XIV Convegno Nazionale GIT
17-19 Giugno 2019
Melfi (Pz)

Sessione tematica : "AMBIENTE E TERRITORIO: ICT E METODI QUANTITATIVI PER L'ANALISI DEI PROCESSI GEOAMBIENTALI".

A fracturing state map for Chiavenna Valley: preliminary geostatistical analysis and optimal spatial sampling design

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UNIVERSITÀ DEGLI STUDI DI MILANO
DIPARTIMENTO DI SCIENZE DELLA TERRA

STUDY PURPOSE

Suceptibility and **hazard** maps for rockfalls, and rockslides at the **regional scale**.

Controlling factors

Rock mass quality and characteristics

Type of factor C=control factor
R=Rockfall
C=critical
H=High

Corominas, 2014

Group	Parameters	Relevance for landslide susceptibility and hazard assessment	Type of factor		Landslide mechanisms		
			C	T	R	S	L
Geology	Rock types	Determine the engineering properties of rock types	●		C	H	C
	Weathering	Types of weathering (physical/chemical), depth of weathering, individual weathering zones and age of cuts are important factors	●		C	H	H
	Discontinuities	Discontinuity sets and characteristics, relation with slope directions and inclination	●		C	M	H
	Structural aspects	Geological structure in relation to the slope angle/direction	●		H	H	H
	Faults	Distance from active faults or widths of fault zones	●		H	H	H

STUDY PURPOSE

Suceptibility and **hazard** maps for rockfalls, and rockslides at the **regional scale.**

Controlling factors

Rock mass quality and characteristics

Geostatistical Spazialitazion

Fracturing grade

Rock Mass hydrogeological behaviour

Joint conditions

Jv + ke + W, JRC, JCS

This study

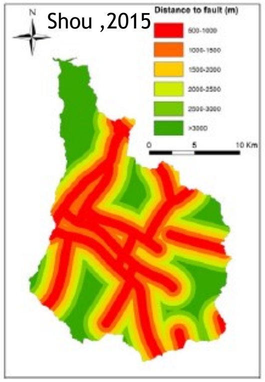
Future study

STUDY PURPOSE

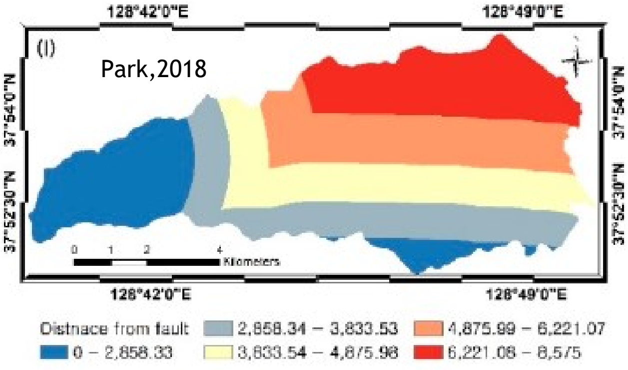
Jv-Joint Volumetric Count (number of fractures/m^3)

$$Jv = \frac{100}{S_{K1}} + \frac{100}{S_{K2}} + \dots + \frac{100}{S_{Kn}}$$ (S=spacing)

Rock mass fracture distribution, discontinuity arrangement reduce both **strength** and **deformability** of the rock mass



(g) distance to fault



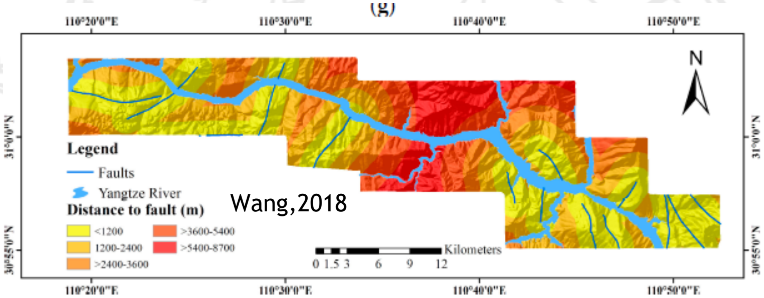
Traditional attempt to include structural influence and stress field

<u>Distance to fault</u>

- Mismatched fault-instability scale
- No distinction between active and
- inactive

  faults behaviour
- Subjectivity of distance classes!

} <u>Critical issues</u>



(h)

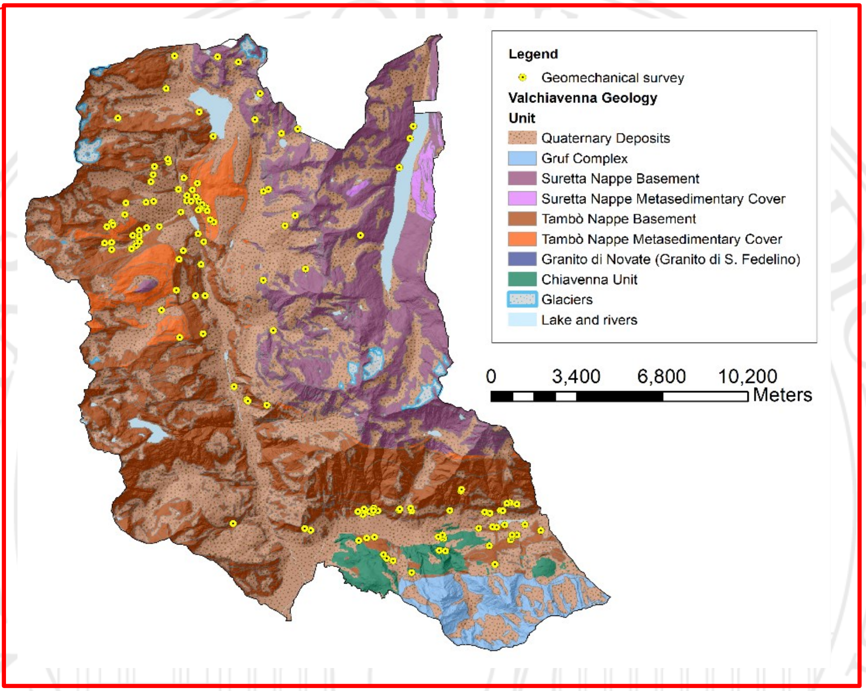
RICH DATA ENVIRONMENT: VALCHIAVENNA

"A problem with structural data is that they are time consuming to collect, and difficult to interpolate spatially over large areas. " (Reichenbach, 2018)

Stazione Valchiavenna per lo studio dell'ambiente alpino

Rich data environment: Valchiavenna case study

-Geomorphological-structural field survey
-Geomechanical field survey



GEOMECHANICAL DATA ANALYSIS

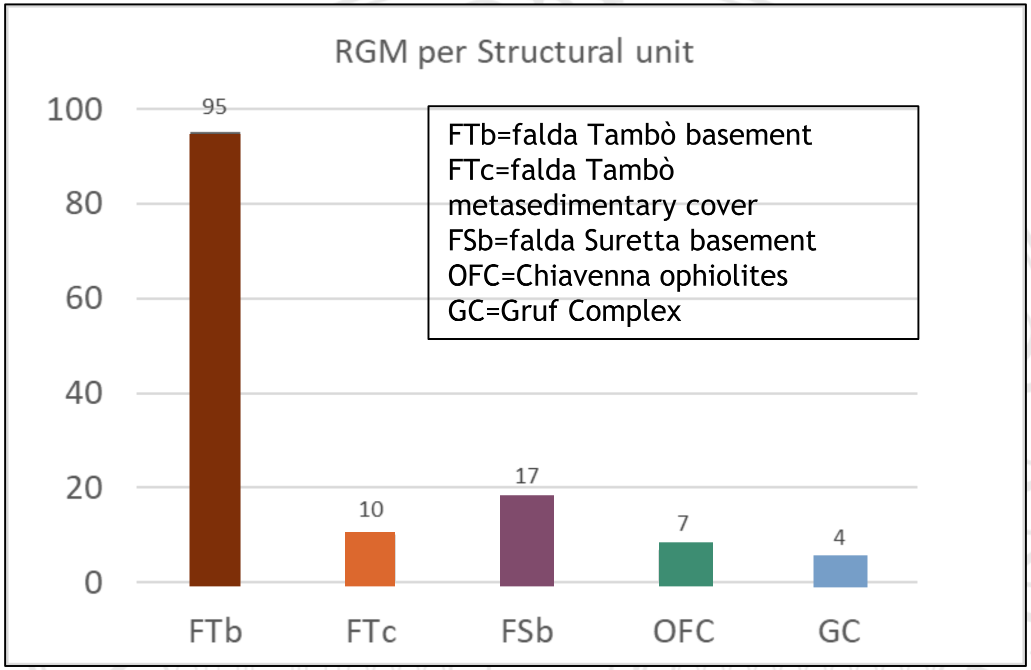
133 Geomechanical survey collected from 2000 to 2018

