Avalanches et changement climatique: un rapide état de l’art

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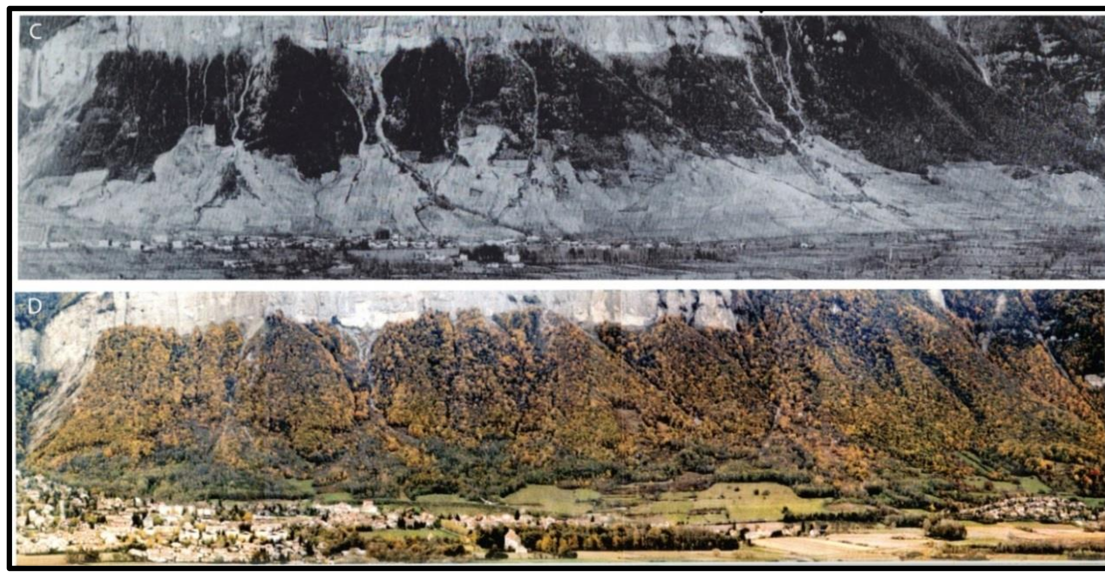
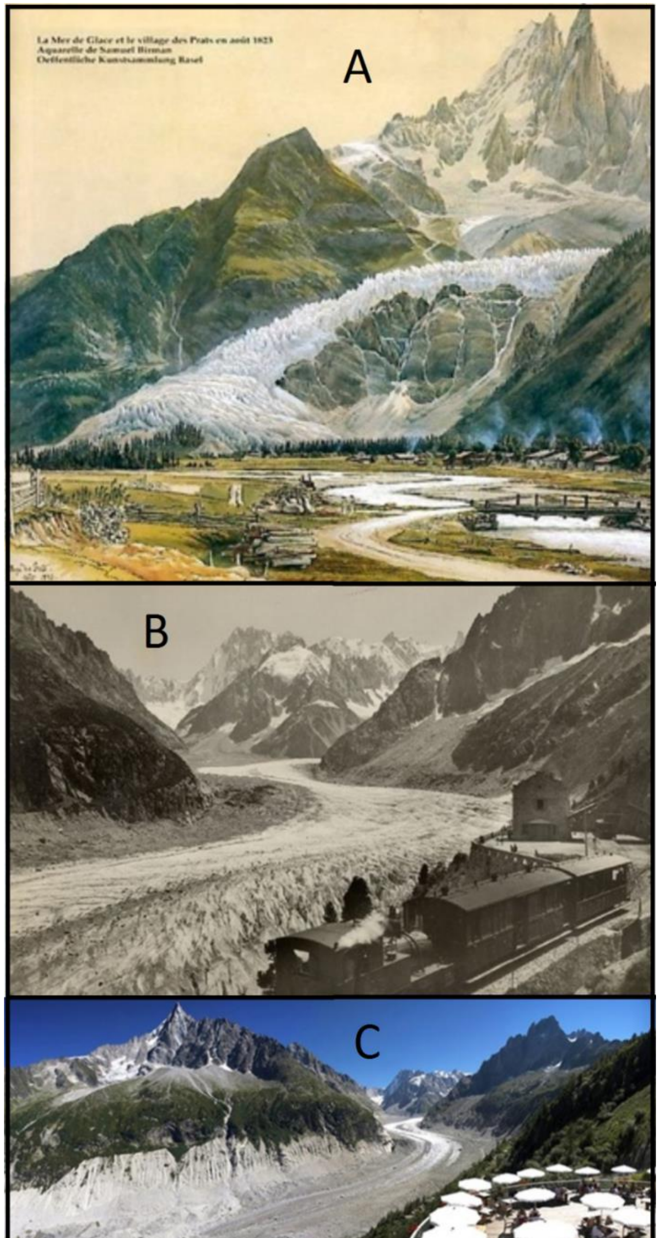
A rapidly changing environment

- 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.



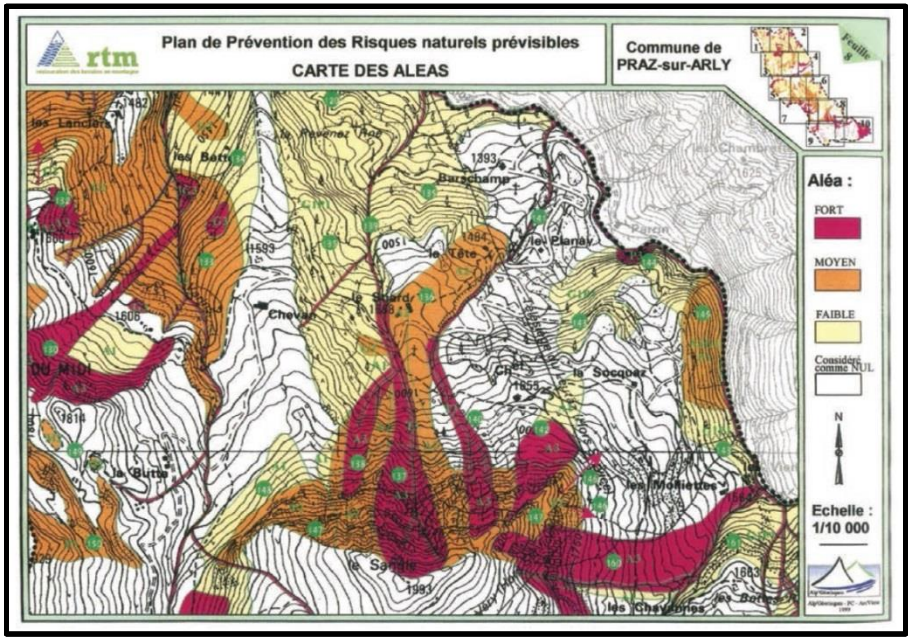
Historical photograph of the Crolles talus slope in 1912 (© Blanchard, 1930) and current photograph of the village of Crolles in 2013 (© J. Lopez-Saez, Irstea).



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.

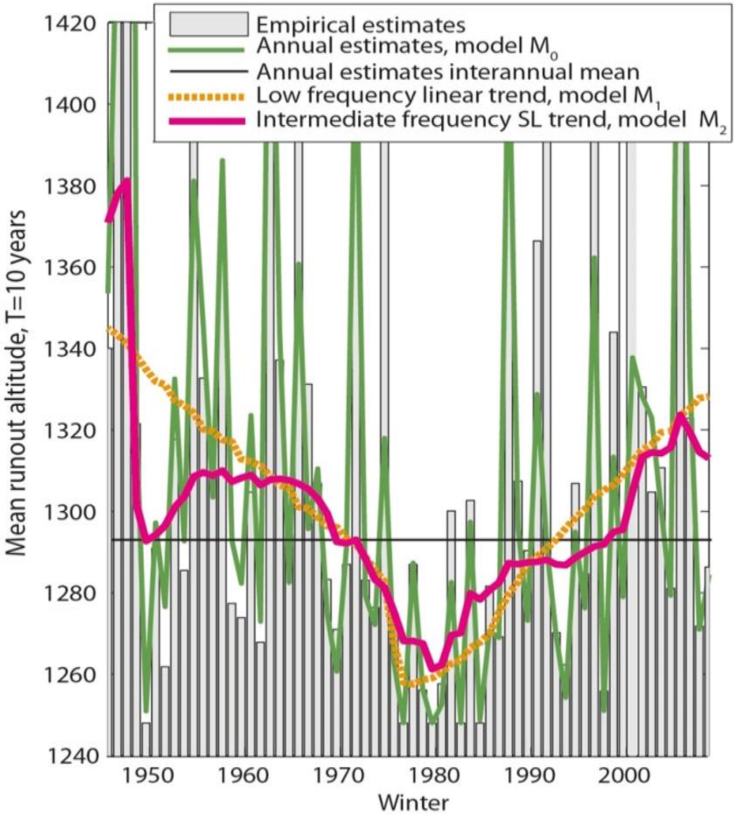
Wet snow avalanche in Saint François Longchamp, French Alps, 2 March 2012, © DAG Modane / data-avalanche.org published in Naaim et al. (2016).

