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REDACt
Rapid Earthquake Damage Assessment ConsorTium

Geotechnical Module in REDAS

- Landslide Hazard
- Liquefaction

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Geotechnical Module

In the event of a strong earthquake part of damages are related to ground failures

We focus on two of them (at a regional scale):

- ☐ **Landslides**
- ☐ **Liquefaction**

The geotechnical module is part of the REDA system and it has been tested at pilot regions where earthquake triggered landslides and liquefaction phenomena occurred.

Landslide Hazard (regional scale)

In the present project 2 different methodological approaches for LHA have been selected:

- The 1st belongs to the physically based methods,
- the 2nd one belongs to the statistically based methods

Cons and Pros:

- *Statistical methods* are oriented to regional scale where spatial variability of geological formations and engineering parameters are important and landslide type relatively complex
- *Physically based methods* are more engineer oriented and better conceived in engineered projects and decision making, provided that geological and geomorphological conditions are fairly homogeneous and landslide types relatively simple, even if inventories are incomplete or inexistant

Statistical landslide probability model

Nowicki et al. (2014) developed an empirical landslide probability model, combining shaking estimates with landslide susceptibility proxies, i.e., topographic slope, surface geology and climate parameters.

Jessee et al. (2018) proposed an updated model regarding the near-real time assessment of seismically induced landslides resulting in the following best fitting model

$$t = \mathrm{Logit}(P) = a + b \times \ln(\mathrm{PGV}) + c \times Slope + d \times Lithology$$
$$+ e \times Land\ Cover + f \times CTI + g \times \ln(PGV) \times Slope,$$

the values of coefficients: a, b, c, d, e, f and g are solved within the regression

The predicted probability of landslide occurrence P(t) can be computed based on the following formula:

$$P(t)=1/(1+\exp(-t))$$

Landslide Hazard (statistical model)

Scenario:

The November 17th, 2015 Lefkada

(Greece) strike-slip Mw 6.4 earthquake

Based on the updated best fitting statistical model of Jessee et al. (2018):

- Peak Ground Velocity (PGV)
- CTI (soil wetness)
- Lithology
- Land cover
- Slope (DEM)

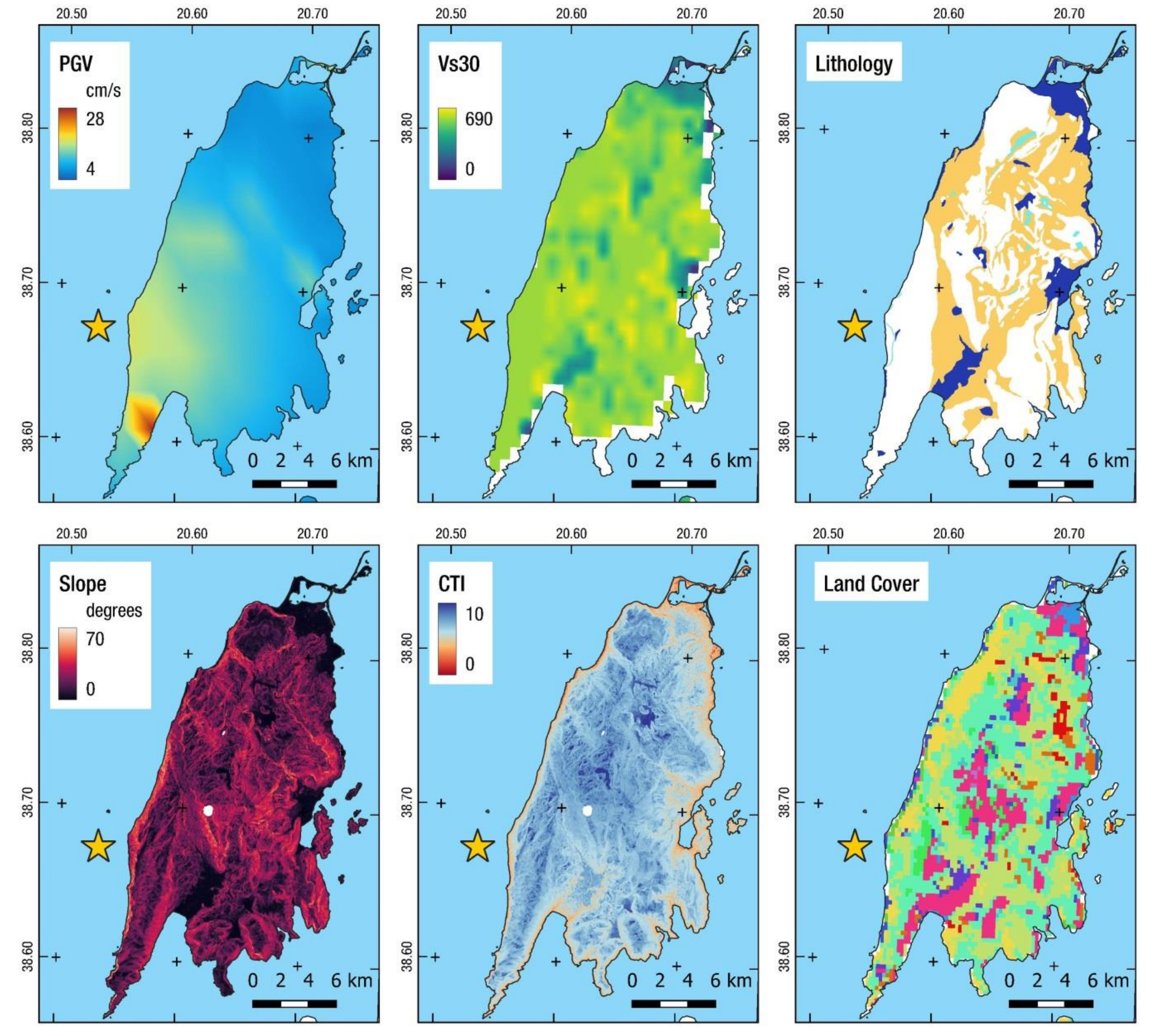
Papathanassiou et al. 2017

Landslide Hazard (statistical model)

Scenario: 2015 Lefkada

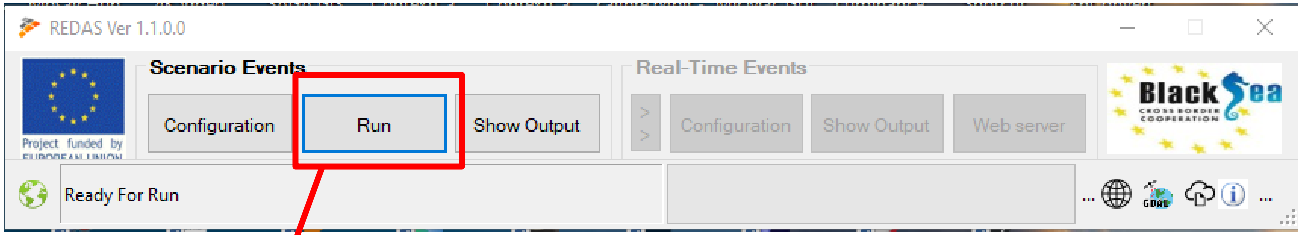
Input layers for statistical landslide model
(Jessee et al. 2018)

- Peak Ground Velocity (PGV)
- Vs30
- Lithology
- Slope (DEM)
- CTI (soil wetness)
- Land cover

