Hazard analysis and modeling of snow avalanches: recent results from Italy

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Snow and avalanche @POLIMI

Ongoing projects

2005-2008 AWARE: a tool for monitoring and forecasting Available WAter REsource in mountain environment. GMES - Global Monitoring for Environment and Security FP6-2003-SPACE-1.

Including: CNR IRSA, TU Wien, SLF Davos, Universidad de Jaume I en Castellon de la Plana, SRDE, Institut Cartografic de Catalunia

2005-2008 Integral Risk Management of Extremely Rapid Mass Movements "IRASMOS" European project. SUSTDEV-2004-3.IV.1.3 Long-term forecasting of landslides and avalanches.

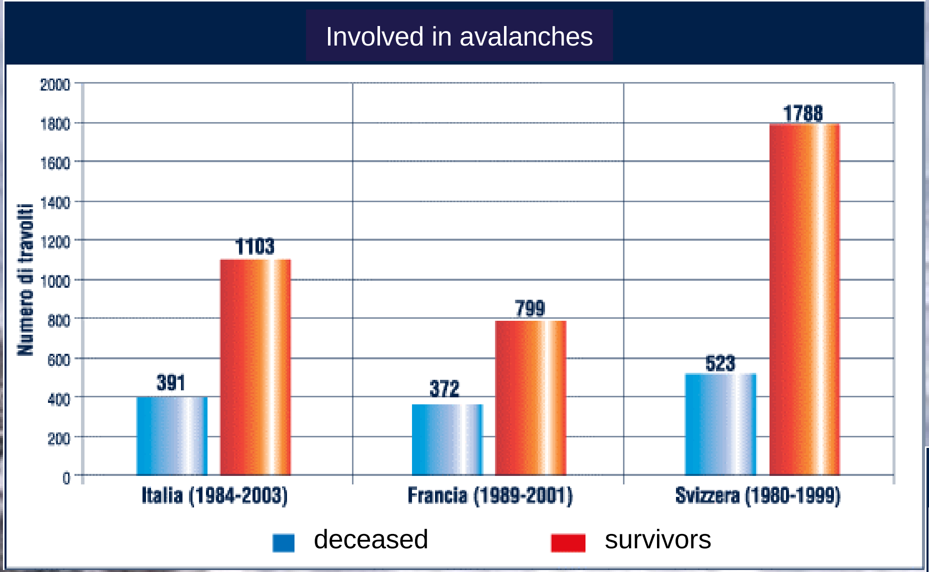
Including: SLF Davos, CUDAM University of Trento, University Pavia, Meteo France, CEMAGREF,BOKU Wien, NGI Oslo

2007-2009 CARiPANDA, Climatic change and water resources in the Adamello park, Cariplo Foundation.

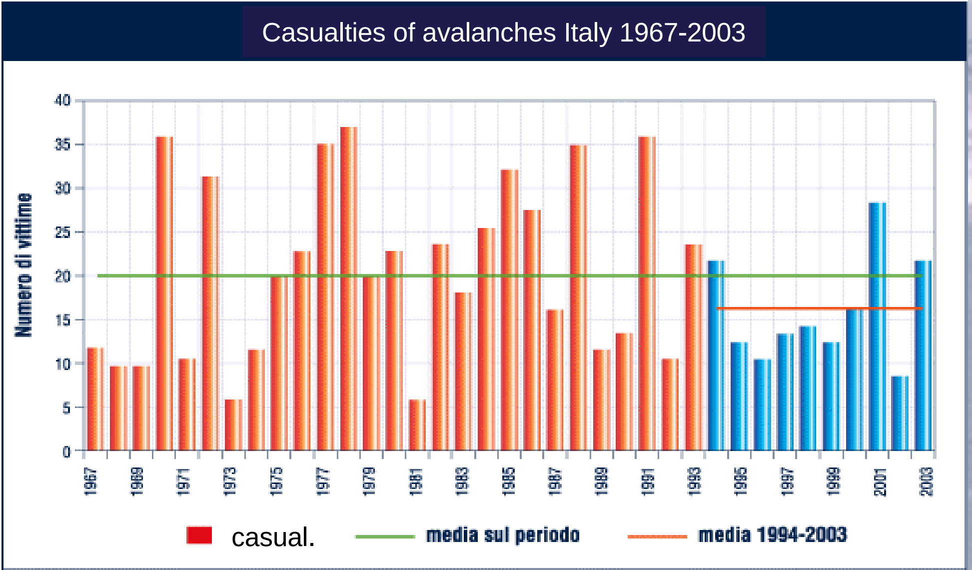
Including: Parco dell'Adamello, Università degli Studi di Milano, Istituto di Fisica Generale Applicata, Dip. di Scienze della Terra, ARPA Lombardia, Università di Brescia

0) Rationale

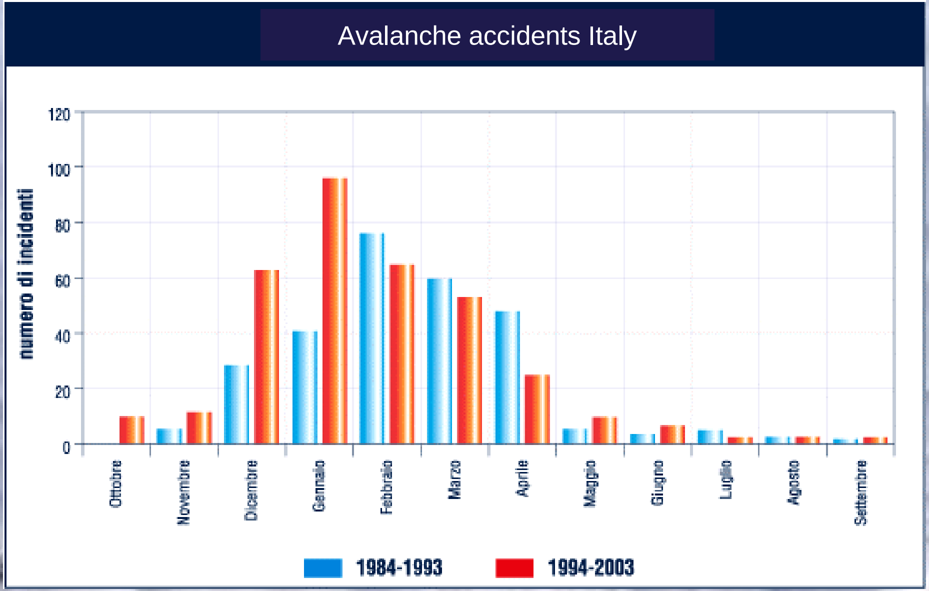
The European Alps are characterized by relevant tourism during winter and feature a considerable amount of ski resort areas. Every year, several avalanches occur in the area, and a large number of casualties occurred in the last 20 years all over the Alps; in more than 1/3 of the cases the people involved died.


Involved in avalanches

The number of fatalities has decreased recently due to the new prevention techniques and risk mapping

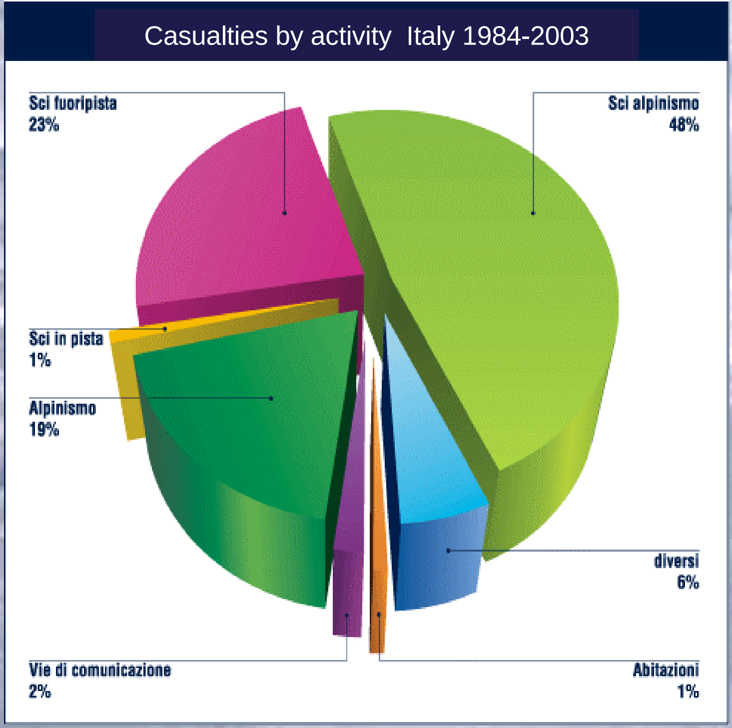

Casualties of avalanches Italy 1967-2003

0) Rationale


Avalanche accidents Italy

The number of avalanche events is strictly correlated with the snow amount and the presence of people in dangerous areas, the maximum value is in January and February

The risk involves all the "users" of the mountain areas


Casualties by activity Italy 1984-2003

1) Criteria for avalanche hazard mapping

$R = H\,E\,V$

Hazard: intrinsic to avalanche phenomena
Exposition: value of the properties
Vulnerability: degree of damage

Swiss procedure, also used in Italy

Cadastre

Topographic data

Meteorological data

Avalanche dynamic calculation

Hazard map

Land use

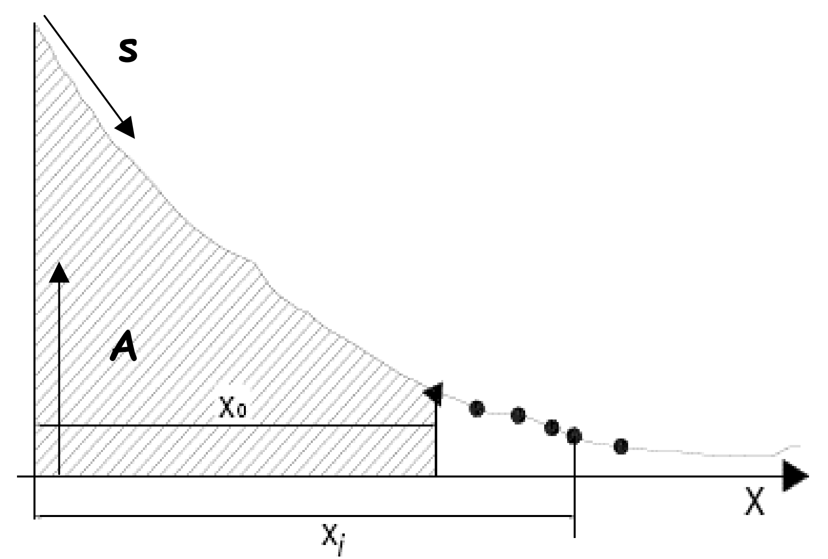
Countermeasures

Red zone
P≥30 kPa , T=300 years
P<30 kPa, T≤30 years

Blue zone
P<30 kPa, 30<T<300 years
powder avalanche P<3 kPa , T<30 years

Yellow zone
P≤3 kPa , T>30 years

2) Runout of avalanches: AF(A?)S approach.



Runout distance/Altitude

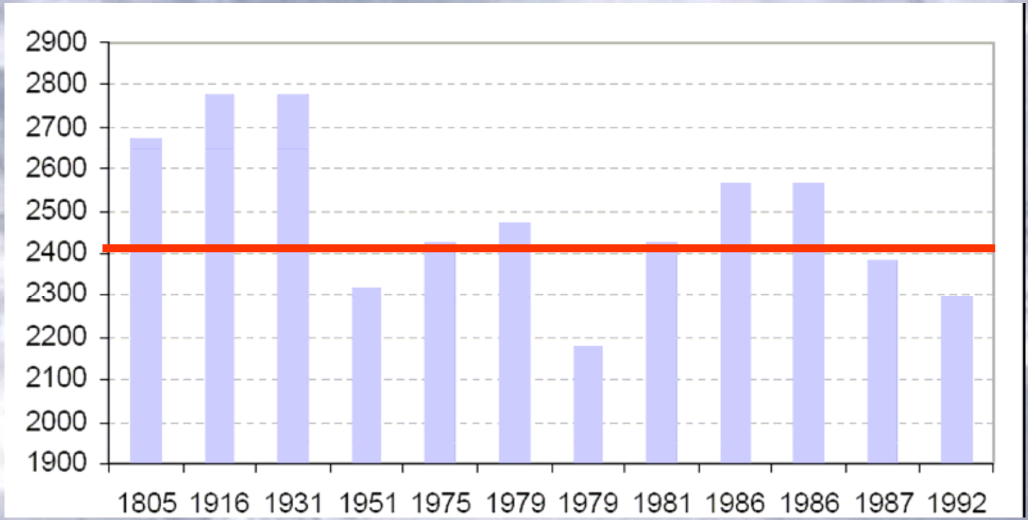
$R = x_i - x_0 \;\; v \;\; s_i - s_0$

The greatest yearly runout can be modeled According to the theory of extremes

Max R (but also Min A)

$$T = \frac{N_{years}}{N_{exceed}}$$

$$R(T) \cong F(\Theta \mid T)$$



Problems:

1) Topographic control
2) No pressures

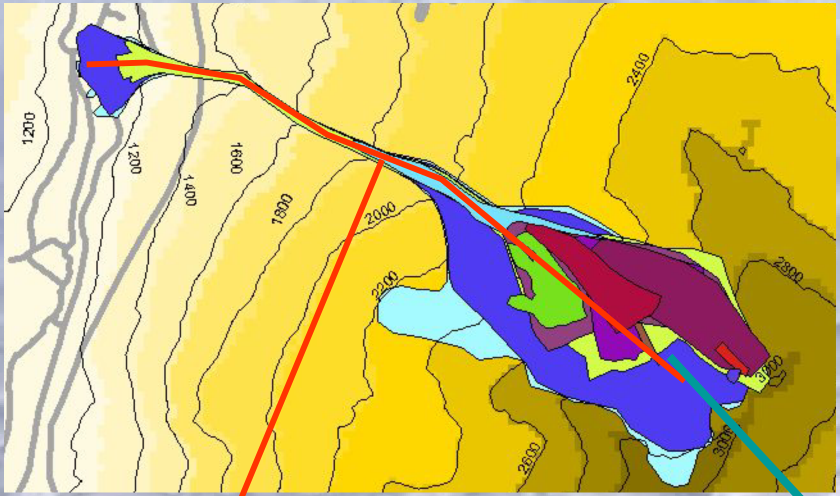
Use:

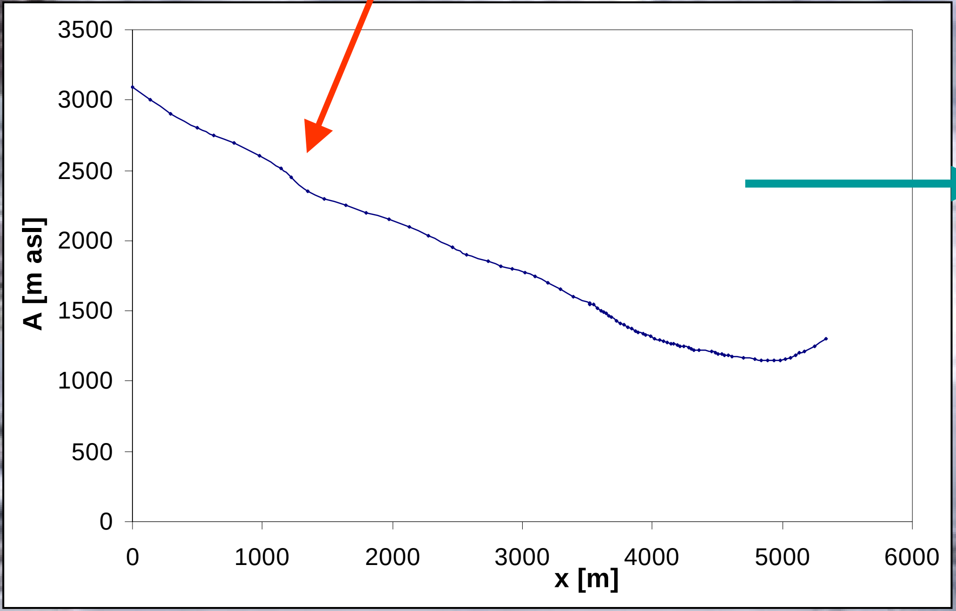
1) Zone mapping
2) Cross check of dynamic models

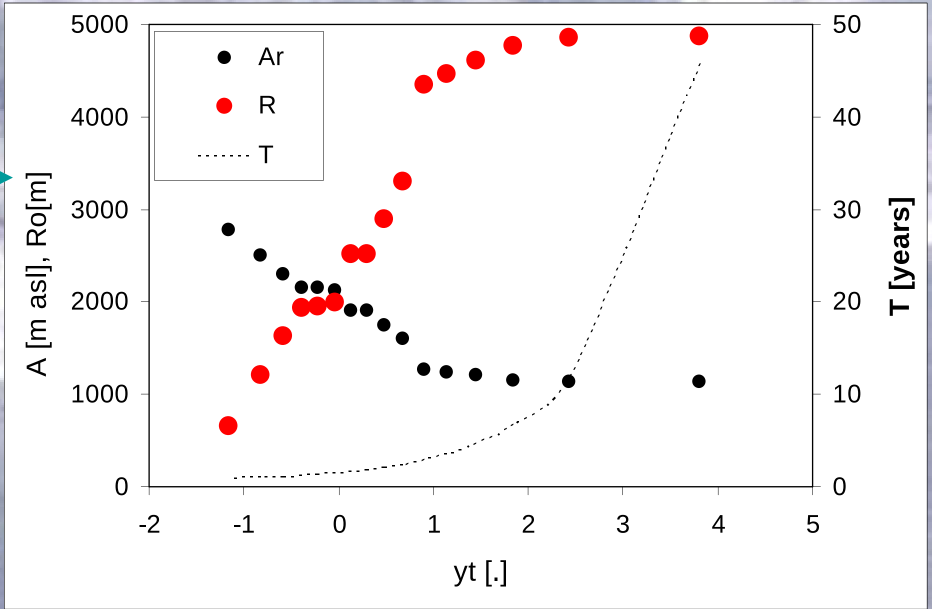
2) Runout of avalanches: AF(A?)S approach.

