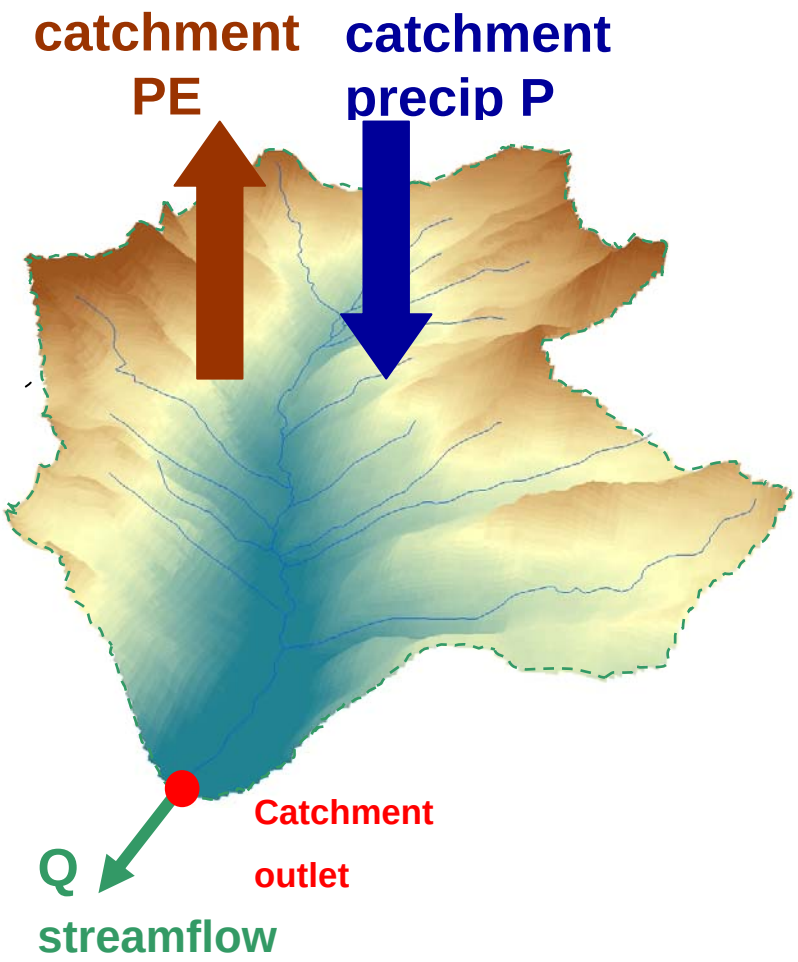
How much complexity is warranted in a snowmelt-snow accumulation routine? (a hydrological perspective)

Audrey Valéry, Vazken Andréassian & Charles Perrin

Cemagref, Antony, France

Philosophical part

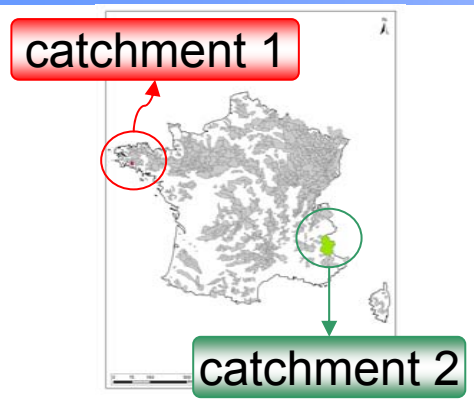
From precipitation to streamflow



This work was done in a hydrological perspective: we worked at the catchment scale, and were interested in reproducing streamflow

The only tools used for analysis were hydrological models
- precipitation P is the input,
- streamflow at catchment outlet Q is the output.

Do we really need a snow routine?



P → HYDROLOGICAL MODEL ← PE

Parameters $\{\theta_i\}$

→ streamflow

air temperature

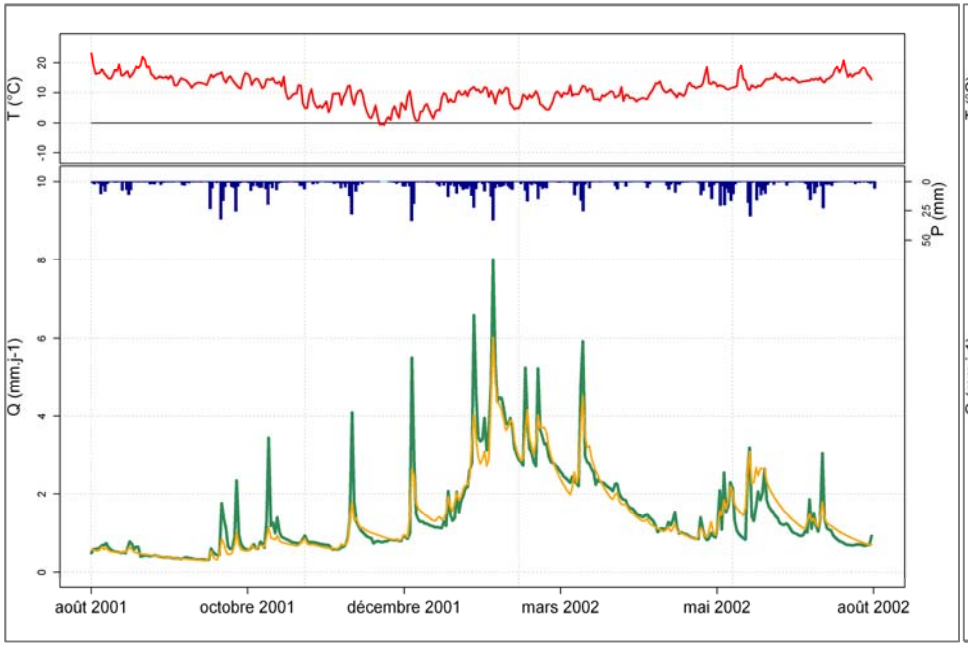
precipitations

precipitations when T < 0°C

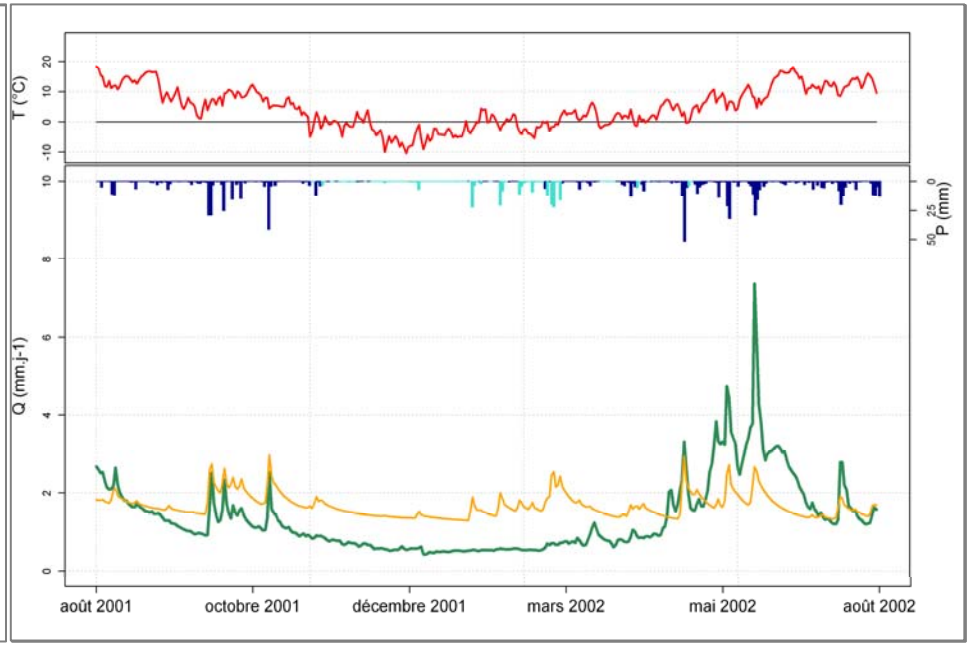
observed flow

simulated flow

catchment 1



catchment 2



Needs

P → PE →

HYDROLOGICAL MODEL

Parameters $\{\theta_i\}$

→ streamflow

air temperature

precipitations

precipitations when T < 0°C

observed flow

simulated flow

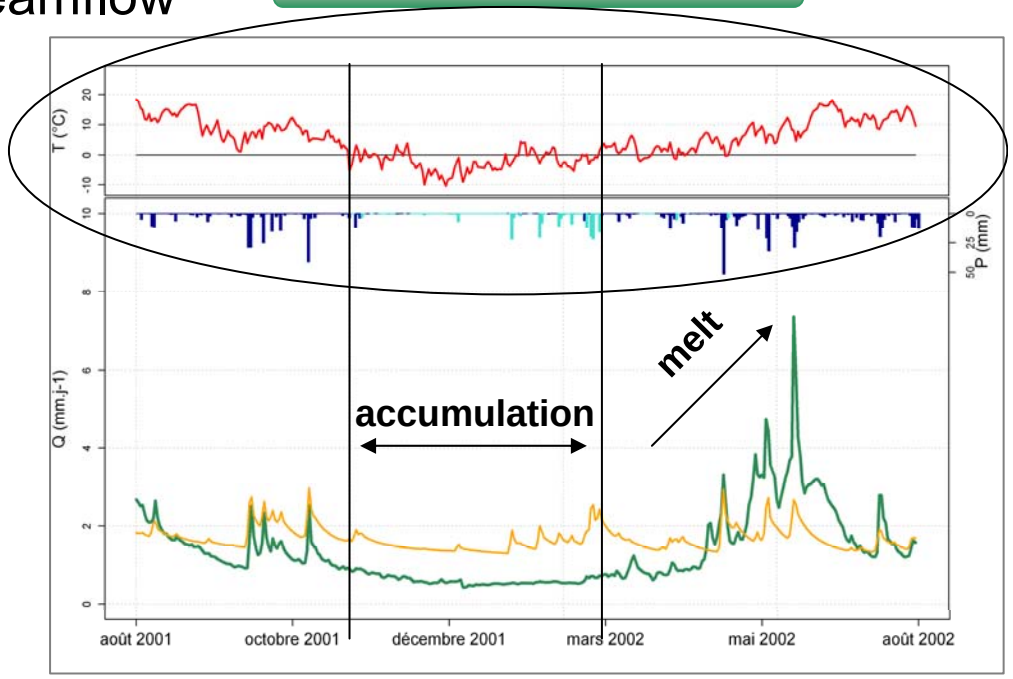
What the hydrological model needs :

1- to know the nature of precipitations (**rain** or **snow**)

2- to account for the specific dynamic of snow cover :

- accumulation = low flows
- melt = flow increases

catchment 2 (alpine)



We should start a scientific research by going straight to what is essential

Courtesy of Sten Bergström, SMHI

We must set the question in terms of system behavior and not physical processes
(*This does not mean that physical processes are uninteresting*)

Citation (both useful and politically-correct in the SMHI context)

‘Going from complex to simpler model structures requires an open mind, because it is frustrating to have to abandon seemingly elegant concepts and theories. It is normally much more stimulating, from an academic point of view, to show significant improvement of the model performance by increasing complexity.’

