Rockfall susceptibility and seismically induced rockfall susceptibility at regional and national scale

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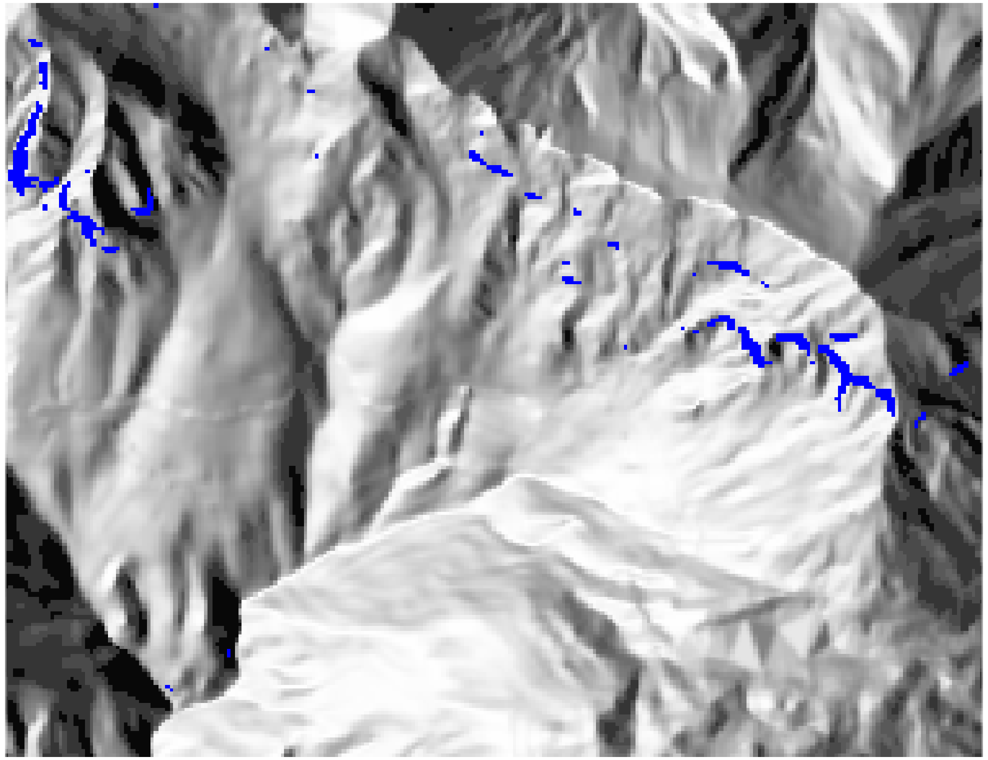
PHYSICALLY BASED MODELING: STONE

- Three-dimensional model for rockfalls



- Assumes point-like boulders
- Simulates trajectories from ***user-defined starting points***
- **Simulated trajectories:** falling, bouncing, rolling
- Boulders stop when kinetic energy is exhausted by friction
- ***Input***: digital elevation model

  (here, 10 m national DEM, 300,000 km^2)
- ***Ancillary data***: terrain geological/lithological information

  ⇒ **terrain parameters** (friction, restitution coefficients)

⇒ Usually applied at ***slope/catchment scale*** with ***static sources*** (susceptibility maps)

⇒ ***We run STONE at national scale***, and ***select sources dynamically (specific trigger)***

Guzzetti et al., Comp. Geosci. (2002)

