Intégrer la non-stationnarité des sources dans un modèle spatio-temporel de risque relatif : application à 200 ans d'activité avalancheuse

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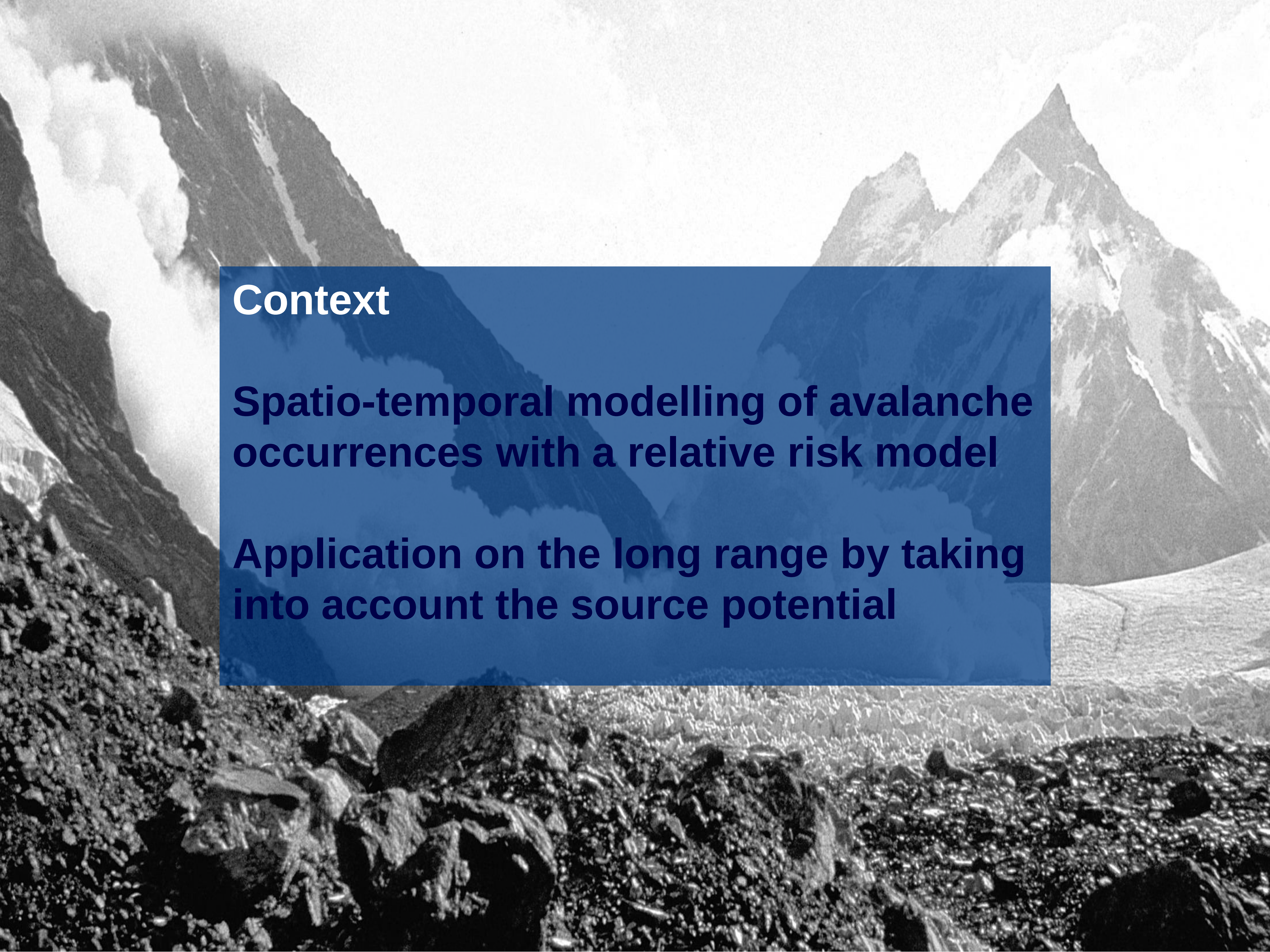
avec des idées de Aurore Lavigne, Eric Parent, Liliane Bel et beaucoup d'autres…

Journée AppliBugs, Lyon, 21 juin 2018



Context

Spatio-temporal modelling of avalanche occurrences with a relative risk model

Application on the long range by taking into account the source potential

Mountain hazards and related risks

- Spectacular phenomena.
- Often related to the cryosphere.
- Deep socio-economic consequences when interacting with elements at risk.

Rockfall ©Tareom.com

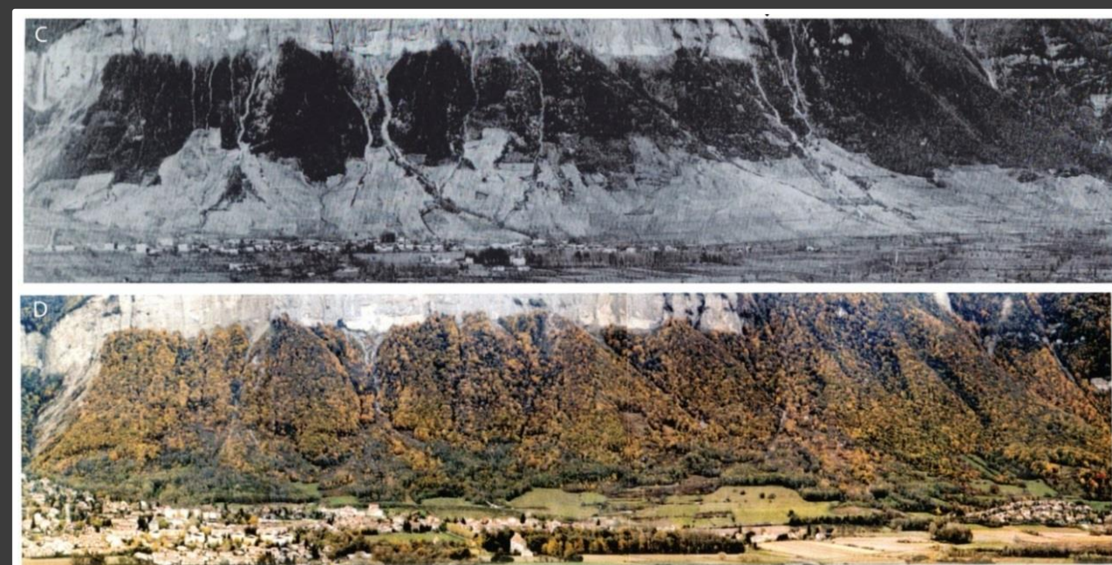
Snow storm and drifting snow © Irstea ETNA

Avalanche deposit on a dwelling house © Irstea ETNA

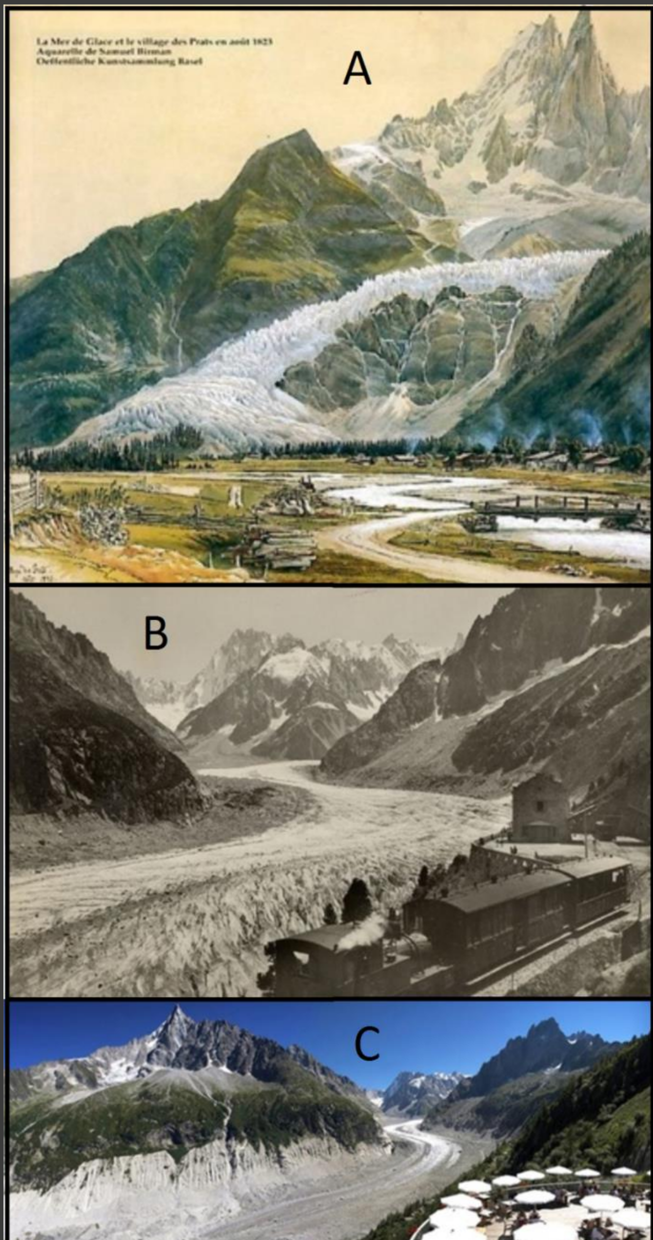
Debris flow deposit © Irstea ETNA

A rapidly changing environment

- Unprecedentedly fast warming since end of PAG.
- Concomitant unprecedentedly fast societal mutations.
- Highly vulnerable system (critical zone).
- Exacerbated changes / response of cryosphere, ecosystems, mountain hazards and risks.



