A scenario-based approach for immediate post-earthquake rockfall impact assessment and case study

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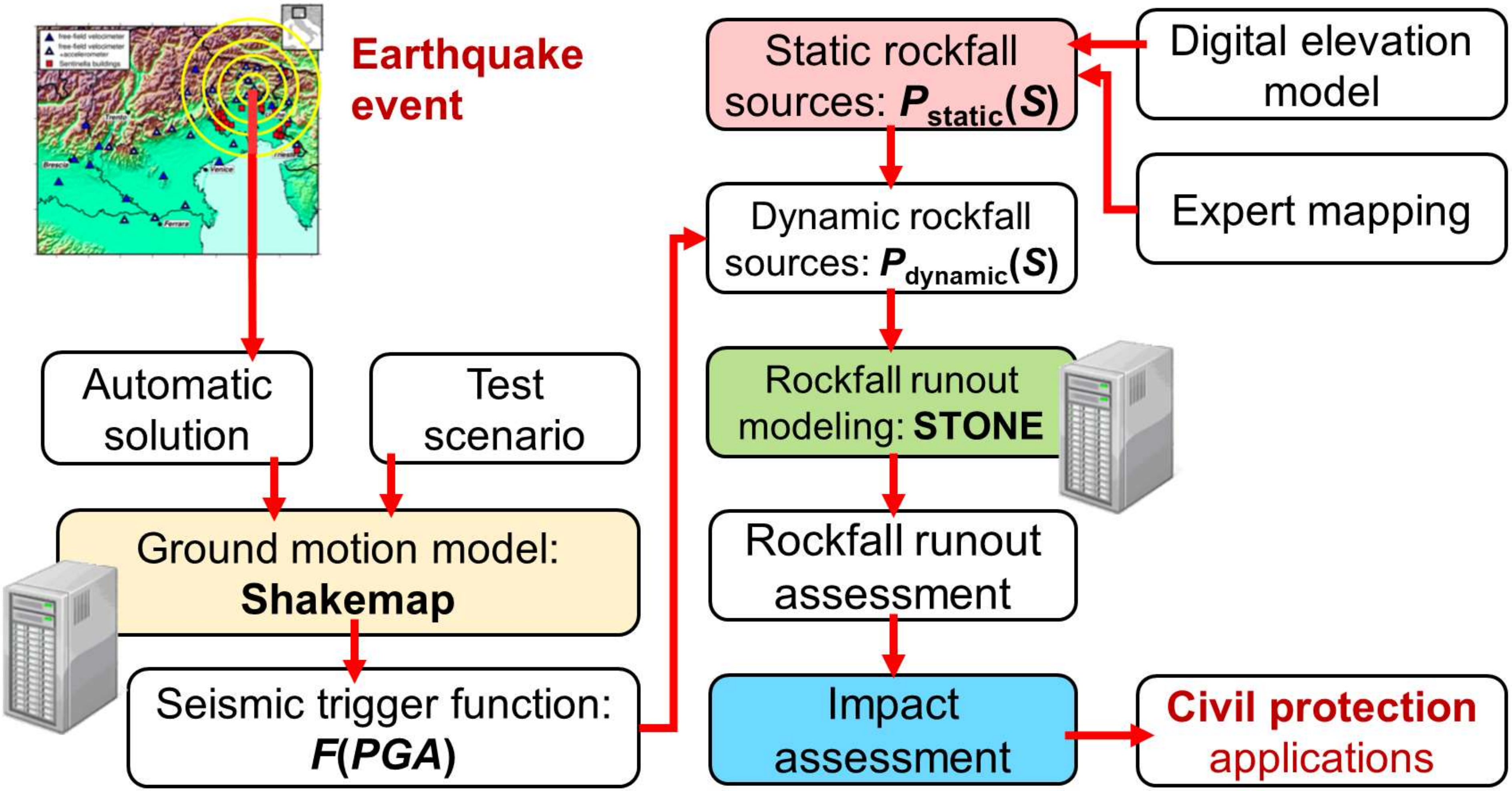
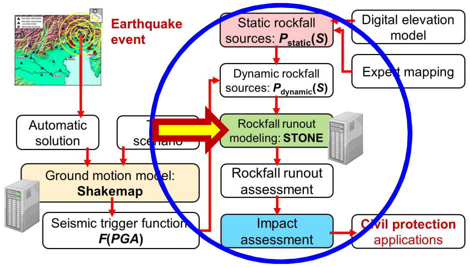
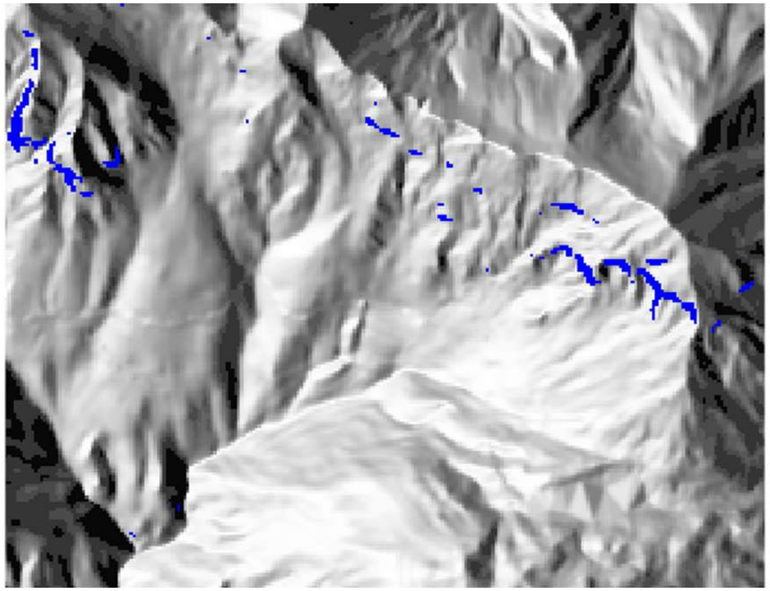
2. Seismological Research Center
National Institute of Oceanography and Applied Geophysics (Udine, Italy)

INTRODUCTION: FROM SEISMIC SHAKING TO ROCKFALL MODELING



PHYSICALLY BASED MODELING: STONE





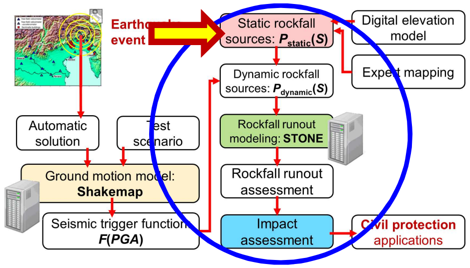
- **Three-dimensional model** for rockfalls
- Describes individual, **point-like** rock **blocks**
- Geometrical **simulation of trajectories** from ***user-defined starting points***
- Trajectories are a sequence of falling, bouncing, and rolling steps - they stop when the block's kinetic energy is exhausted

Input: digital elevation model (here, 10 m national DEM); ***map of sources***

Ancillary data: terrain geological/lithological information

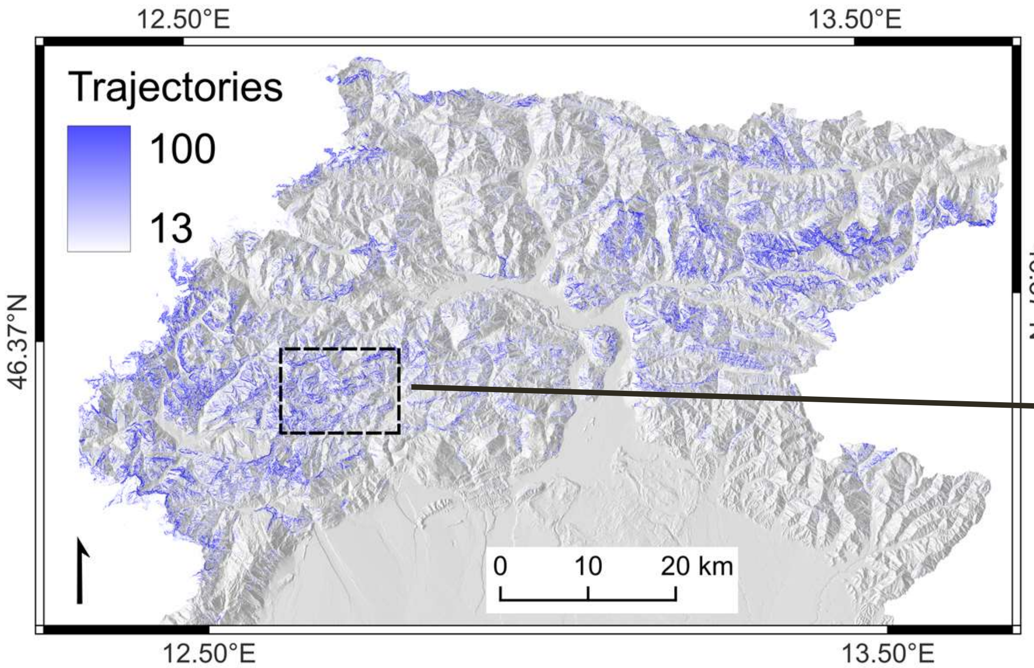
⇒ **terrain parameters** (friction coefficient, normal & tangential restitution)

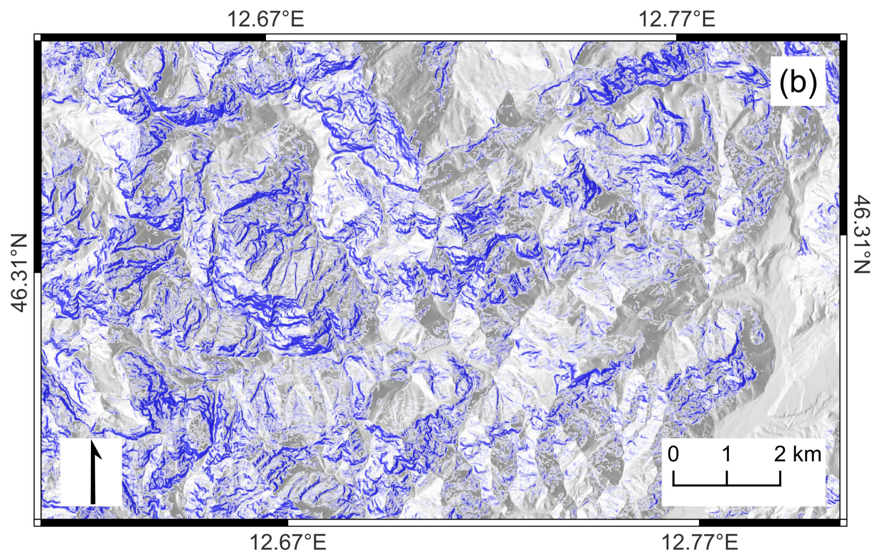
STATIC (TRIGGER-INDEPENDENT) ROCKFALL SOURCES



Study area Friuli 1976 with
static, unquenched static sources:

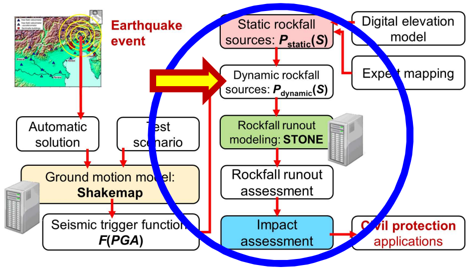
$$P_{stat}(S) = a(S/90)^{b}$$





Alvioli et al., Engineering Geology (2021)

DYNAMIC (TRIGGER-BASED) ROCKFALL SOURCES



- *Probabilistic*, ***static*** approach consists of:

$$P_{static}(S) = a\left(\frac{S}{90}\right)^{b}$$

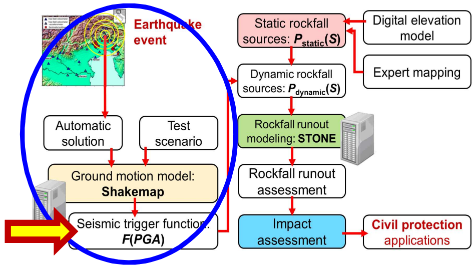
- Ground shaking **activates** a few static sources ⇒ ***dynamic*** source map
- Using peak ground acceleration (PGA):

$$P_{dynamic}(S, PGA) = P_{static}(S)\, F(PGA)$$

$F(PGA)$: ***PGA → [0,1]*** ⇒ *a few sources are* ***activated by the EQ trigger***

Alvioli et al., Geomorphology (2023)
Alvioli et al., Geomatics, Natural Hazards and Risk (2023)