A case study: the Vallecetta avalanche site

A number of avalanches were mapped ever since 1886





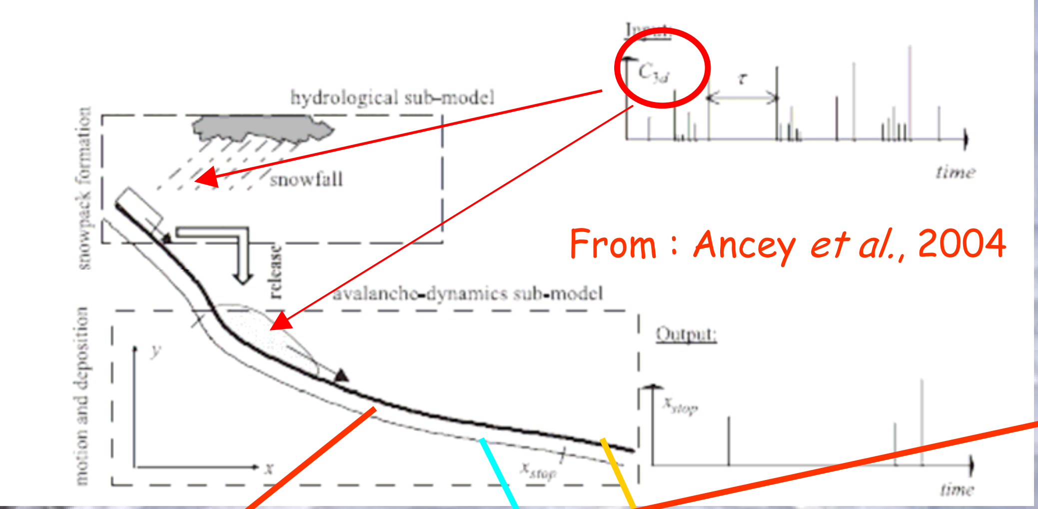


3) Deterministic-statistic approach for hazard mapping

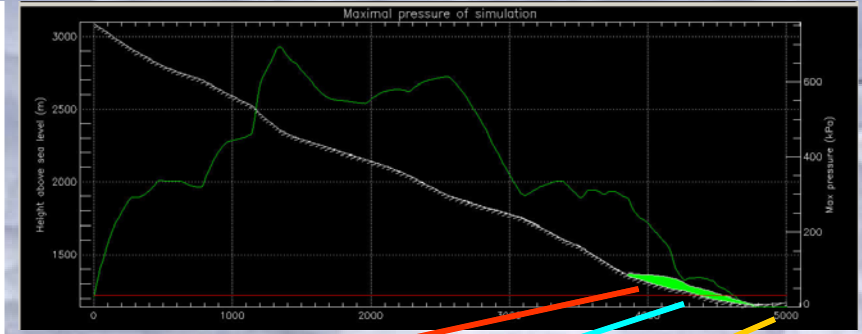
Input factors Swiss guidelines, also used in Italy

$C_{3d} = H_{72}$: Maximum annual three days cumulated snow fall

Among other factors, H_{72} noticeably affects avalanche volume, runout and eventually hazard mapping exercise



From : Ancey *et al.*, 2004



Red zone
$P \geq 30$ kPa , $T = 300$ years
$P < 30$ kPa, $T \leq 30$ years

Blue zone
$P < 30$ kPa, $30 < T < 300$ years
powder avalanche $P < 3$ kPa , $T < 30$ years

Yellow zone
$P \leq 3$ kPa , $T > 30$ years

$$P_{\max} = C_P \, \rho \, U_{\max}^2$$

$$C_P = \frac{1}{2} \quad \textit{powder avalanche}$$

$$C_P = 1 \quad \textit{dense avalanche}$$

Evaluation of H_{72}:

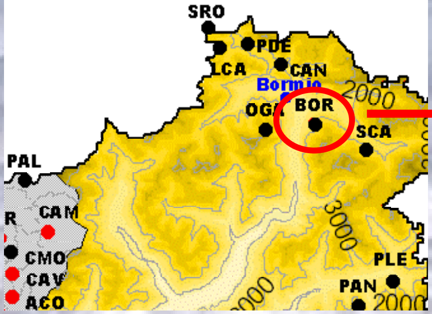
$H_{72} = H_S$ (day 4th) – H_S (day 1st)

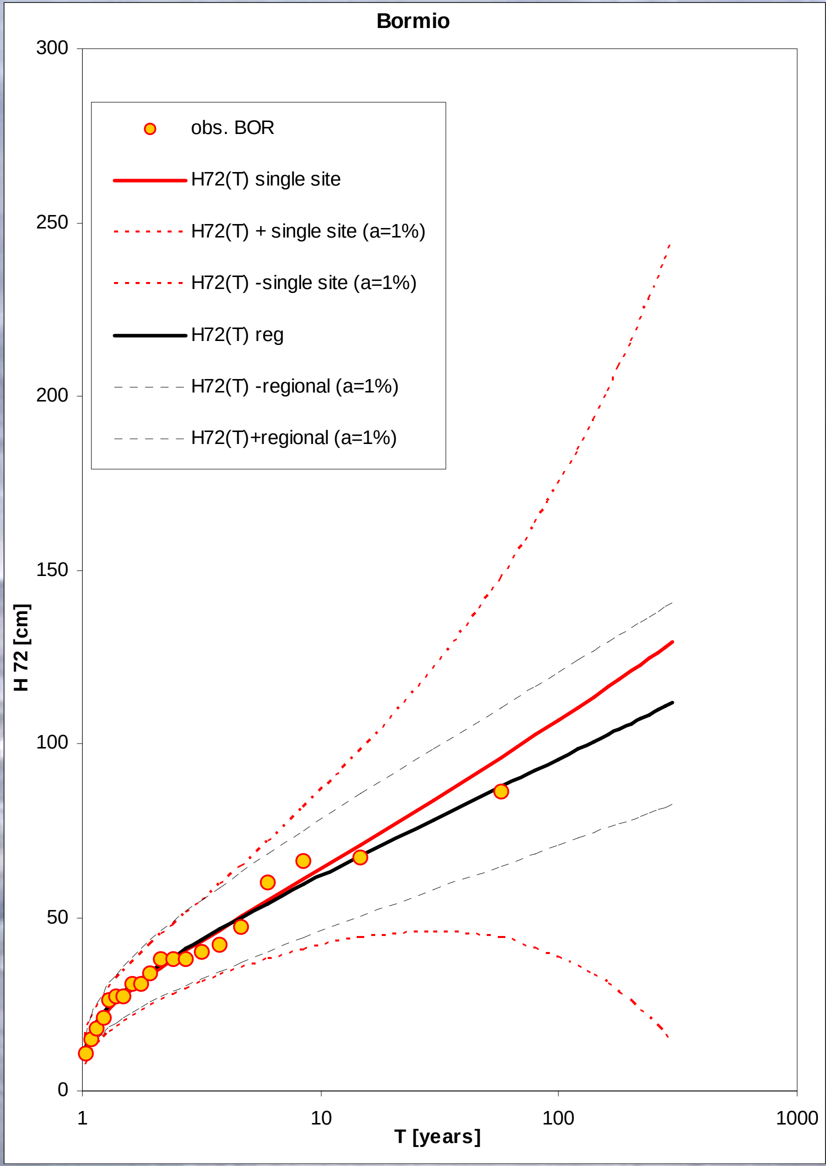
3) Deterministic-statistic approach for hazard mapping

Design values of H_{72}

Single site series analysis is often used for evaluation of T-years design value of H_{72} for hazard mapping procedure.

Evaluation of H72i(T) for a single site station (20 years of observations). Notice the **low predicted return periods** using the site observed data (Y_i=15 years) and the considerable uncertainty for the highest return periods

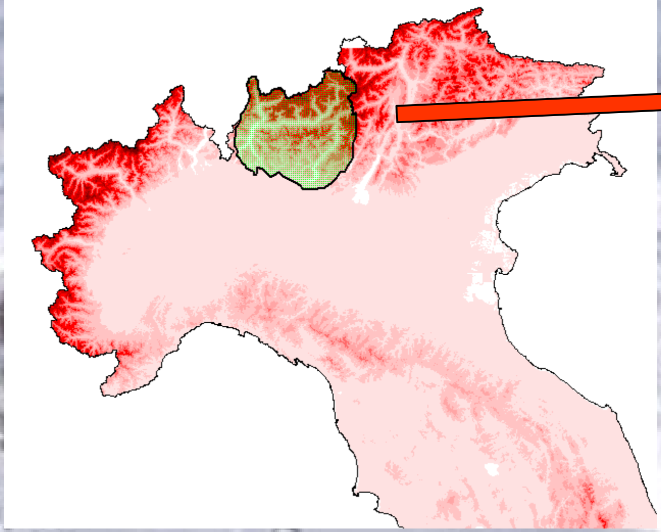


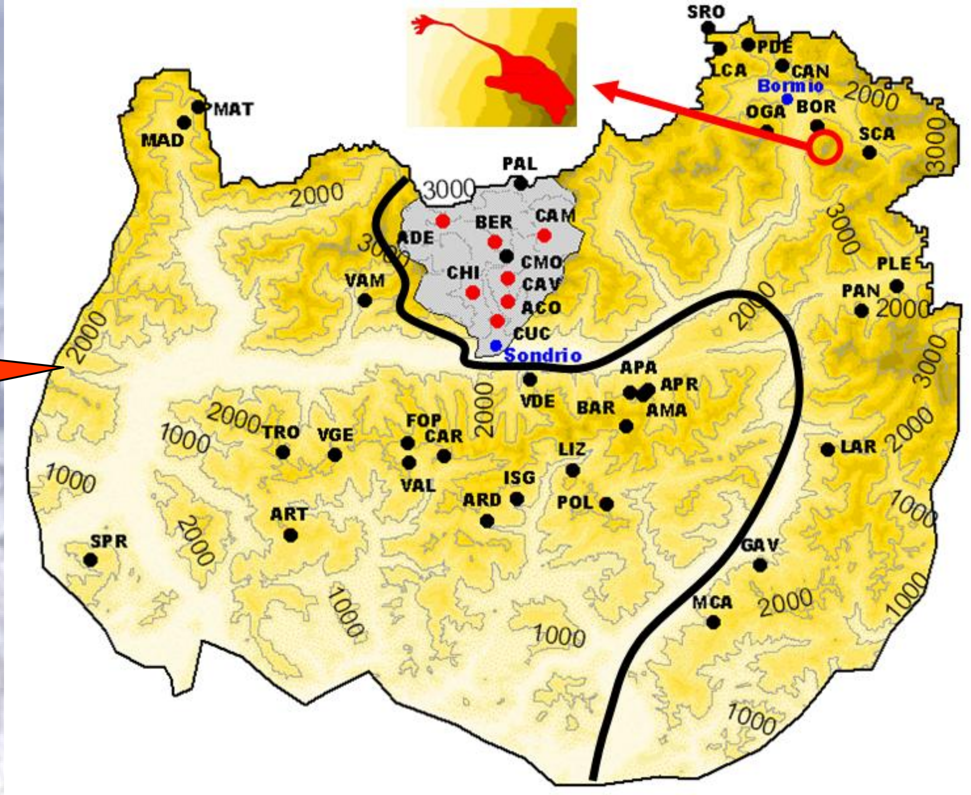


For the design of more reliable estimates one can carry out evaluation of *H72* using regional approach. Regional approach is often adopted in the field of hydrology for evaluation of floods and storms statistics. This in turn requires assessment of **regional homogenity**

4) Regional approach to evaluation of the climatic forcing

The case study area is the Alpine Area of Lombardia region, N-W Italy





Several avalanches occur in the area, and in the period from 1990 to 2000 at least 7200 avalanche events were mapped, with at least 215 casualties,

Analysis based on L-coefficients

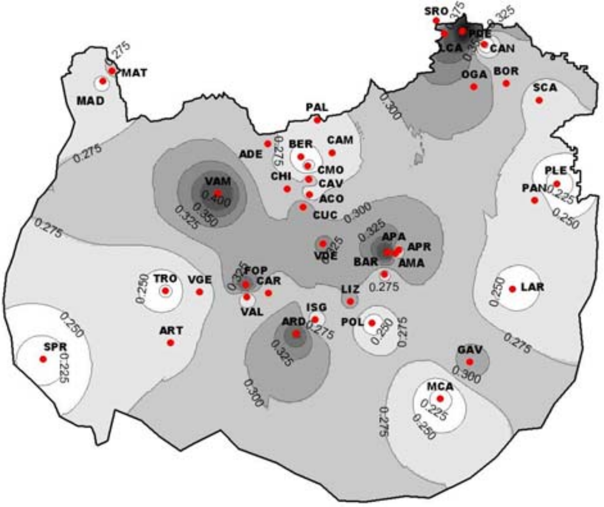
Evaluation of *H_{72}* using regional approach (*e.g.* Barbolini, Natale, Savi, 2002) requires assessment of regional homogenity

The area investigated is found climatically homogenous according to former studies (e.g. De Michele and Rosso, 2002), and the regime of daily snow precipitation is found to be reasonably homogeneous (Bocchiola and Rosso, 2007).

On this basis, the distribution of *H_{72}* is investigated

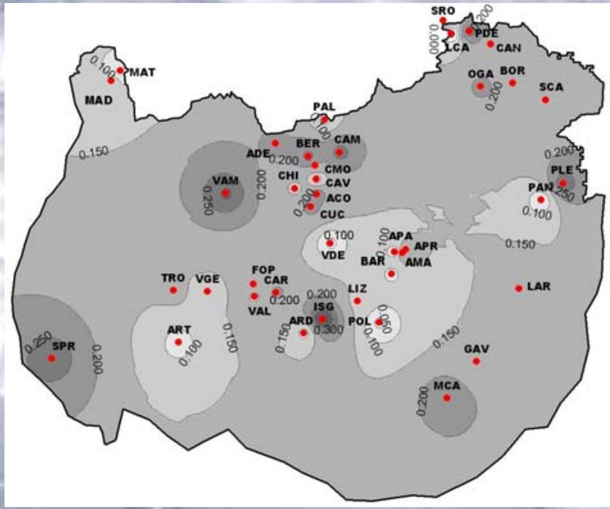
The approach proposed by Hosking an Wallis (*e.g.* Hosking and Wallis, 1993) is used here to test the homogeneity of the region in term of *H_{72}*

L-CV H_{72}

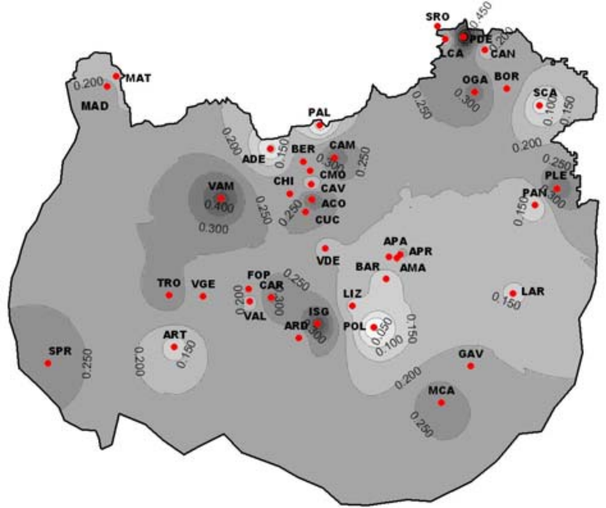


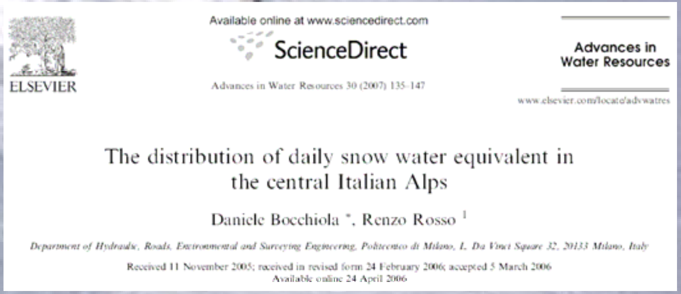
L-coefficients maps are evaluated

L-SK H_{72}



L-KU H_{72}





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The distribution of daily snow water equivalent in the central Italian Alps

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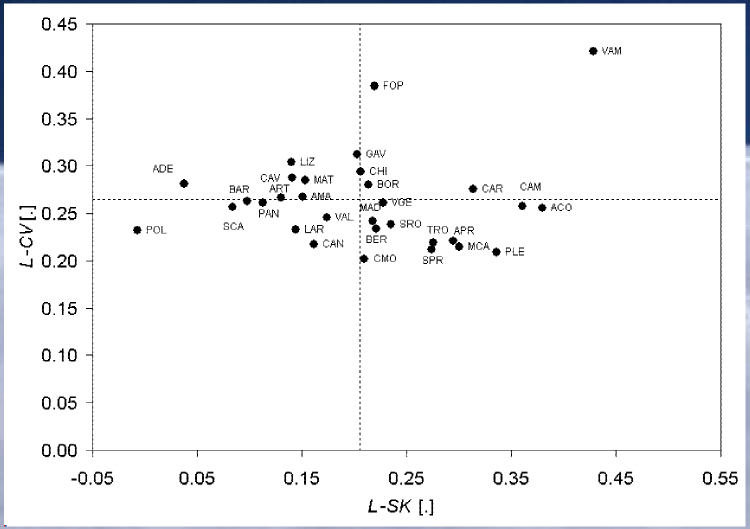
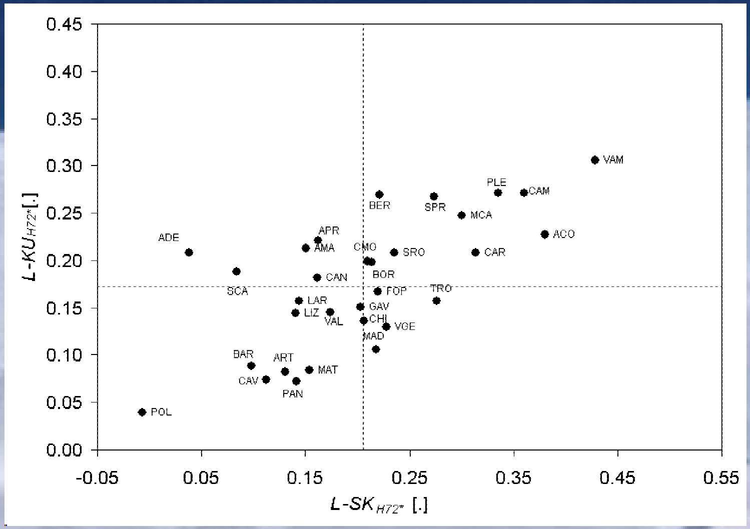


L-coefficients charts shows the degree of scatter of the *L-coefficients* (*e.g.* Hosking and Wallis, 1993)



Proper statistical tests show a reasonable degree of homogeneity of the region

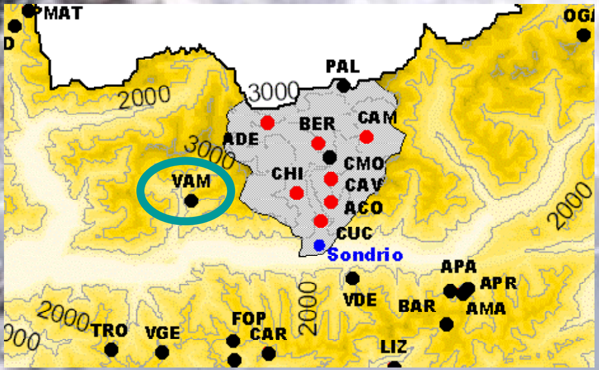
$$D_i = \frac{1}{3}(u_i - \bar{u}_i)^t S^{-1}(u_i - \bar{u}_i)$$

$D_i \leq 3$ indicates that the site is homogeneous

$$u_i = \left[L_i - CV_{H72*} \quad L_i - SK_{H72*} \quad L_i - KU_{H72*}\right]^t$$

$$S = (N-1)^{-1}\sum_i^N (u_i - \bar{u}_i)(u_i - \bar{u}_i)^t$$

D>3 only for VAM stations (D_i= 4.99)