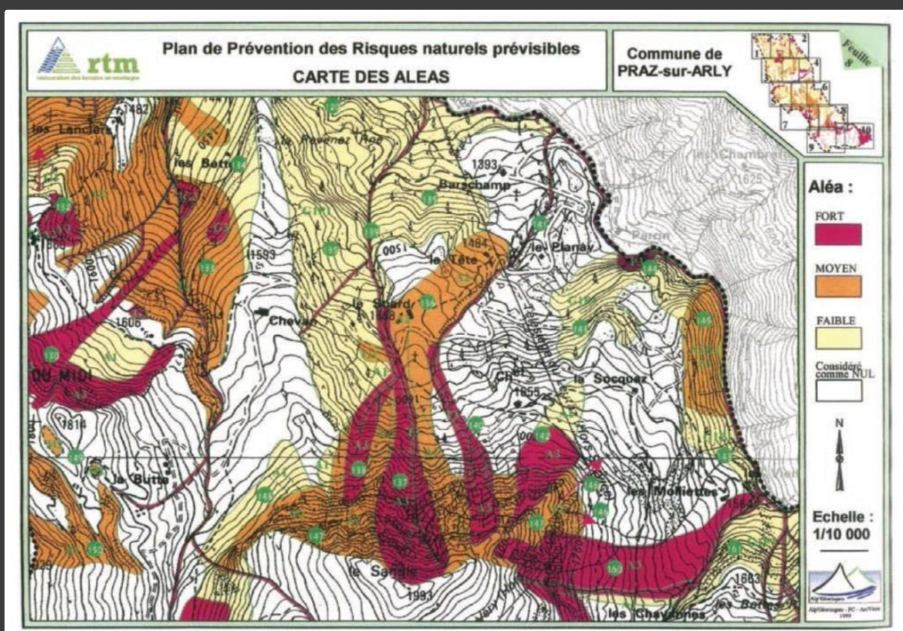
Historical photograph of the Crolles talus slope in 1912 (© Blanchard, 1930) and current photograph of the village of Crolles in 2013 (© J. Lopez-Saez, Irstea).



Shrinkage of the Mer de Glace since the end of the Little Ice Age. A) glacier des Bois in 1823, © Basel museum; B) Mer de Glace and Montenvers resort in 1949, © ETZ archives; C) Mer de Glace in 2015 from the Montenvers resort, © Chamonix-sightseeing-tours.com.

Recurrent and emerging hazards / risks

- Recurrent hazards: long term forecasting on the basis of history. Yet, frequency, magnitude, timing, typology, etc. may by affected by environmental changes.
- Emerging hazards: “new” phenomena related to glacier shrinkage, permafrost thawing, mutation of ecosystems, etc.
- “Grey” boundary between these classes.



Legal hazard (avalanches, landslides, rockfall, torrential flood) map of Praz sur Arly (Haute Savoie, France) reprinted from MEDDE (2015). Colored surfaces correspond to strong, medium and low hazard levels according mostly to historical information.

Wet snow avalanche in Saint François Longchamp, French Alps, 2 March 2012, © DAG Modane / data-avalanche.org published in Naaim et al. (2016).

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Now an old problem in our field

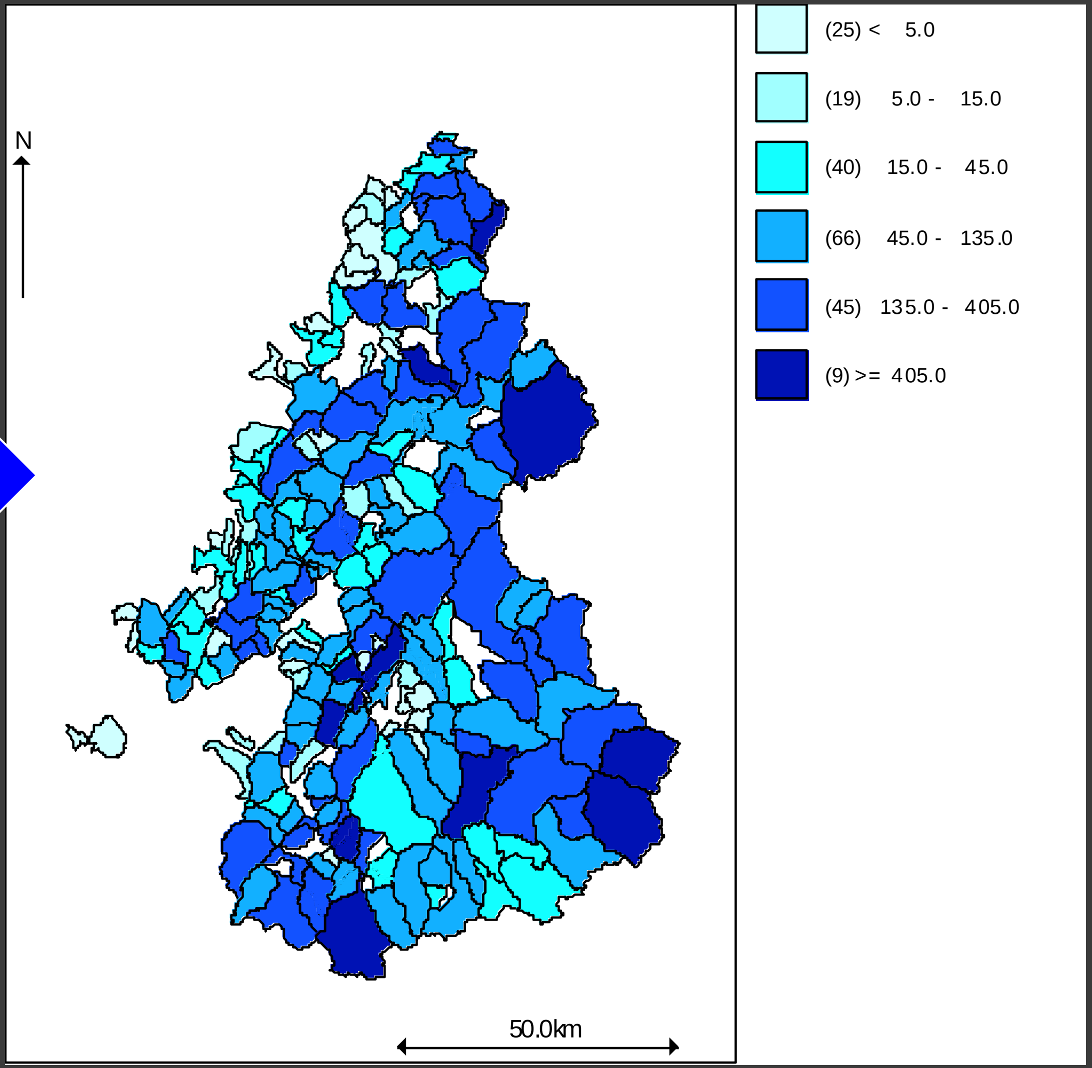
Modelling avalanche occurrence data
In the Northern French Alps:
Savoie and Haute Savoie departments

