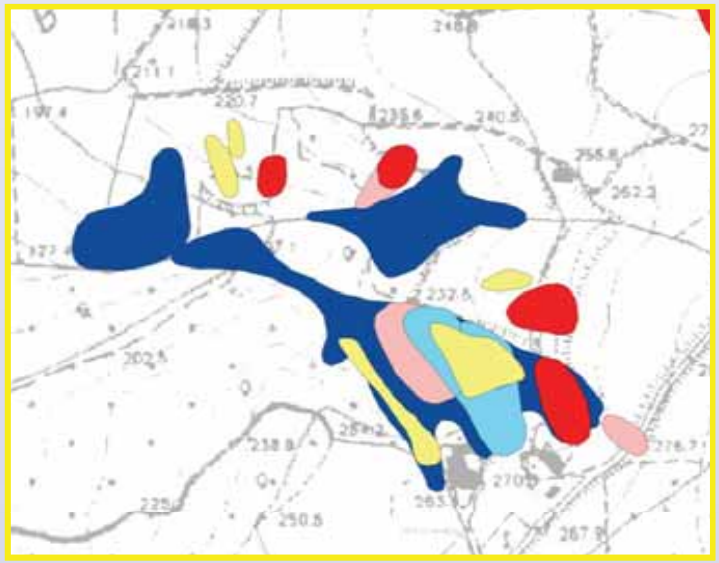
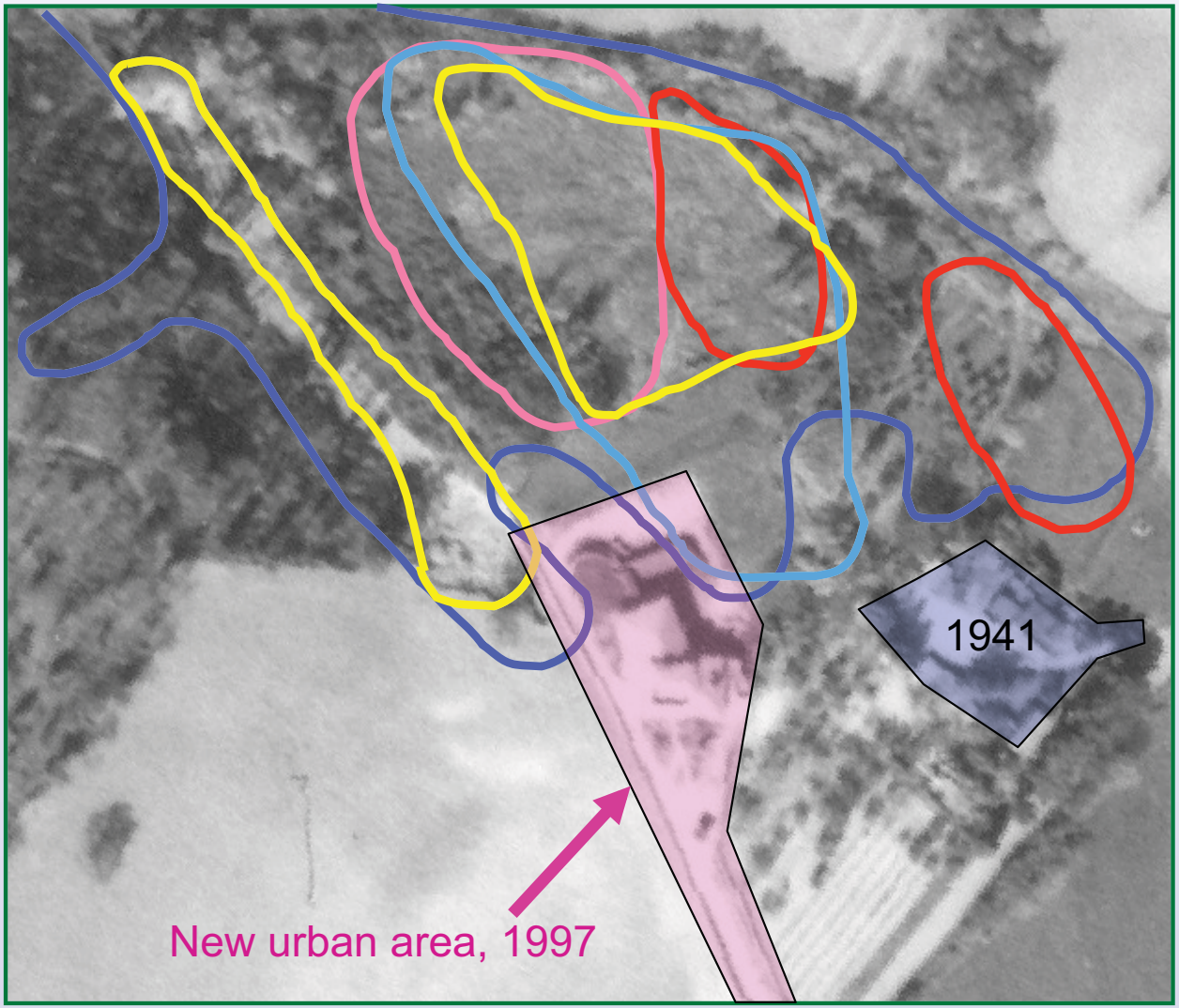
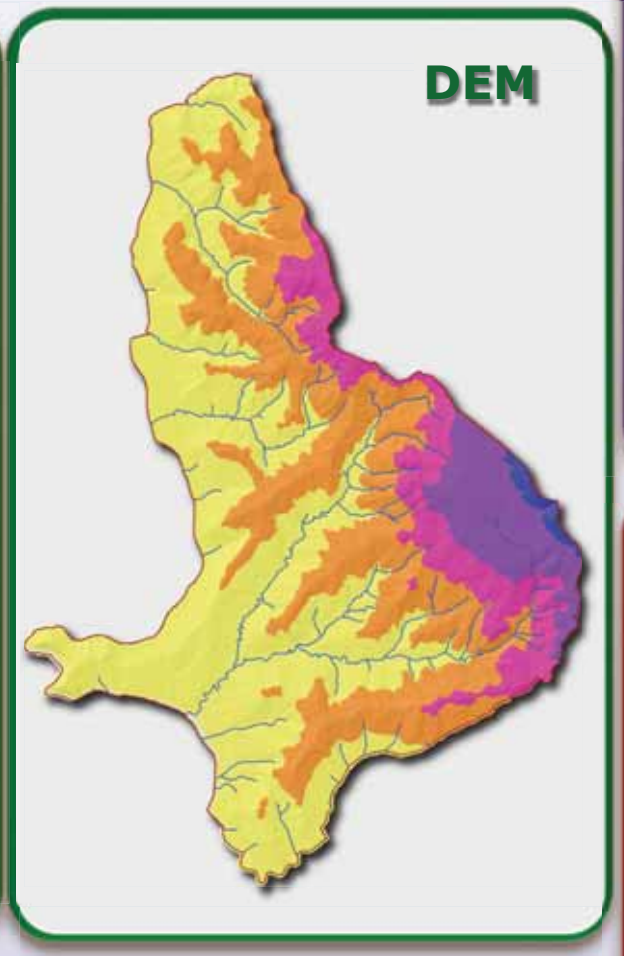
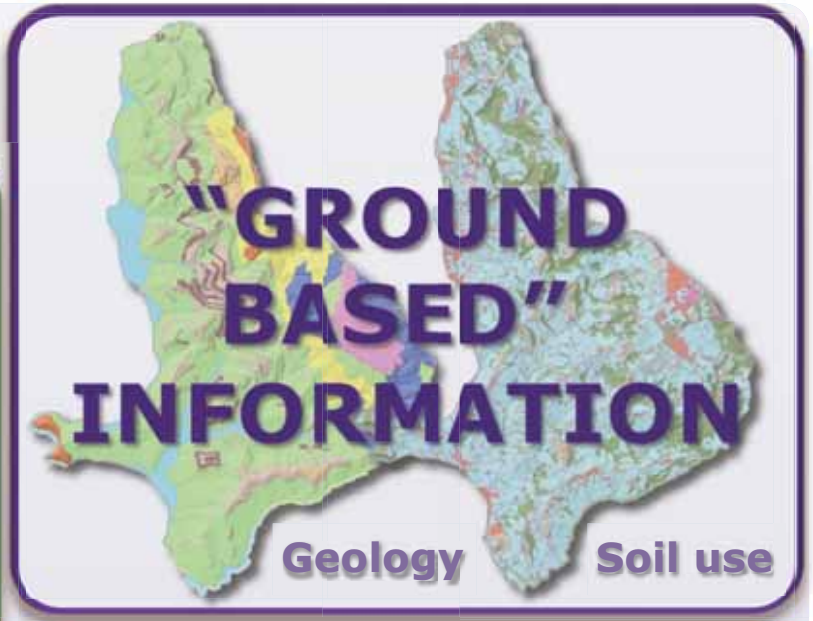




1941 1954-77 1985 1997

MULTI-TEMPORAL INVENTORY





THEMATIC INFORMATION

- We evaluated the **landslide susceptibility** using three statistical models (linear and quadratic discriminant analysis, and a logistic regression models), and we adopted a **logistic regression model**, to obtain a forecast combination of the single zonation.