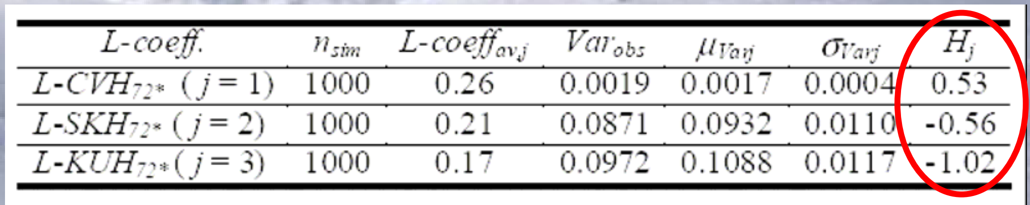
$$Var_{LCV} = \frac{\sum_{i=1}^{N} Y_i (LCV_i - LCV_{av})^2}{\sum_{i=1}^{N} Y_i}$$

$$Var_{LSK} = \frac{\sum_{i=1}^{N} Y_i \left[(LCV_i - LCV_{av})^2 + (LSK_i - LSK_{av})^2\right]^{0.5}}{\sum_{i=1}^{N} Y_i}$$

$$Var_{LKU} = \frac{\sum_{i=1}^{N} Y_i \left[(LSK_i - LSK_{av})^2 + (LKU_i - LKU_{av})^2\right]^{0.5}}{\sum_{i=1}^{N} Y_i}$$

$$H_j = \frac{Var_j - \mu_{Varj}}{\sigma_{Varj}}$$

$H \leq 2$ for noticeably homogeneous behavior



L-coeff.	n_{sim}	*L-coeff*$_{av,j}$	Var_{obs}	μ_{Varj}	σ_{Varj}	H_j
L-CVH$_{72*}$ ($j = 1$)	1000	0.26	0.0019	0.0017	0.0004	0.53
L-SKH$_{72*}$ ($j = 2$)	1000	0.21	0.0871	0.0932	0.0110	-0.56
L-KUH$_{72*}$ ($j = 3$)	1000	0.17	0.0972	0.1088	0.0117	-1.02

Index value approach to evaluation of H_{72}

Dimensionless values of H_{72} with respect to an **index value** can be grouped together to provide a T-years quantile growth curve. *F_i* is the distribution function, valid at each site

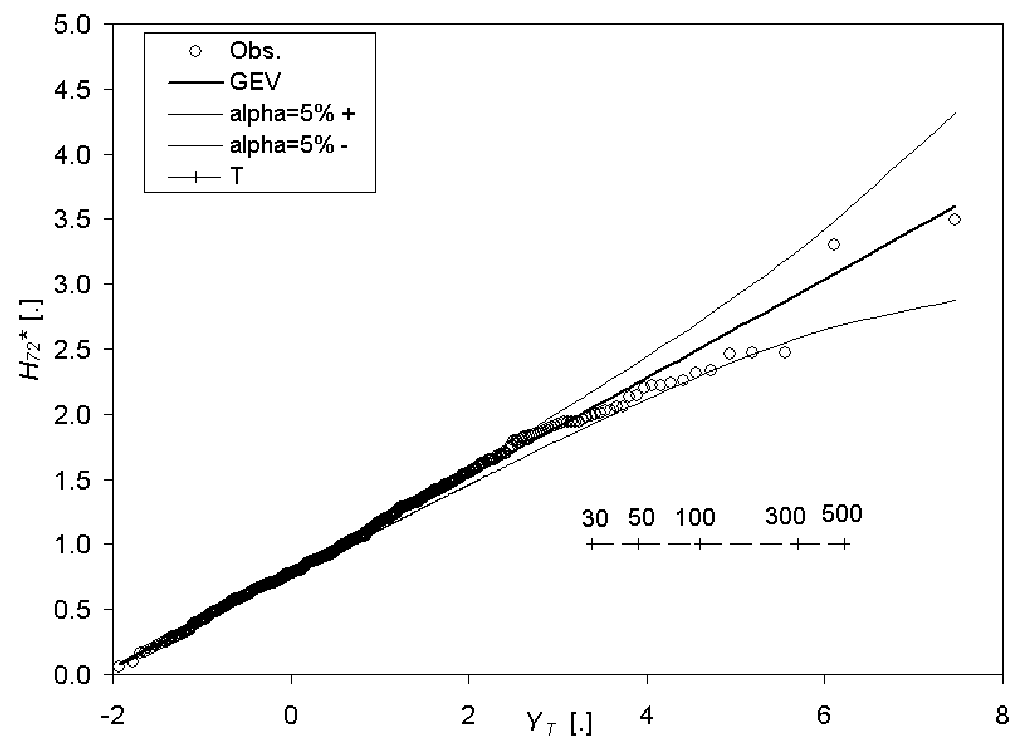
$$H^{*}_{72i} = \frac{H_{72i}}{\mu_{H72i}} \approx F_i(1;..)$$

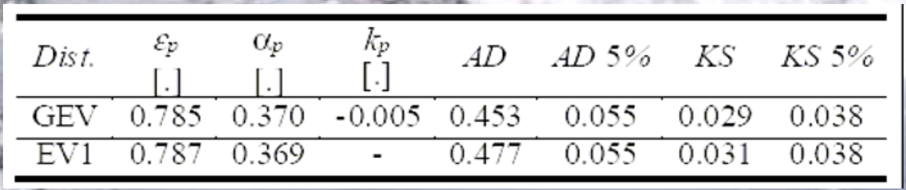
Generally, the **index value** is given by the single site *i* sample average

$$\mu_{H72i} = \frac{1}{Y_i}\sum_{y=1}^{Y_i} H_{72i,y}$$

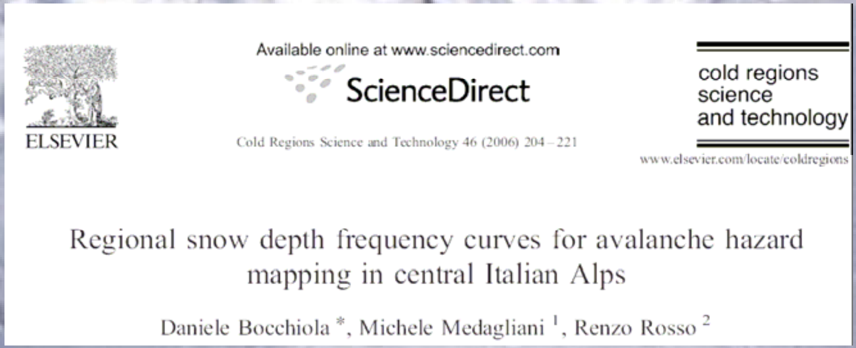
Distribution fitting provides the analytical expression of the growth curve

$$H^{*}_{72}(T) = \varepsilon_p + \frac{\alpha_p}{k_p}\left(1-\exp\left(-k_p y_T\right)\right)$$





Dist.	ε_p [.]	α_p [.]	k_p [.]	*AD*	*AD 5%*	*KS*	*KS 5%*
GEV	0.785	0.370	-0.005	0.453	0.055	0.029	0.038
EV1	0.787	0.369	-	0.477	0.055	0.031	0.038



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Regional snow depth frequency curves for avalanche hazard mapping in central Italian Alps

Daniele Bocchiola *, Michele Medagliani [1], Renzo Rosso [2]

Sensitivity analysis of hazard mapping H_{72}

The approaches currently adopted for the sensitivity analysis of the avalanche hazard maps require probabilistic assessment of the distribution of the input value *$H_{72i}(T)$, i.e.* the design value *$H_{72i}(T)$*, and a measure of its uncertainty, *e.g.* its standard deviation, σ_{H72iT}

The regional approach yields a standard deviation that is smaller than that provided by the approach based on single site distribution fitting

$$\sigma_{H72*}(T) = \left[\left(\frac{\alpha_p^2}{n_{tot}}\right)\exp\left(y_T\,\exp\left(-1.823\,k_p - 0.165\right)\right)\right]^{0.5}$$

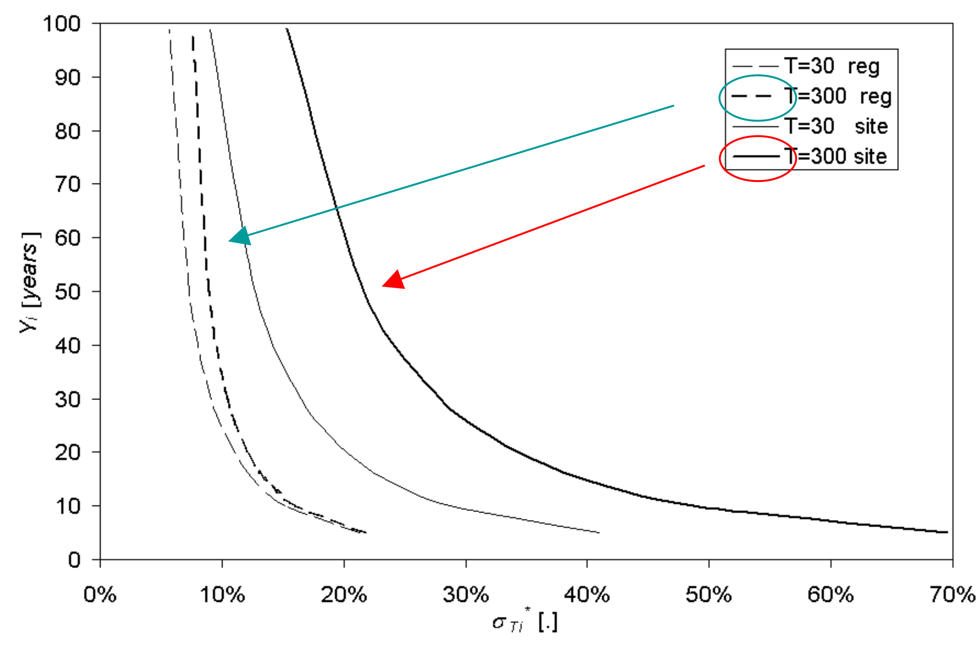
$$\sigma^2_{\mu\,H72i} = \mu_{H72i}\cdot CV\Big/\sqrt{Y_i}$$

$$\sigma^*_{Ti} = \frac{\sigma_{H72iT}}{H_{72i}(T)} = \sqrt{\frac{\sigma^2_{\mu\,H72i}\,\sigma^2_{H72*} + \sigma^2_{H72*}\,\mu^2_{H72i} + \sigma^2_{\mu\,H72i}\,H^{*2}_{72}}{\mu^2_{H72i}\,H^{*2}_{72}}} = \sqrt{\sigma^{*2}_{\mu i}\sigma^{*2}_{H72*} + \sigma^{*2}_{H72*} + \sigma^{*2}_{\mu\,i}}$$

Here the standard deviation is given with respect to the design value of *$H_{72i}(T)$*.

This is evaluated against the number of available years of observations *Y_i* to estimate the local average.

Notice the decrease in the standard deviation using the regional approach

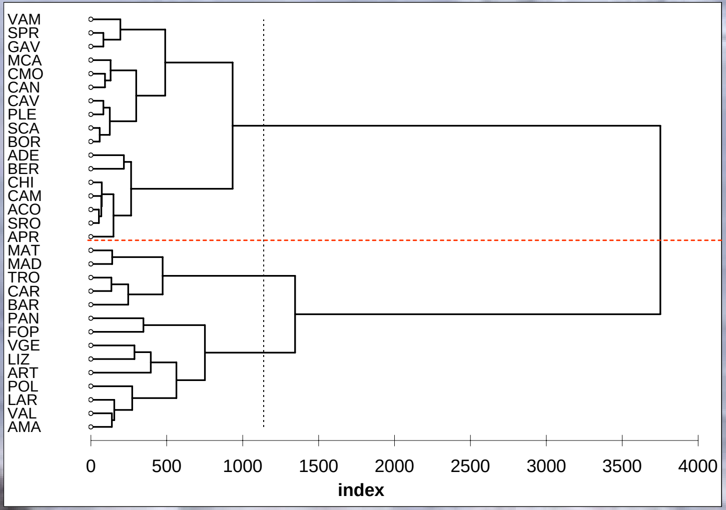


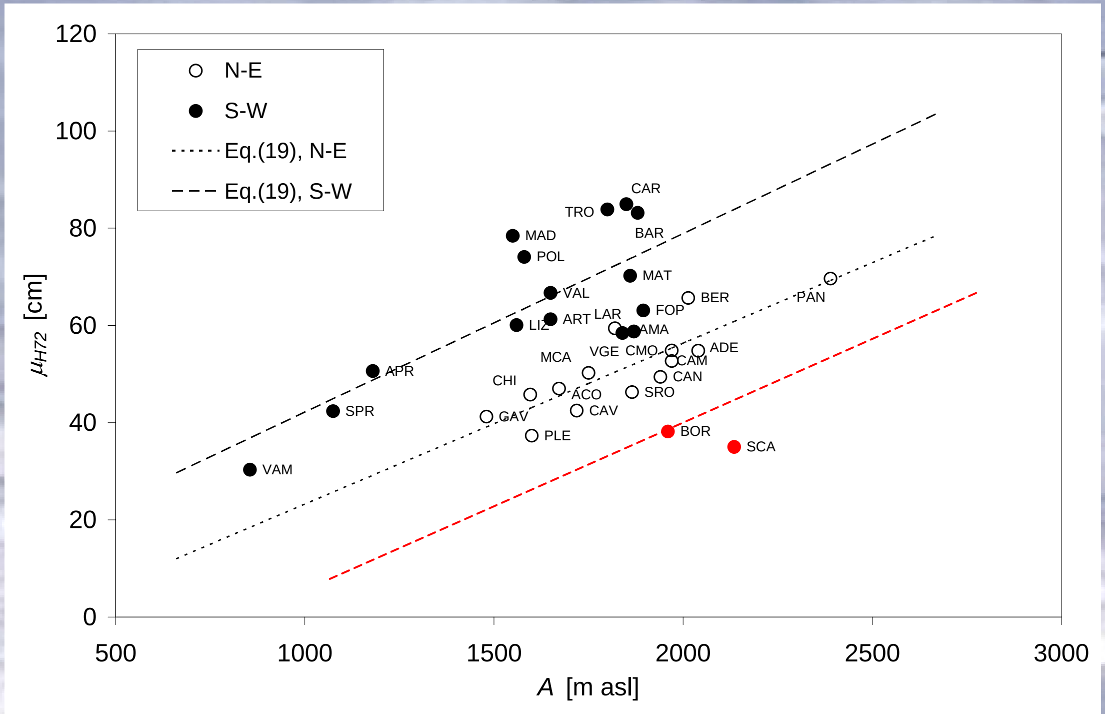
Increase of H_{72} with altitude

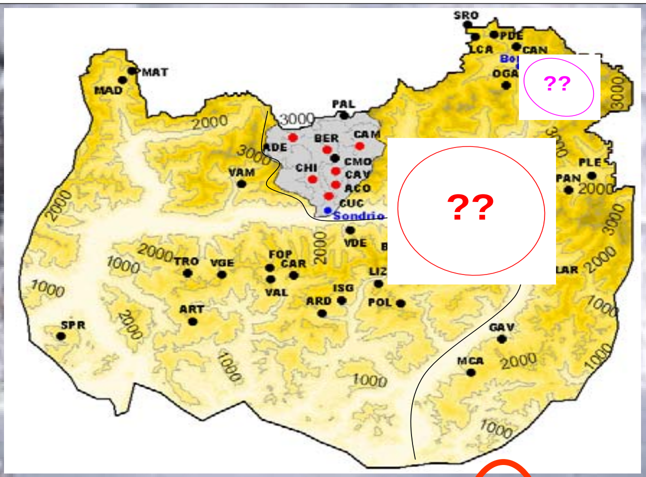
In ungagued sites, the average value of H_{72} has to be estimated using indirect approach

Often, (linear) scaling with altitude is adopted

Use of coupled cluster and scaling analysis showed two areas with defined scaling of μ_{H72}







Region	Ns	c	μ_0	R^2	p	$E[\mu_{H72}]$	$\hat{\sigma}_{E[H72]}$	σ_c	$\hat{\sigma}_{\mu H72ux}$	$\sigma_{\mu i}{}^*$
	[.]	[cm/100 m]	[cm]	[.]	[.]	[cm]	[cm]	[cm/m]	[cm]	[.]
S-W	15	3.7	5.4	0.59	10-mar	64.41	15.63	0.009	10.07	0.09
N-E	14	3.3	-9.87	0.72	10-apr	51.18	9.15	0.006	4.85	0.15