USE OF PEAK GROUND ACCELERATION GRIDS



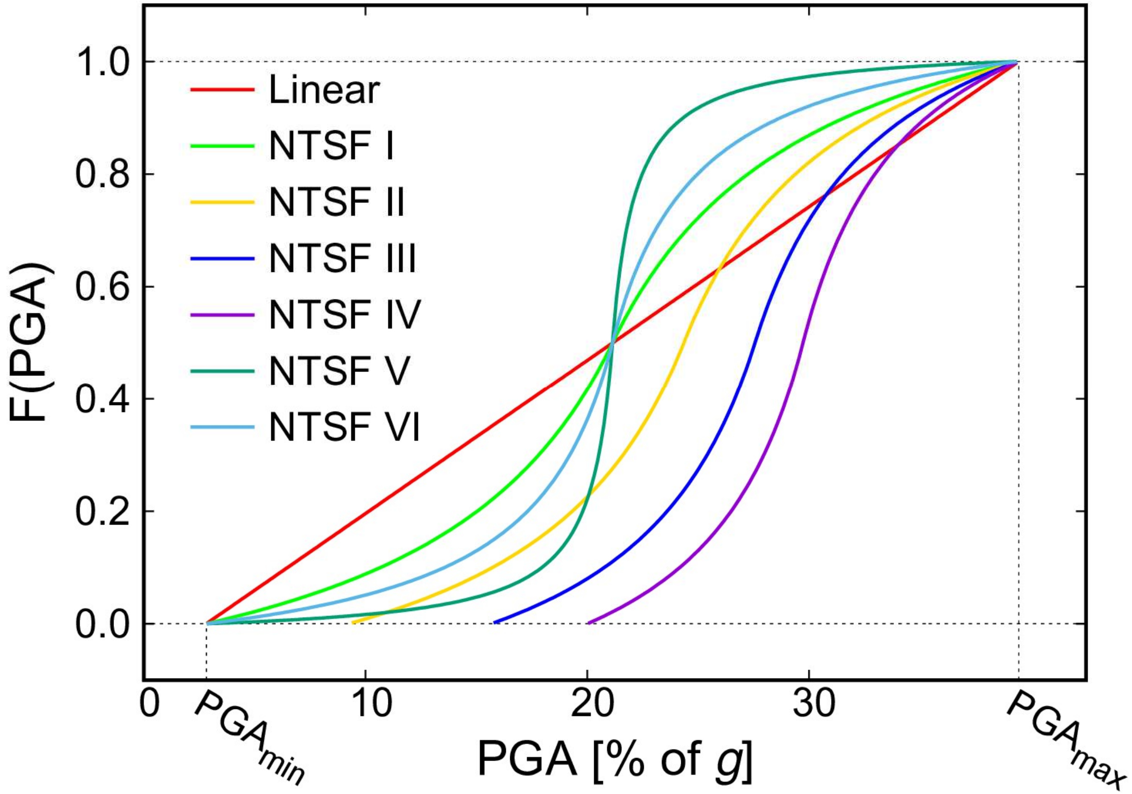
$$P_{dynamic}(S, PGA) = P_{static}(S)\, \boldsymbol{F(PGA)}$$

- Linear mapping:

$$\boldsymbol{F(PGA)} = \frac{\boldsymbol{PGA - PGA_{min}}}{\boldsymbol{PGA_{max} - PGA_{min}}}$$

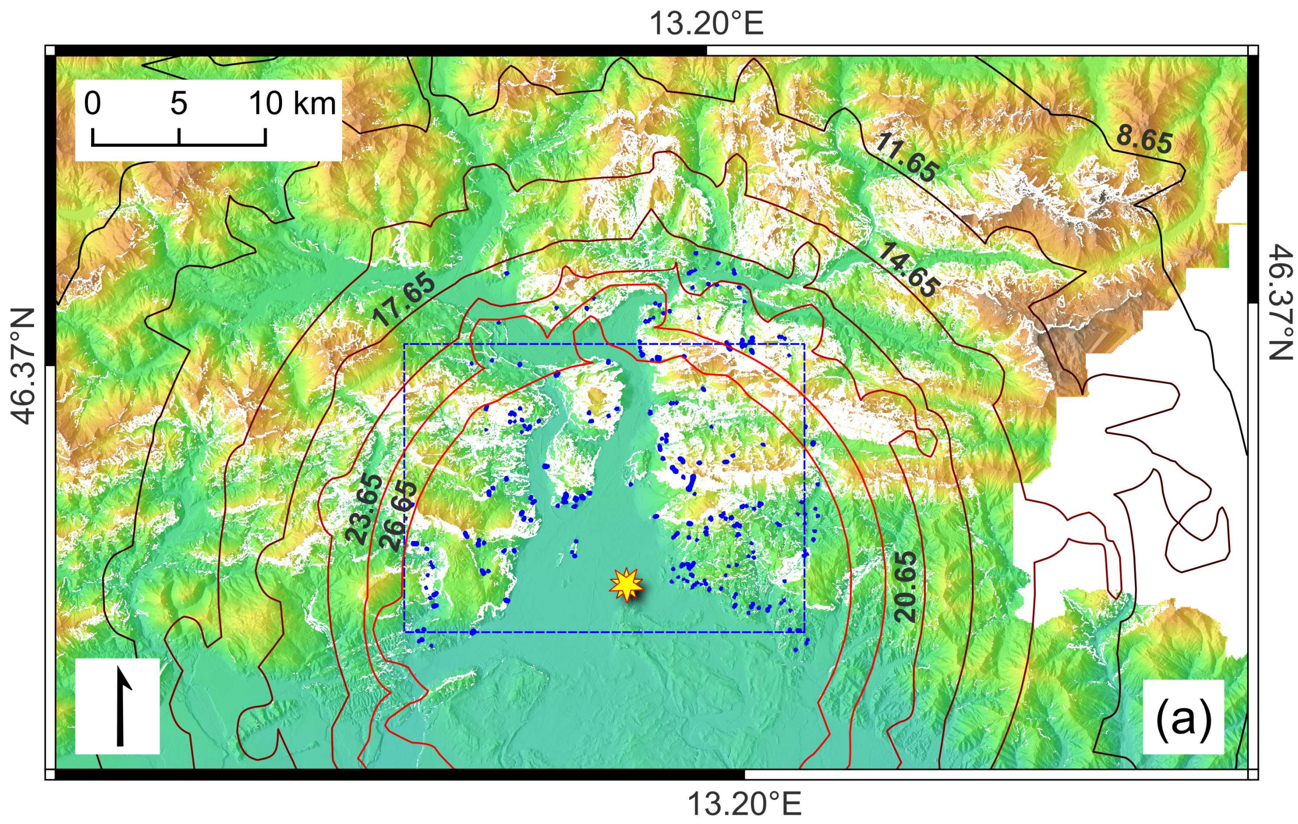
- Normalized tunable sigmoid function:

$$\boldsymbol{F(x)} = \frac{1}{2}\left(\frac{\boldsymbol{x - k\,x}}{\boldsymbol{k - 2k|x| + 1}} + 1\right)$$



Alvioli et al., Landslides (2024)

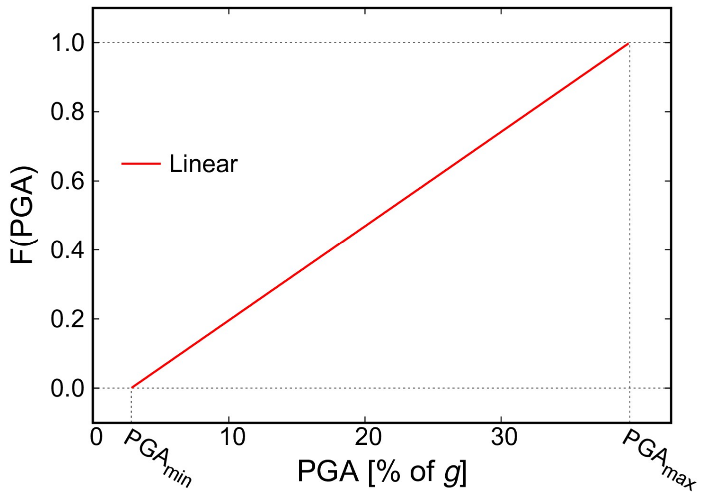
ROCKFALL SOURCES: RESULTS



Study area Friuli 1976
PGA contour lines +
quenched static sources:

$$P_{dyn}(S, PGA) = P_{stat}(S)\ F(PGA)$$

with **F(PGA)** linear approximation



Alvioli et al., Landslides (2024)

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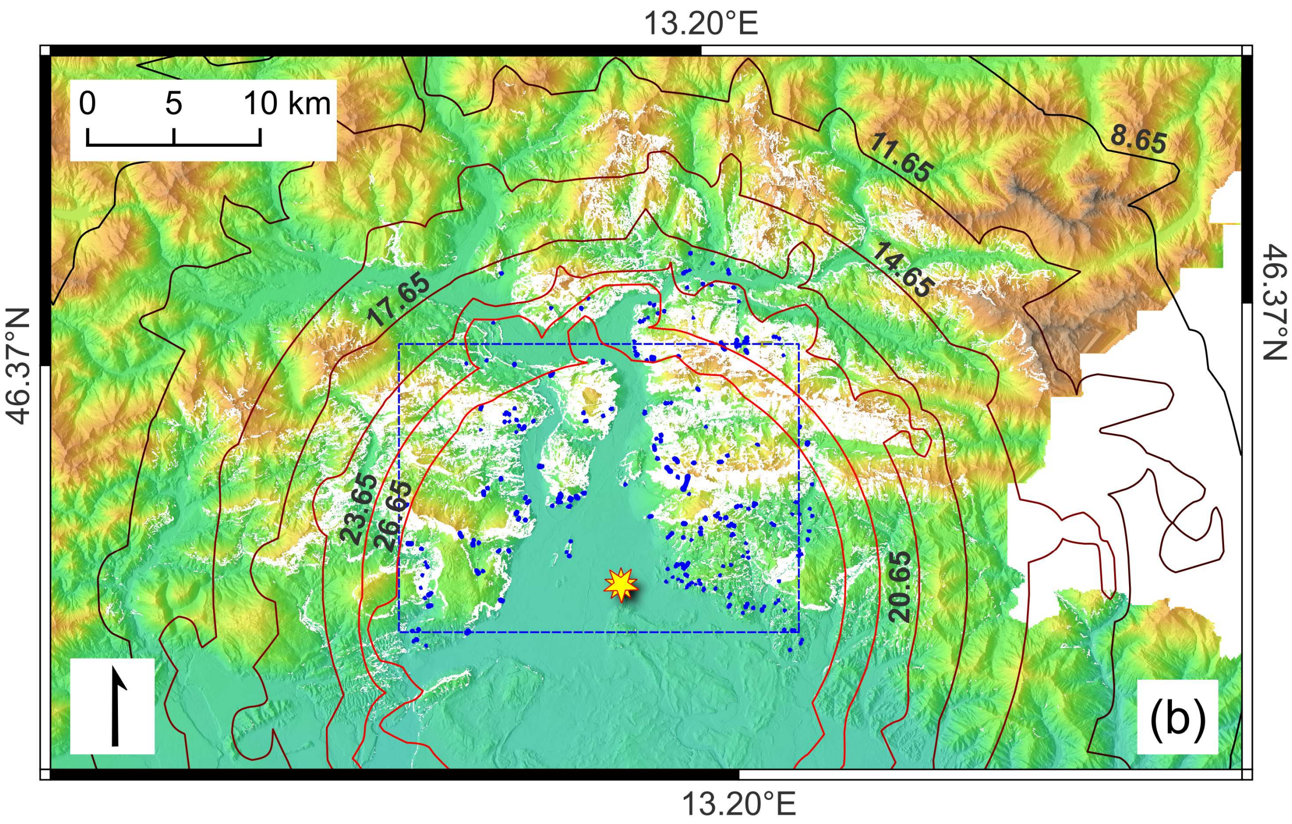

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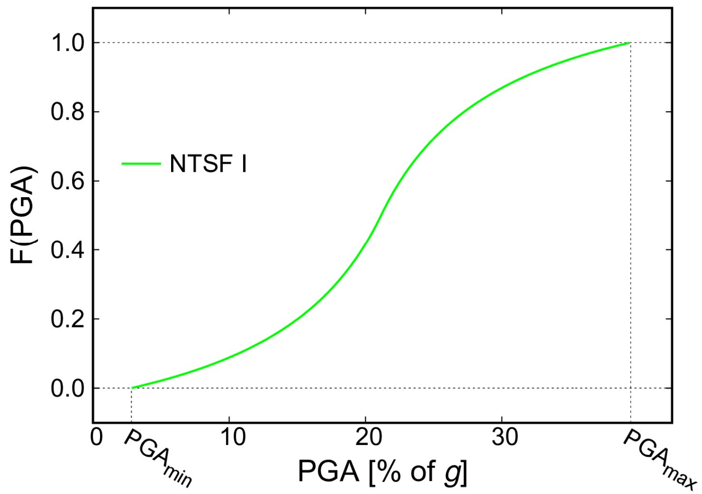
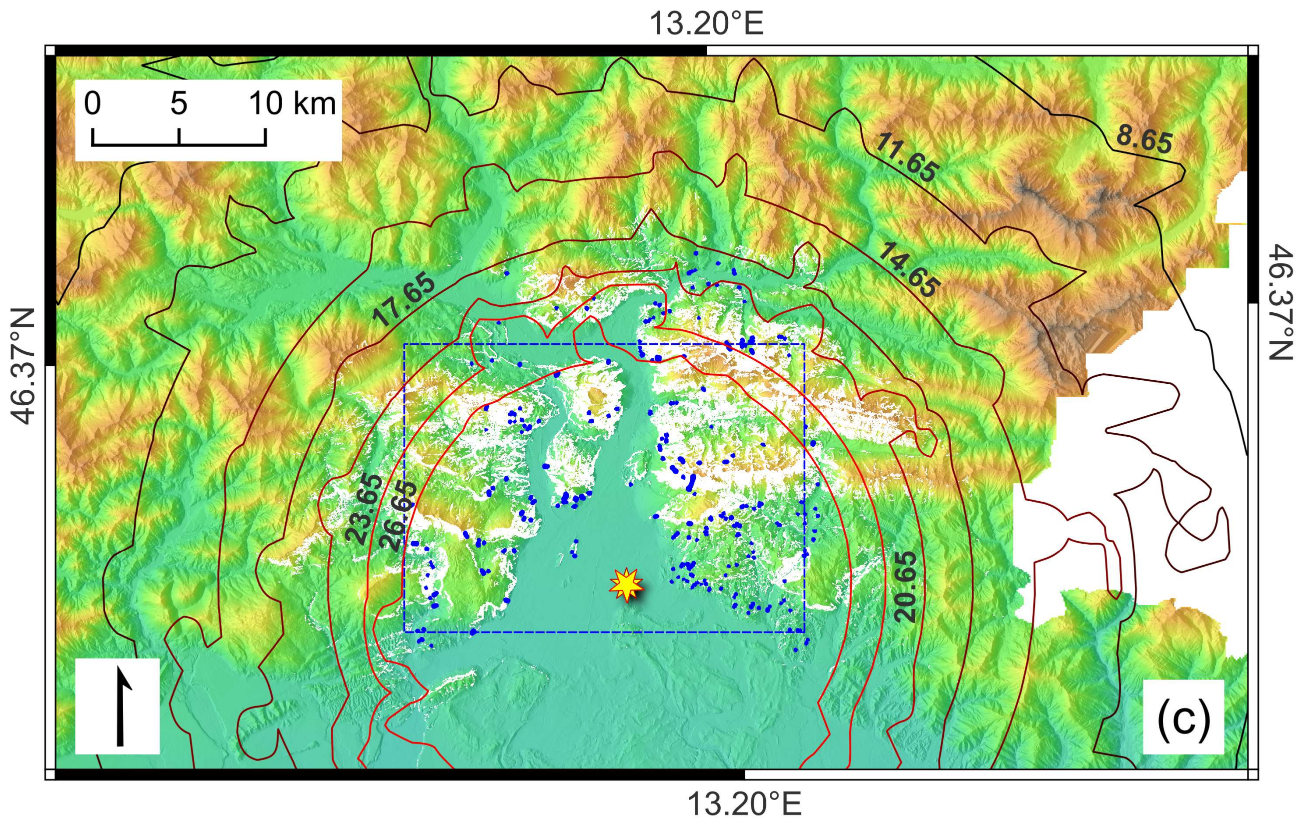
with **F(PGA)** approximation **NTSF I**