- Information internal heterogeneity and incompleteness (SUB-DATABASES)
- Data clustering

Depending on survey purpose, problem scale and logistic conditions

<u>Most collected</u>
-Jv, spacing, frequency (133)
- JRC (130)

<u>Less collected</u>
-Aperture (72)
- JCS natural and fresh (63)



<u>Primary variables</u>
spacing, intercept, aperture, JCS, JRC

<u>Secondary variables</u>
Jv, GSI, RMR, weathering grade, weathering delta, equivalent permeability

GEOSTATISTICAL ANALYSIS: Esploration Data Analysis

Ordinary Kriging

Jv independence from the other primary variables

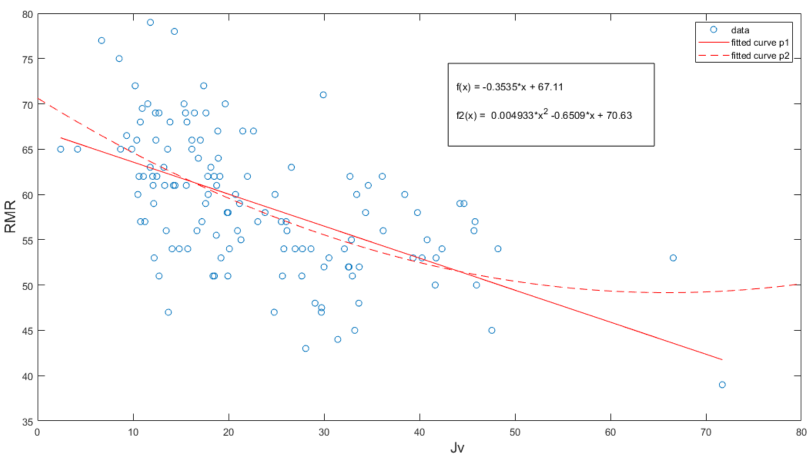
Bivariate Analysis – Correlation Matrix

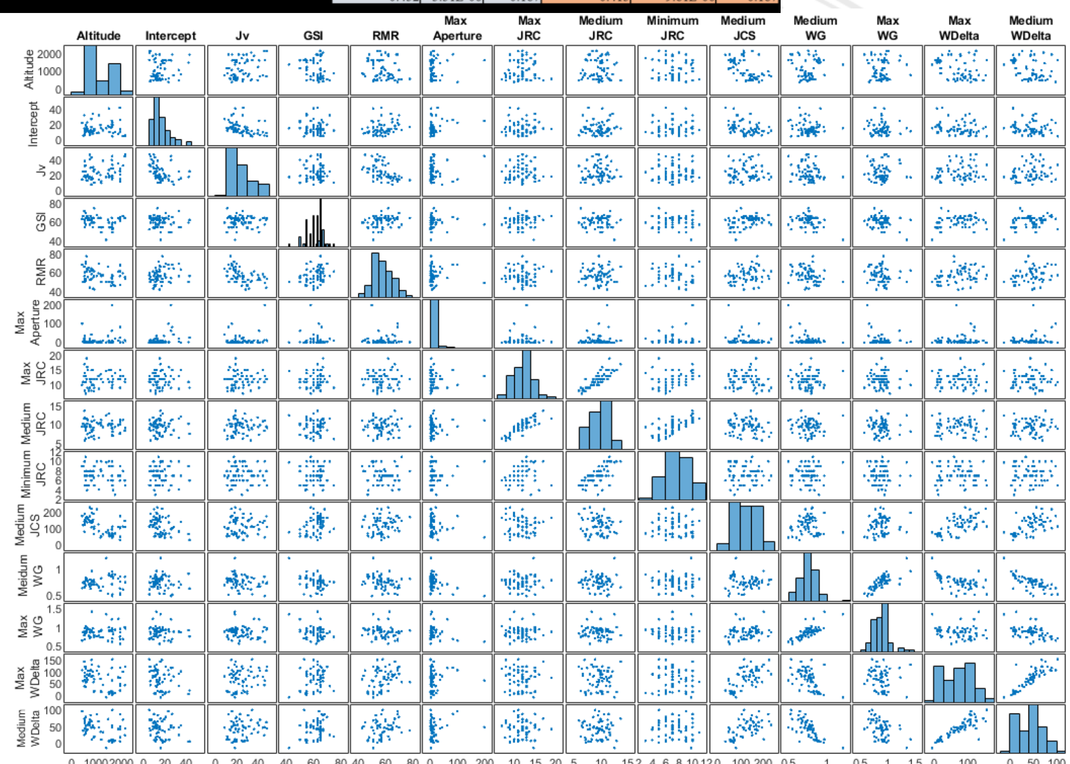
	r-Pearson	p-value	R²	r-Spearman	p-value	R²
[redacted]	-0.3345	0.0074	0.119	-0.3279	0.0087	0.1889
[redacted]	-0.3285	0.0086	0.108	-0.3379	0.0068	0.1812
[redacted]	-0.5646	1.44E-06	0.3188	-0.5683	1.19E-06	0.4153
[redacted]	-0.355	0.0043	0.126	-0.3433	0.0059	0.1261
[redacted]	0.3434	0.0059	0.1179	0.3516	0.0047	0.131
[redacted]	0.3094	0.0136	0.0958	0.2496	0.0048	0.128
[redacted]	-0.4991	1.09E-05	0.249	-0.5171	4.58E-06	0.3336
[redacted]	-0.432	3.31E-06	0.187	-0.413	9.81E-06	0.187

Sub-database dependency

RMR=-0.3535Jv+67.11
r_Pearson=-0.5613
p=2.5524E-12
R^2 =0.315

RMR=0.0049Jv2-0.6509Jv+70.63
r_Spearman=-0.5891
p=1.09E-13
R2 =0.3363





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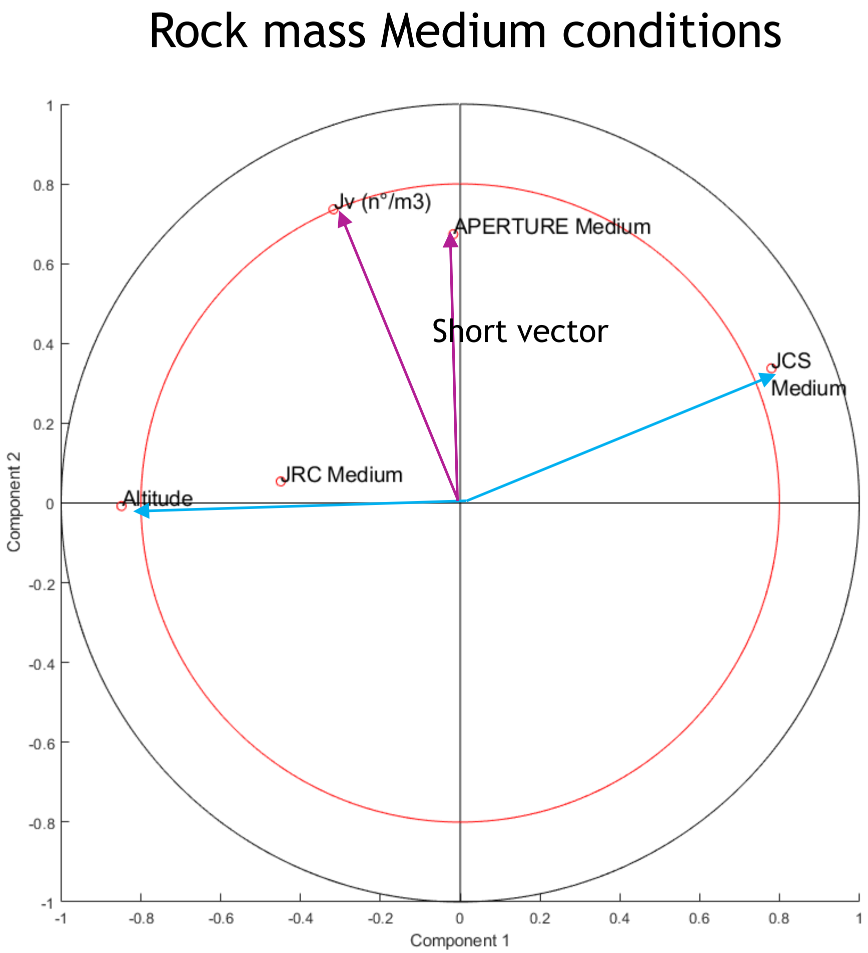
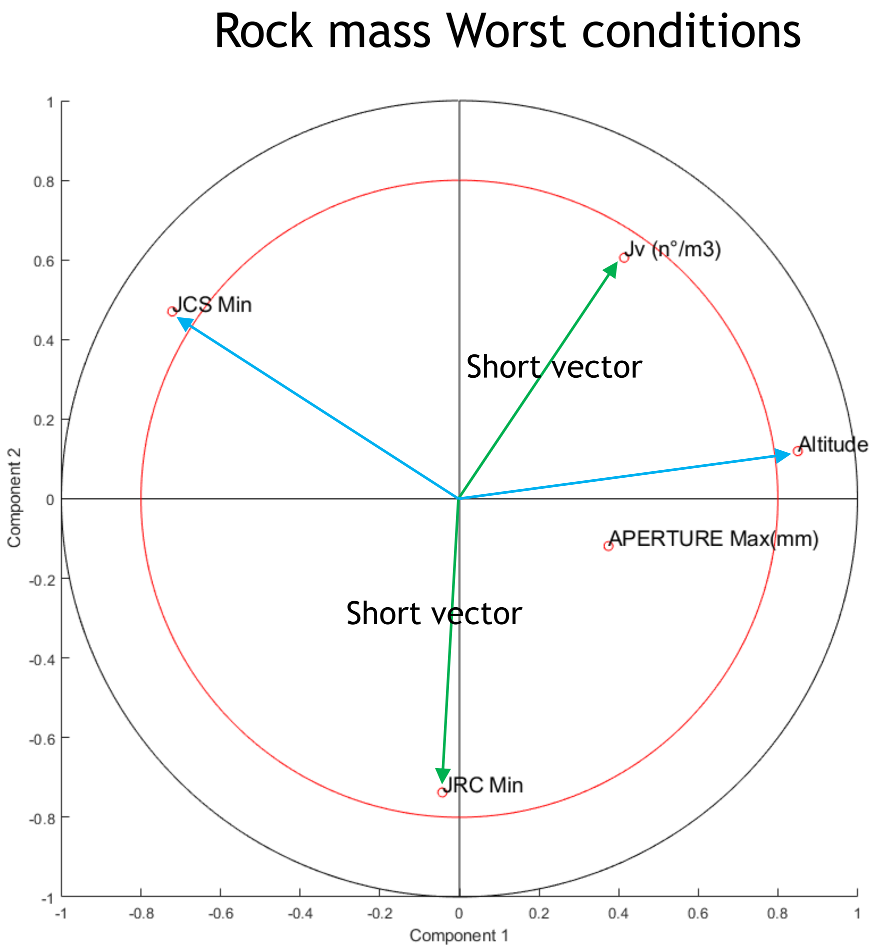
Multivariate Correlations: Principal Component Analysis