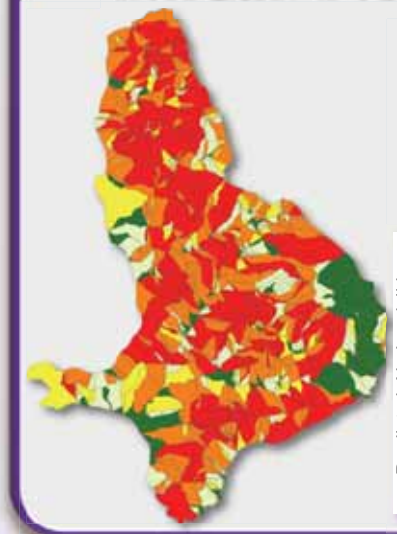
- In the models, the **grouping variable** is the **presence or absence of landslide** in each mapping unit, and the **explanatory variables** are obtained from **thematic information**.

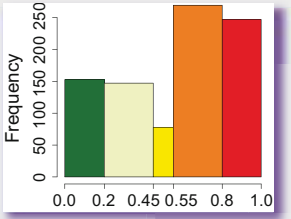
- For each susceptibility model, we evaluated the **model skills** and we tested the **model predictive performance** using independent landslide information.

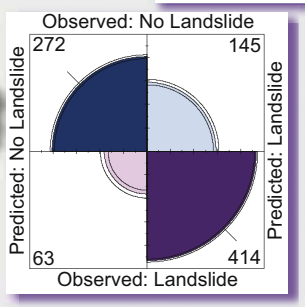
SUSCEPTIBILITY MODELS

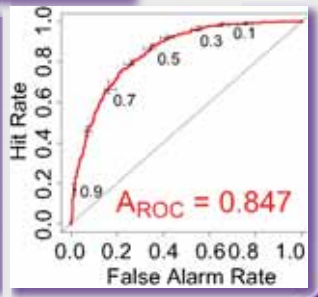
DTM
Lithology
Structural data
Soil use

Linear Discriminant Analysis

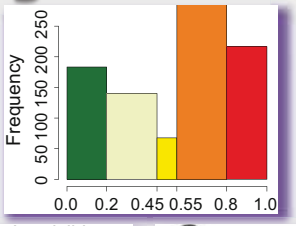


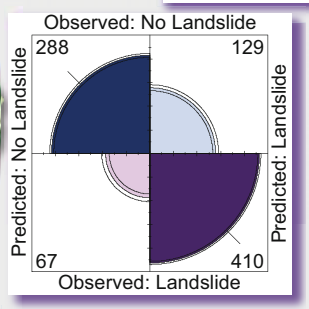


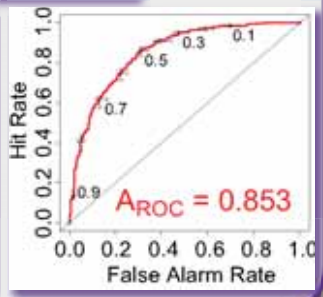




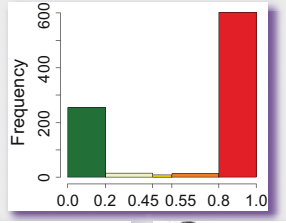
Logistic Regression

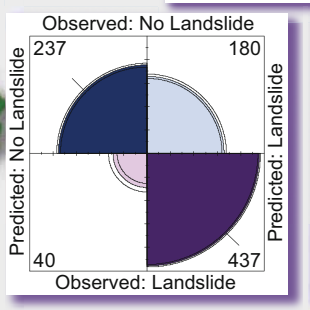