1946-2005

Township scale (small spatial scale):
204 townships

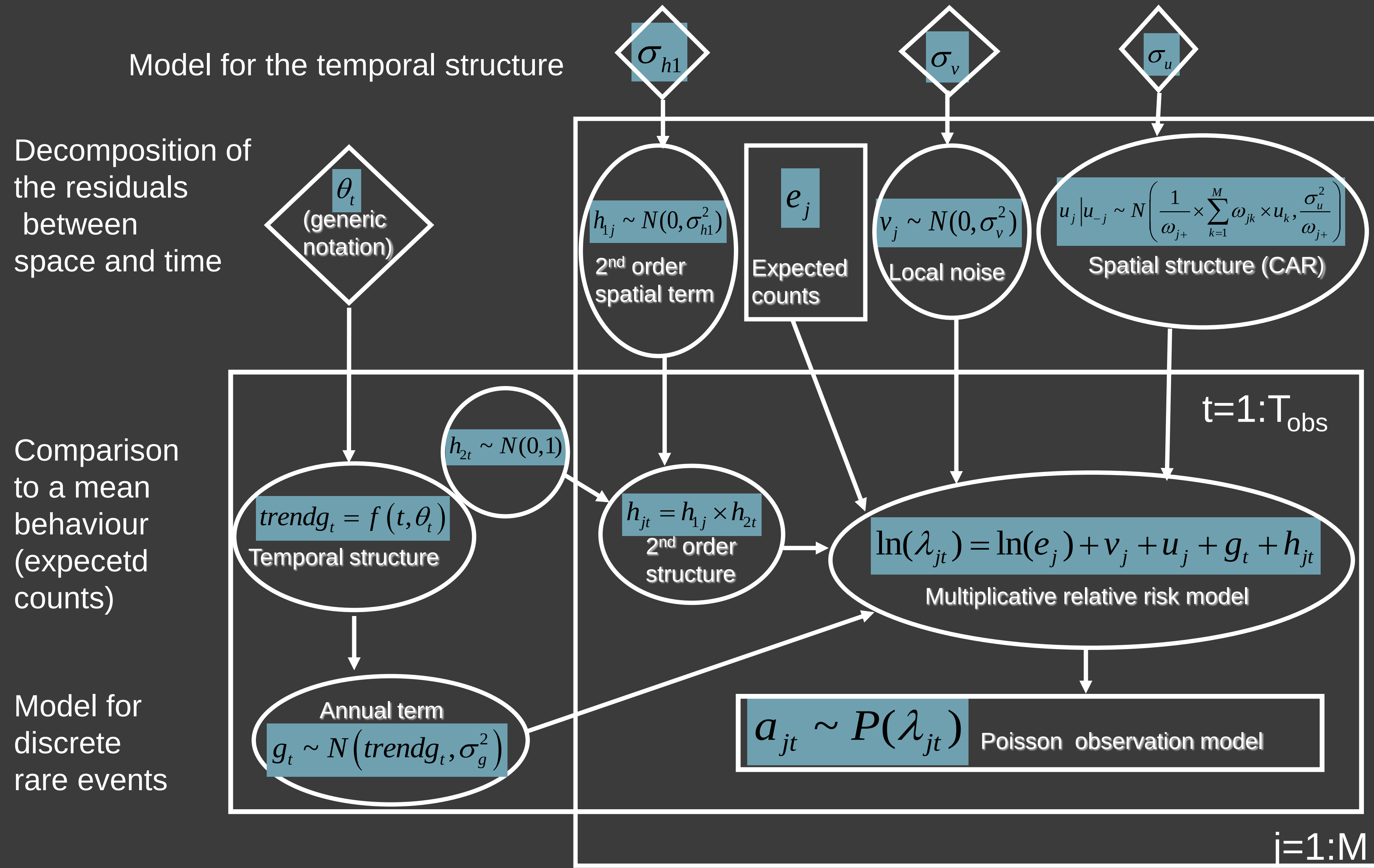
Statistical tests to discard years
with missing events

21,682 events considered



Total number of avalanches per township over the considered period

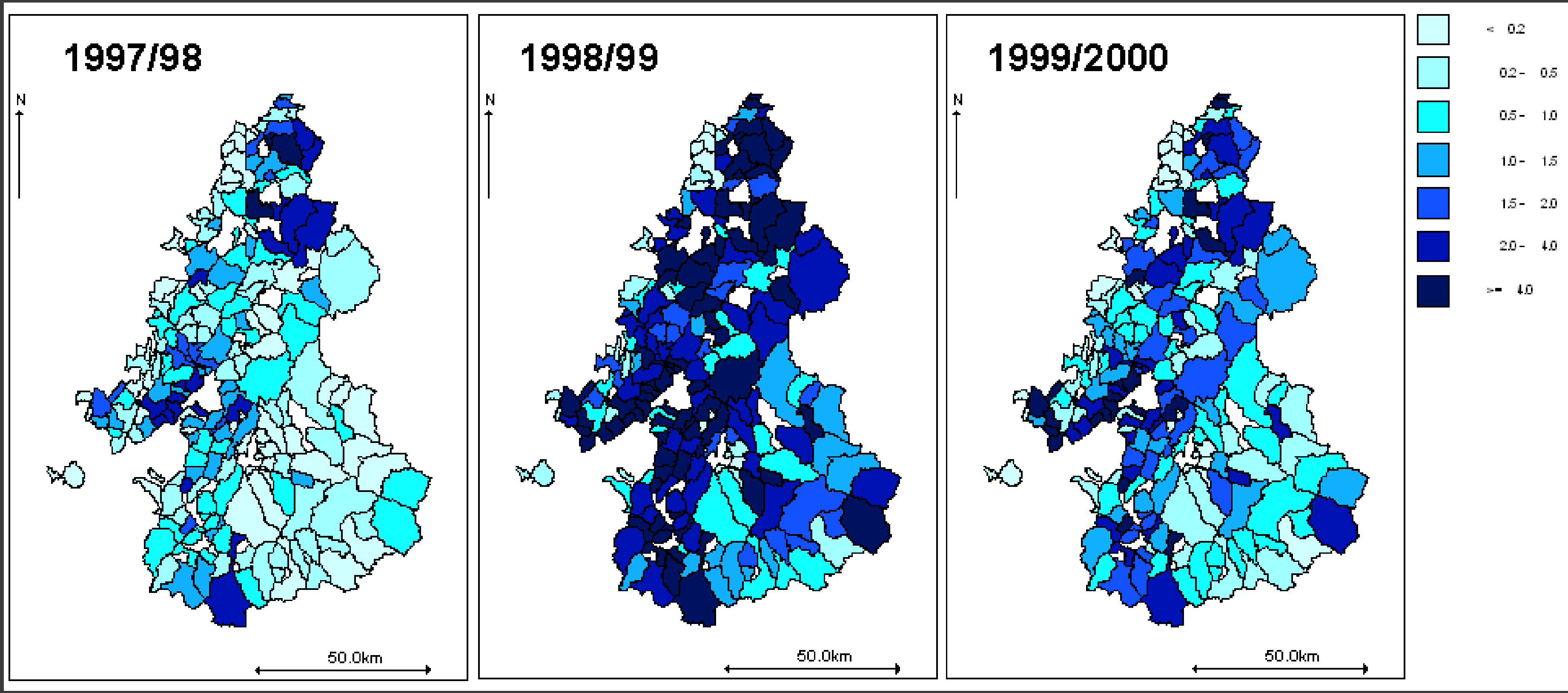
Spatio-temporal model for avalanche occurrences



Annual fluctuations of the normalised avalanche numbers

$$RR_{jt} = \frac{\lambda_{jt}}{e_j} = \exp\left(u_j + v_j + g_t + h_{jt}\right)$$

- Spatial structure is conserved
- Weighted by the annual term
- Perturbed by interactions effects



Spatio-temporal modelling of the number of avalanche occurrences in the Northern French Alps (Eckert et al., 2010). Relative risks for three consecutive winters. avalanche activity was abnormally low, abnormally high and standard, respectively.

