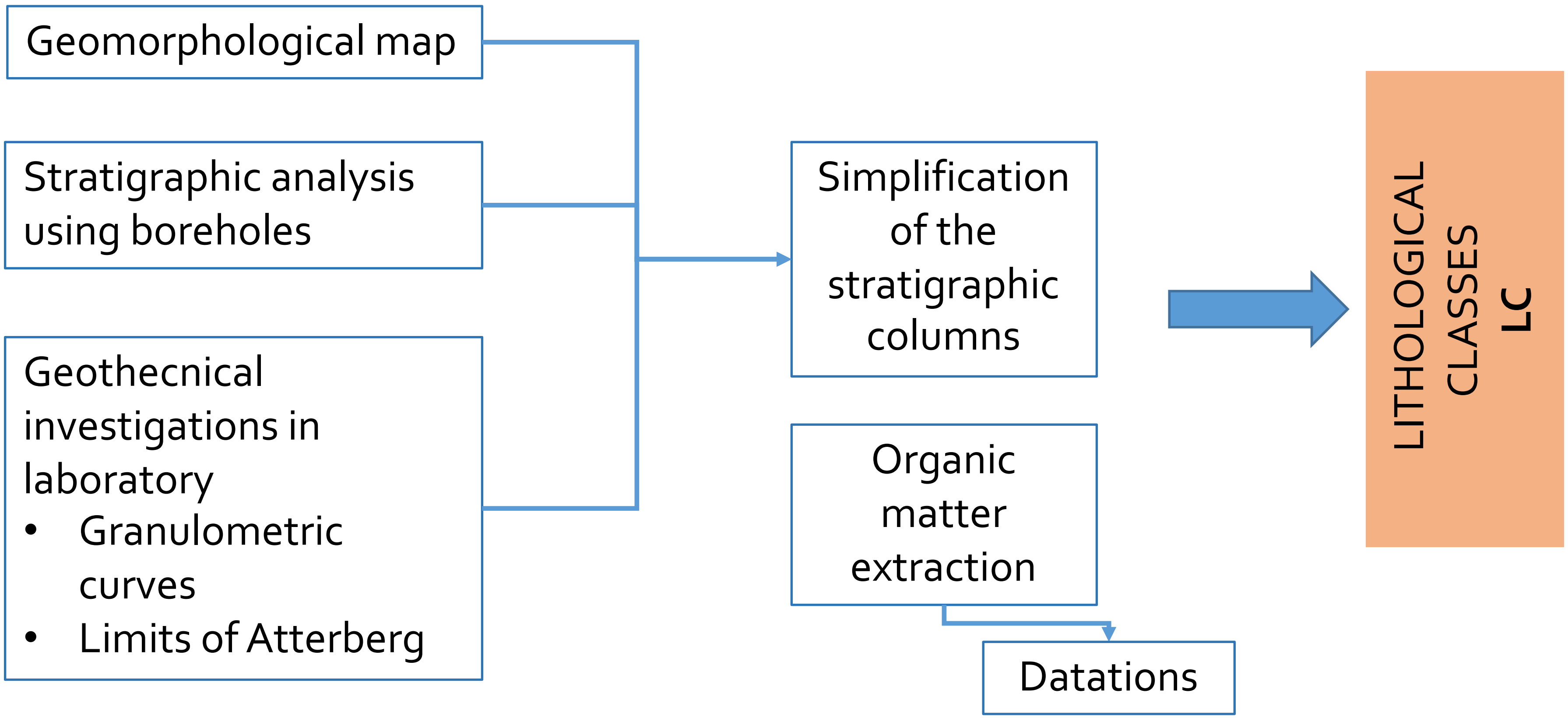


Derived from LIDAR (1x1m) and aerial photointerpretation

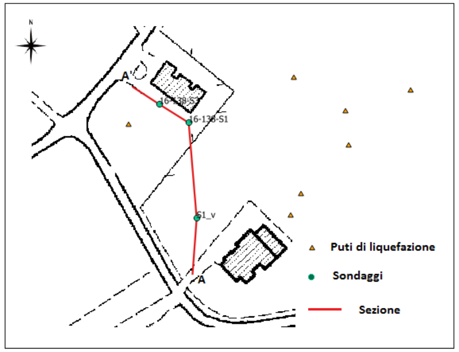
Castaldini, 2018

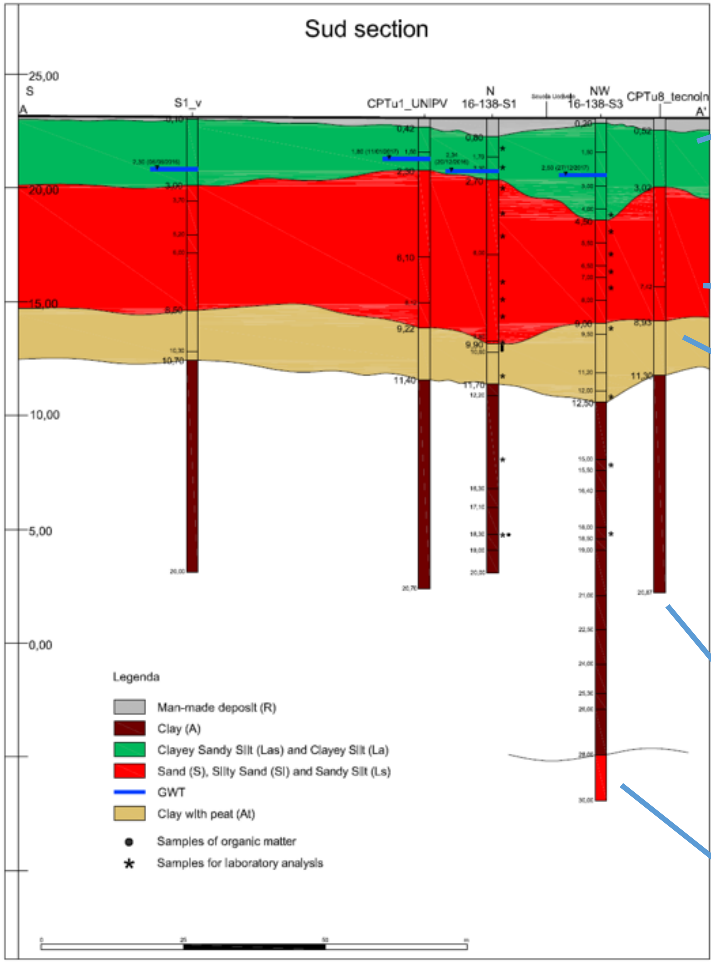
CONSTRUCTION OF GEOLOGICAL MODEL IN CAVEZZO

Lithological classes detection



CONSTRUCTION OF GEOLOGICAL MODEL IN CAVEZZO





UNITA’ A: estremamente eterogenea, prevalenza delle classi litologiche (La, Las), con intercalazioni di sabbia limosa (Sl) generalmente di modesto spessore (Piana alluvionale recente).

UNITA’ B: classi litologiche S, Sl, Ls (Canali fluviali).

UNITA’C:argilla (A) con abbondante sostanza organica (At), (Ambiente lacustre/palustre).

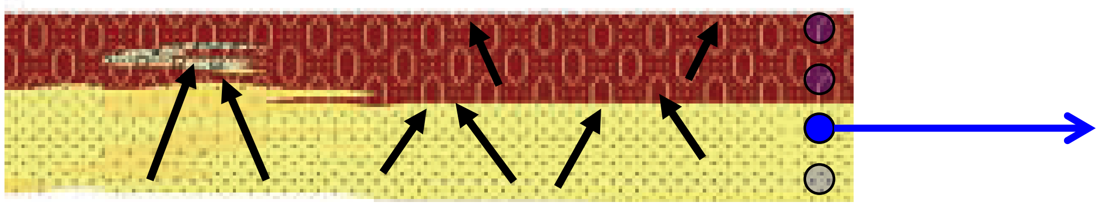
UNITA’D: costituita essenzialmente da argilla (A),(Piana alluvionale antica).

UNITA’E: sabbie molto addensate (Canali fluviali più antichi) .