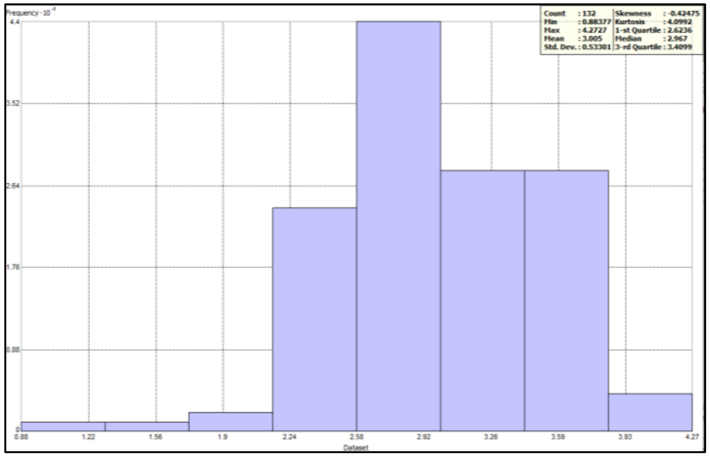


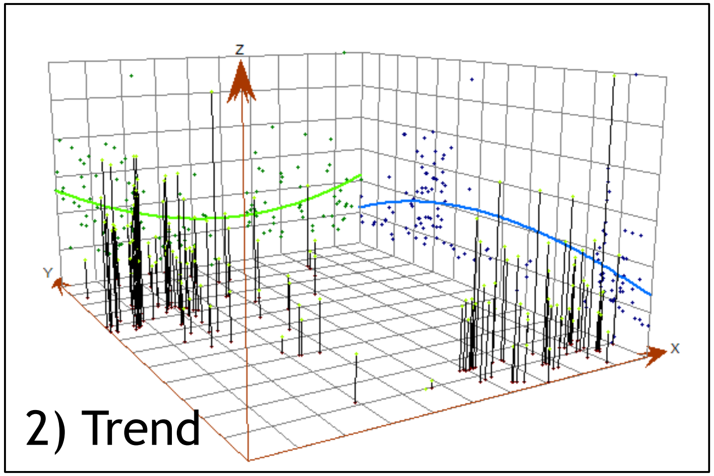


In both cases ~75% of system variability can be explained by 3 principal components.

GEOSTATISTICAL ANALYSIS: Esploration Spatial Data Analysis

1) Normality→ log-transformation



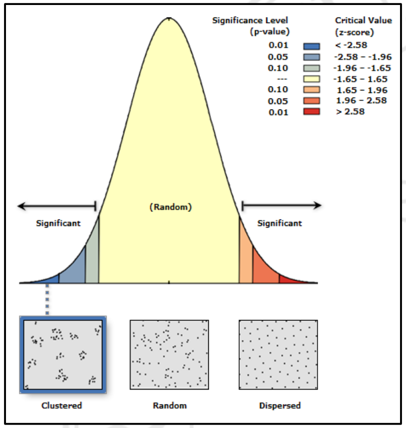


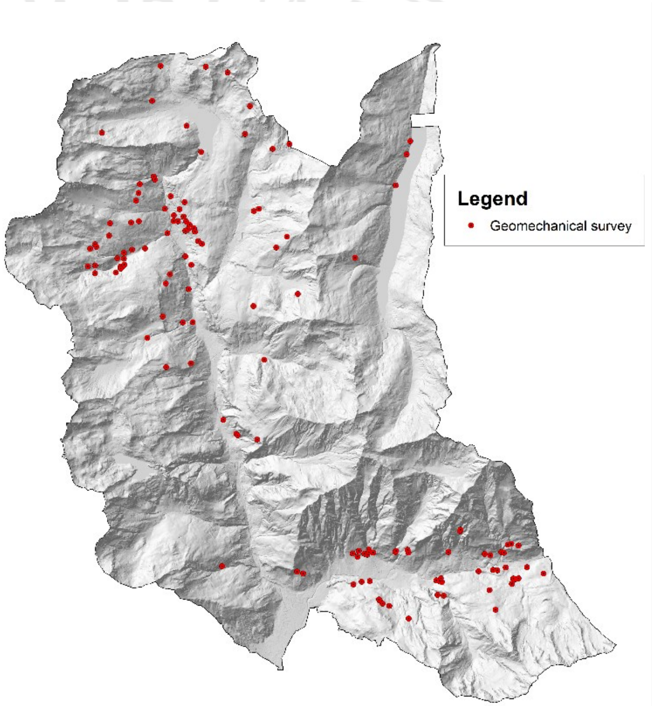
2) Trend

Geostatistical analyses are more reliable and robust if these conditions are satisfied