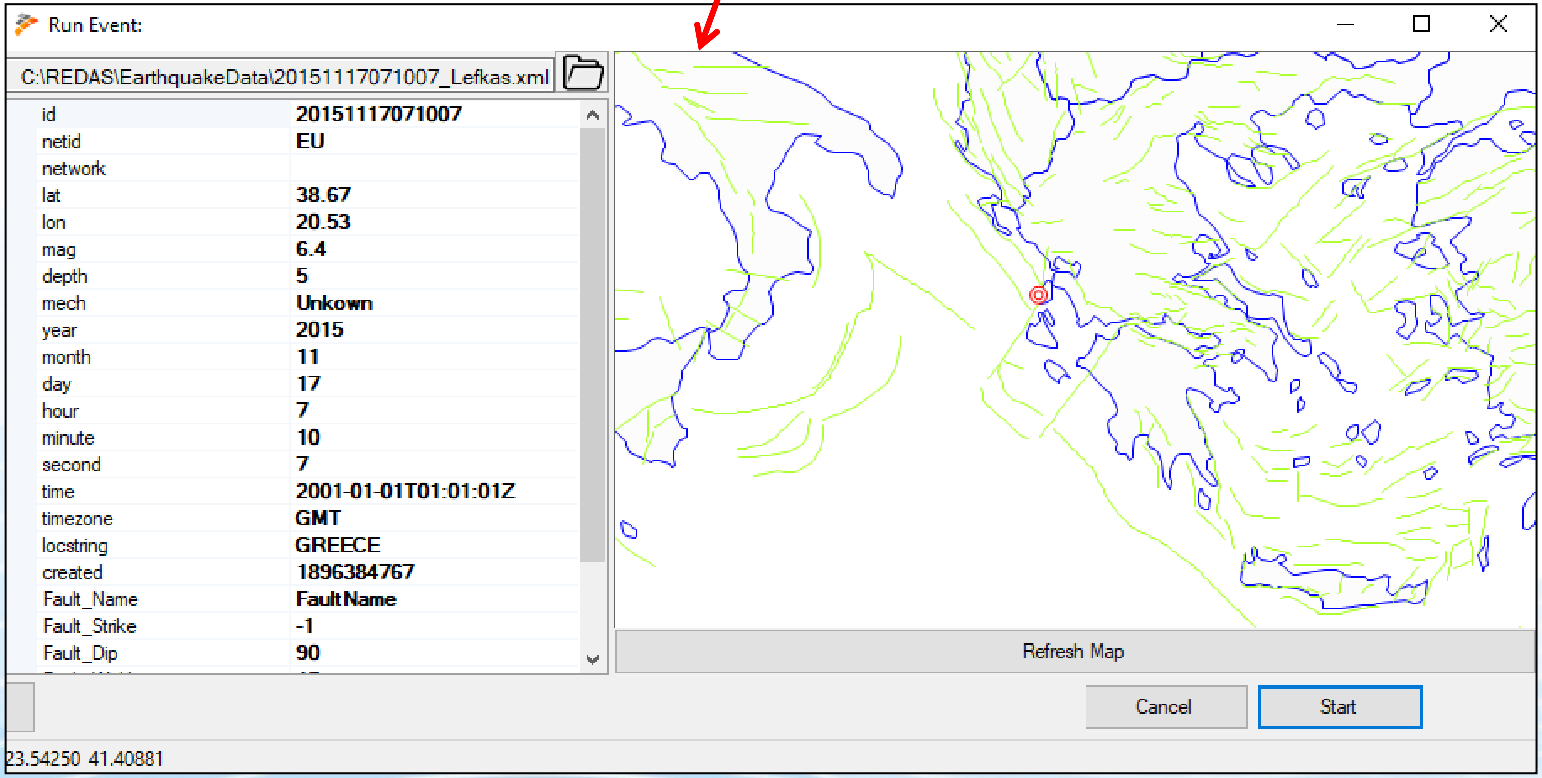


Landslide Hazard (statistical model)

Scenario: 2015 Lefkada


REDAS Ver 1.1.0.0

Ready For Run


Run Event:

C:\REDAS\EarthquakeData\20151117071007_Lefkas.xml

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network	
lat	38.67
lon	20.53
mag	6.4
depth	5
mech	Unkown
year	2015
month	11
day	17
hour	7
minute	10
second	7
time	2001-01-01T01:01:01Z
timezone	GMT
locstring	GREECE
created	1896384767
Fault_Name	FaultName
Fault_Strike	-1
Fault_Dip	90

23.54250 41.40881

Landslide Hazard (statistical model)

Statistical landslide probability model (Jessee et al. 2018)

Proposed additional constraints and thresholds:

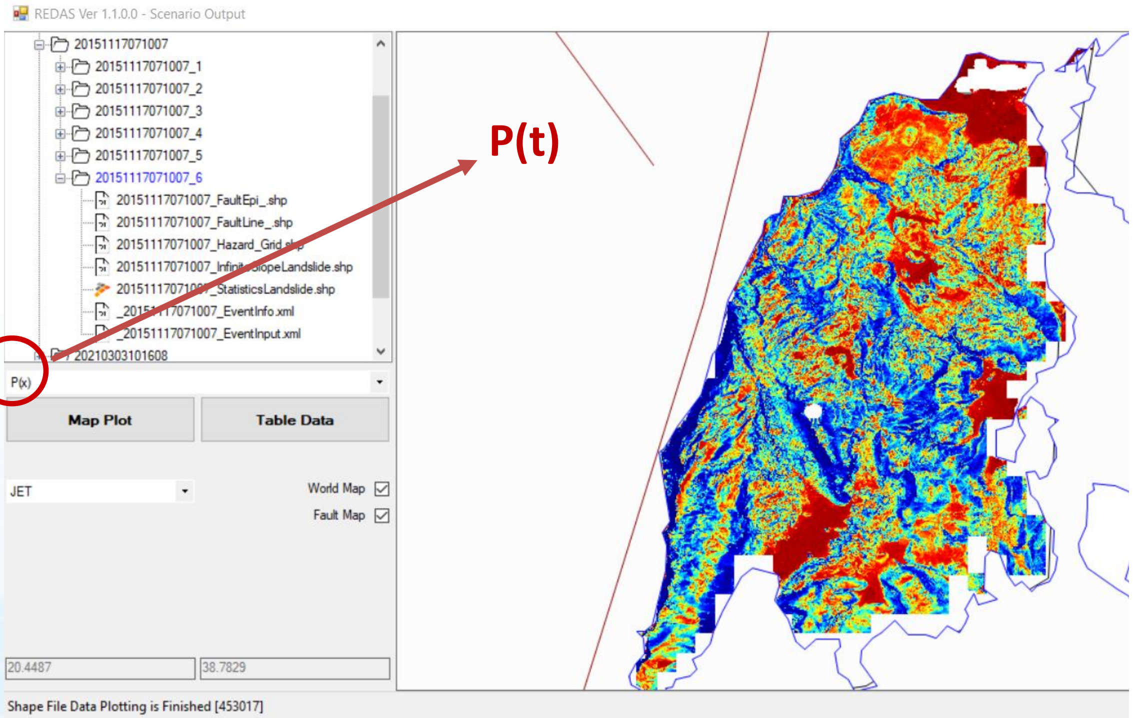
- Slope > 5 degrees

Spatial Resolution:

- High resolution (e.g. 0.00025 deg) offers better spatial resolution and takes advantage of available high resolution Digital Elevation Models

Landslide Hazard (statistical model)

Statistical landslide probability model (Jessee et al. 2018)



REDAS Ver 1.1.0.0 - Scenario Output

- 20151117071007
  - 20151117071007_1
  - 20151117071007_2
  - 20151117071007_3
  - 20151117071007_4
  - 20151117071007_5
  - 20151117071007_6
    - 20151117071007_FaultEpi_.shp
    - 20151117071007_FaultLine_.shp
    - 20151117071007_Hazard_Grid.shp
    - 20151117071007_InfiniteSlopeLandslide.shp
    - 20151117071007_StatisticsLandslide.shp
    - _20151117071007_EventInfo.xml
    - _20151117071007_EventInput.xml
- 20210303101608

P(x)

JET

World Map ☑

Fault Map ☑

20.4487

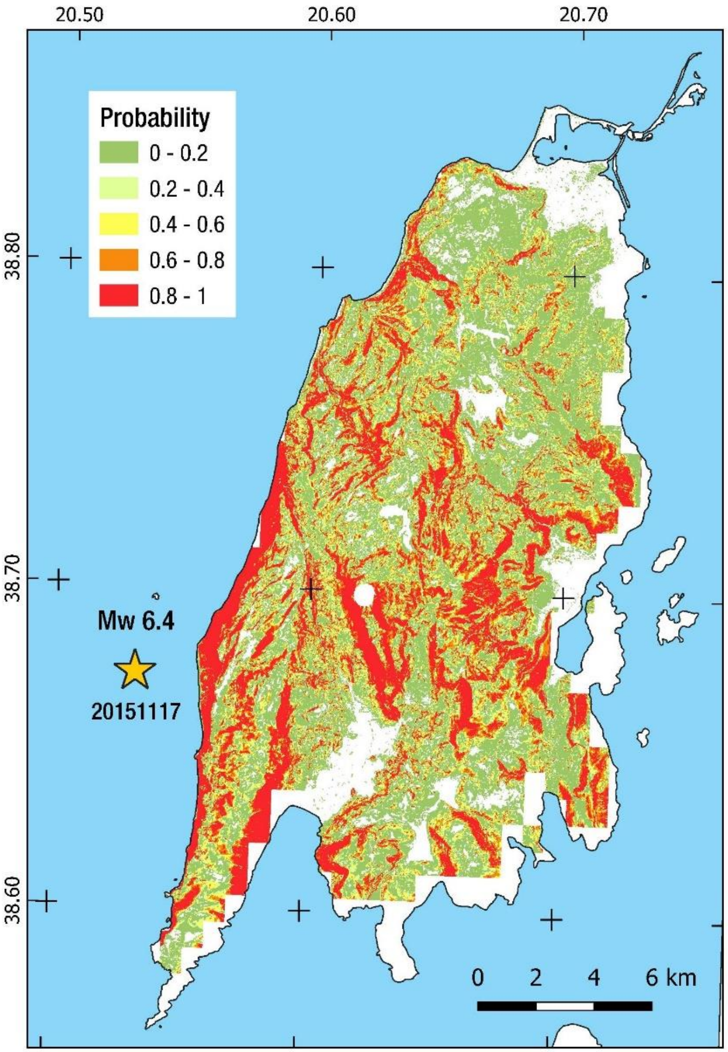
38.7829

Shape File Data Plotting is Finished [453017]

P(t)

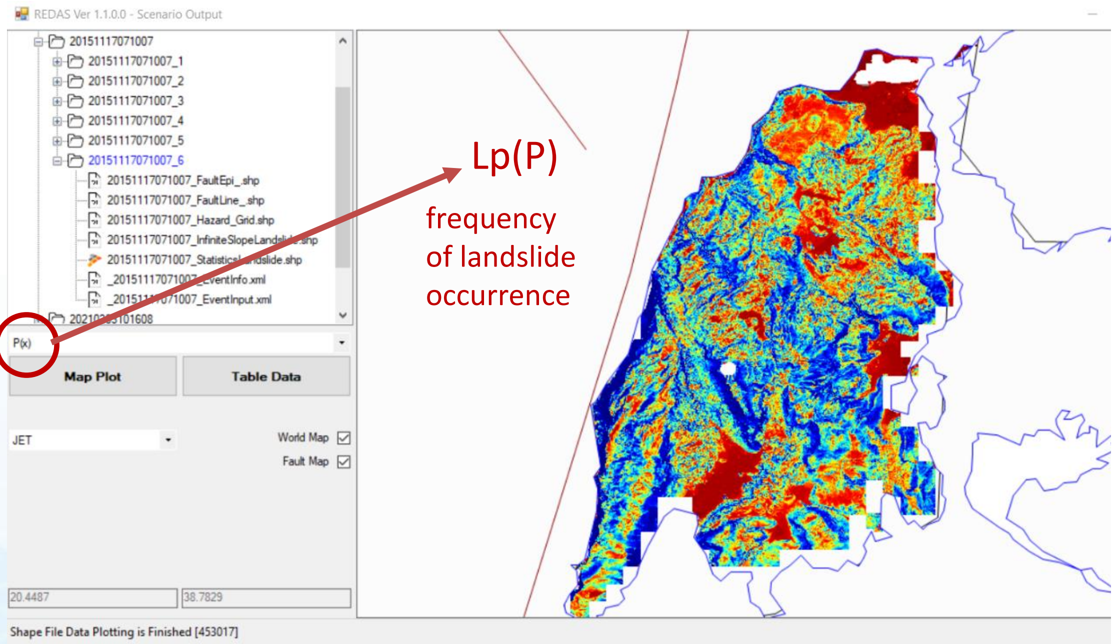
REDAS output

QGIS



Landslide Hazard (statistical model)