Alvioli et al., Landslides (2024)

ROCKFALL SOURCES: RESULTS



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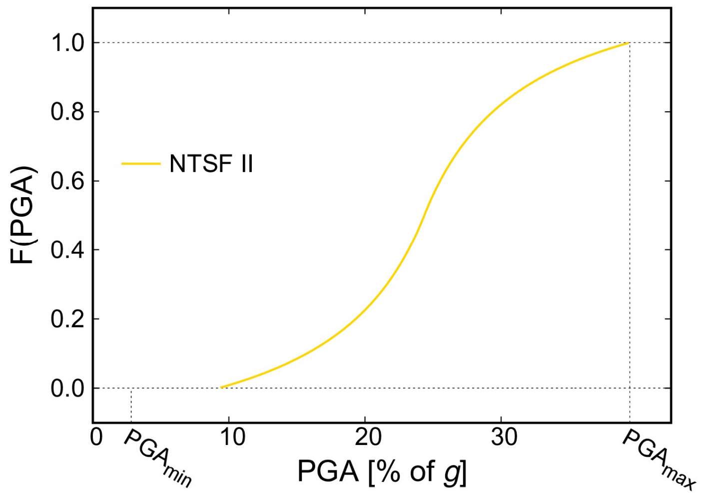
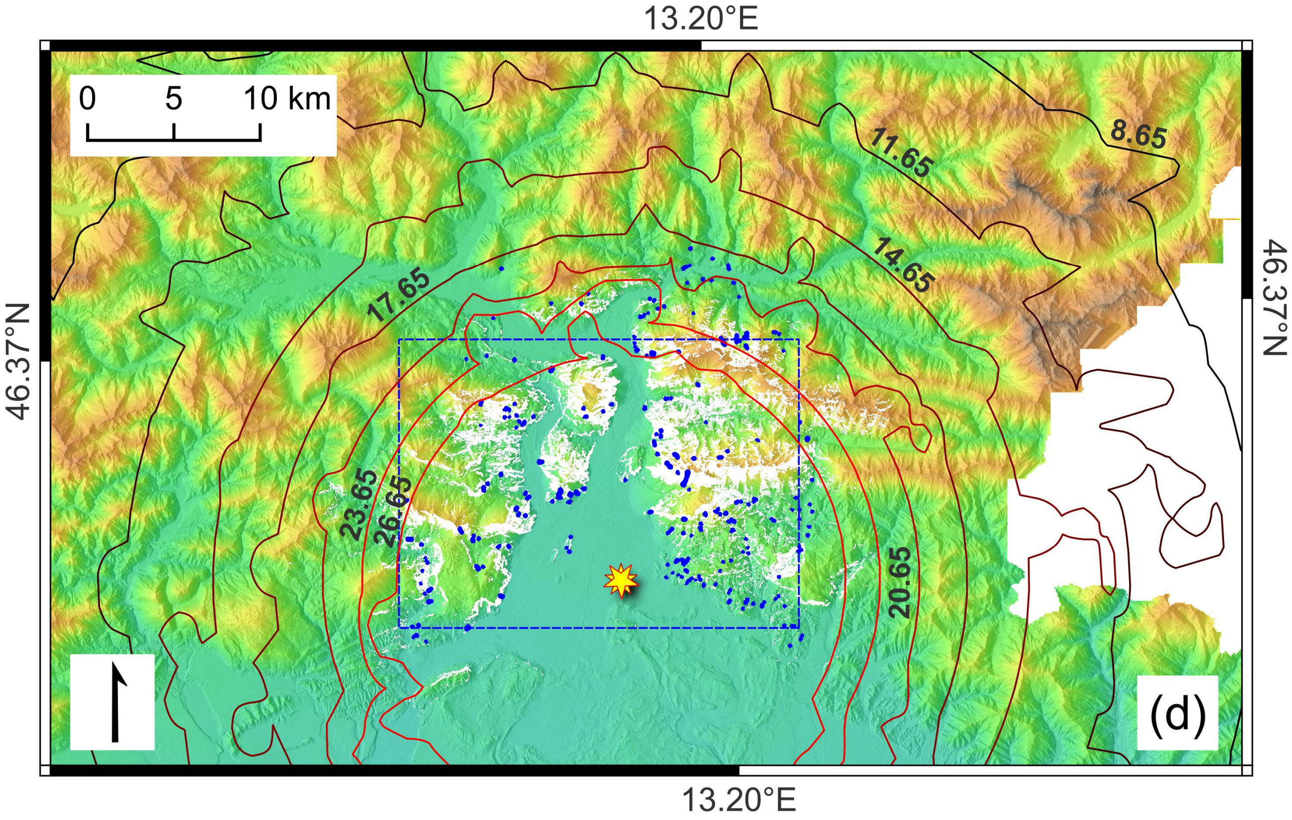
with **F(PGA)** approximation **NTSF II**



Alvioli et al., Landslides (2024)

ROCKFALL SOURCES: RESULTS



Study area Friuli 1976
PGA contour lines +
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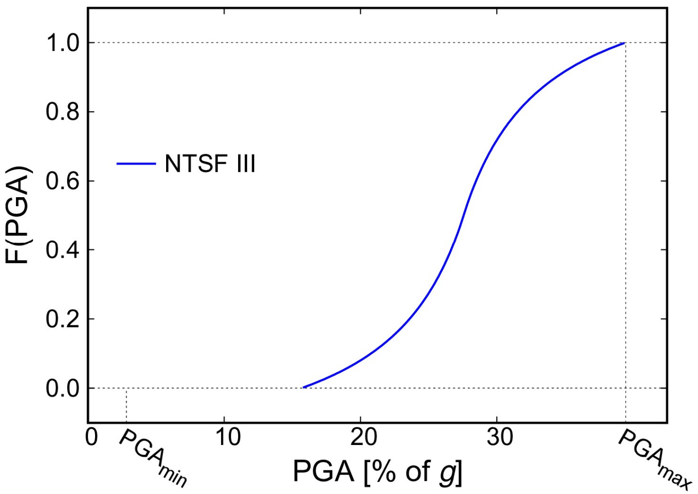
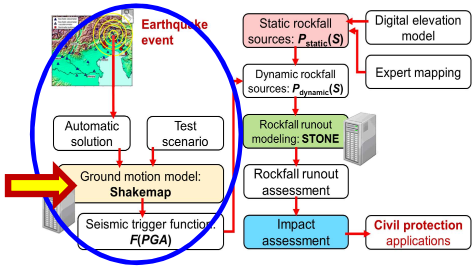
$$P_{dyn}(S, PGA) = P_{stat}(S)\, F(PGA)$$

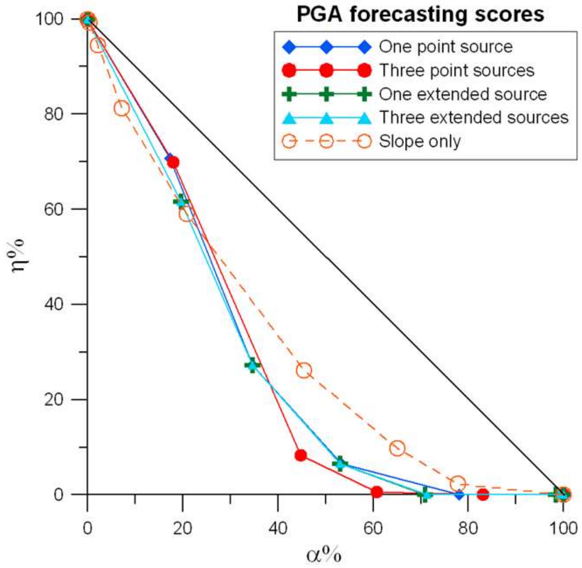
with **F(PGA)** approximation **NTSF III**



Alvioli et al., Landslides (2024)

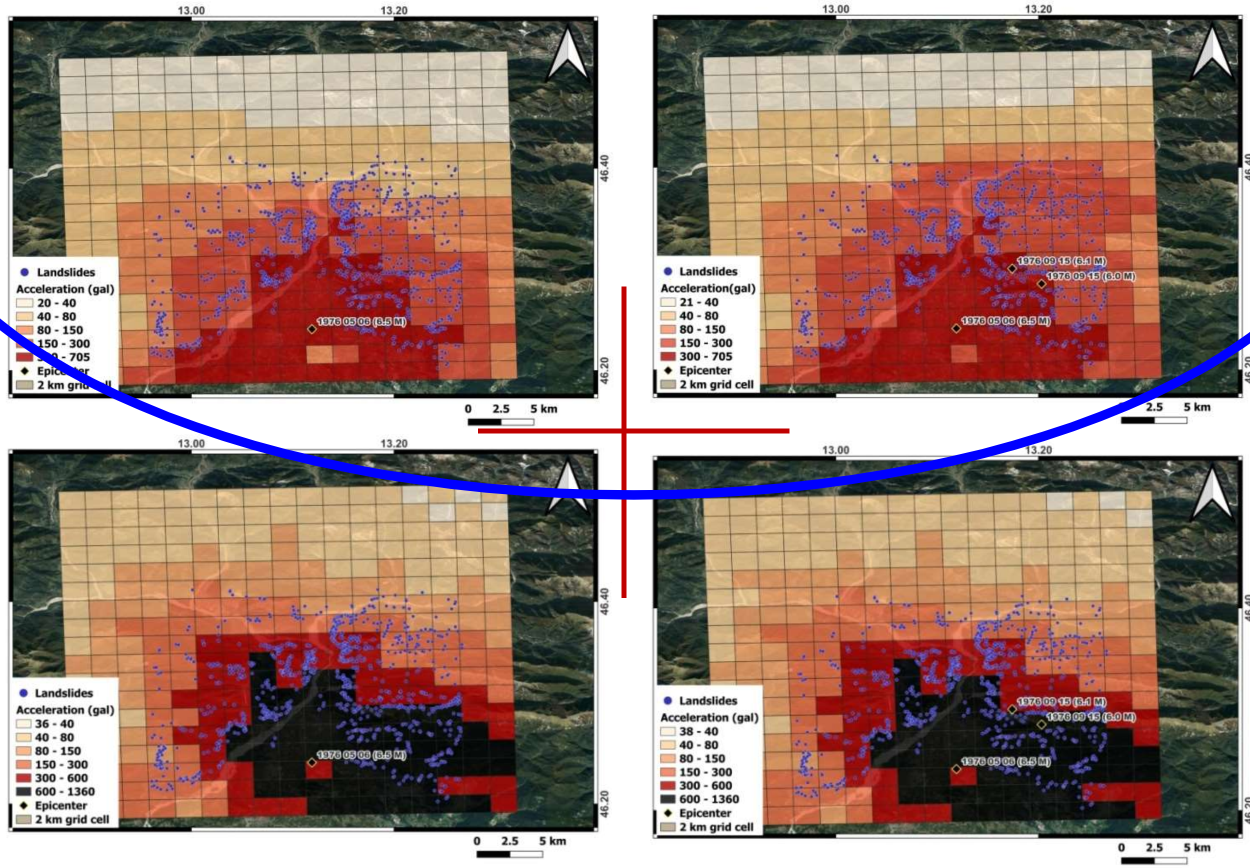
ACCURATE SEISMIC SCENARIO MODELING





One point source (mainshock)

Three point sources (main + aftershocks)