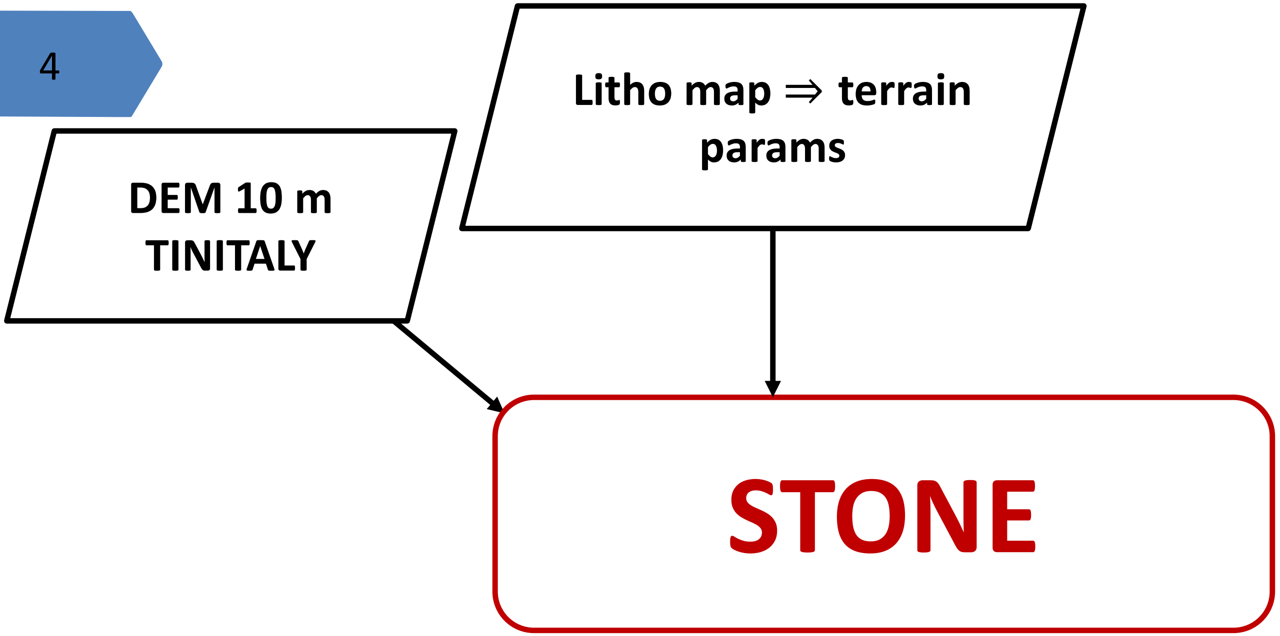
ROCKFALL SOURCES: PROBABILISTIC APPROACH

STONE

↓

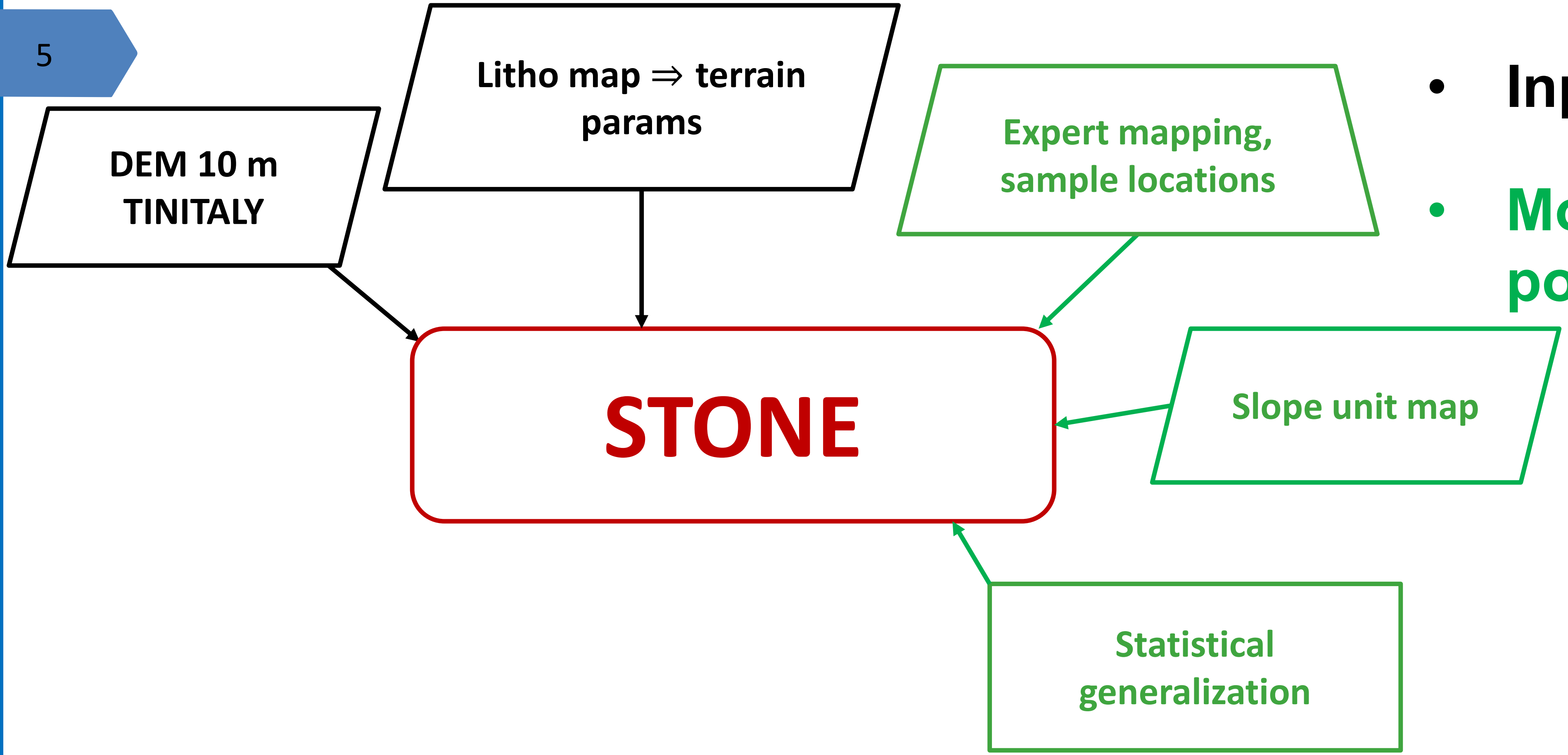
PHYSICALLY BASED ROCKFALL SUSCEPTIBILITY

ROCKFALL SOURCES: PROBABILISTIC APPROACH



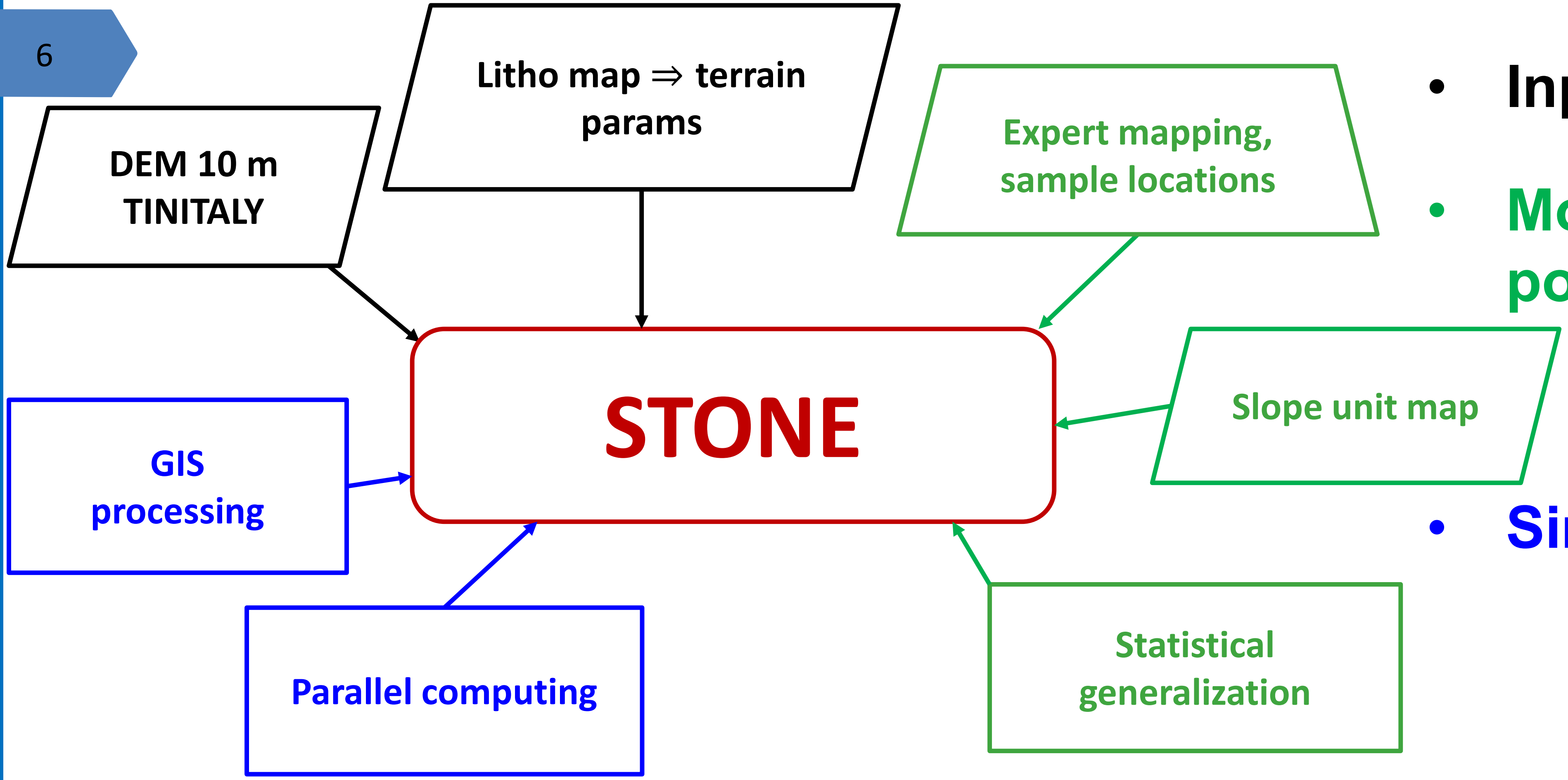
- **Input data**

Rockfall SOURCES: Probabilistic Approach



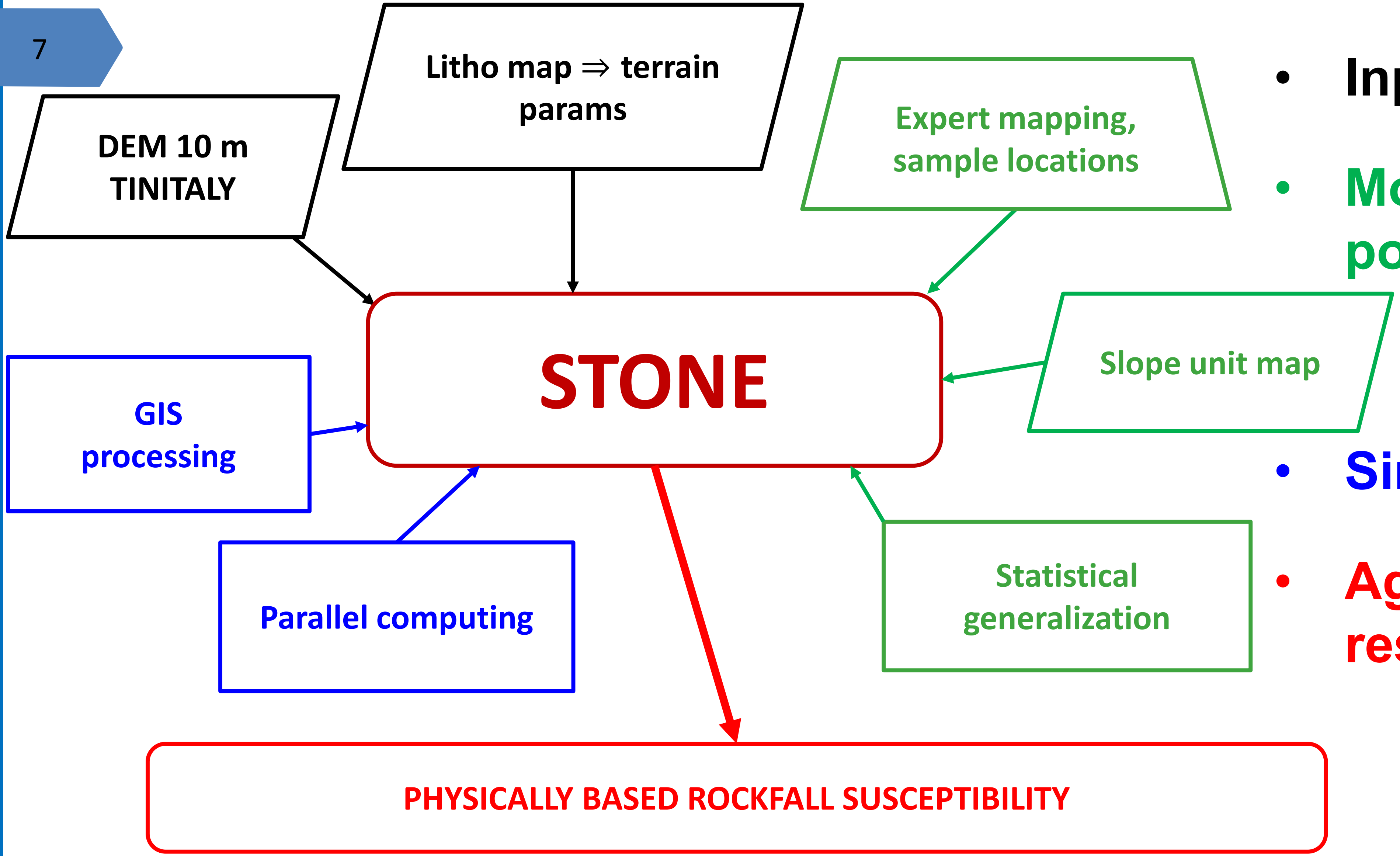
- **Input data** +
- **Modeling of potential sources**

ROCKFALL SOURCES: PROBABILISTIC APPROACH



- **Input data** **+**
- **Modeling of potential sources** **+**
- **Simulations**

ROCKFALL SOURCES: PROBABILISTIC APPROACH



- **Input data** +
- **Modeling of potential sources** +
- **Simulations** +
- **Aggregation of results** =

ROCKFALL SOURCES: PROBABILISTIC APPROACH

Expert mapping, sample locations

- Expert mapping of **potential rockfall sources**
- Sample **representative locations**
- **Visual interpretation** on google Earth

ROCKFALL SOURCES: PROBABILISTIC APPROACH

Expert mapping, sample locations

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- Sample representative locations
- Visual interpretation on google Earth

Slope unit map

- Slope units: **homogeneous terrain polygons**, Optimal mapping units for landslides
- **Complete mapping** in selected slope units
- **300k slope unit polygons** all over Italy

Alvioli et al., Geomorphology (2020)

Statistical generalization

ROCKFALL SOURCES: PROBABILISTIC APPROACH

Expert mapping, sample locations

- Expert mapping of potential rockfall sources
- Sample representative locations
- Visual interpretation on google Earth

Slope unit map

- Complete mapping in selected slope units
- Slope units: homogeneous terrain polygons, most suitable mapping units for landslides
- 300k slope unit polygons all over Italy

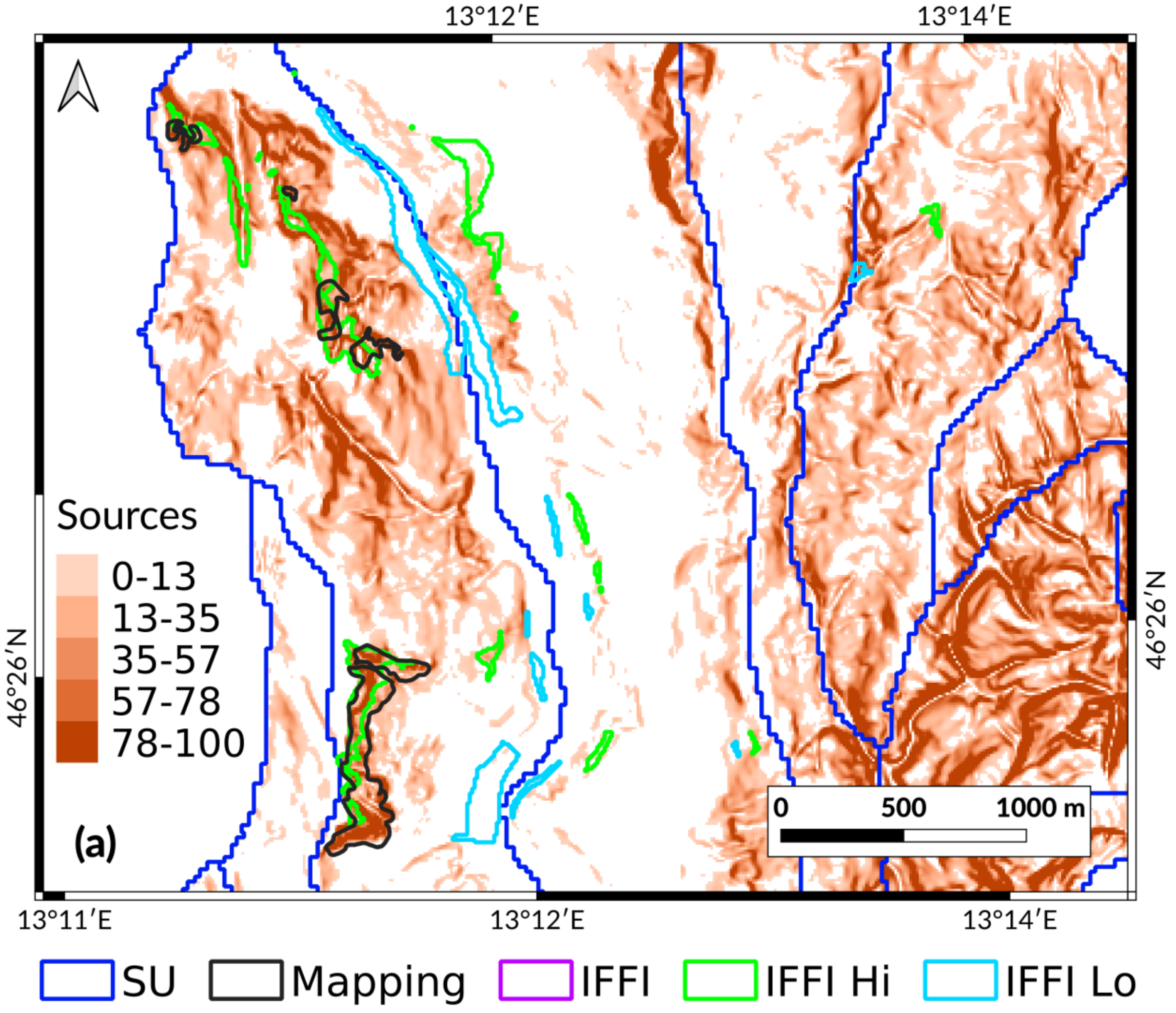
Alvioli et al., Geomorphology (2020)

Statistical generalization

- Statistical generalization ⇒ $\mathbf{P_{static}(S)}$
- Probabilistic sources as a function of slope **S**
- Source map **independent of specific trigger**

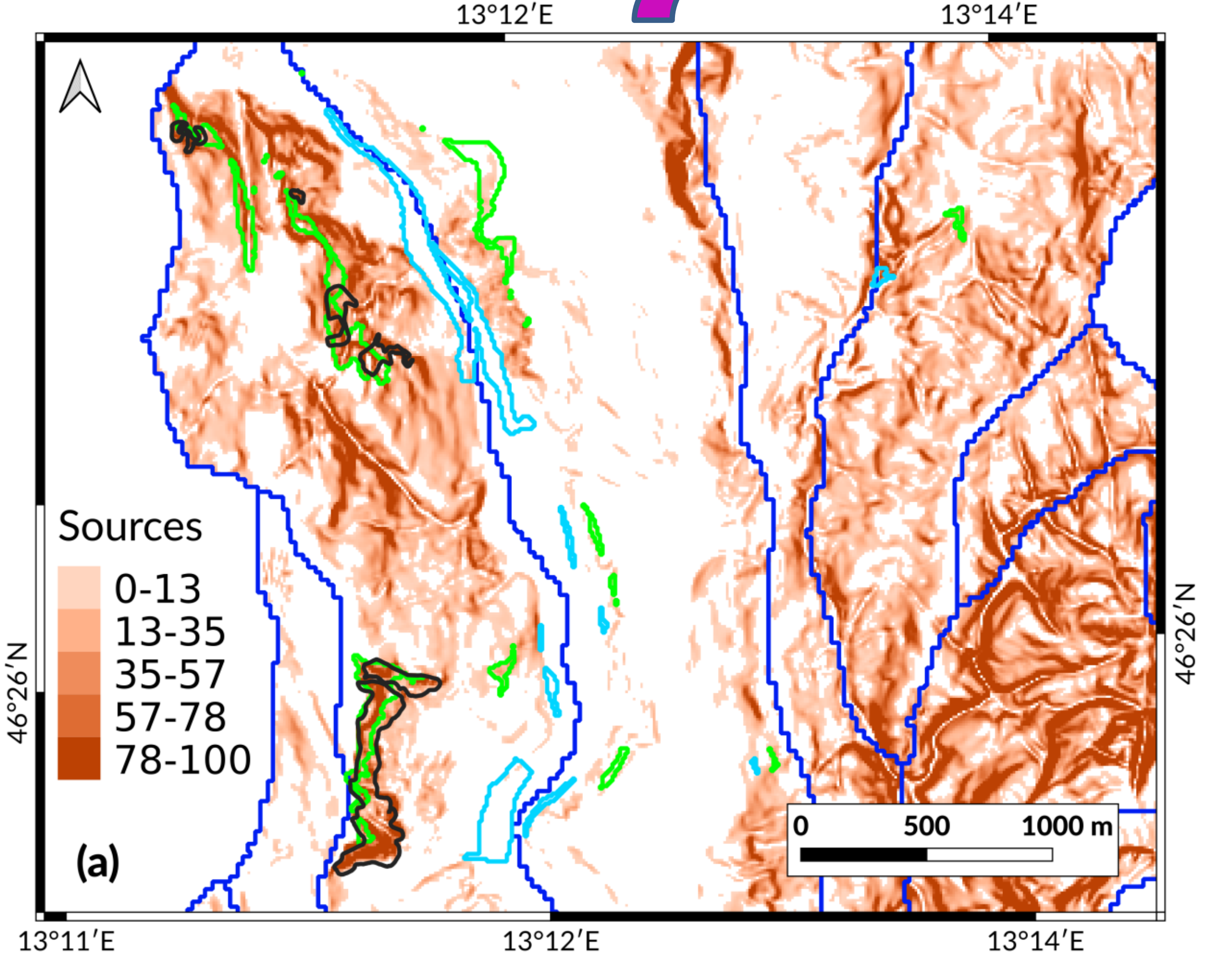
Alvioli et al., Engineering Geology (2021)

