Risk Institute
Université Grenoble Alpes

PEPR Risques (IRiMa)

RÉPUBLIQUE FRANÇAISE — FRANCE 2030 — PROGRAMME DE RECHERCHE RISQUES — PILOTÉ PAR brgm, cnrs, UGA Université Grenoble Alpes

Prévision à court et long terme de l'activité avalancheuse et du risque associé

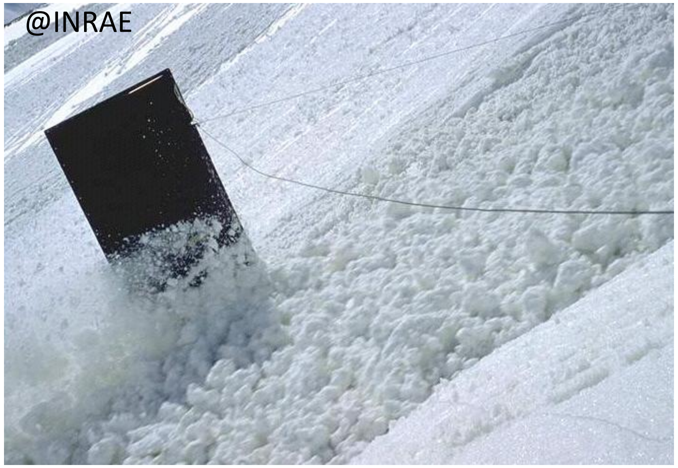
N. Eckert et al.

INRAE la science pour la vie, l'humain, la terre — AQUA — OSUG Observatoire des Sciences de l'Univers de Grenoble — IGE Institut des géosciences de l'environnement — Université Grenoble Alpes

Snow avalanches

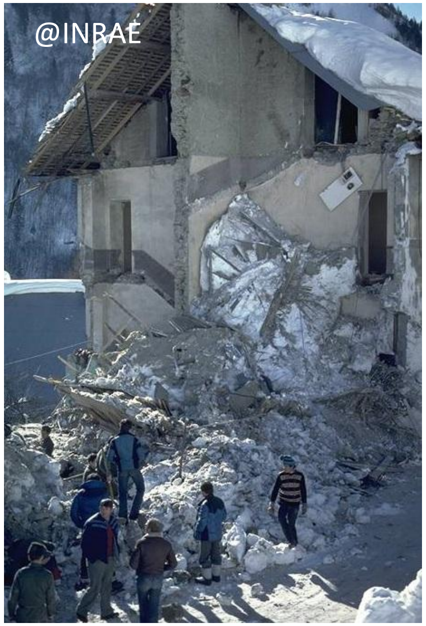
- Complex snow flows with different release processes, flow regimes, snow types, seasonality, etc.

- Constraining factors for avalanche activity:
- Topography;
- snow and weather parameters.



Risks due to snow avalanches

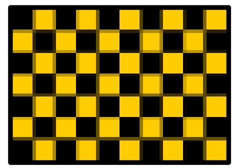
- Disaster risk for people, settlements, critical infrastructures, forest stands, etc.
- Wider risks: compromise between safety and sustainability of mountain communities, biodiversity conservation versus grey protection structures, etc.



Destruction of an hotel by an avalanche in RigoPiano (2017), 29 casualties

Short and long term forecasting

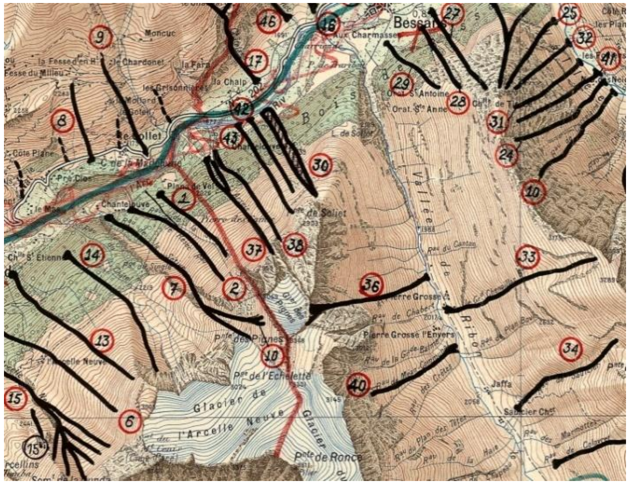
- ***Short term forecasting***:
  - When closing a road? A ski slope?
  - When evacuating a settlement?
  - Forecasts conditional to snow and weather (traffic) conditions