Bergström, S., 1991. Principles and confidence in hydrological modelling. Nordic Hydrology, 22: 123-136.

With a snow routine

P T PE

SNOW MODULE

Parameters $\{\theta_{Gi}\}$

HYDROLOGICAL MODEL

Parameters $\{\theta_i\}$

Streamflow

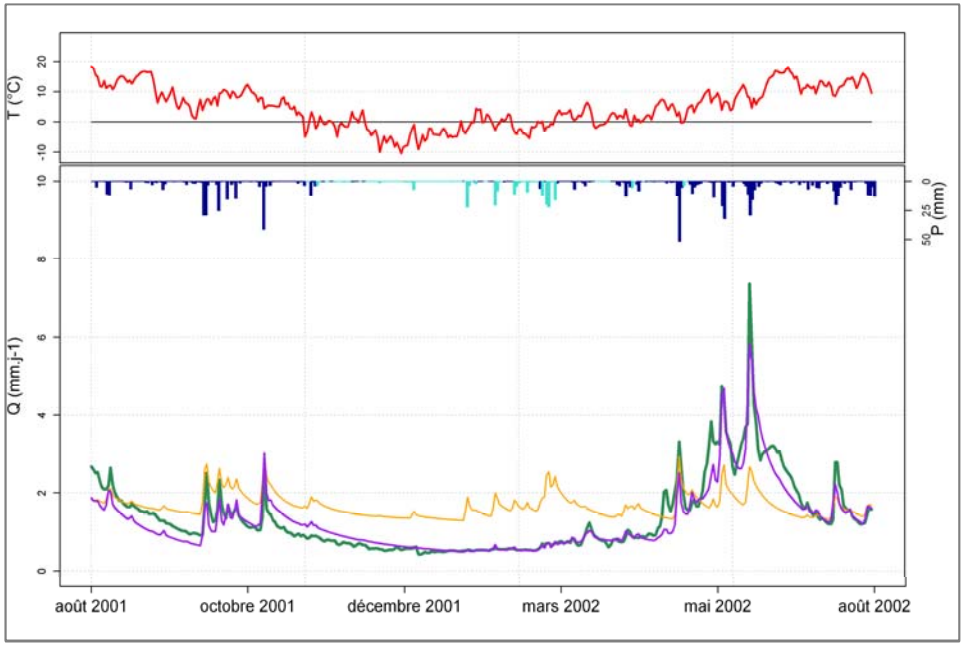
air temperature

observed flow

flow simulated without snow routine

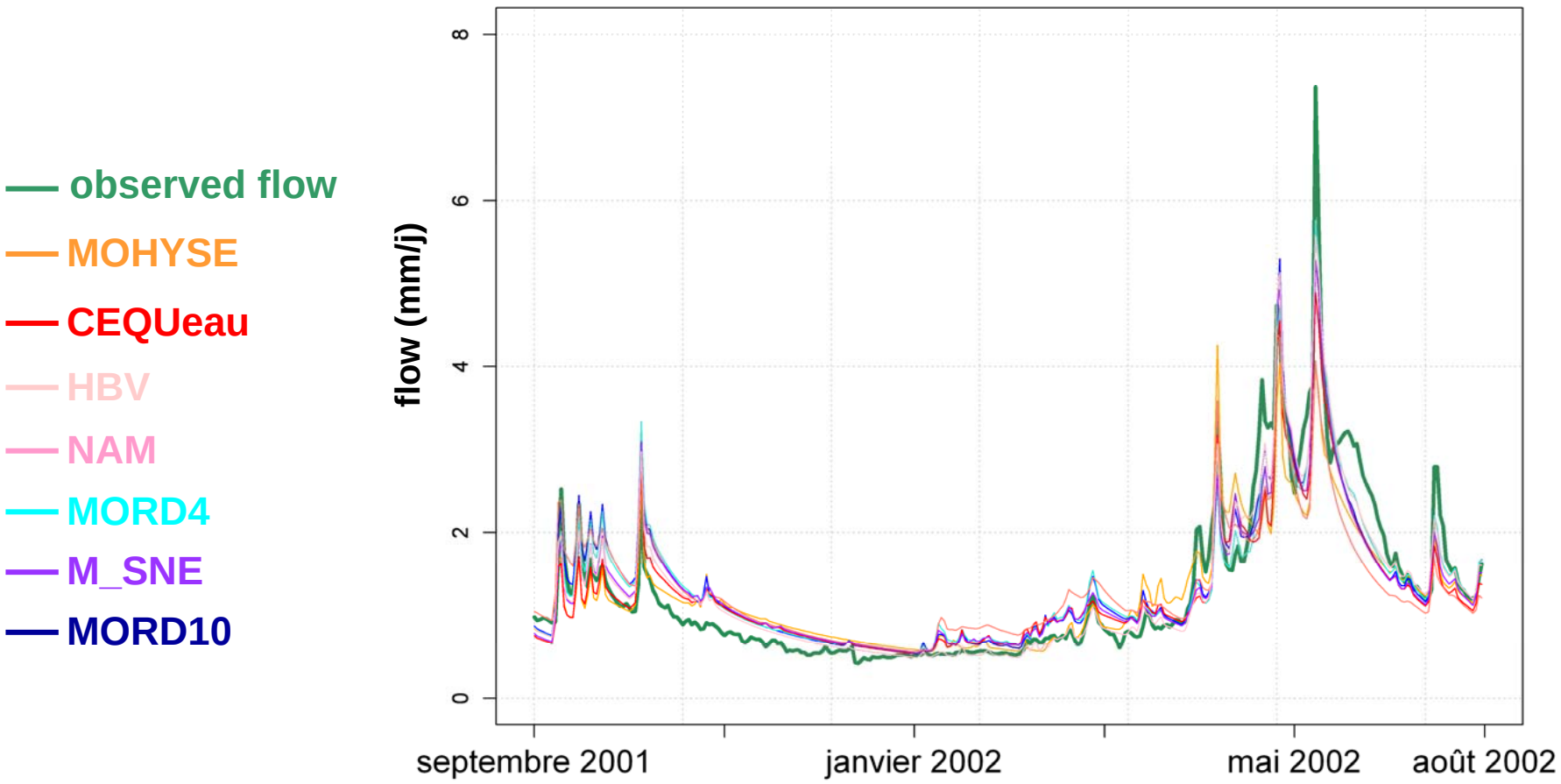
flow simulated with a snow routine

alpine catchment



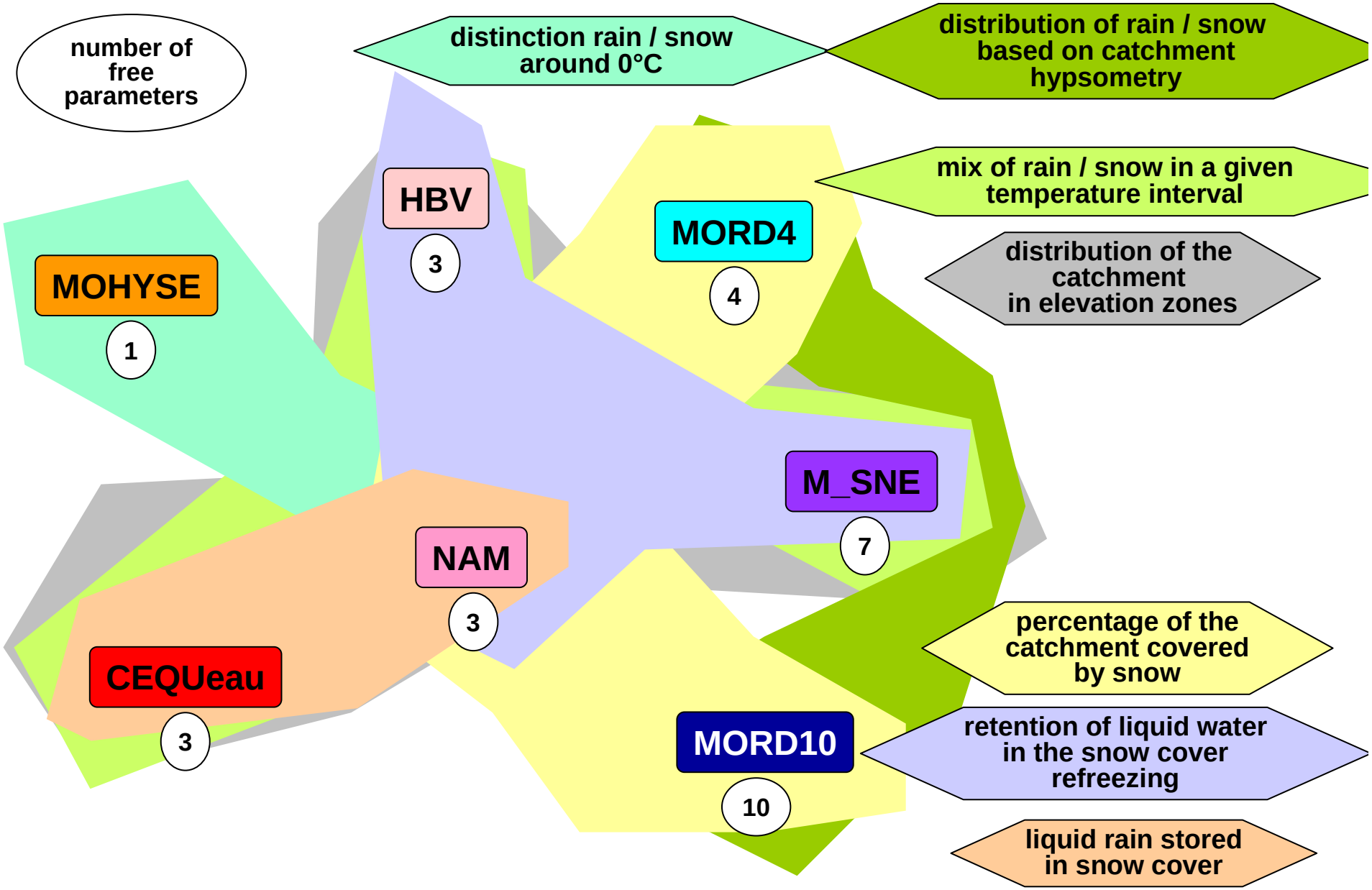
Review of the existing

Many snow routines exist already



Comparative studies are scarce (*WMO, 1986*)

