Accounting for Non-stationarity in Extreme Snow Loads
a Comparison with Building Standards in the French Alps

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Context: Extreme snow load on roof can generate both **economic & human damages**:

- USA: **excess of $200 million** in roof damages in 1993
- Poland: roof collapse lead to **62 dead** in 2006

Credit: TwinCities PioneerPress

Credit: Ryan McFarland 2009. Collasped roof

Our goal: **Ensure Building Standards are resilient**

- study past trends in hazard of snow load
- then compare hazard in 2019 with roof standards

Two main results: **Hazard of snow load** is

- **decreasing** with time in the French Alps
- **exceeding roof standards** for half massifs at 1800 m

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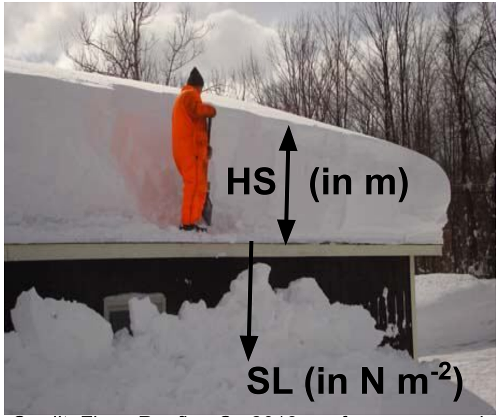
Ground snow load (GSL)

Relation to other snow metrics

Meteorological metric

Precipitation (rainfall + snowfall) in mm, same as kg m^{-2}

Snowpack metrics



Credit: Flynn Roofing Co 2018. roof snow removal

Snow Depth (**HS**) measured in m

x snow density, that vary from 100 to 800 kg m^{-3}

Snow water equivalent measured in kg m^{-2}

x gravitational acceleration (g = 9,8m s^{-2})

Snow Load (**SL**) measured in N m^{-2}, same as Pa

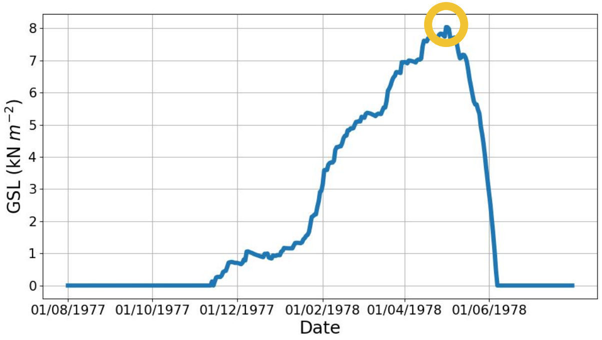
We focus on the pressure of accumulated snow load on the ground:
the **ground snow load** (**GSL**)

Data

GSL (Ground snow load) reanalysis data from the Météo-France Safran-Crocus chain

Annual maximum of GSL in 1978

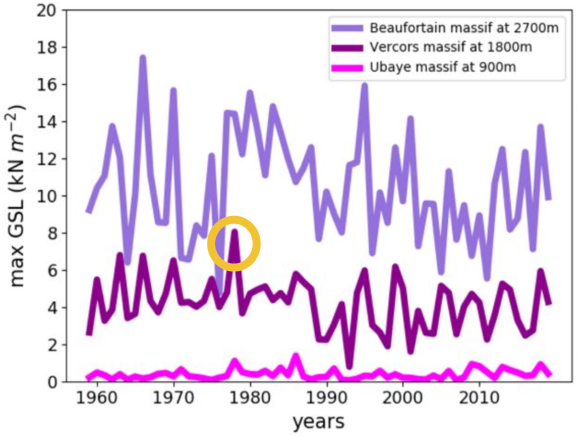
for the Vercors massif at 1800 m

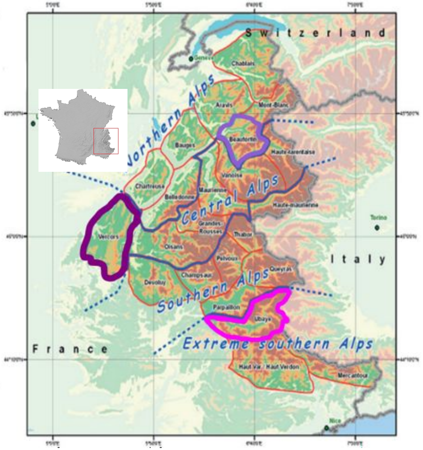


Every 300 m of altitude, we extract the **annual maximum** of ground snow load (GSL) at the massif-scale