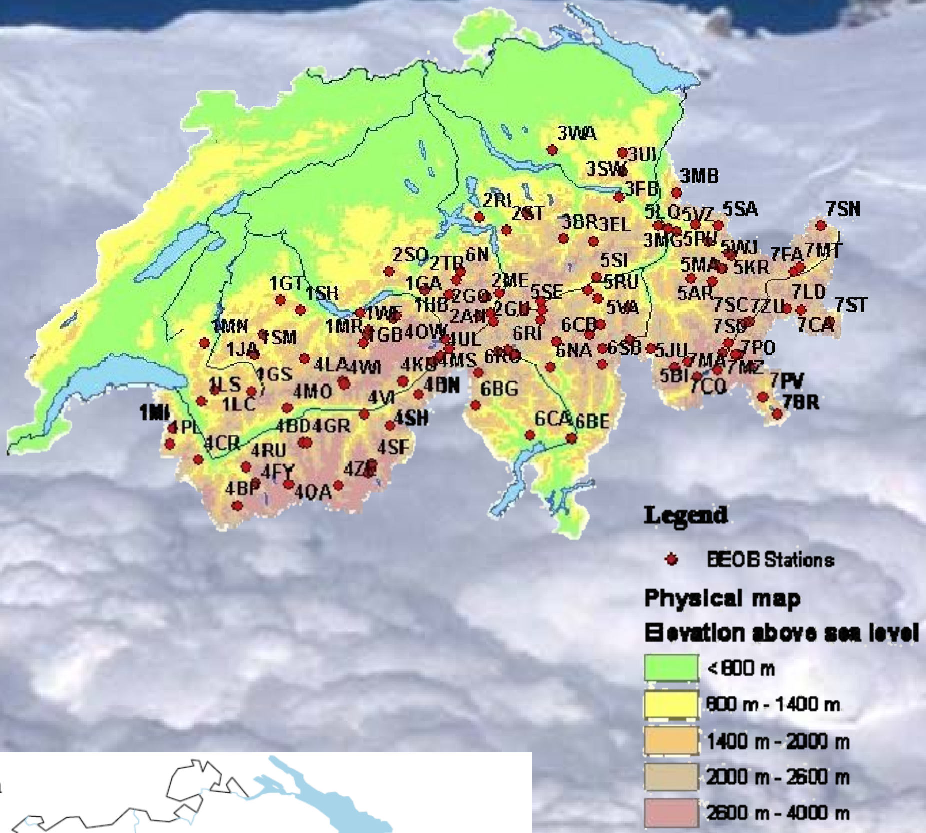
Exporting the regional approach

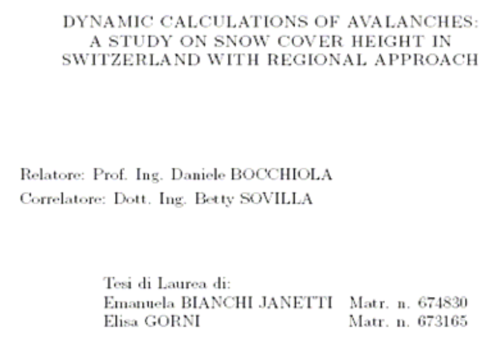
The case of Switzerland

- 114 measurement stations
- About 25 E³ KM²

•On the average, 45 years of data

•The data base of the gauging stations is managed by the personnel of SLF Davos





DYNAMIC CALCULATIONS OF AVALANCHES:
A STUDY ON SNOW COVER HEIGHT IN
SWITZERLAND WITH REGIONAL APPROACH

Relatore: Prof. Ing. Daniele BOCCHIOLA
Correlatore: Dott. Ing. Betty SOVILLA

Tesi di Laurea di:
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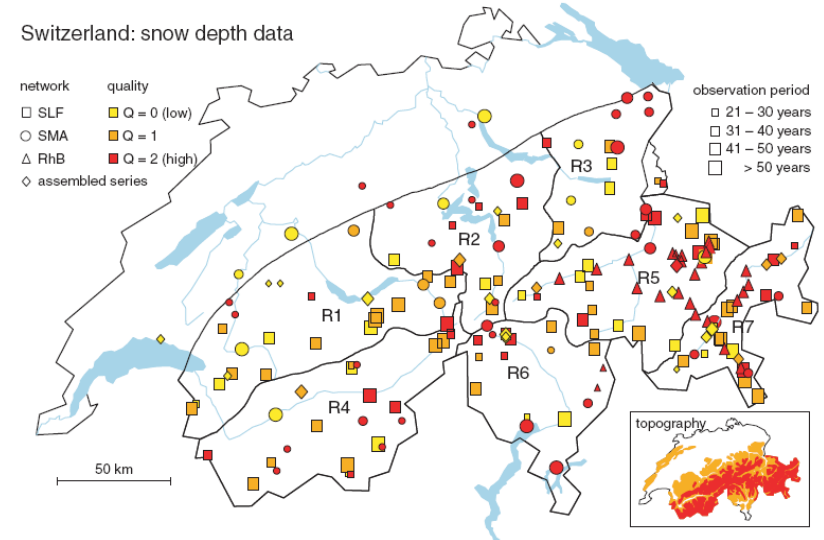
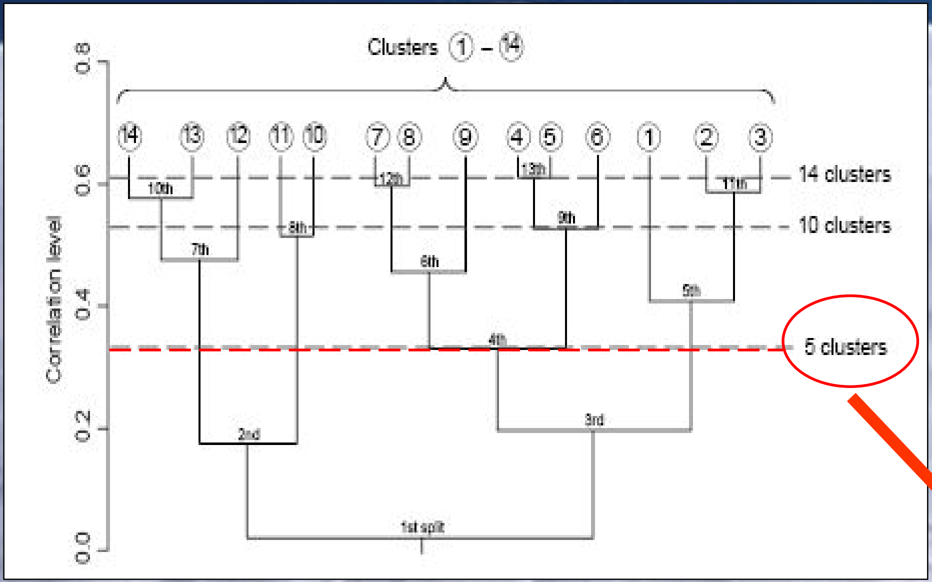


REGIONAL EVALUATION OF THREE DAY SNOW DEPTH FOR AVALANCHE HAZARD MAPPING IN SWITZERLAND
Bocchiola, D. , Bianchi Janetti, E., Gorni, E., Marty, C., Sovilla, B., Submitted NHESS, February 2008

Homogeneous regions of Switzerland

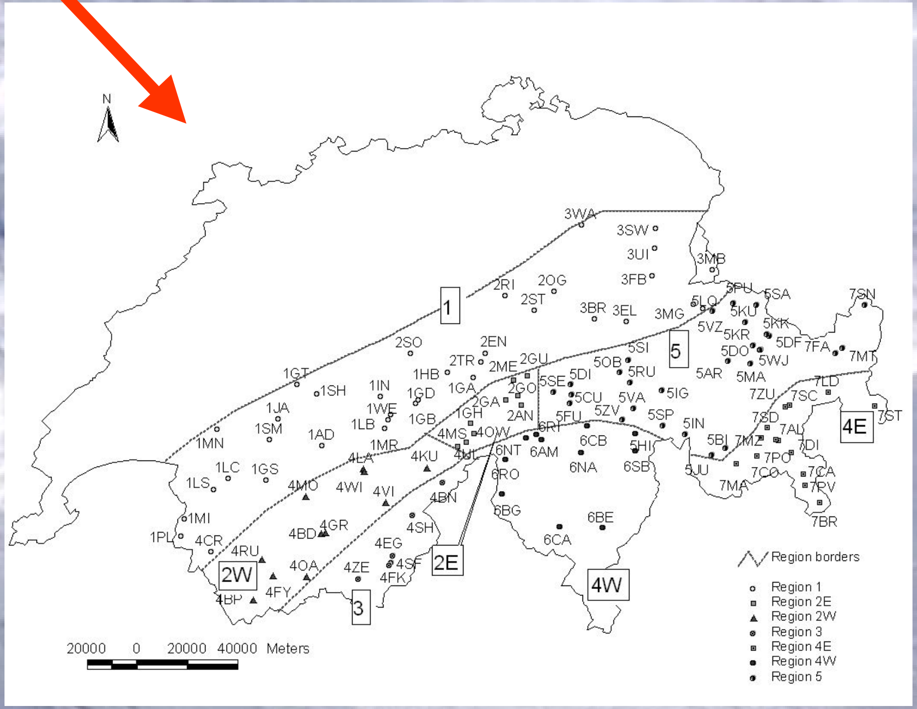


- Laternser (2002) used a cluster analysis based on H_S

Here, the homogenous regions were defined according to an iterative procedure with respect to H_{72}:

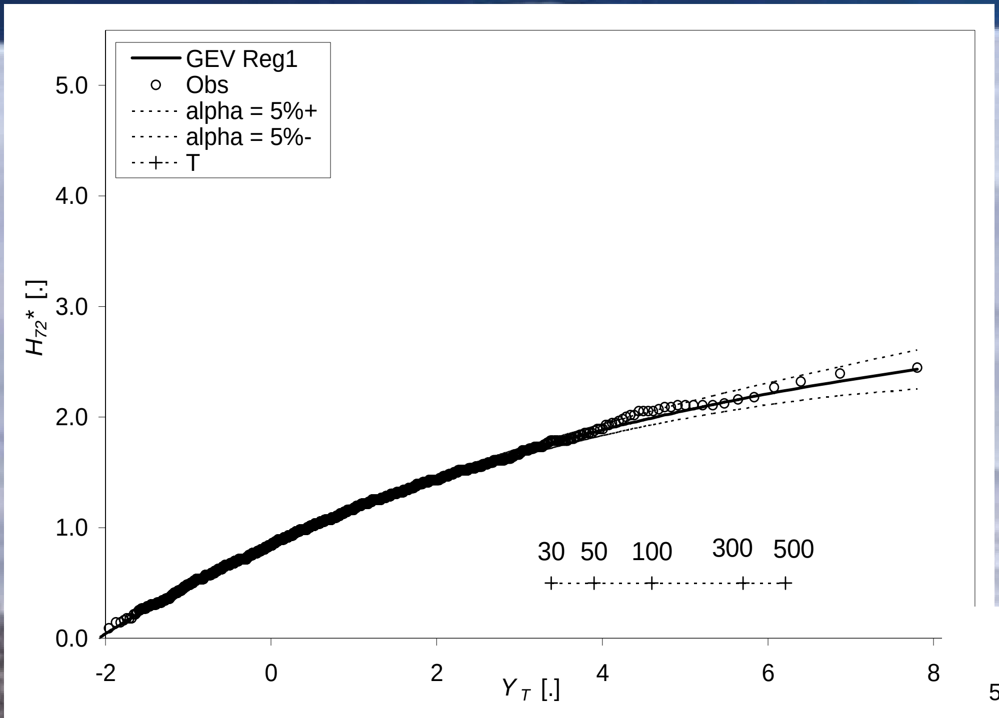
-Homogeneity tests

-Relation of H_{72} to altitude A



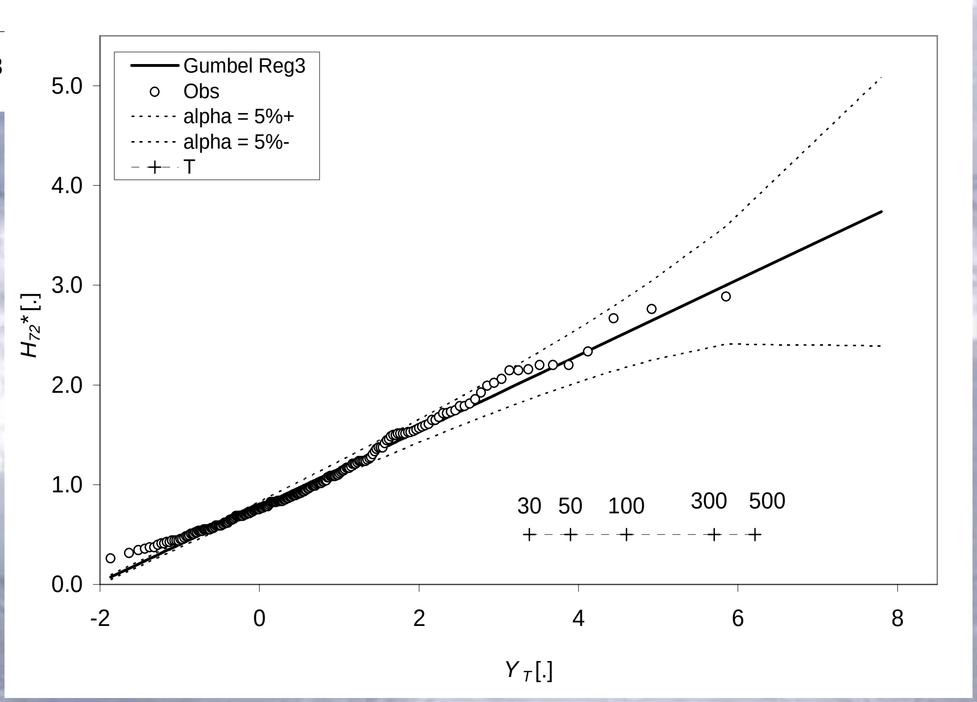
Region 1, the north west belt crossing the country from west to east, Region 2W, the Rhone Valley, Region 2E, the Gotthard Range and Region 5, the northern part of Grison. Region 3, the southern valleys of east Valais, Region 4W covering Ticino and Region 4E covering the southern part of Grison.

Extreme values distributions

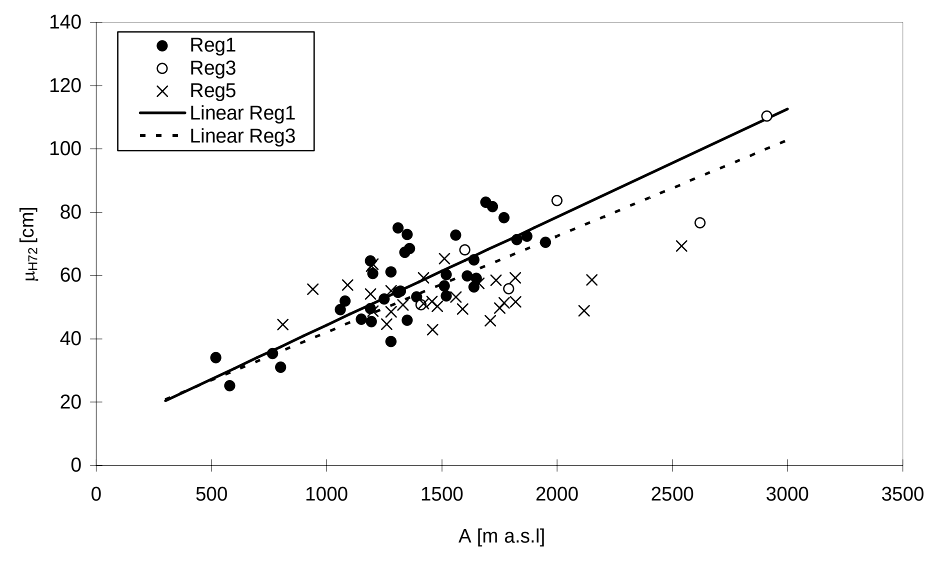


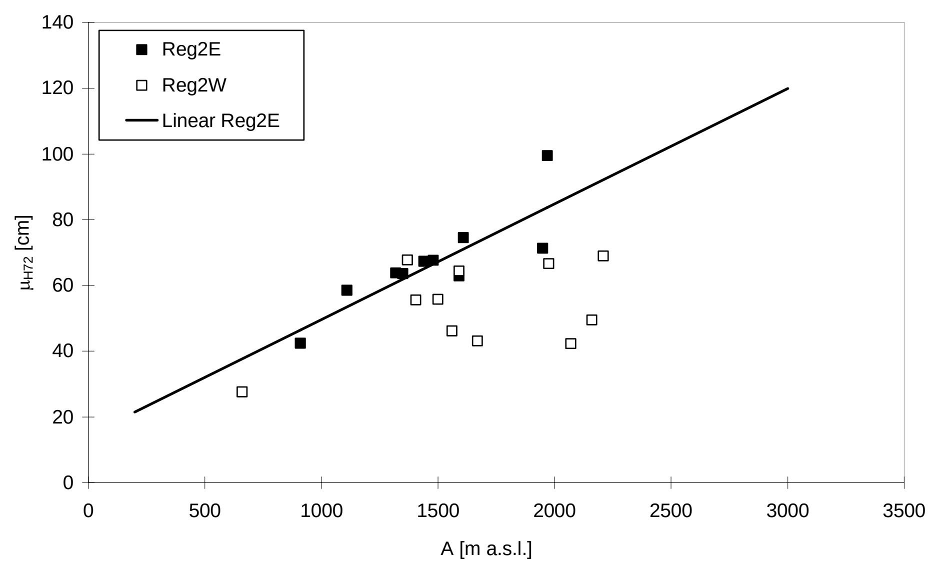
Region 1 is accommodated by a GEV distribution featuring k>0, indicating upper boundary and a slower increase variation with return period.

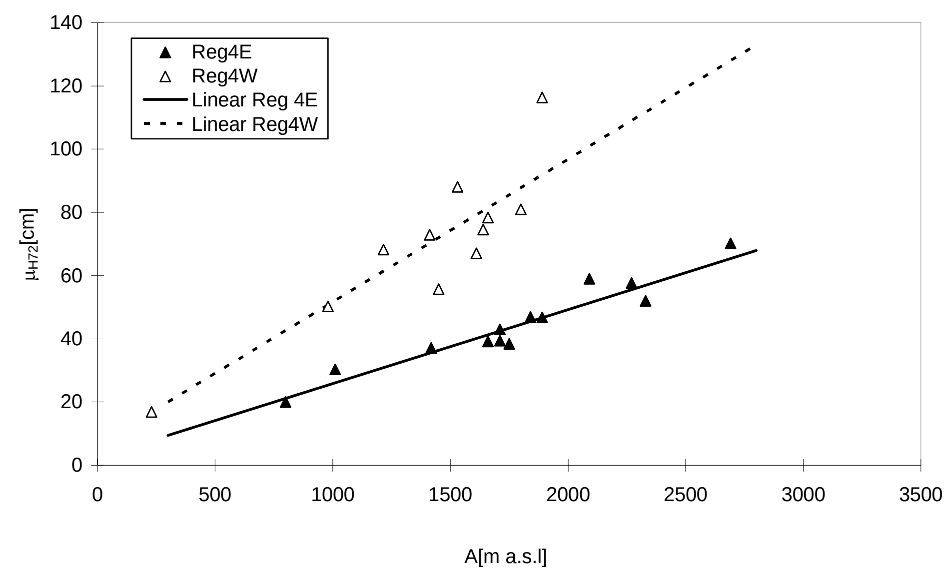
Regions from 2 to 5 are accommodated by a EV1 (Gumbel) distribution, featuring k=0, indicating no upper boundary and a faster increase variation with return period.