Statistical landslide probability model (Jessee et al. 2018)



REDAS Ver 1.1.0.0 - Scenario Output

- 20151117071007
  - 20151117071007_1
  - 20151117071007_2
  - 20151117071007_3
  - 20151117071007_4
  - 20151117071007_5
  - 20151117071007_6
    - 20151117071007_FaultEpi_.shp
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    - 20151117071007_Hazard_Grid.shp
    - 20151117071007_InfiniteSlopeLandslide.shp
    - 20151117071007_StatisticalLandslide.shp
    - _20151117071007_EventInfo.xml
    - _20151117071007_EventInput.xml
- 20210[illegible]3101608

P(x)

JET

World Map ☑

Fault Map ☑

20.4487 | 38.7829

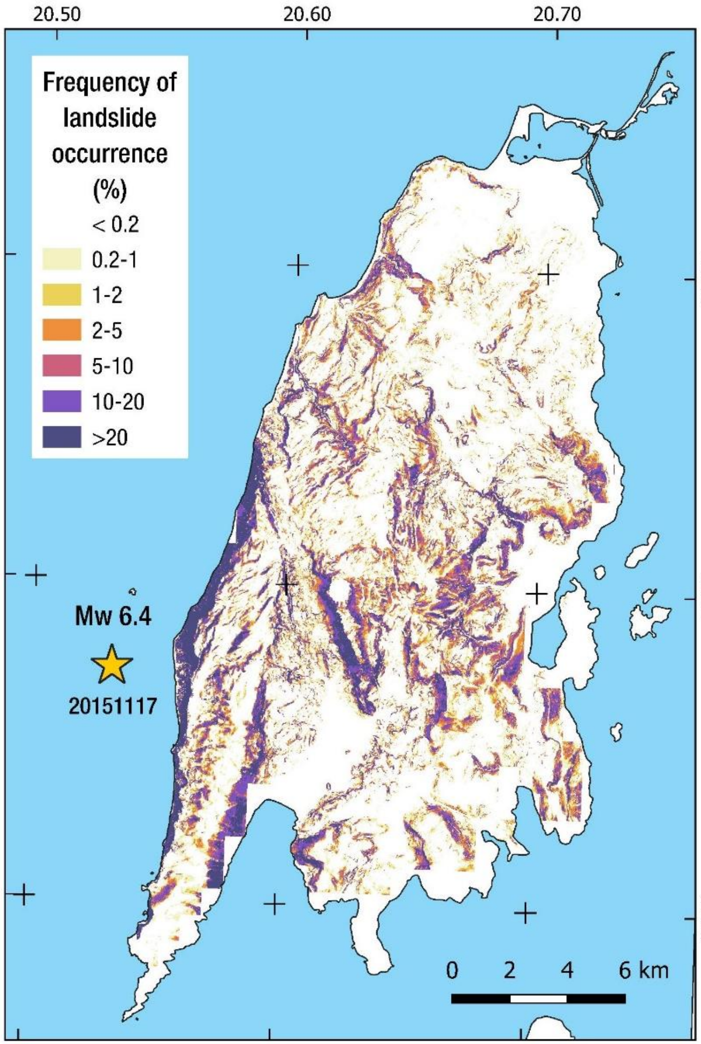
Shape File Data Plotting is Finished [453017]

Lp(P)

frequency of landslide occurrence

REDAS output

QGIS

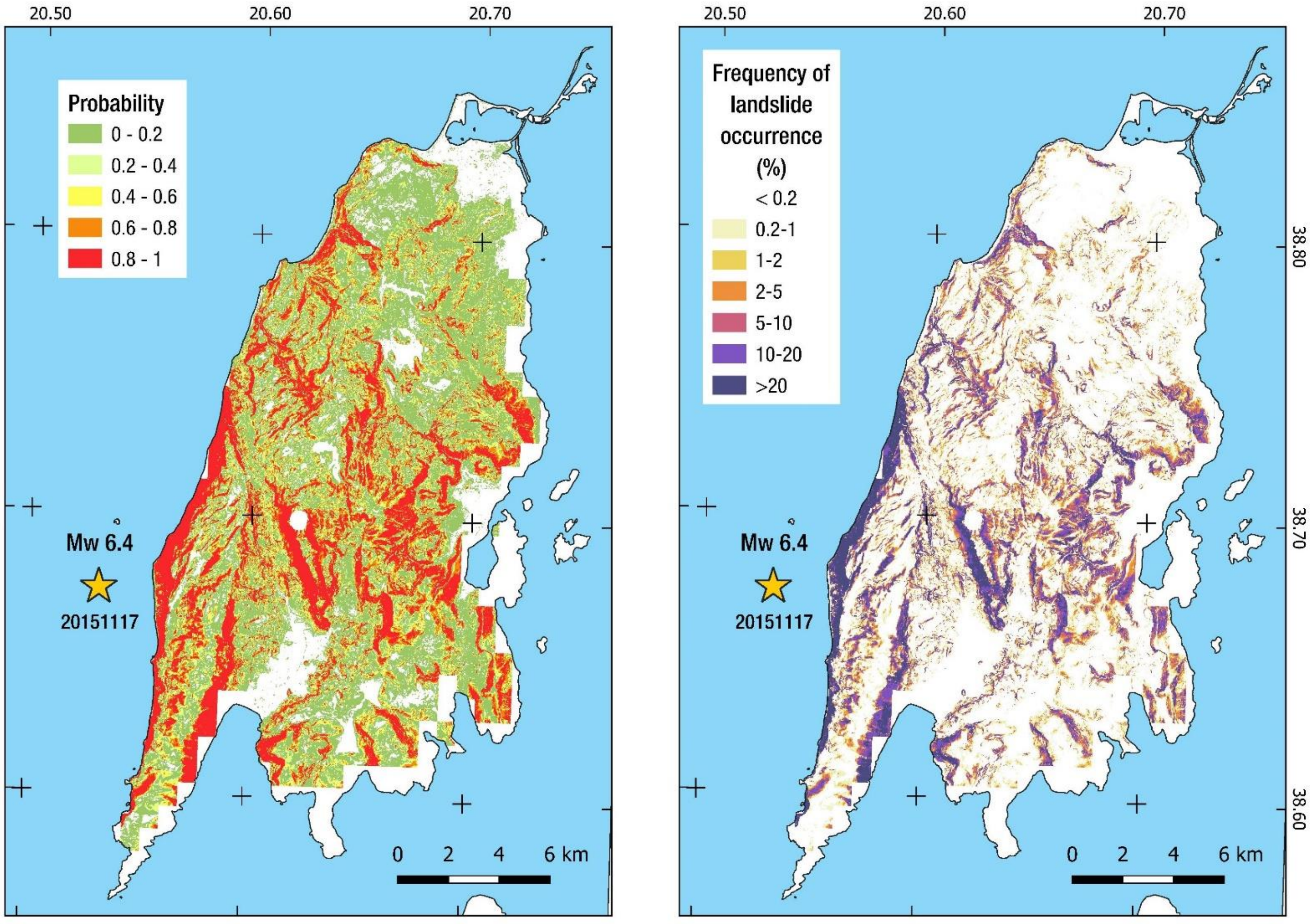


Landslide Hazard (statistical model)