3) Clustering
R=0.57 nearest neighbour index

R=1 random ✓
R<1 clustered ✗
R>1 dispersed ✗





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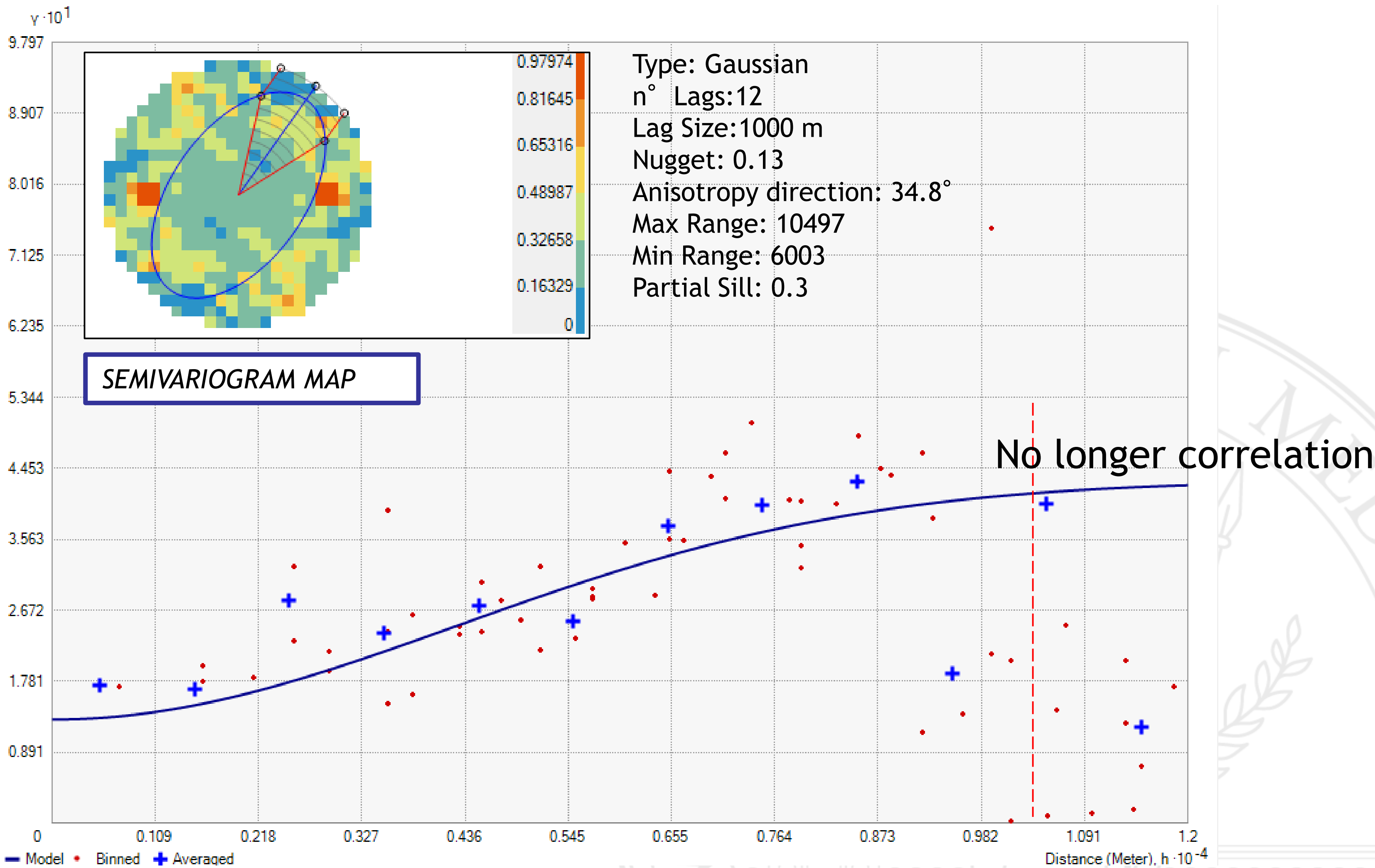
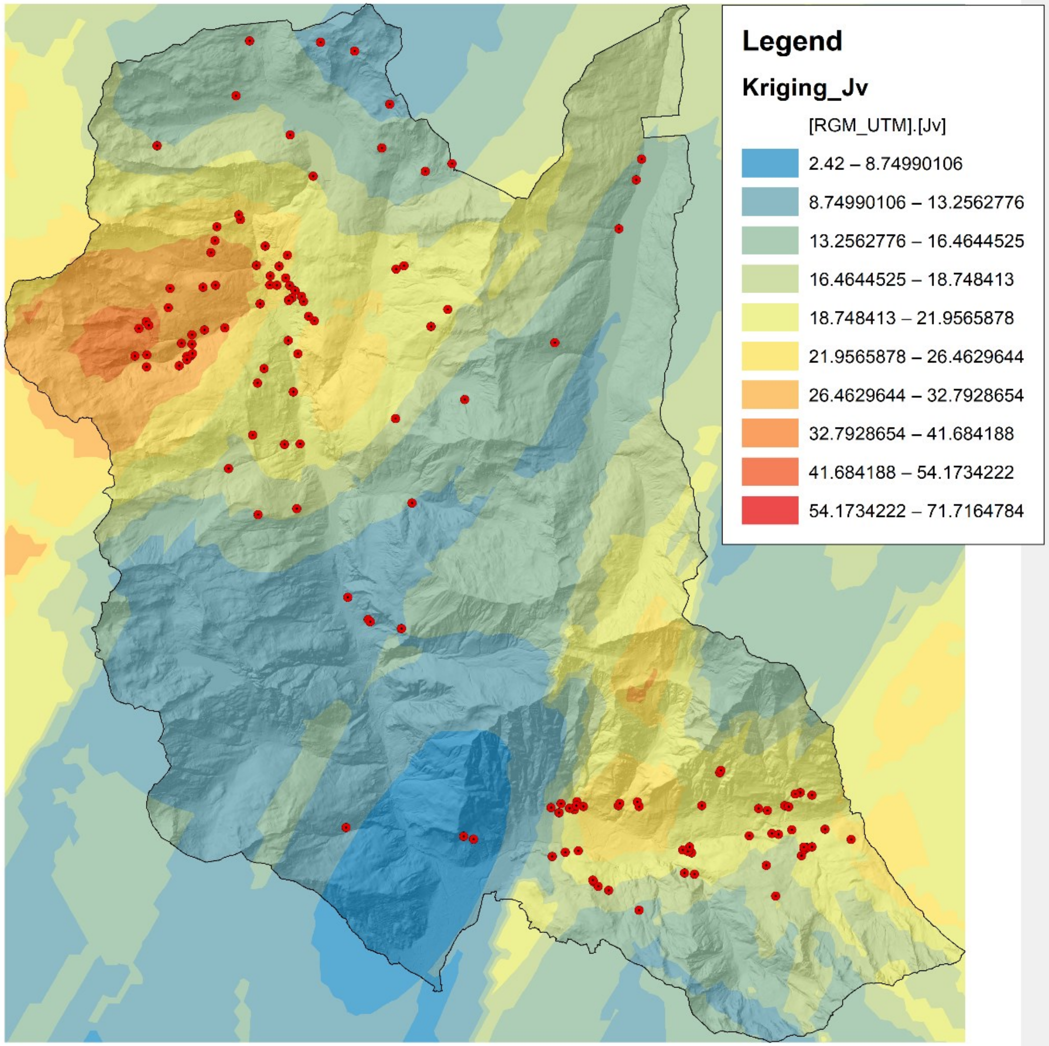
GEOSTATISTICAL ANALYSIS: Variography