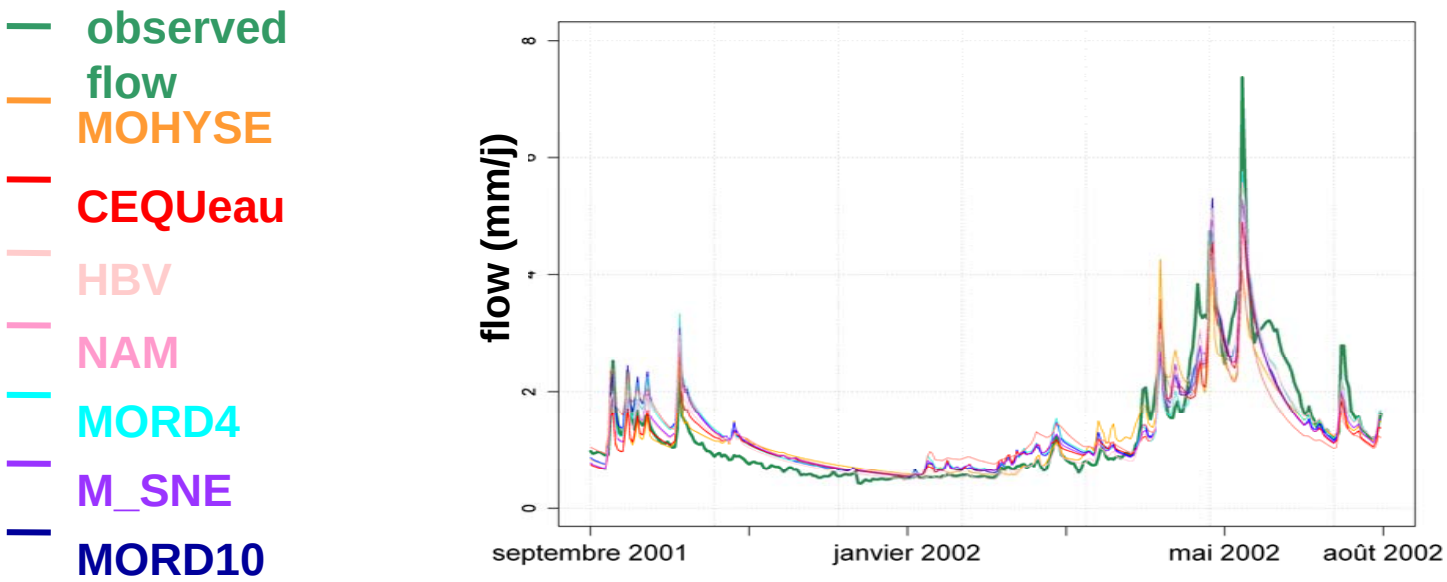
A rough typology of snow routines



About the existing snow routines

We do not know:

- the relative importance of all the modelled processes
  - we can observe them at the point scale, but what happens at catchment scale?
- the robustness of these routines for generic applications
  - in different environments
  - in combination with different hydrological models



Scientific questions

How to represent the impact of snow in a hydrological model ?

- which structure to choose in order to maximize the benefit in terms of streamflow simulation ?

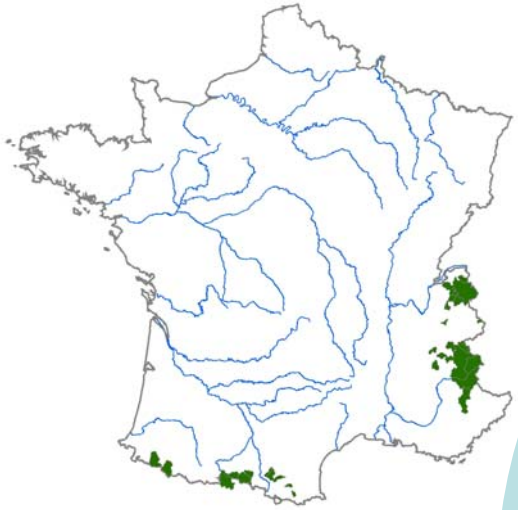
- which structure can work based only on the commonly available data ?

- which structure can be generic enough in order to adapt to different catchments and to different hydrological models ?

Hydrological part

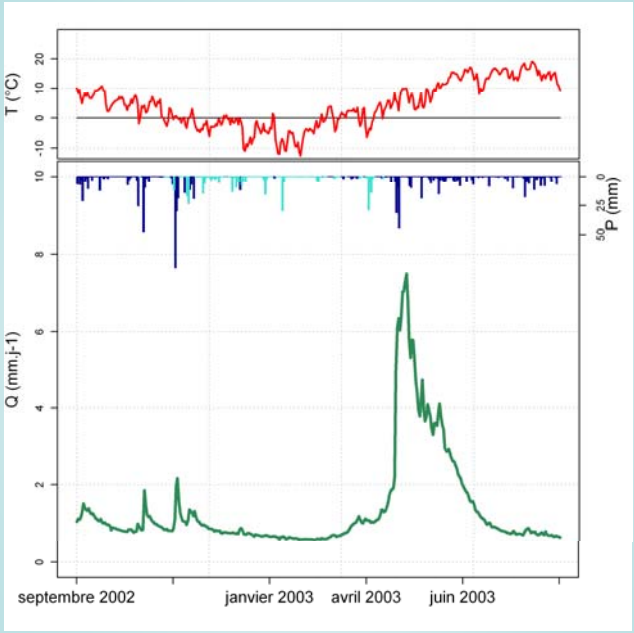
Case studies

Catchments with a marked nival regime : highlands



France

Switzerland

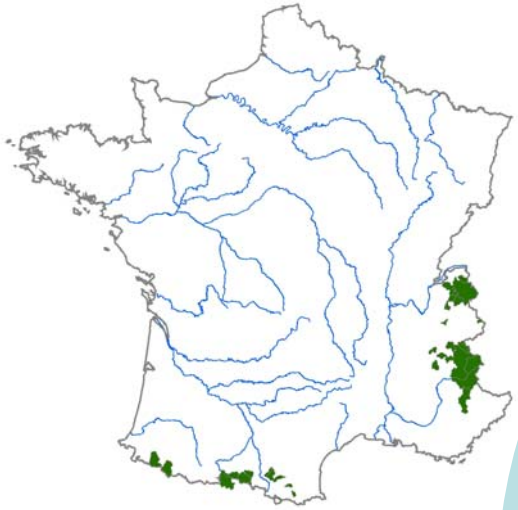


Le Guil à Montdauphin (France – 725 km²)

Sweden

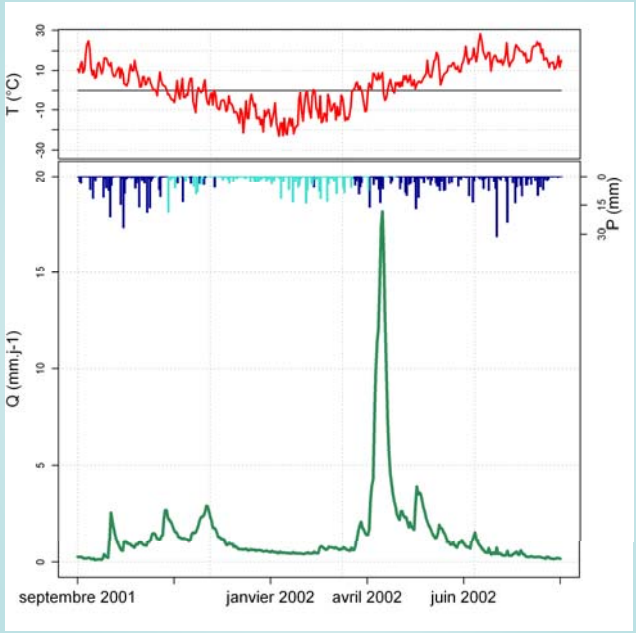
Case studies

Catchments with a marked nival regime : lowlands in ‘cold’ climates



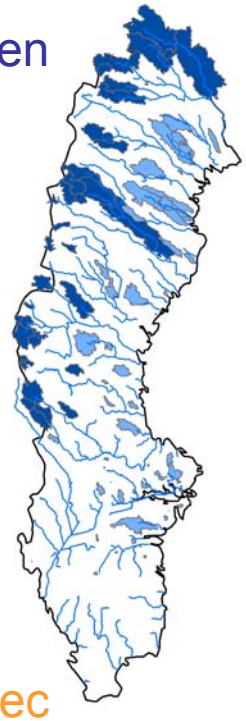
France

Switzerland

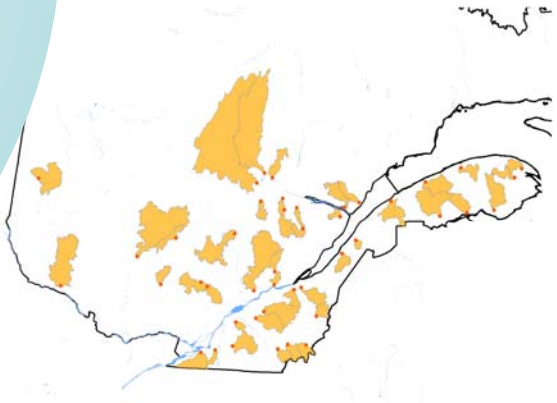


Maskinongé à St Didace (Québec – 825 km²)

Sweden

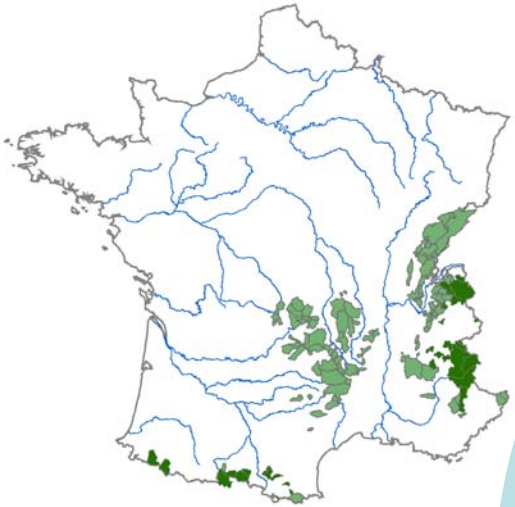


Québec

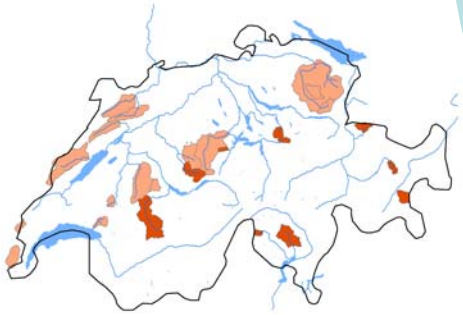


Case studies

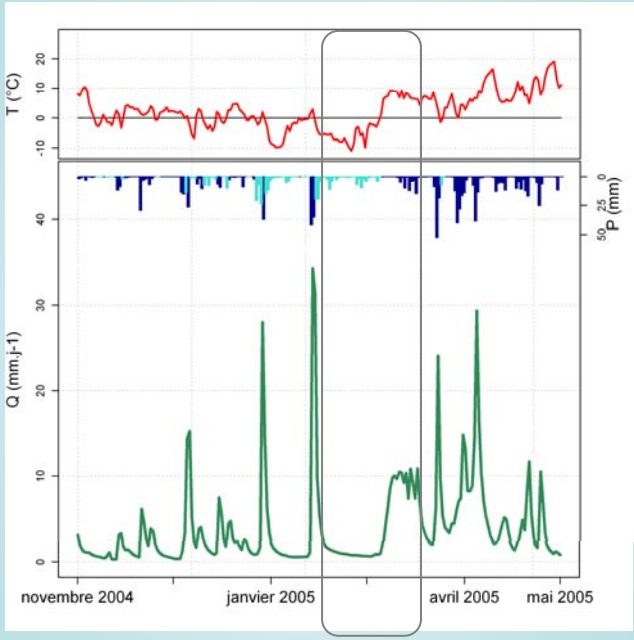
Catchments with occasional snow influence :
plains & lower mountains