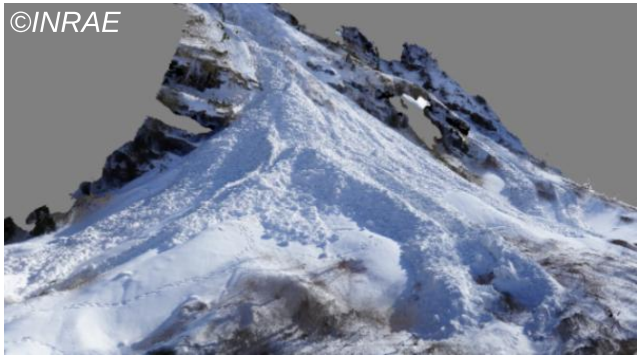
- ***Long term forecasting***:
  - Land-use planning (lack of space): where to “draw the line”? Building defense structures?
  - Return levels
  - “Unconditional” modelling

Data sources

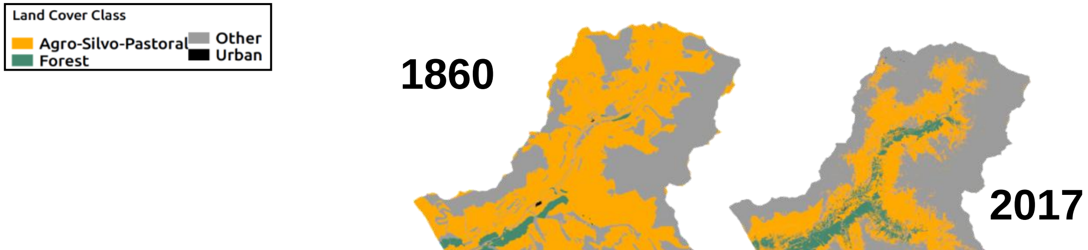
- Data difficult/dangerous to acquire : overall, sparse/lacunar snow avalanche time series.
- In France “excellent” data:
  - Avalanche database “*EPA*” (~4000 selected paths);
  - Top-seed measurements (LIDAR, remote sensing);
  - Archival and paleo-environmental data;
  - Surrogate data (results from snow cover simulations).
- “Full set” of environmental data: past and future snow and weather conditions, past land cover and population changes, etc.



Historical avalanche map (Mougin, 1922) on which avalanche paths were drawn manually



3D avalanche deposits measurements in the same area



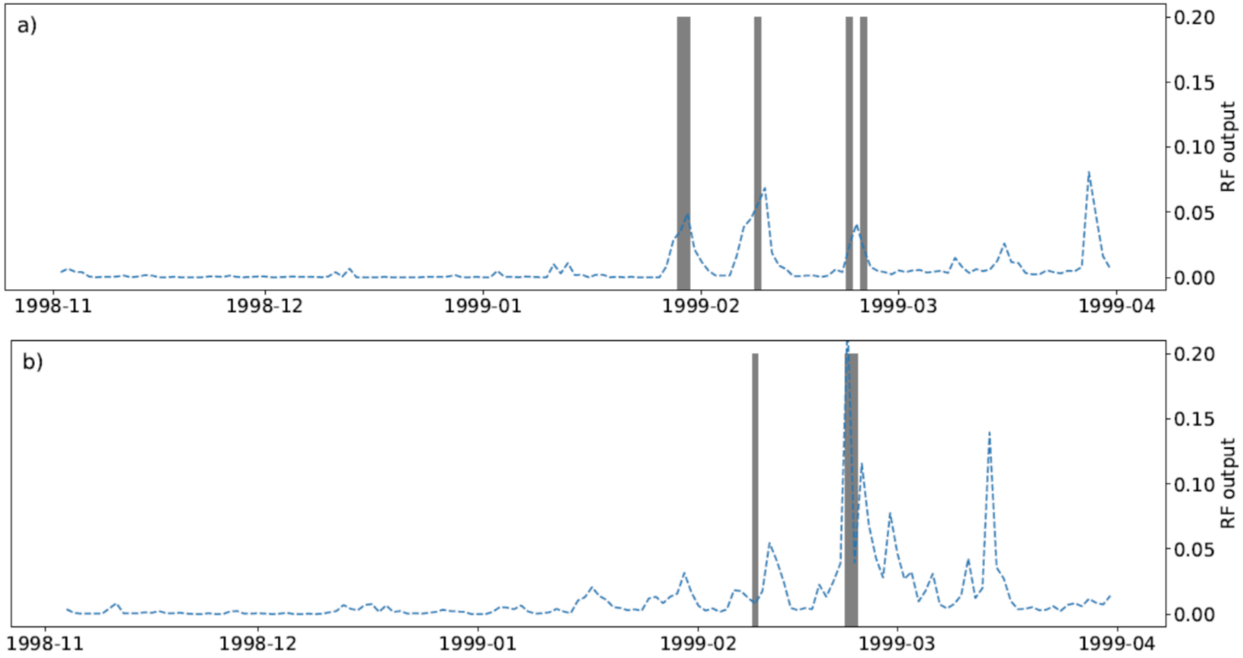
Land cover changes in a high valley of the French Alps. (Zgheib et al., GPC, 2020)