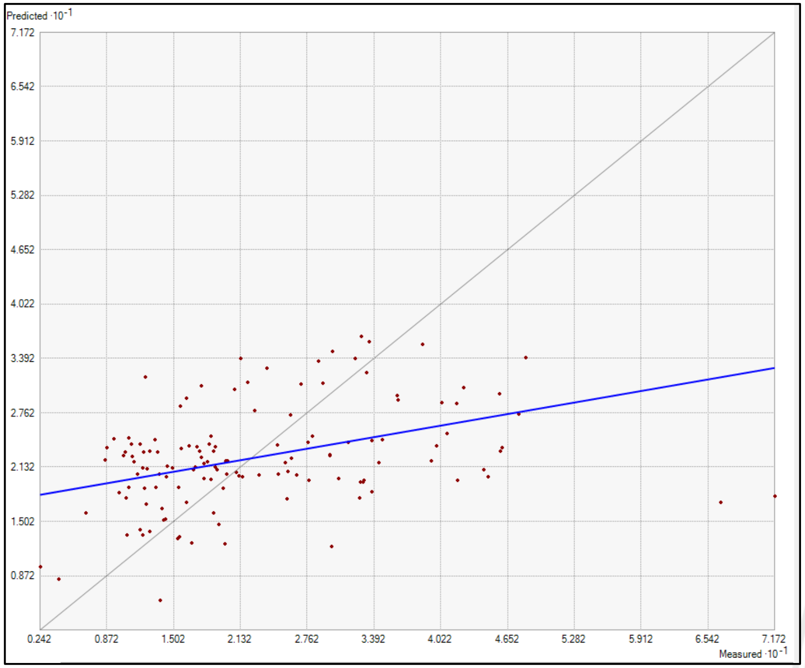


GEOSTATISTICAL ANALYSIS: Prediction

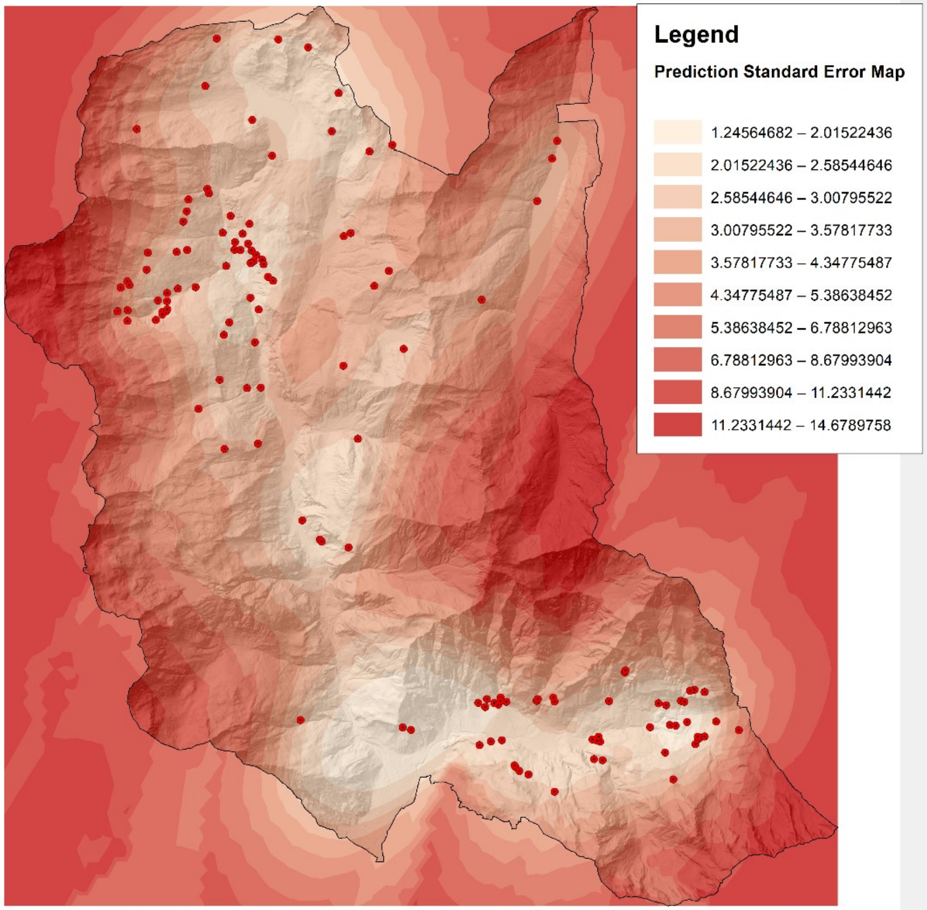


GEOSTATISTICAL ANALYSIS: Cross Validation and Error

CROSS VALIDATION



RMS 11.48
Standard_RMS 1.46
Average Standard Error 9.28



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SURVEY PLANNING

→ Exploration Data Analysis suggests the necessity to **homogenize and complete the old database**

→ Geostatistics on Jv suggests the necessity of a **new survey to densify data →30**

- Declustering previous data
- Improving spatialitazion robustness and reliability

Addressing COST, TIME, REACHABILITY by maximising the geostatistics prediction
and
Taking inspiration from other disciplines such as ecology and agriculture (Digital Soil Mapping)

Implementation of the MODEL BASED SAMPLING TECHINQUE of

SPATIAL SIMULATED ANNEALING (SSA) implemented in the R platform

(Van Groeningen et al 2000, Brus et al 2018)

SPATIAL SIMULATED ANNEALING ALGORITHM: THEORY

ITERATIVE RANDOM SEARCH OPTIMIZATION =sequence of possible sampling scheme is generated

S0 initial random scheme

S_{i+1} Random Perturbation of S0 configuration over a vector

Transition acceptance probability Pt defined by Metropolis Criterion

ϕ(S)= fitness function to be minimized i.e. MKV

$$\begin{cases} P_T(S^* \rightarrow S_i) = 1 & \phi(S_i) \leq \phi(S^*) \\ P_T(S^* \rightarrow S_i) = exp\left(\frac{\phi(S^*) - \phi(S_i)}{T}\right) & \phi(S_i) > \phi(S^*) \end{cases}$$

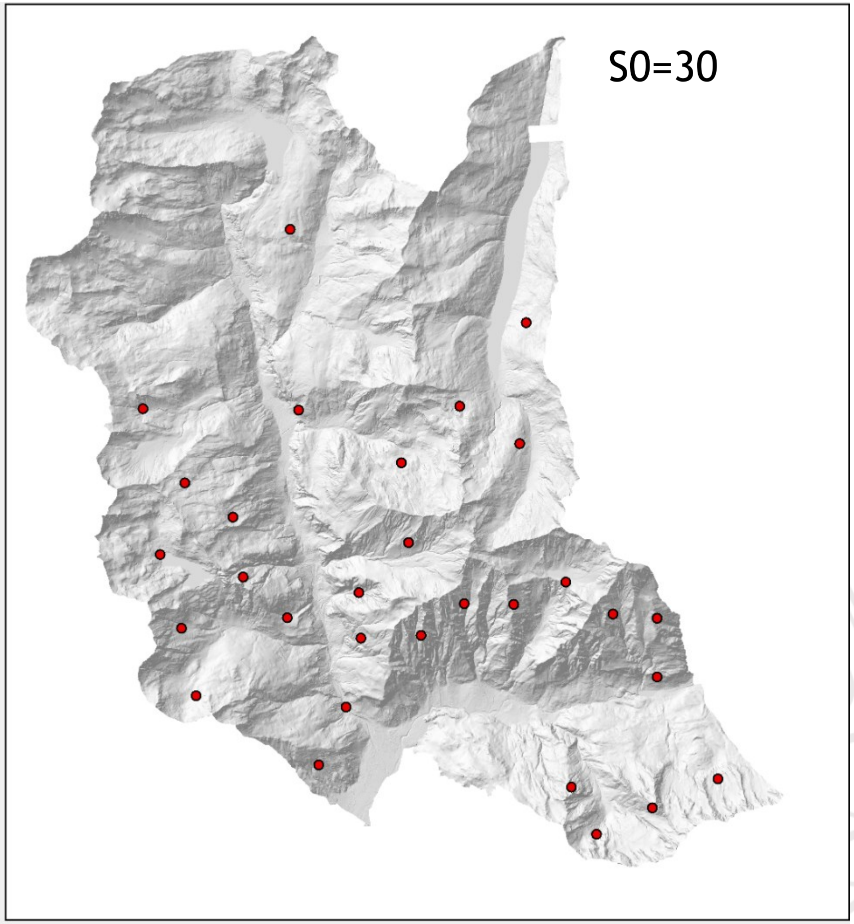
P is function of T=annealing temperature
Worse combination accepted with a certain P to avoid local minima

T0 initial system Temperature is decreased by a **cooling rate** towards 0, thus worse combination acceptance → 0

Stop criterion: persistence of the optimal transient solution for a given number of iterations (Nstop)

SPATIAL SIMULATED ANNEALING ALGORITHM: PRACTICE

S0	Random initial sampling (same number of the new sampling) produced by SPCOSA R package
Grid of the study area	GRID 250x250 superimposed by OUTCROP MAP of the area to avoid soil or vegetation covered areas in the sampling scheme
Previous data	PREVIOUS COLLECTED RGMFIXED PART OF THE SAMPLING SCHEME i.e. RANDOM VECTOR =0
Prediction grid	Square grid derived from initial GRID where MKV is computed at each iteration
Kriging variance layer	Kriging layer deriving from Ordinary Kriging on previous RGM
Model paramete rs	Cooling rate=0.9 and geometric law Stop criterion Nstop=10 Initial Temperature T0=0.1 and T0=0.002



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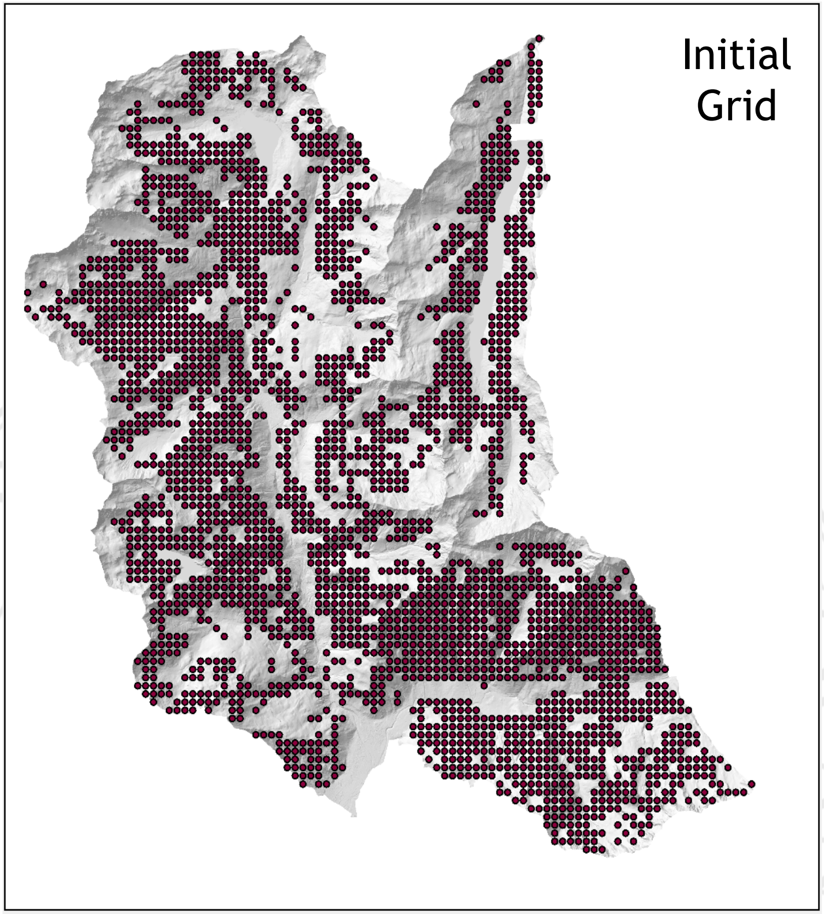