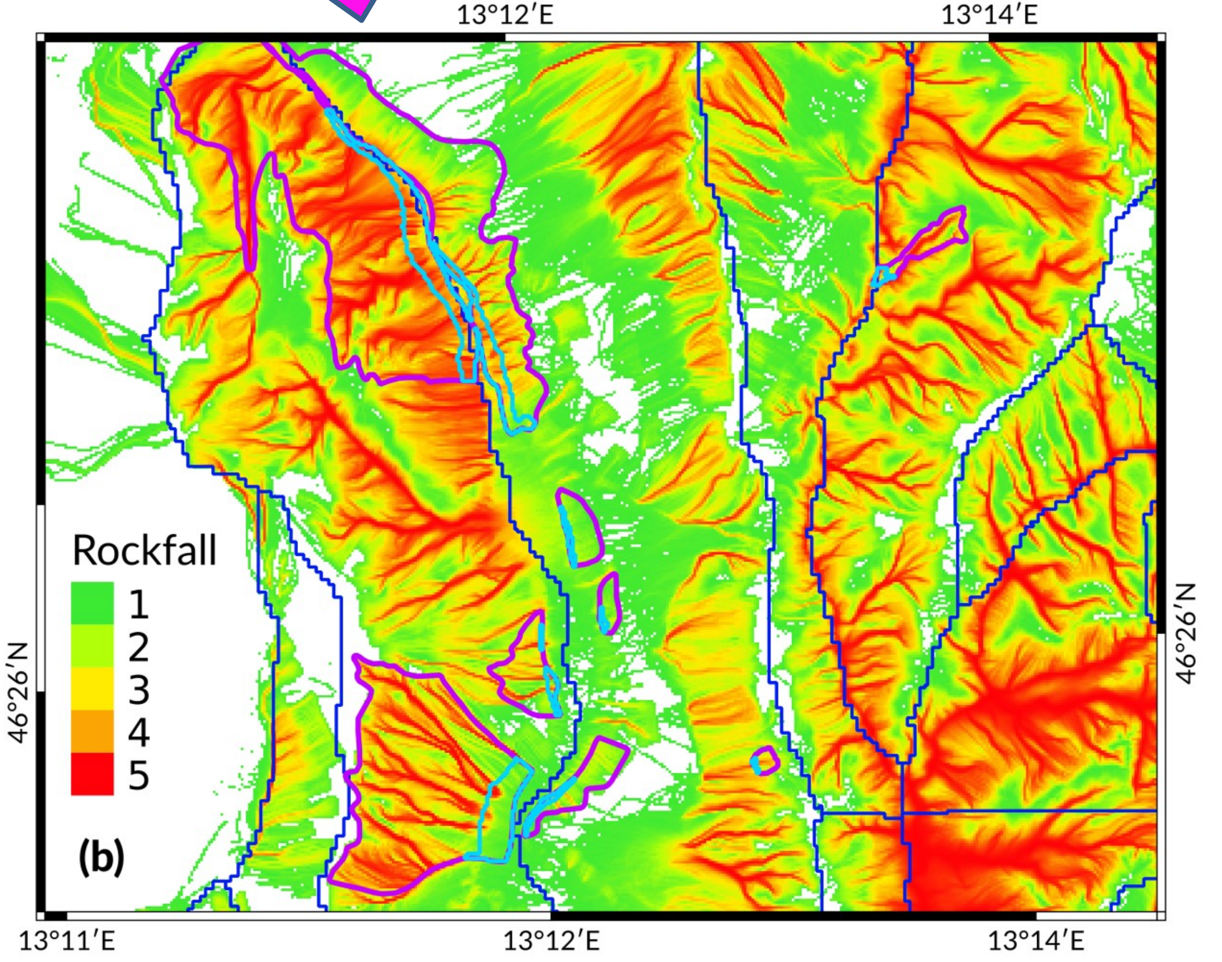
STATISTICAL GENERALIZATION ⇒ $P_{static}(S) = a\left(\frac{S}{90}\right)^{b}$



NATIONAL ROCKFALL SIMULATION - 1

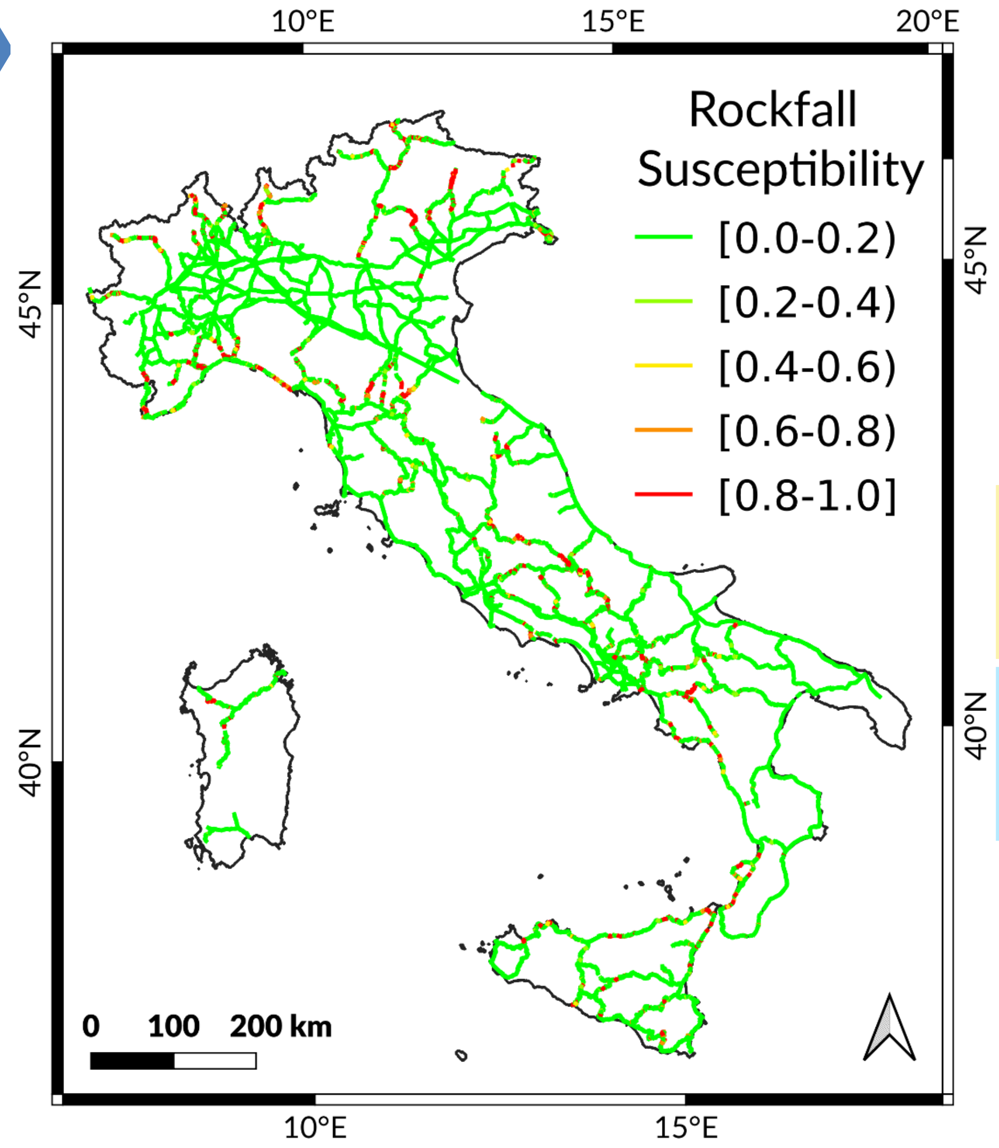
STONE





SU Mapping IFFI IFFI Hi IFFI Lo

National Rockfall Simulation - 1



- Rockfall susceptibility of ***1-km segments of railway***
- National railway: more than 17,000 km (**16,084 km** on slopes)

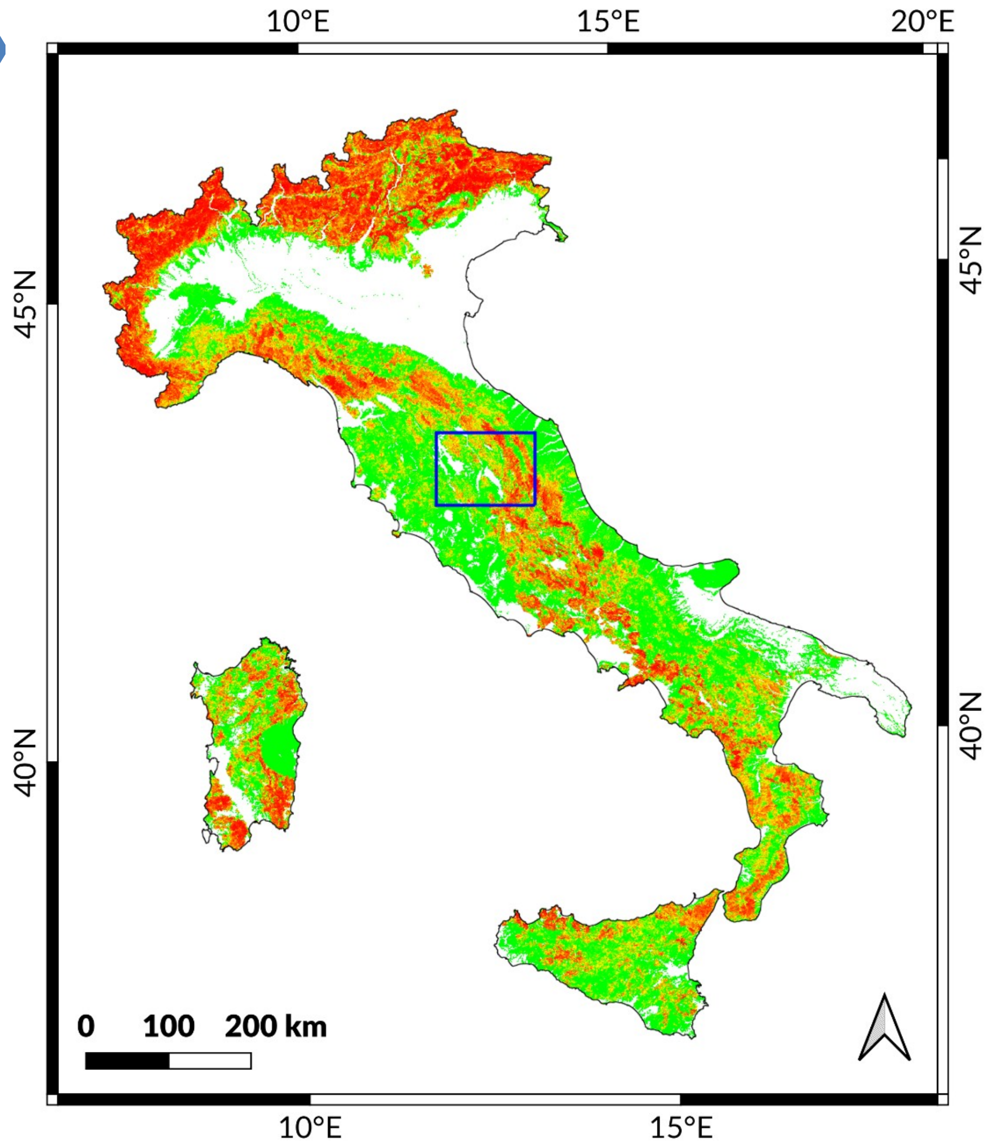
0 – 0.2	0.2 – 0.4	0.4 – 0.6	0.6 – 0.8	0.8 – 1	SUM
14,724	238	170	163	789	16,084