Scaling with altitude

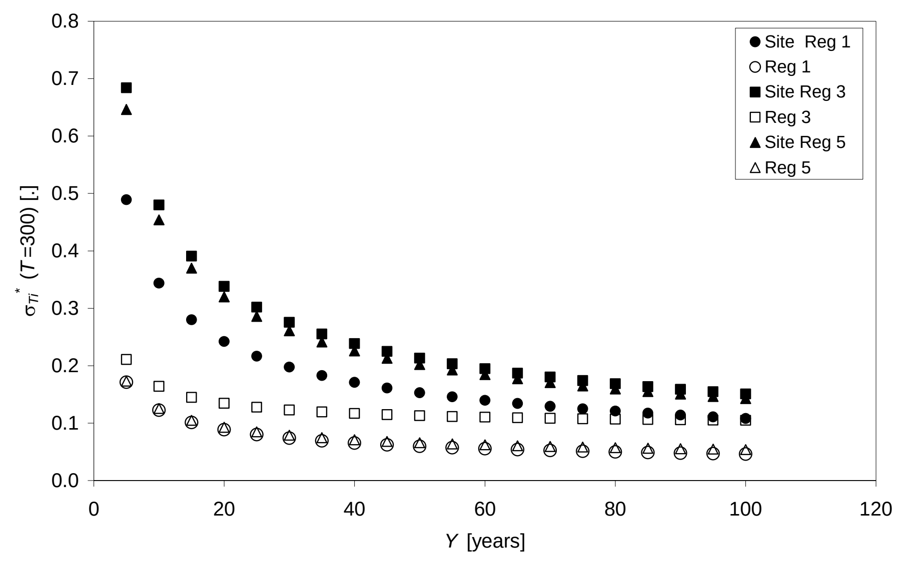


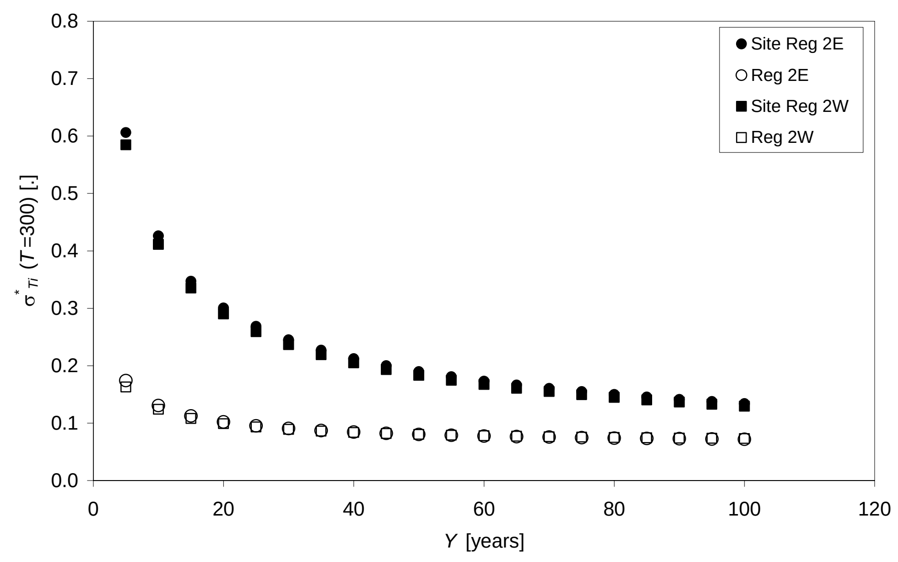


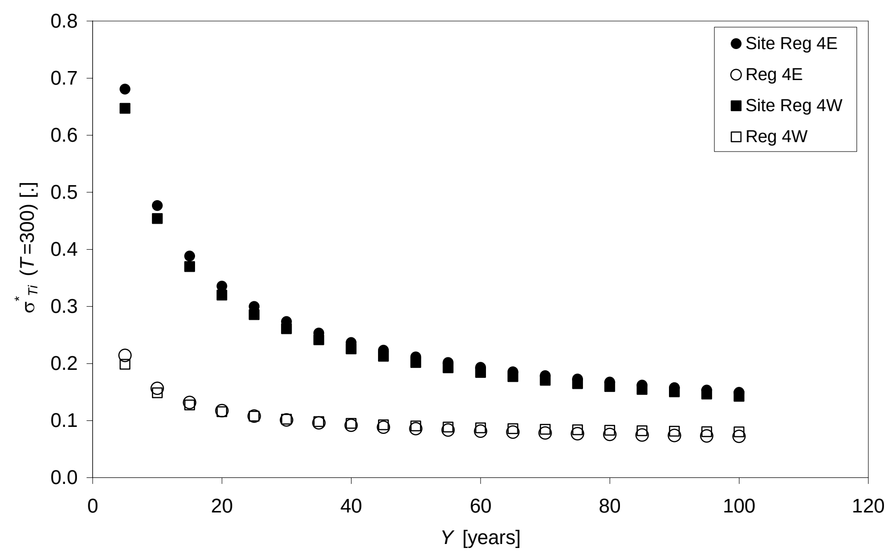


A noticeable difference in the regional scaling of E[H_{72}] against altitude is observed.
This is confirmed by the available literature and is linked to climatic and orographic patterns leading to heavy snowfall

Accuracy of the 300 years estimates



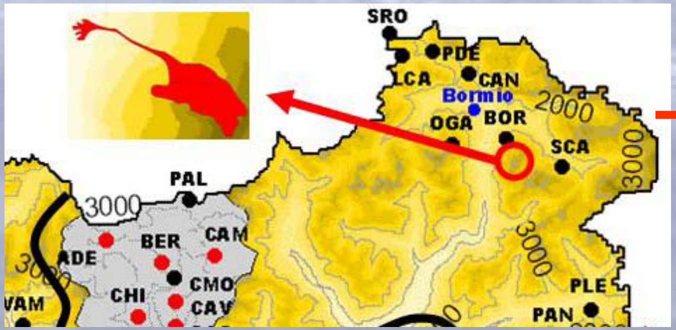




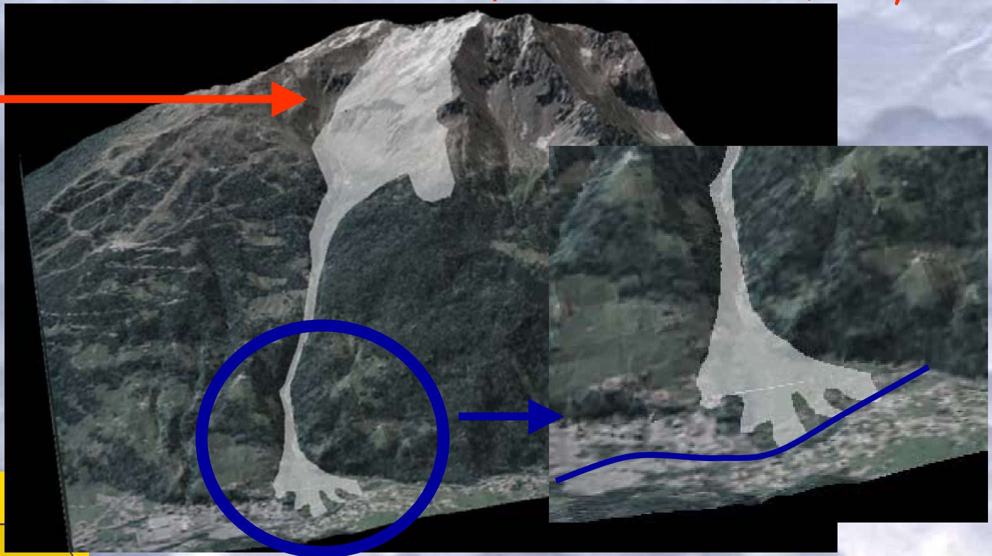
A noticeable increase in accuracy of the 300 years quantile is observed. Albeit this might be slightly decreased due to inter site correlation, still a considerable gain is attained

5) Case studies of hazard mapping: the Lombardia region.

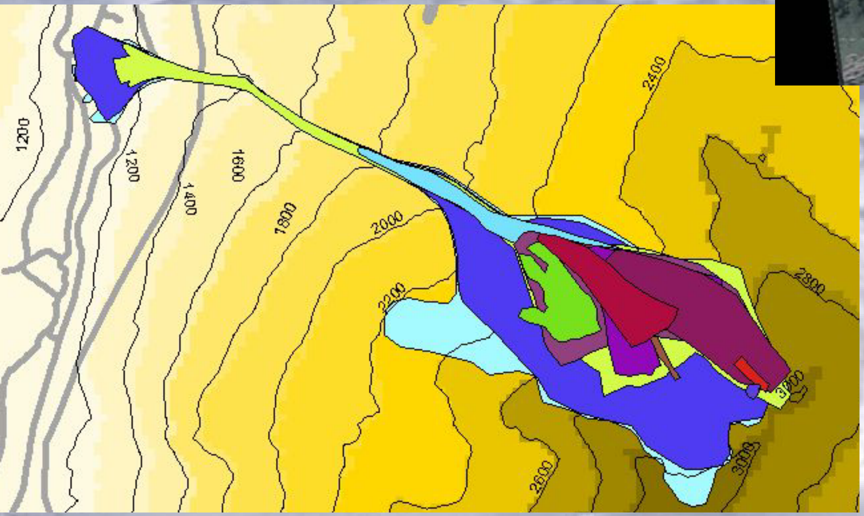
Vallecetta avalanche site, Bormio (So)



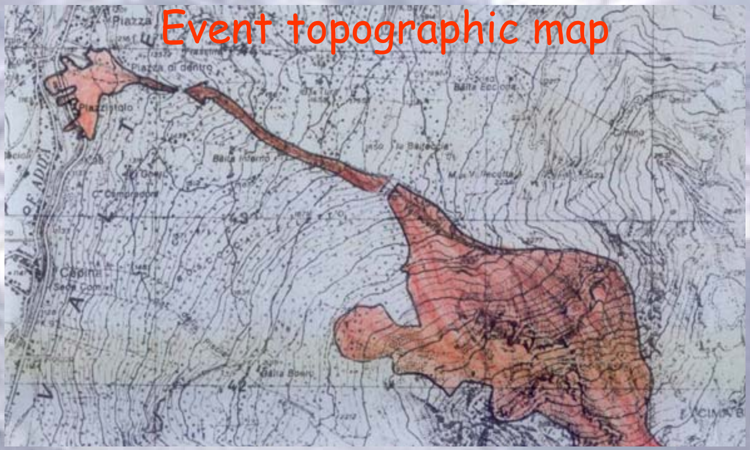
3D view of historical endmark, 16/5/1983



A number of mapped events

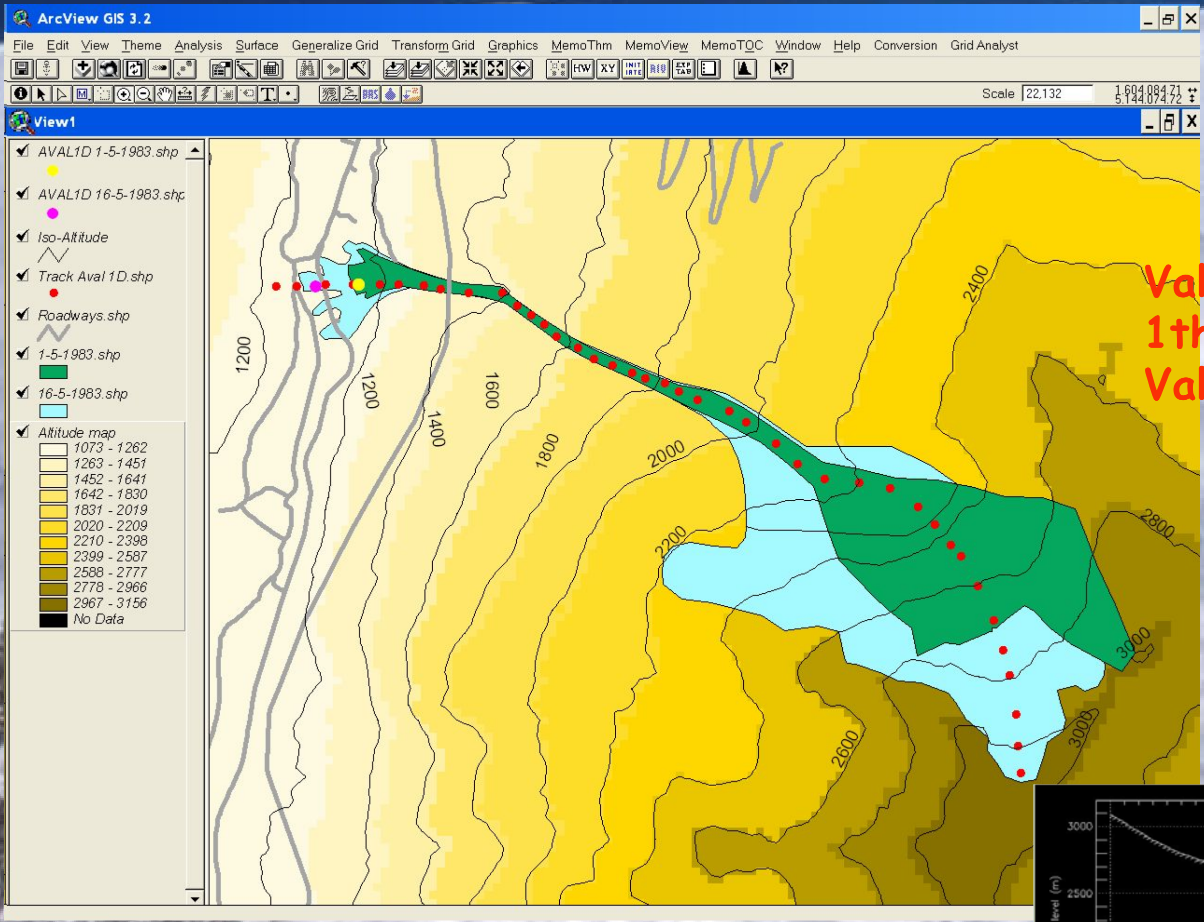


Event topographic map

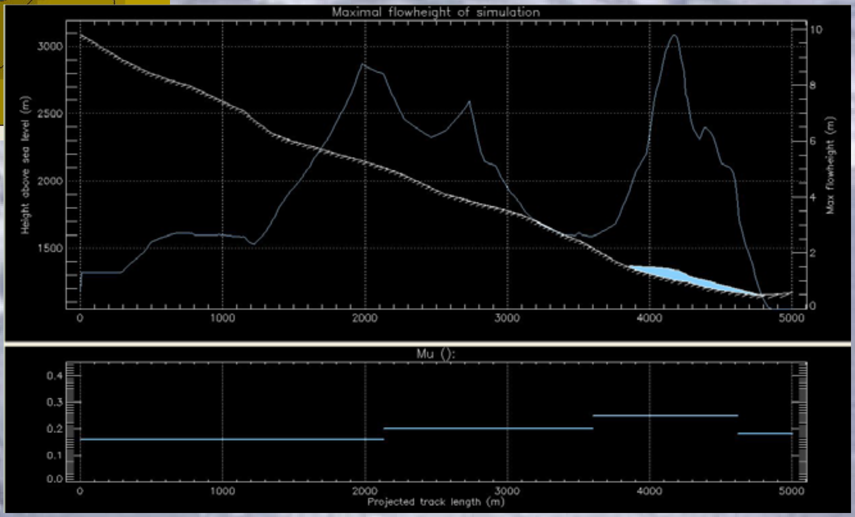


Riboni, A., Sovilla,B., Bocchiola, D., Rosso, R., *A regional approach to the calculation of the avalanche depth at release and application to two case studies in Lombardia*, Neve e Valanghe, 55, 22-39, 2005.
Paper in Italian language

Validation of AVAL1D

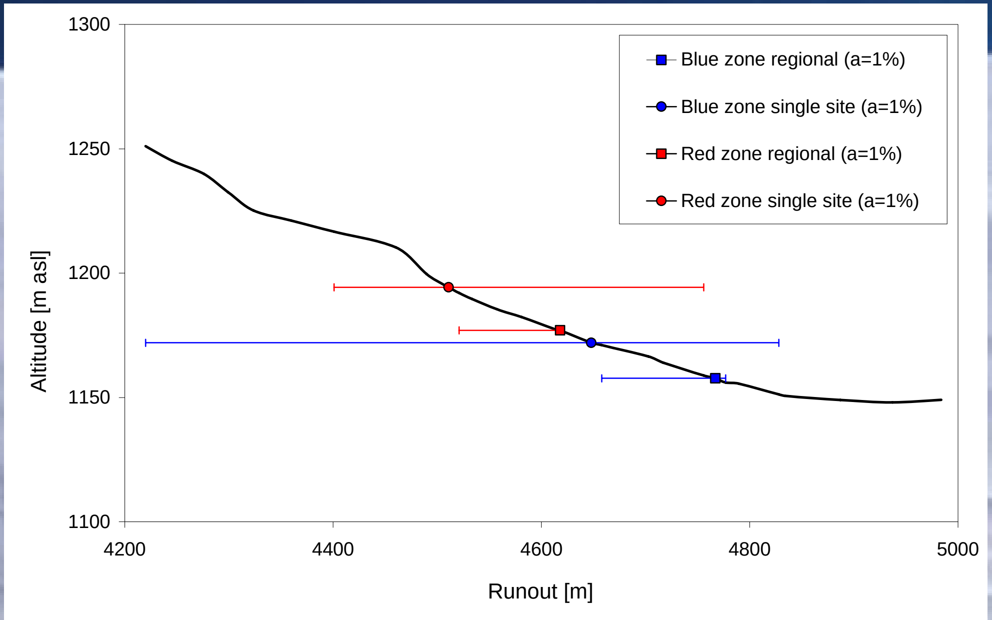


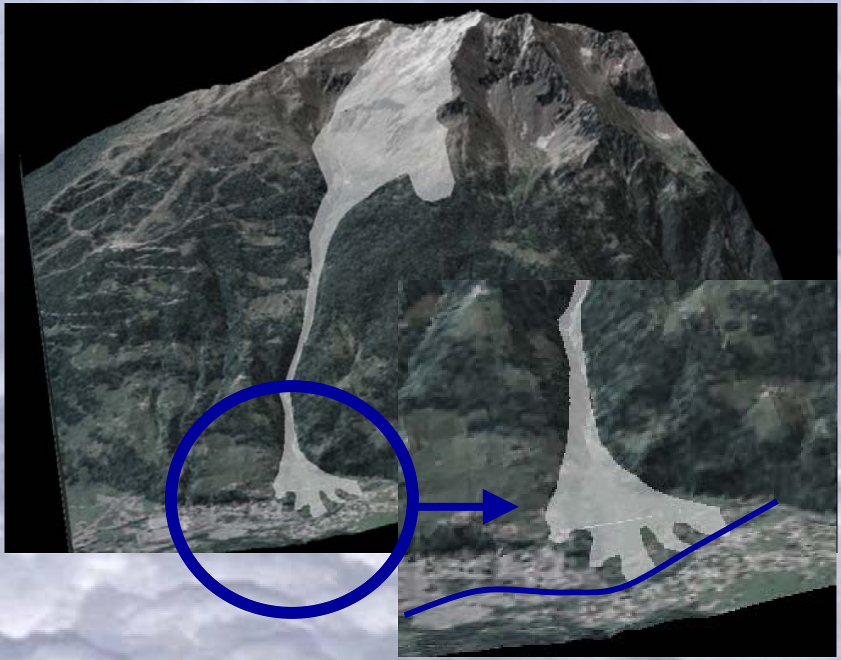
Vallecetta avalanche events on 1th and 16th May 1983 and Validation of Aval1D®.