Short-term forecasting (1)

- Avalanche operational forecasting: real time snow and weather data assimilation and modelling and expert evaluation of a 5 classes hazard level.

- Model-based forecast: “Classical” classification (2-5 classes) as function of forecasted snow conditions.

- No “full” risk assessment but risk for skiers by taking into account additional loading (accidental trigger).



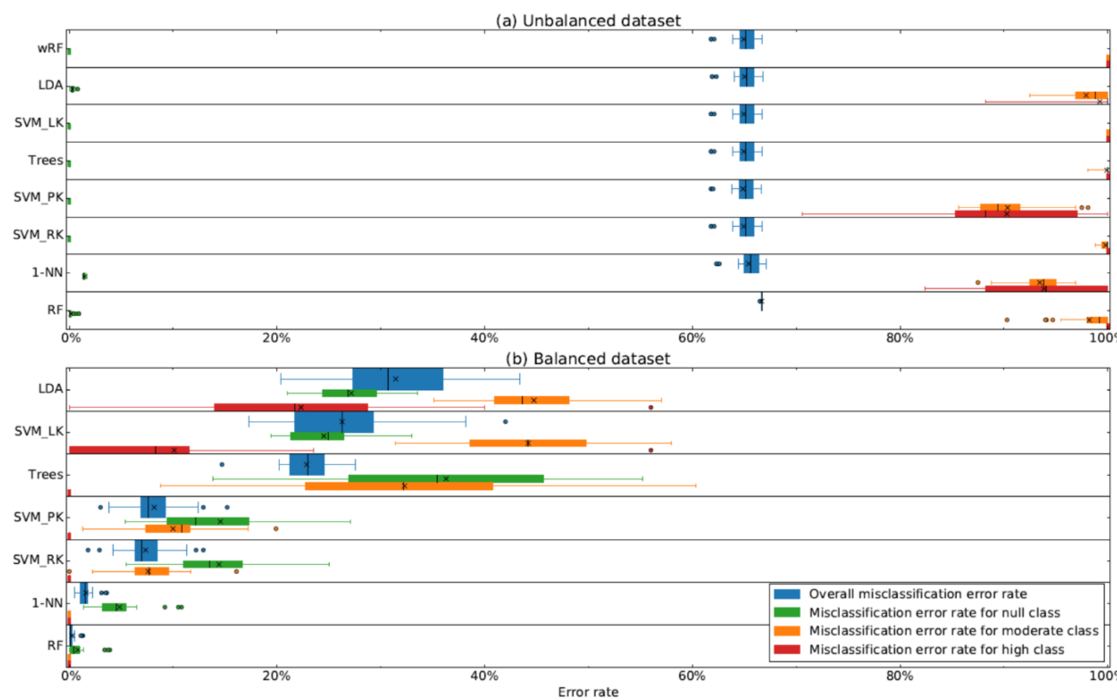
Avalanche probability versus observed counts, 2 classes random forest classifier, Viallon-Galinier et al. (2022).

Short-term forecasting (2)

- Use of basic to deep learning techniques.
- Distinction between “forecast” and “nowcast” contexts.
- Standard tools for forecast evaluation: confusion matrix, accuracy and error rates, specificity/sensitivity, ROC curves, etc.

		Predicted class		
	Classes	C_1	$\cdots$	C_k
True Class	C_1	$n_{1,1}$	$\cdots$	$n_{1,k}$
	$\vdots$	$\vdots$	$\ddots$	$\vdots$
	C_k	$n_{k,1}$	$\cdots$	$n_{k,k}$