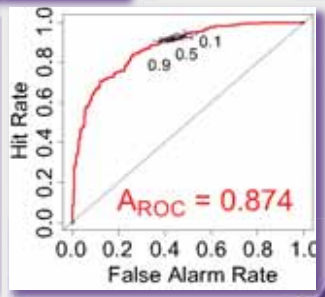




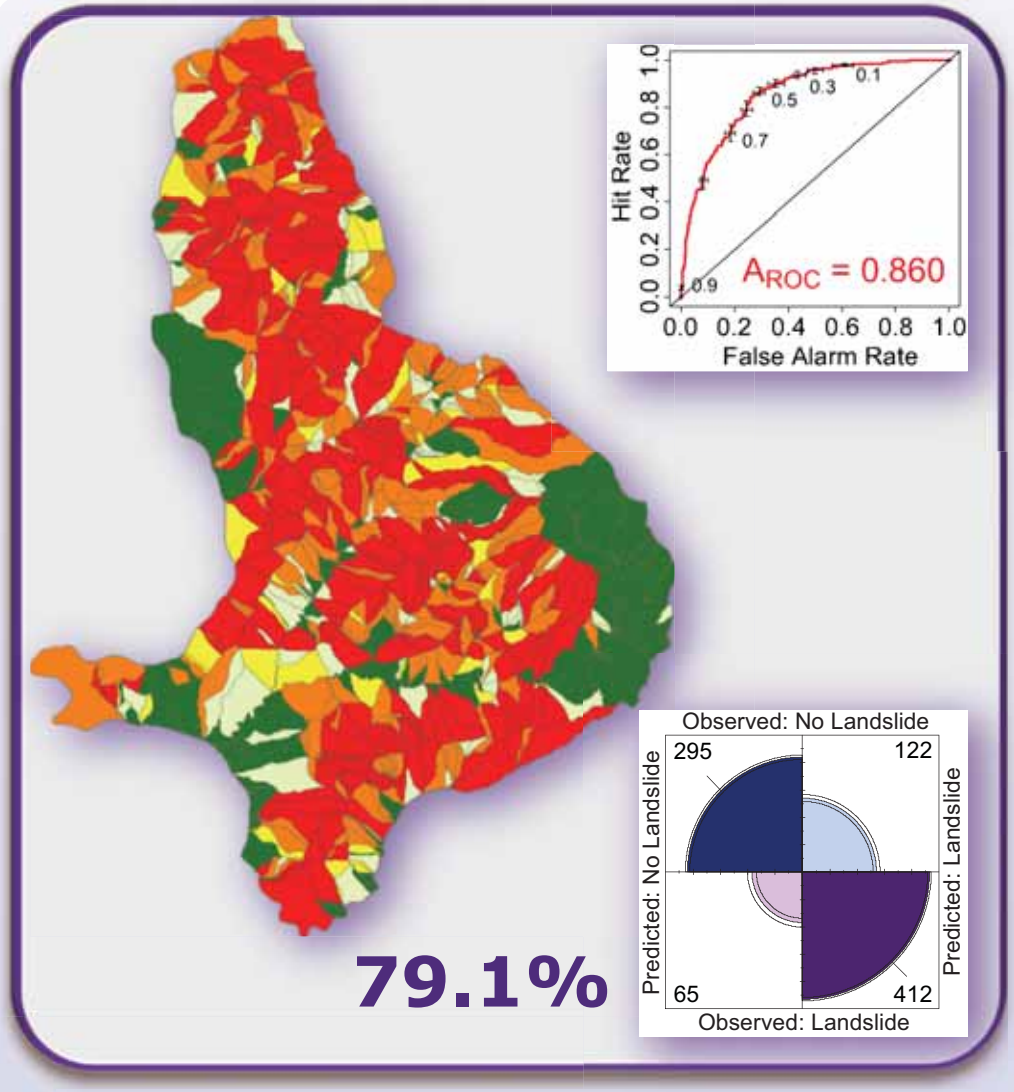
Quadratic Discriminant Analysis

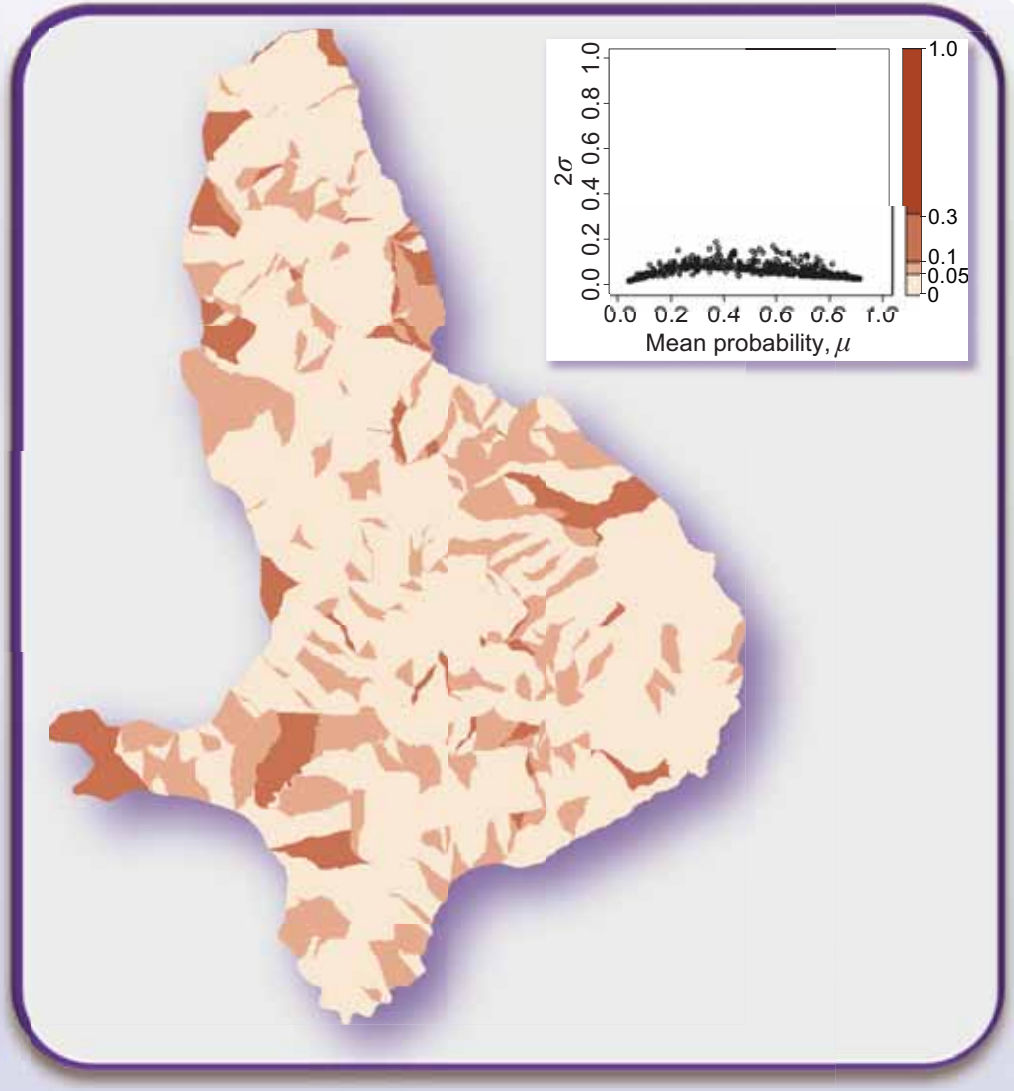






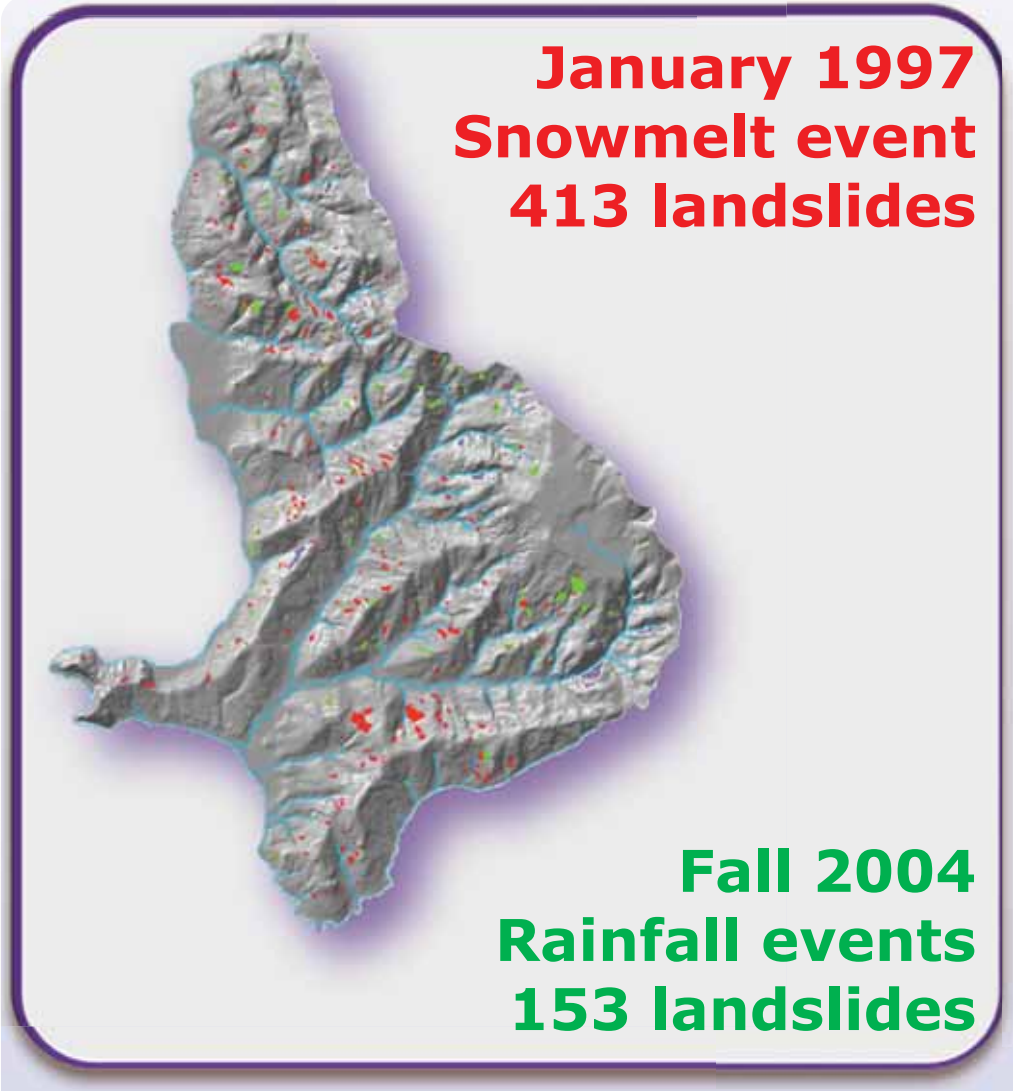
SUSCEPTIBILITY MODELS

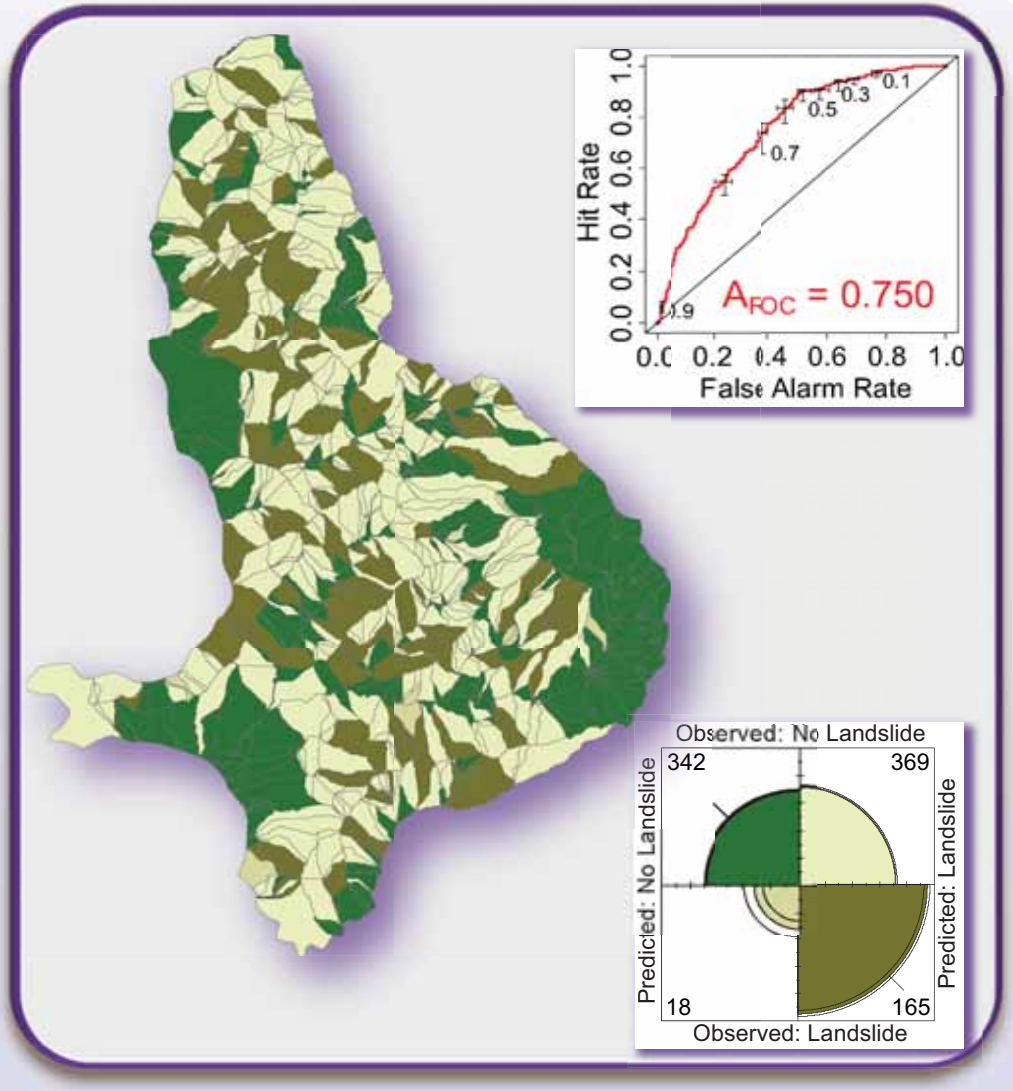




model | **model error**

SUSCEPTIBILITY MODEL

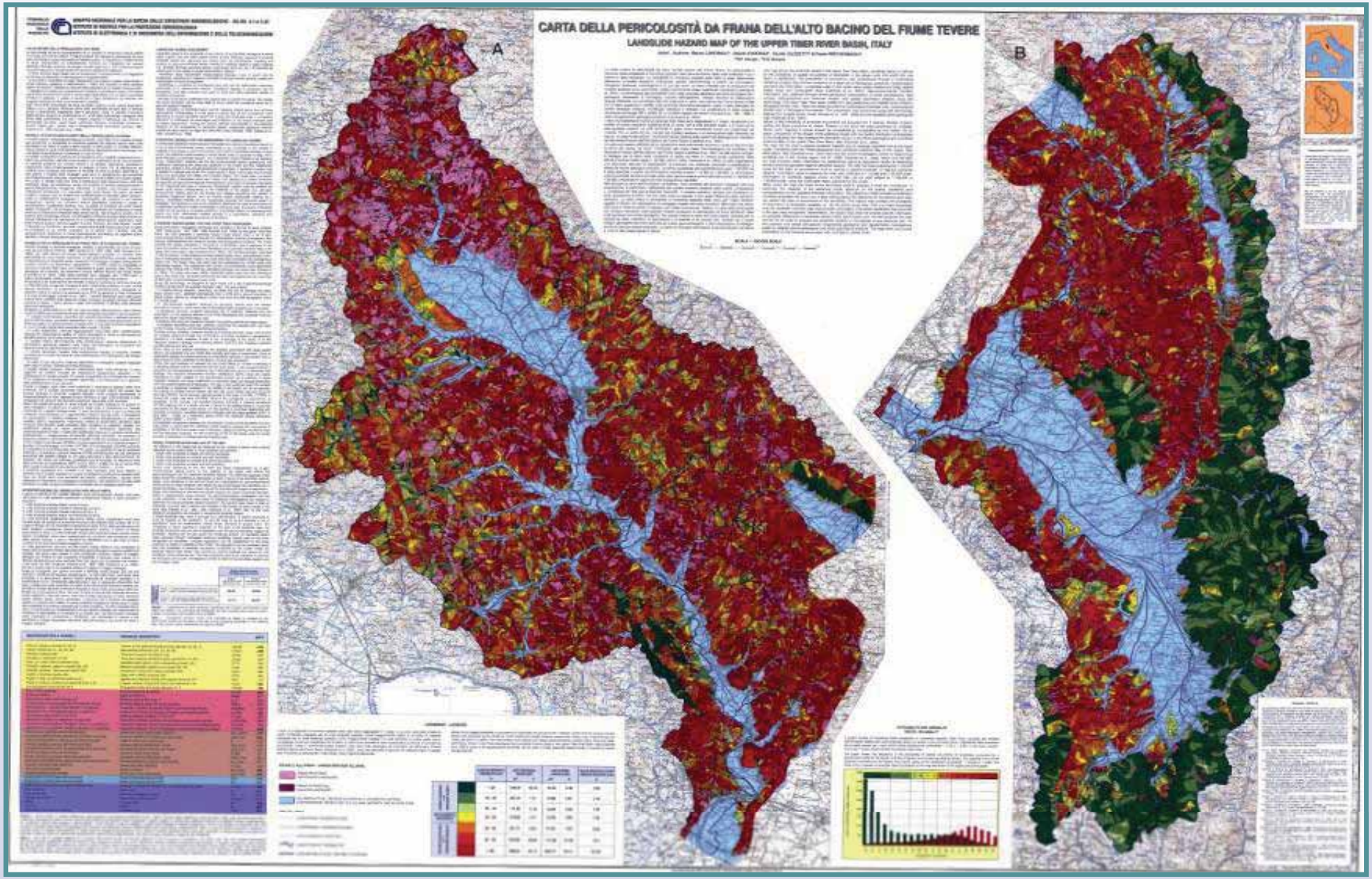




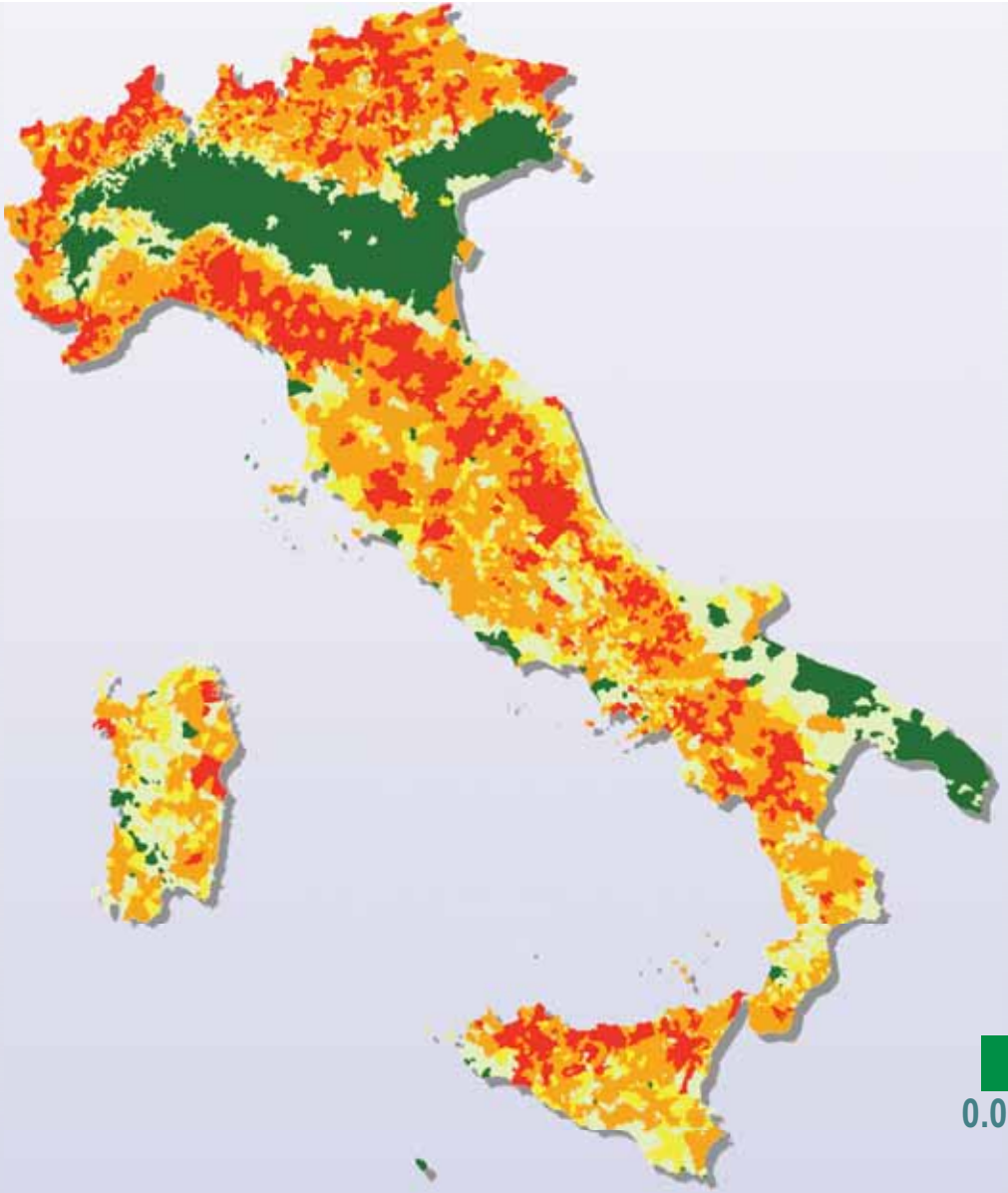
Recent events

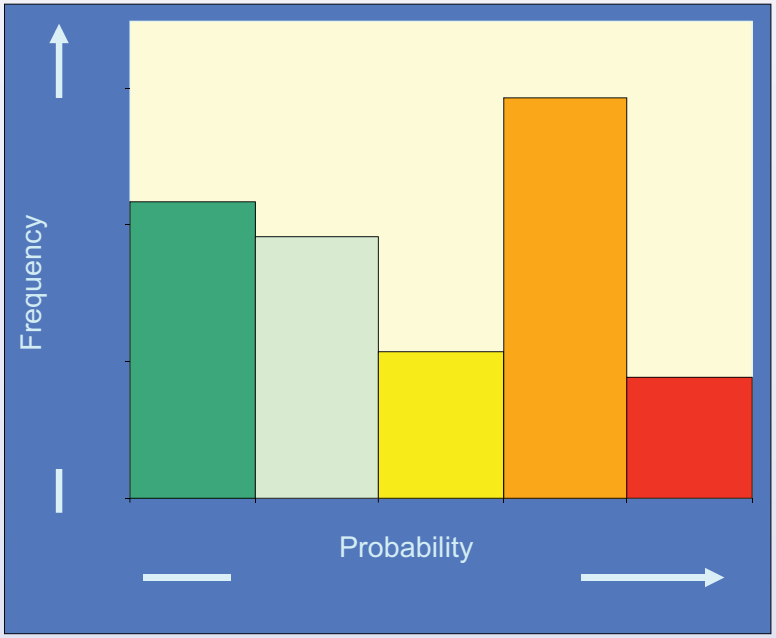
Validation

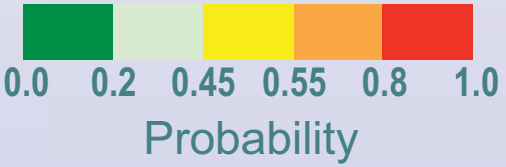
MODEL VALIDATION



THE UPPER TIBER BASIN







LANDSLIDE SUSCEPTIBILITY

Collazzone area 80 km²	Upper Tiber river basin 4150 km²	Italy 301,263 km²
Multi-temporal inventory	Geomorphological inventory	Historical inventory
Slope units	Hydro-morpho-lithological terrain units	Administrative boundaries
Detailed thematic information	Aerial photo interpretation information	National-scale thematic information
16 thematic variables (out of 47)	41 thematic variables (out of 139)	20 thematic variables (out of 60)

LANDSLIDE SUSCEPTIBILITY

- ***How reliable the spatial models are?***
- ***How do we obtain independent information to validate our models?***
- ***Is there new information available to improve the forecasts?***
- ***How do we combine multiple spatial forecasts?***
- ***How environmental and climate changes will affect the geographical distribution of future landslides?***

OPEN PROBLEMS

The probability of landslide size is the likelihood that a failure will exceed a given area.

$$P(AL) = P[AL \geq aL]$$

Two distributions have been shown to describe the frequency-area statistics of landslides.