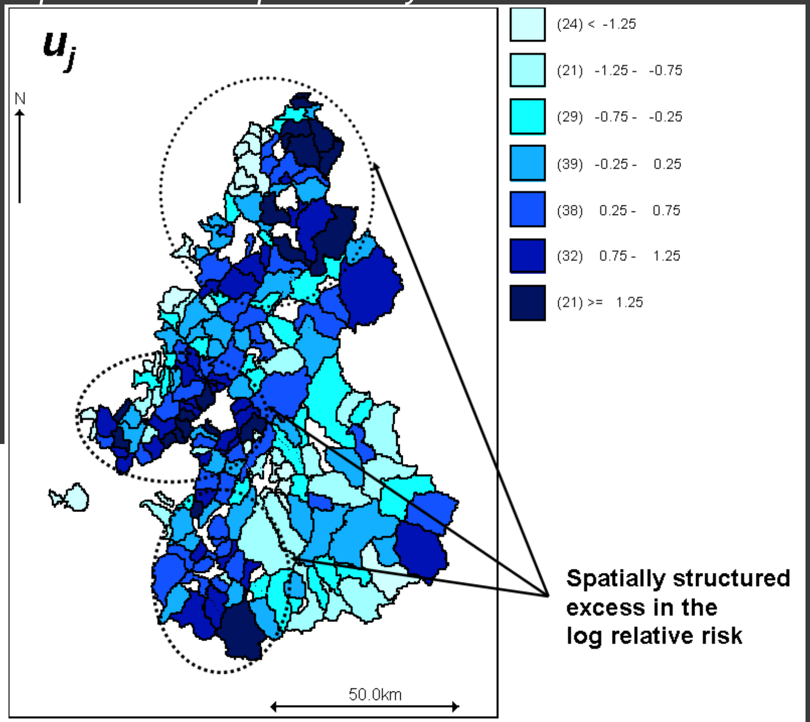
Decomposition between space and time

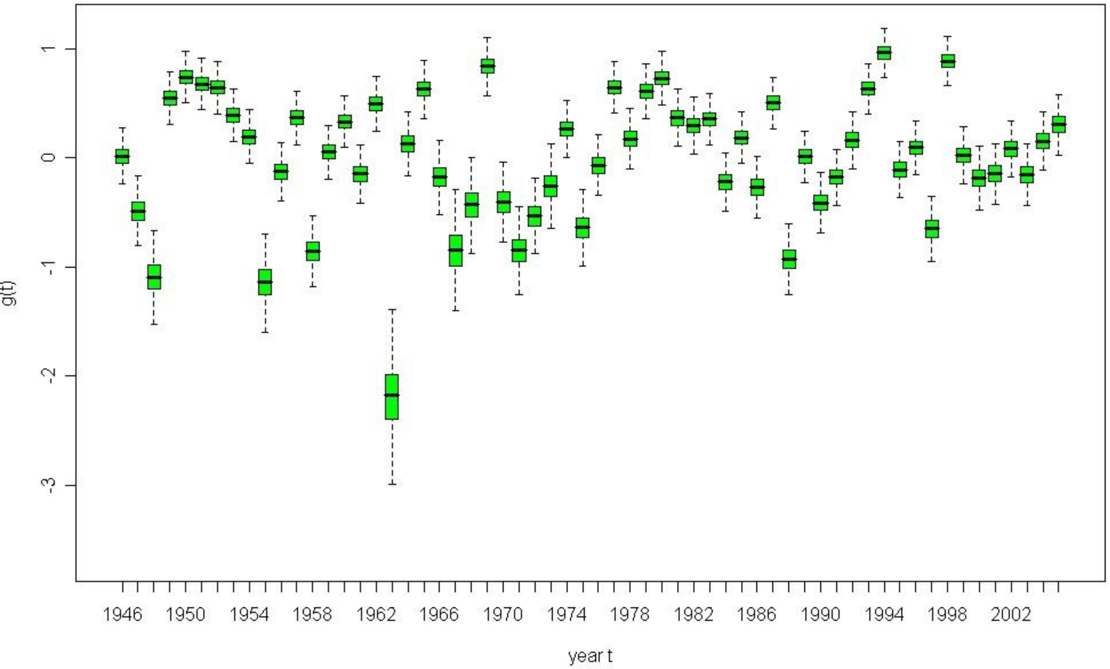
Spatial variability dominates :

$$r_{temp} = \frac{VAR[u]}{VAR[u] + \sigma_v^2 + \sigma_g^2 + \sigma_h^2} = 0.55$$

$$r_{temp} = \frac{\sigma_g^2}{VAR[u] + \sigma_v^2 + \sigma_g^2 + \sigma_h^2} = 0.17$$

Spatial structure provided by the model





- Consistence with history
- Complex patterns : no systematic evolution, but strong interannual fluctuations, how to model them?

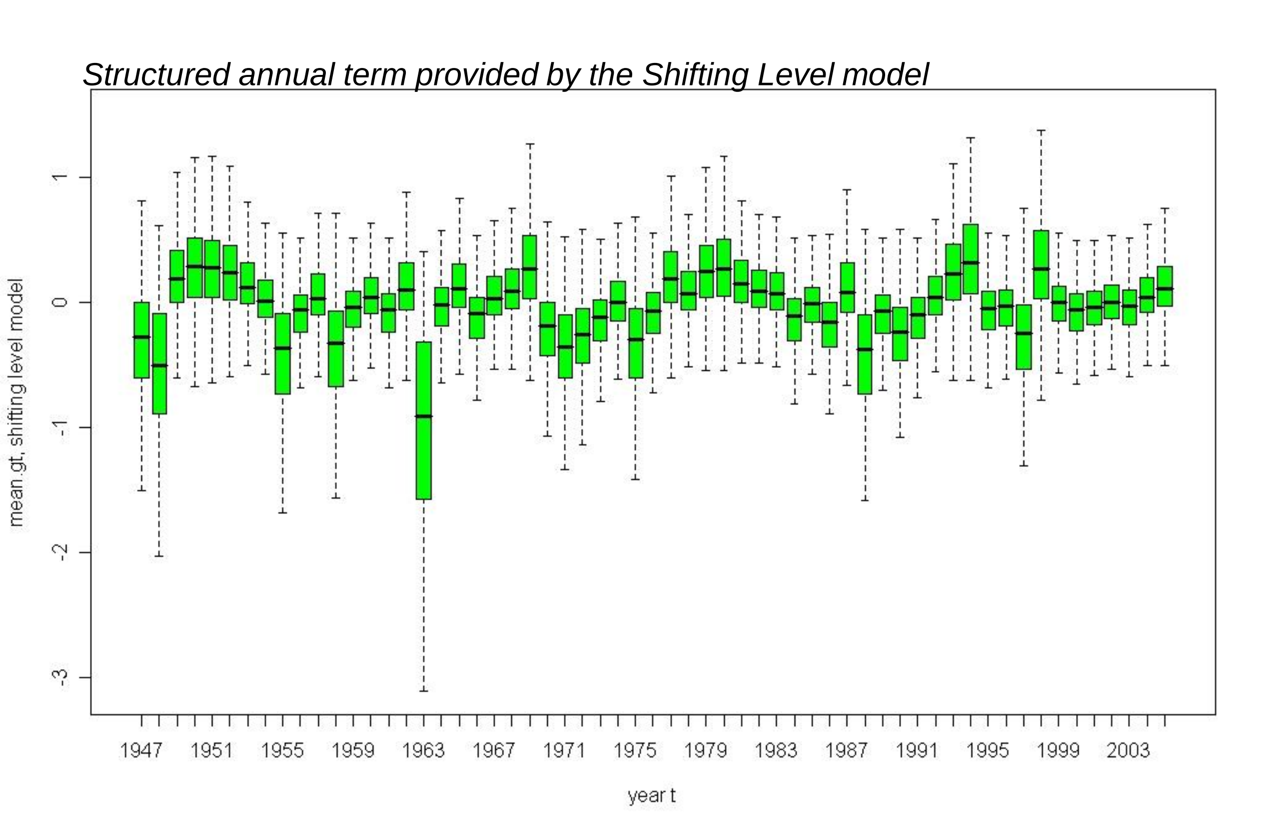
Underlying trend with a shifting level model

- Introduced by Salas and Boes (1980) for discharge series
- Segments of variable length separated by level shifts
- Rather flexible model, especially in the Bayesian context

$$trendg_t = z_t \times b_t + (1 - z_t) \times trendg_{t-1}$$

$$z_t \sim dBern(\varsigma)$$

$$b_t \sim N(0, \sigma^2_{shift}) \quad \text{with} \quad \sigma^2_g = \left(\frac{1-w}{w}\right)\sigma^2_{shift}$$



$$r_{struc_g} = \frac{VAR[mean.g_t]}{VAR[mean.g_t] + \sigma^2_g} = 0.42$$

- about 40% of the interannual variability,
- about 10% of the total variability.

- Pseudo periodic cycles disrupted by brutal changes.
- Good model fit (flexibility), but very frequent level shifts: model not perfectly adapted to data.