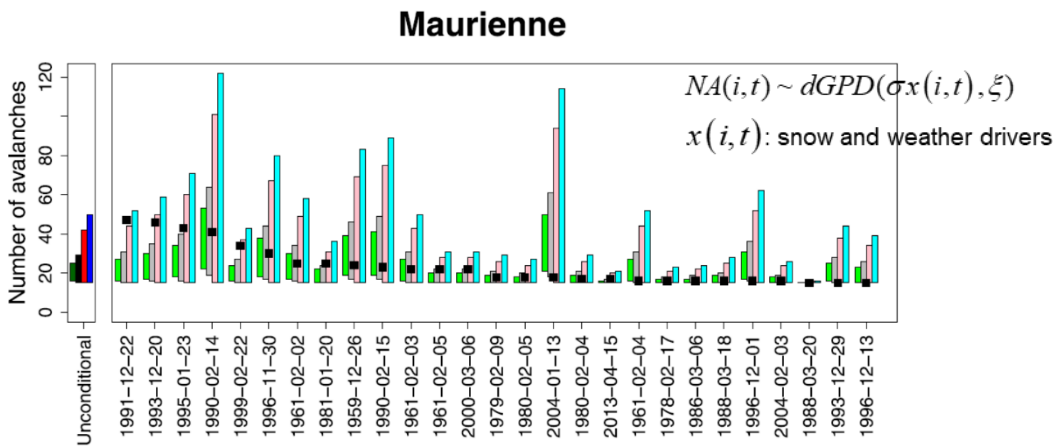
Synthetic representation of a confusion matrix



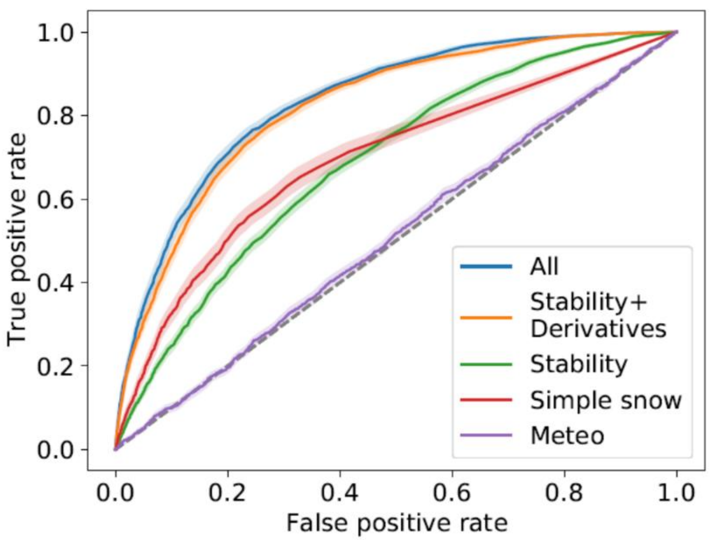
Error rates for a 3 classes avalanche hazard classifier for different classification techniques and with/without class balancing, Dkegne Sielenou et al (2021).

Short-term forecasting (3): recent developments

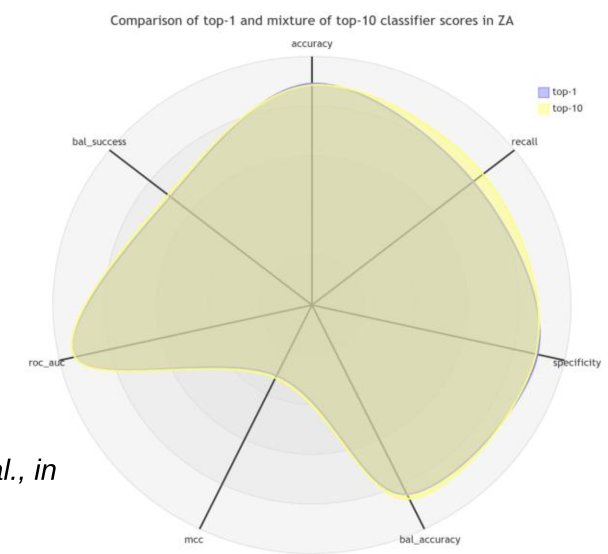
- Refined description of snow stratigraphy/physics as predictors to improve classification;
- Ensemble and probabilistic forecasts.



Evin et al., WCE 2021.



Viallon-Galinier et al., TC 2022.