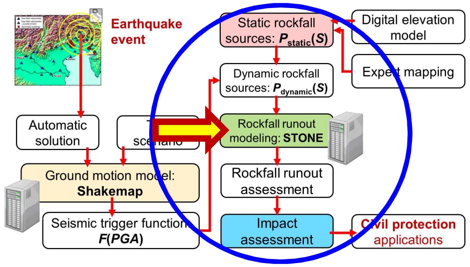


One extended source

Three extended sources

Peresan et al., *under review*

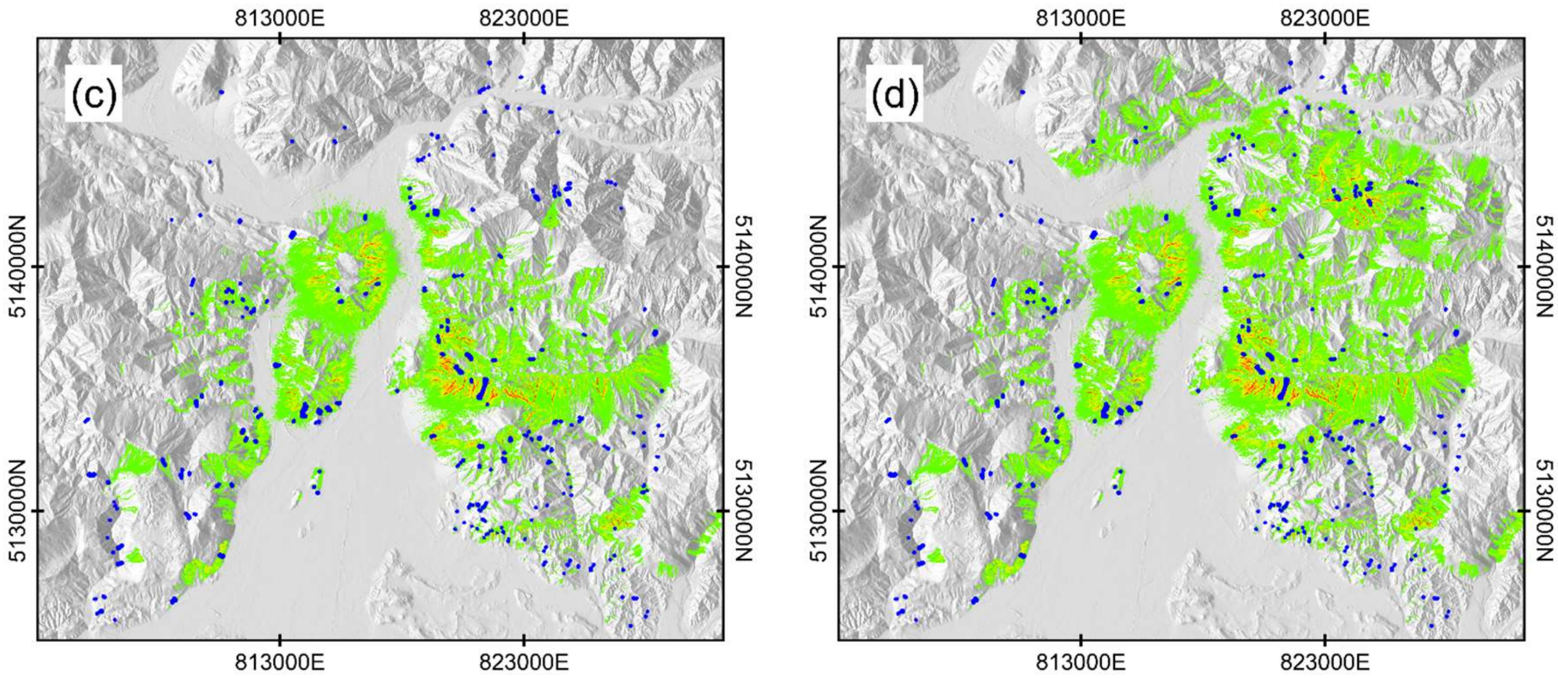
PHYSICALLY BASED MODELING OF ROCKFALL TRAJECTORIES



Seismic input: Three point sources (main + aftershocks)

Linear coupling F(PGA)

Non-linear coupling F(PGA)



Peresan et al., *under review*

SUMMARY

- We developed a **modeling chain** including:
  ➟ **Ground shaking** modeling
  ➟ **Three-dimensional rockfall** modeling

Alvioli et al., Landslides (2024)

- Tuning of the seismic-rockfall models coupling is specific of the area
- The method is **amenable for application** in the same area with a new PGA map, immediately **after an earthquake occurs**

- **Advanced seismic simulations** better match with observed rockfalls if:
  ➟ Modeling mainshock (1 seismic source) + **aftershocks** (3 sources)
  ➟ **Points sources** instead of extended sources

Peresan et al., *under review*

Essential BIBLIOGRAPHY

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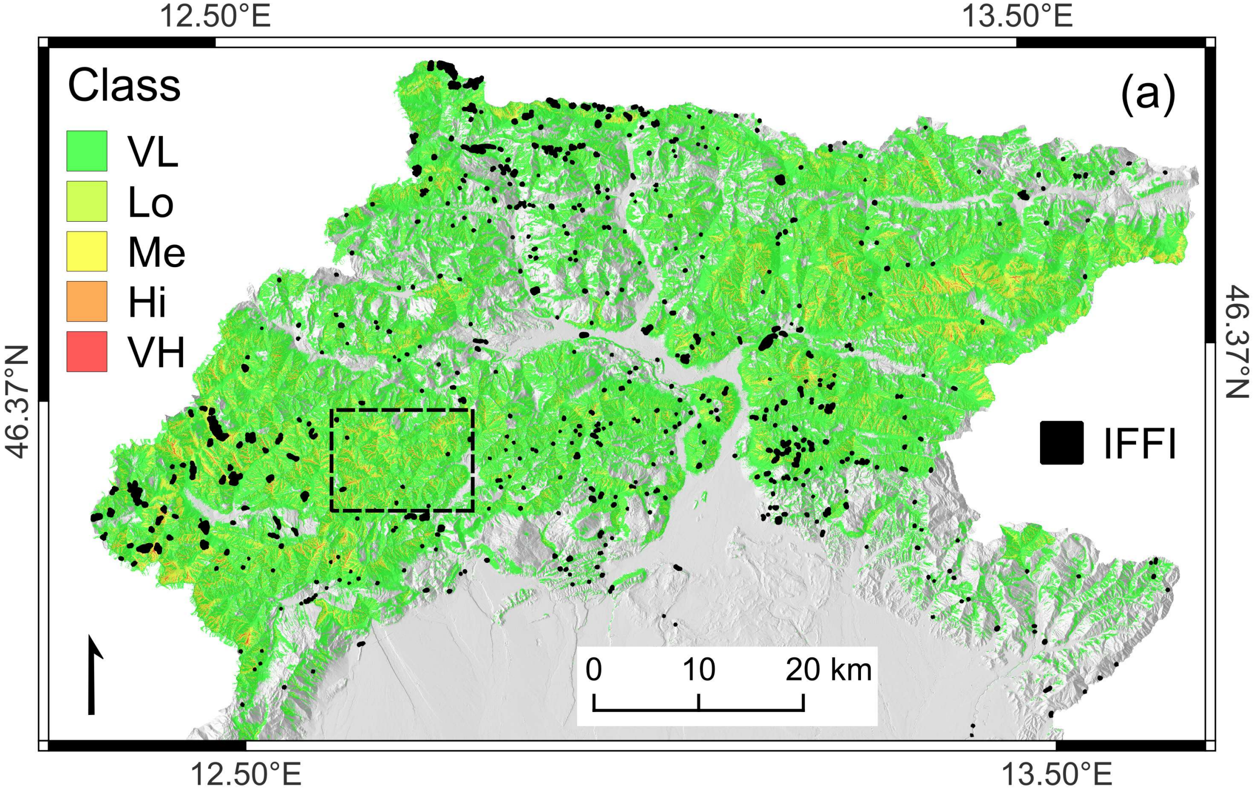
- G.F. Panza, C. La Mura, A. Peresan, F. Romanelli, F. Vaccari: " Seismic hazard scenarios as preventive tools for a disaster resilient society". Advances in Geophysics 53, 93 (2012). https://doi.org/10.1016/B978-0-12-380938-4.00003-3
- A. Peresan, M. Alvioli, E. Zuccolo, F. Vaccari, H. Badreldin: "An approach to rockfall hazard scenarios based on earthquake ground motion". *Under review*

ADDITIONAL SLIDES

RUNOUT FROM STONE: RESULTS



Study area Friuli 1976
PGA intensity +
unquenched static sources:

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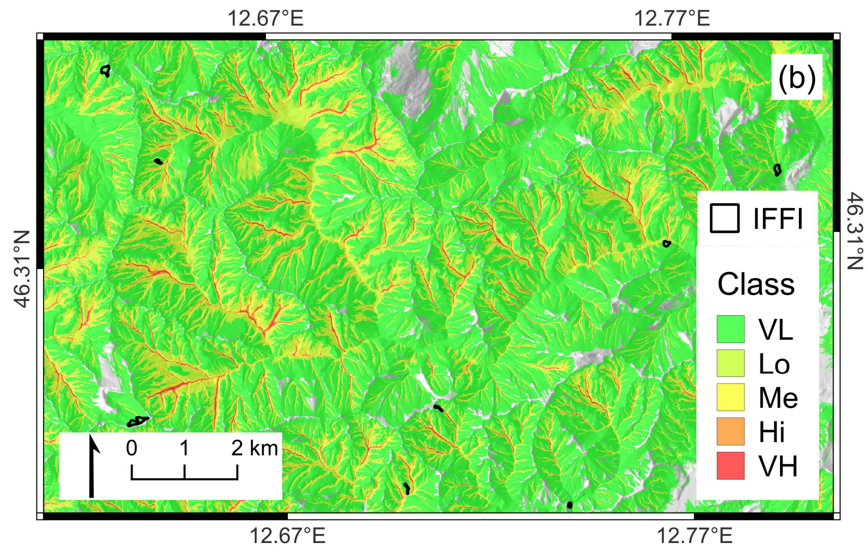

Alvioli et al., Landslides (2024)

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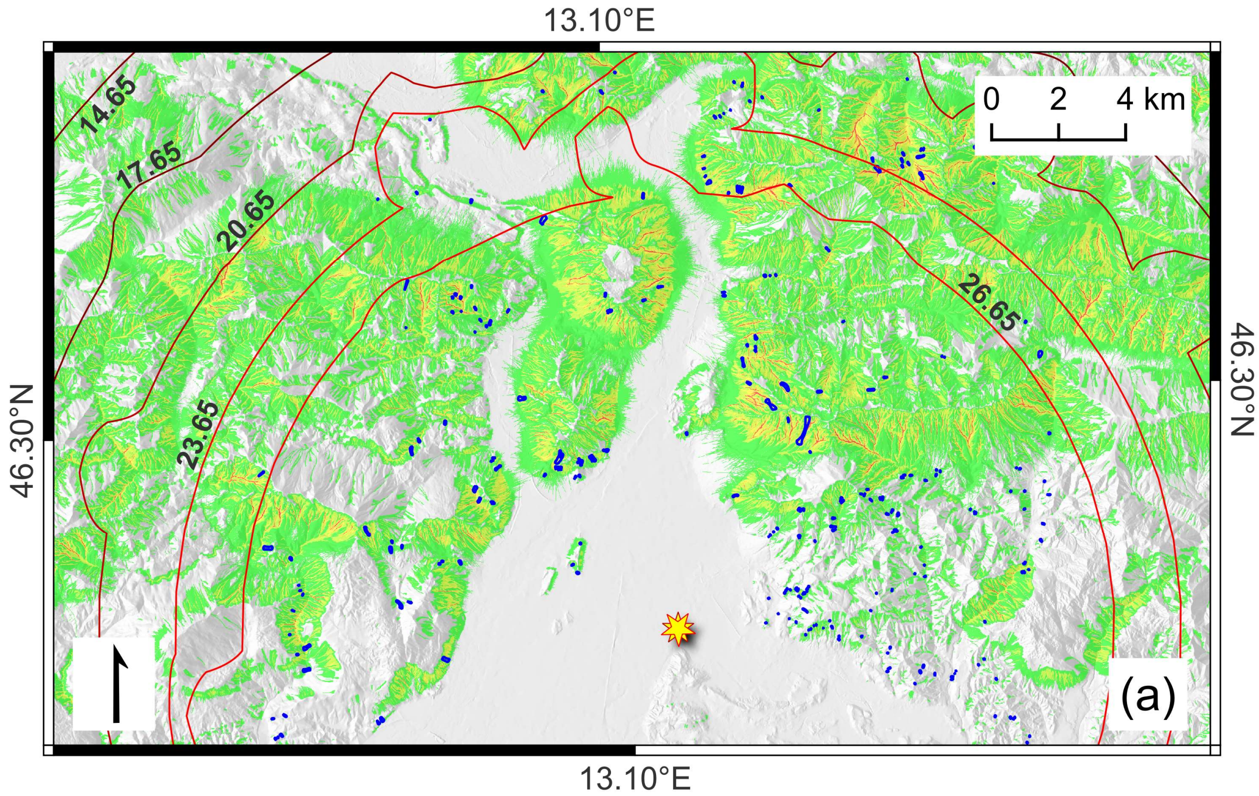

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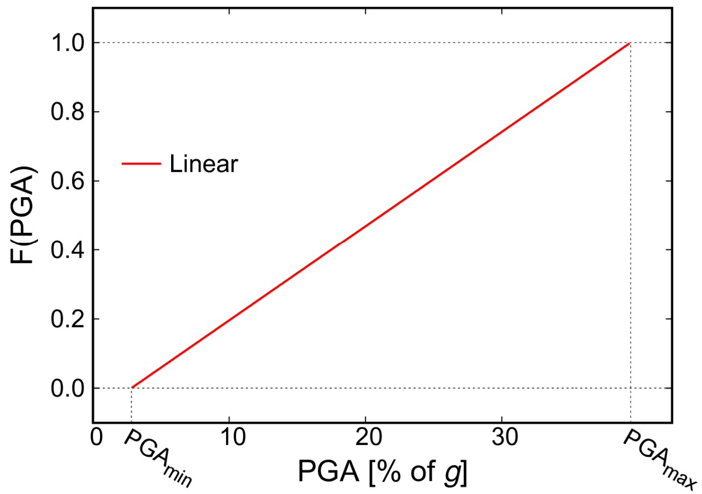