Avalanche activity in a changing climate

- Climatic control of snow avalanches is intuitive, but difficult to assess:
  - Non linear response to snowpack evolution, with close safe/unsafe conditions;
  - Additional non-linearity: “zero” thresholding effect ;
  - Lack of reliable and long avalanche data series (observation is difficult/dangerous).

- A few Indirect evidences:
  - Snow/climate and avalanche activity changes (Lazard and Williams, 2007; Castebrunet et al., 2014) ;
  - Indirect data: dendrogeomorphology and lichnometry (McCarroll, 1993; Corona et al., 2013; Ballesteros-Canovas et al., 2018);
  - Rare statistical analyses of real avalanche data, mostly since ~1950 .

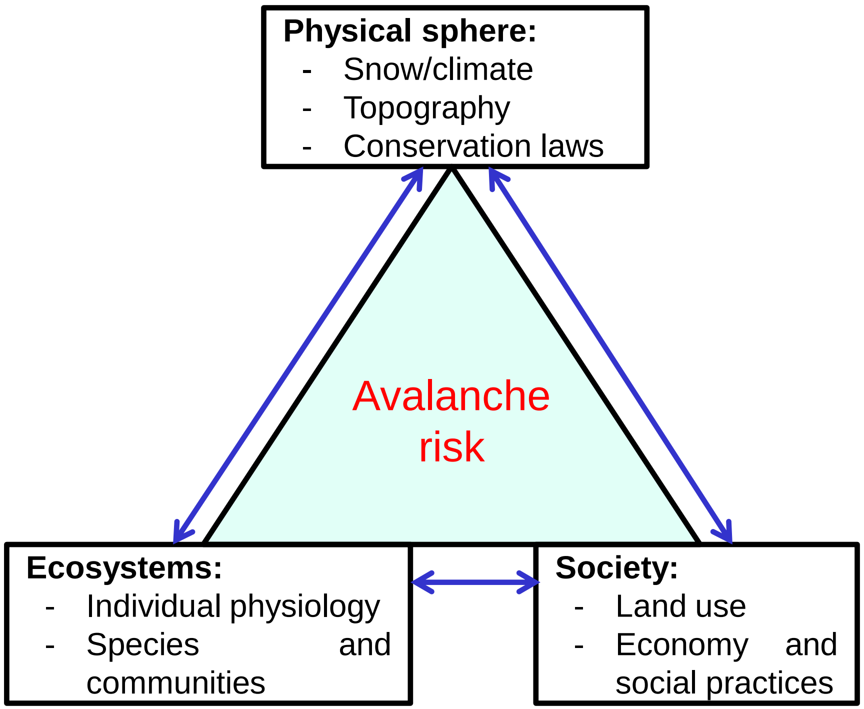
- A topic that remains debated (cf. incoming SROCC IPCC report).

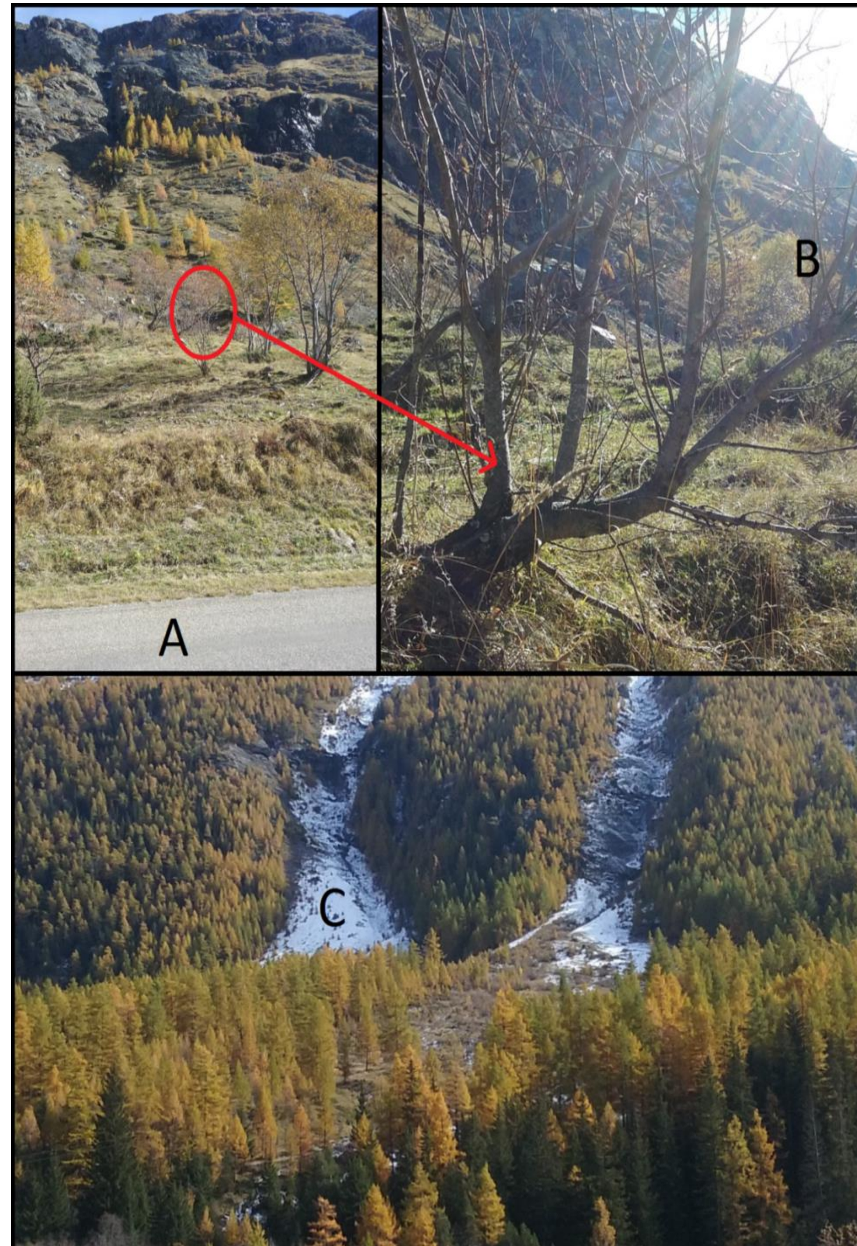


Runout altitude corresponding to a return period of 10 years on a mean path from the French Alps (Eckert et al. 2013).

At the interaction between physical, ecological and social spheres

- Avalanche risk as a result of complex interactions and retroactions:

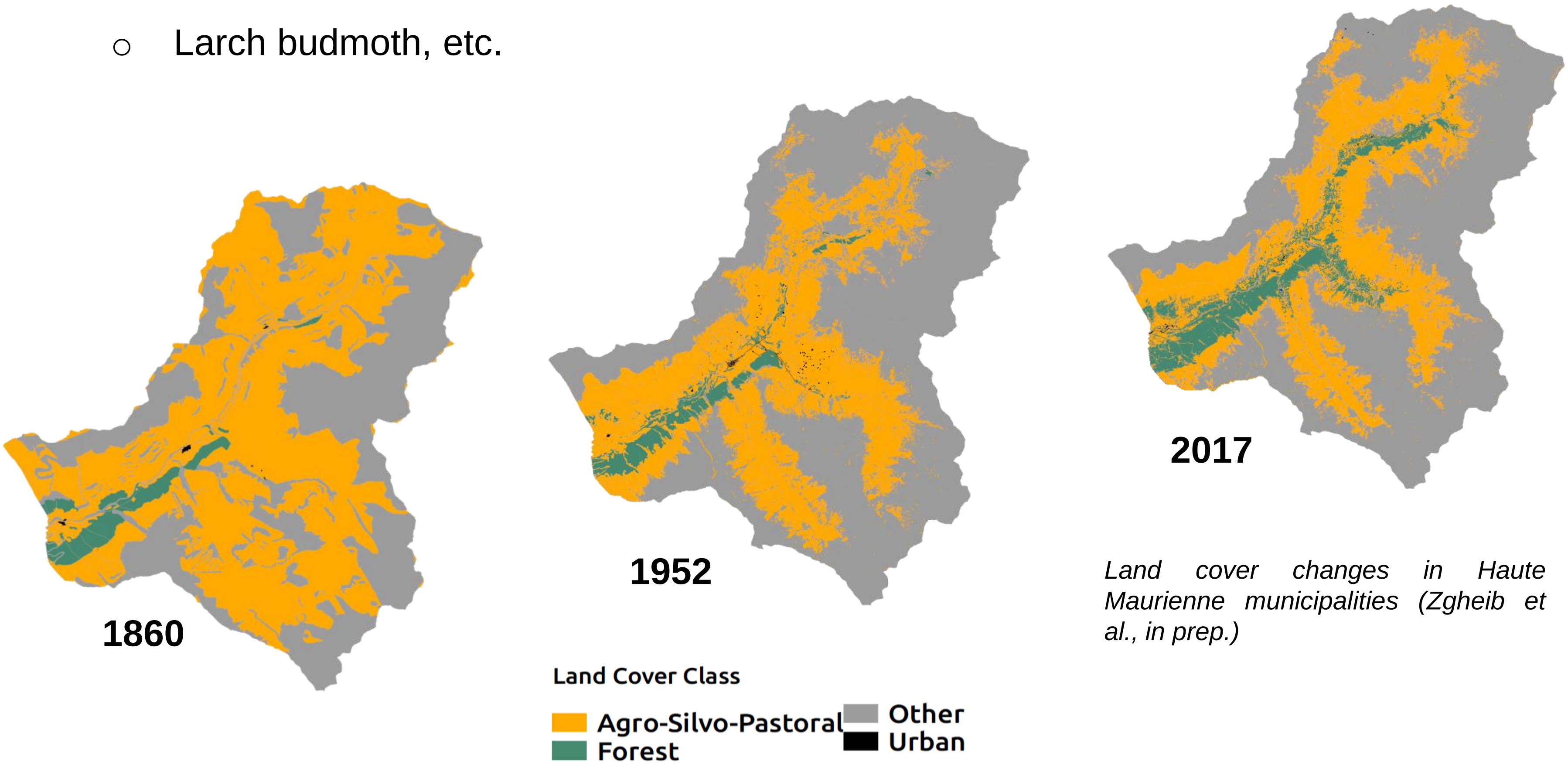




Example: avalanche paths around Bessans, French Alps. A) Avalanches frequently hit the road, with direct and indirect losses. B) The runout zone is a former grazing area in a rapid afforestation phase, where trees show characteristic marks of regular avalanche activity. C) More densely forested runout zone, showing typical stratification in tree size, age and species © N. Eckert, Irstea.

Many confounding factors

- Sources;
- Land use and social practices;
- Mitigation measures;
- Larch budmoth, etc.

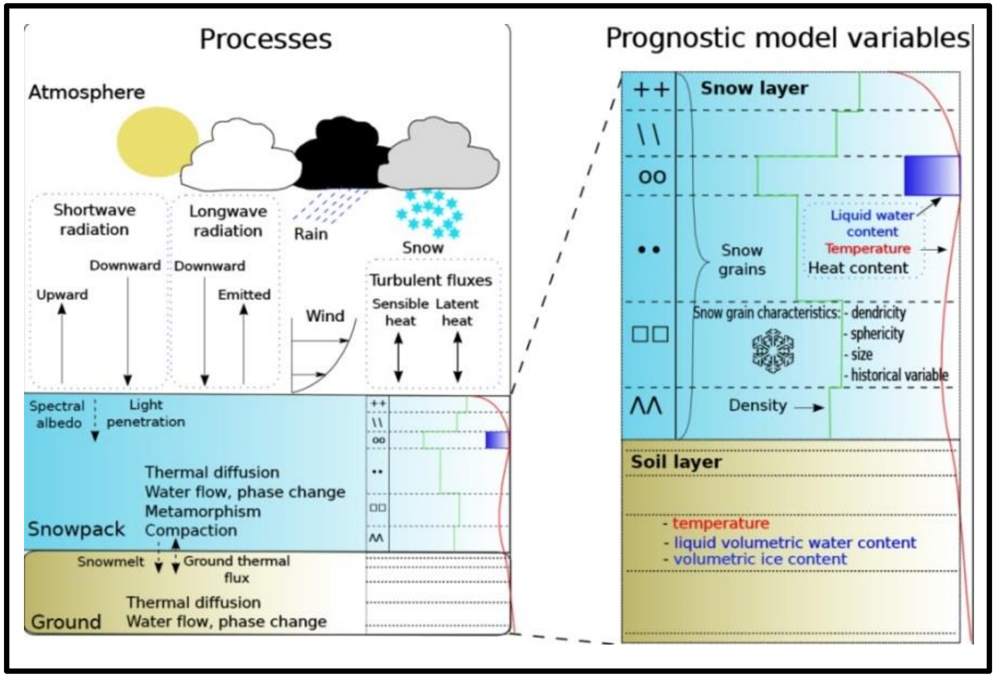


Land cover changes in Haute Maurienne municipalities (Zgheib et al., in prep.)

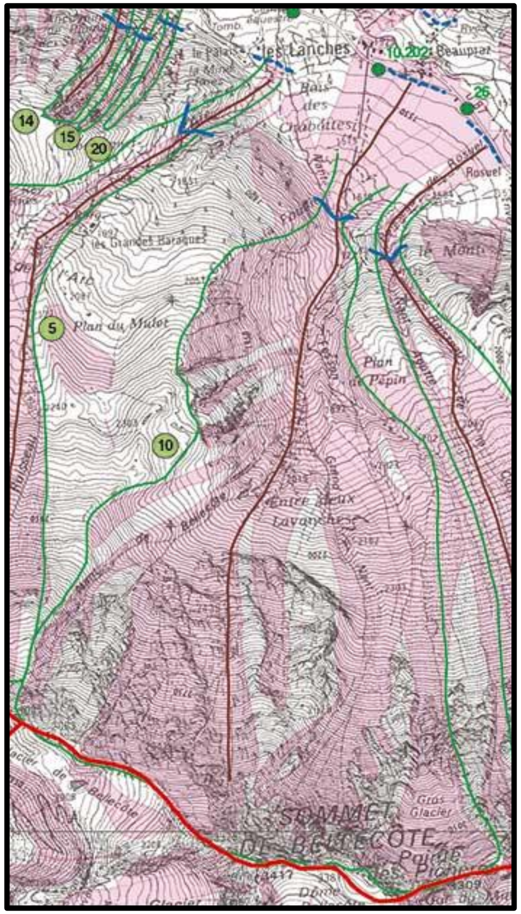
The French Alps, a favourable context

- Excellent data from rather old observatories:
  - Avalanche database “*EPA*” (about ~4000 selected paths);
  - Avalanche map CLPA;
  - Observation by ski patrollers in ski resorts;
  - Etc.

- A comprehensive set of covariates:
  - Safran-Crocus reanalyses and projections;
  - “dense” network of weather stations;



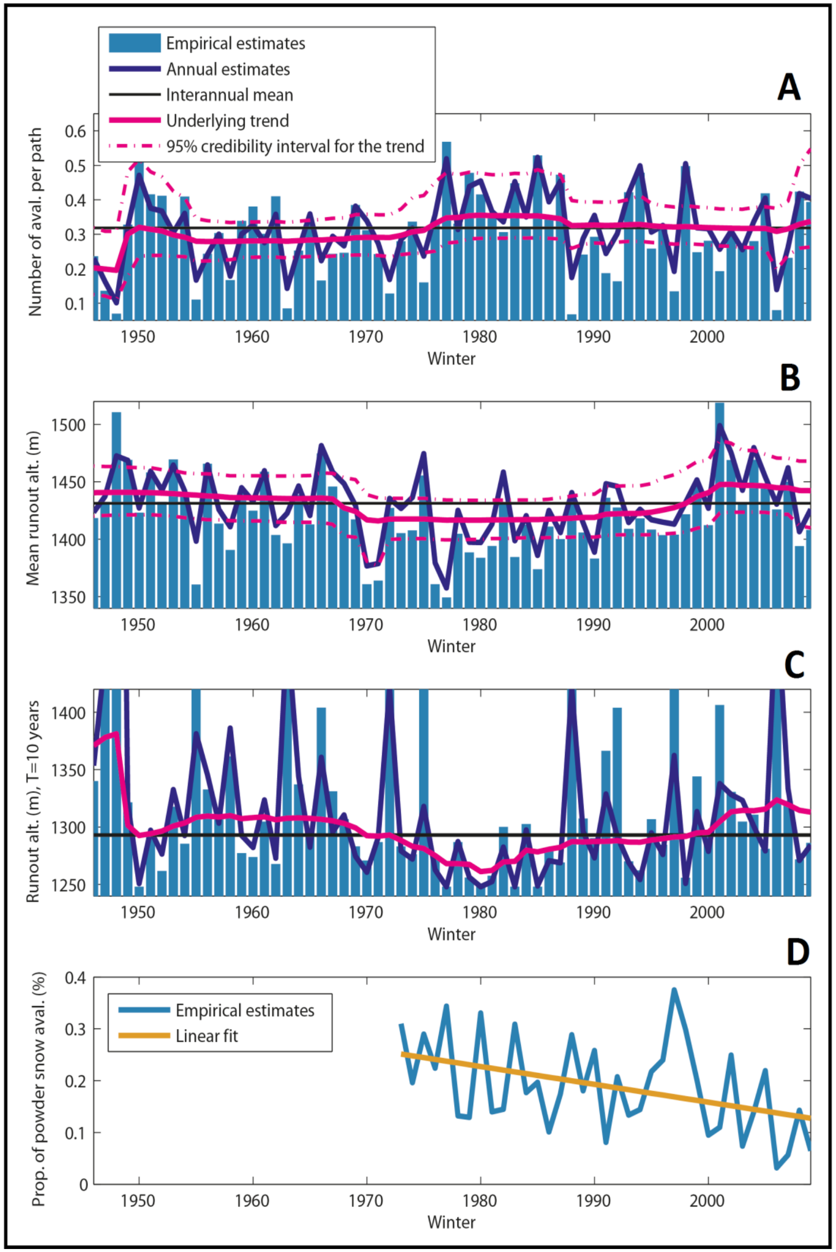
SURFEX/ISBA-Crocus model structure: explicit coupling with multi-layer ground scheme (Lafaysse et al., 2013)