Landslide Statistical Model Output

$P(t)=1/(1+\exp(-t))$

$$L_P(P) = e^{\left(a+b\times P+c\times P^2+d\times P^3\right)},$$



$a = -7.592$

$b = 5.237$

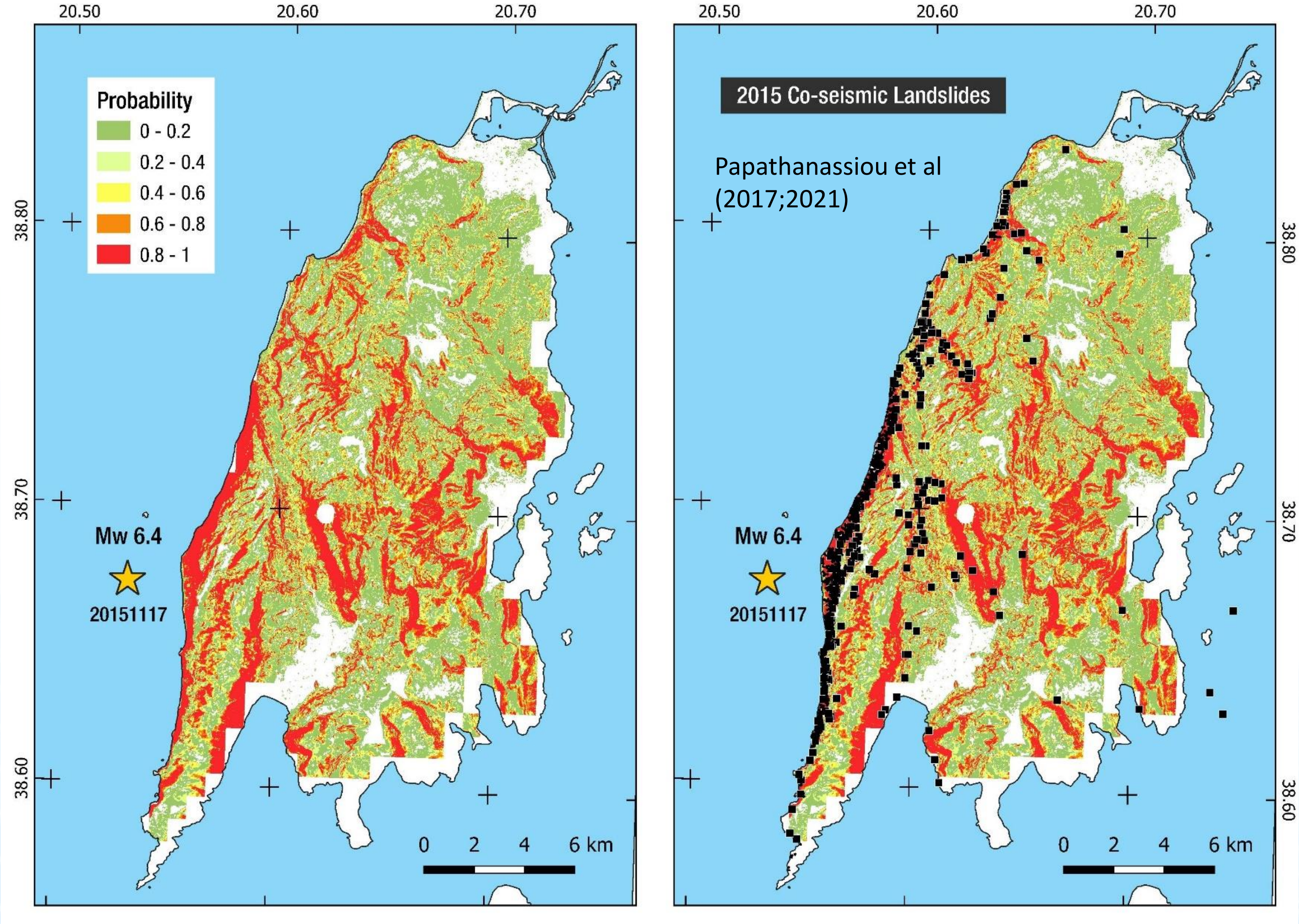
$c = -3.042$

$d = 4.035$

This equation corrects the predicted probability. Represents the **frequency of landslide occurrence** i.e. the portion of each cell expected to have landslide occurrence (areal coverage)

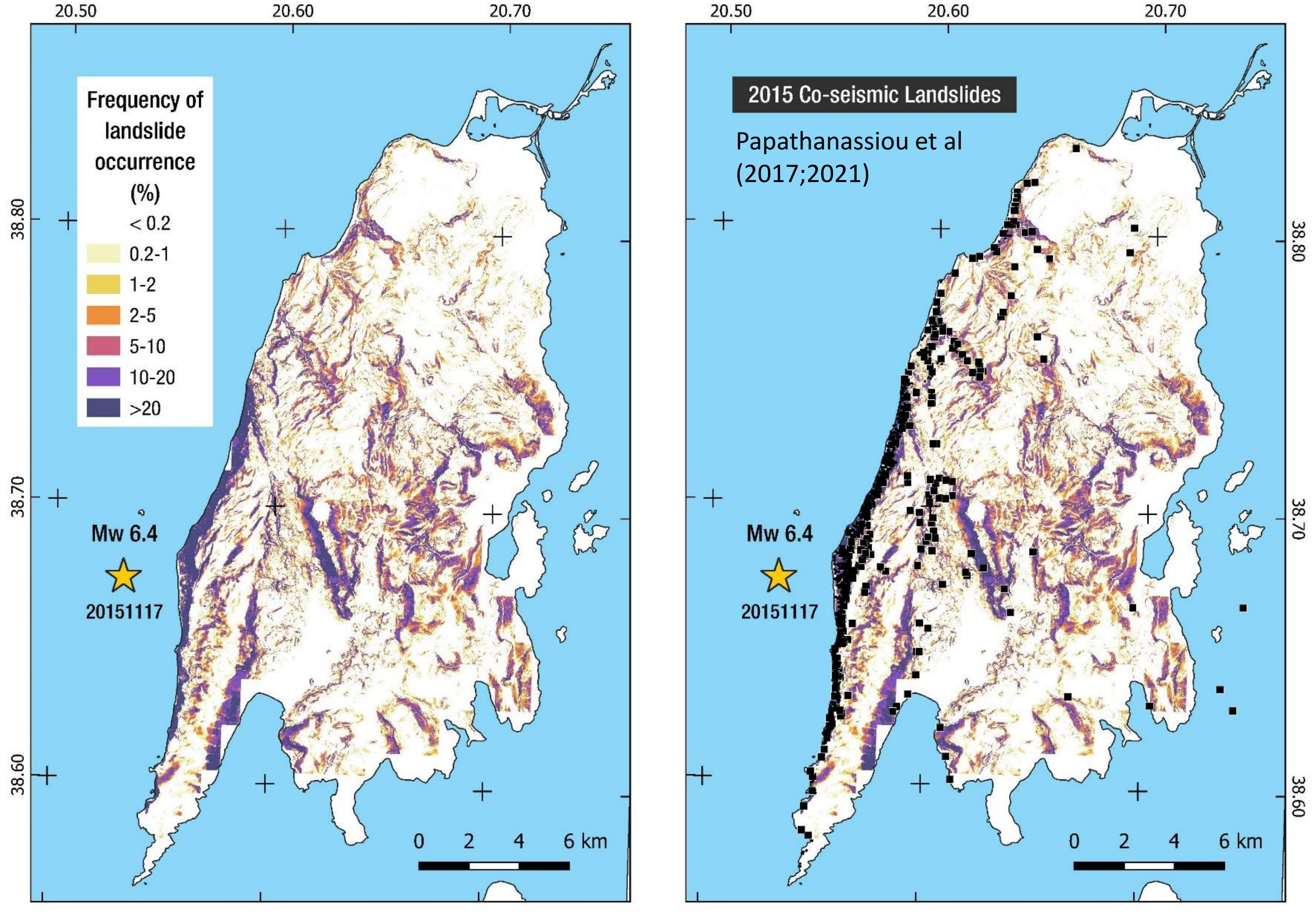
Landslide Hazard (statistical model)

Landslide Statistical Model Output – Validation with surveyed co-seismic landslides



Landslide Hazard (statistical model)

Landslide Statistical Model Output – Validation with surveyed co-seismic landslides

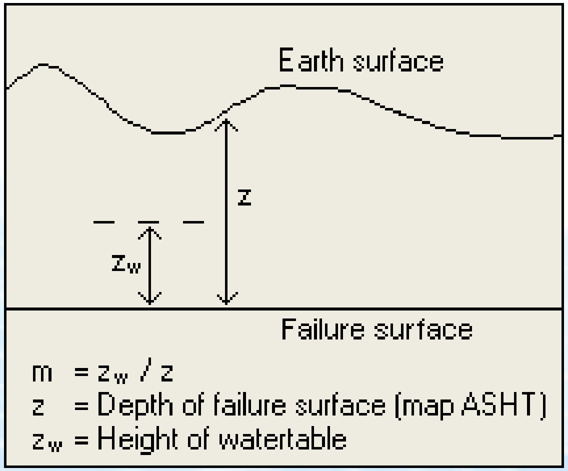


Physically based methods

Physically based landslide hazard assessment methods are based on the modelling of slope failure processes and the output is the F_S values.

Use of the infinite slope model, is suitable for shallow earthquake induced landslides. The driving equation is:

$$F = \frac{c' + (z\gamma\cos^2\beta - z\rho\alpha\cos\beta\sin\beta - \gamma_w z_w \cos^2\beta)\tan\phi'}{z\gamma\sin\beta\cos\beta + z\rho\alpha\cos^2\beta}$$

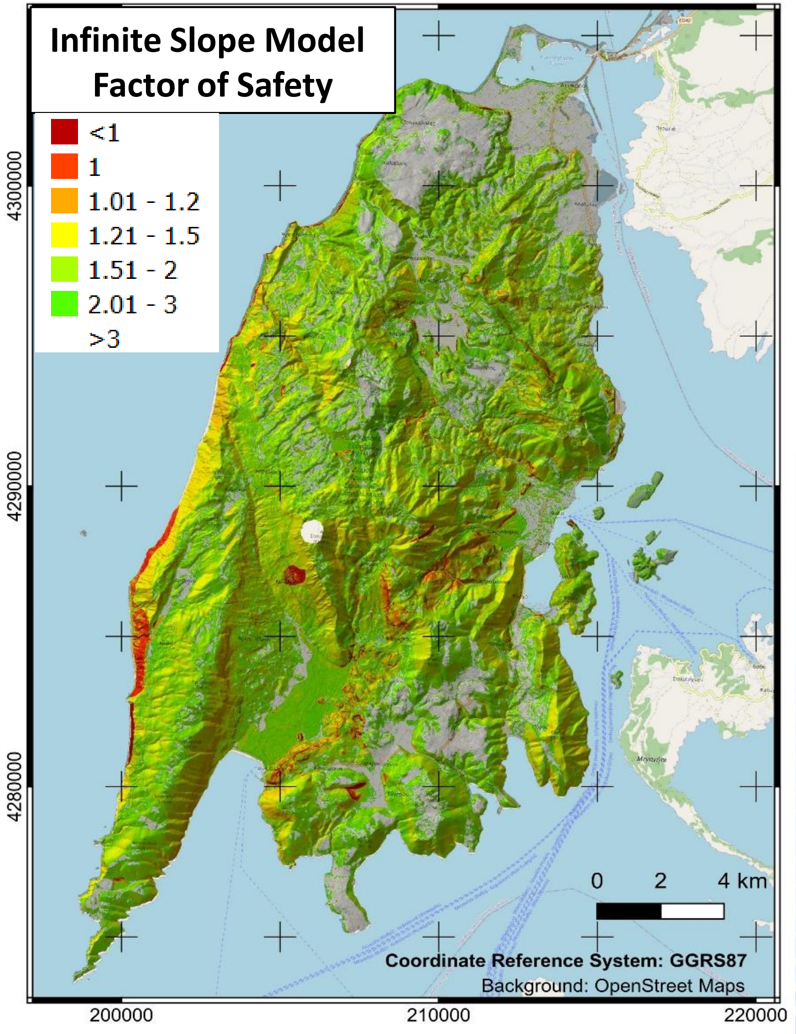


ϕ': effective angle of friction of geomaterial (^{0})
c’: effective cohesion of geomaterial (kPa),
β: slope angle (Deg),
ρ: bulk density (Kg/m^3)
γ: specific weight (kN/m^3),
γ_w: specific weight of the water (kN/m^3),
a : earthquake acceleration (m/s^2)
z: normal thickness of the failure slab (m)
m = z_w/z % of the water saturated failure slab