Towards non-separable models, with prior information

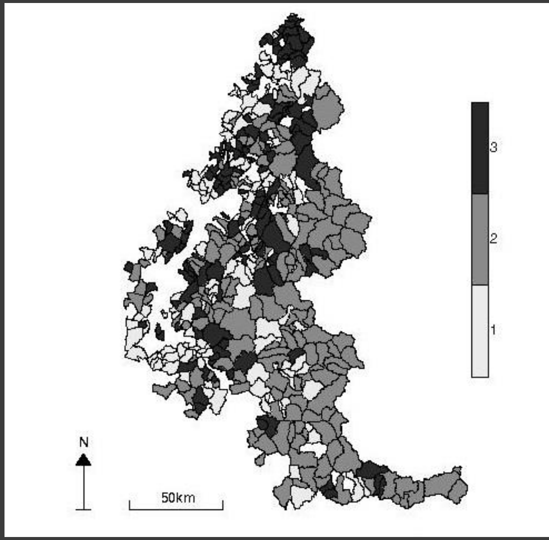
Idea: $\log(RR_{it}) = \alpha_i + \beta'_{it} + \ldots$

$$\beta'_{it} = \beta'_{\cdot}\left[b_{ik}\right]$$

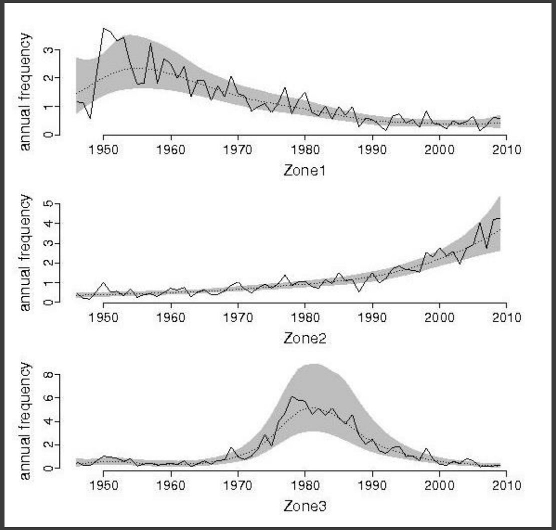
$$b_{ik} \sim dmulti\left(p_{ik}\right)$$

$$p_{ik} = f(x_i)$$

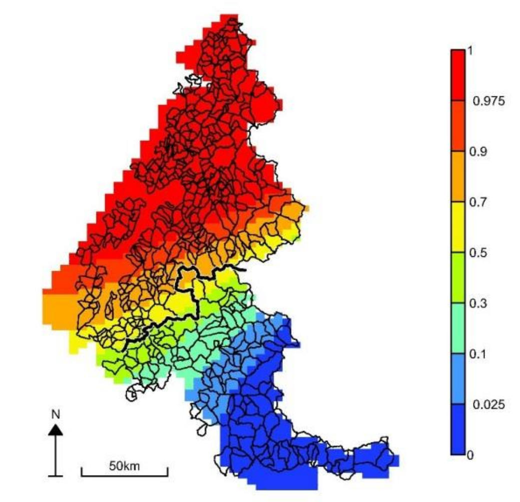
Spatial classification as function of temporal evolution modelled as a smooth non-parametric trend (Whaaba, 1978)



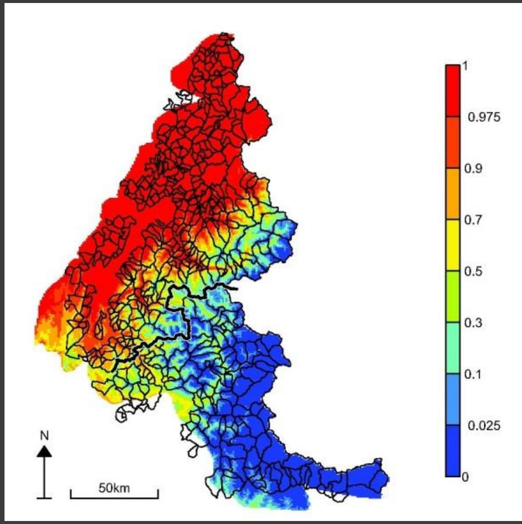
Township allocation with a three cluster model, from Lavigne et al., environmetrics 2012



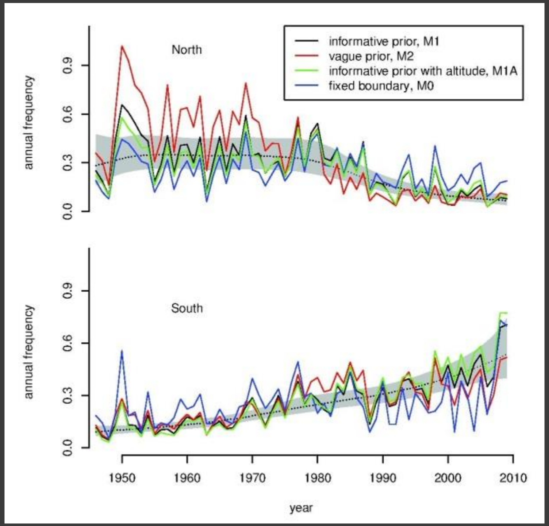
Corresponding time trends, from Lavigne et al., environmetrics 2012



Elicited a priori climatic boundary, from Lavigne et al. JRSSC 2015



Corresponding posterior probability to belong to the north zone, with altitude included in the classification, from Lavigne et al. . JRSSC 2015



Corresponding time trends, from Lavigne et al., . JRSSC 2015

Context

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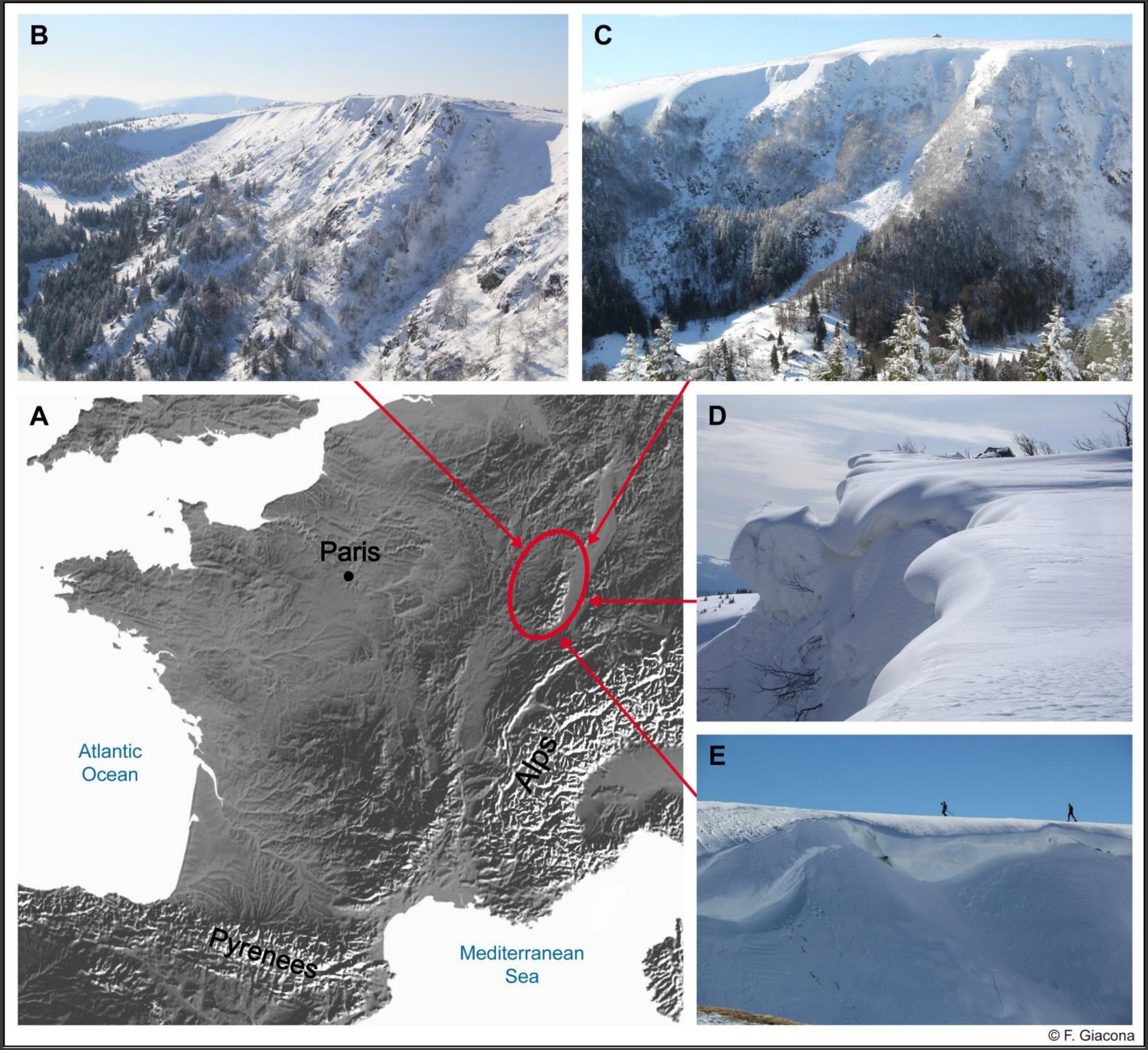
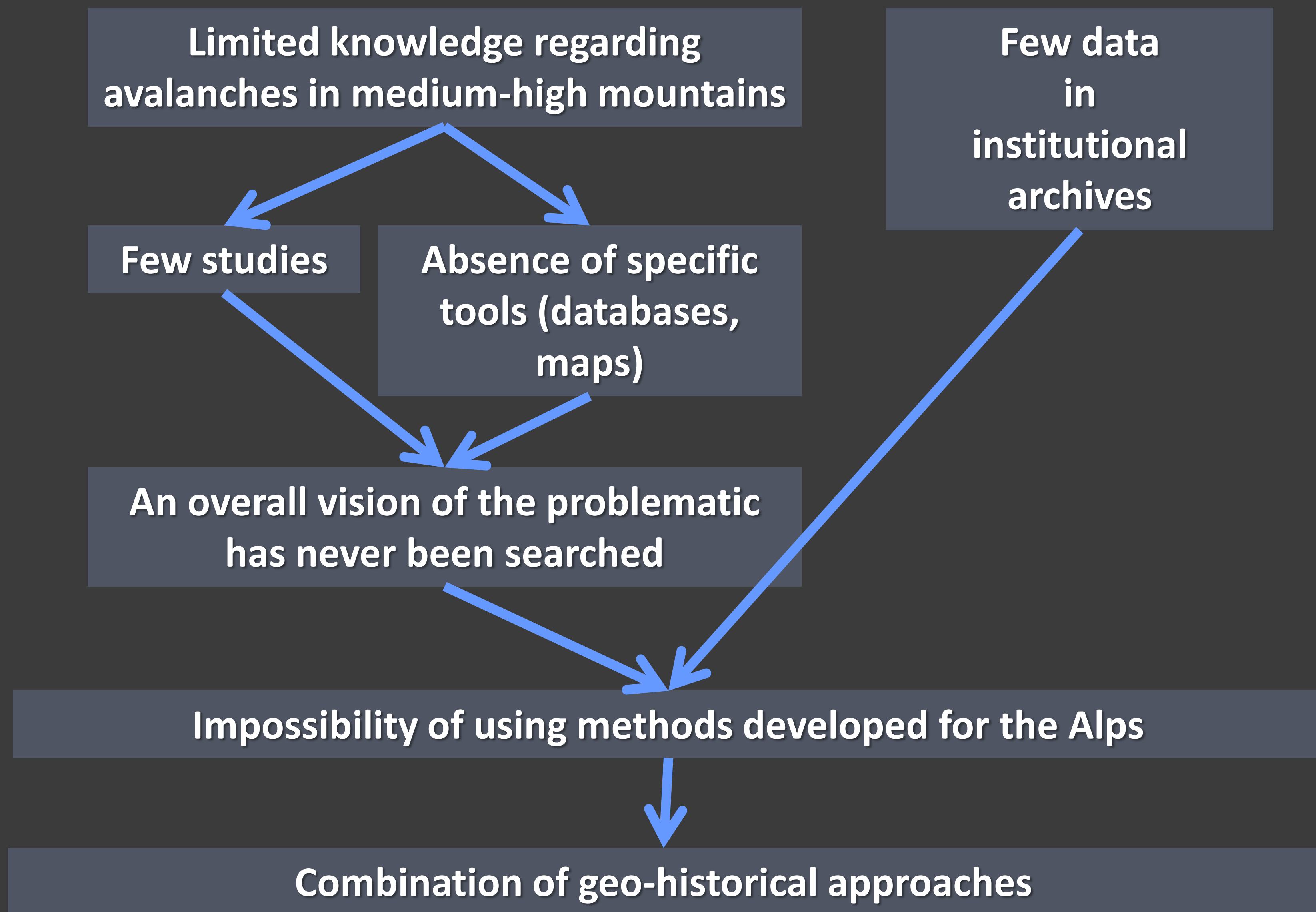
Application on the long range by taking into account the source potential