EPA avalanche map (Savoie)
© www.avalanches.fr

Trends inferred from EPA over the last decades

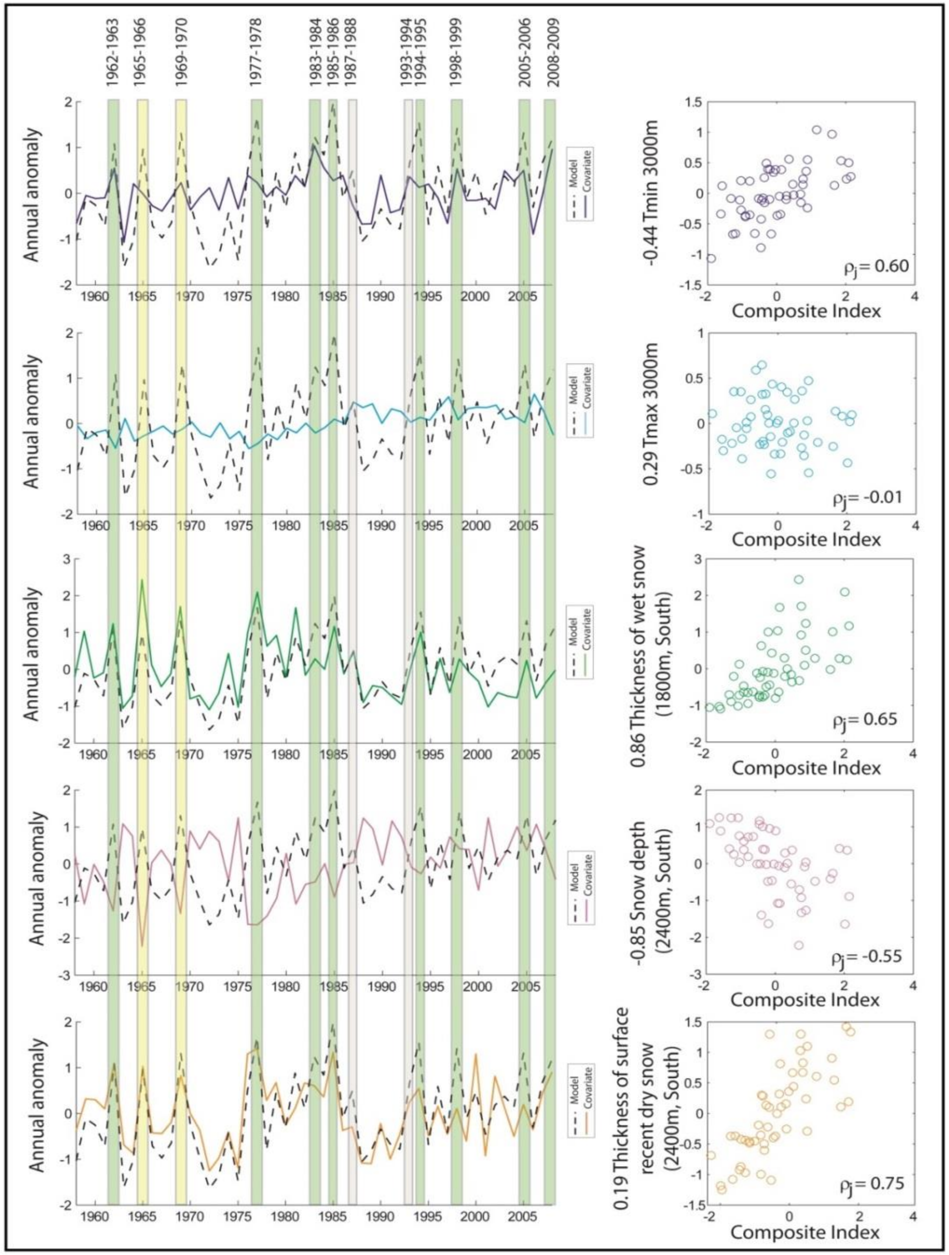
- Investigation using hierarchical time series analysis models;
- Avalanche activity series: clearly strong evolutions over the 1946-2009 period;
- Empirically, good correlations with winter conditions: pleads for a snow and temperature control of avalanche activity at climatic time scales.;
- Analysis to be done (and slightly reconsidered) with last 8 years of data.



Time trends in different avalanche variables in the French Alps (Eckert et al., 2013). A) Mean number of avalanches per winter and path: annual signal and underlying trend. B) Mean runout altitude. C) Runout altitude corresponding to a return period of 10 years (mean 10 year return level). D) Proportion of powder snow avalanches.

Modelling the hazard-climate relationship

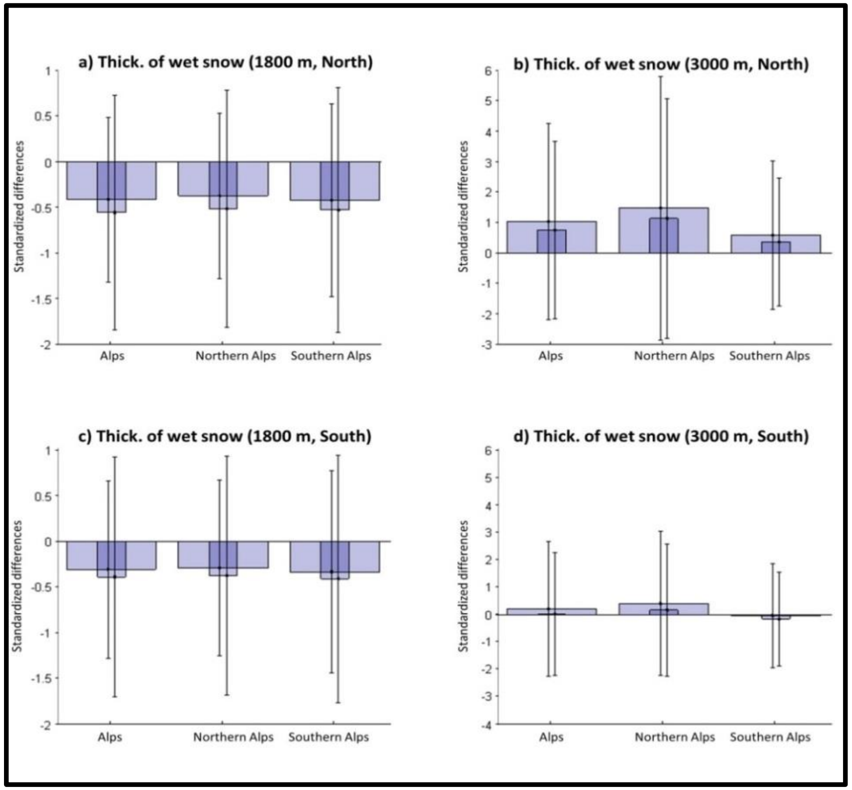
- From time explicit to time implicit modelling: distinguishes “climatic trends” and “climatic peaks” from other temporal structures.
- Example: relating different avalanche indexes to the best set of explanatory reanalysed variables (Safran-Crocus, variables selection issue).
- Accurate models with a small number of physically meaningful covariates: strengthens our confidence in the climate control of avalanche activity fluctuations.