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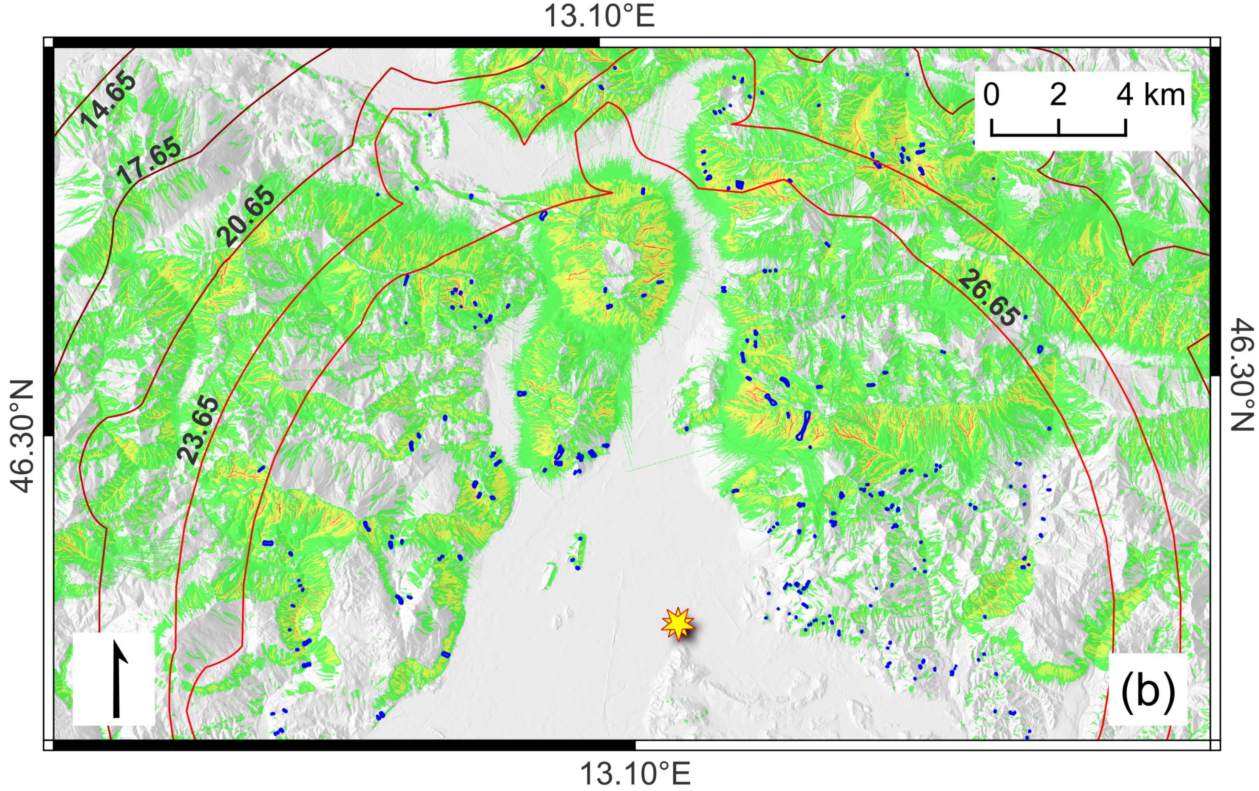

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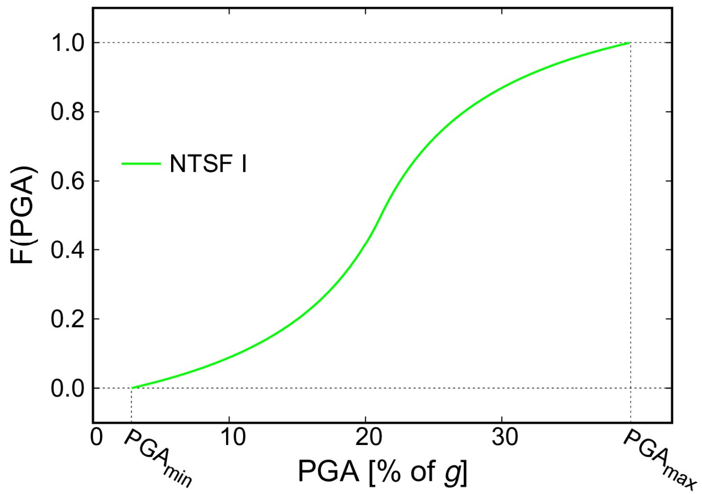
with **F(PGA)** approximation **NTSF I**



Alvioli et al., Landslides (2024)

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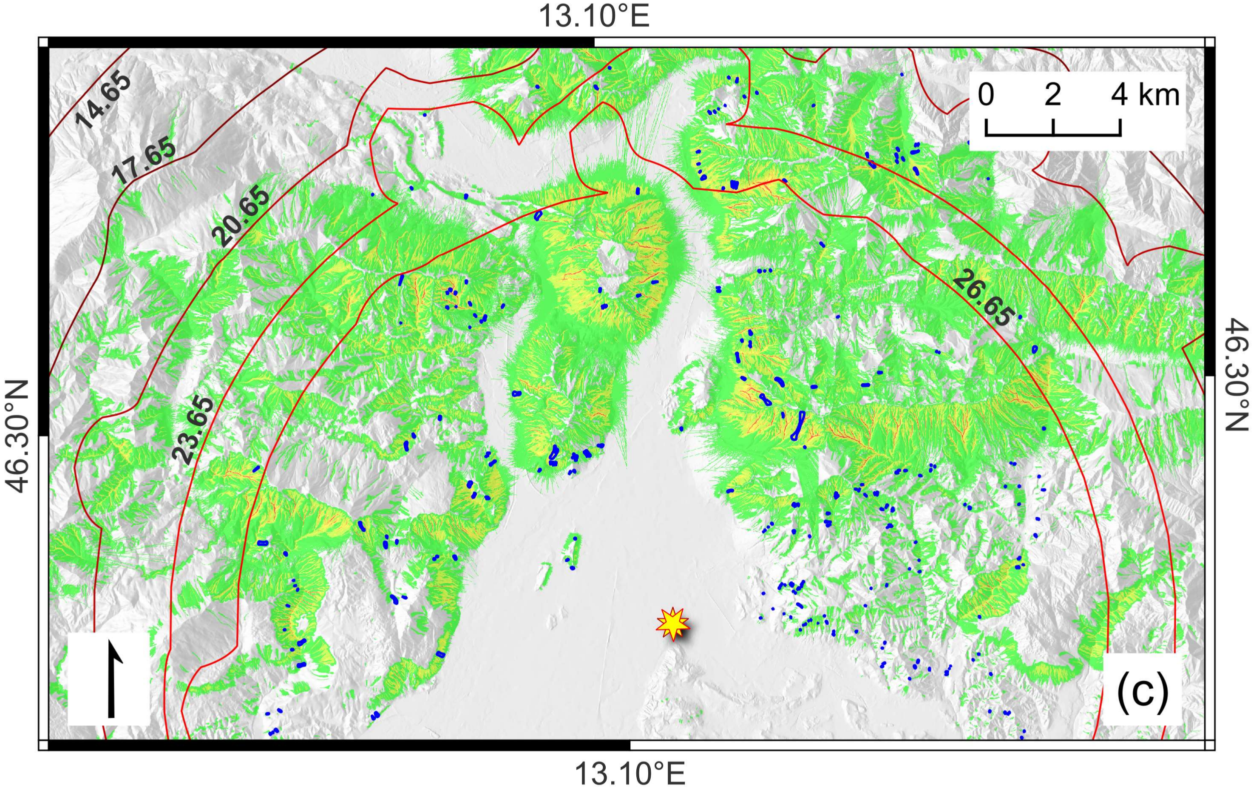

Study area Friuli 1976
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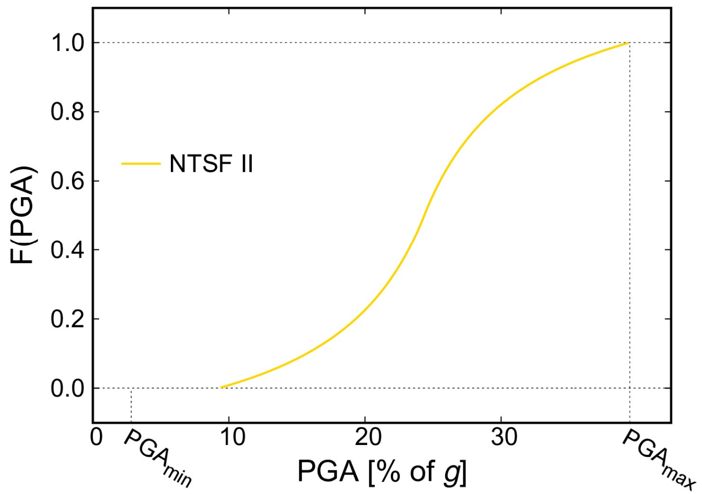
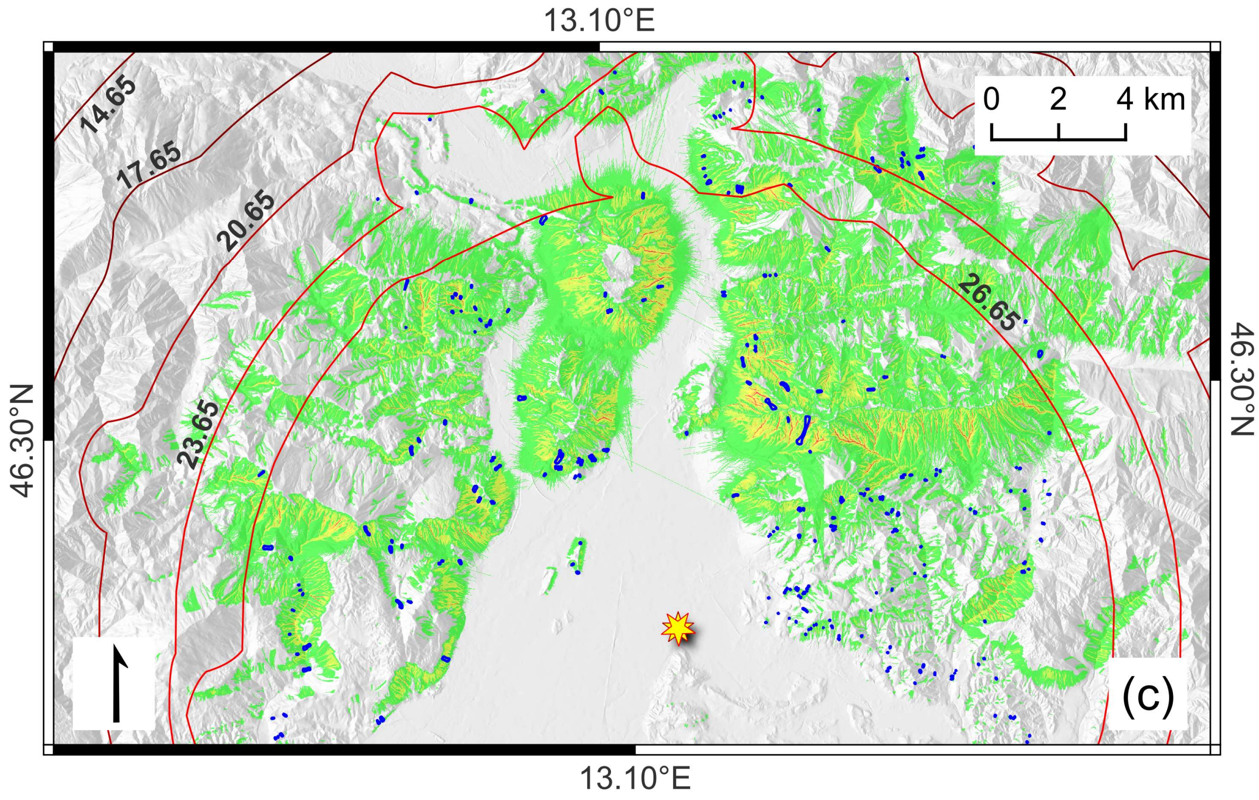
with **F(PGA)** approximation **NTSF II**



Alvioli et al., Landslides (2024)

RUNOUT FROM STONE: RESULTS



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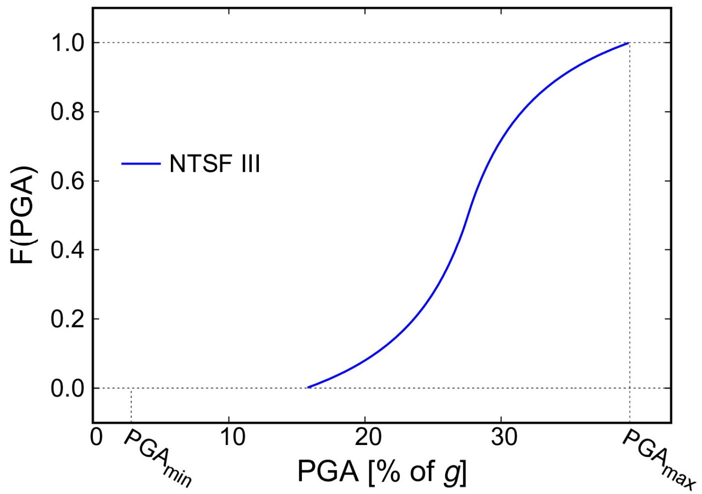
with **F(PGA)** approximation **NTSF III**



Alvioli et al., Landslides (2024)