Context of the study



Context of the study



Historical data gathering

Few information in “traditional” sources (departmental and municipal archives)

- Few toponyms related to avalanches
- Scientific literature: sporadic and brief references to avalanches
- Non-scientific and local literature: data on some old and recent occurrences
- Regional and local media (newspaper, television news): information related to avalanche accidents needing rescue missions
- Photographs boom since the 1990’s
- Oral memory: more and more occurrences, especially since the 1990’s
- Other sources more rarely used: questionnaire survey, forums and web sites

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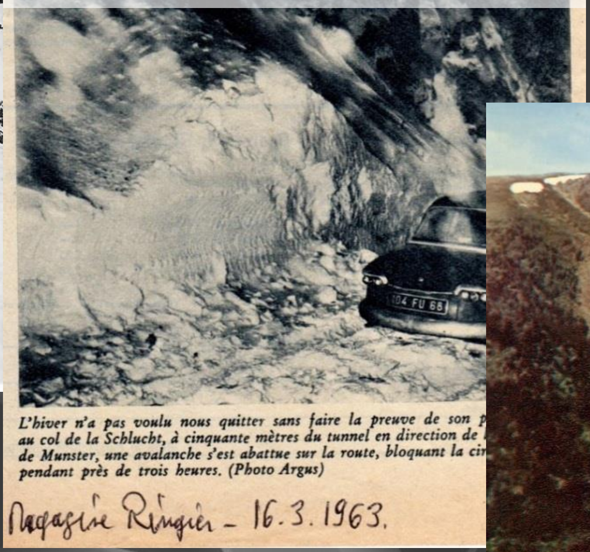
Avalanche activity in the Vosges mountains