ASSESSMENT OF LIQUEFACTION POTENTIAL

Capacity of the soil to resist liquefaction (susceptibility)

CRR *Cyclic Resistance Ratio*



Factor of safety against Liquefaction and Probability of liquefaction

Seismic demand on a soil layer

CSR *Cylic Stress Ratio*

Point-wise assessment of liquefaction at different depths combined into a **single index**, such as Liquefaction Potential Index LPI, Liquefaction Severity Number LSN, etc.

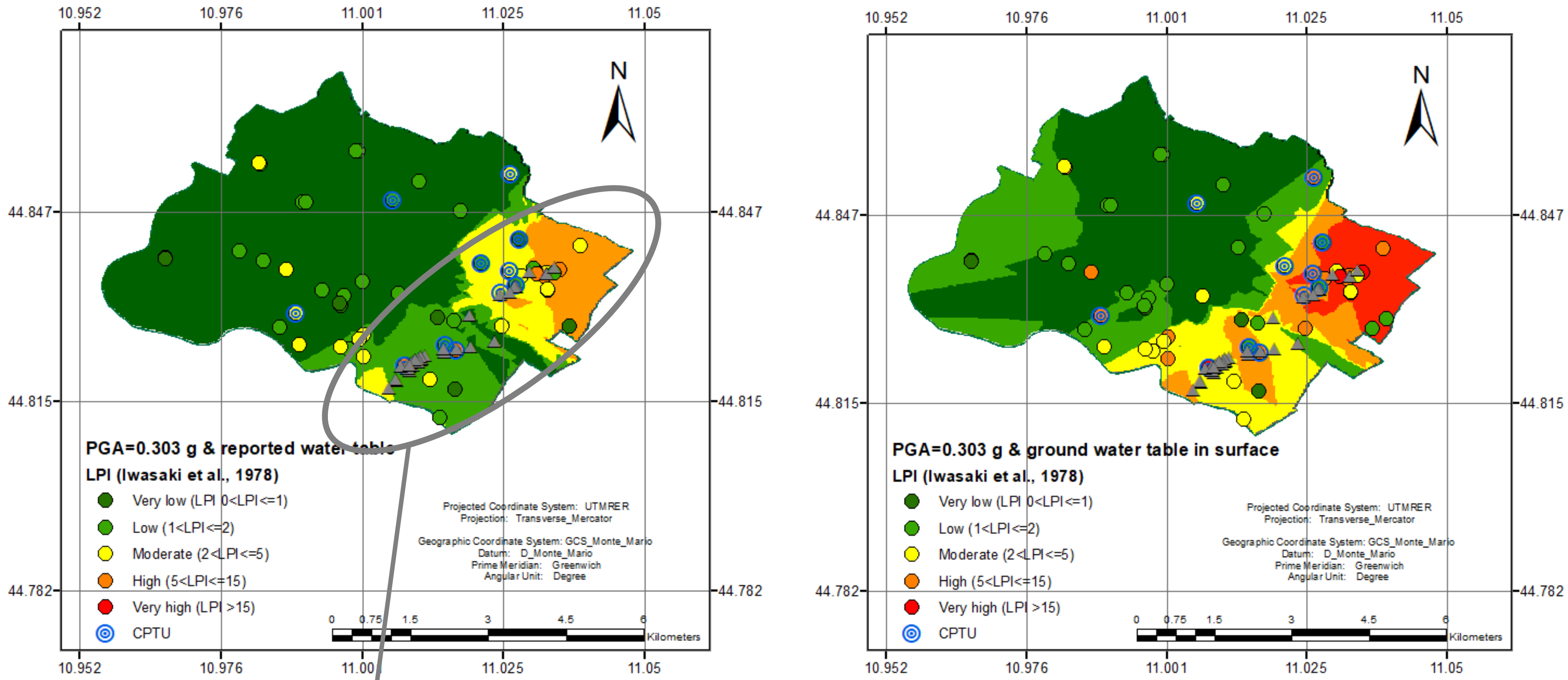
For CPT (e.g. ICMS-RER, 2015; Green et al., 2014; Cubrinovski et al., 2017), three independent empirical methods applied :

- *Methodology A: Robertson (2009)*
- *Methodology B: Boulanger e Idriss (2015)*
- *Methodology C: Moss et al. (2006)*

Procedure takes into account epistemic uncertainty by **using logic tree**.