RFI *Gruppo Ferrovie dello Stato*

(National railway company)

Alvioli et al., Eng. Geol. (2021)

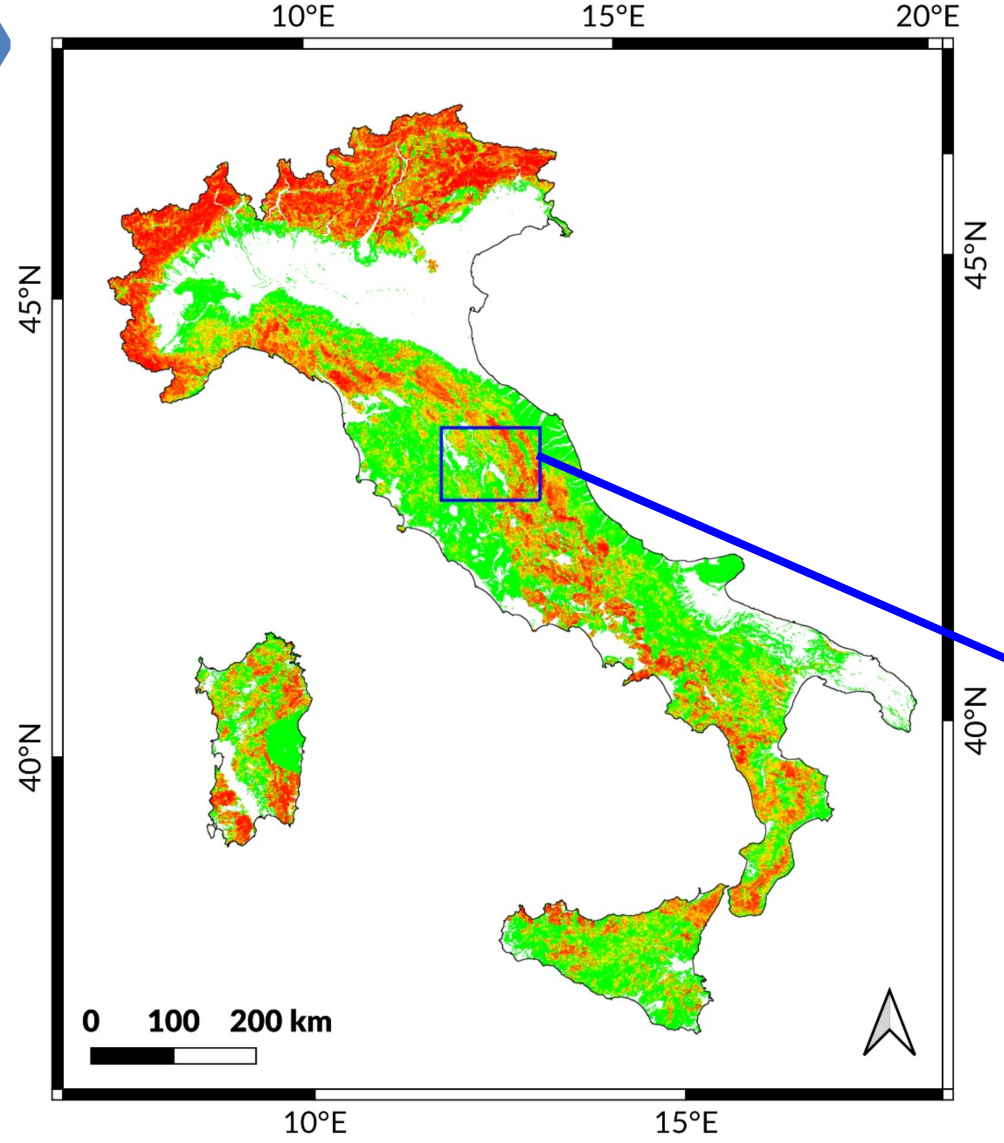
NATIONAL ROCKFALL SIMULATION - 2



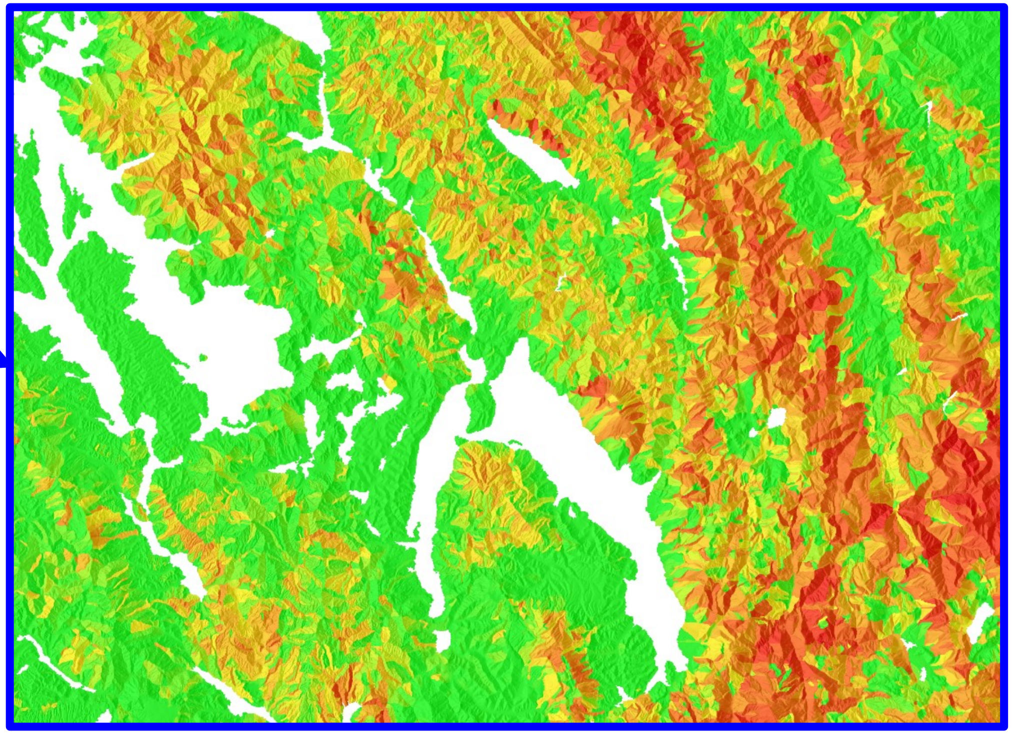
- Rockfall susceptibility at ***slope unit level***
- National coverage of slope units: **224,032 km²** (no plains)

Preliminary results

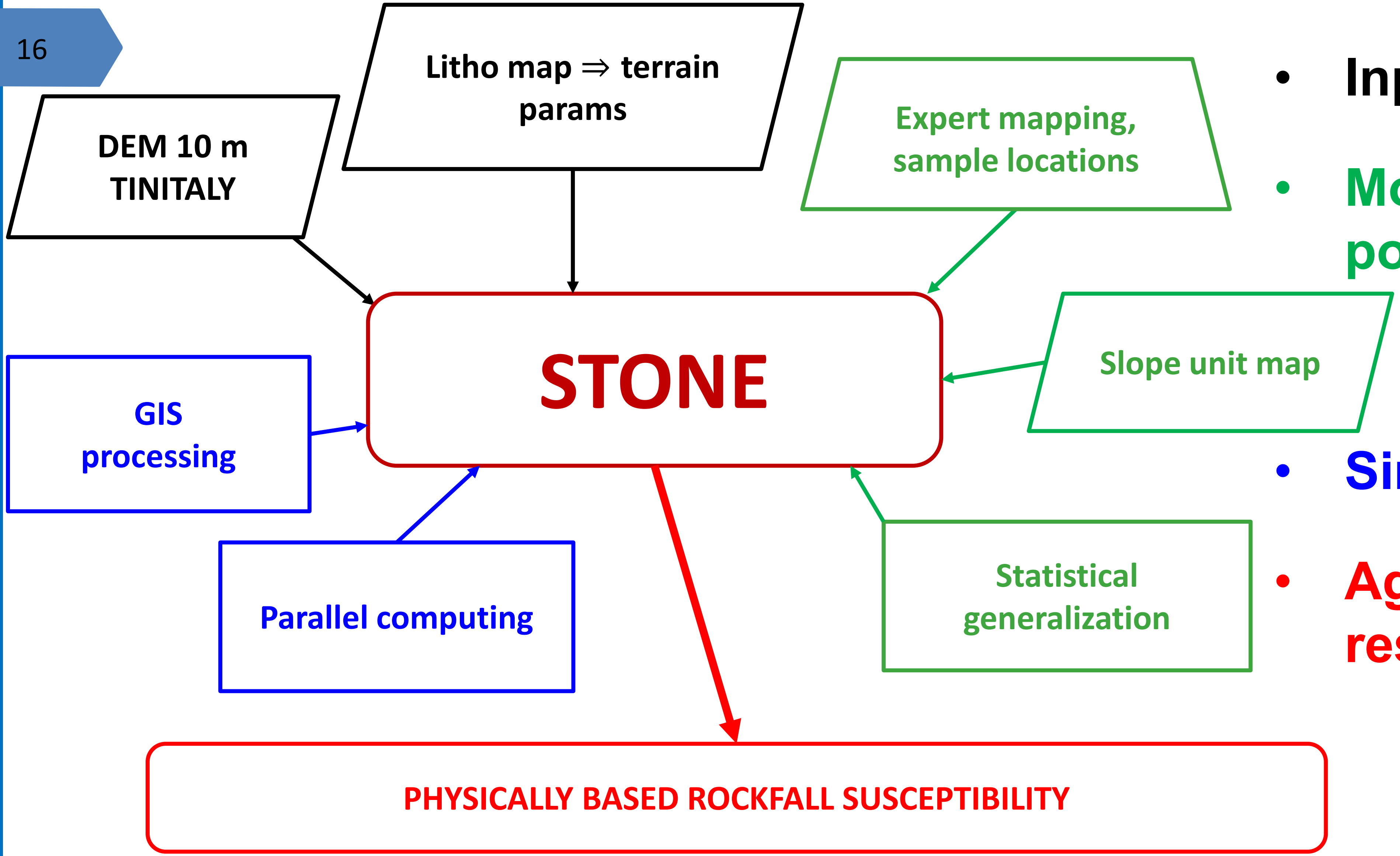
NATIONAL ROCKFALL SIMULATION - 2



- Rockfall susceptibility at ***slope unit level*** (originally at 10 m)
- National coverage of slope units: **224,032 km²** (no plains)