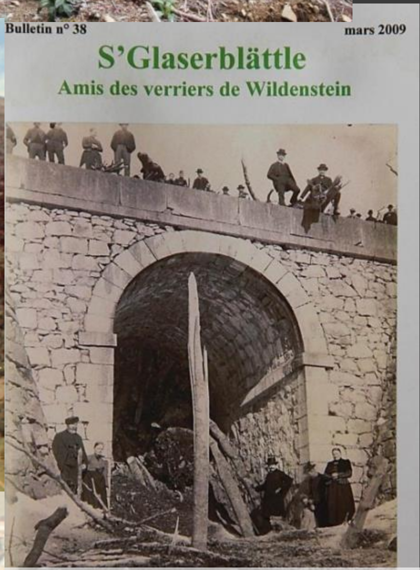
Tanet, January 1941

Schlucht Pass, 1963



Rothenbachkopf, 2010

Rothenbachkopf, 1952

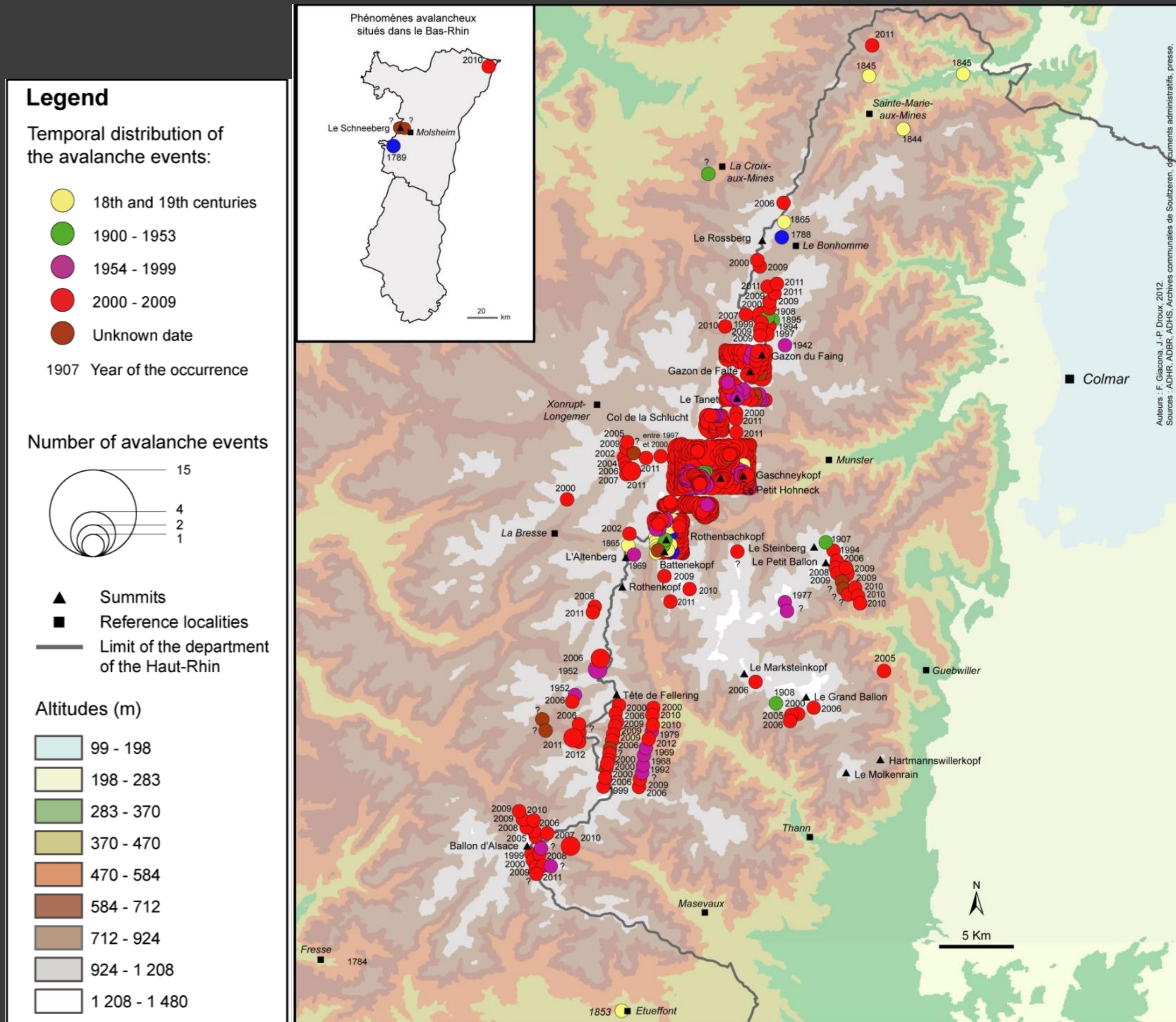


Rothenbachkopf, February 1895

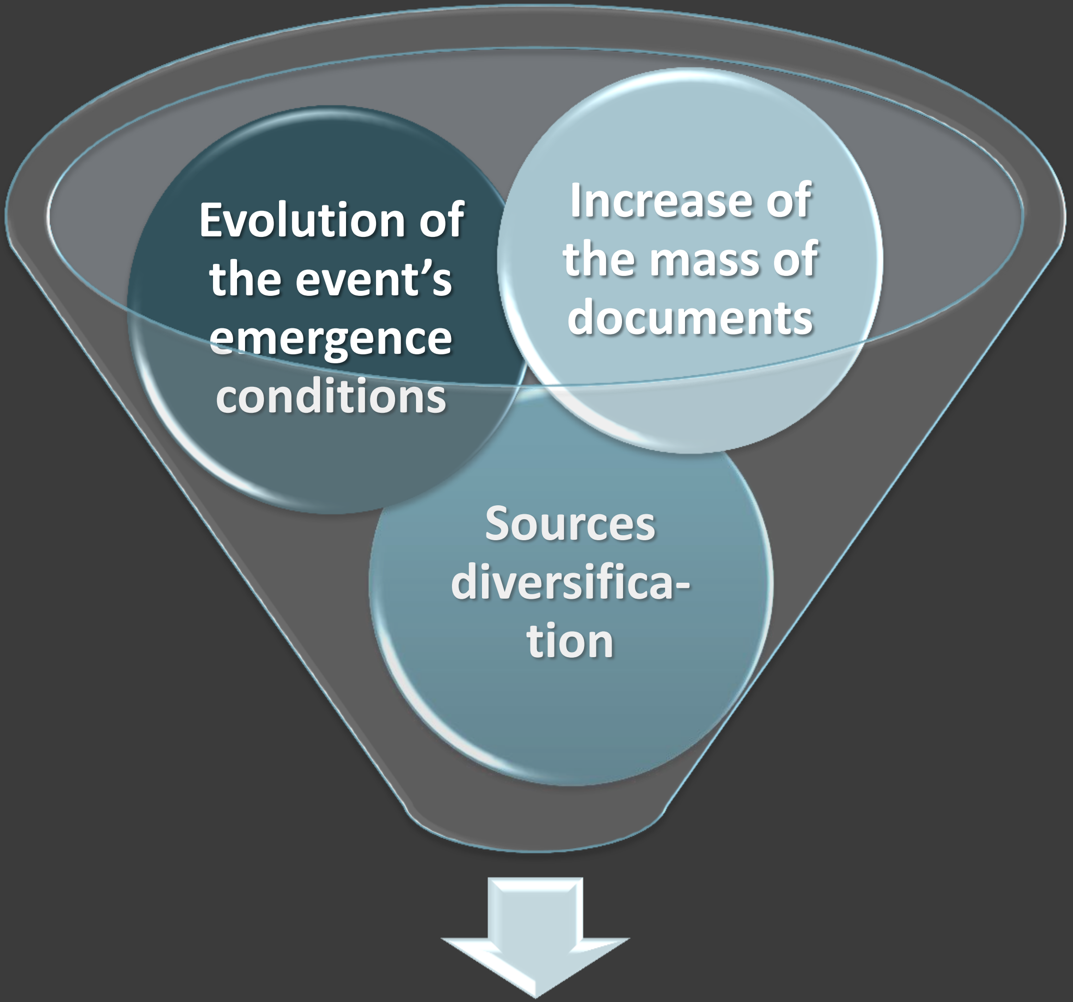
Tanet, Winter 1985-1986

Kastelberg, February 2012

A geo-chronology marked by discontinuities in time and space



A geo-chronology marked by discontinuities in time and space



« Source effect »

A geo-chronology marked by discontinuities in time and space

1743-1784 – 1842-1843

- Institutional archives
- Indirect oral memory
- Memorial crosses

1843-1844 – 1869-1870

- Local newspaper
- Scientific literature
- Local non-scientific literature

1870-1871 – 1939-1940

- Iconographic documents

1940-1941 – 1992-1993

- Direct oral memory
- Mountain actors documentation
- Regional and national newspapers
- Forest landscape, indicators of avalanche dynamics

1993-1994 – 2013-2014

- Field observations
- Local radio

Taking into account the source potential in the modelling

- Historical enquiry results:
  - 731 avalanches events in 50 sectors
  - Very strong temporal inhomogeneity, but 2.5 centuries of data!

- Log-Poisson relative risk model, with non-homogenous expected numbers

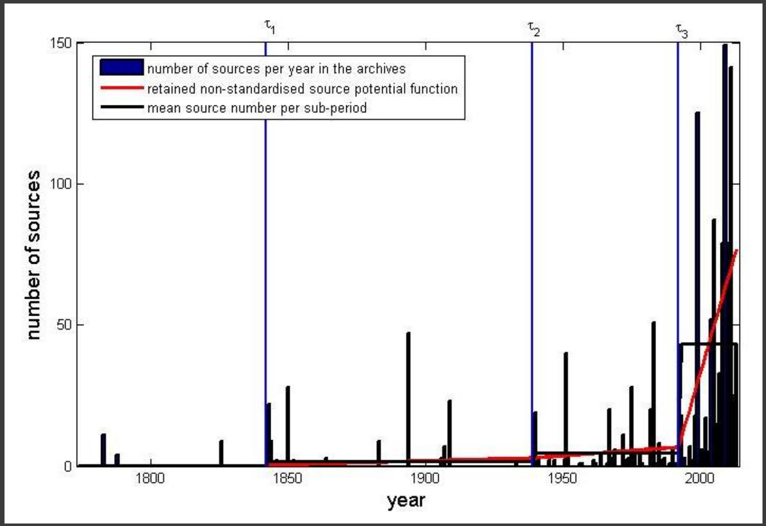
$$\ln(\lambda_{it}) = \ln(e_{it}) + v_i + g_t + z_t$$

with

$$e_{it} = POT_t \times \frac{c_i}{\sum_{i=1}^{N} c_i} \times \frac{1}{P} \sum_{i=1}^{N} \sum_{t=t_o+T_{obs}-P-1}^{t_o+T_{obs}-1} \frac{a_{it}}{POT_t}$$