France : 219 catchments

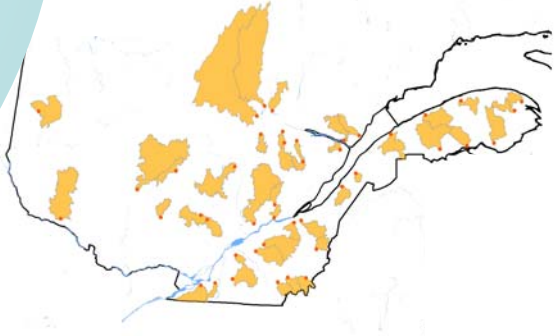


Suisse : 31 catchments



La Bienne à St Claude
(France – 416 km²)

Sweden : 94 catchments

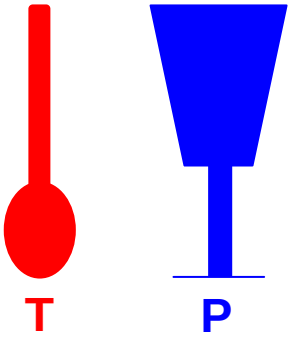


Québec : 36 catchments

Some work is needed before starting to model

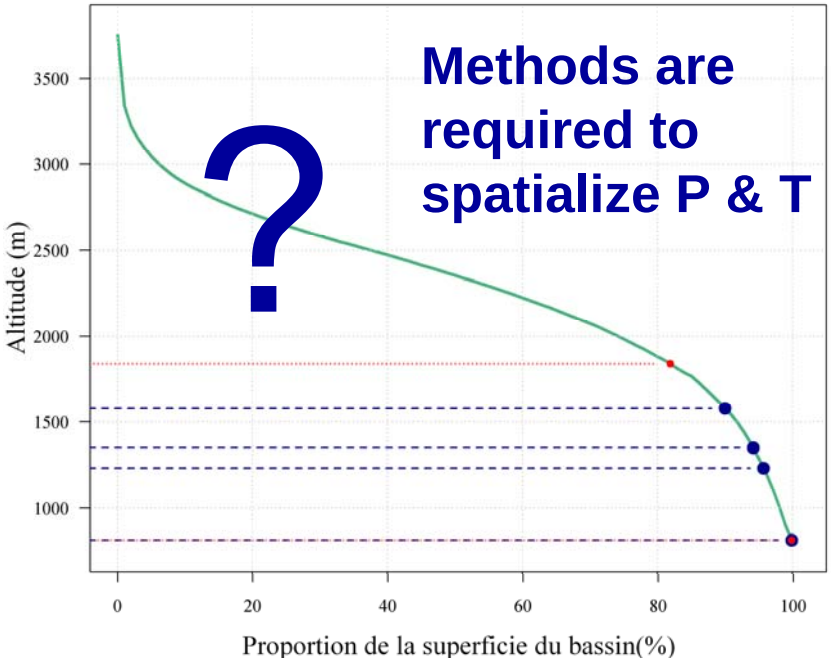
Our knowledge of inputs is often biased

This issue must be addressed first, because it can have an impact on the structure of the snow routine



temperature gage

precipitation gage



Representing melt – time dynamics

Phase change heat:

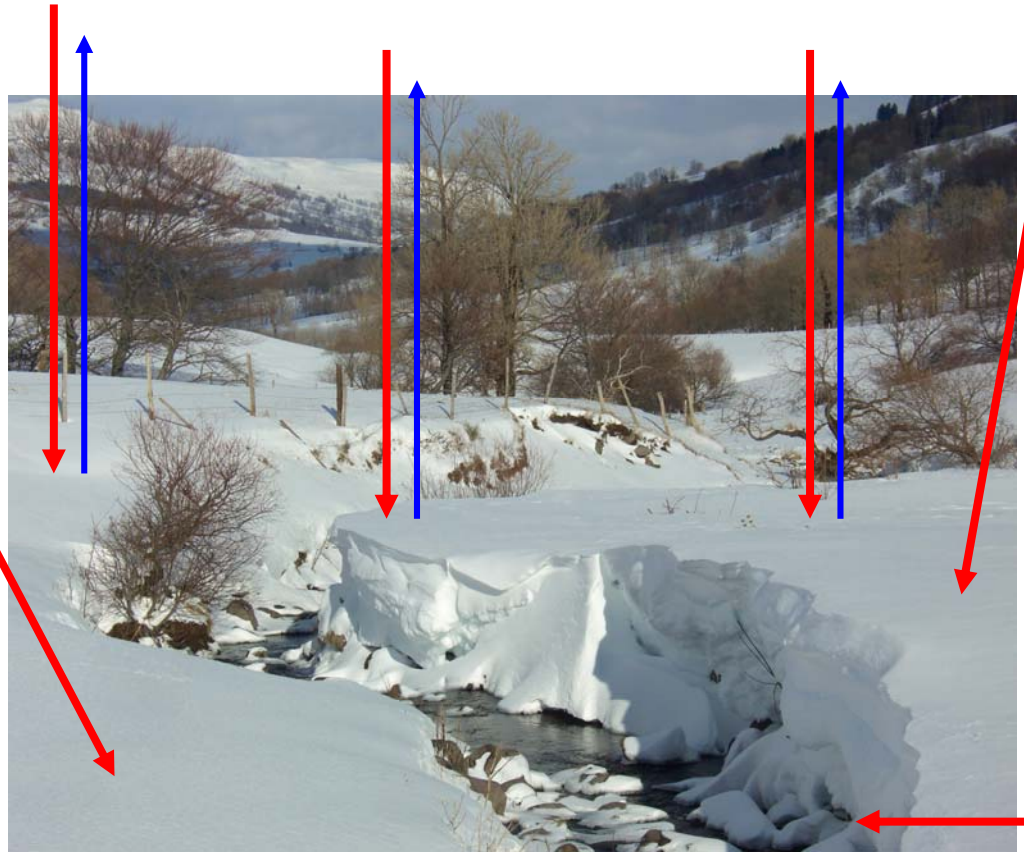
- ~~wind speed~~
- ~~vapor pressure~~
- ~~surface temp.~~

Shortlength radiation :

- ~~nebulosity~~
- ~~albedo~~
- extraterrestrial radiation

Largelength radiation :

- ~~nebulosity~~
- surface temp.
- ~~emissivity~~



Heat exchanges at the rain / snow interface:

- ~~rain temp.~~
- rain amount
- ~~snow temp~~

Sensible heat (air / snow interface):

- ~~wind speed~~
- air temp.
- ~~surface temp.~~

Heat exchanges at the soil / snow interface:

- ~~soil moist.~~
- ~~soil temp.~~

Melt – time dynamics

Empirical formulation based on the most-commonly available variable :

$$MELT(t) = \theta_{G1} \times (T(t) - T_{melt})$$

parameters to identify :

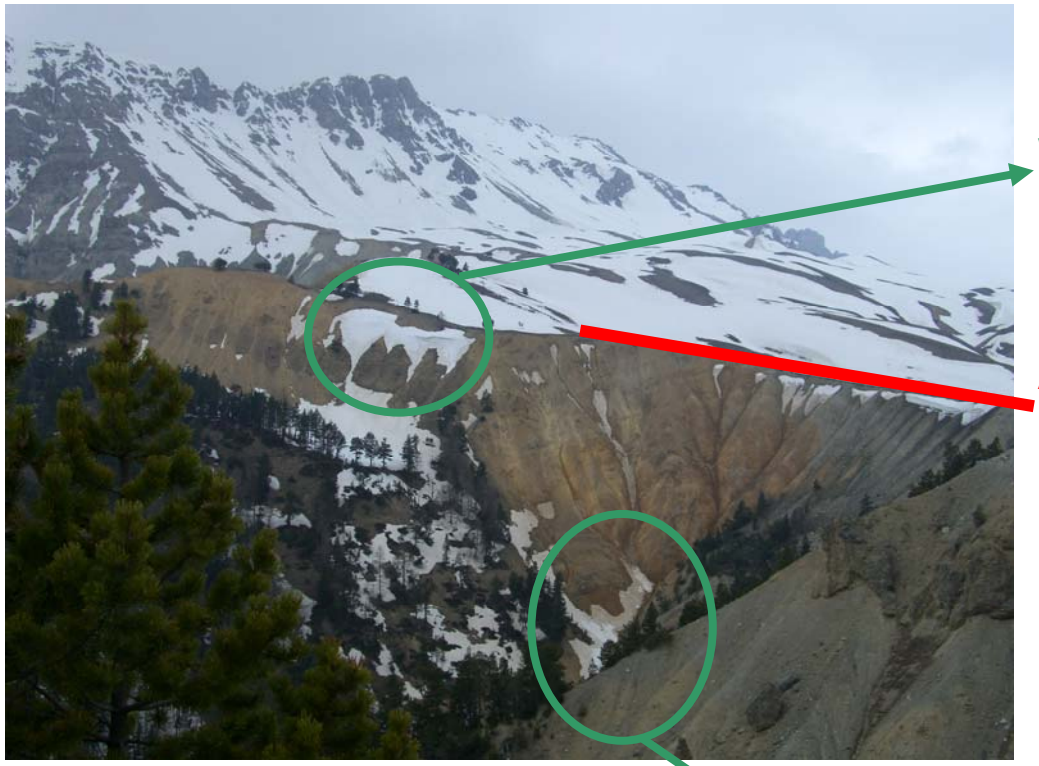
θ_{G1} (mm/°C) → melt factor

T_{melt} (°C) → temp. threshold for melt

air temp. → index integrating the energy exchanges which are responsible for melt

Melt – spatial dynamics

Combes des Thures,
commune de Névache
(Haute-Alpes – mai 2008)



Rivière la Clarée,
Pont de la Souchère
(Haute-Alpes – mai 2008)

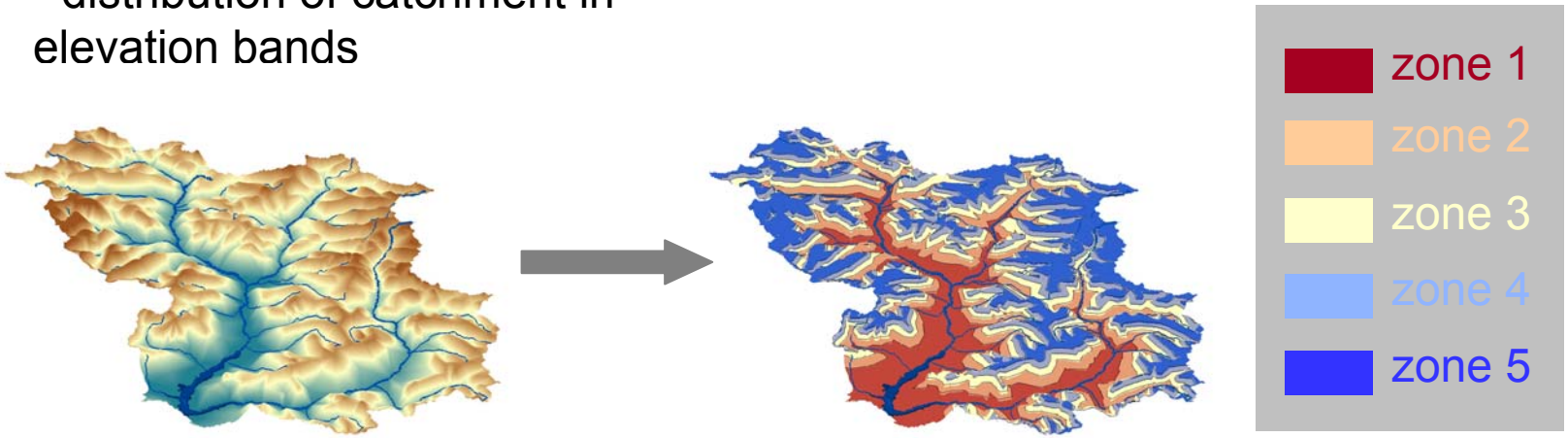
north facing slope + shading by trees

south facing slope + no trees

Melt – spatial dynamics

Universally accessible information :