Landslide Hazard (Infinite Slope Model)

Sliding mass thickness: 1m

Wet conditions

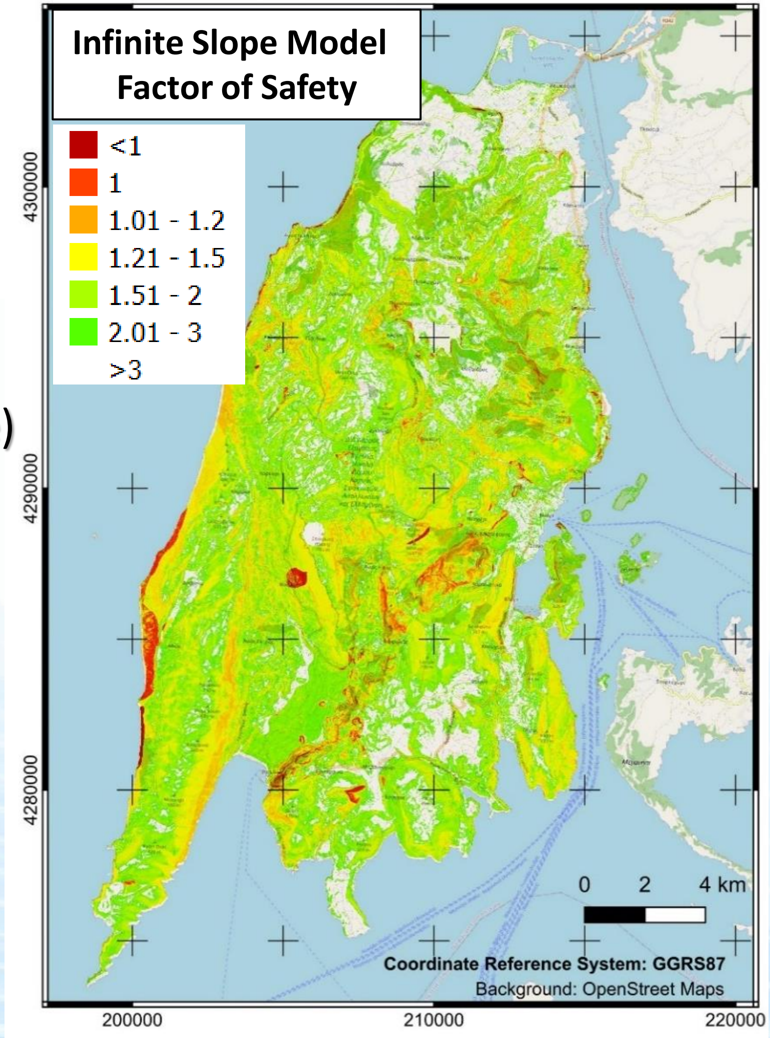


17-11-2015

Lefkada (Greece)