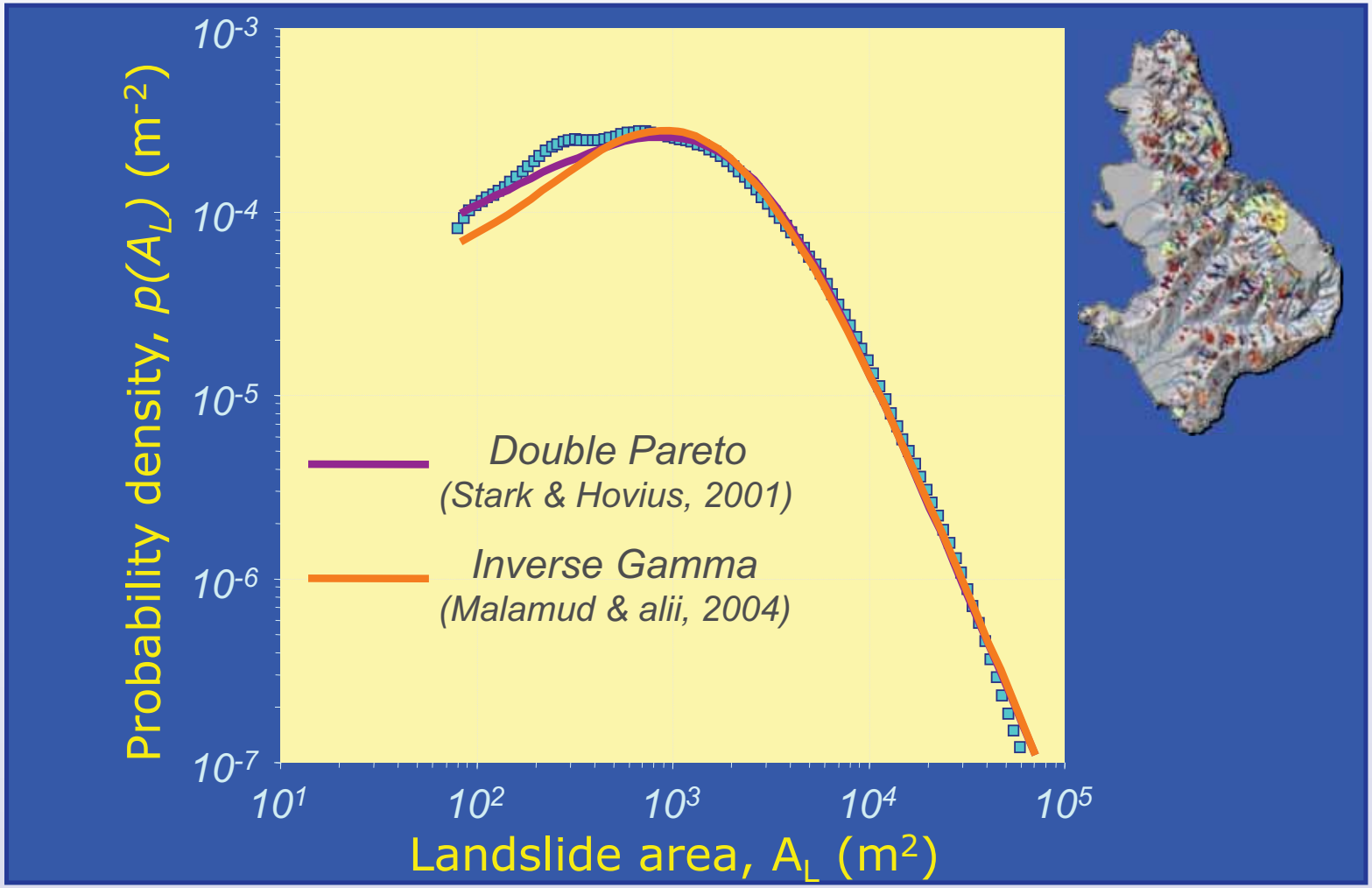
Double Pareto distribution *(Stark & Hovius, 2001)*

$$P(A_L) = \int_{a_L}^{\infty} p(A_L;\alpha,\beta,l,m,c)dA_L = \int_{a_L}^{\infty} \frac{\beta}{l(1-\delta)}\left[\frac{\left[1+(m/l)^{-\alpha}\right]^{\beta/\alpha}}{\left[1+(A_L/l)^{-\alpha}\right]^{1+(\beta/\alpha)}}\right](A_L/l)^{-(\alpha+1)}dA_L$$

Inverse Gamma distribution *(Malamud & alii, 2004)*

$$P(A_L) = \int_{a_L}^{\infty} p(A_L;\rho,a,s)dA_L = \int_{a_L}^{\infty} \frac{1}{a\Gamma(\rho)}\left[\frac{a}{A_L-s}\right]^{\rho+1} exp\left[-\frac{a}{A_L-s}\right]dA_L$$

PROBABILITY OF LANDSLIDE SIZE



The plot shows the probability density of landslide area obtained from the multi-temporal inventory. The curves can be used to model the probability that a landslide will exceed a given size.

PROBABILITY OF LANDSLIDE SIZE

- *We lack a physically based model for the probability of landslide size.*
- *Is landslide area a good proxy for magnitude?*
- *Are there better proxies?*
- *Will statistics of landslide size remain the same in the future, as they were observed in the past?*

OPEN PROBLEMS

The temporal probability of failures depends on the number of landslides that occur in a period.

$$P(N_L) = P[N_L(t) \geq 1]$$

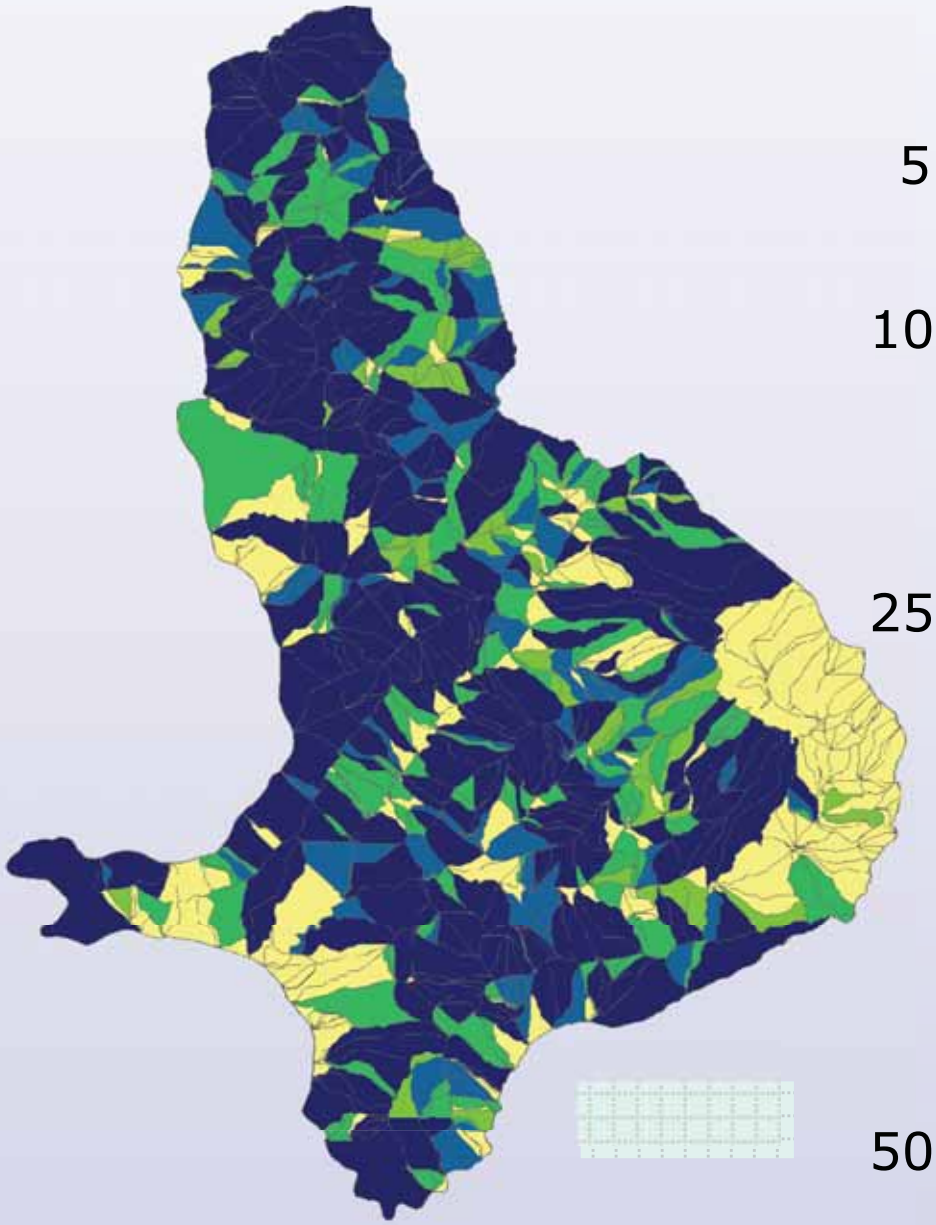
Different distributions can be adopted, including Poisson, binomial, Weibull, and mixed exponential distributions.

$$P[N(t) \geq 1] = 1 - P[N(t) = 0] = 1 - \exp(-\lambda t) = 1 - \exp(-t/\mu)$$

(Crovelli, 2000)

Assuming a Poisson distribution, the probability of experiencing landslides during time t is conditioned on the rate of landslide occurrence (λ), which is related to the mean recurrence interval between events (μ).