Annual maxima of GSL from 1959 to 2019

for the Ubaye massif at 900 m
for the Vercors massif at 1800 m
for the Beaufortain massif at 2700 m





First motivation:
What are the **temporal trends in the hazard** associated to these annual maxima **of GSL ?**

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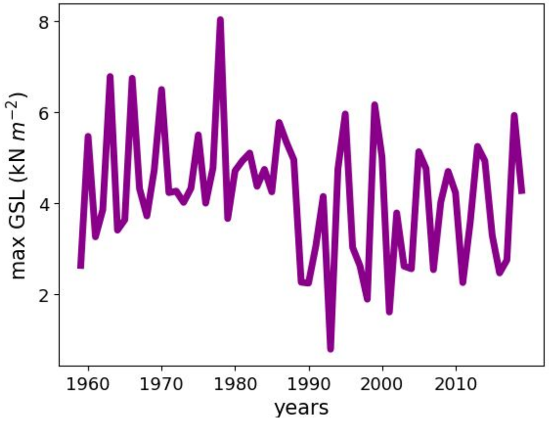
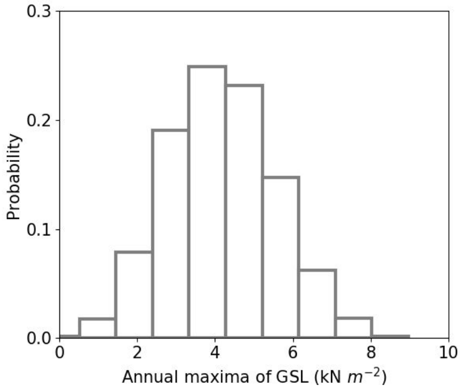
Statistical Methodology

Non-stationary modelling

Annual maxima of ground snow load (**GSL**)



Stationary model
(Generalized extreme value distribution)



Examples of **non-stationary model**
(i.e. probabilities change with time)

1. the histogram could slide linearly to the left with time (= less intense annual maxima in average)

2. the histogram could spread with time (= increase variance of annual maxima)

For each time series of observations:
we select the model (stationary or non-stationary)
that minimized the AIC score, i.e. the model that both:

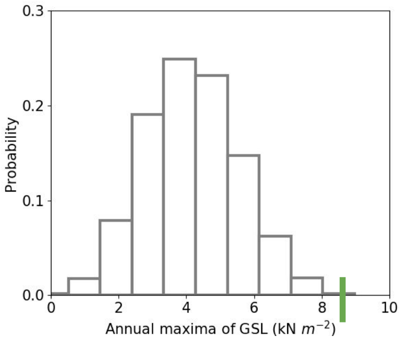
- explain well the observations
- have few parameters

Result 1. Temporal decrease of snow load hazard

Decrease in 50-year return level of ground snow load (GSL)

Hazard definition:

Hazard = 50-year return level =
The quantity exceeded once every 50 years **in average**

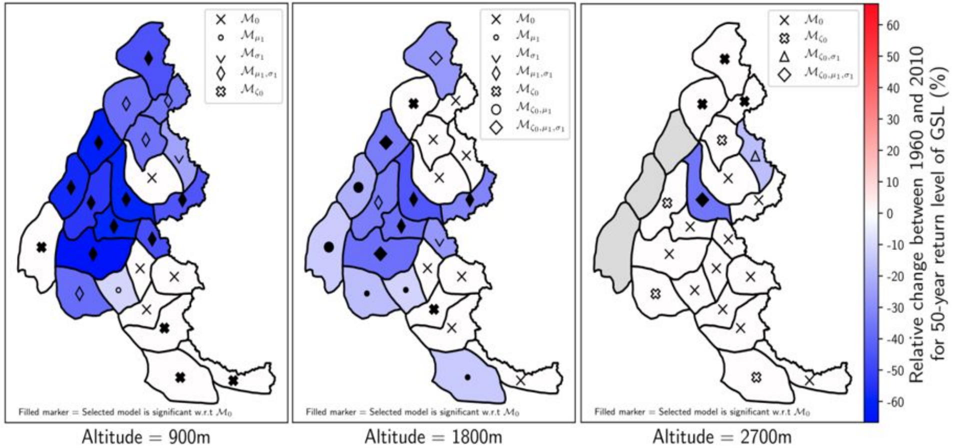


49/50 years **in average**

once every 50 years **in average**

Stationary hazard
The probabilities stay the same with time
Thus, return level stays the same with time