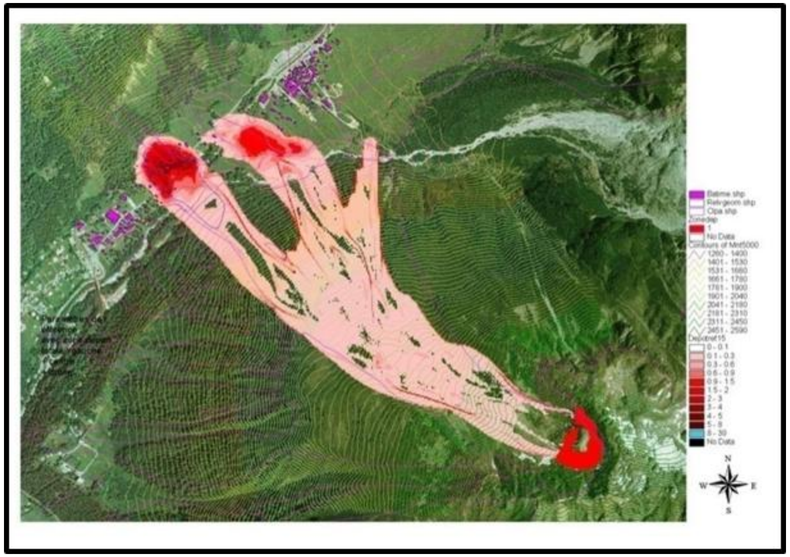
Dkegne Sielenou et al., in preparation

Numerical-probabilistic long term forecasting (1)

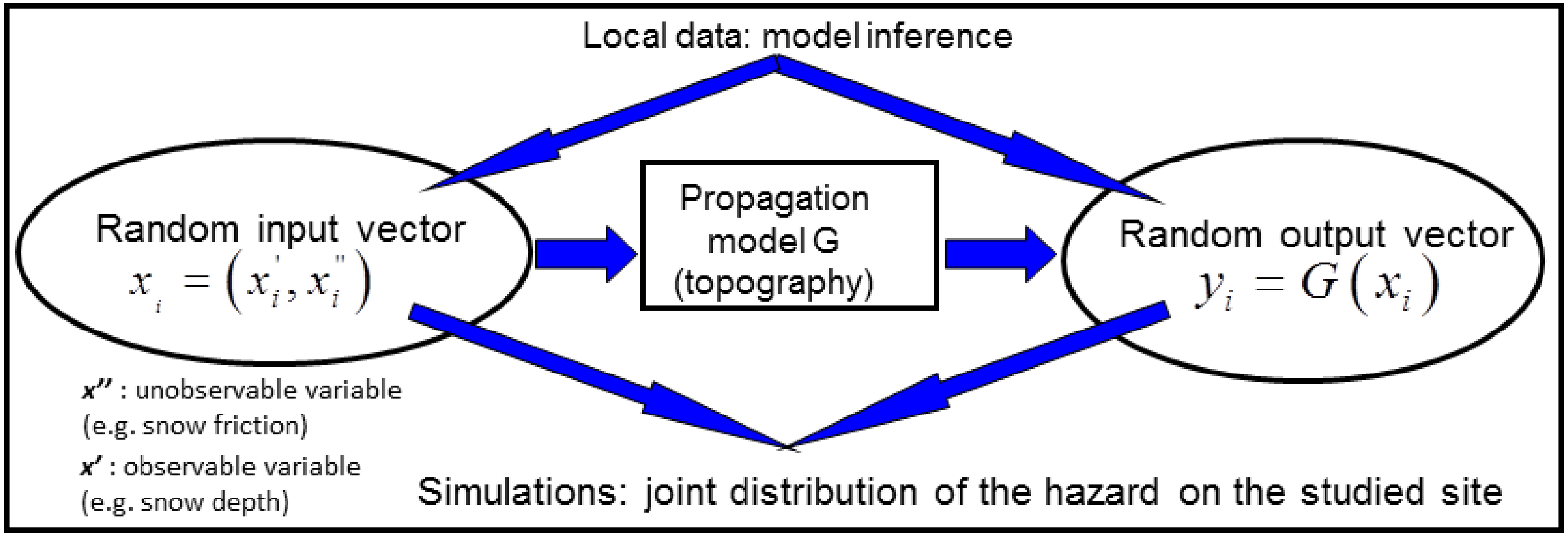
- Evaluation of unconditional return levels usable for hazard and risk assessment in runout zones.

- Physically based model with probabilistic framework: not explicit for “outputs”, but multivariate and using real topography and “robust” physics.

- Inference on local series, spatial extrapolation to “fill gaps”.