RUNOUT FROM STONE: RESULTS

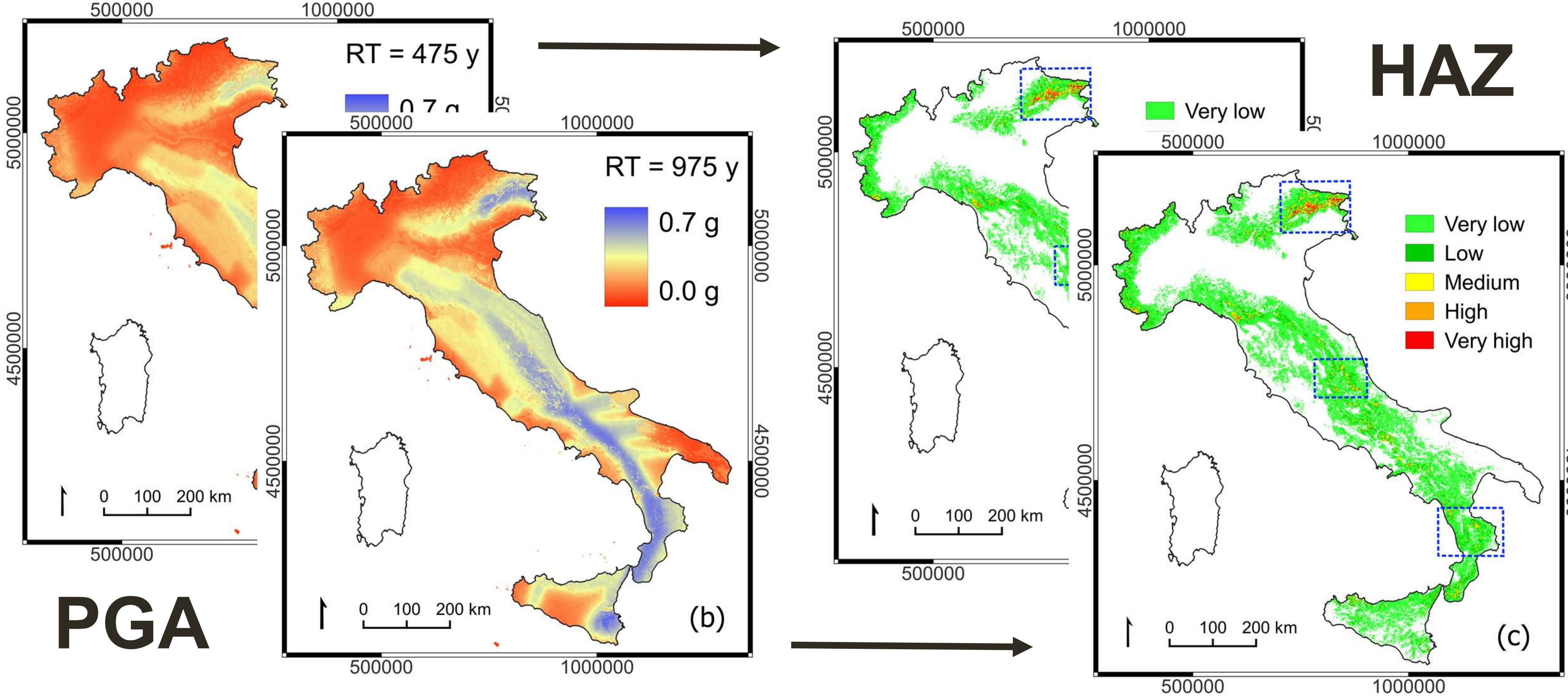
Alvioli et al., Landslides (2024)

- Comparison: **classified runout** and **observed triggered landslides**
- We show percentage of landslide cells in each class:

CLASS	Static	Linear	NTSF I	NTSF II	NTSF III
1	6.5%	8.1%	4.1%	4.1%	4.4%
2	12.4%	11.4%	6.1%	7.1%	6.8%
3	18.4%	18.4%	9.6%	10.2%	12.4%
4	28.6%	**30.0%**	21.4%	21.8%	24.5%
5	34.0%	32.2%	**56.1%**	53.4%	44.1%
Total	100%	**100%**	97.2%	96.7	92.2%

- ***Goal***: maximize agreement with the least possible number of source pixels

NATIONAL SCALE, PGA & RETURN TIME: EQ-ROCKFALL HAZARD



Alvioli et al., Geomorphology (2023)

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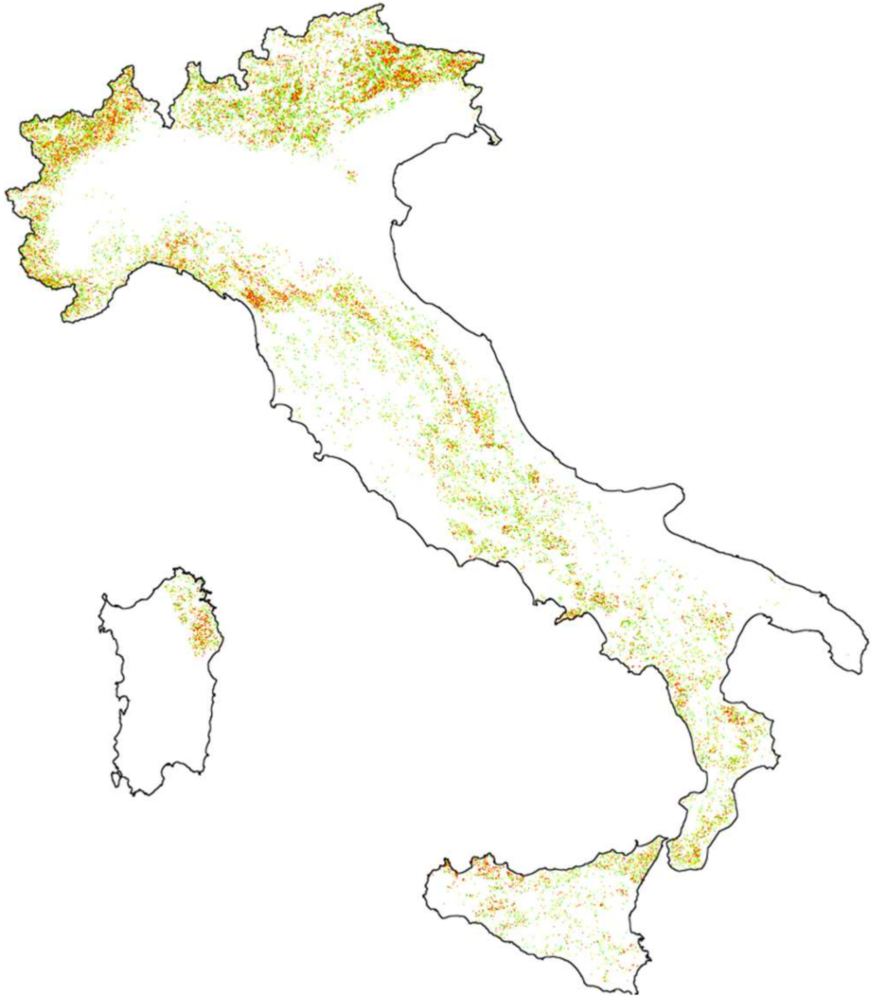
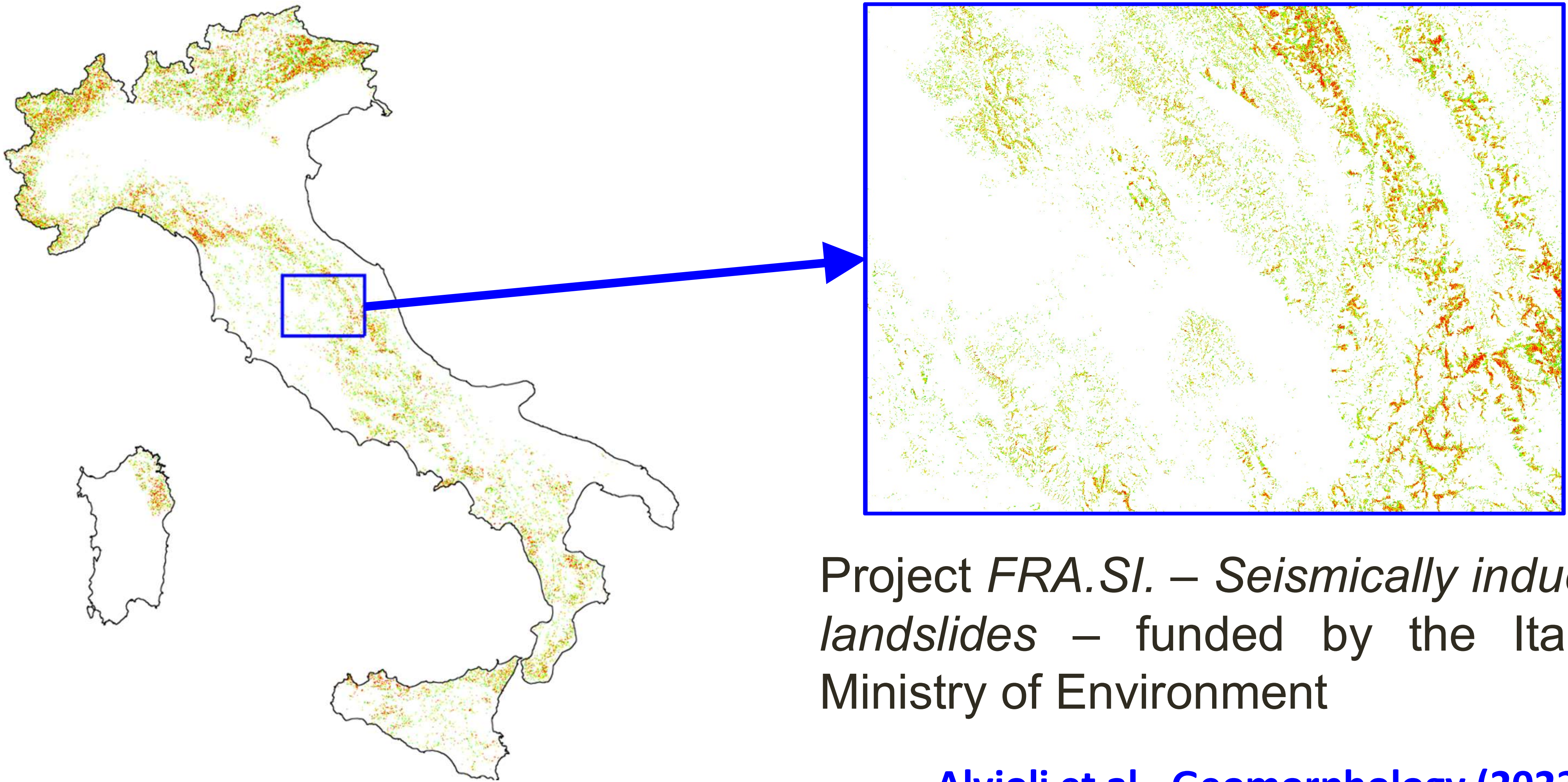


- Quenched sources: estimated **average PGA with 475 y return time**
- *Seismically-induced Rockfall susceptibility at 475 y return time*
- National coverage of slope units: **224,032 km^2** (no plains)

Project *FRA.SI. – Seismically induced landslides* – funded by the Italian Ministry of Environment

Alvioli et al., Geomorphology (2023)

NATIONAL SCALE, PGA & RETURN TIME: EQ-ROCKFALL HAZARD



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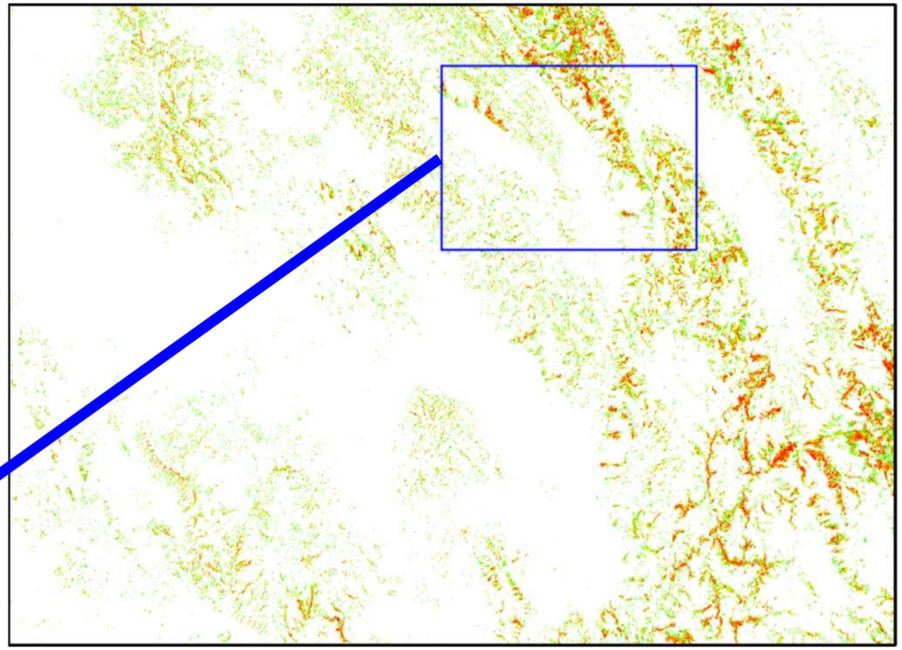