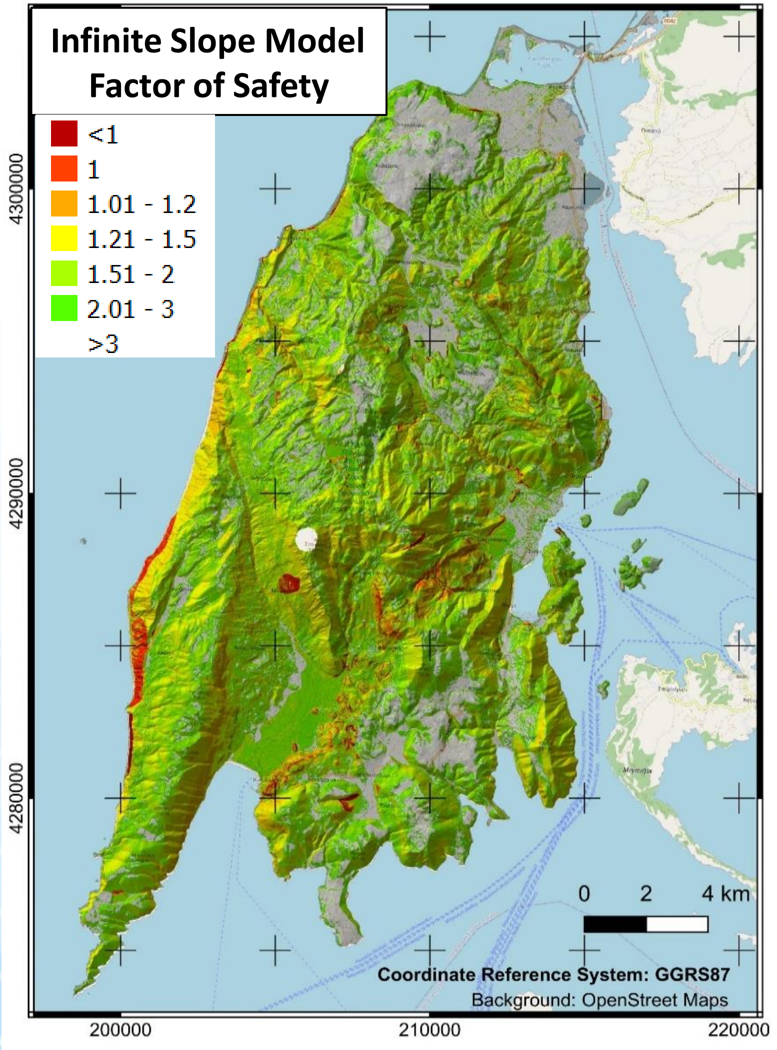
Mw 6.4

Dry conditions

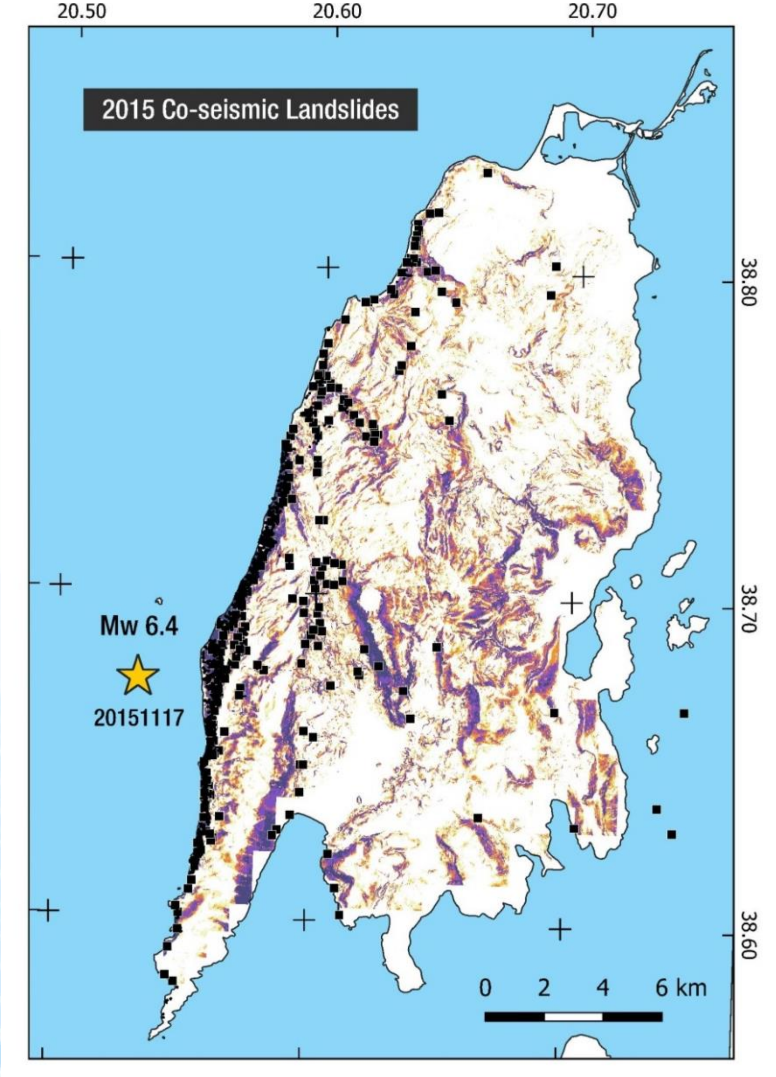


Landslide Hazard

Wet conditions Sliding mass thickness: 1m



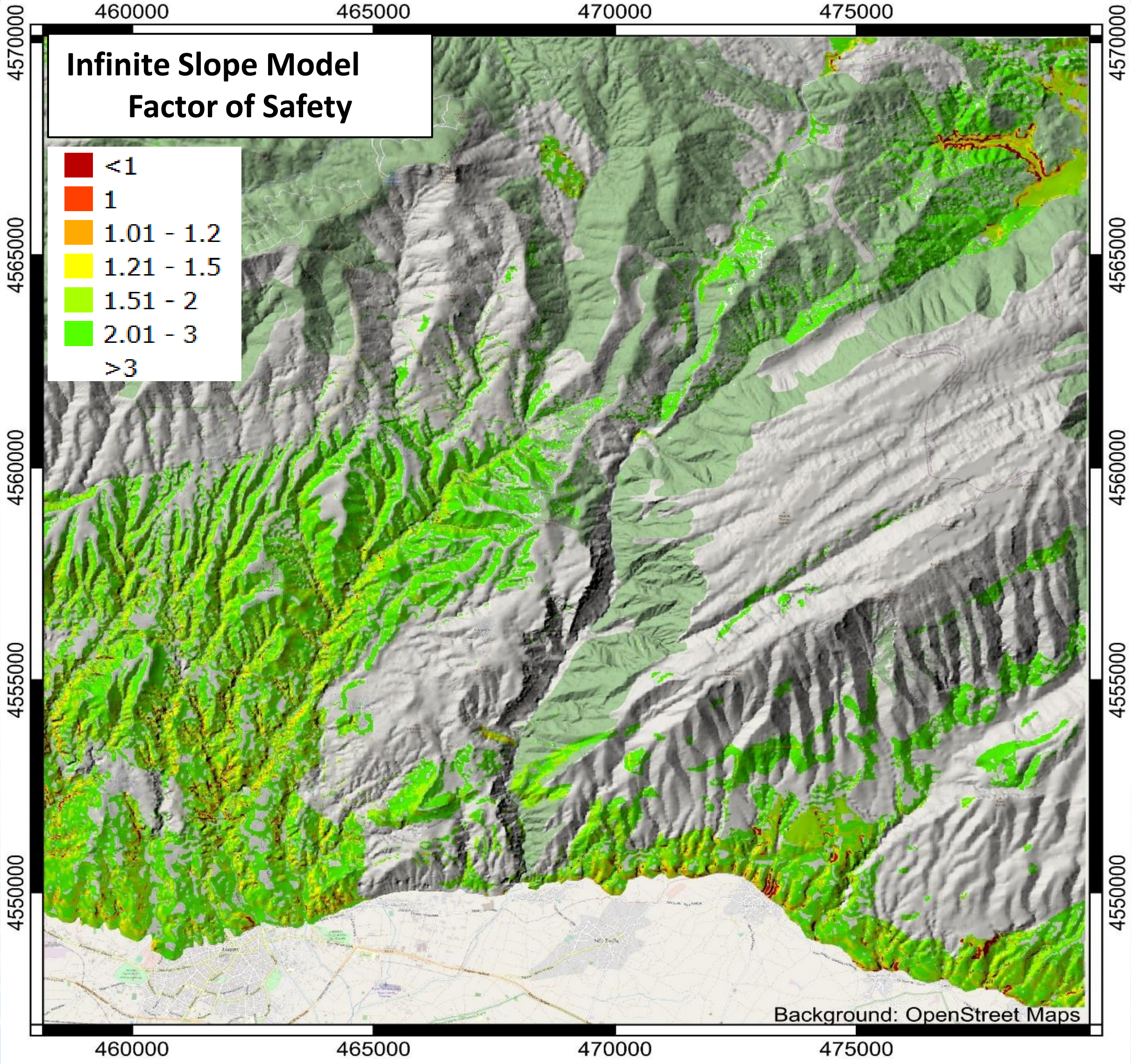
Statistical model and observed landslides



Landslide Hazard (Infinite Slope Model)

Blind test prediction northern of Serres mountainous area

Sliding mass thickness: Variable based on slope and lithology (0-2m)



Liquefaction

Probability of liquefaction based on Zhu et al (2017) methodology

Probability of liquefaction

$$P(x) = \frac{1}{1 + e^{-x}}$$

Coastal region (dc<20km)

$$x = 12.345 + 0.301 \times \ln(PGV) - 2.615 \times \ln(Vs_{30}) + 5.556 \times 10^{-4} \times Precip - 0.0287 \times \sqrt{dc} + 0.0666 \times dr - 0.0369 \times (\sqrt{dc} \times dr)$$

Non Coastal region (dc>20km)

$$x = 8.801 + 0.334 \times \ln(PGV) - 1.918 \times \ln(Vs_{30}) + 5.408 \times 10^{-4} \times Precip - 0.2054 \times dw - 0.0333 \times wtd$$

Where:

PGV (cm/s): Peak ground velocity
VS_{30} (m/s): Shear wave velocity to 30m depth
Precip (mm): Precipitation (mean annual)
dc (km): Distance to the nearest coast
dr (km): Distance to the nearest river
dw (km): Distance to the nearest water body
wtd (m): Water table depth

Spatial extent of liquefaction

$$L(P) = \frac{a}{(1 + be^{-cP})^2}$$

Where

Parameters	Coastal	Non Coastal
a	42.08	49.15
b	62.59	42.4
c	11.43	9.165

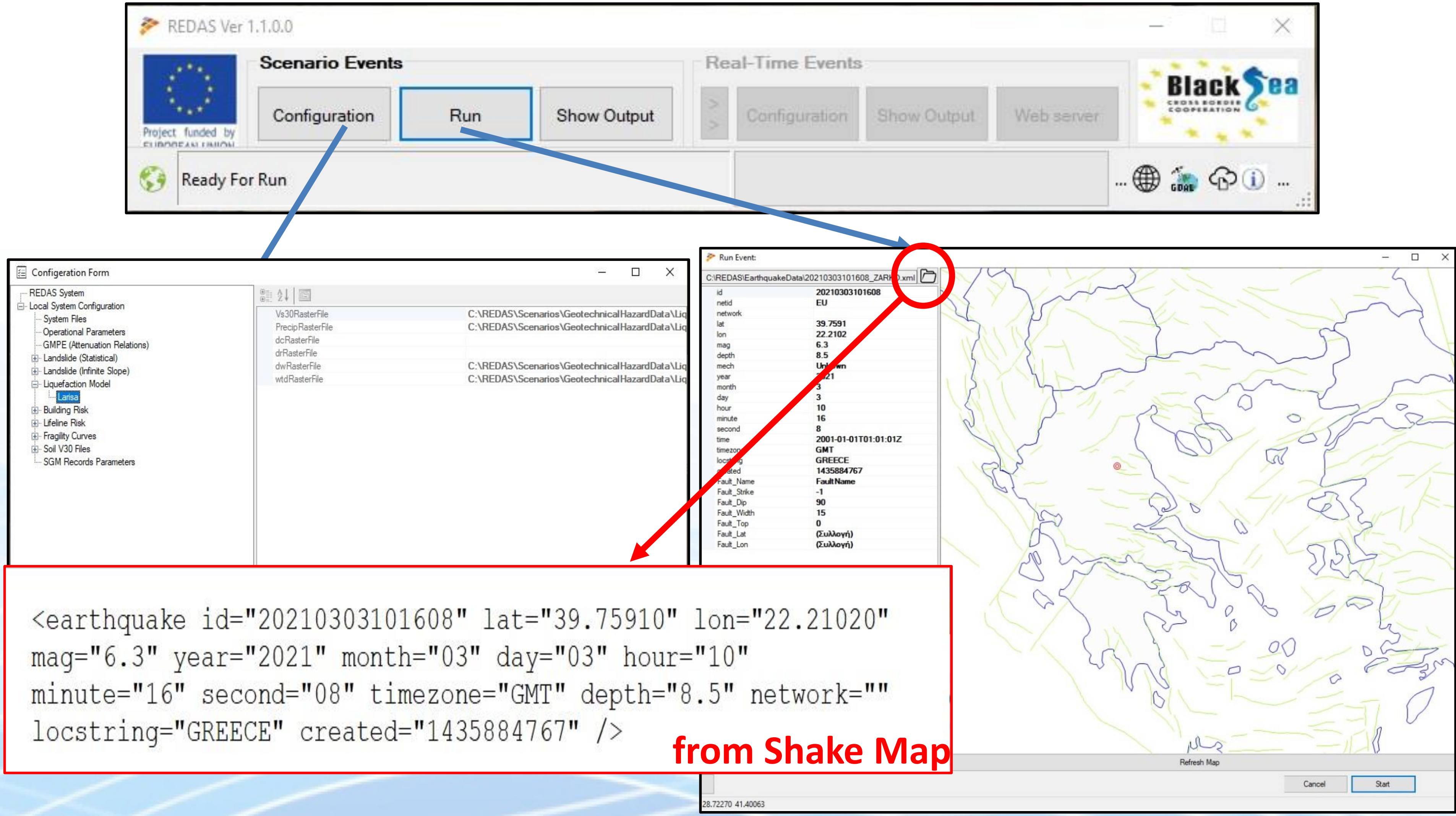
$$PGV_{used} = PGV_{(shake\ map)} \times SF$$

$$SF = \frac{1}{1 + exp(-2[M - 6])}$$

for M (earthquake magnitude) we use Mw

Liquefaction

REDAS – M6.3 Larisa, Greece (03/03/2021)



Vs30RasterFile	C:\REDAS\Scenarios\GeotechnicalHazardData\Liq
PrecipRasterFile	C:\REDAS\Scenarios\GeotechnicalHazardData\Liq
dcRasterFile	
drRasterFile	
dwRasterFile	C:\REDAS\Scenarios\GeotechnicalHazardData\Liq
wtdRasterFile	C:\REDAS\Scenarios\GeotechnicalHazardData\Liq