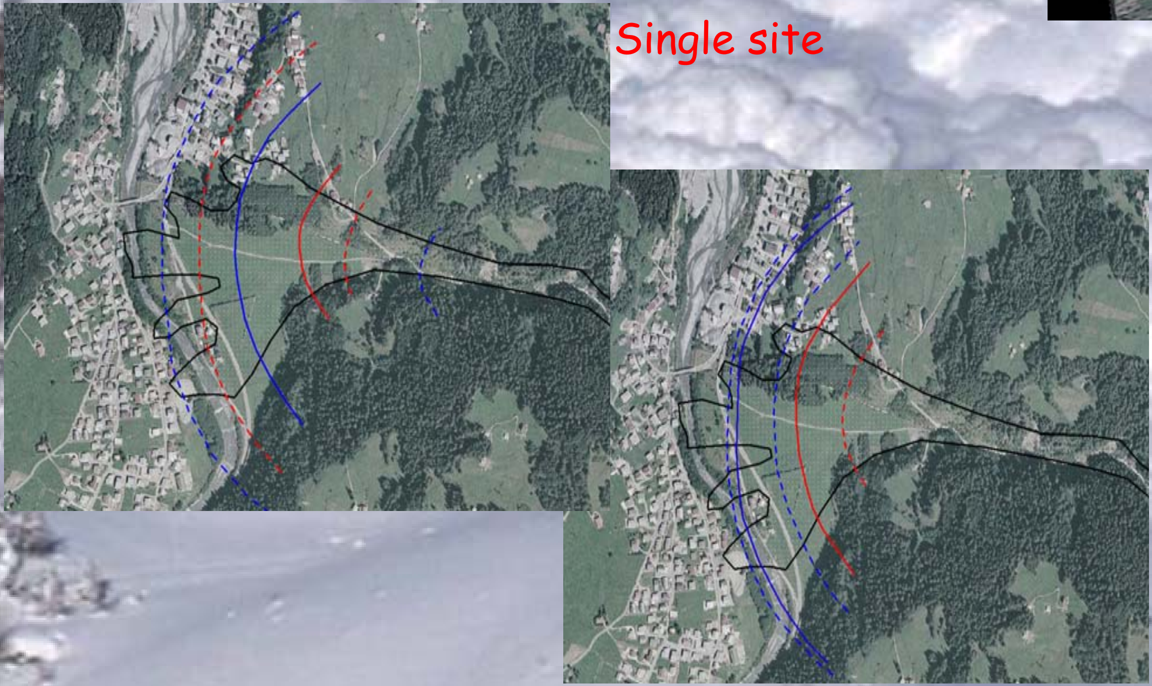


Source	A_0 [m asl]	A_R [masl]	R [m]	E_R [%]	H_s [m]	W_0 [m]	L_0 [m]	V_0 [m^3]
Observed 1th May 1983	2950	1174	4877	-	0.9	800	1110	7.99E^5
AVAL1D® 1th May 1983	//	1176	4838	-0.5%	//	//	//	//
Observed 16th May 1983	3140	1144	5172	-	1.3	1300	1254	2.118E^6
AVAL1D® 16th May 1983	//	1149	5110	-1.1%	//	//	//	//

Hazard mapping- sensitivity analysis







Single site

Regional

Adv. Geosci., 14, 201–209, 2008
www.adv-geosci.net/14/201/2008/
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Advances in Geosciences

Application of a regional approach for hazard mapping at an avalanche site in northern Italy

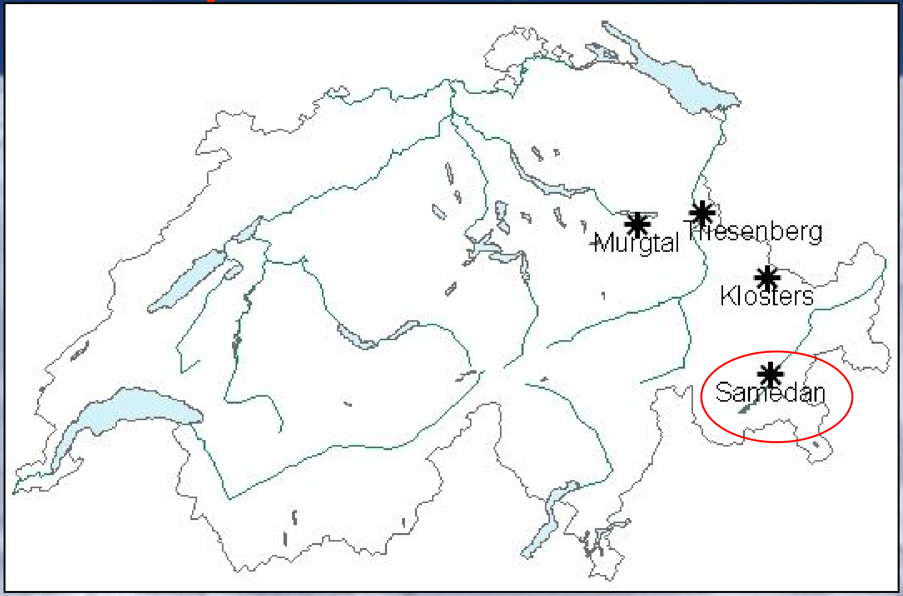
D. Bocchiola and R. Rosso

Politecnico di Milano, L. Da Vinci Square 32, 20133 Milano, Italy

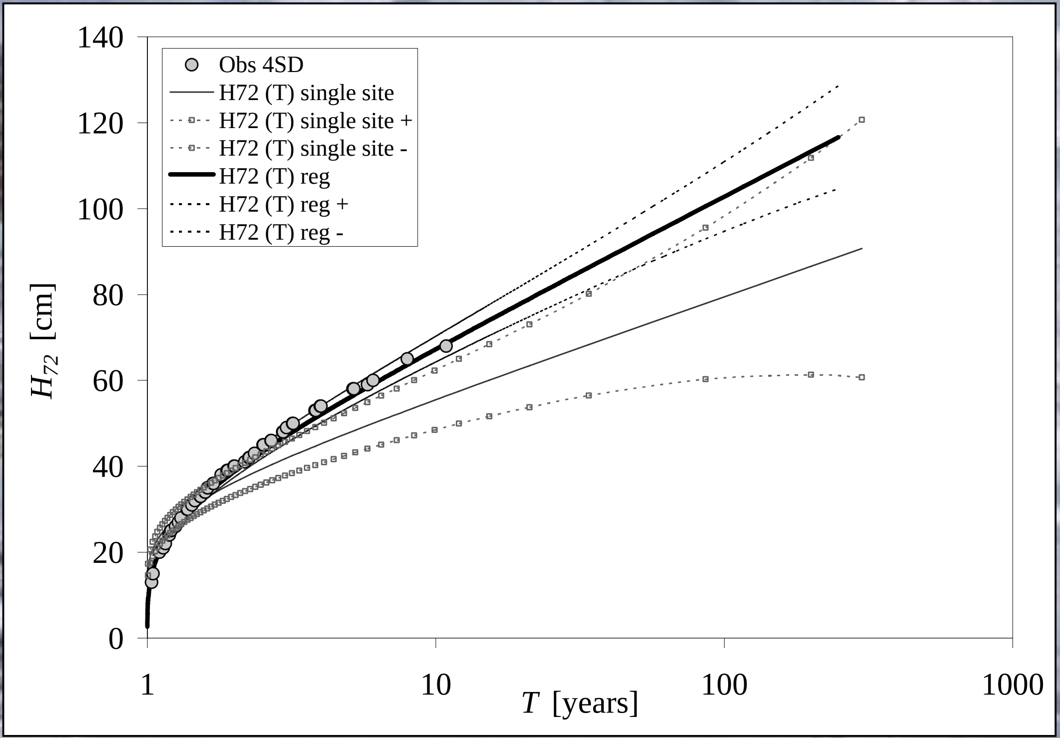
Received: 2 May 2007 – Revised: 19 February 2008 – Accepted: 20 February 2008 – Published: 10 April 2008

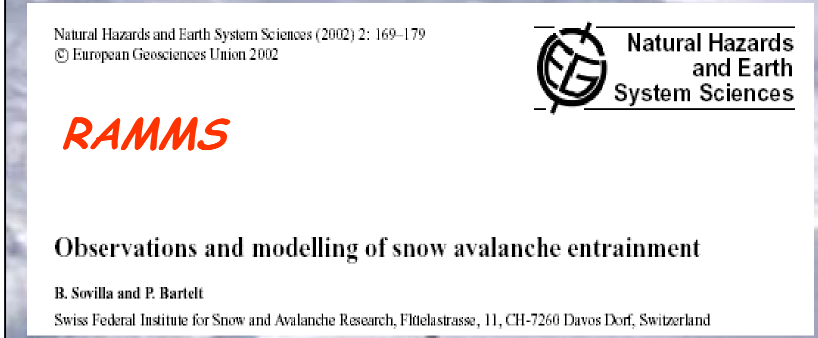
6) A case study in Switzerland

21 January 1951:
Samedan avalanche,
Engadina
Return period labeled:
T=300 years



$H_{72}(T)$ in Samedan




Natural Hazards and Earth System Sciences (2002) 2: 169–179
© European Geosciences Union 2002

Natural Hazards and Earth System Sciences

RAMMS

Observations and modelling of snow avalanche entrainment

B. Sovilla and P. Bartelt

Swiss Federal Institute for Snow and Avalanche Research, Flüelastrasse, 11, CH-7260 Davos Dorf, Switzerland

Samedan avalanche

Data

- Volume at release
- Run out

Model tuning using run out distance:

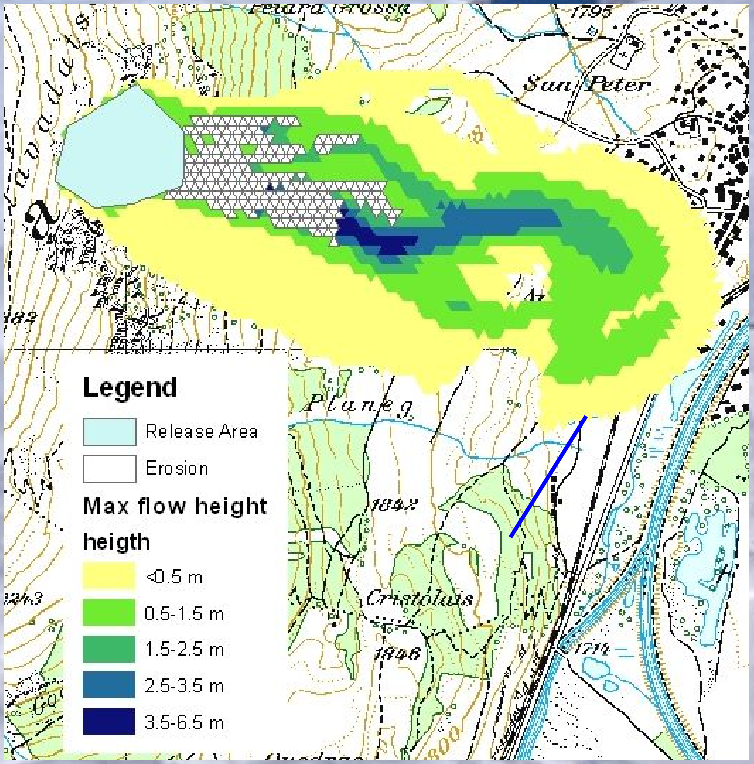
$$\mu = 0.15$$

$$\xi = 2500\,ms^{-1}$$

$$\lambda = 2.5$$

Critical stress

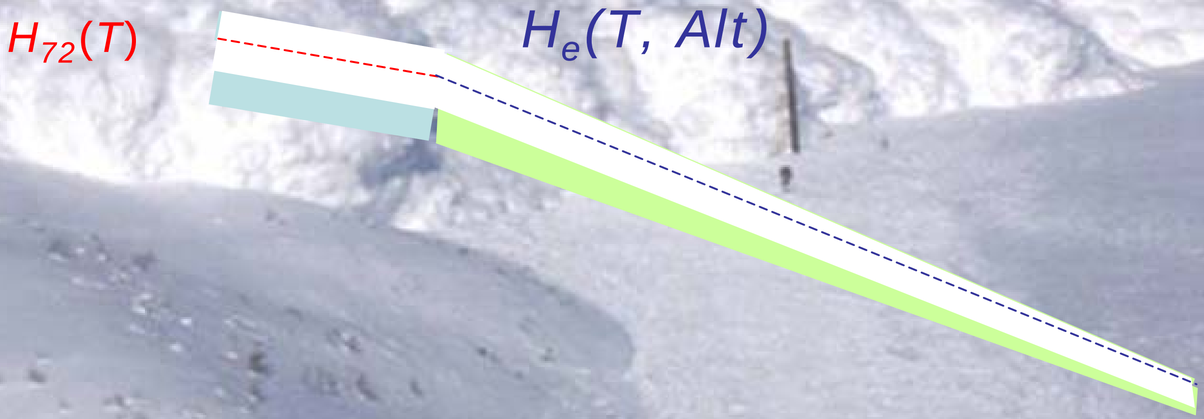
$$\tau_{cr} \cong 195 - 220\,\text{kPa}$$



Use of regional approach (+ uncertainty)

- h_r regional analysis = $H_{72}(T)$

-H_e variable with altitude= $H72(T,Alt)$

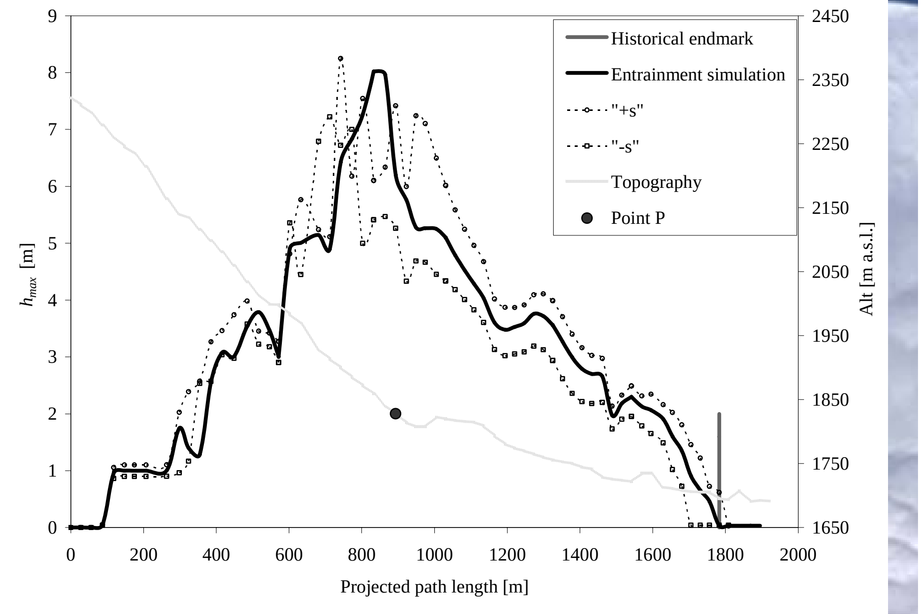


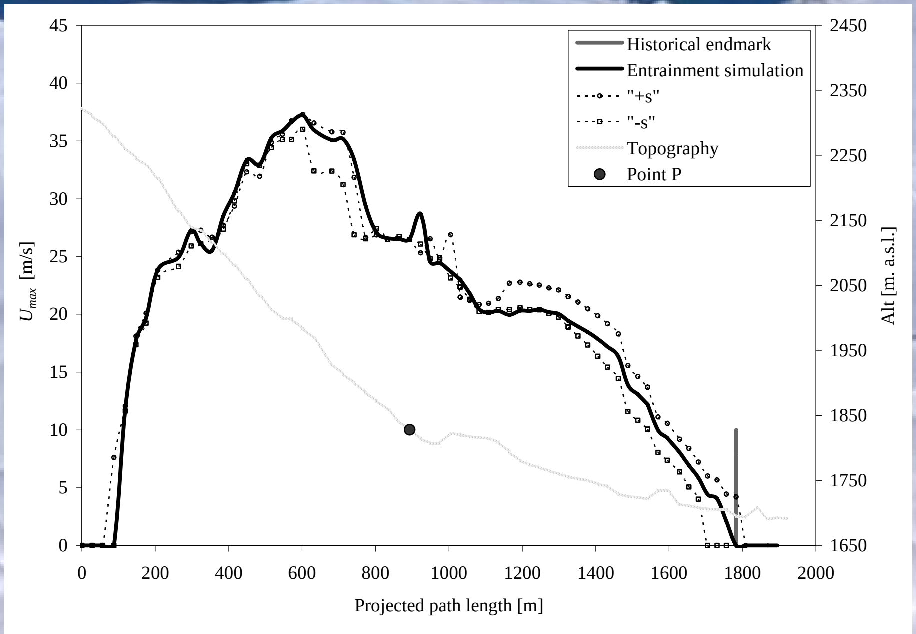
Uncertainty

h_r+s, H_e+s, variable

h_r -s, H_e-s, variable

Hazard maps





Sensitivity analysis:

Blue and red zones,

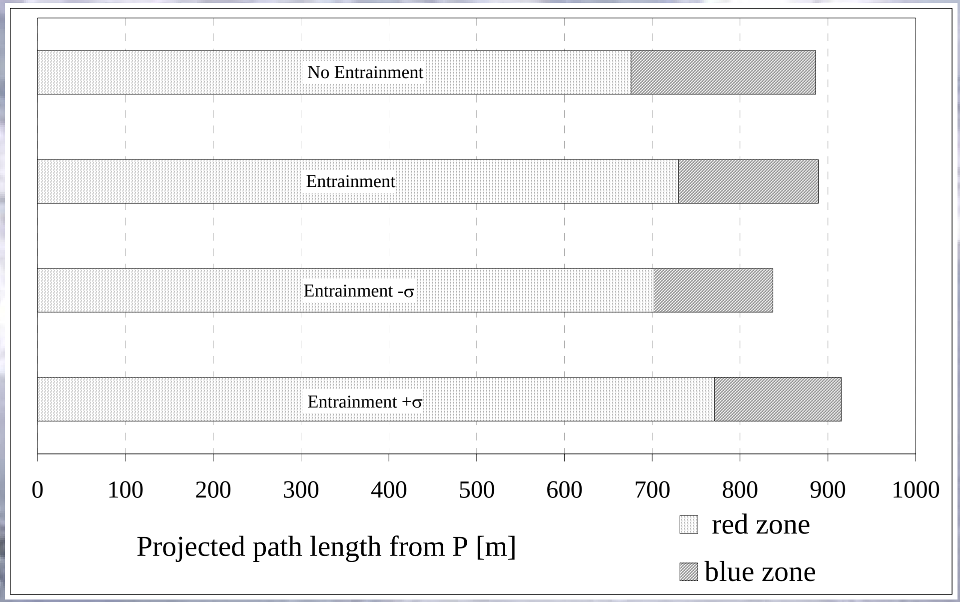
95% reference level

Annals of Glaciology 49 2008 1

Regional snow-depth estimates for avalanche calculations using a two-dimensional model with snow entrainment

Emanuela BIANCHI JANETTI,[1,2] Elisa GORNI,[1,2] Betty SOVILLA,[1]
Daniele BOCCHIOLA[2]

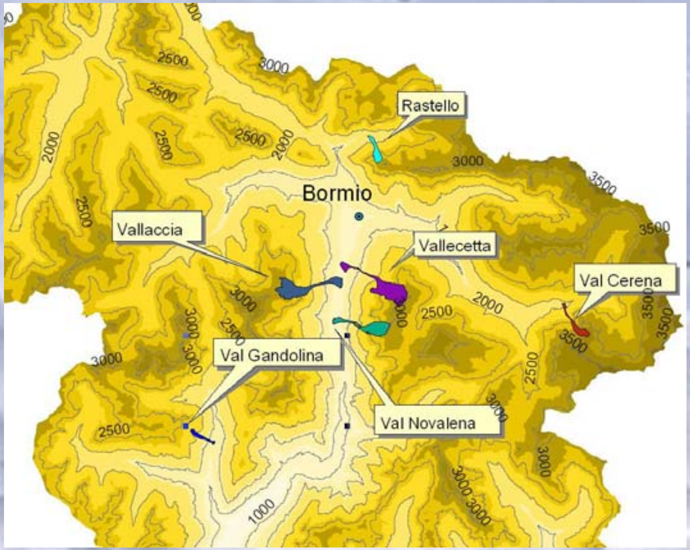
[1] *WSL Swiss Federal Institute for Snow and Avalanche Research SLF, Flüelastrasse 11, CH-7260 Davos-Dorf, Switzerland*
[2] *Dipartimento di Ingegneria Idraulica, Ambientale, Infrastrutture Viarie e Rilevamento, Politecnico di Milano, Piazza Leonardo da Vinci 32, I-20133 Milan, Italy*
E-mail: daniele.bocchiola@polimi.it



7) Long term simulation of avalanche frequency

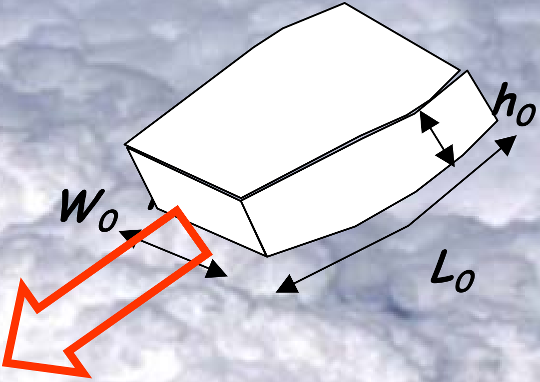
A collection of data related to avalanche events in Bormio region was gathered

Data from 69 avalanche events were gathered, dating back until 1886
These include avalanche type, snow conditions, morphology, release altitude, depth, area, runout lenght and volume.