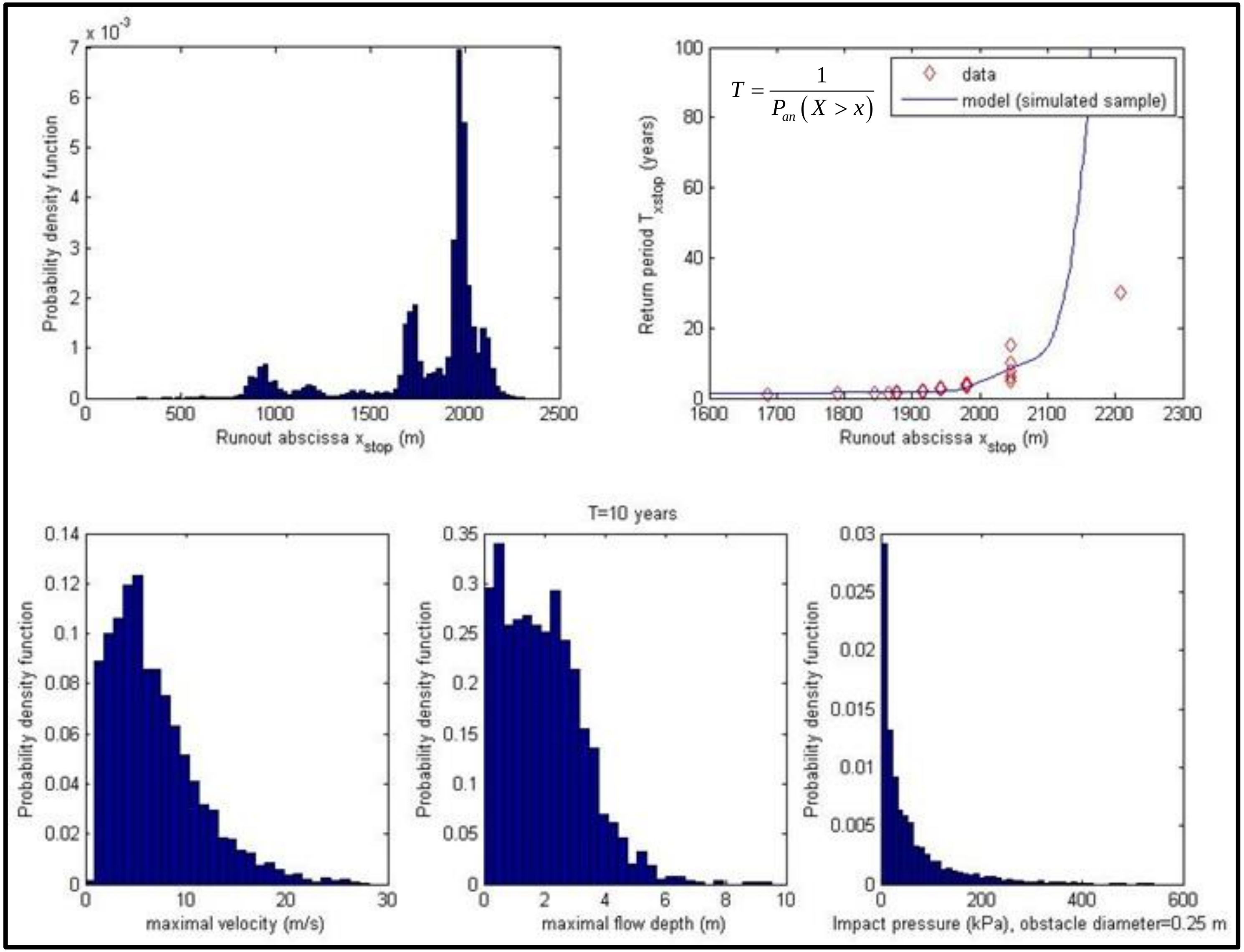
Avalanche simulation for hazard mapping, © M. Naaim, INRAE



Principle of a numerical-probabilistic approach associated with Bayesian inference (Eckert et al., 2012)

Numerical-probabilistic long term forecasting (2)

- *Pseudo POT model relying on a* depth-averaged flow code: provides outputs that include relevant physics .
- *Bayesian inference (MCMC techniques).*
- Different compromises between computation times and realism of the physical description of the flow.