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Grid of the study area

GRID 250x250 superimposed by OUTCROP MAP of the area to avoid soil or vegetation covered areas in the sampling scheme

Previous data

PREVIOUS COLLECTED RGM FIXED PART OF THE SAMPLING SCHEME i.e. RANDOM VECTOR =0

Prediction grid

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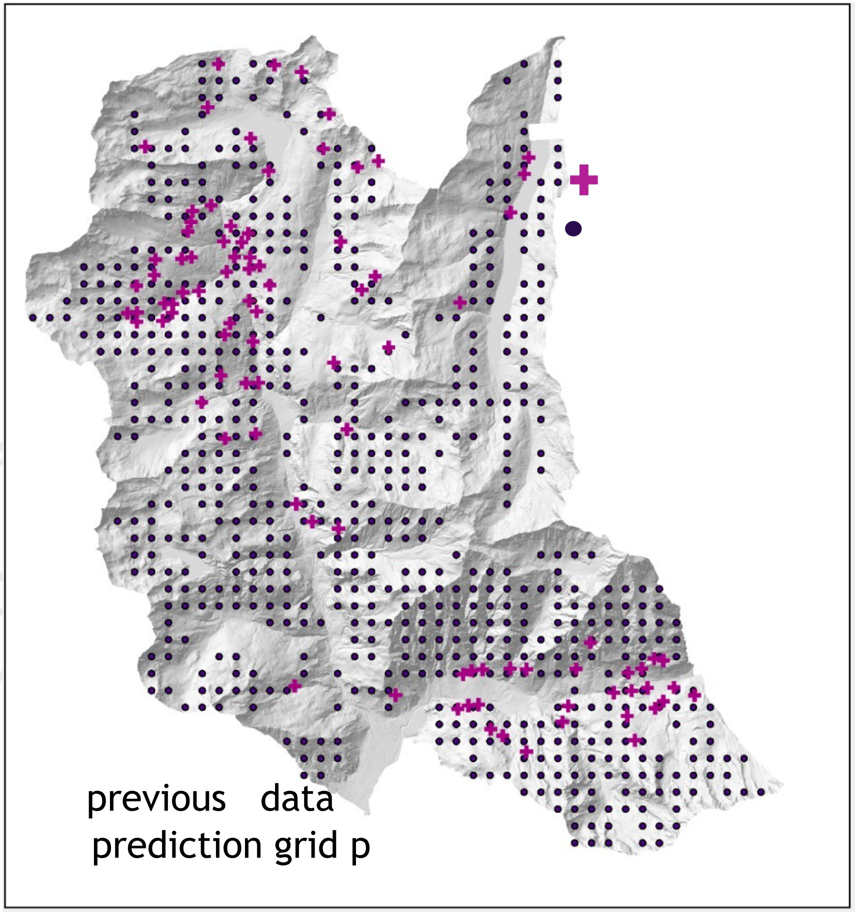

SPATIAL SIMULATED ANNEALING ALGORITHM: PRACTICE

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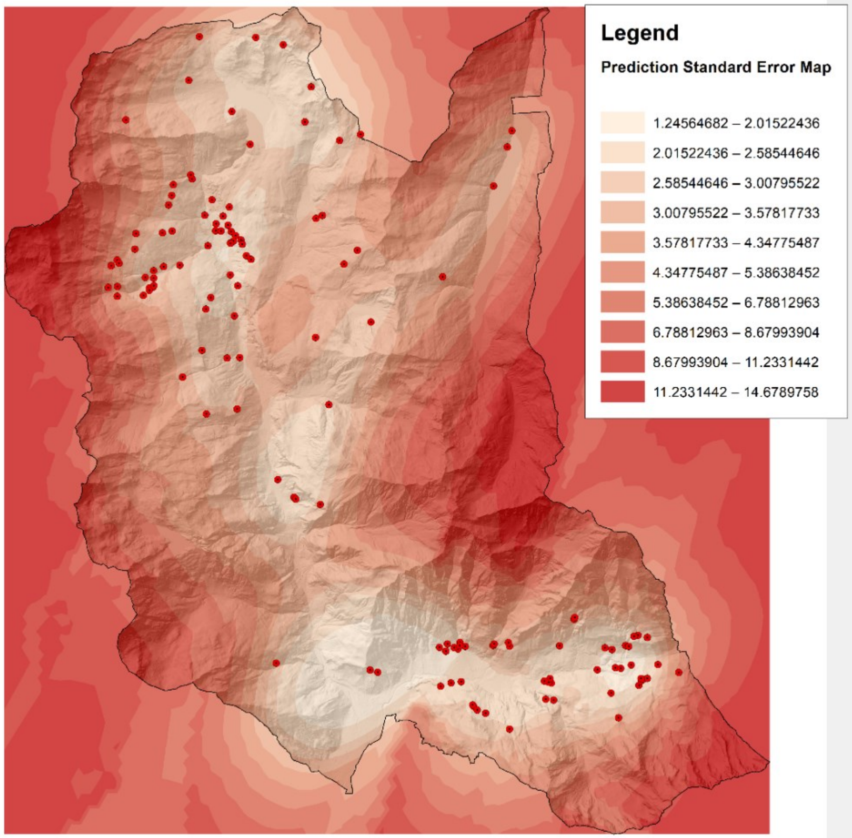

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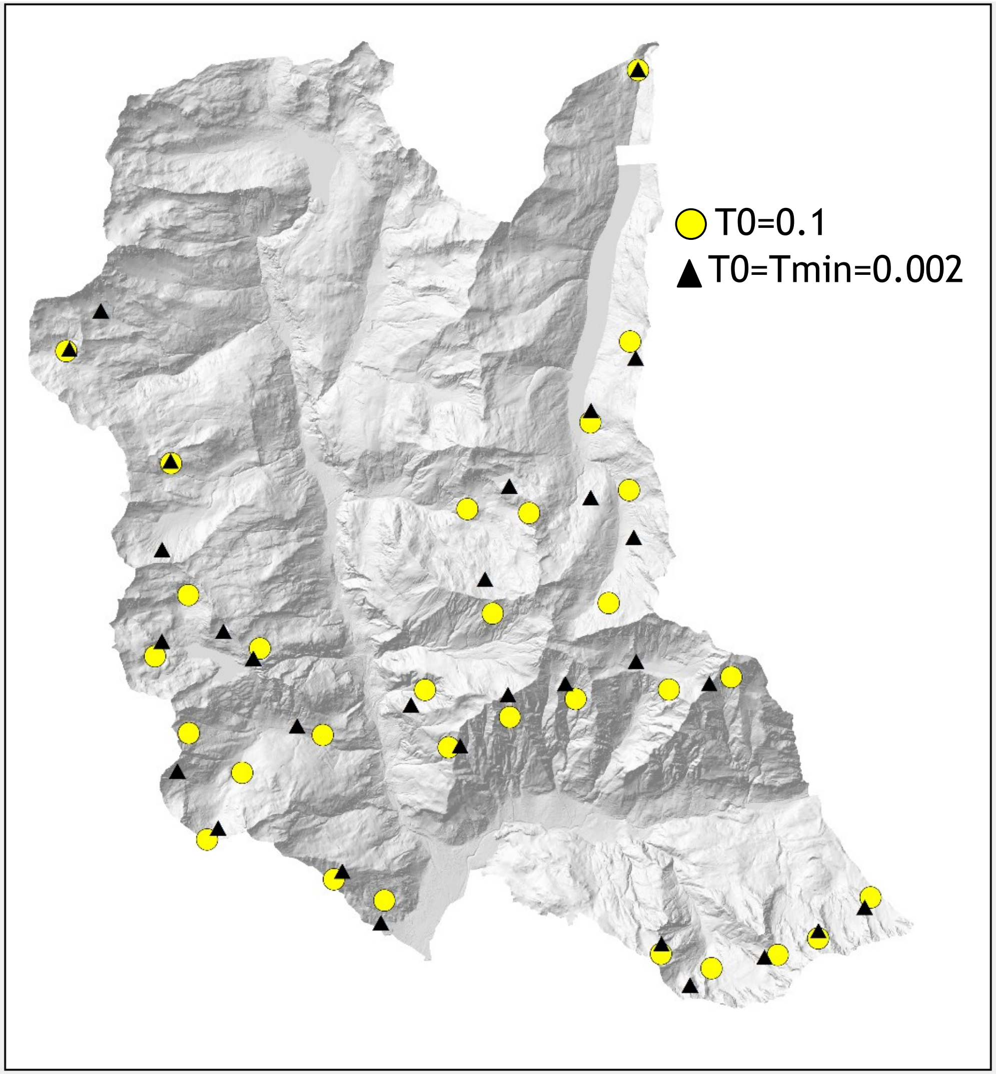
Optimal parameters inferred from literature and different tests