- distribution of catchment in elevation bands



Some of the options we tested

distribution of the catchment in elevation bands

making use of daily temperature extremes

spatial evolution of snow cover

different methods for distinguishing between rain / snow

snow cover ripening:

- **addition of a thermal state**
- **retention of liquid water**
- **refreezing capacity**

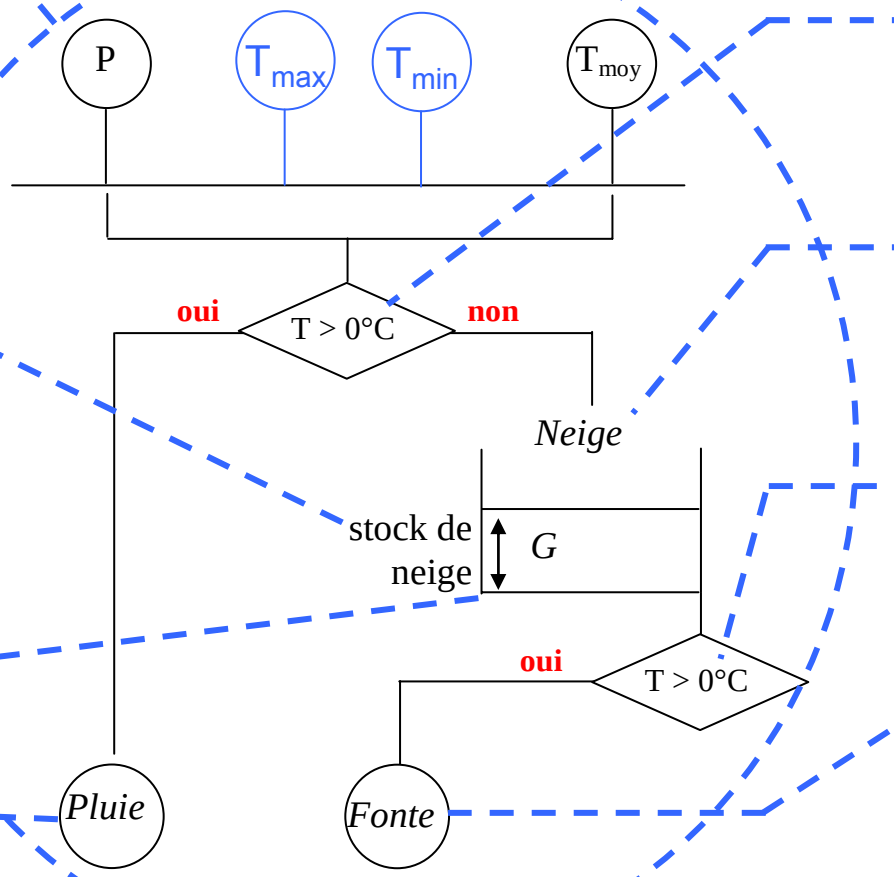
correction of estimated snow quantities

modification of melt temperature

melt at the base of snow cover

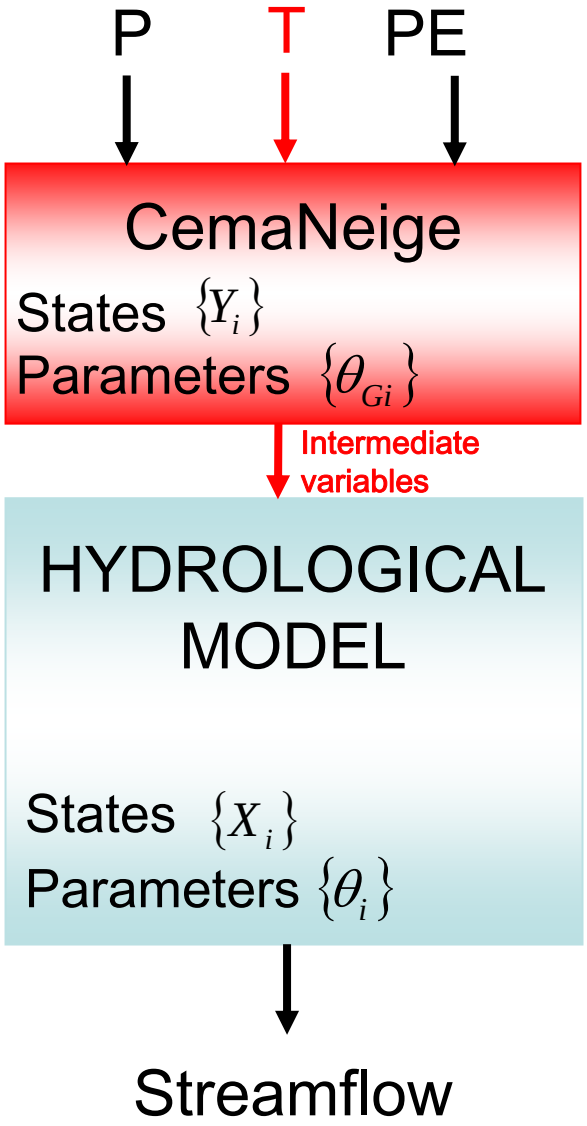
seasonality of melt speed

rain on snow events

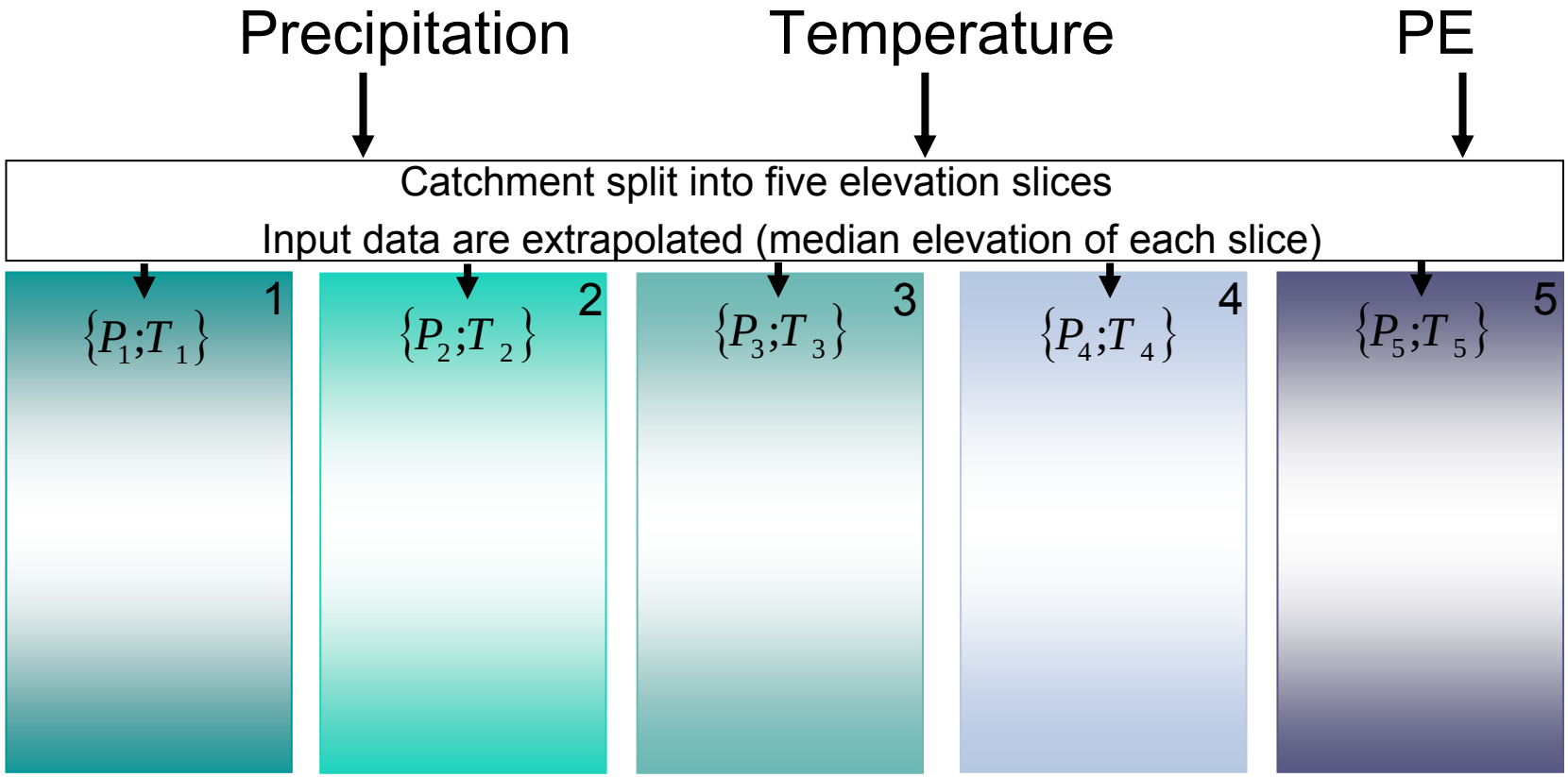


Results

Description of CemaNeige

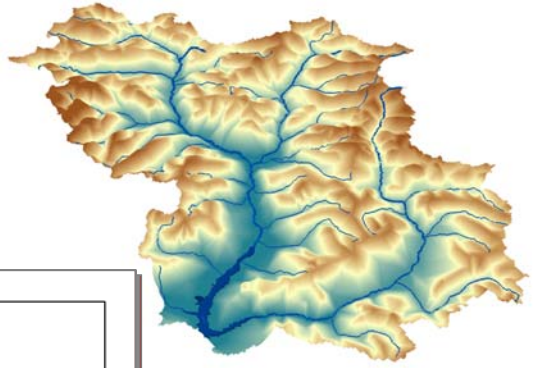


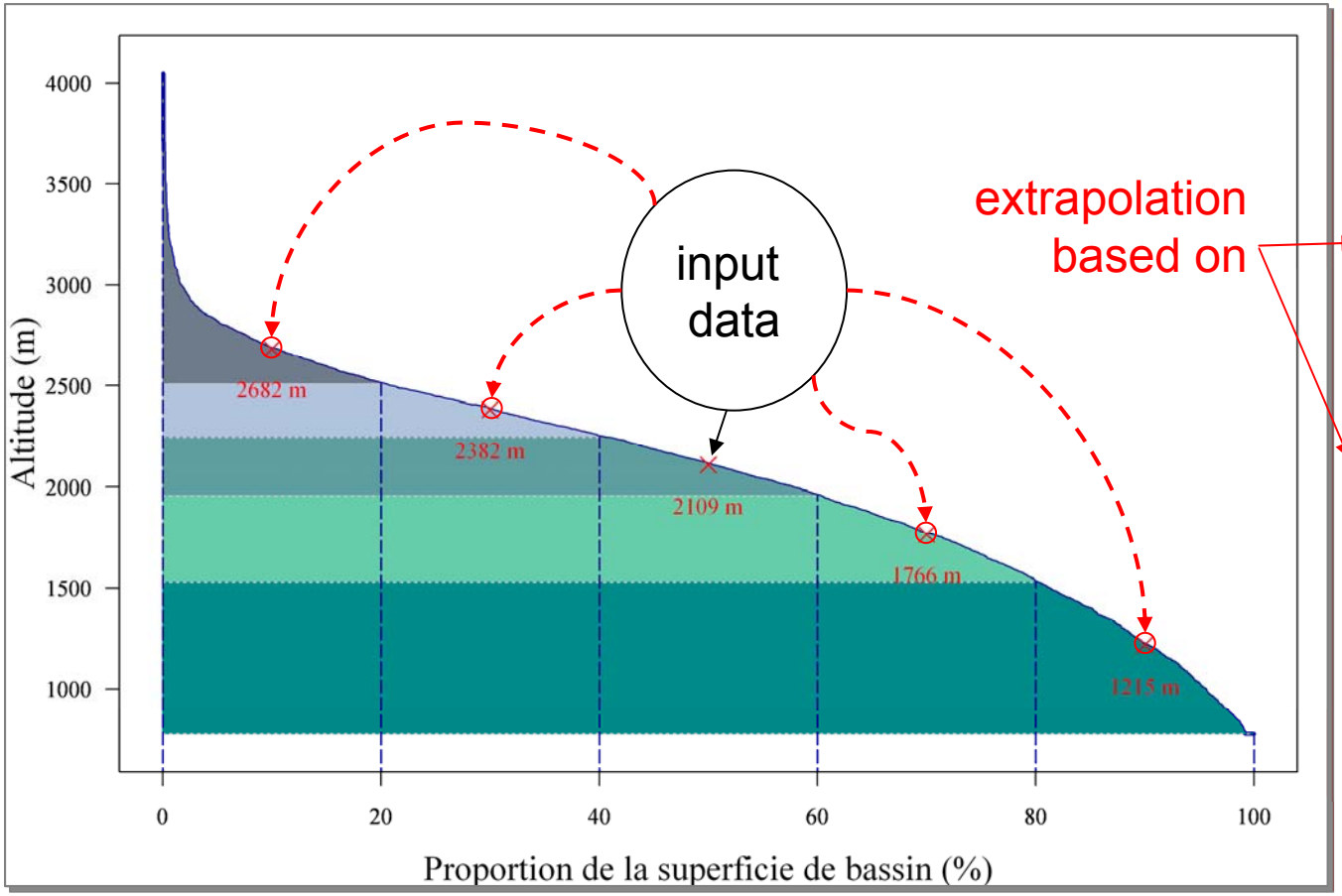
CemaNeige


Precipitation
Temperature
PE
Catchment split into five elevation slices