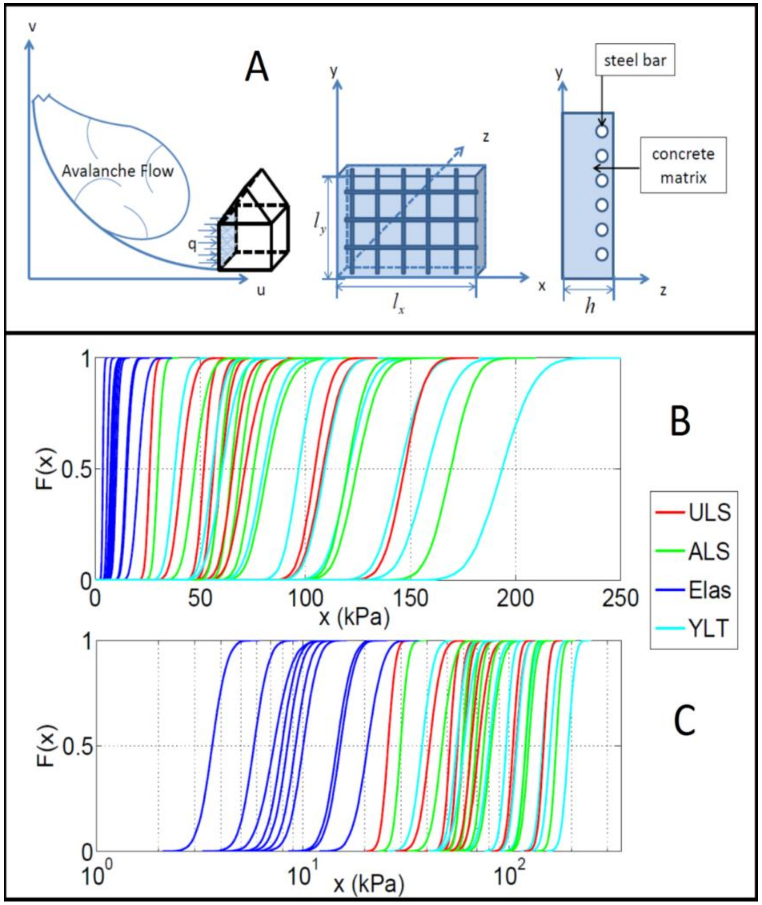


The statistical-dynamical model Eckert et al. (2010) provides the one-to-one relation between runout distance and return period, and, for each runout distance, the joint distribution of all other variables.

Snow avalanche risk for buildings and people inside

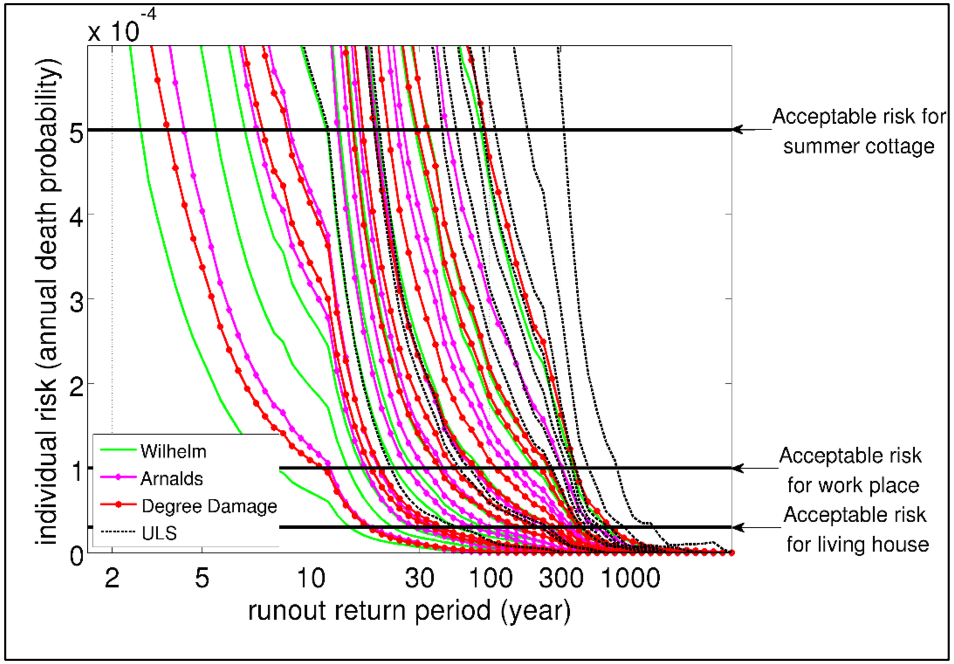
$$R_z \propto E_y\left[V(z,y)\right] = \int p(y)V(z,y)dy$$

- V(z,y): deterministic link between hazard magnitude and damage level for the element at risk z;
- p(y): (stochastic model: describes the variability on the studied site.



Evaluation of fragility curves for various types of reinforced concrete (RC) buildings (Favier et al., 2014a).

- ○ Evaluation of death rates (individual risk) as function of space in the runout zone.
- ○ Expected damage as standard approach / alternatives (VAR, CTE) in development.
- ○ Empirical or numerical data for vulnerability.