SPATIAL SIMULATED ANNEALING ALGORITHM: RESULTS



Sensitivity to Initial Temperature

T0=0.1 Initial acceptance rate 100% for the first iterations

T0=0.002=Initial average acceptance rate 95%

calculated by running a fast (rapid temperature decrease) schedules
T0=1 with cr=0.5,0.85,0.9
T0=10 with cr=0.5,0.85,0.9

However the variation is generally acceptable with +/- essential points (i.e. the ones with > coincidence)
"Real" surveys will be necessary adjusted to logistic and terrain conditions

SUMMER 2019 SURVEY PLAN

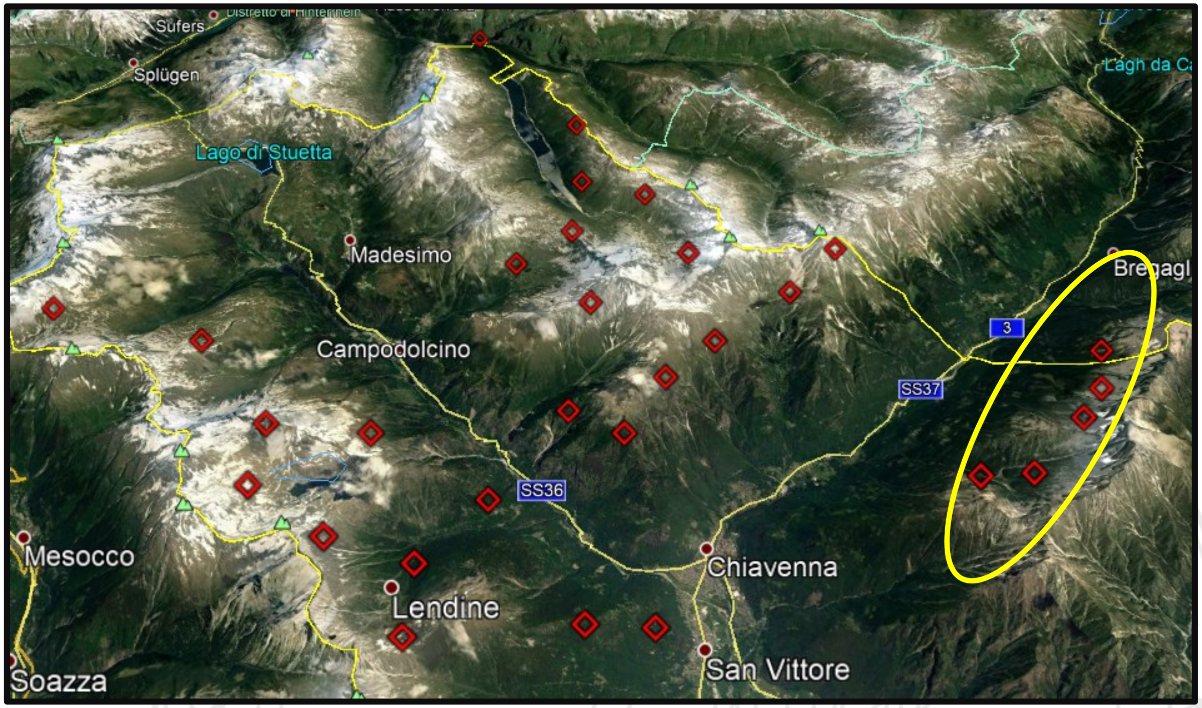
Tracks checking and facilities (Shelters, roads..) individuation

South Bergell Valley inaccessible areas

UAV

And/or

Land photogrammetry



CONCLUSIONS and FUTURE PERSPECTIVES

1. Homogenizing and completing old surveys → Reconsidering bivariate and multivariate correlations

2. Implementing new 30 survey wich would maximize geostatistical prediction thanks to SSA → New Geostatistical spatialization by OK, but also considering others techniques (e.g. 3D ordinary kriging and Sequential simulations, MPS)

3. Comparing the results with other fracturing maps sources

Thanks for your attention!

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Dott. Corrado Camera

Prof.ssa Tiziana APUANI

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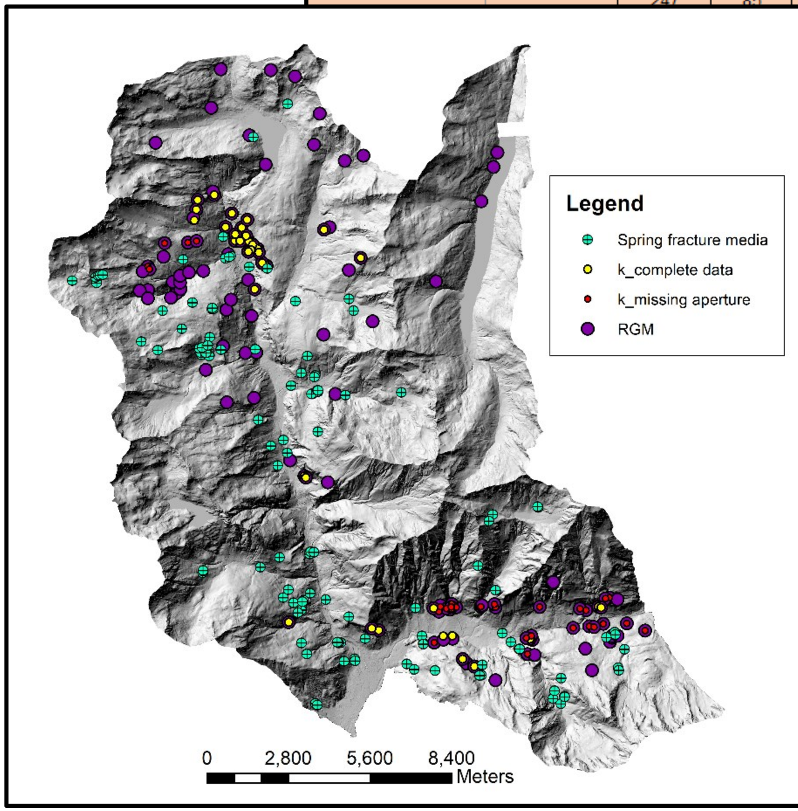
MATERA 2019 OPEN FUTURE

Approfondimenti

PERMEABILITY TENSOR AND EQUIVALENT PERMEABILITY

Codice originario	UNITA' formazionale	imm	incl	strike	spaziatura sistema(m)	frequenza sistema(1/m)	Apertura (mm) misurata	JRC (10cm)	Apertura Idraulica m	K equivalente m/s
cp01	FTb	128	30	38	0.098	10.235	0.07	6	5.56E-08	4.92E-06
		104	70	14	0.122	8.197	0.05	9	1.03E-08	
		153	45	63	0.312	3.205	28	8	4.33E-03	
		260	60	170	0.227	4.398	0.23	8	2.92E-07	
cp02	FTc	210	80	120	0.135	7.435	2.01	11	1.01E-05	1.73E-09
		116	40	26	0.058	17.241	0.11	5	2.16E-07	
		298	65	28	0.103	9.681	1.7	11	7.20E-06	
cp03	FTb	148	35	58	0.183	5.461	14.7	10	6.83E-04	0.6456
		345	78	75	0.910	1.099	83.7	15	8.04E-03	
		247	85	157	1.866	0.536	52.4	7	2.12E-02	
				117	0.191	5.247	15.8	14	3.40E-04	
				41	0.106	9.434	0.06	6	4.08E-08	4.65E-07
				113	0.146	6.849	36.9	12	2.73E-03	
				1	0.158	6.329	0.06	12	7.22E-09	
				72	0.149	6.702	2.1	9	1.81E-05	5.25E-09
				132	0.207	4.824	1.8	11	8.07E-06	
				120	0.313	3.196	0.8	12	1.28E-06	
				21	1.086	0.921	2.1	9	1.81E-05	



Matlab script automatic calculation of permeability tensor from in situ data

$$\underline{\boldsymbol{K}} = \frac{g}{12\nu} \cdot \sum_{i=1}^{N} f_i \cdot e_i^3 \cdot \left[\mathbf{I} - \overrightarrow{\boldsymbol{n}_i} \otimes \overrightarrow{\boldsymbol{n}_i}\right]$$

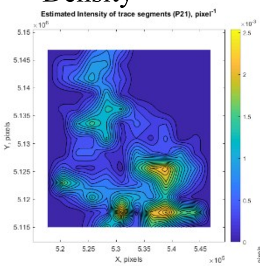
$$e = \frac{E^2}{JRC_0^{2.5}}$$

Problem: Incomplete dataset and extremely clustered data

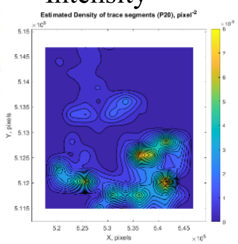
Structural/fracturing setting information sources