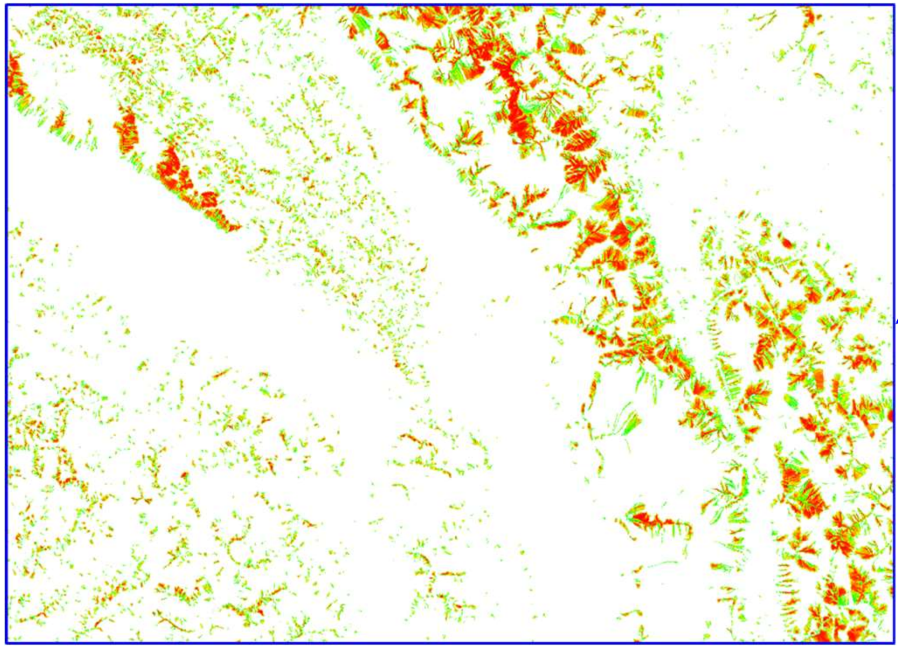

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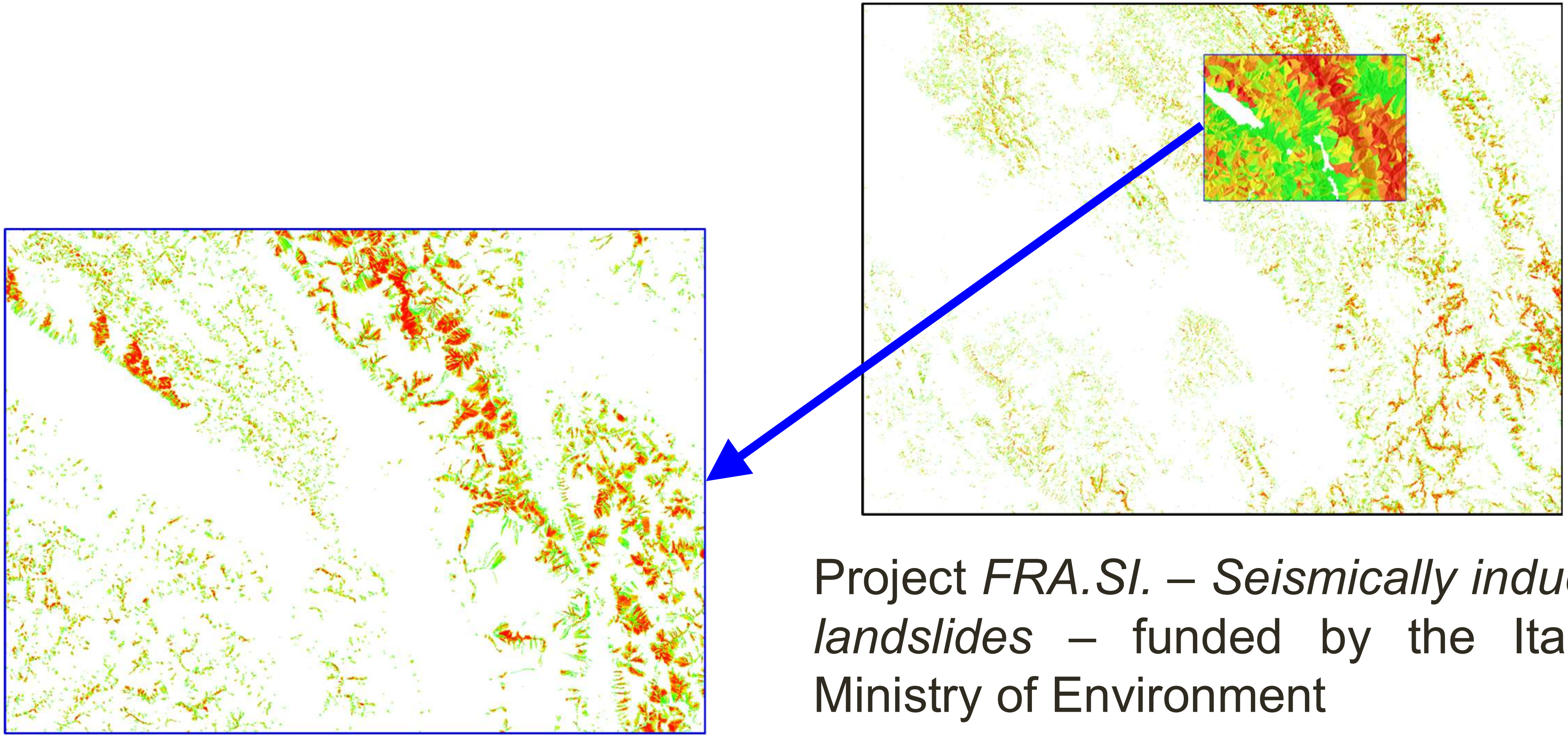

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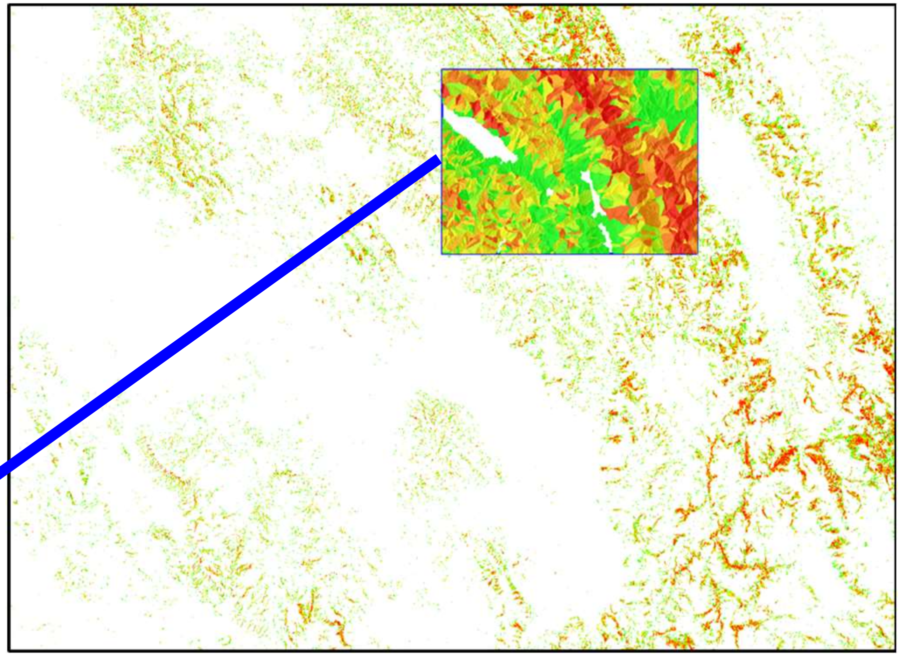

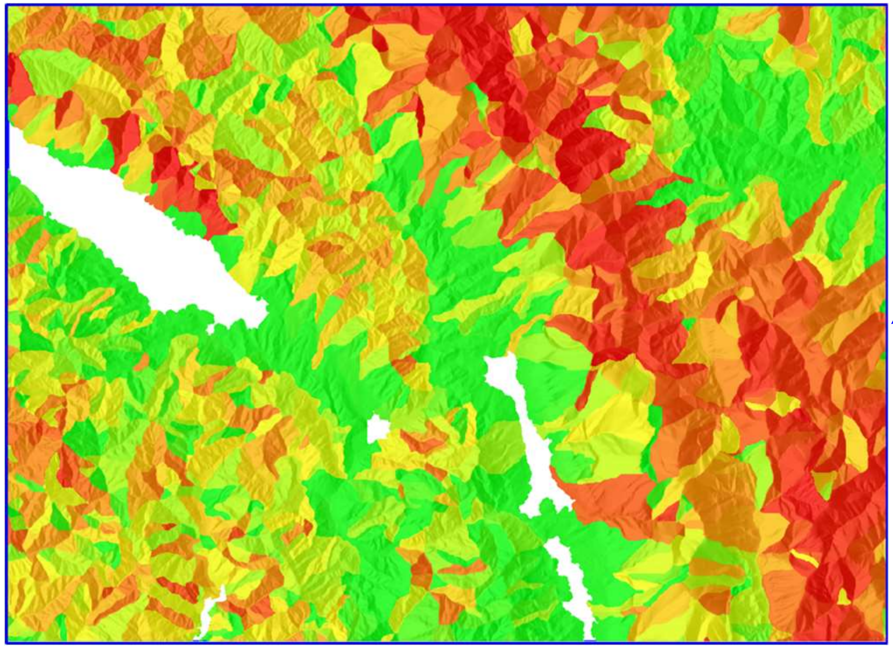

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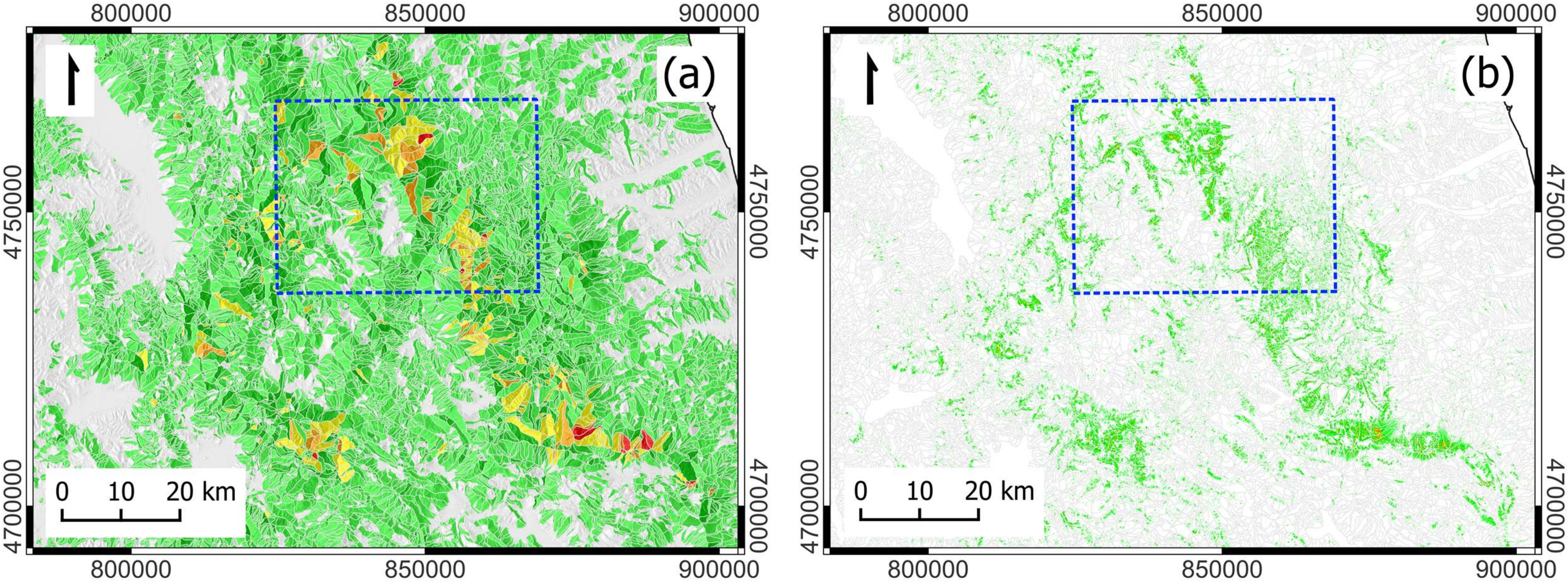
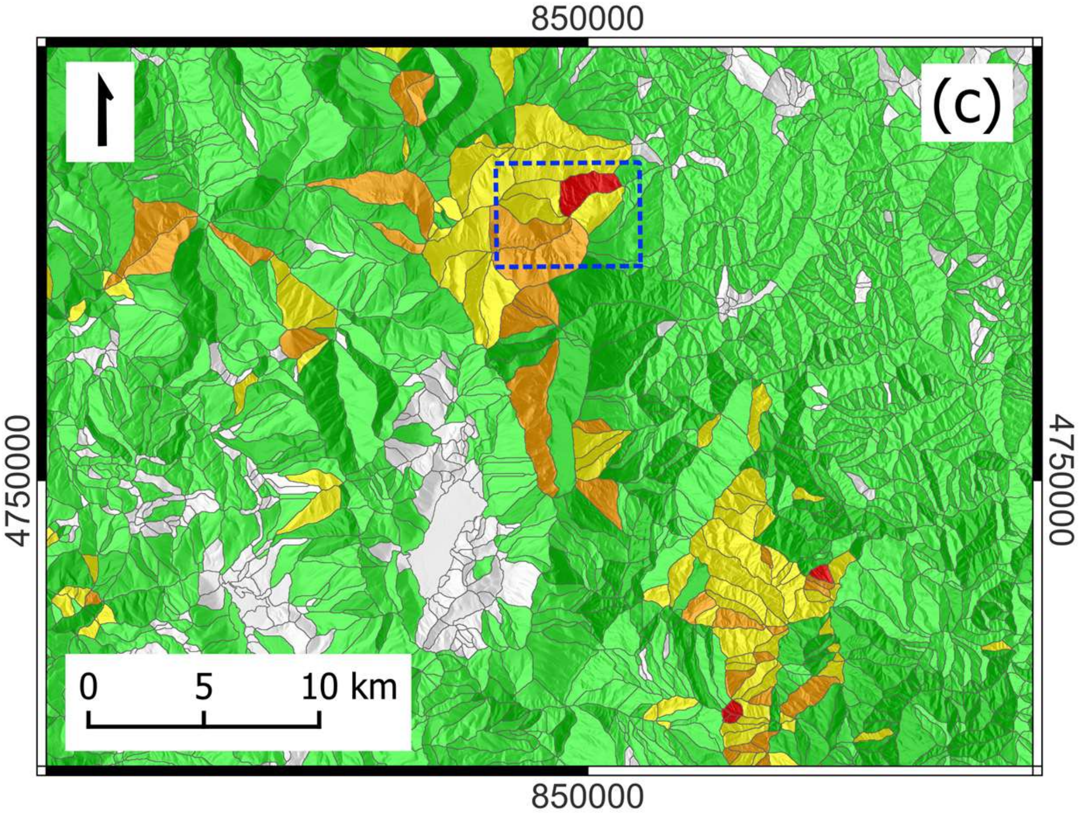
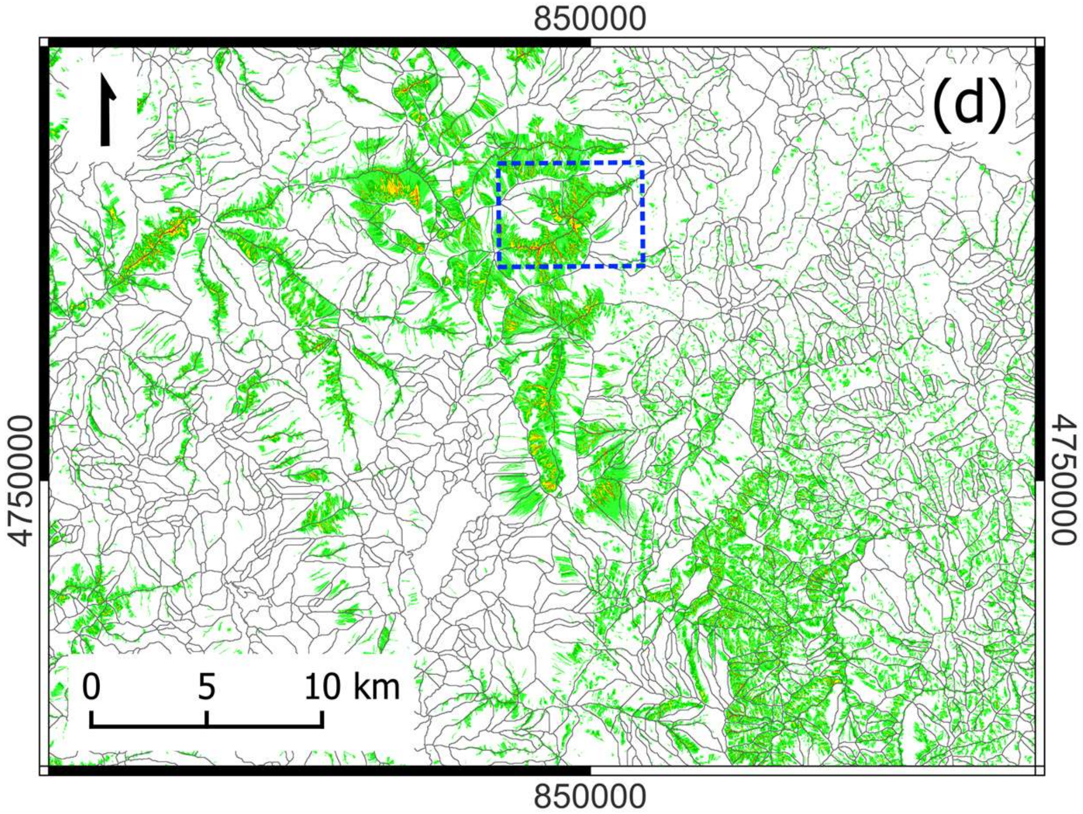