Input data are extrapolated (median elevation of each slice)
1
$\{P_1;T_1\}$
2
$\{P_2;T_2\}$
3
$\{P_3;T_3\}$
4
$\{P_4;T_4\}$
5
$\{P_5;T_5\}$

CemaNeige

Extrapolation of input data for the median elevation of each zone



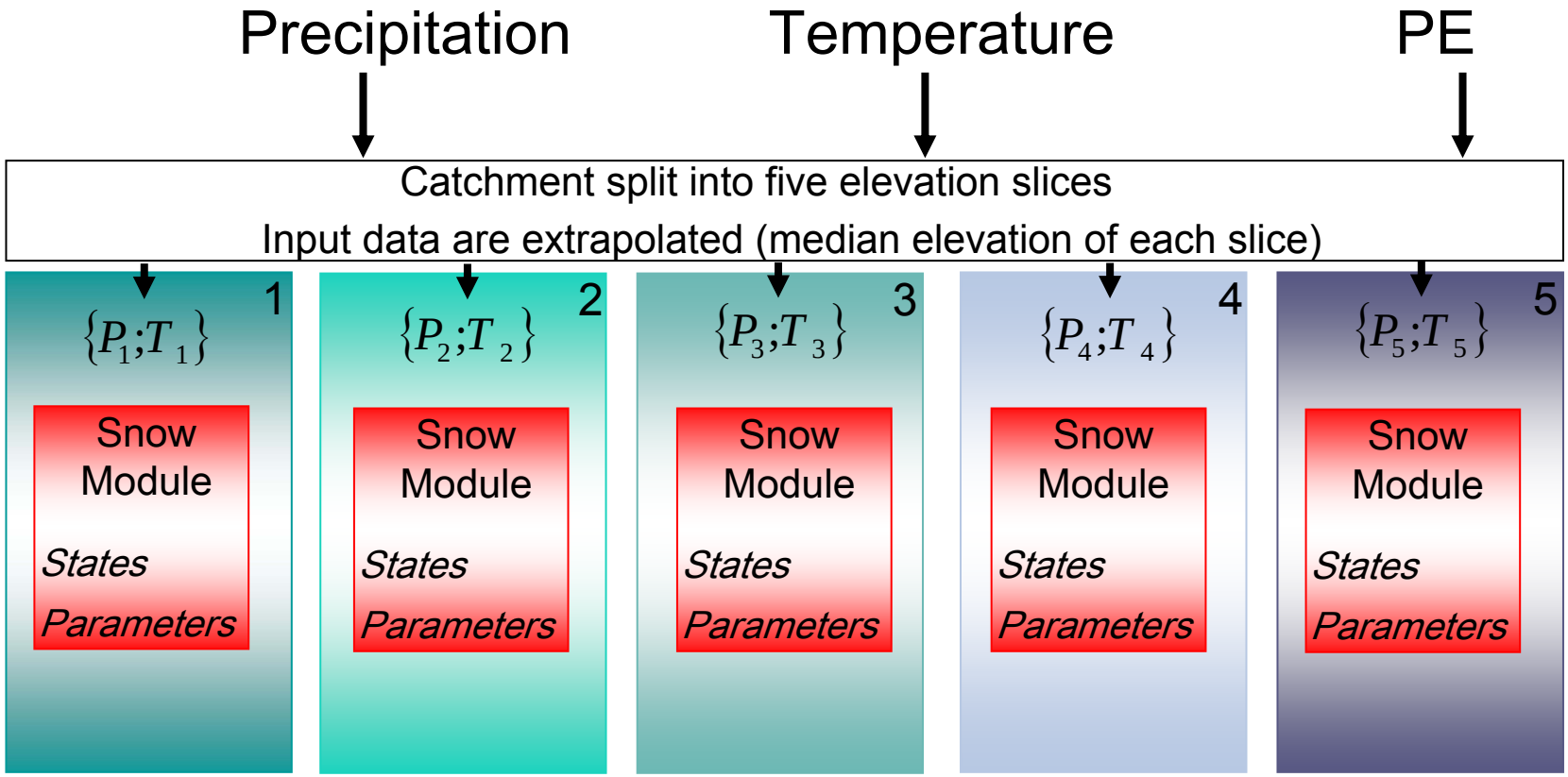


seasonnal temperature gradients

constant precipitation gradient

Durance à Serre-Ponçon (France)
surface : 3580 km²

CemaNeige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Catchment split into five elevation slices
Input data are extrapolated (median elevation of each slice)
1
$\{P_1;T_1\}$
Snow Module
States
Parameters
2
$\{P_2;T_2\}$
Snow Module
States
Parameters
3
$\{P_3;T_3\}$
Snow Module
States
Parameters
4
$\{P_4;T_4\}$
Snow Module
States
Parameters
5
$\{P_5;T_5\}$
Snow Module
States
Parameters

CemaNeige

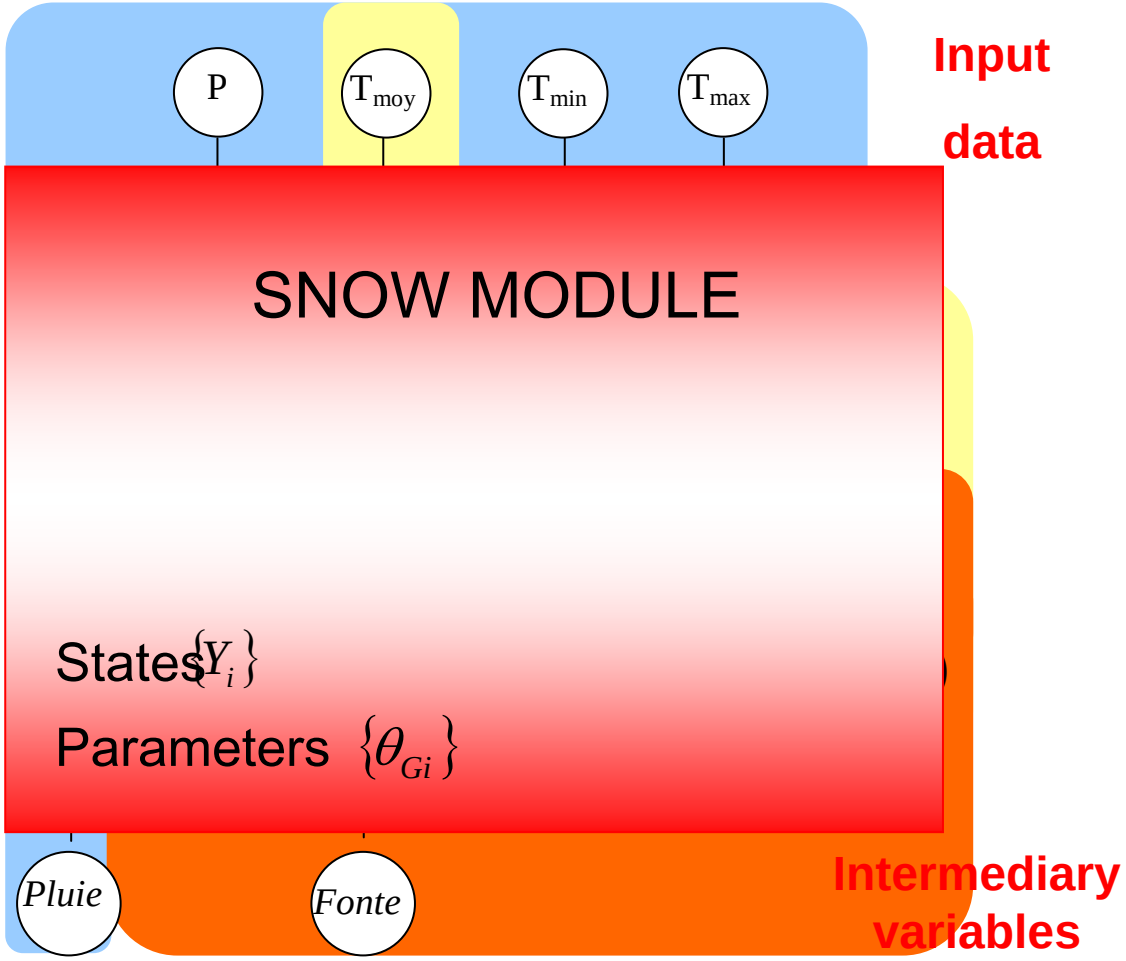
Computation of the solid fraction of precipitations