TEMPORAL PROBABILITY



5 yrs.

10 yrs.

25 yrs.

50 yrs.

◀ Time

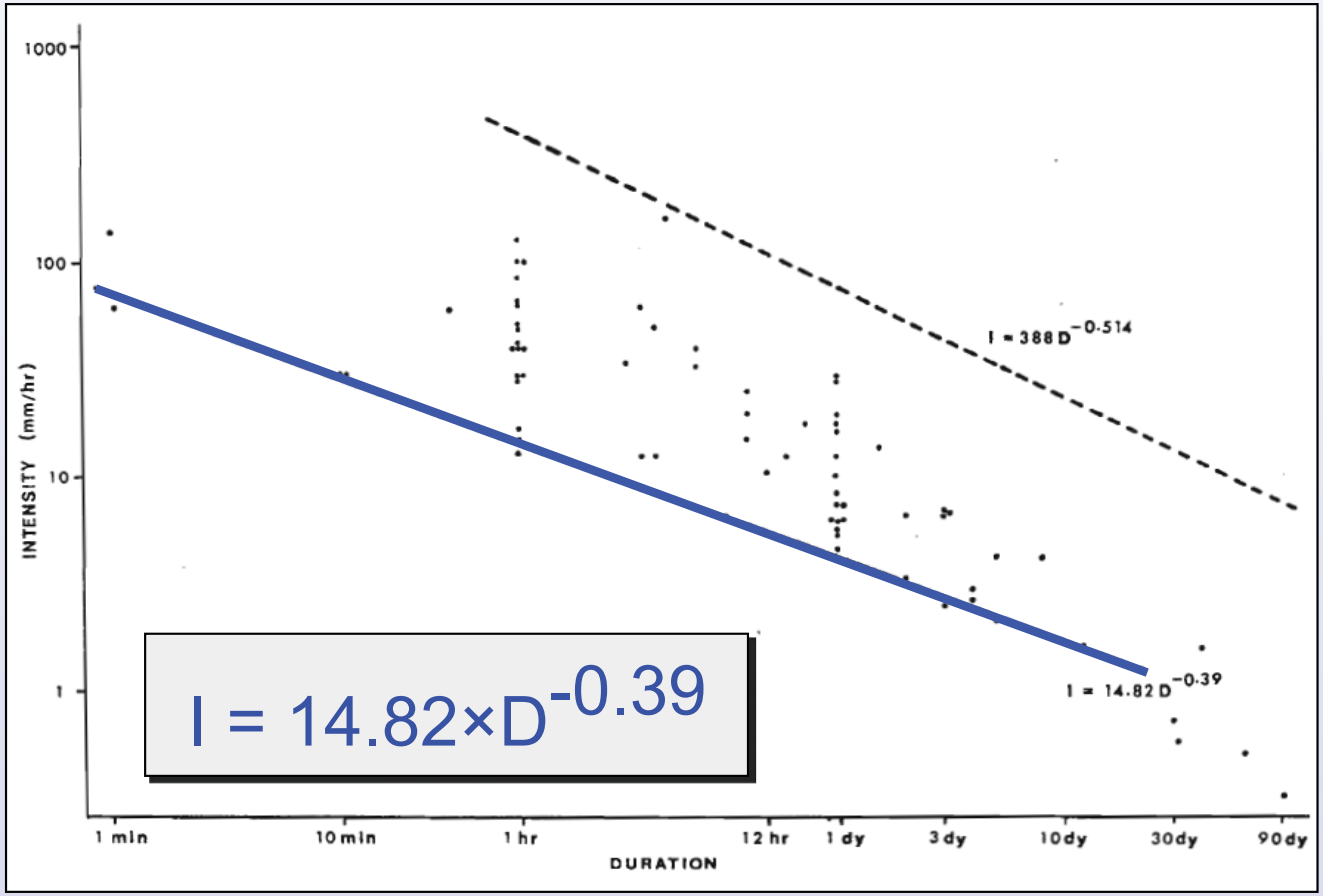
[0.0-0.2] (0.2-0.4] (0.4-0.6] (0.6-0.8] (0.8-1.0]

TEMPORAL PROBABILITY

- ***Are landslides random events in time?***
- ***How climate and environmental changes will affect the frequency of landslides?***
- ***Will the recurrence of landslides remain the same in the future?***
- ***Can we use past events to predict future events?***