PRELIMINARY APPLICATION AT CAVEZZO

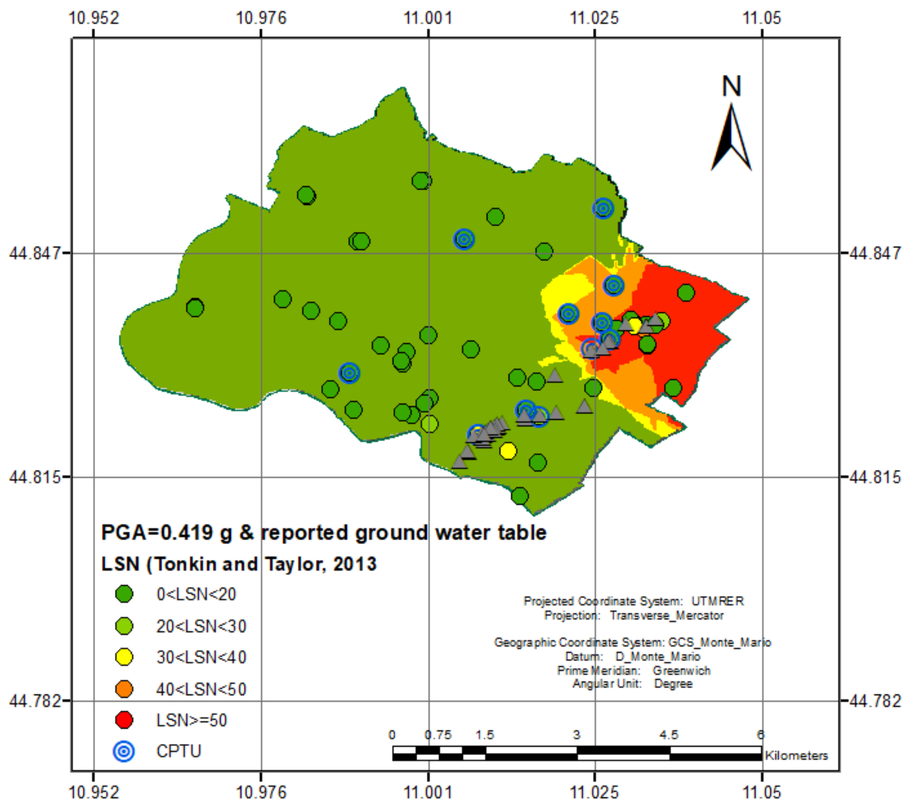
Liquefaction Potential Index (LPI)