Evolution of the snow stock, *G*

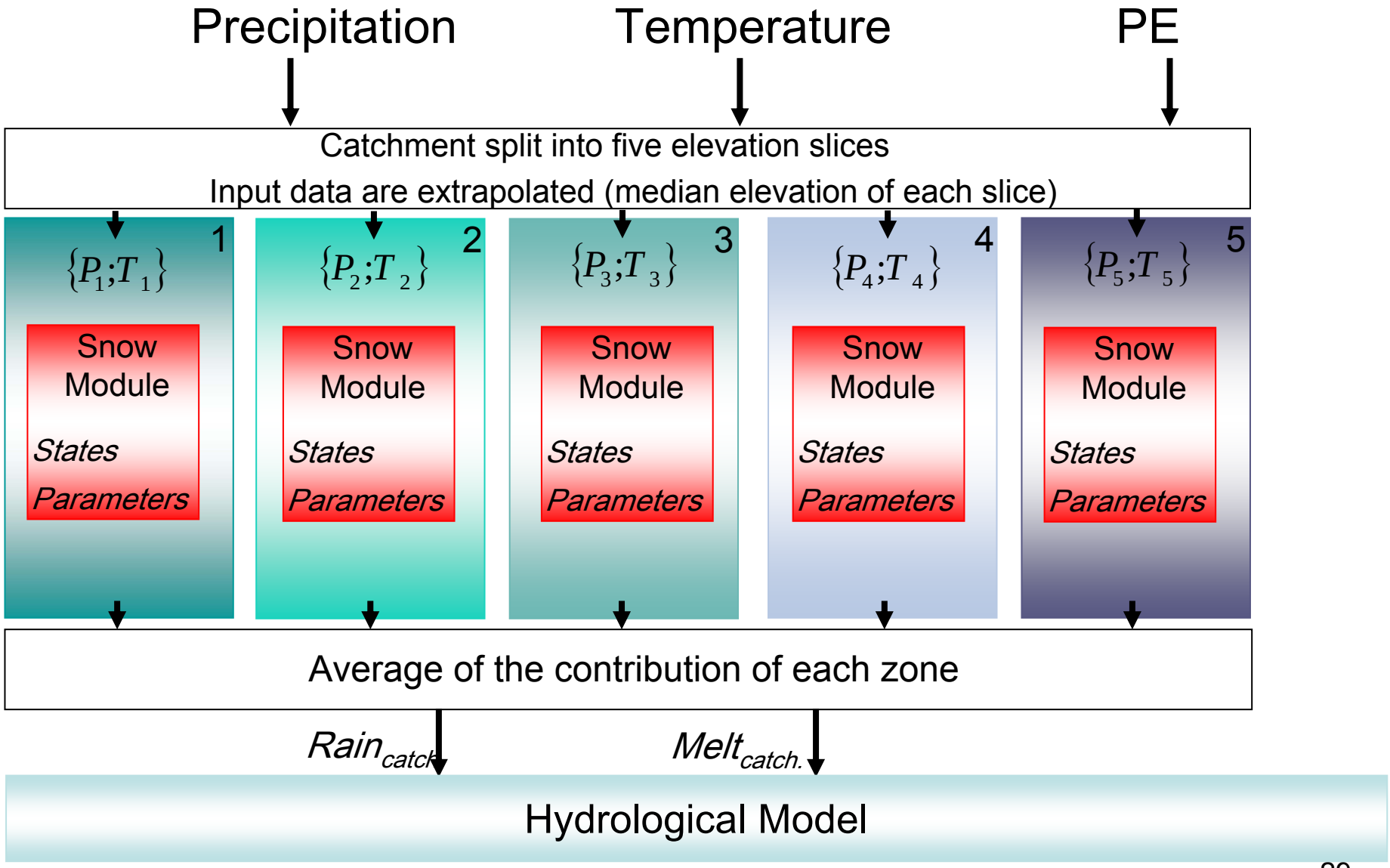
Evolution of the thermal index of the stock, eT_G

Computation of daily *melt*

- Only if eT_G=0 °C
- Degree-day approach with a free parameter, θ_{G1}
- *melt* can be reduced based on the remaining snow amount (based on a fixed parameter)



CemaNeige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Catchment split into five elevation slices
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Snow Module
States
Parameters
4
$\{P_4;T_4\}$
Snow Module
States
Parameters
5
$\{P_5;T_5\}$
Snow Module
States
Parameters
Average of the contribution of each zone
$Rain_{catch.}$
$Melt_{catch.}$
Hydrological Model

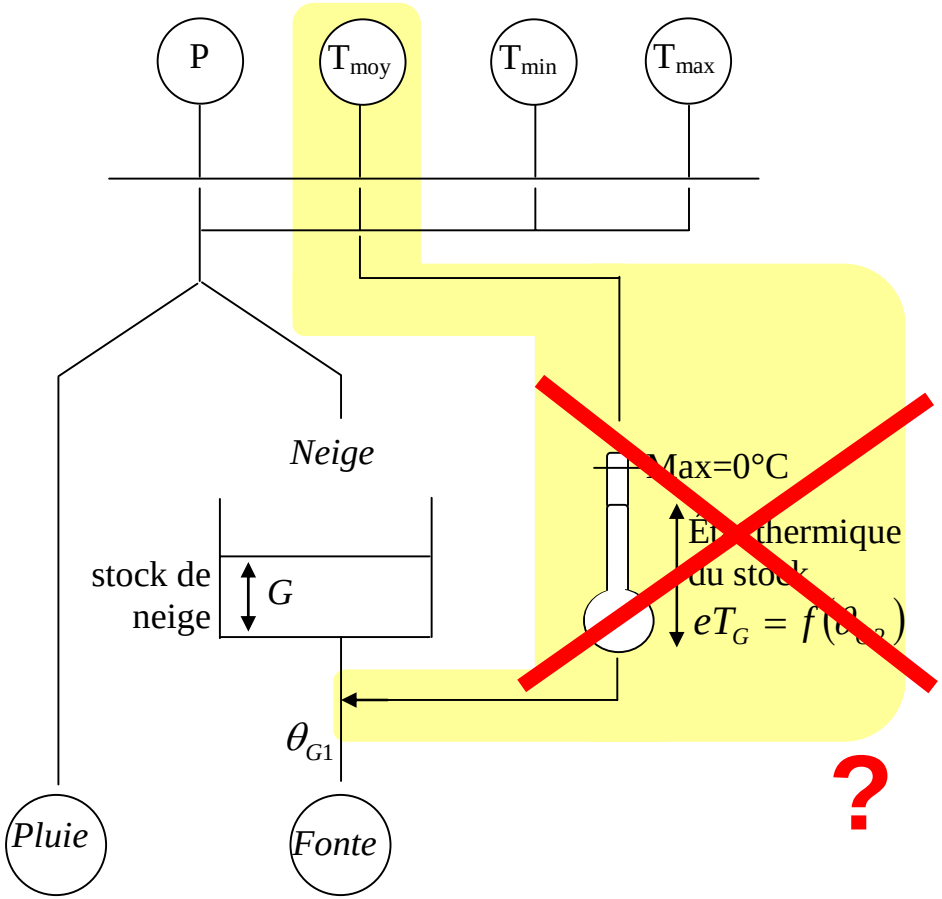
Sensitivity analysis

We finished with an exhaustive sensitivity analysis in order to assess the relative importance of each component:

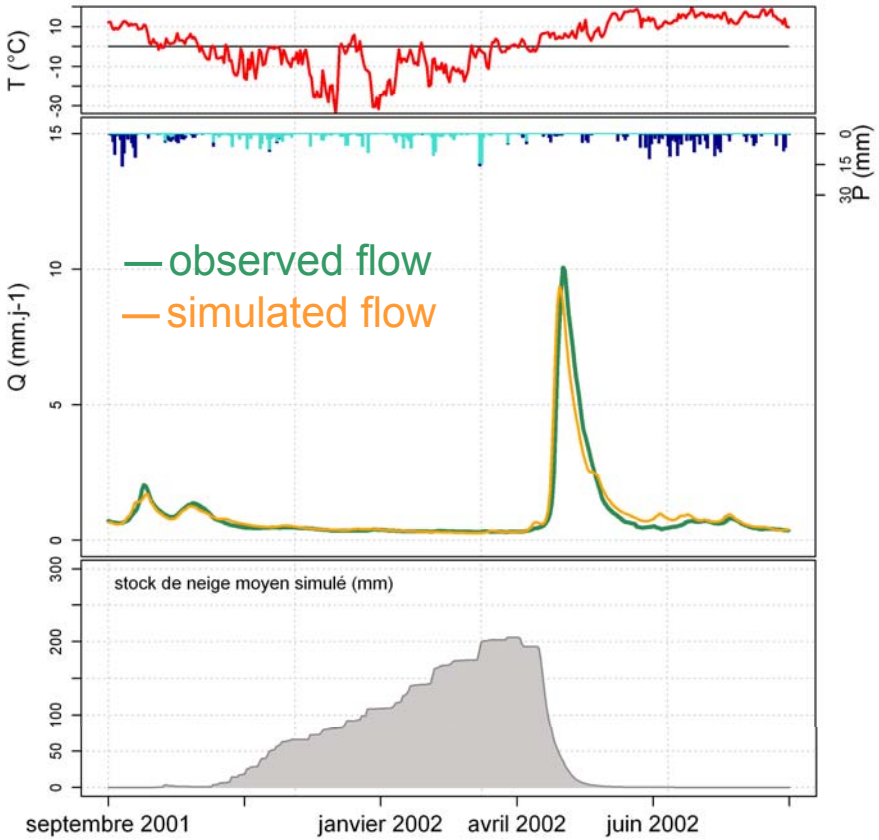
- complexity of the rain / snow separation,
- <u>ripening of snow cover,</u>
- distribution in elevation ‘slices’,
- etc.