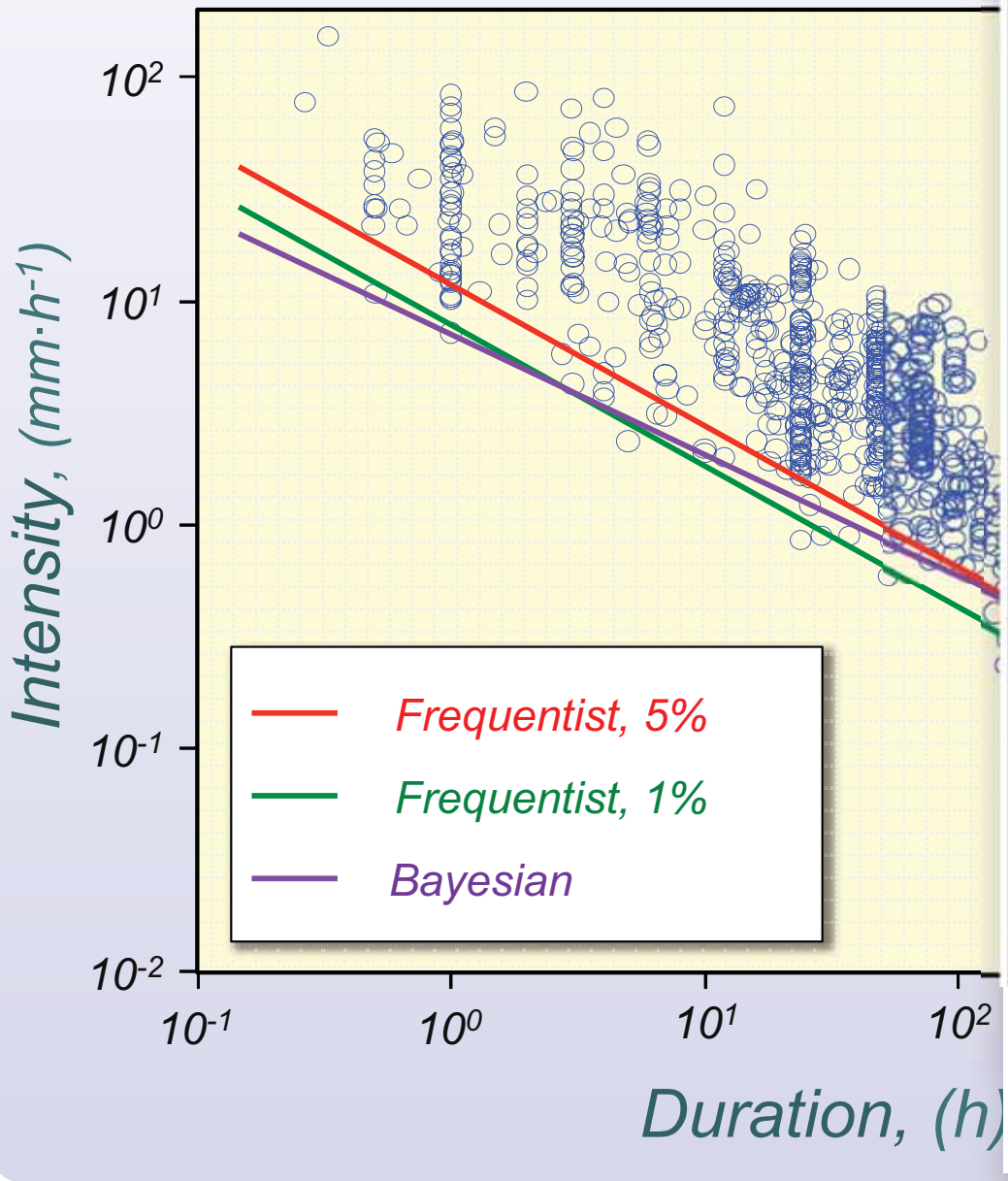
OPEN PROBLEMS

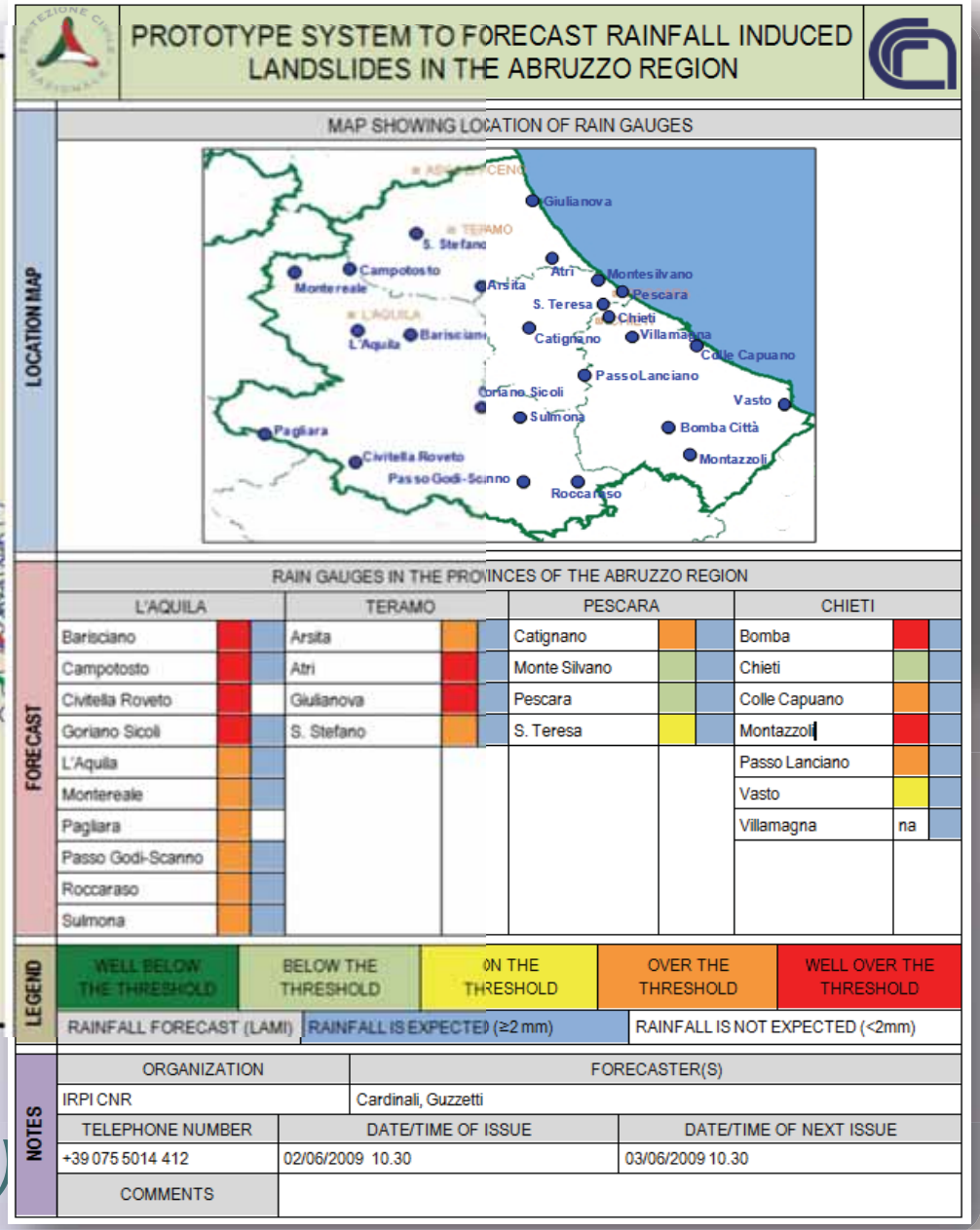
Caine N (1980) *The rainfall intensity-duration control of shallow landslides and debris flows*. Geogr. Ann. A 62: 23-27



Caine was first to attempt a world wide analysis of the rainfall intensity-duration conditions that can result in landslides

INTENSITY-DURATION THRESHOLD

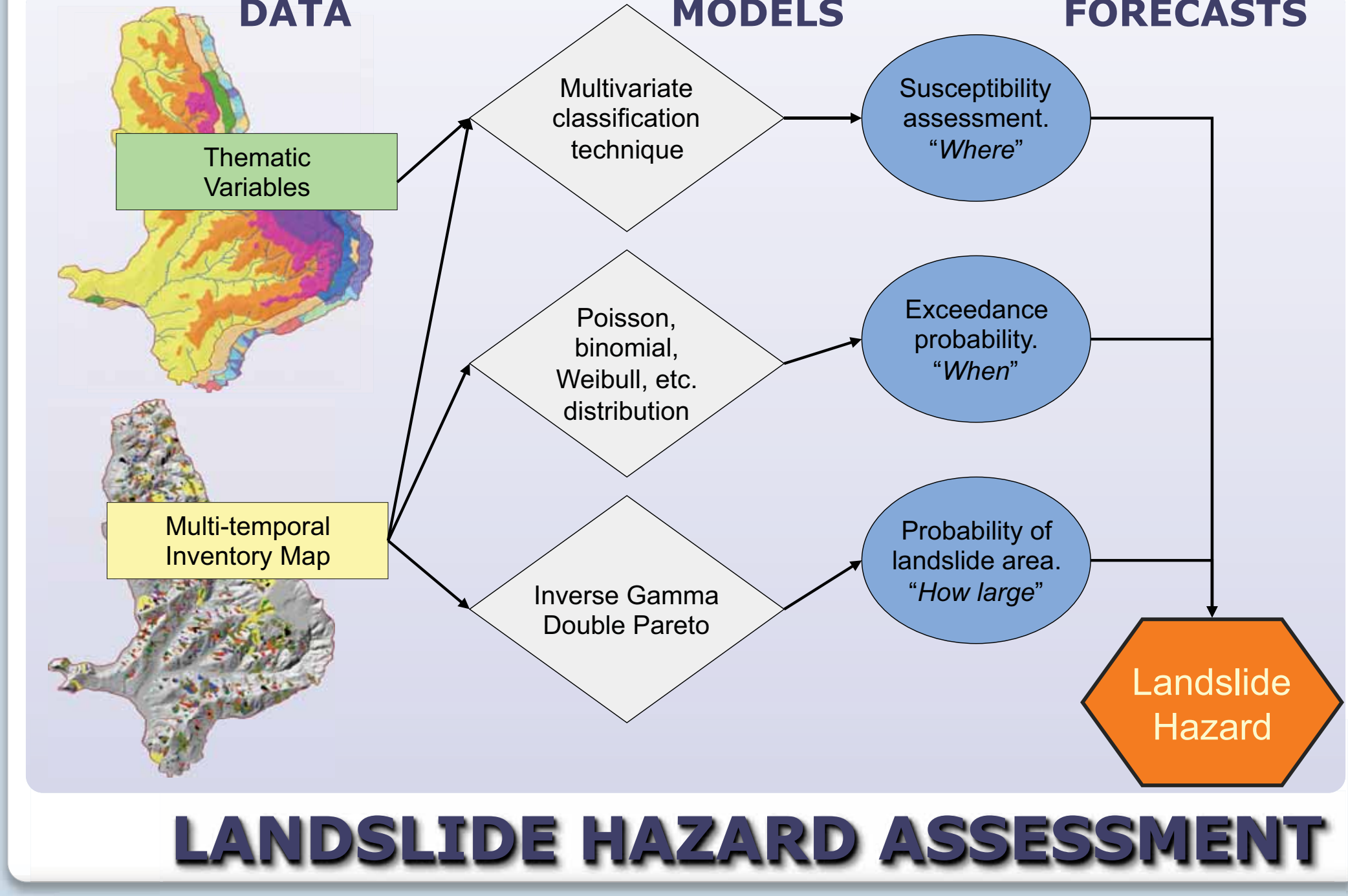




RAINFALL I-D THRESHOLDS IN ITALY

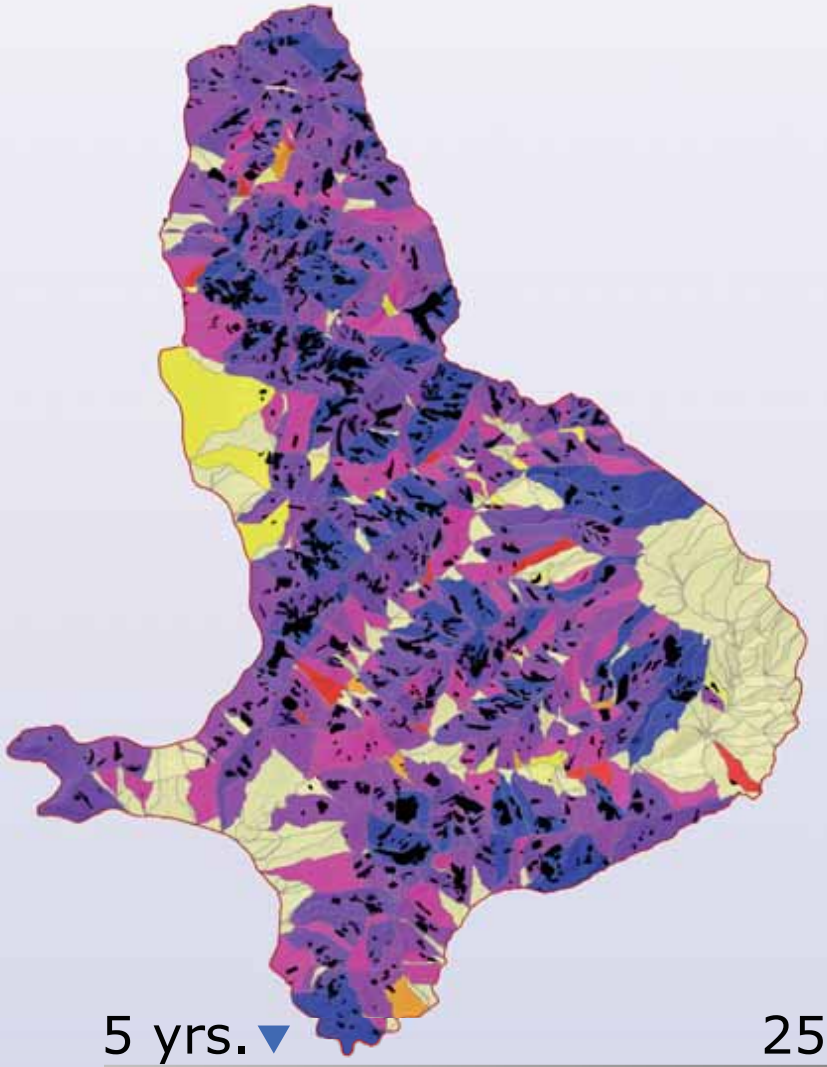
- ***How reliable are our empirical rainfall thresholds***
- ***How can we determine rainfall thresholds where landslide and rainfall information is not available?***
- ***To what extent climate change will affect existing rainfall thresholds?***
- ***How can we incorporate empirical rainfall thresholds in probabilistic hazard assessments?***