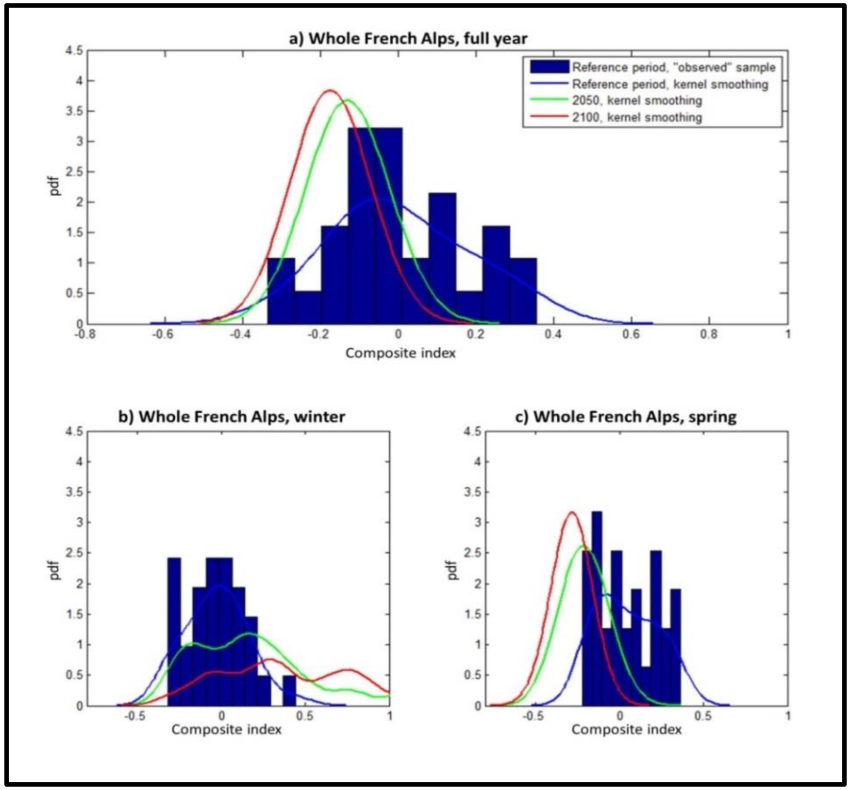
Avalanche activity (composite index CI) as a function of its snow and weather drivers (Castebrunet et al., 2012). Temporal evolution of the covariates retained. Green bands correspond to years for which the CI and its regression model exceed the 80th percentile of their interannual distribution. Yellow and grey bands correspond to years for which only the model or the CI exceeds this threshold, respectively.

Forecasting inferred relations under future climate

- Future climate scenarios from IPCC AR4 (GCM, RCM, adaptation to mountain topography, bias correction and snow cover modelling);
- Future hazard according to past hazard-climate relations;
- IPCC AR5 still to be implemented!



Forecasted future wet snow amounts in the French Alps. Safran-Crocus simulations forced with downscaled IPCC 2007 scenarios. Results are expressed as standardized anomalies with regards to the 1960-1990 period (Castebrunet et al., 2014).

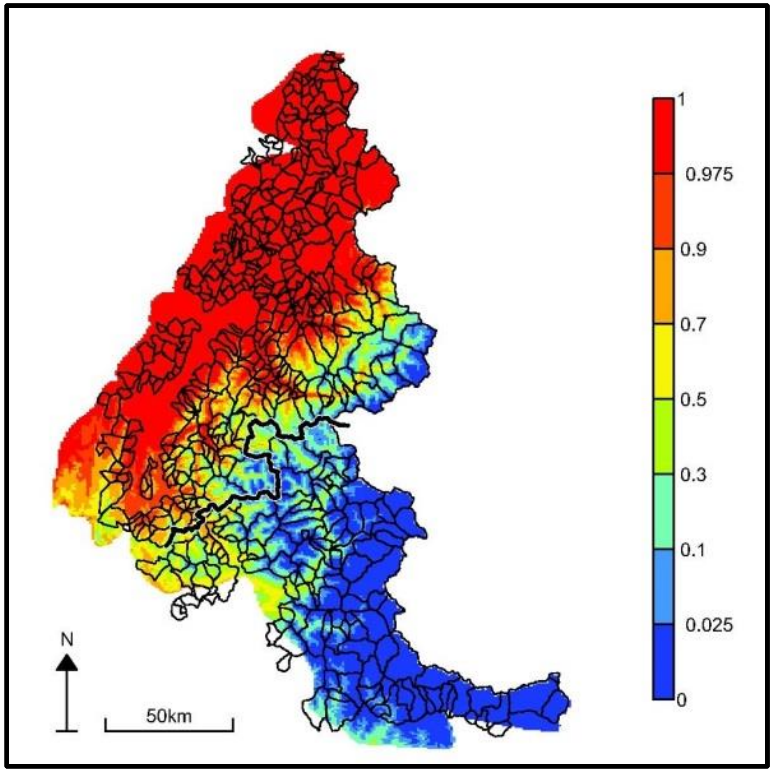


Distribution of the avalanche activity CI over the reference period (1960-90, Castebrunet et al., 2012) and in 2020-50 and 2070-2100. Results are expressed as standardized anomalies with regards to the 1960-1990 period (Castebrunet et al., 2014).

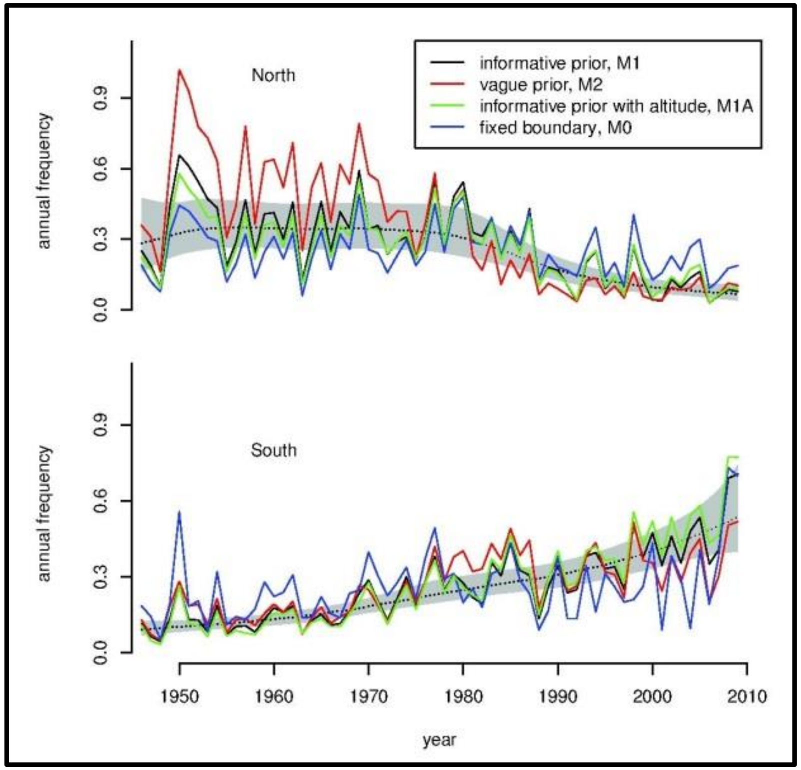
Spatio-temporal patterns and altitudinal gradients

- Spatio-temporal clustering approach getting rid of the separability assumption. North/South differences in occurrence regimes result from complex interactions between predominant atmospheric flows and topography. with a clear altitudinal segregation between two trends;

- "Low" altitude decrease vs high altitude "transitional" (?) increase (Balllesteros-Canovas et al., 2018).



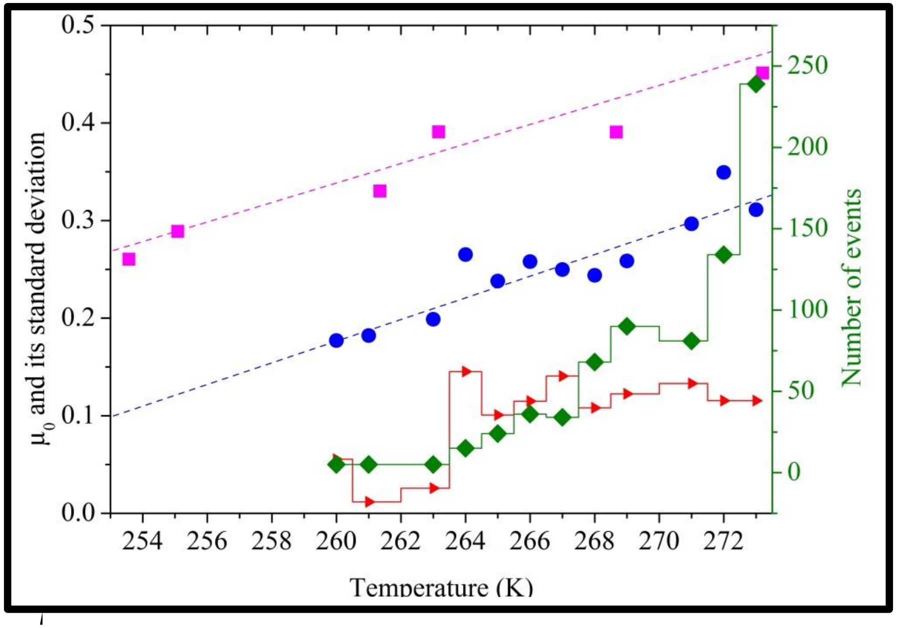
Probability for each township to belong to the "north zone", with altitude included in the classification, from Lavigne et al. (2015).