Non-stationary hazard.
The histogram (i.e. the probabilities) change with time
Thus, return level is changing with time



Results:
For snow load hazard, we find either:

- a **decrease** (non stationary model)
- no trends (stationary model)

The decrease in snow load hazard is:

- Mainly located in the Northwest
- Less important for higher altitudes

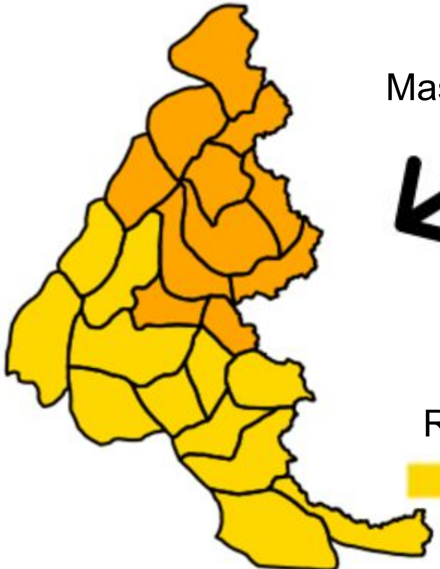
Building standards in the French Alps

How to obtain the 50-year return level of snow load on a roof ?

roof shape, exposure
and thermal transmission ?

Massif ?

Step 1



Step 3

50-year return
level of snow load
on the roof

Altitude ?

Step 2

50-year return level of ground
snow load (**GSL**) with
stationary model &
approximated GSL

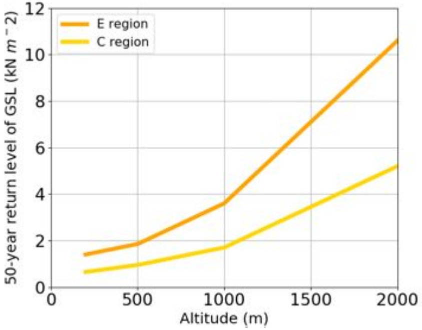
Step 3

Region type ?

or

Step 2

Building standards
define 2 clusters:
region C and **region E**



Axe X: altitude (in m) until 2000 m
Axe Y: 50-year return level of GSL

Second motivation:
for each massif & altitude,
find the 50-year return level of
GSL using a **snowpack model** & taking into account
potential **non-stationarity**

Comparison between our approach and French standards

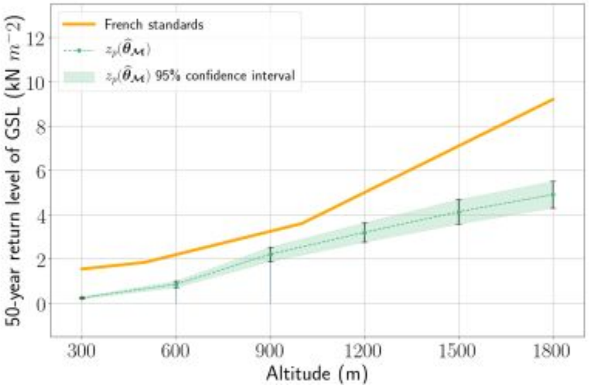
Two differences: Models used & the type of GSL data used

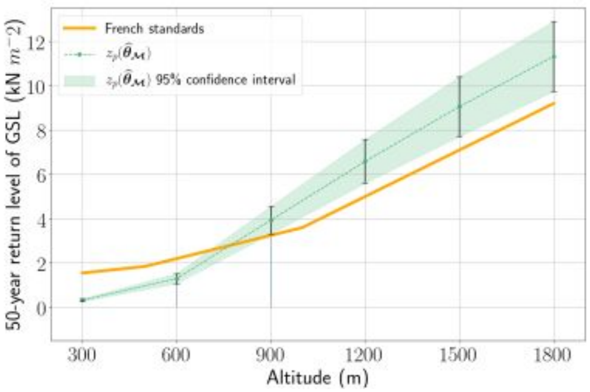
Example for the Beaufortain massif:

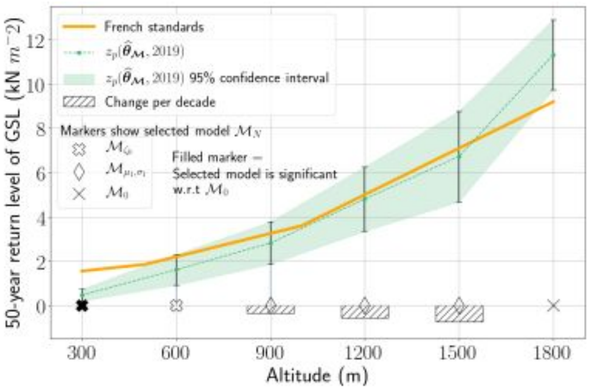
Left: **Similar to French standards**
= stationary model
& approximated GSL
(with snow depth & snow density equal to 150 kg m^{-3}).

Center:
stationary model & actual GSL (with a snowpack model).

Right: **Results with our approach**
Selected model (stationary or non-stationary) & actual GSL.







No exceedances

Exceedances between 900 m and 1800 m

Exceedances only at 1800 m

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Result 2. Return levels of GSL exceed French Standards

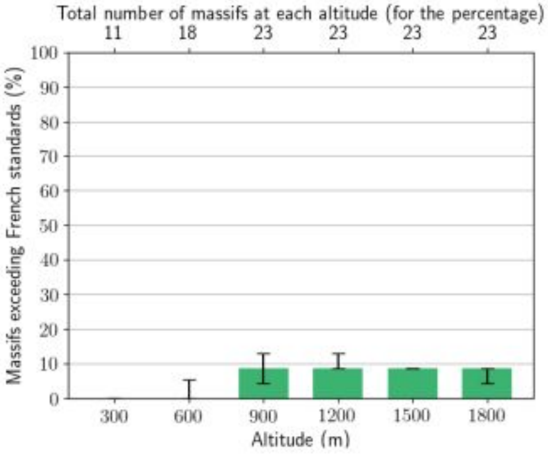
Percentage of massifs that exceed standards

Summary of exceedances for all massifs:

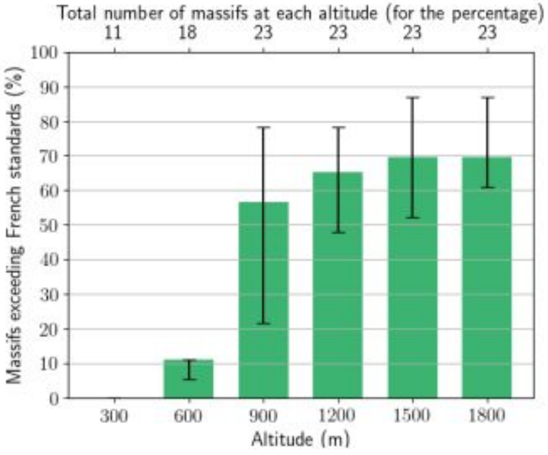
***Left*: Similar to French standards = stationary model & approximated GSL.**

Center: **stationary model & actual GSL (with a snowpack model).**

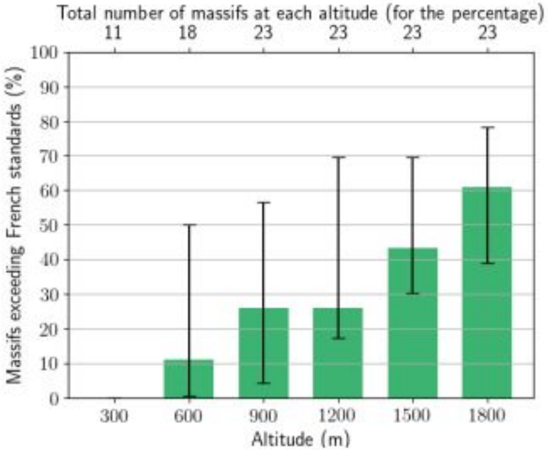
***Right*: Results with our approach Selected model (stationary or non-stationary) & actual GSL.**



Almost no exceedances



Many exceedances (>50%) between 900 m and 1800 m



Many exceedances (>50%) only at 1800 m

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Main results: **Hazard of ground snow load** is

- **decreasing** with time in the French Alps
- **exceeding roof standards** for half massifs at 1800 m