OPEN PROBLEMS



LANDSLIDE HAZARD ASSESSMENT

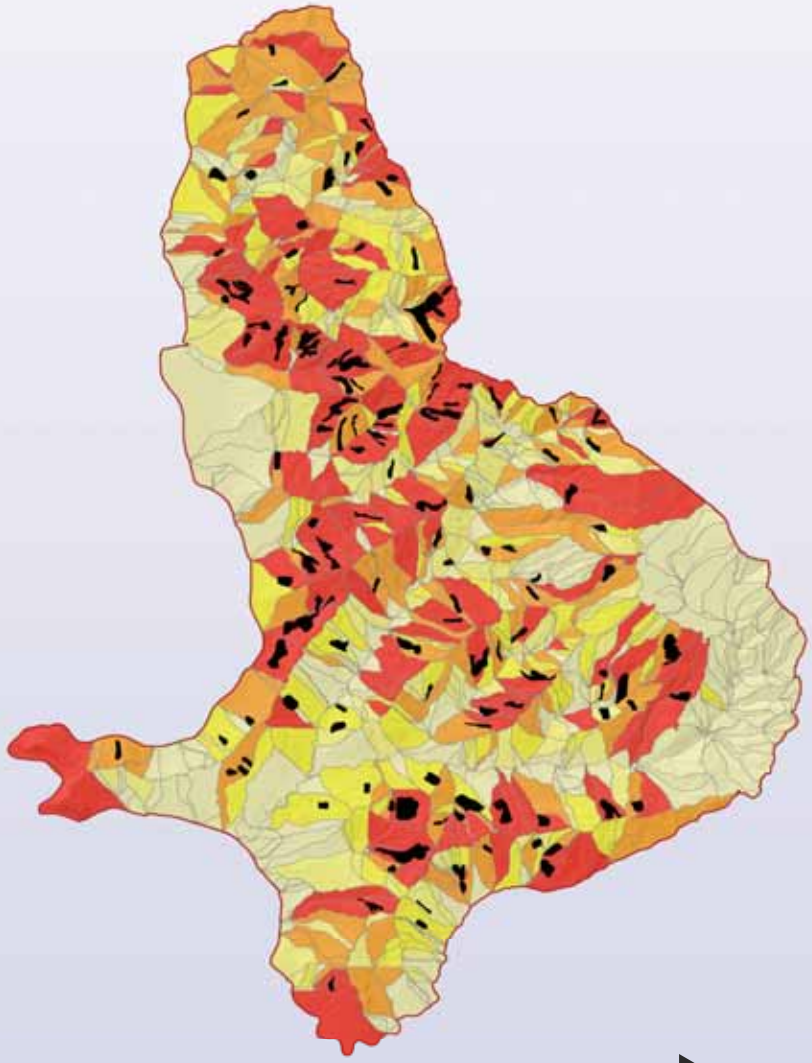
Landslide area ≥ 1000 m²



[0.00-0.02]
(0.02-0.04]
(0.04-0.06]
(0.06-0.08]
(0.08-0.10]
(0.10-0.30]
(0.30-0.50]
(0.50-0.70]
(0.70-1.00]

LANDSLIDE

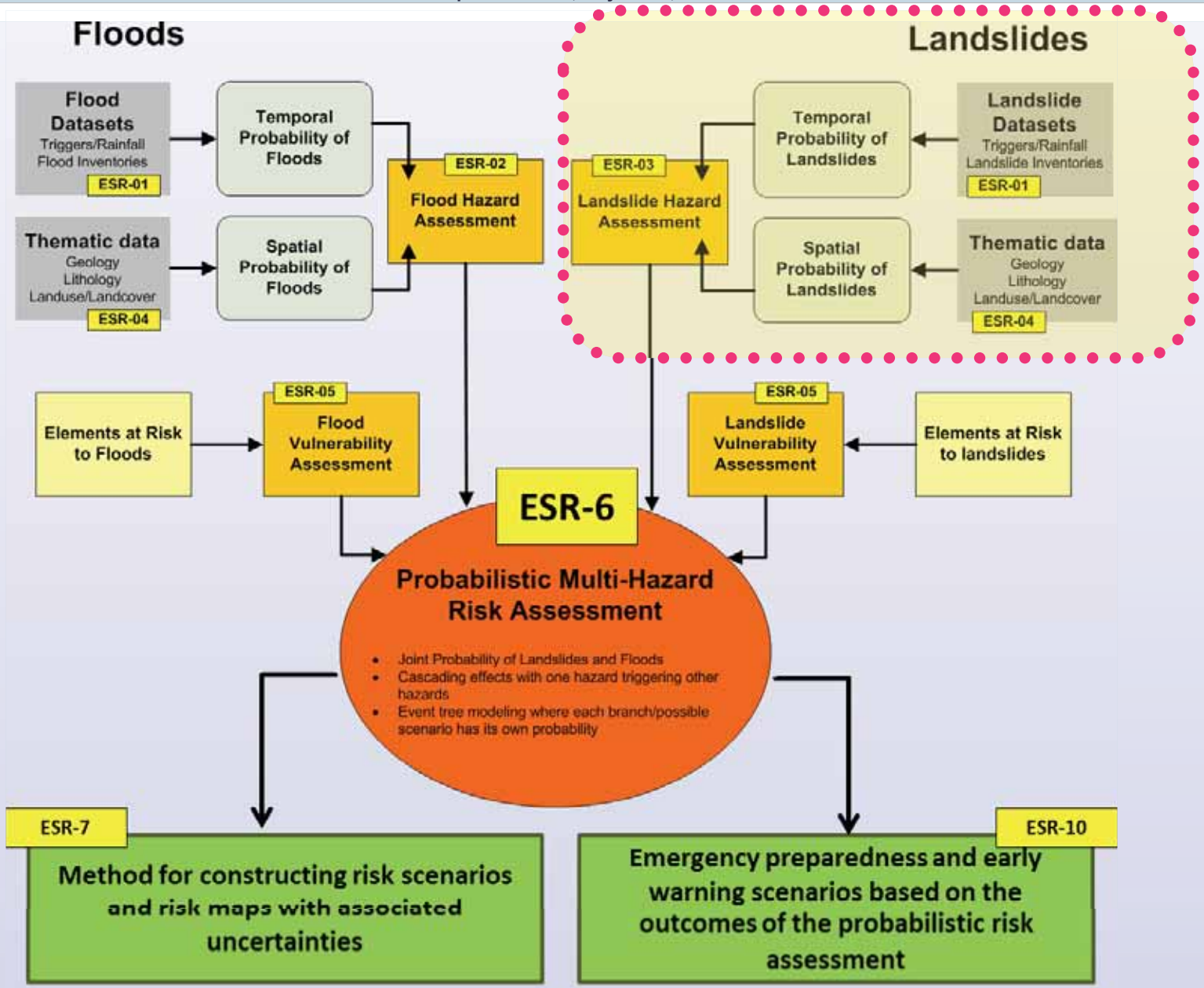
Landslide area ≥ 10,000 m²



5 yrs. ▼ 25 yrs. ▼

10 yrs. ▲ 50 yrs. ▲

LANDSLIDE HAZARD



LANDSLIDE HAZARD ASSESSMENT

- ***Will landslides occur in the future under the same circumstances and because of the same factors that produced them in the past?***

- ***Are the three probabilities of landslide size, of landslide temporal occurrence, and of spatial occurrence of landslides, independent?***

OPEN PROBLEMS

- DIFFERENT METHODS HEVE BEEN PROPOSED TO PREPARE SUSCEPTIBILITY MAPS
- SUSCEPTIBILITY MAPS CAN BE PREPARED USING CONSISTENT, SCIENTIFICALLY-BASED, AND REPRODUCIBLE METHODS
- SUSCEPTIBILITY MAPS CAN BE PREPARED FOR LARGE AREAS
- THE QUALITY OF A LANDSLIDE SUSCEPTIBILITY MODEL SHOULD BE VERIFIED AND TESTED
- LANDSLIDE SUSCEPTIBILITY EVALUATION IS AN IMPORTANT COMPONET FOR THE HAZARD

FINAL REMARKS

- METHODS FOR THE TEMPORAL PROBABILITY AND PROBABILITY OF LANDSLIDE SIZE HAVE BEEN PROPOSED
- THE PREDICTIVE SKILL OF A LANDSLIDE HAZARD MODEL SHOULD BE VERIFIED AND TESTED
- FOR EACH COMPONENT OF THE LANDSLIDE HAZARD EVALUATION WE HAVE IDENTIFIED SEVERAL PROBLEMS
- LANDSLIDE HAZARD EVALUATION IS AN IMPORTANT COMPONENT FOR THE RISK ASSESSMENT

FINAL REMARKS

http://geomorphology.irpi.cnr.it/publications

PROBLEMS??? QUESTIONS???