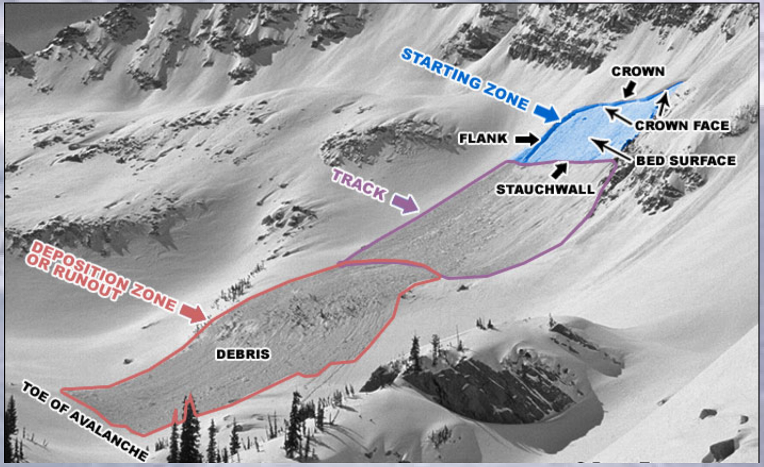
In 68% of the events, avalanche cause is related to heavy snowfall

h_0: depth at release
W_0: width “ ”
L_0: length “ ”
V_0: volume “ ”

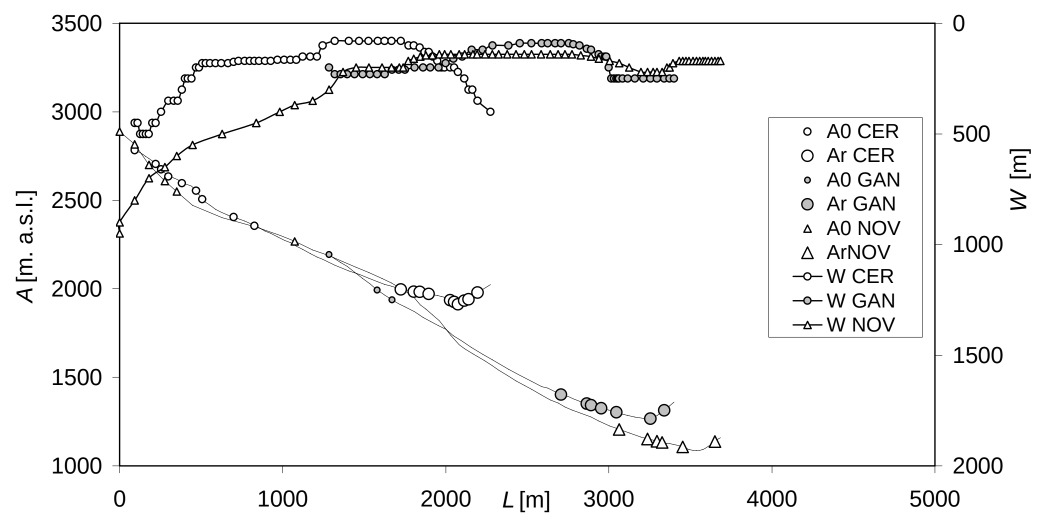


L: runout length
R: absolute runout

Reported in:
Bocchiola, D., Medagliani, M. (2007). Morfologia delle valanghe, uno studio nell’area del Bormiese [Morphology of avalanches: a study in the Bormio area], Neve e Valanghe, 3, 70-79, in Italian language with Abstract in English. Available upon request or at: http://www.aineva.it/presenta.html



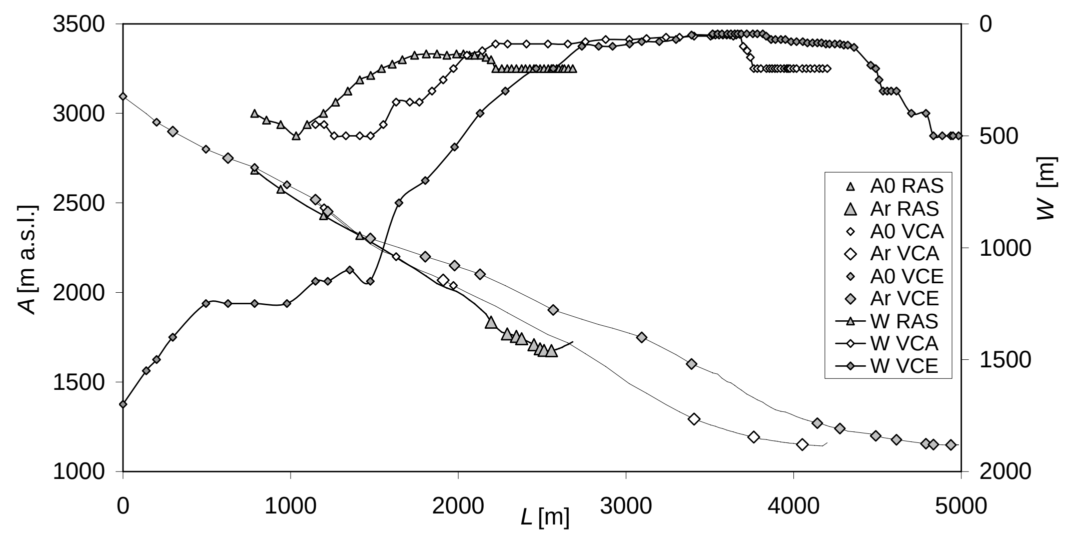
Regional similarity



Avalanche track geometry. E[s_0] is average track slope including the release area, E[s_f] is average track slope including the flow area, E[s_f] is average track slope including the runout area (average track slope). L_0′ is percentage of track length including release area, L_f' is percentage of track length including flow area.

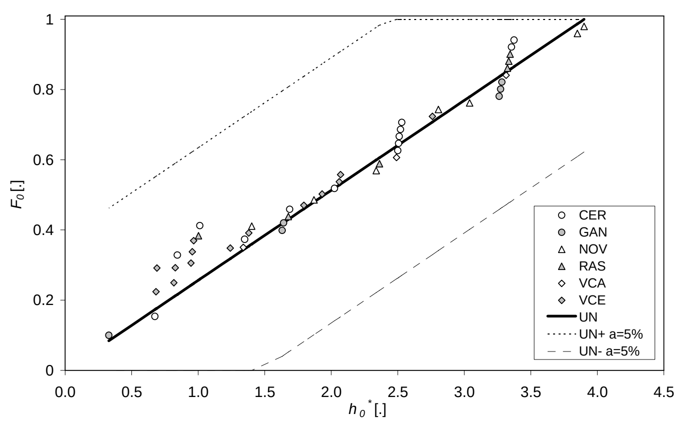
	CER	GAN	NOV	RAS	VCA	VCE	E[.]	CV[.]
E[s_0] [°]	30.2	30.3	30.0	30.1	29.2	28.3	29.7	2.6%
E[s_f] [°]	25.7	28.5	29.2	31.1	28.1	24.2	27.8	8.9%
E[s_r] [°]	20.9	23.2	25.6	29.7	24.9	21.5	24.3	13.2%
L_0' [%]	35%	30%	29%	39%	28%	30%	32%	13.1%
L_f' [%]	78%	73%	79%	80%	78%	78%	77%	3.1%

Reasonable geometric similarity might indicate a possible statistical homogeneity of scaled geometric properties



Regional similarity

A regional approach based on index value is tentatively adopted to increase sample dimensionality for distribution fitting of the observed avalanche properties



Avalanche release probability is evaluated as a function of dimensionless snow depth, as

$$h_0^* = h_0 / \mu_{H72}$$

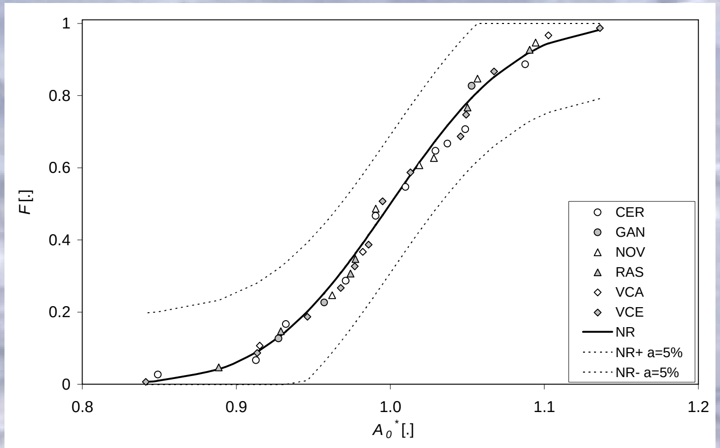
$p_{rel} = F_0(h_0)$

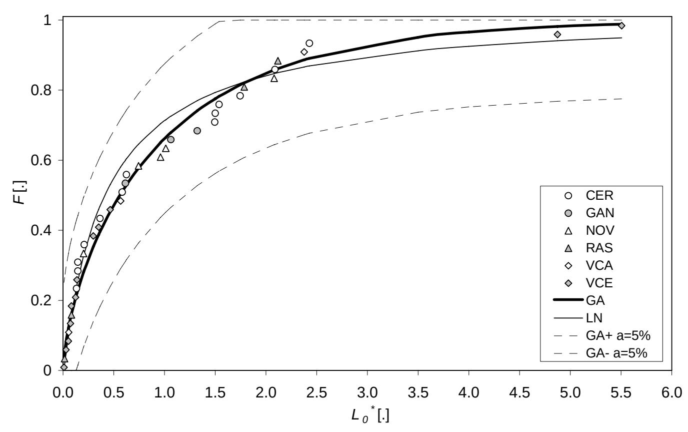
Release altitude is accommodated as a Normal (NR) distribution

$$A_0^* = A_0 / \mu_{A0}$$

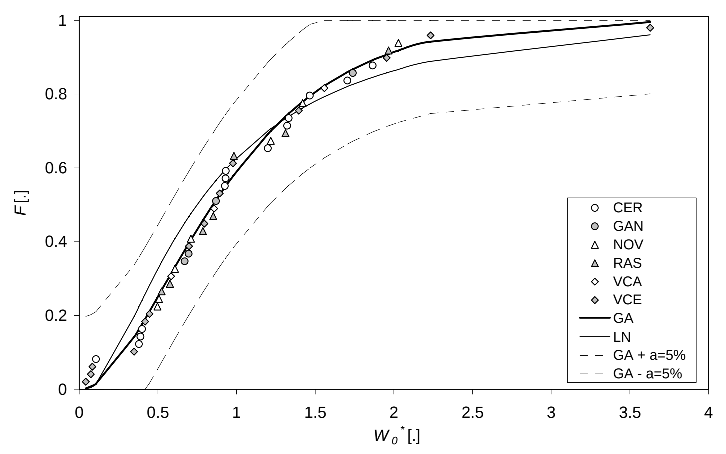
$$W_0^* = W_0 / \mu_{W0}$$

$$L_0^* = L_0 / \mu_{L0}$$



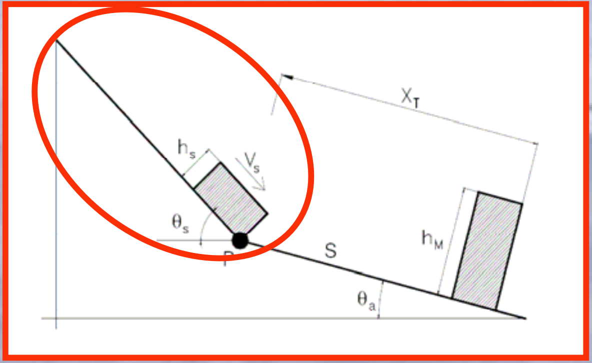


Avalanche release widht and length are accommodated using a GA distribution



Dynamic model

Dynamic model: Voellmy-Salm (insofar)



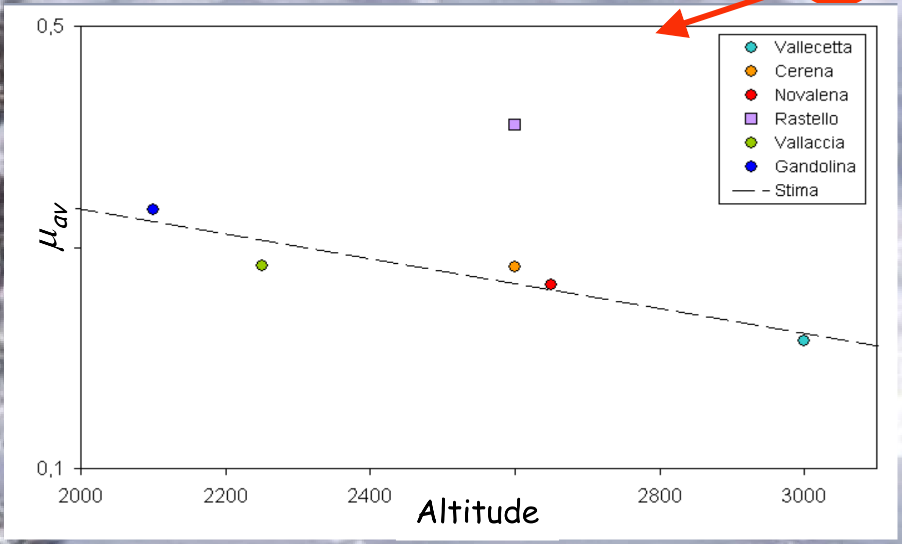
$$f_R = \frac{\rho g}{\xi} V_s^2 + \mu \rho g h_s \cos\theta_s$$

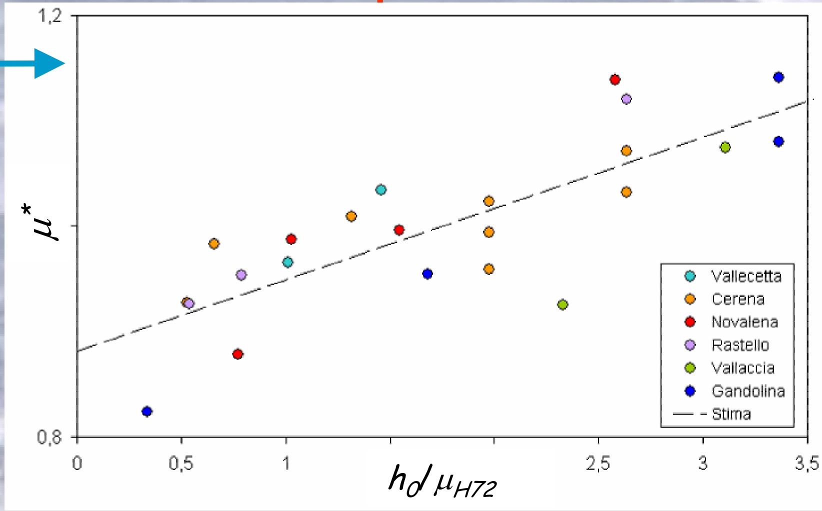
Turbulent friction → topography

Coulomb friction → Calibration against observed runout

Coulomb friction is evaluated against release altitude and snow depth

$$\mu = \mu_{av} \, \mu^*$$

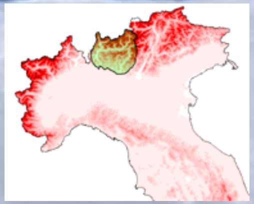


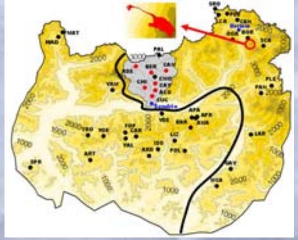


Reported in:
Bocchiola, D., Medagliani, M. (2007). Morfologia delle valanghe, uno studio nell'area del Bormiese [Morphology of avalanches: a study in the Bormio area], Neve e Valanghe, 3, 70-79, in Italian language with Abstract in English. Available upon request or at: http://www.aineva.it/presenta.html

A case study

Case study: Vallecetta mountain





Climatic input:

H_{72} calculated @ the release altitude

Avalanche occurrence:

Input snow depth H_{72} is used to give release probability, p_{rel}. Random extraction from a Uniform distribution, p_u is used to evaluate occurrence using a binomial approach (yes, $p_u > p_{rel}$; no $p_u <= p_{rel}$)

Avalanche release altitude:

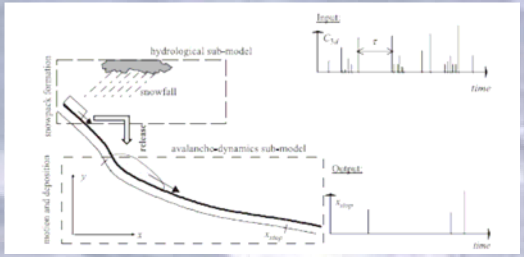
Drawn from the proposed NR statistical distribution

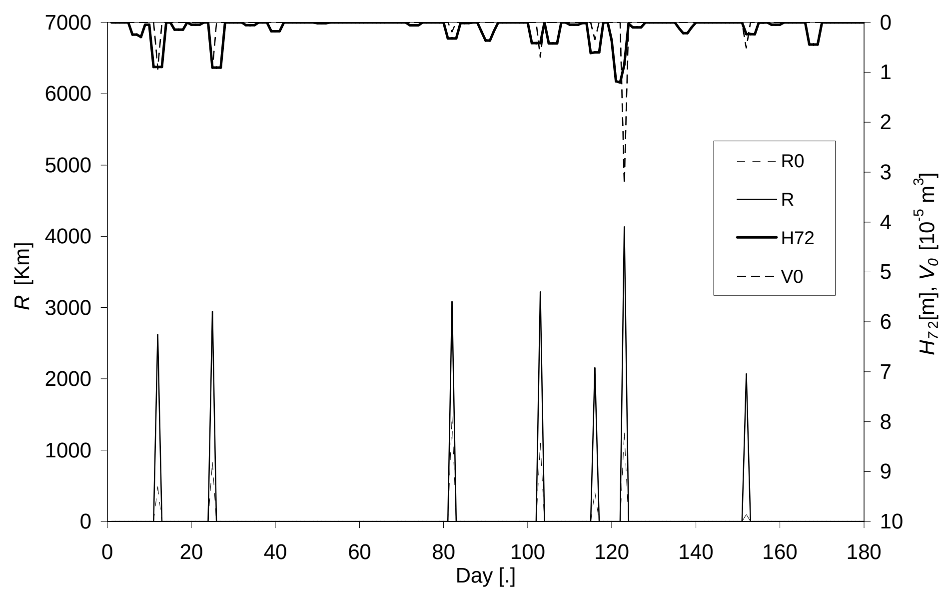
Avalanche release width, length:

Drawn from the proposed GA statistical distributions

Avalanche release volume:

$V_0 = W_0 * L_0 * H_{72} * f(\text{slope})$

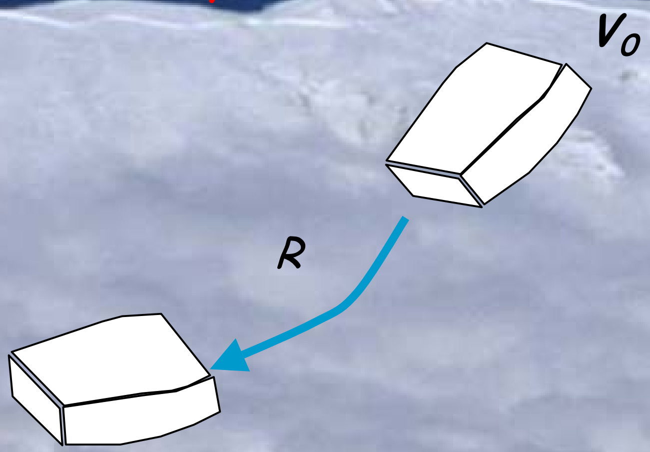


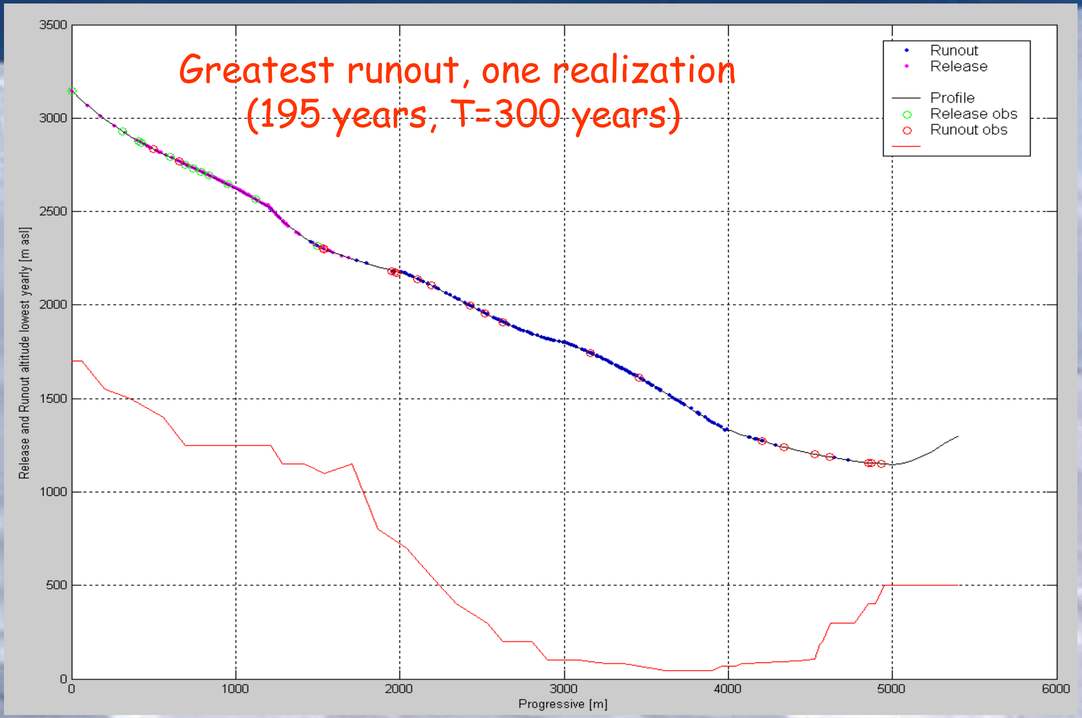


Bocchiola, D., Medagliani, M., Rosso, R., Use of a regional approach for long term simulation of snow avalanche regime: a case study in the Italian Alps, Arctic Antarctic and Alpine Research , March 2008, Submitted.

Hazard mapping

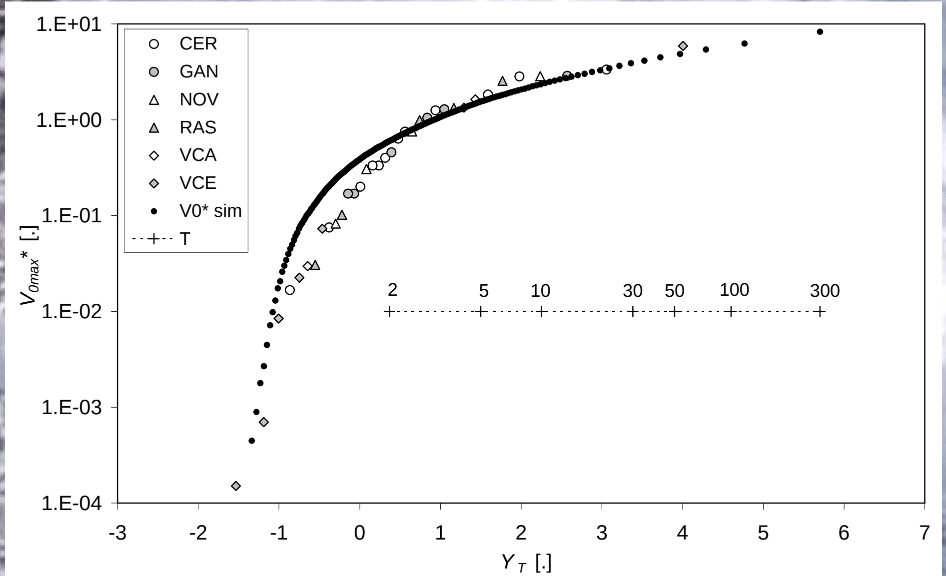
Release volume, runout

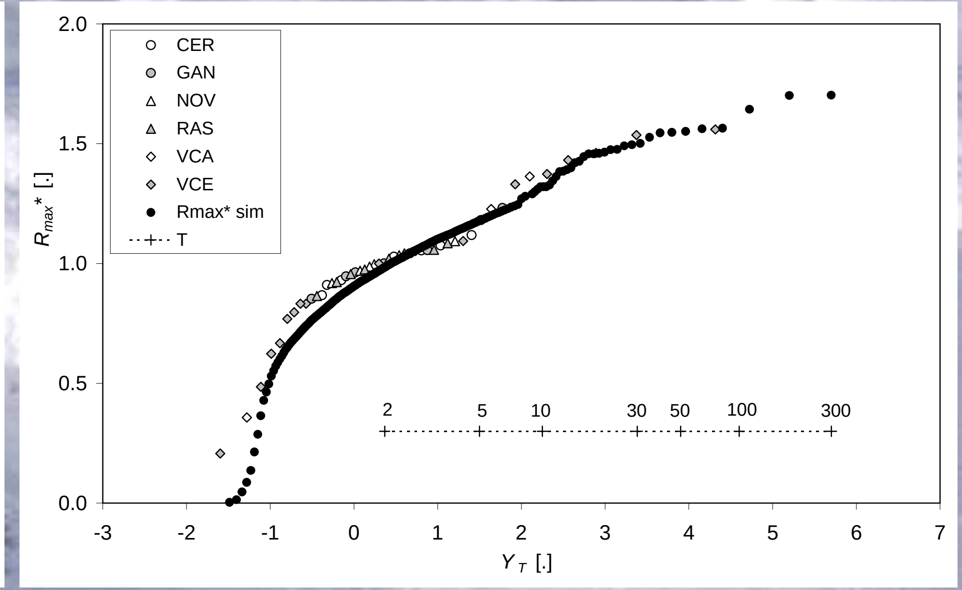




Greatest runout, one realization (195 years, T=300 years)

Fitting to the regionalized plotting position is verified to indirectly validate the approach





Hazard maps

Hazard maps: *Sp* modified for Italy

ZONA ROSSA	- T=30anni; P≥3kPa - T=100 anni; P≥15kPa
ZONA BLU	- T=30anni; 0kPa≤P<3kPa - T=100 anni; 3 kPa ≤P<15kPa

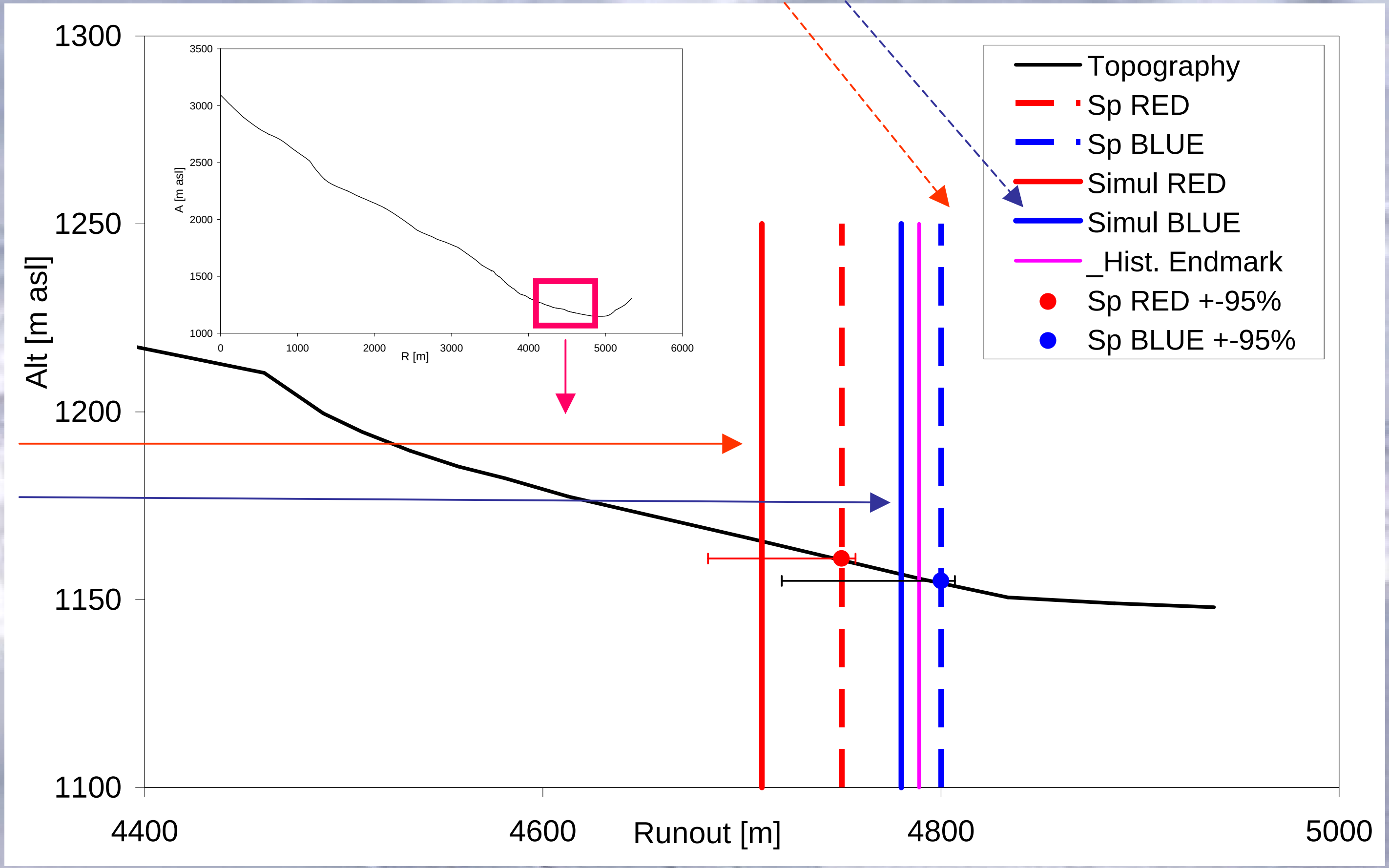
$$R(T)=R\left(H_{72}(T)\right)$$
$$P(T)=P\left(H_{72}(T)\right)$$

$$T = \quad 30, \boxed{100}$$

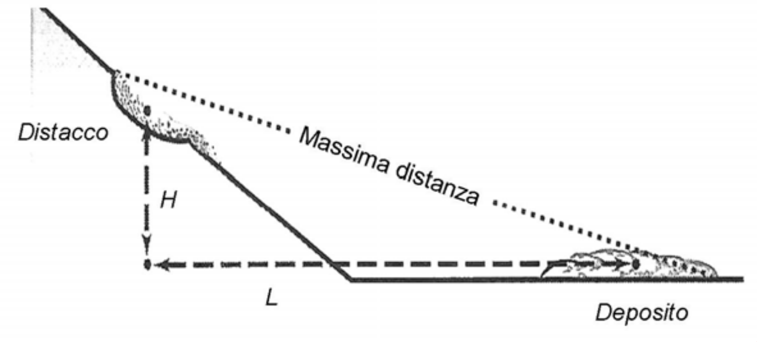
Runout length and pressures return period *T* is directly evaluated from the long term simulated plotting position

$$R = R\left(\hat{T} = 30,100\right)$$
$$P = P\left(\hat{T} = 30,100\right)$$

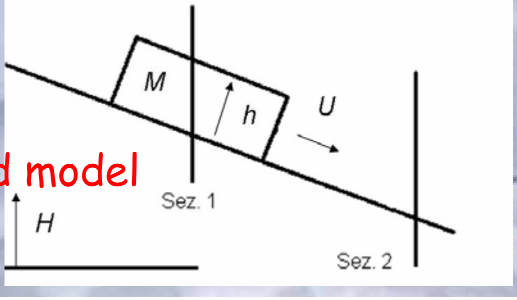
"Classical" *Sp* approach



8) A simple developed avalanche model

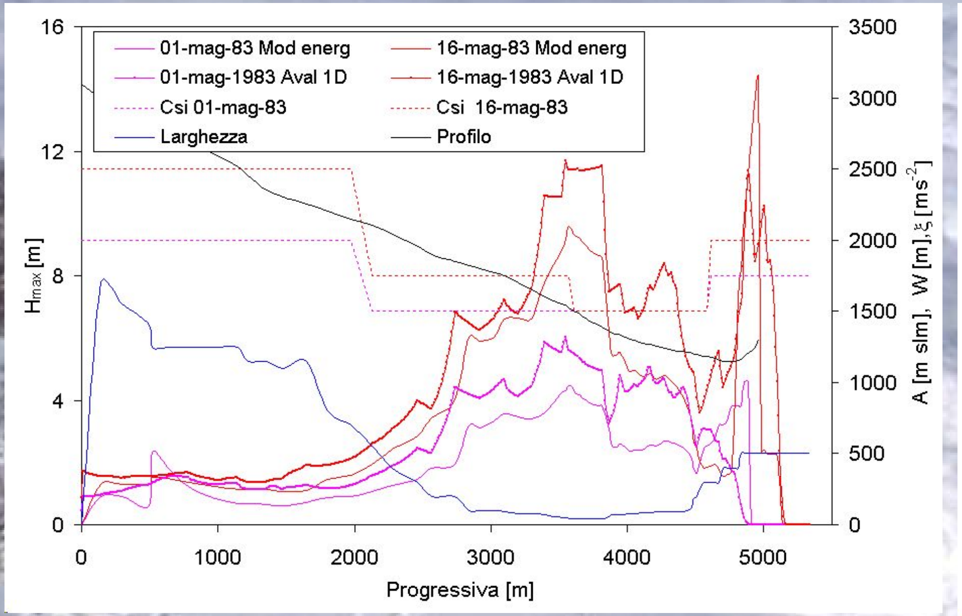


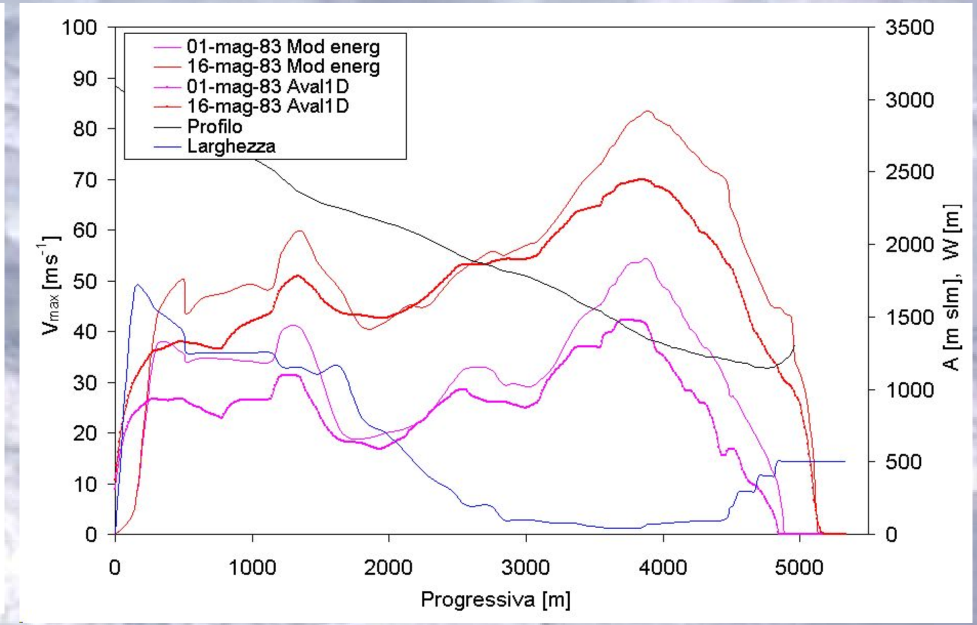
We preliminarily developed and tested a simple avalanche dynamics model,to be used joint with long term simulation module



Mass centre, 1D, energy based model

Vallecetta (Again ?????): calibration of observed runout





Edmondo Arena Lo Riggio, Mirko Mura, Daniele Bocchiola, Maria Cristina Rulli, Renzo Rosso, Un modello a formulazione energetica per il calcolo dinamico delle valanghe [An energy conservation based model for avalanche dynamics]. Neve e Valanghe, in press. Paper in Italian language, abstract in english. Available upon request

9) Some remarks

Land use planning in mountain range requires reliable avalanche hazard mapping, forecasting and design of countermeasures

Lack of avalanche data requires coupling of dynamic modelling and long term snow fall series for design of extreme events

Statistical methods based on regional approaches might be used to increase sample dimensionality, so gaining considerable information and decreasing uncertainty in avalanche design exercise

Long term assessment of avalanche hazard based on synthetic simulation provides a tool avalanche for hazard mapping based on full simulation of avalanche history

Also, synthetic simulation may provide input for long term assessment of avalanche risk for human settlements, and the impact of countermeasures, in case under climate change scenarios

EU and nationally fostered projects like IRASMOS are highly necessary to stimulate the debate and provide the researchers with means to bring forward new techniques and concepts

…………and watch your track !!!