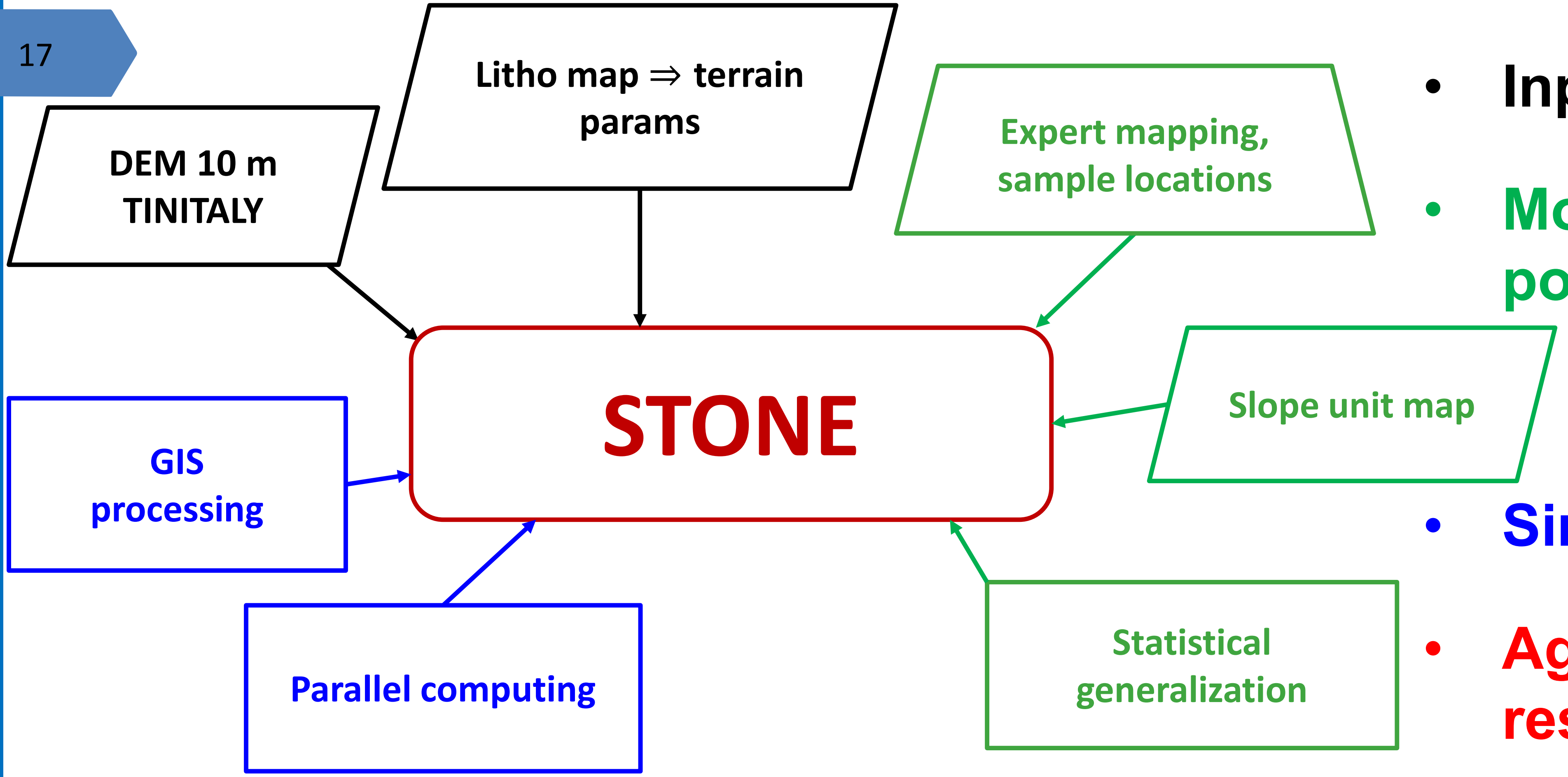


ROCKFALL SOURCES: PROBABILISTIC DYNAMIC APPROACH



- **Input data** +
- **Modeling of potential sources** +
- **Simulations** +
- **Aggregation of results** =

ROCKFALL SOURCES: PROBABILISTIC **DYNAMIC** APPROACH



- **Input data** **+**
- **Modeling of potential sources** **+**
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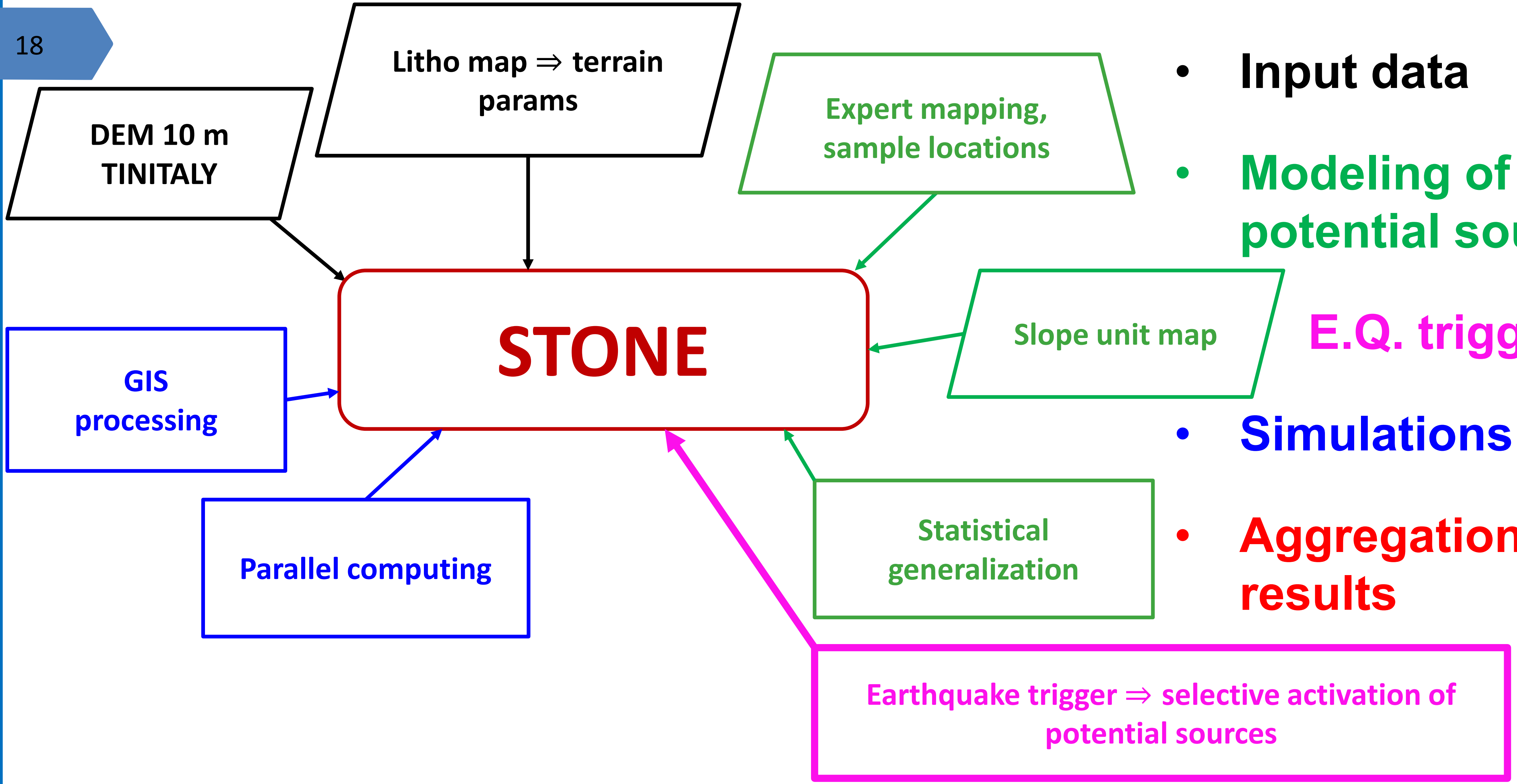
ROCKFALL SOURCES: PROBABILISTIC **DYNAMIC** APPROACH



- **Input data** +
- **Modeling of potential sources** +
- **E.Q. trigger** +
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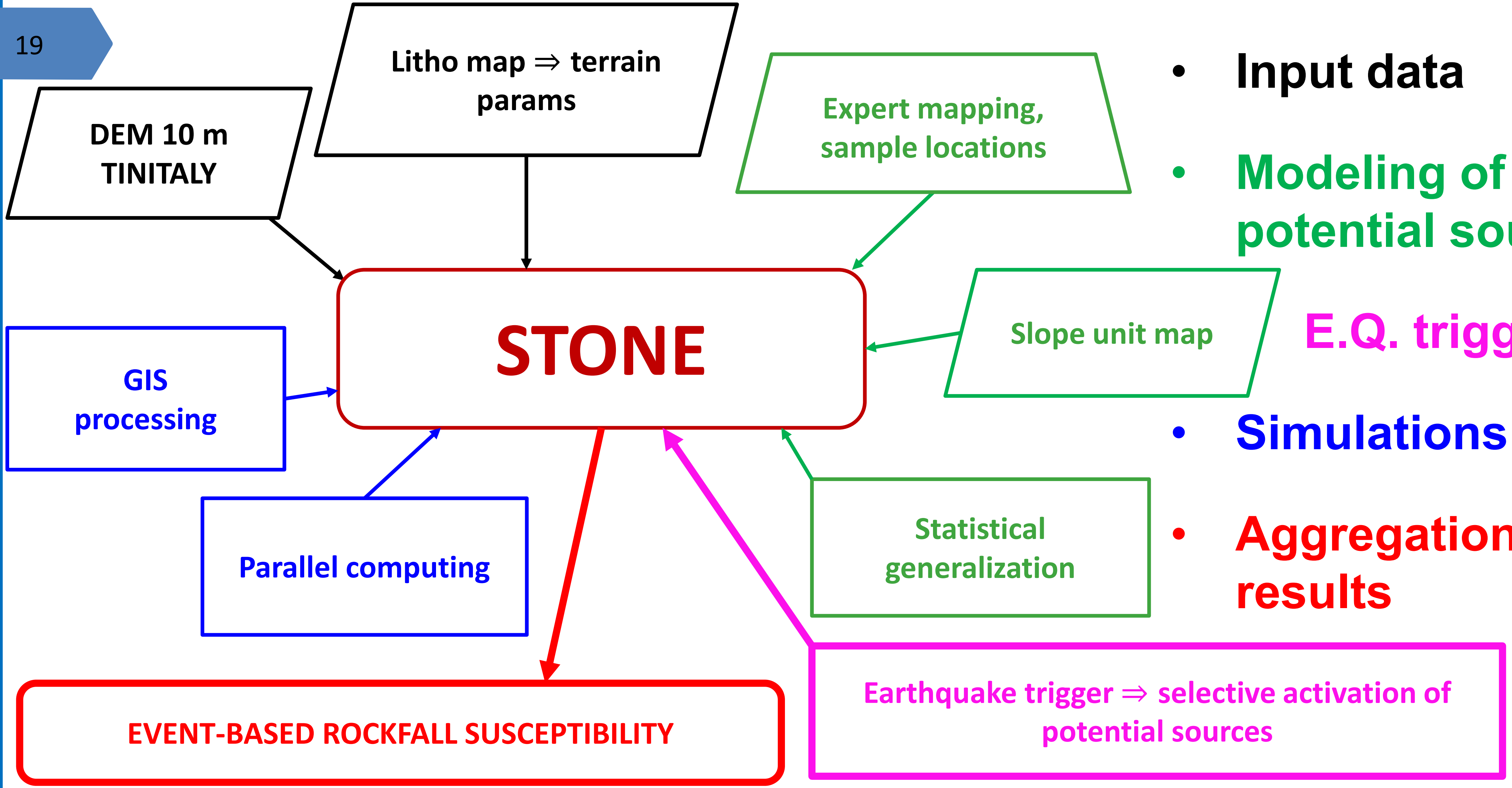
ROCKFALL SOURCES: PROBABILISTIC **DYNAMIC** APPROACH



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- **Modeling of potential sources** **+**
- **E.Q. trigger** **+**
- **Simulations** **+**
- **Aggregation of results** **=**

ROCKFALL SOURCES: PROBABILISTIC DYNAMIC APPROACH

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

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

- Need to ***selectively activate sources*** using a measure of ground shacking to obtain a ***probabilistic, dynamic*** source map

- We use peak ground acceleration (PGA):

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

Where $F(PGA)$ ***maps values of PGA into the interval [0,1]***, for a specific earthquake event ⇒ *only a few sources are* ***activated by the trigger***

ROCKFALL SOURCES: PROBABILISTIC **DYNAMIC** APPROACH

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

Where $F(PGA)$ ***maps values of PGA into the interval [0,1]***, for a specific earthquake event ⇒ *only a few sources are* ***activated by the trigger***

We consider different functions $F(PGA)$:

- **Linear** mapping: $F(PGA) = \frac{PGA - PGA_{min}}{PGA_{max} - PGA_{min}}$
- Normalized tunable **sigmoid function**: $F(x) = \frac{x - k\,x}{k - 2k|x| + 1}$

with $x = 2\,\frac{PGA - PGA_{cut}}{PGA_{max} - PGA_{cut}} - 1$ and different values of $\boldsymbol{k}$ and PGA_{cut}