1) Structural/geomorphological on-field survey (1:10000)

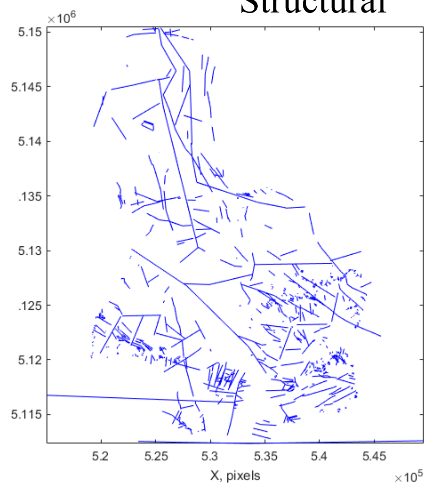
Density



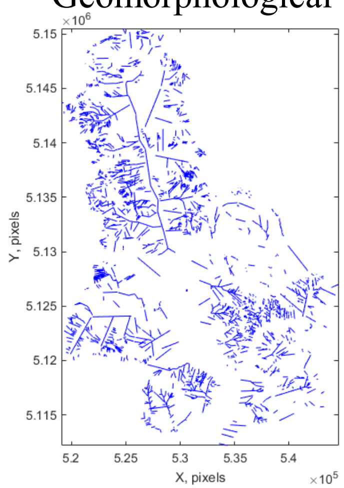
Intensity



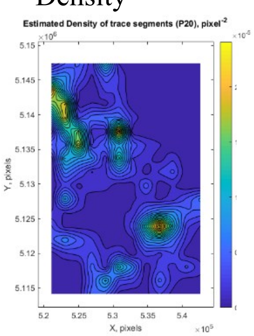
Structural



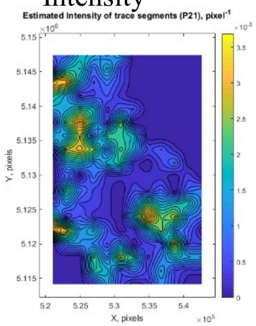
Geomorphological



Density



Intensity



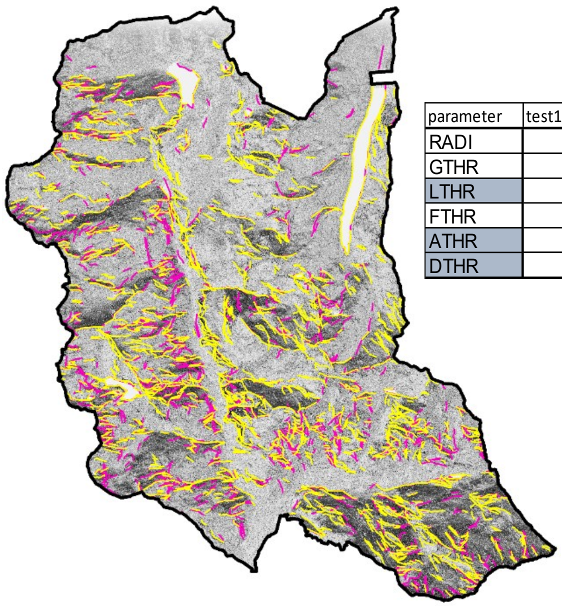
2) Morpholineament extraction from DEM

From DTM to Hillshade
1) 0°45° 90°135°
2) 180°225° 270°315°

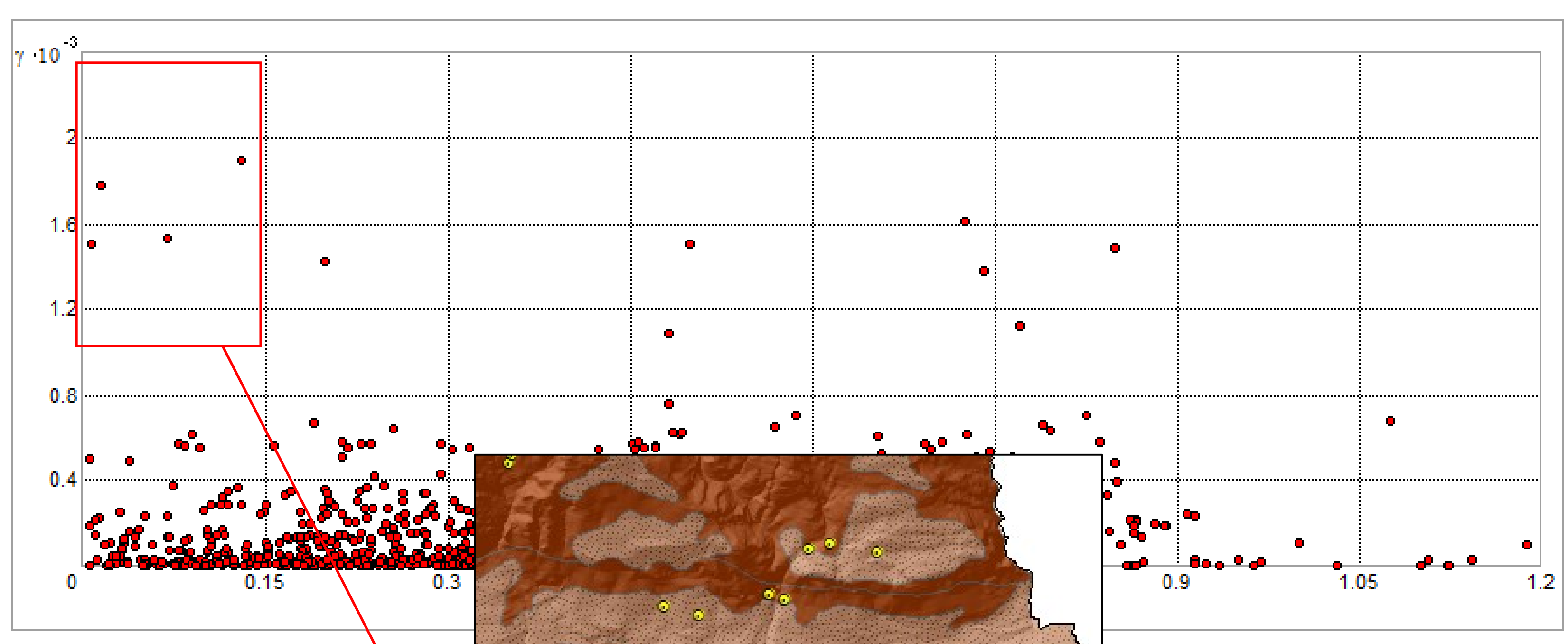
→ Combine ArcGIS tool

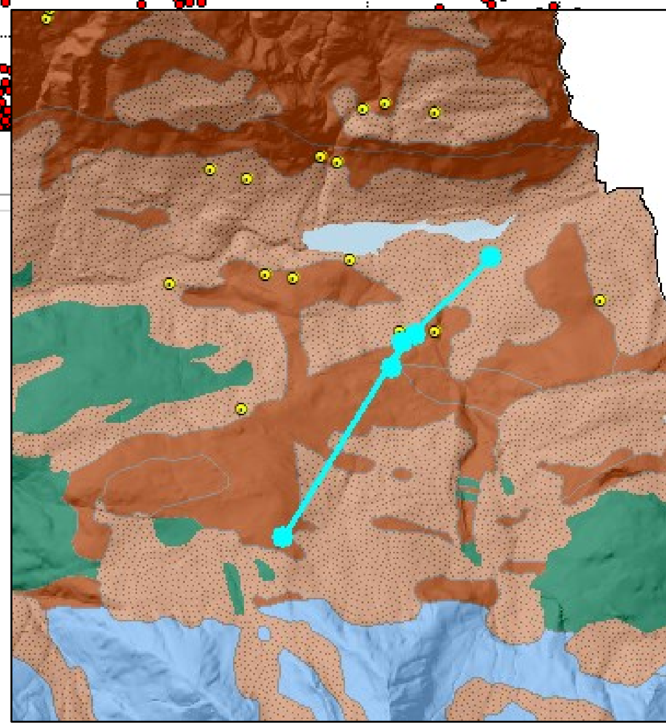
1) edge detection
2) thresholding
3) curve extraction

→ PCI Geomatica



parameter	test1	test2	test3	test4	test5
RADI	10	10	10	10	10
GTHR	100	100	100	100	100
LTHR	30	50	40	50	100
FTHR	5	5	5	5	5
ATHR	30	30	45	30	30
DTHR	20	100	50	20	20





Rm 08,10,11,12 hanno Jv tra I 12 e I 20 mentre Rm09 ha Jv 71..Rm09 è una zona di cataclasi perchè la parete è attraversata da faglia locale