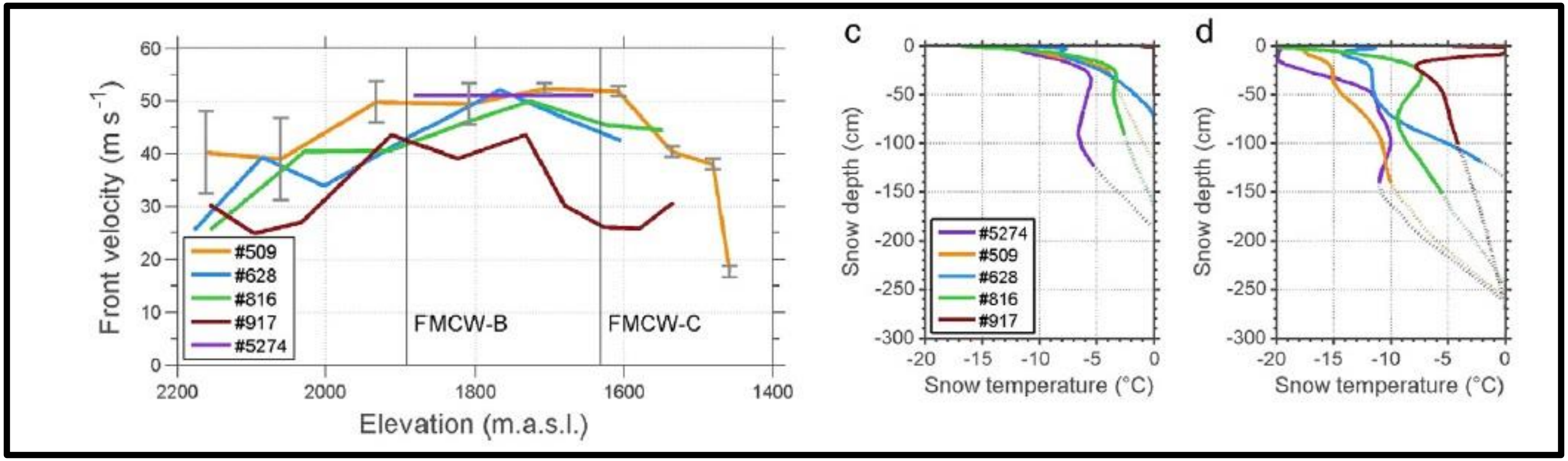


Corresponding time trends, from Lavigne et al. (2015). Shows the altitudinal control on north decrease / south increase.

Into the physics (why should we care about climate?)

- Increasing research results demonstrates links between physical properties of snow and avalanche dynamics;
- Especially applies to snow temperature.





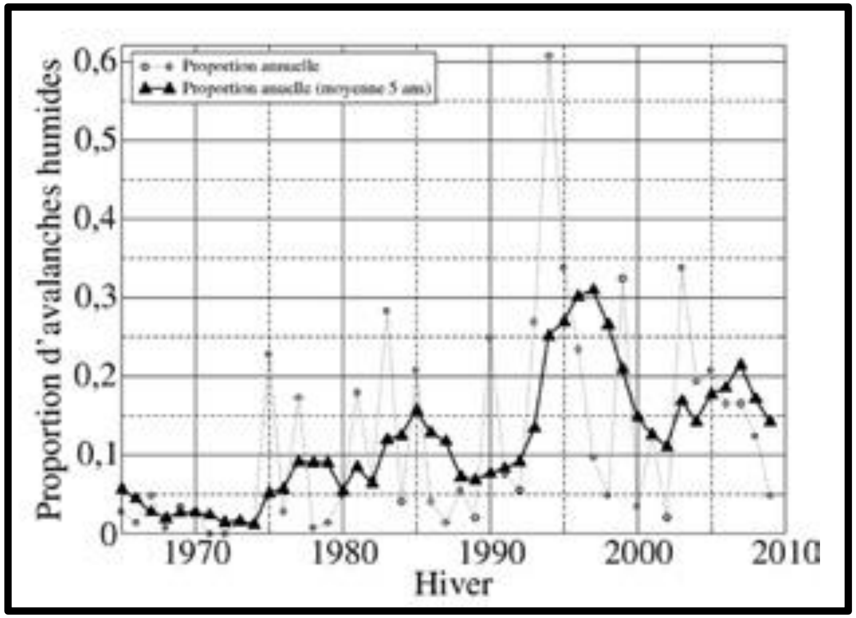
Velocity longitudinal profiles and snow cover temperature profiles at two positions along the path for 4 avalanches artificially triggered at Vallee de la Sionne (Steinkogler et al., 2014) .

Wet snow avalanche activity increase?

- Firsts question addressed within the avalanche climate change topic (Martin et al., 2001). Now converging past/future results;

- Wet snow avalanche episodes such as in winter 2017-18 as analogues of future conditions (Stoffel and Corona, 2018)? “Transitional “regime of increased activity due to wet snow events at high altitude and during “full winter”?

- Specific dynamics/rheology still poorly understood (high pressures close to rest, uncommon trajectories, etc.).

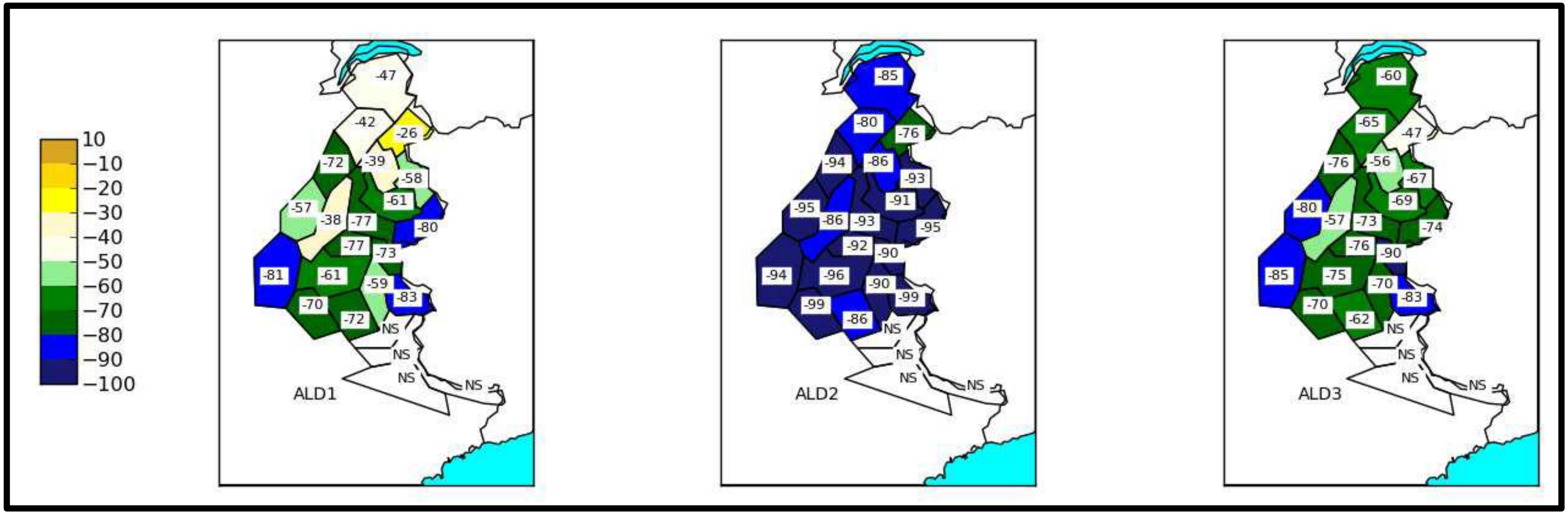


Proportion of wet snow avalanches in the Mont Blanc massif (Naaim et al., 2016)

Wet snow avalanche deposit, january 2018 Bessans, Savoie (photo Irstea).

Shorter time scales – avalanche cycles

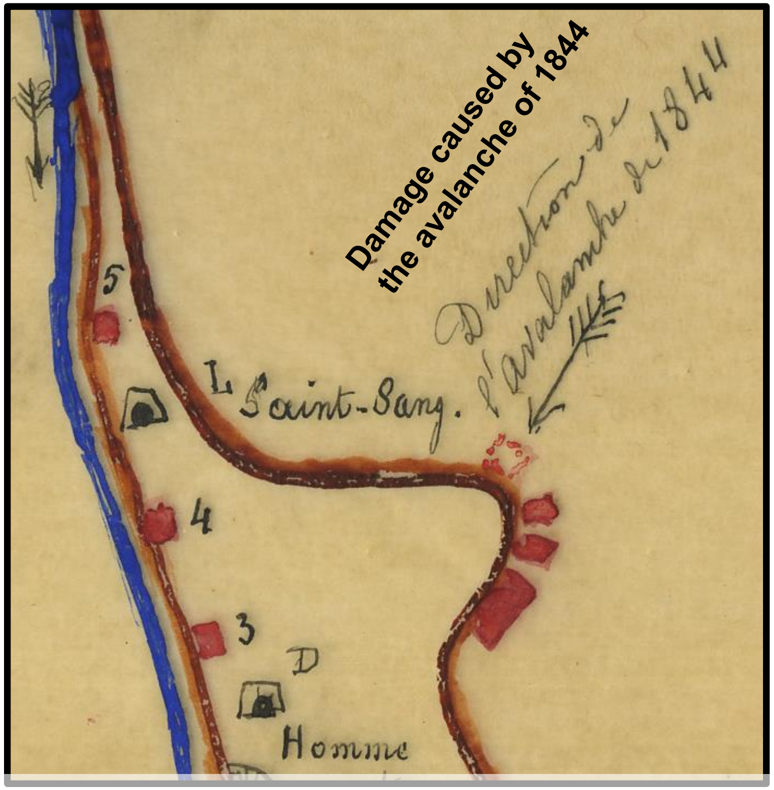
- Implies redoing all the work on the basis of clusters of occurrences over 1-7 days. Preliminary results obtained with MEPRA index instead of observed avalanche activity;
- More difficult: requires an explicit extreme-value framework for discrete events (not straightforward);
- Theoretical developments (Sielenou et al., 2016), still need to be implemented and combined with future climate projections.