C:\REDAS\EarthquakeData\20210303101608_ZARKO.xml

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netid	EU
network	
lat	39.7591
lon	22.2102
mag	6.3
depth	8.5
mech	Unknown
year	2021
month	3
day	3
hour	10
minute	16
second	8
time	2001-01-01T01:01:01Z
timezone	GMT
locstring	GREECE
created	1435884767
Fault_Name	FaultName
Fault_Strike	-1
Fault_Dip	90
Fault_Width	15
Fault_Top	0
Fault_Lat	(Συλλογή)
Fault_Lon	(Συλλογή)

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minute="16" second="08" timezone="GMT" depth="8.5" network=""
locstring="GREECE" created="1435884767" />
```

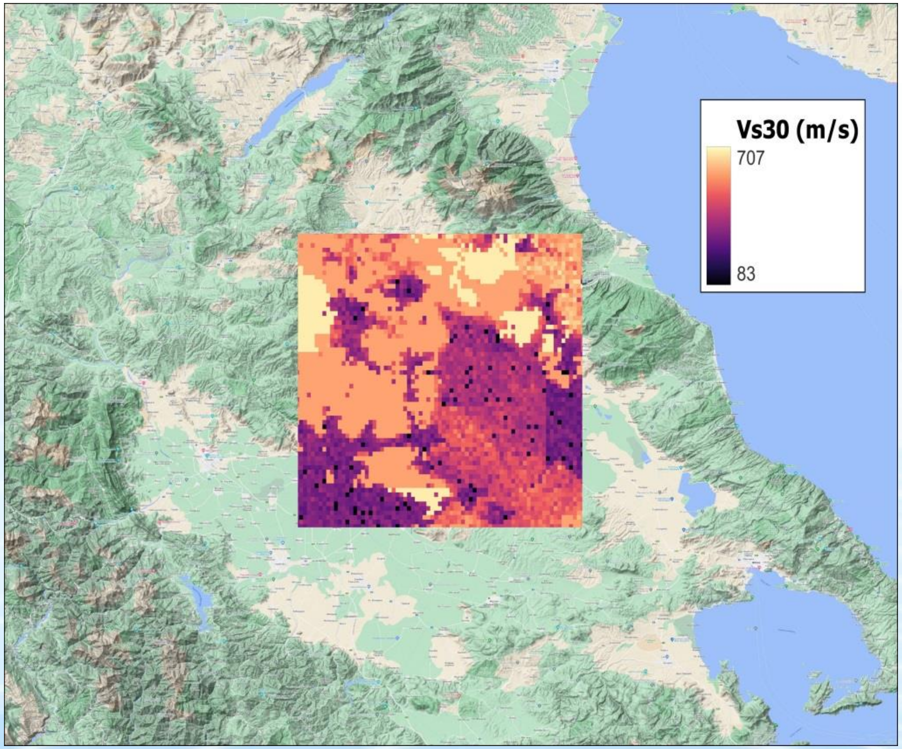
from Shake Map

Liquefaction

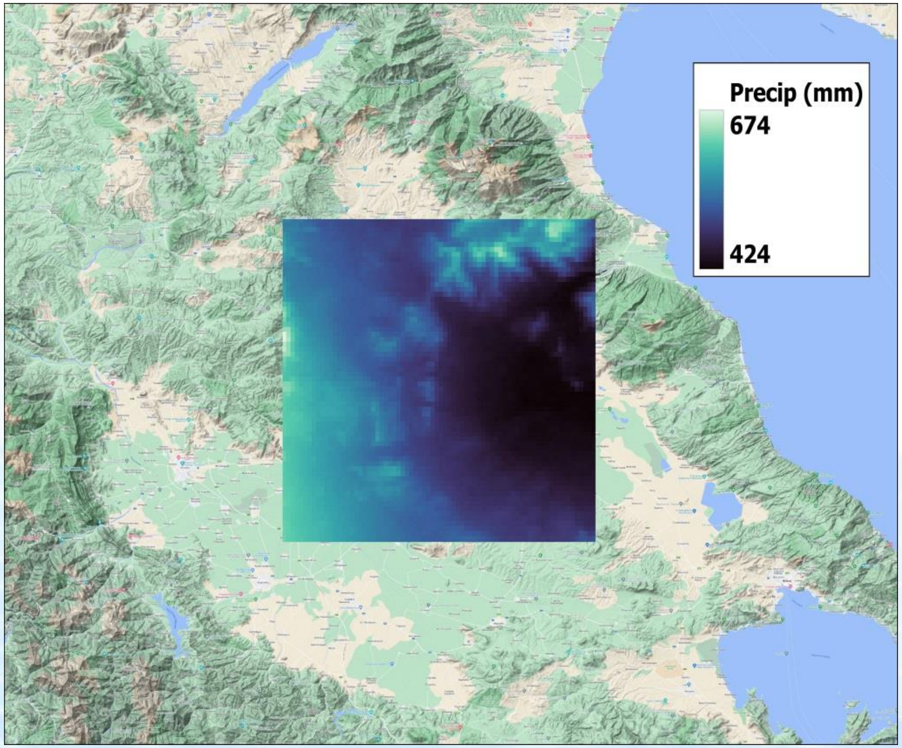
M6.3 Larisa, Greece (03/03/2021)

Input Data

Vs_{30} (m/s)



Precipitation (mm)

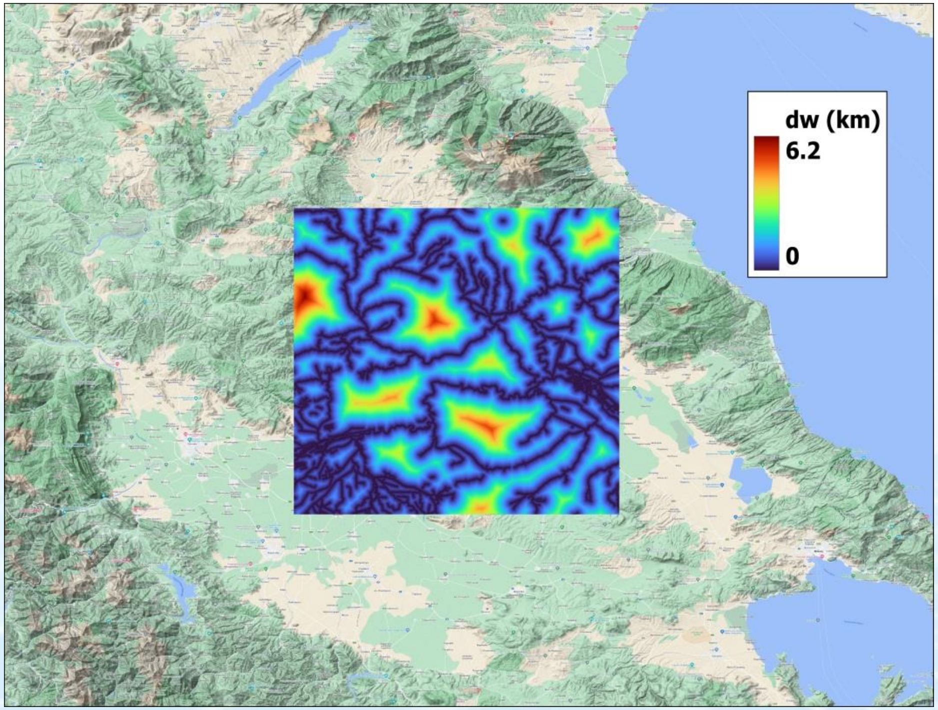