ROCKFALL SOURCES: PROBABILISTIC DYNAMIC APPROACH

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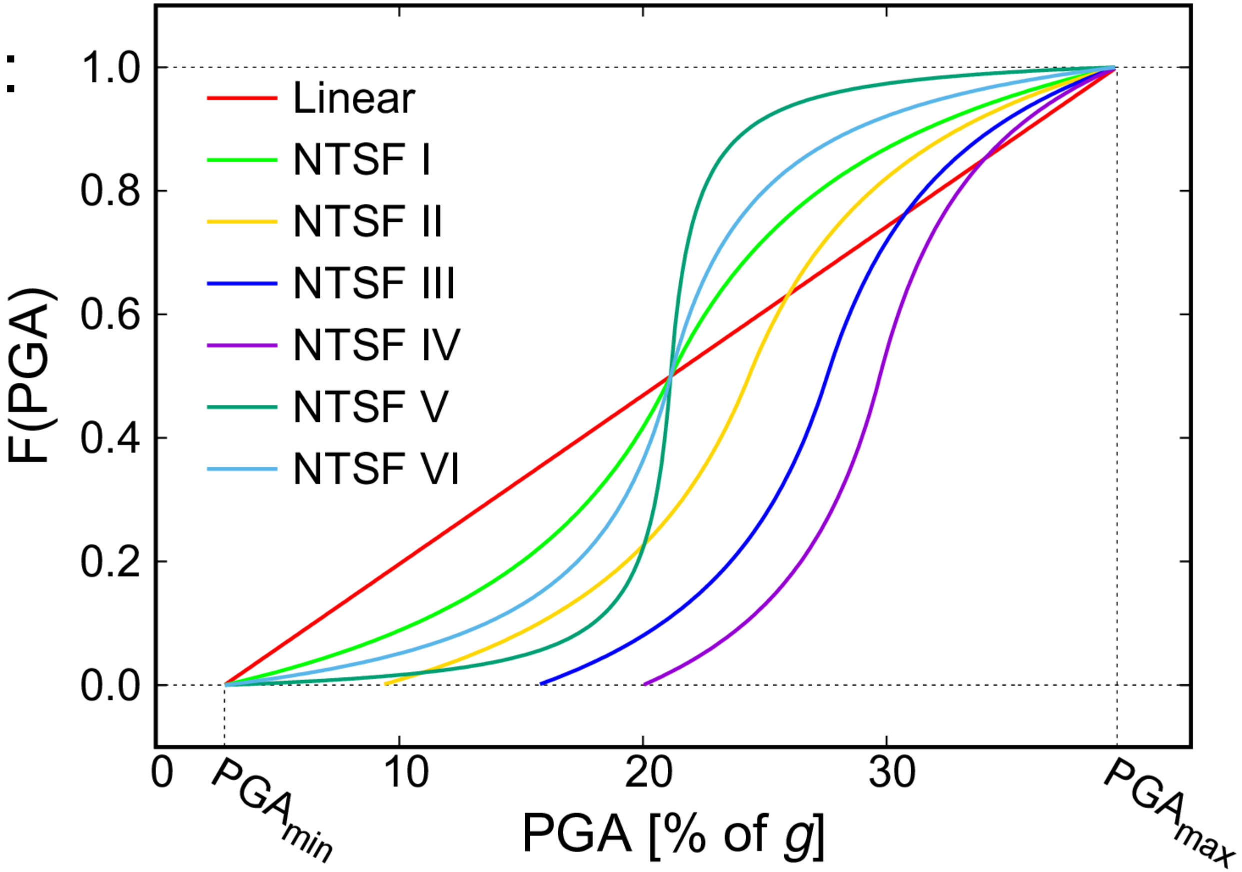
k and PGA_{cut} parameters



ROCKFALL SOURCES: PROBABILISTIC **DYNAMIC** APPROACH

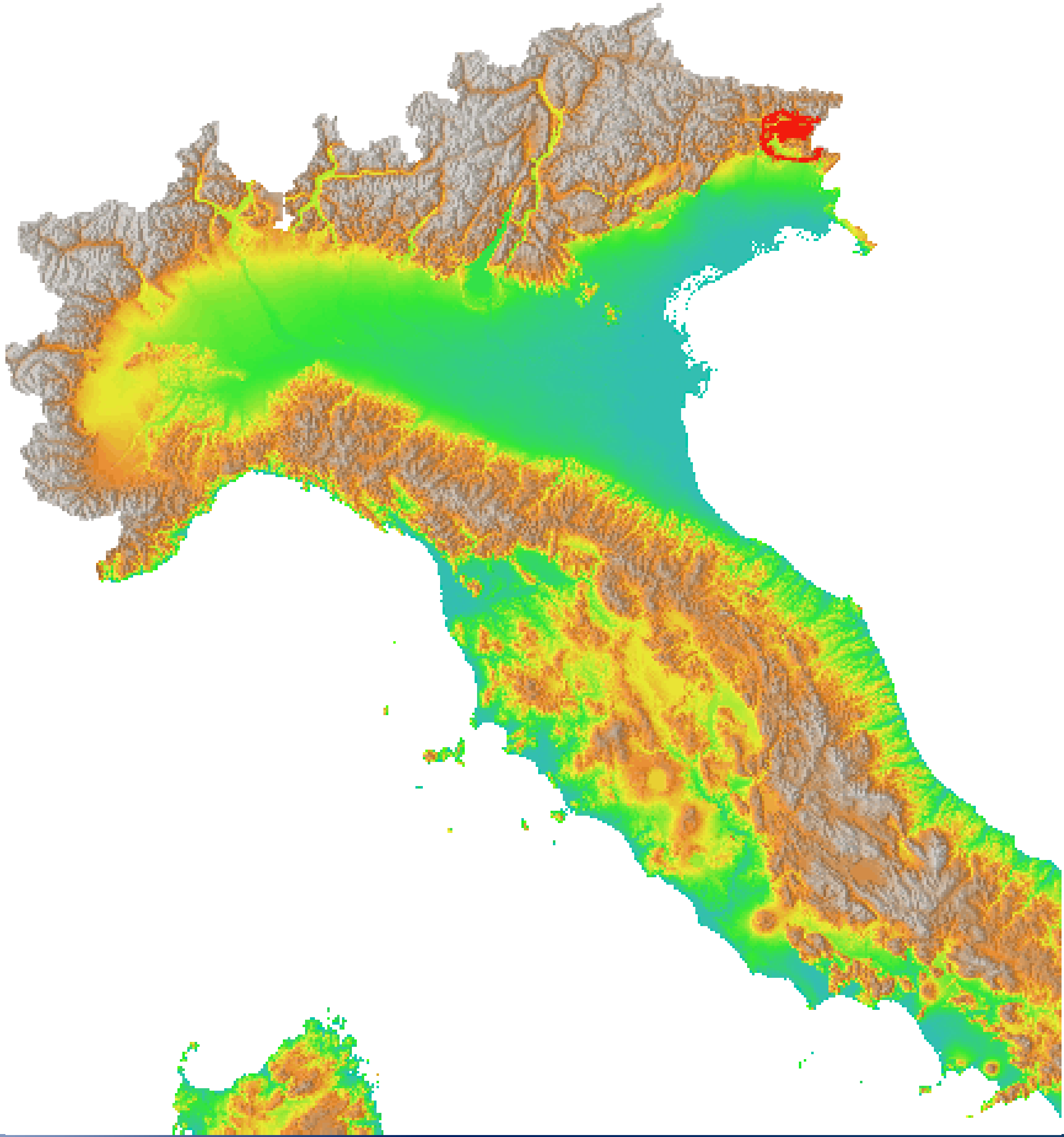
- A few historical ***earthquake events*** exist, for which we know both:

  ⇒ ***seismically induced rockfalls***

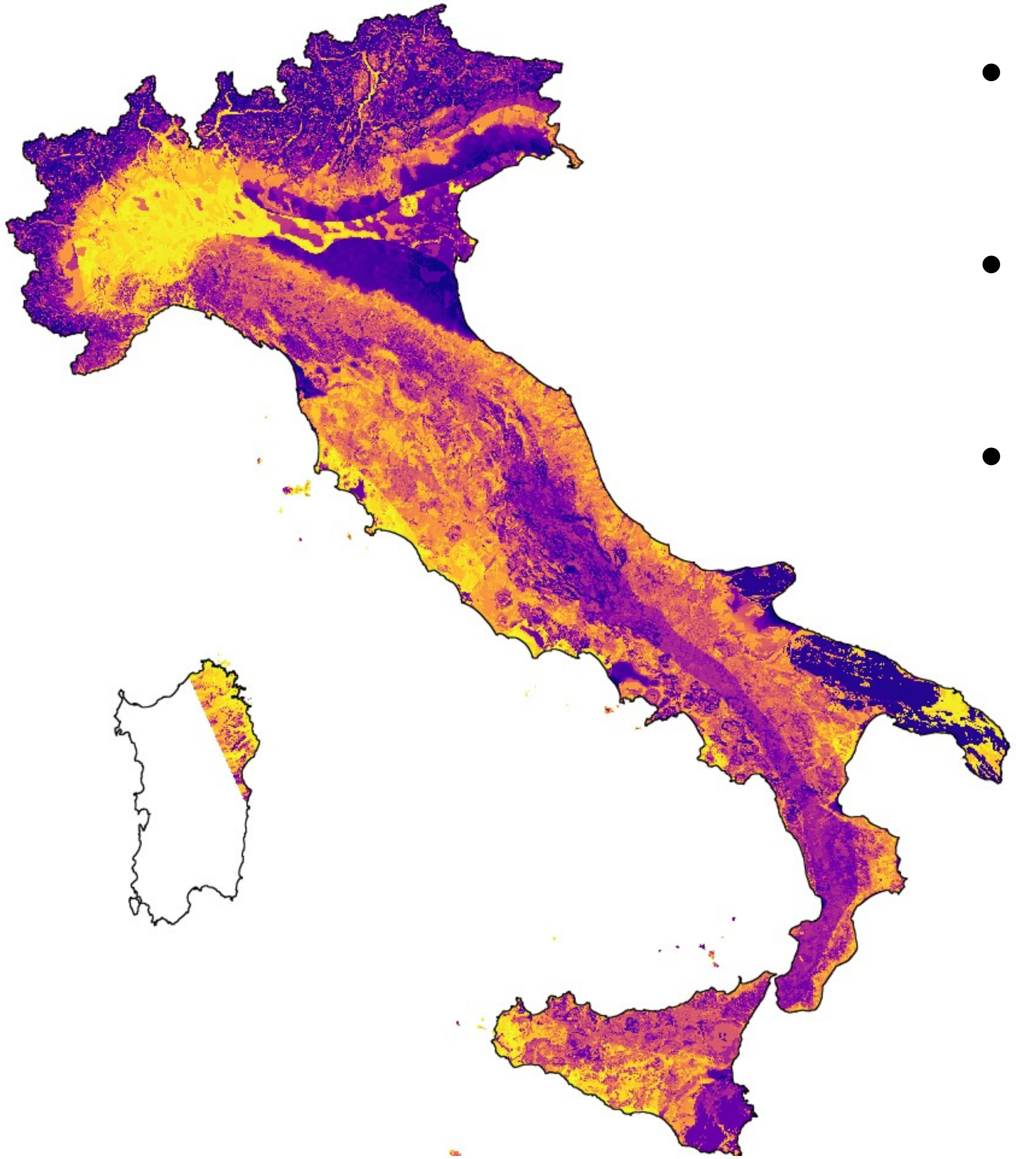
  ⇒ ***PGA map*** *(figure)*

- **Friuli, 1976**
- **Umbria-Marche 1997**
- **L'Aquila, 2009**

⇒ ***calibration of F(PGA) parameters***

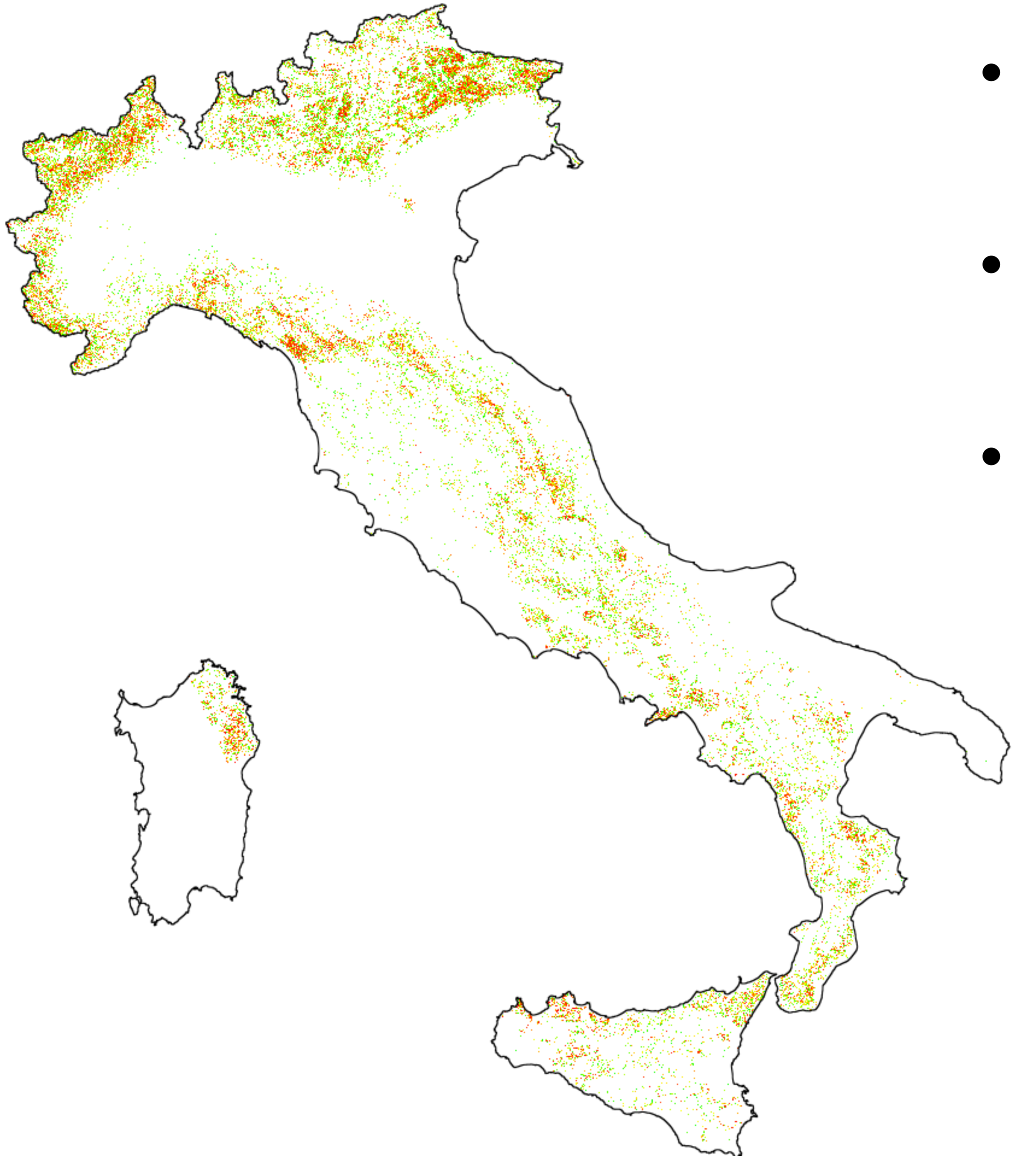


National Rockfall Simulation – 3



- 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)