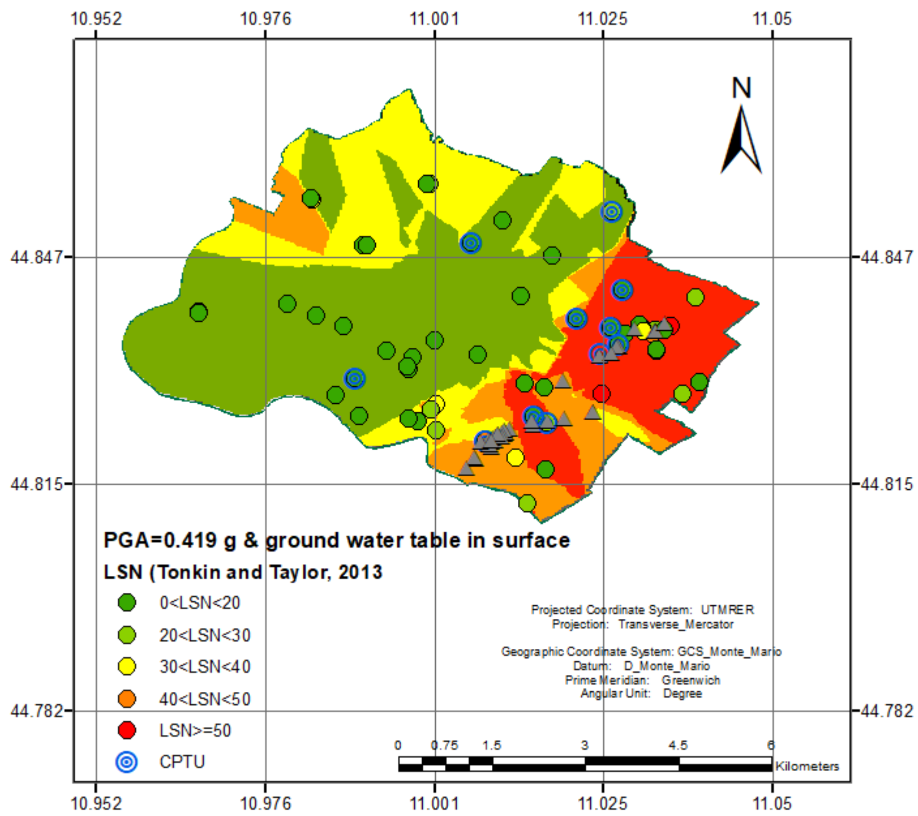


Liquefaction occurrences after May 29, 2012 earthquake

PRELIMINARY APPLICATION AT CAVEZZO

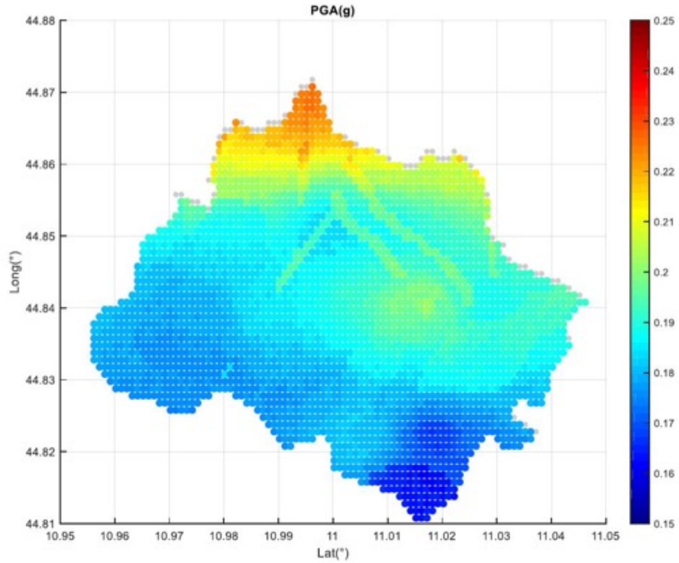
Liquefaction Severity Number (LSN)



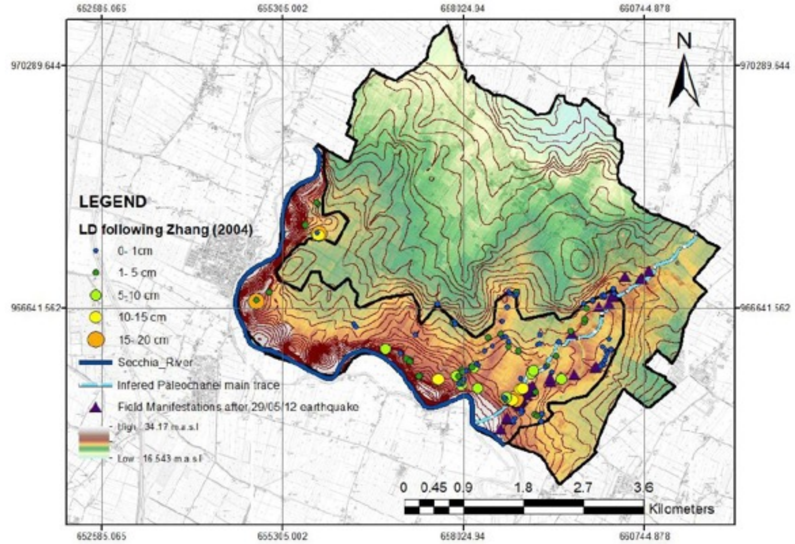


ONGOING ACTIVITIES

Ground response analysis



Assessment of lateral spreading



Coupled advanced numerical modelling (critical state-based)