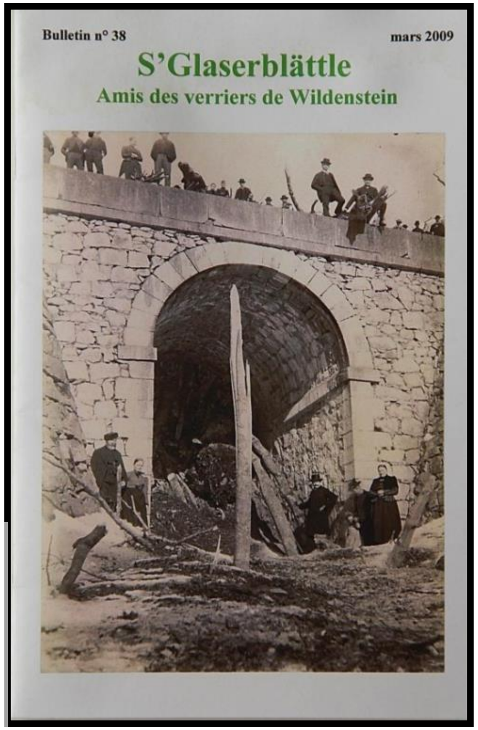
Anomaly (%) in the evolution of very high risk avalanche situations modeled at the end of the century for scenario B1, A2 and A1B (ALD3). NS indicates a non-significant value.*(Giraud et al., 2013)*

To go further (1) : historical archives

- Old maps, photographs, administrative archives, etc.
- Example: reconstruction of avalanche activity in the Vosges Mountains (Giacona et al., NHESS 2017).
- Work started in Haute Maurienne – Queyras.



Old map, 1845-1850, © Archives de la Société industrielle de Sainte-Marie-aux-Mines, albums Lesslin.



Avalanche in Wildenstein, February 1895, local newspaper front page and personal picture.

Adapting the modelling framework to archives

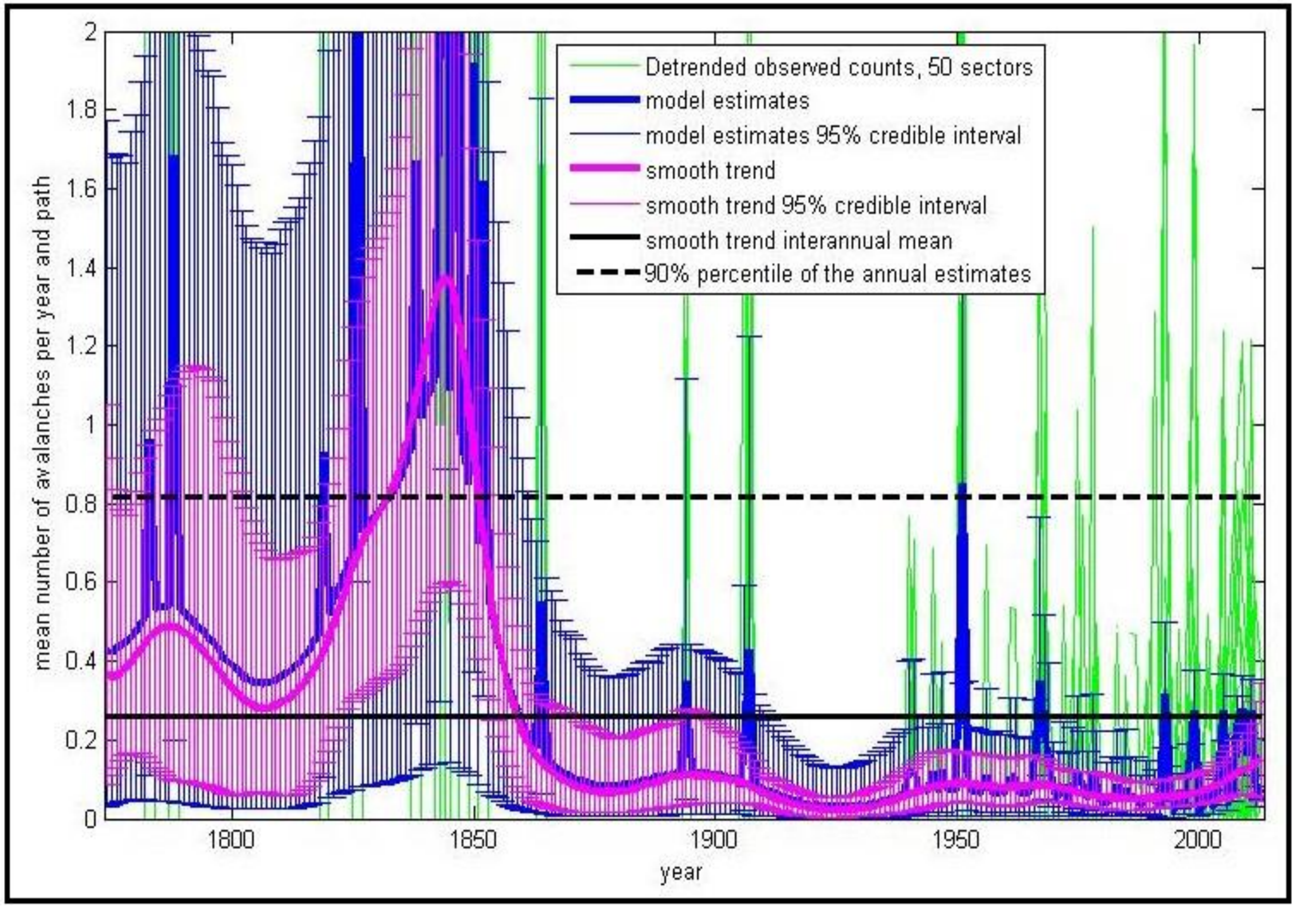
- 240 years of archival data in the Vosges mountains (Giacona et al., NHESS 2017);
- HBM taking the social context into account to evaluate avalanche activity changes over the long range;
- Despite the limited number of records at the beginning of the study period, the inferred smooth trend documents a drastic drop at the Little Ice Age termination.

$$p\left(a_{it}\middle|\lambda_{jt}\right)=\frac{\lambda_{it}^{a_{it}}}{a_{it}!}\times\exp\left(-\lambda_{it}\right)$$

$$\ln(\lambda_{it})=\ln(e_{it}\times RR_{it})$$

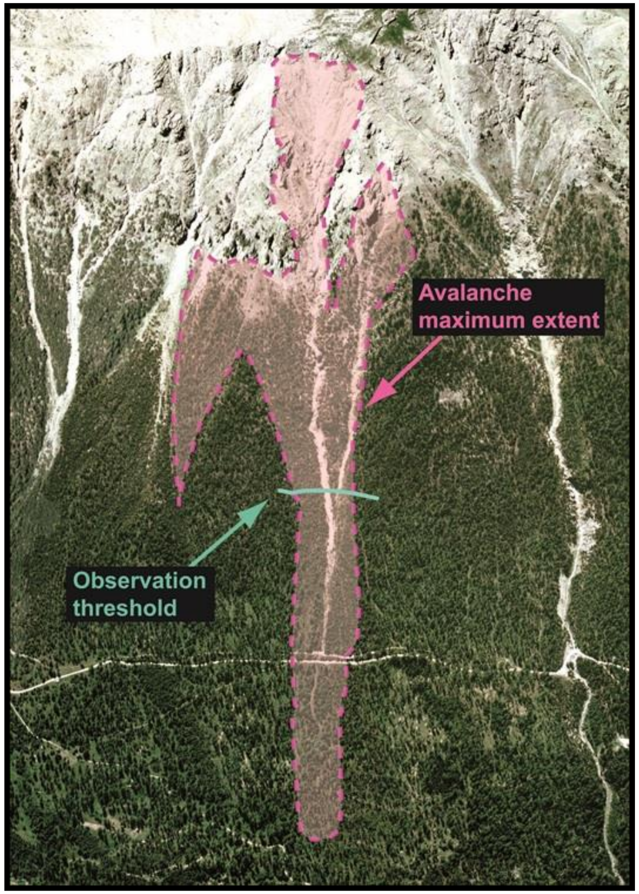
$$e_{it}\propto s_t$$

Relative risk model in a Poisson ST regression, with expected numbers depending on the social context (source potential s_t).