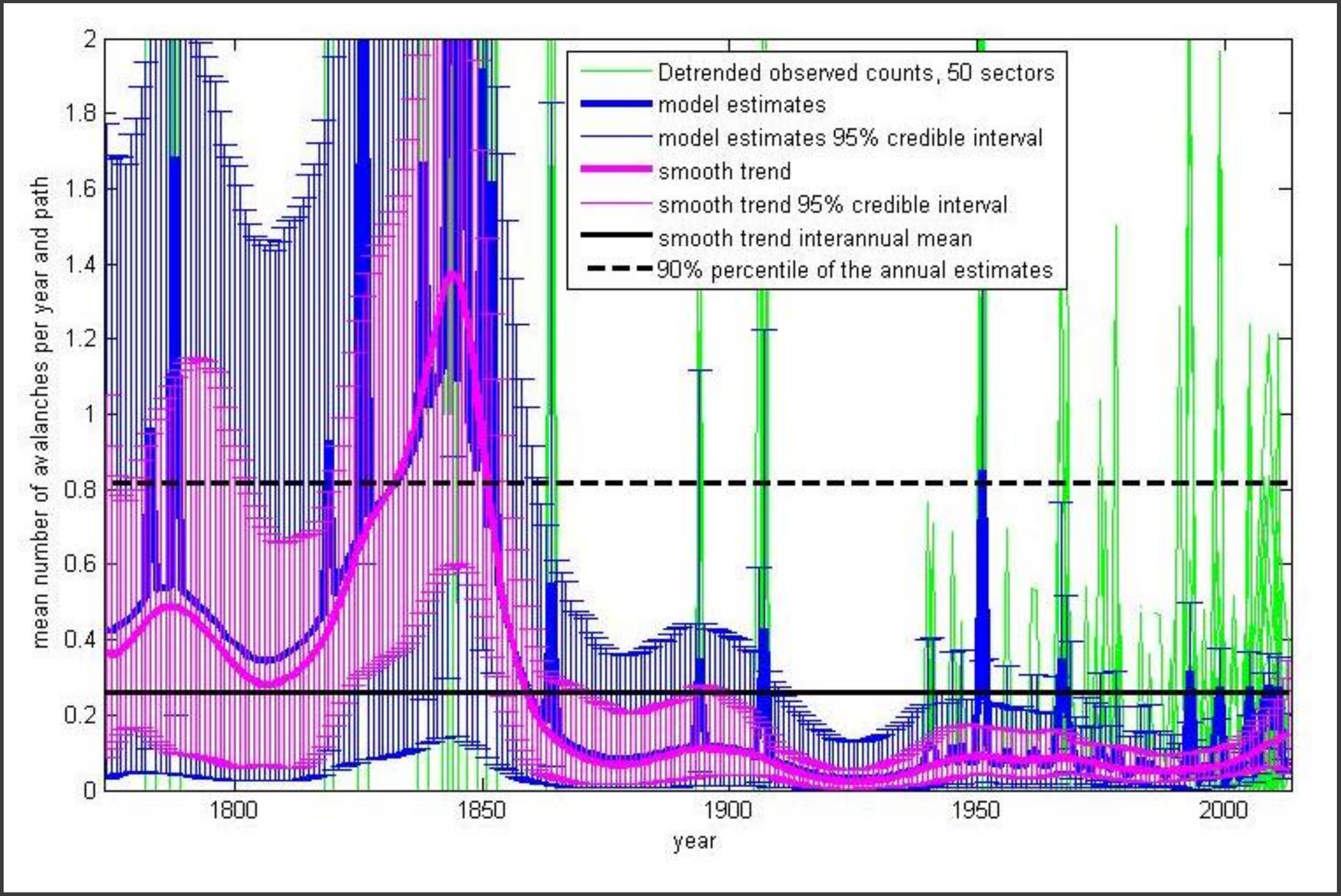
- Modelling information availability: the source potential
  - Number of sources referring to events;
  - Existence of supports (newspapers, pictures, etc.)
  - Stepwise-linear approximation that respects suitable properties:

$$\left.\begin{array}{l} \lim_{t \to \tau_j -} POT_t = \lim_{t \to \tau_j +} POT_t \\ C \int_{\tau_j}^{\tau_{j+1}} POT_t \, dt = \sum_{t=\tau_j}^{\tau_j+1} s_t \end{array}\right\}$$



Source potential fitted on the number of sources per year

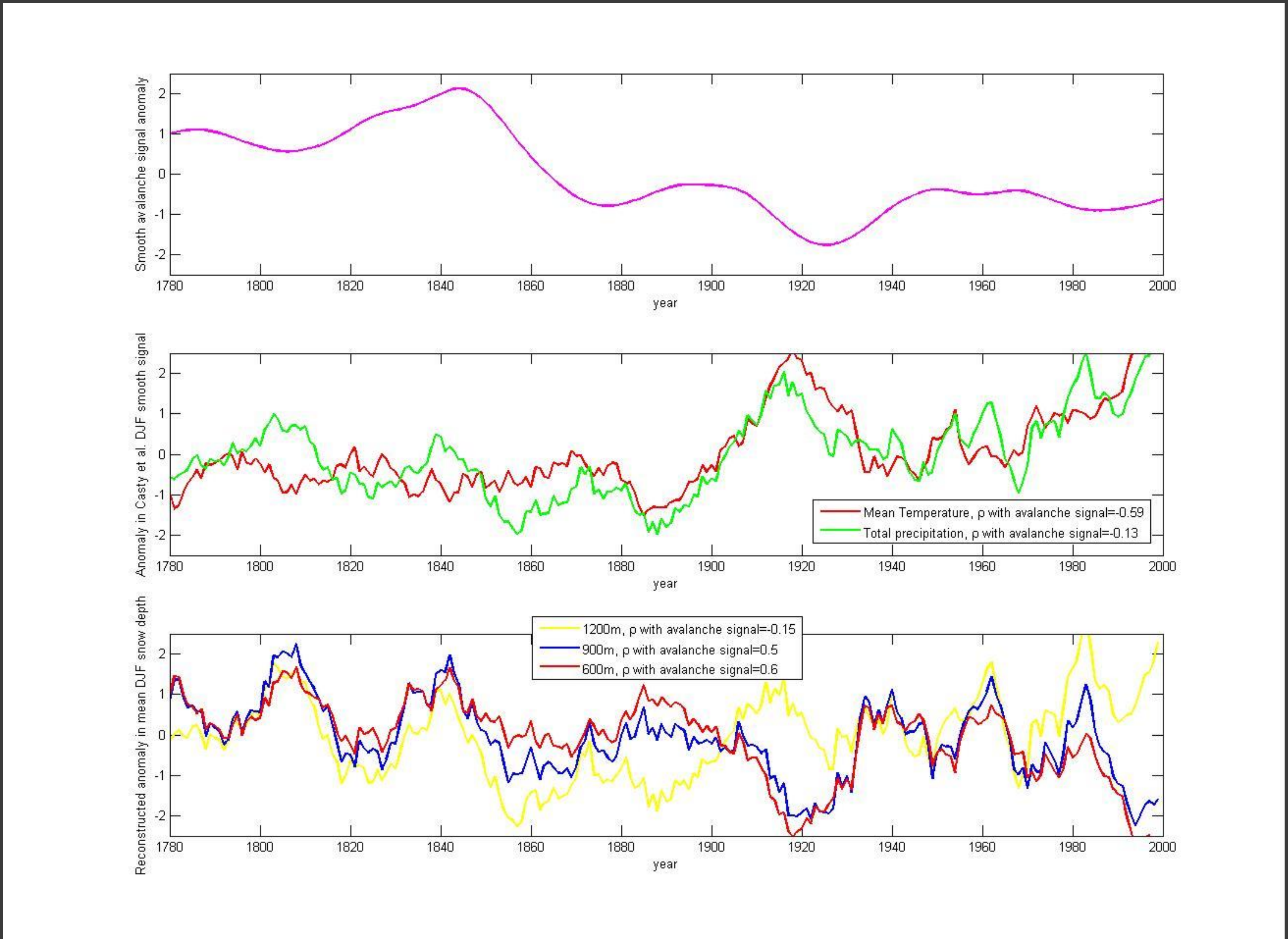
Result: homogeneised activity over 230 years - mean avalanche number per year and path



"High activity regime" : *~0.6 avalanches per winter and path*

"Low activity regime" : *~0.1 avalanches per winter and path*

Snow-climate control of avalanche activity on the long range



Temperature increase and hence snow cover reduction at low to mean altitudes as the main driver!

Take home messages

Space –time modelling of avalanche occurrence data:

- Initiated by transposition from spatial epidemiology, now an “old” problem in the field;
- Different modelling refinements with different covariance structures for the log-relative risk;
- Evaluation of expected counts was “the last frontier” to be able to work on longer time scales, which lead nice results regarding the process response to climate change.

Avalanche des Lanches en provenance de la face nord de Bellecote le 25 février 1995 © F. Rapin, Irstea.

Generic outcomes relevant for a variety of problems:

- Interdisciplinary as a key to progress, and statistical modelling as way to integrate knowledge;
- Importance of the complex interactions between environment and society resulting in risk (socio-historical dimension of risk).

Acknowledgements:

- For your attention;
- Jeremy (organisation);
- Many projects: ANR MOPERA, DGPR ECANA project, UGA RARETES and Trajectories projects, Irstea Project ZORRINO

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