National Rockfall Simulation – 3



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Preliminary results

Progetto FRA.SI - *frane sismoindotte*

CNR IRPI/IGAG/IREA; MATTM

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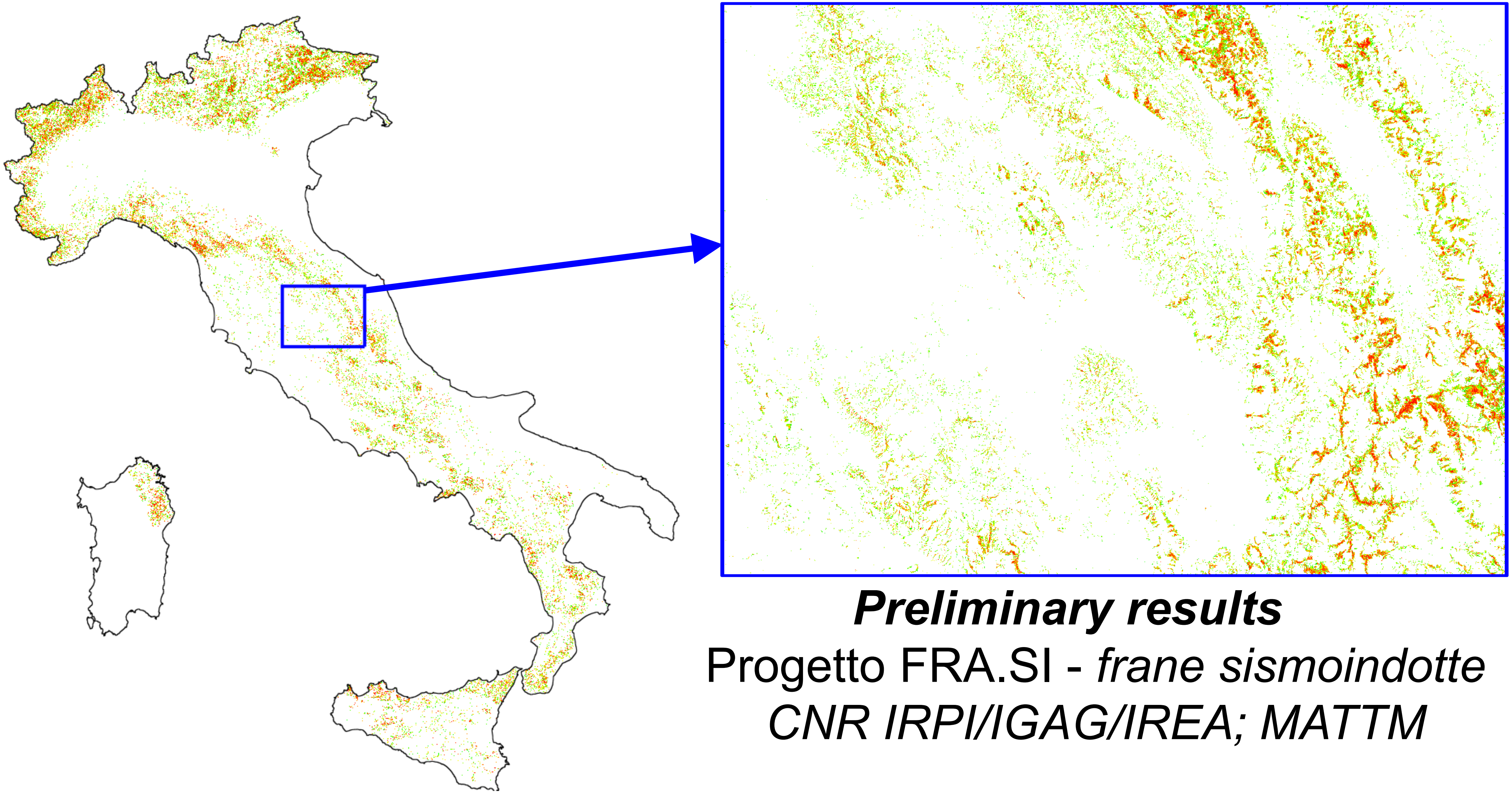

Preliminary results

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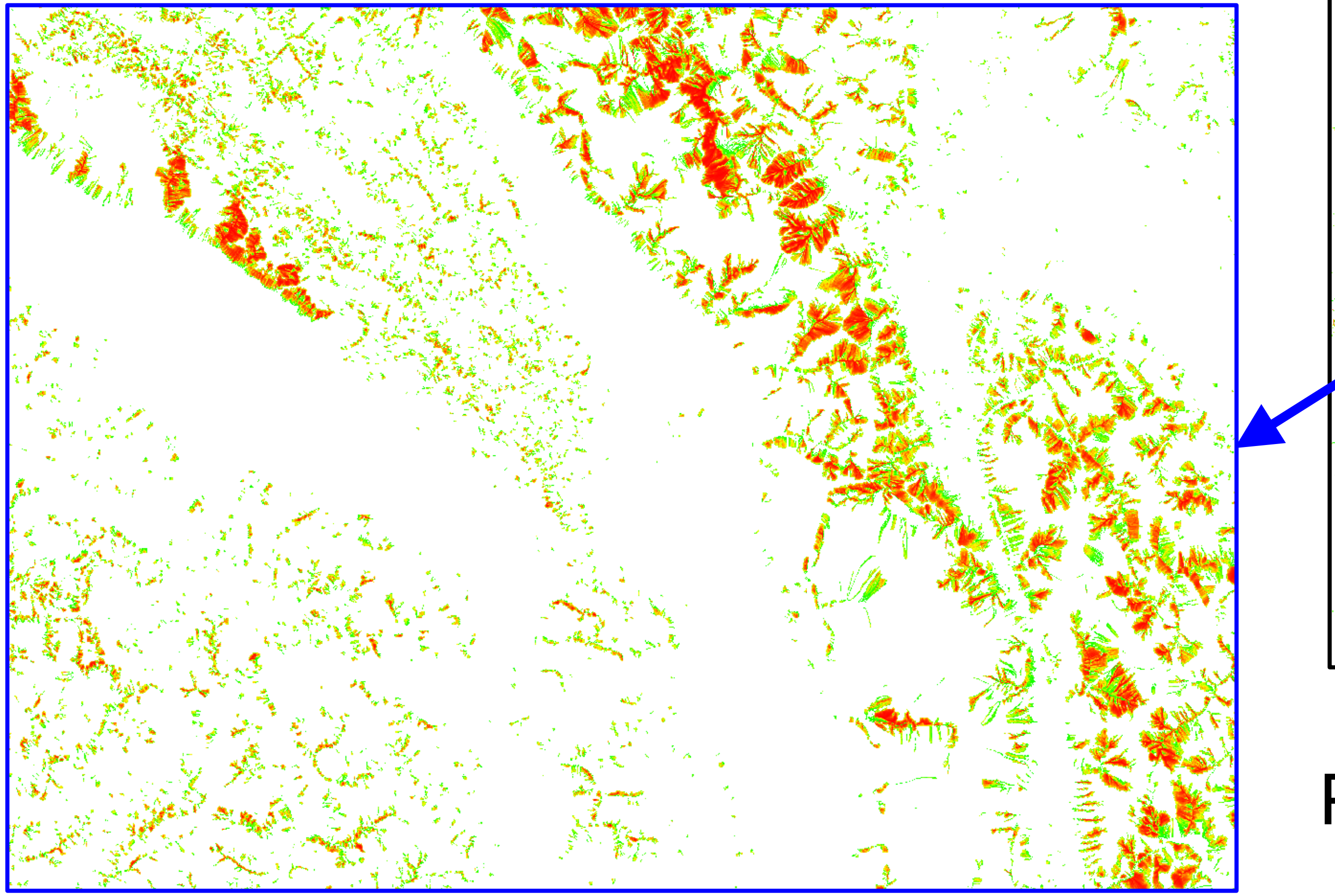
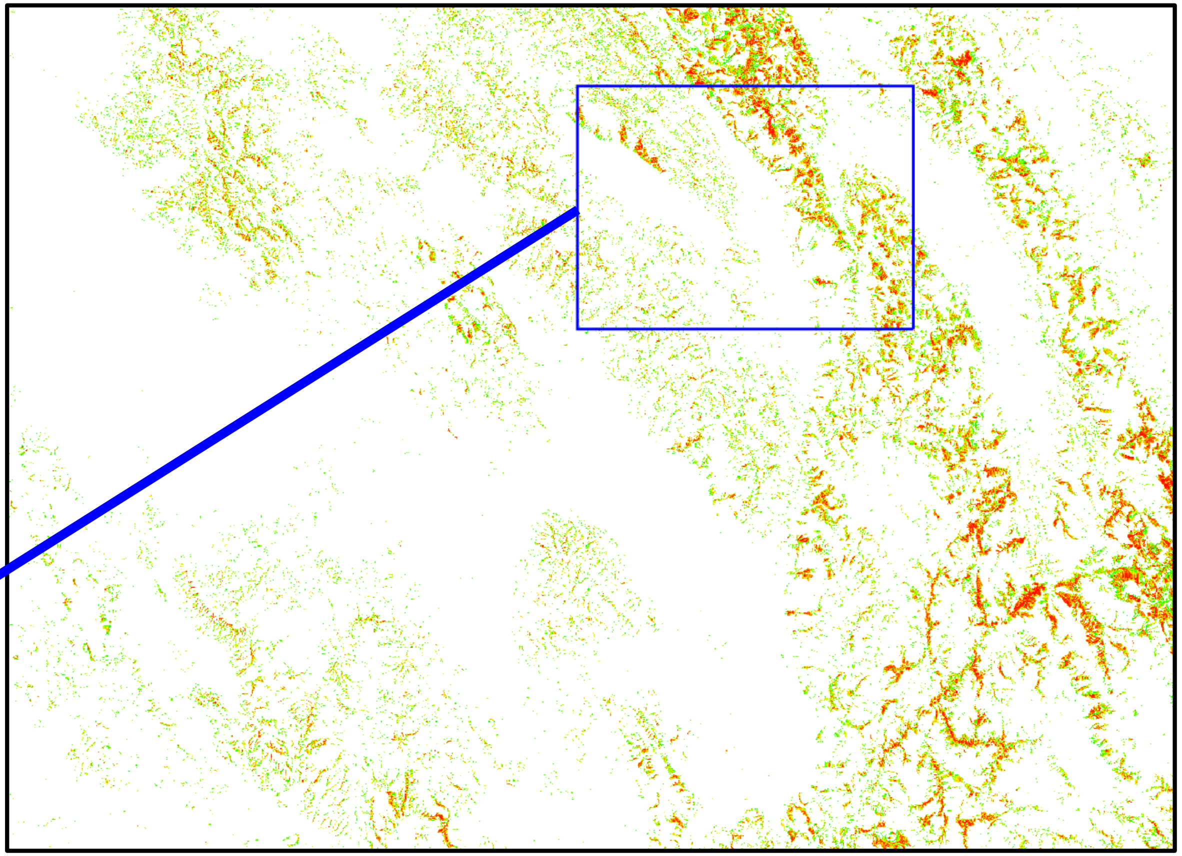
NATIONAL ROCKFALL SIMULATION – 3