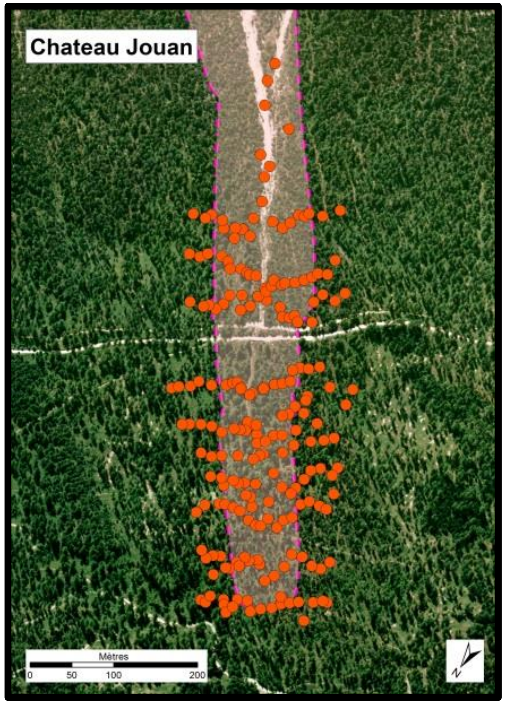


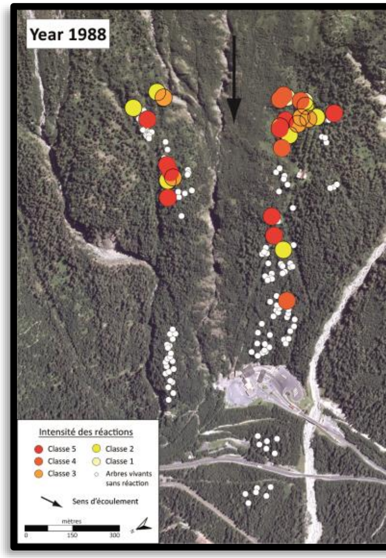
Homogenised avalanche activity over 240 years in the Vosges mountains (Giacona et al., in prep).

To go further (2): tree ring data

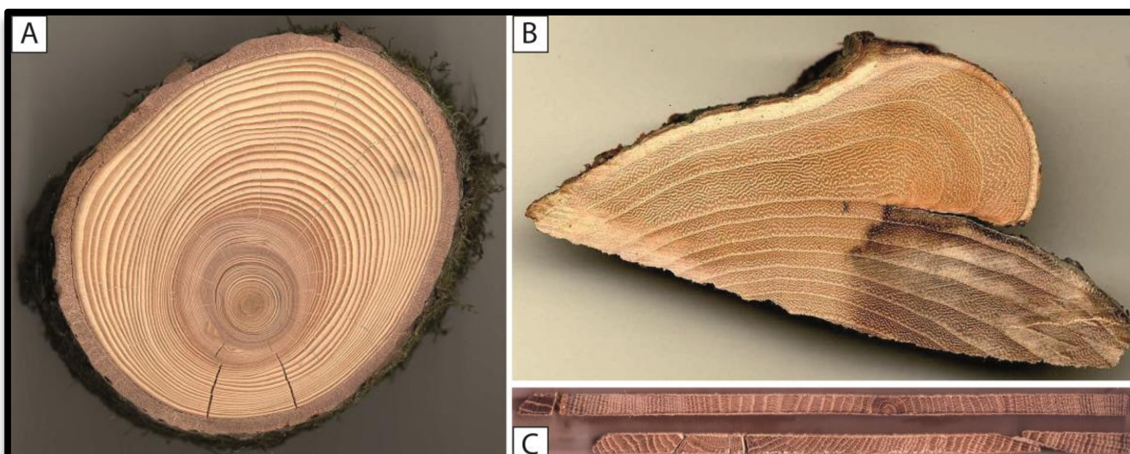


Château Jouan avalanche path, French Alps. Maximal extent and observation threshold in historical chronicle (EPA database) from Schläppy et al. (AAAR 2013).





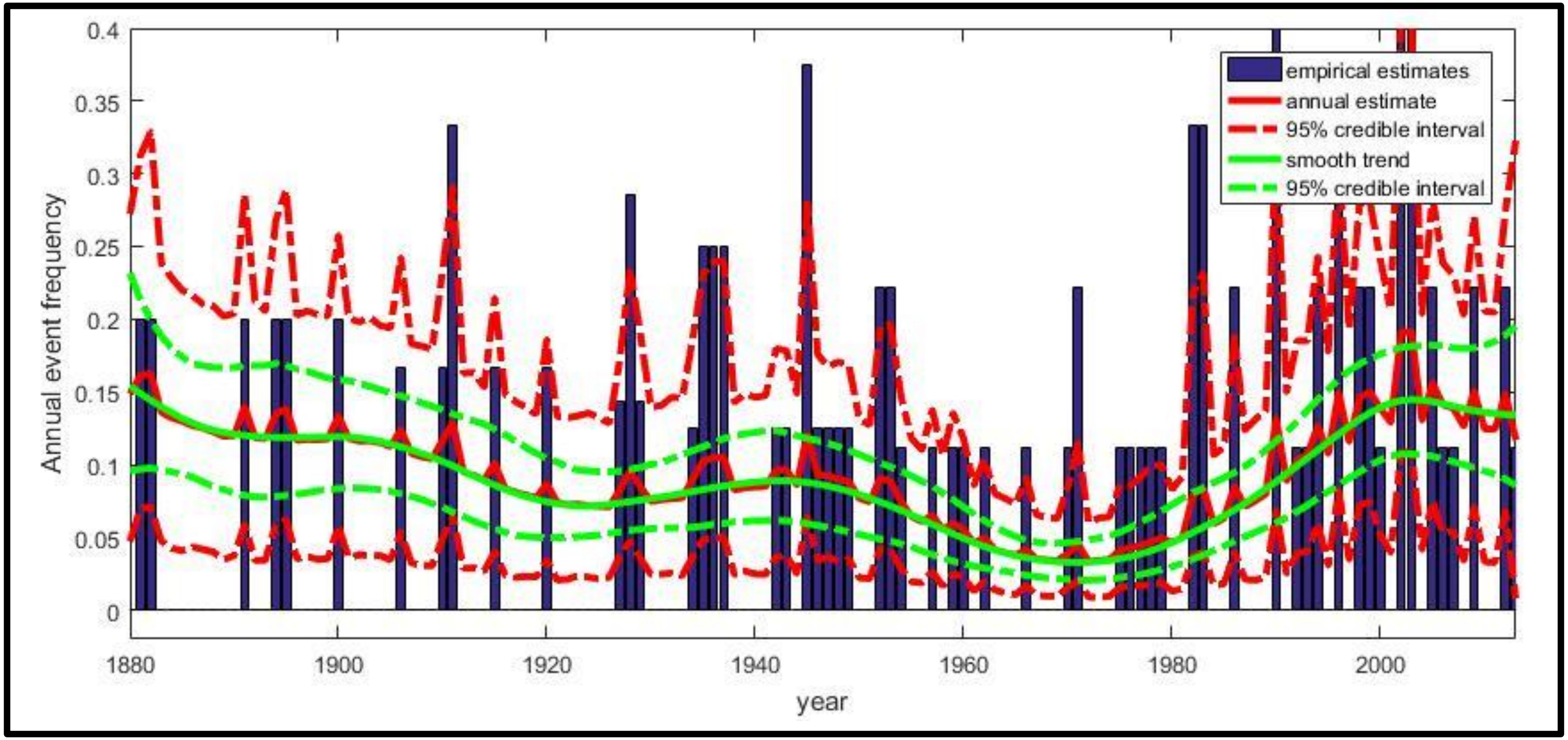
Location of the sampled trees and example of detection of one past event (number, intensity and location of growth disturbances that year), Schläppy et al. (AAAR 2013).



Example of tree samples: cross sections and increment core (© R. Schläppy).

Adapting the framework to tree-rings

- 140 years of tree ring data in Valais (CH);
- Similar detrending to account for the “tree stand effect”;
- Work in Progress in Quyras and Haute Maurienne (~5 centuries of data!);



Homogenised avalanche activity over 140 yars in tValais (CH) (Favillier et al., in prep).

What’s next?

- The French Alps: an exceptional playground to study avalanche-climate relationships: “excellent” data and cutting-edge modelling techniques (snow-climate, statistics);

- Many methodological developments already done, which could be used in a successful POIA project;

- Major challenges/objectives:
  - Updating results regarding last decades with last seasons avalanche data and IPCC AR5 projections;
  - Working on the long range on selected hotspots (completing and combining archives and tree rings, discarding confonding factors);
  - Working on short time scales (past and future) to better characterize/anticipate 2018-like situations;
  - …

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