Liquefaction

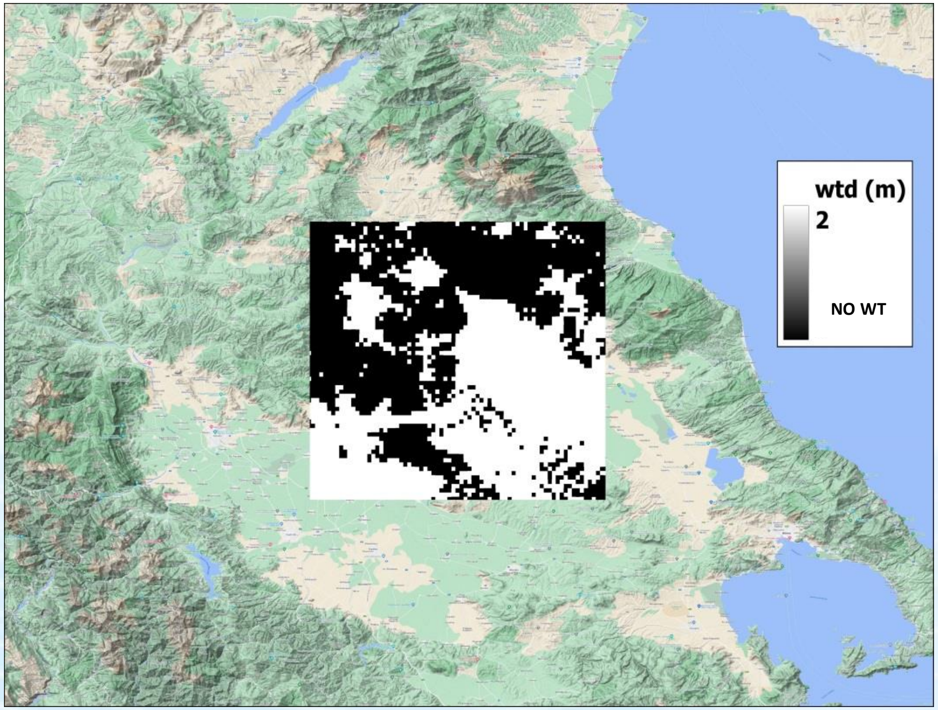
REDAS – M6.3 Larisa, Greece (03/03/2021)

Input Data

Dw (km)



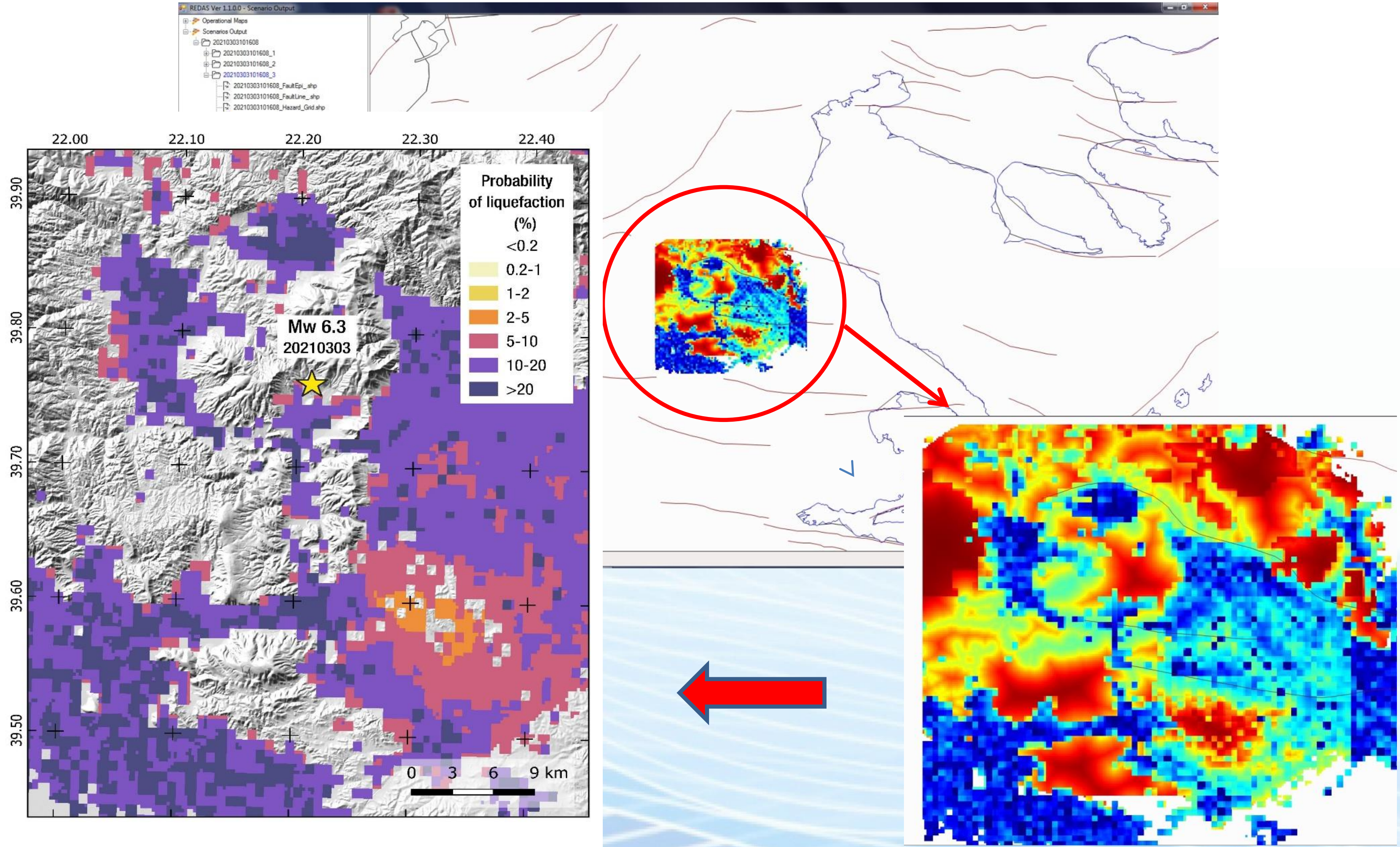
Wtd (m)



Liquefaction

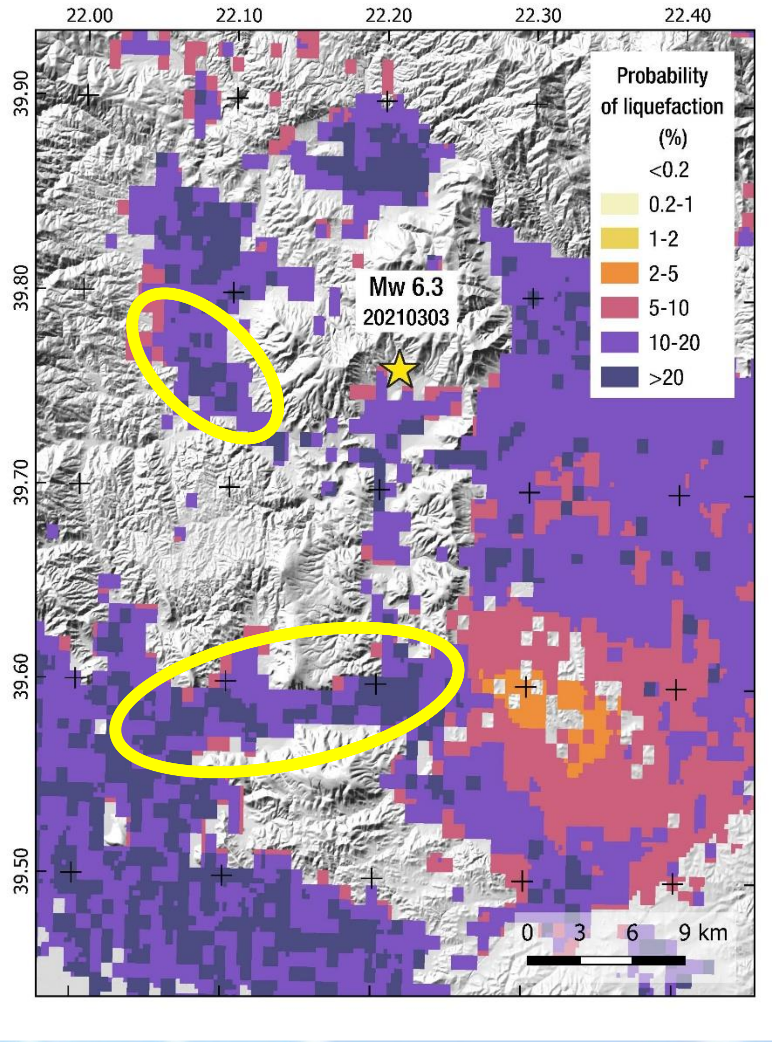
Probability of liquefaction - P(x)

REDAS – M6.3 Larisa, Greece (03/03/2021)

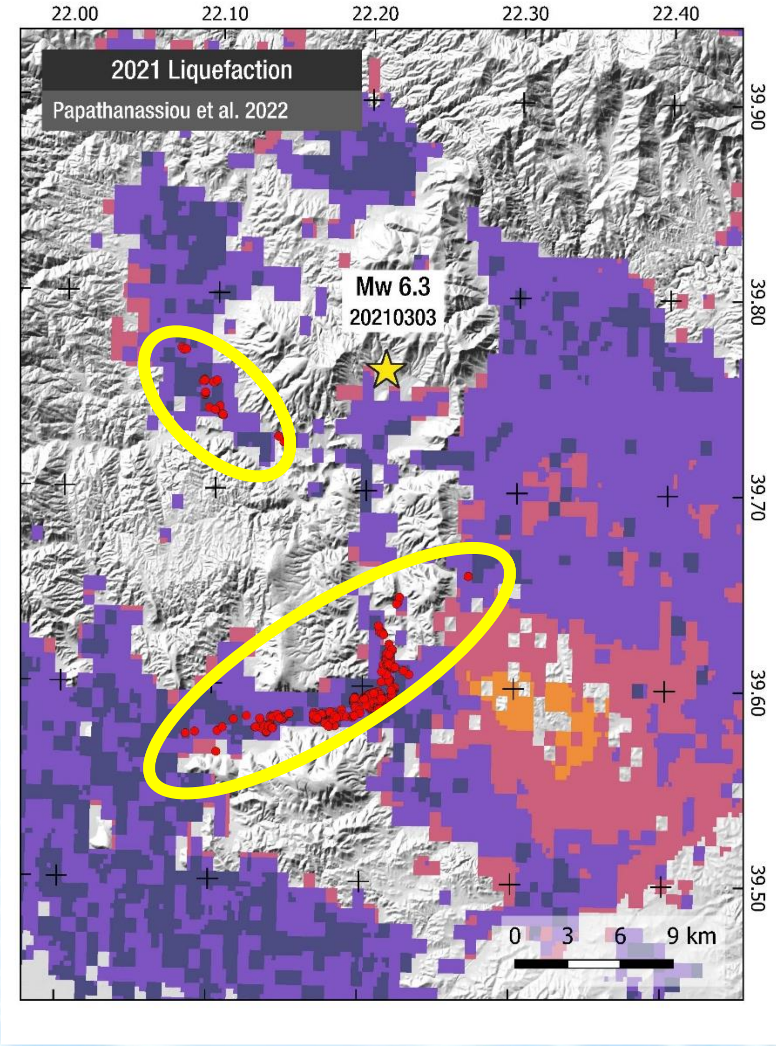


Liquefaction

Probability of liquefaction - P(x)



REDAS – M6.3 Larisa, Greece (03/03/2021)



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Rapid Earthquake Damage Assessment consorTium

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Thank You!

- A Black Sea Basin Joint Operational Programme

2014-20 project

https://www.redact-project.eu/

June 2023

Common borders. Common solutions.

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