Alvioli et al., Geomorphology (2023)

National scale, PGA & Return TIME: EQ-Rockfall HAZARD





Alvioli, Falcone et al. (under review)

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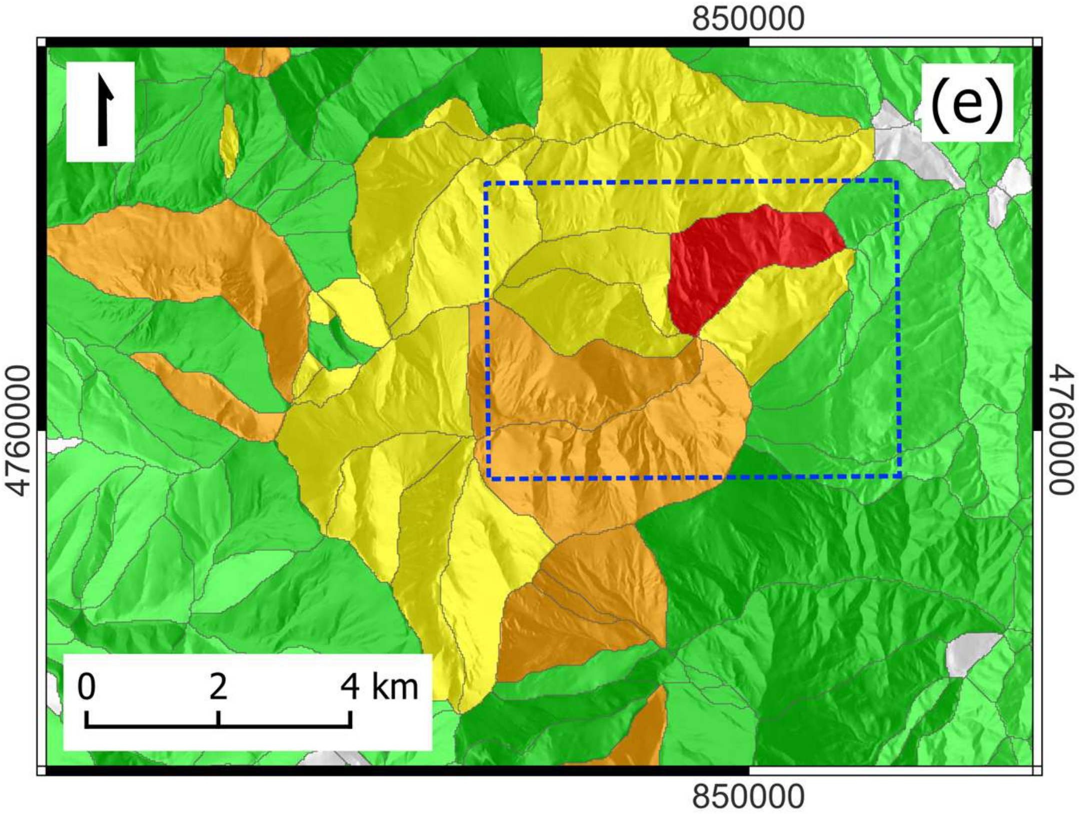

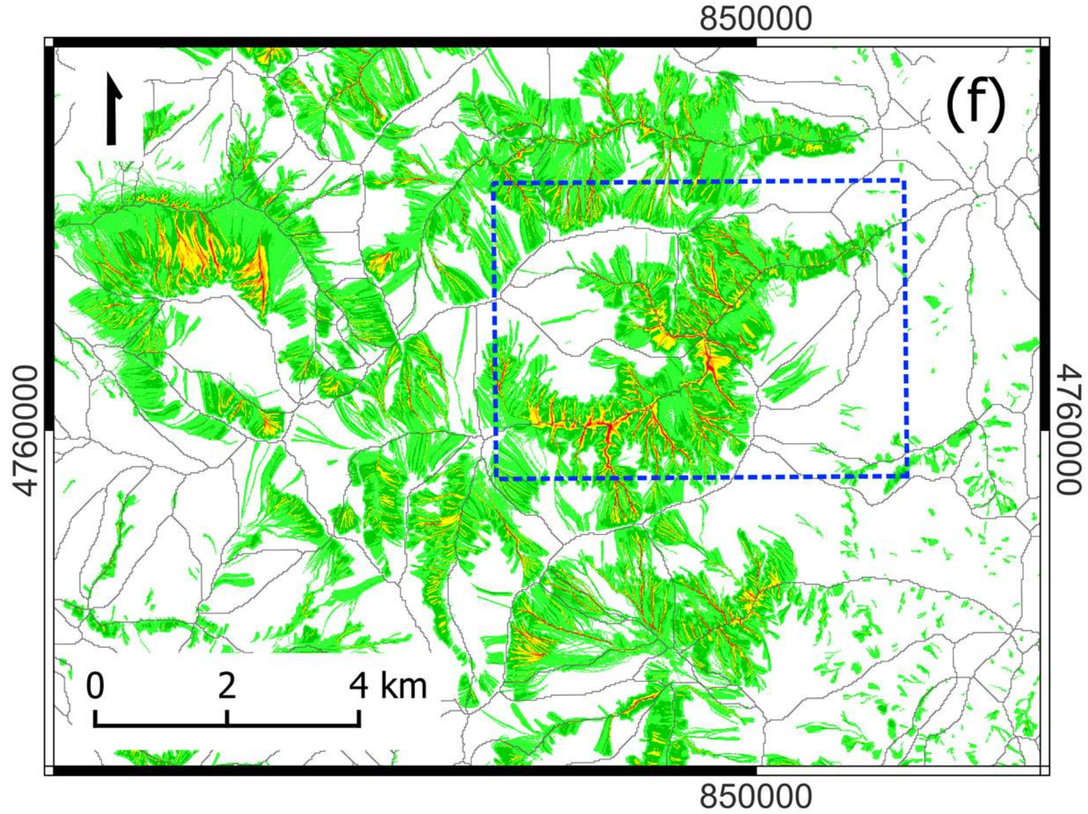

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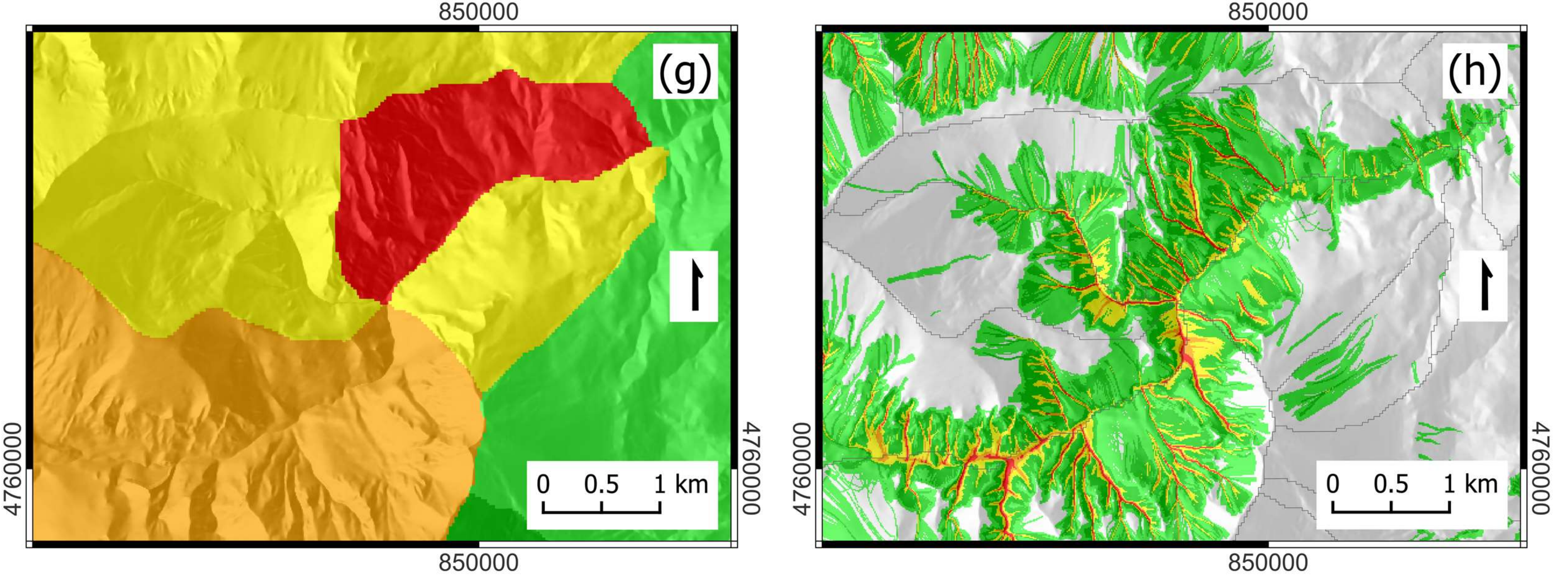

Alvioli, Falcone et al. (under review)

SUMMARY: A TRULY MULTISCALE MODEL FOR ROCKFALLS

- **National Scale**:
  - ➟ **10 m** resolution all over Italy, **probabilistic rockfall sources**
  - ➟ results **aggregated at slope unit** level
  - ➟ PGA with different return times, rockfall hazard
- **Regional (individual EQ event) scale**:
  - ➟ **10 m** resolution all over Italy, **probabilistic sources**
  - ➟ **full resolution** results, **fine tuning** of parameters for a few **events**
- **Local scale**:
  - ➟ **high-resolution** elevation data, **LiDAR**
  - ➟ **field surveys**, detailed study of sources (beyond probabilistic)