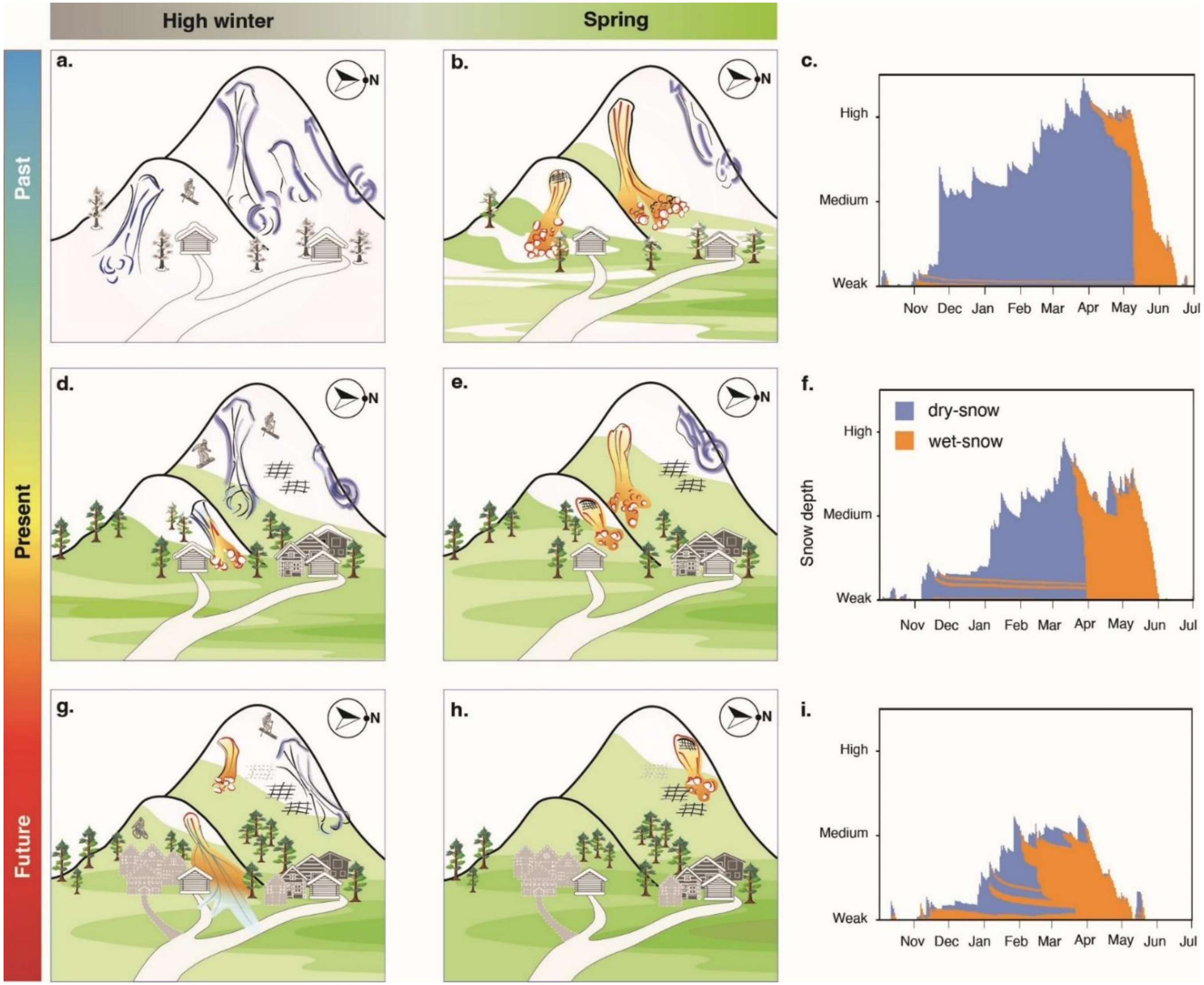


Evaluation of death rates (individual risk) as function of space in the runout zone (Favier et al., 2014b).

The grand-challenge: non-stationarity

- Climate and socio-environmental changes affect hazards and risks drastically

- Big picture gradually emerges, but slope-scale projections still unavailable as function of horizon / warming rate



A conceptual model of ongoing changes from a review of methods, data and established facts, Eckert et al., NREE 2024

Take home messages

- **Snow avalanches and related risks:**
  - Strong impacts (“local” scale);
  - Highly non-stationary (up to emergence / disappearance).

- **For the future : perspective and needs**
  - Rather abundant data especially in France, but divergent spatio-temporal scales: challenge of combination;
  - More widely, efforts to integrate existing modelling tools
  - A small world: need for new human resources.

Massive dense avalanche deposit in the French Alps © INRAE.

Chamonix Mont Blanc, May 2023, picture @ONF