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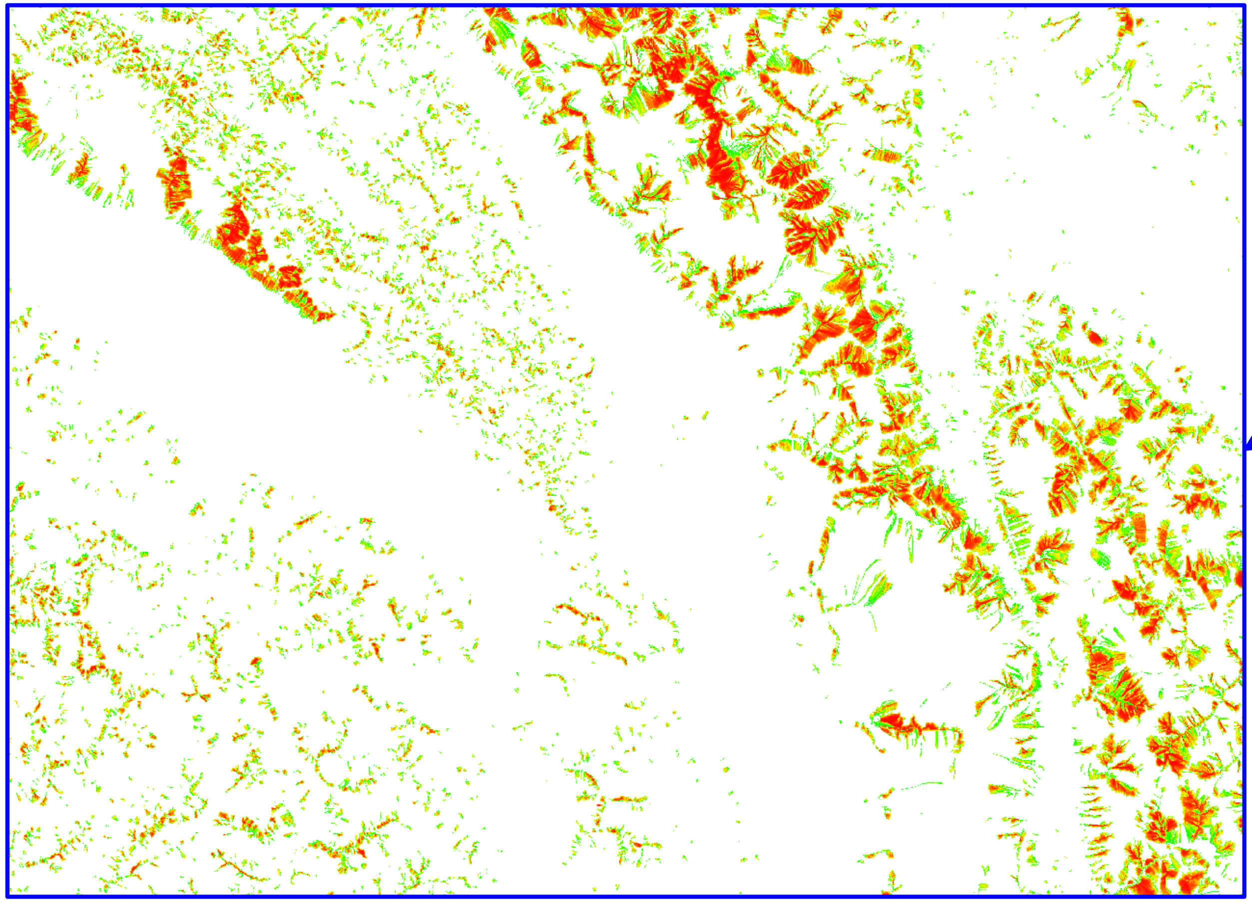

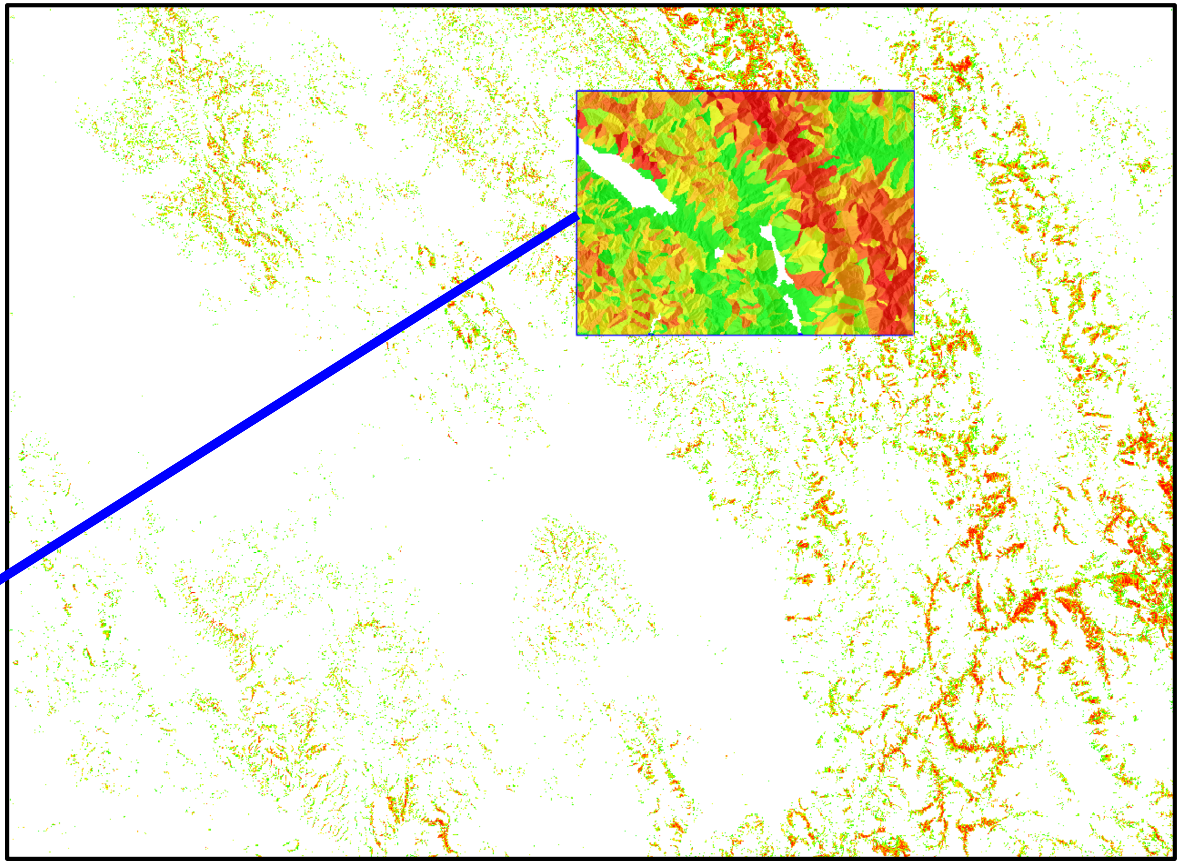

Preliminary results

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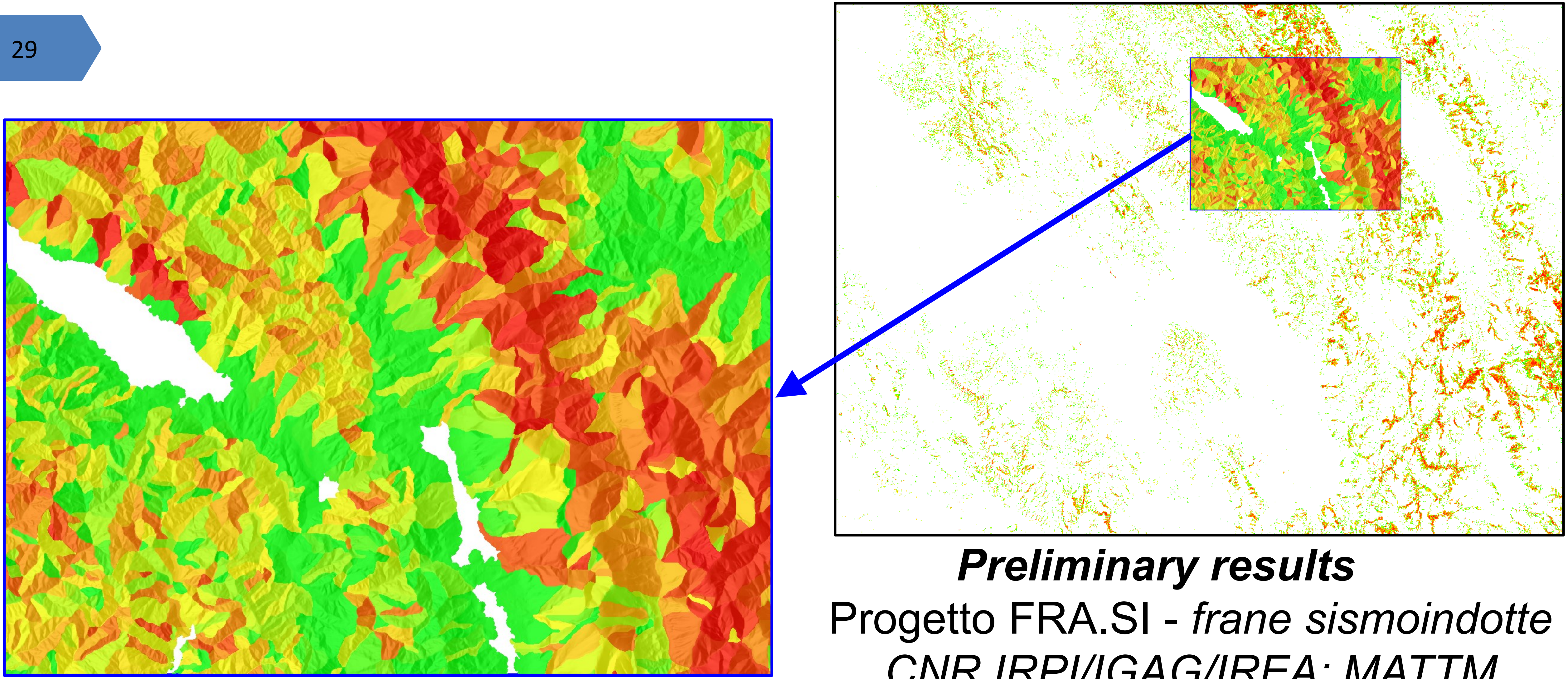

Preliminary results

Progetto FRA.SI - *frane sismoindotte*

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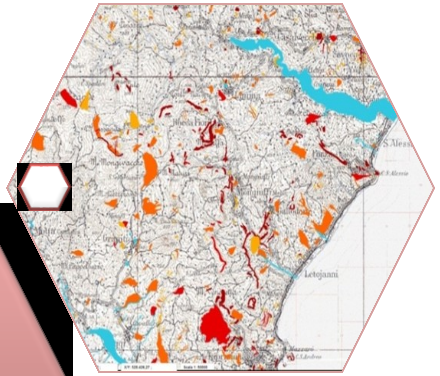
SUMMARY

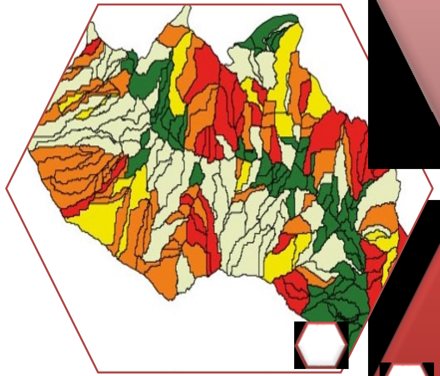
- We obtain ***potential rockfalls sources*** as a function of slope, $P_{static}(S)$
- Method based on expert mapping in sample locations & generalization
- Sources used in STONE to simulate rockfall trajectories ⇒ susceptibility
- Generalization of the method to a ***dynamic seismic trigger***:

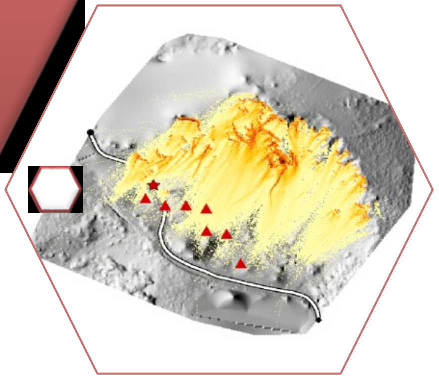
$$P_{dynamic}(S,PGA) = P_{static}(S)\ F(PGA)$$

- Calibration of ***F(PGA)*** with EQ events with known triggered landslides
- In principle, method applicable in ***near-real time*** ⇔ ***PGA availability***

…That's all.







THANK YOU!

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