Sensitivity analysis

Component managing the ripening of the snow cover



Melt only allowed when the snow cover is ripe

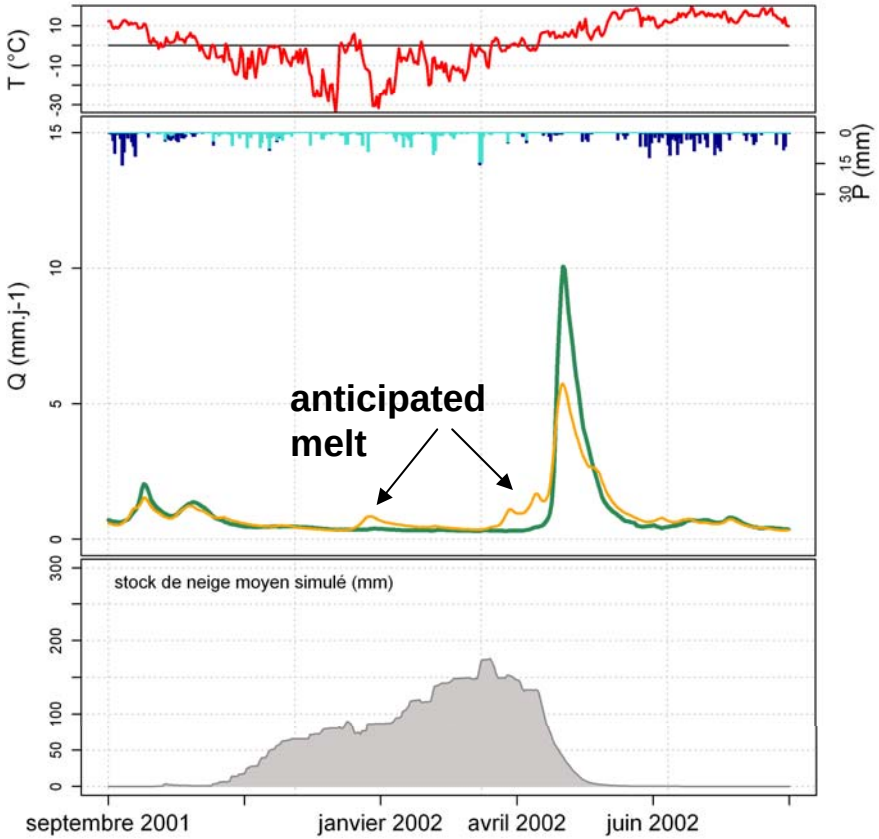


Raneälven à Niemisel
(Suède – 3780 km²)

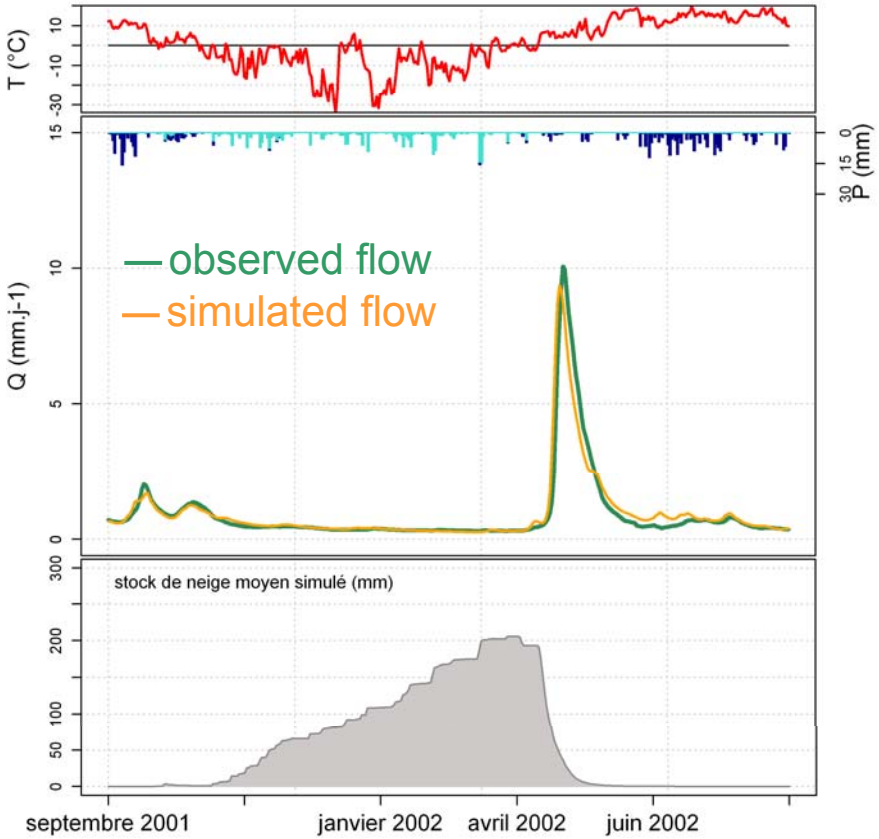
Sensitivity analysis

Component managing the ripening of the snow cover

Melt possible as soon as T_{air} > 0°C



Melt only allowed when the snow cover is ripe



Raneälven à Niemisel
(Suède – 3780 km²)

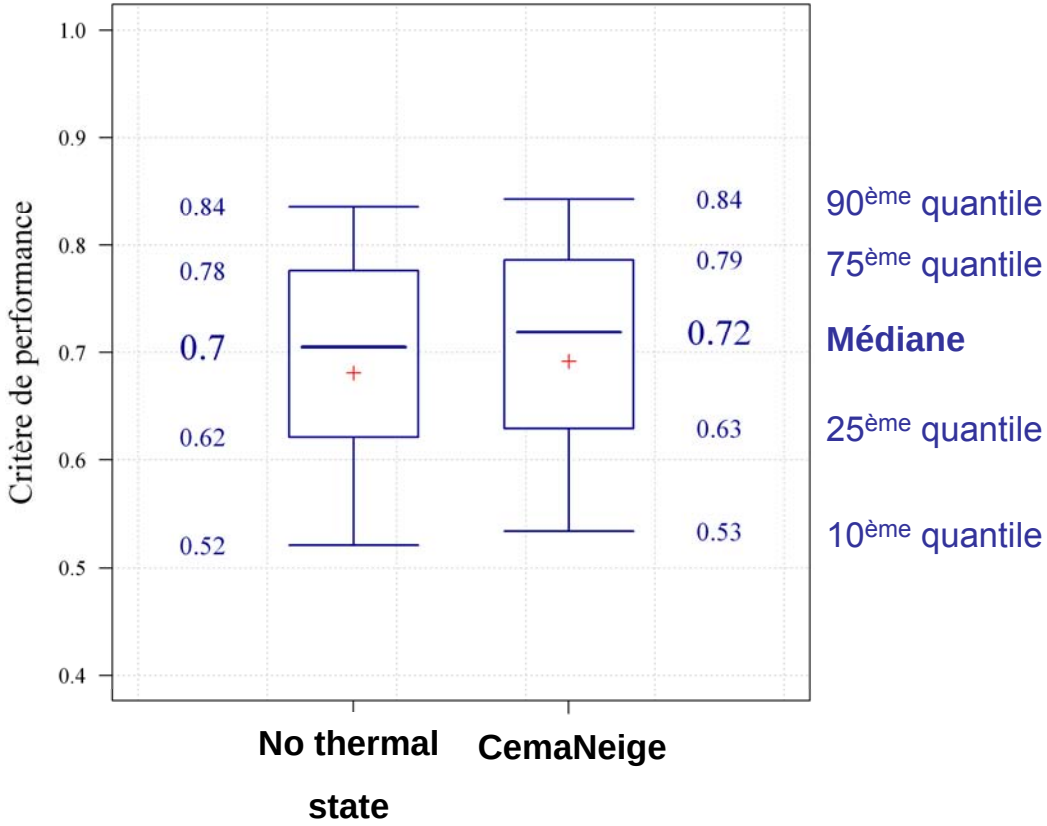
Analyse de sensibilité

Component computing the thermal index of the snow cover

→ the thermal index allows to manage the ripening of the snow pack

Hydrological model: GR4J

Dataset: 380 catchments

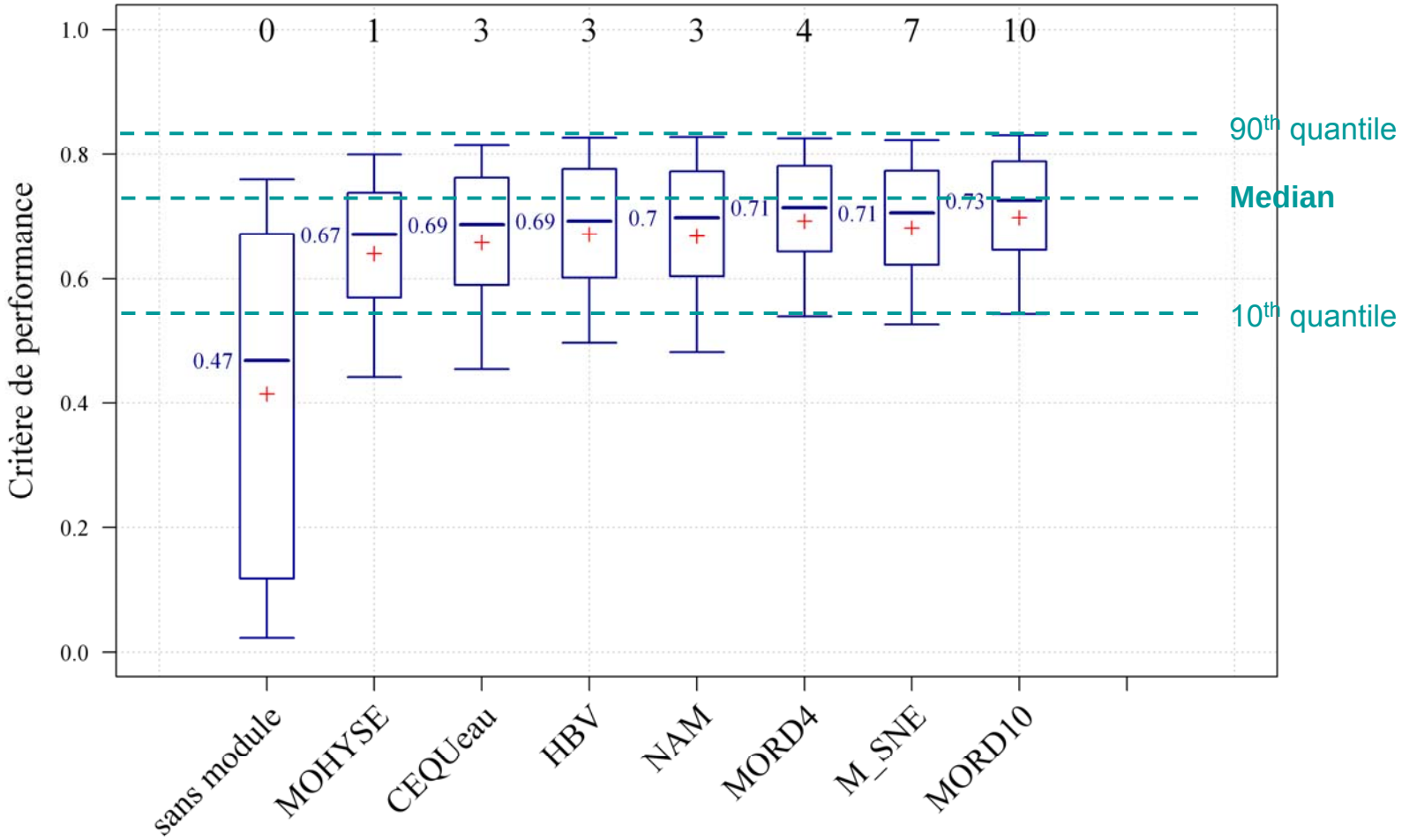


1 additional free parameter

Comparative results

Hydrological model: GR4J

Dataset : 380 catchments



Comparative results

Hydrological model: GR4J

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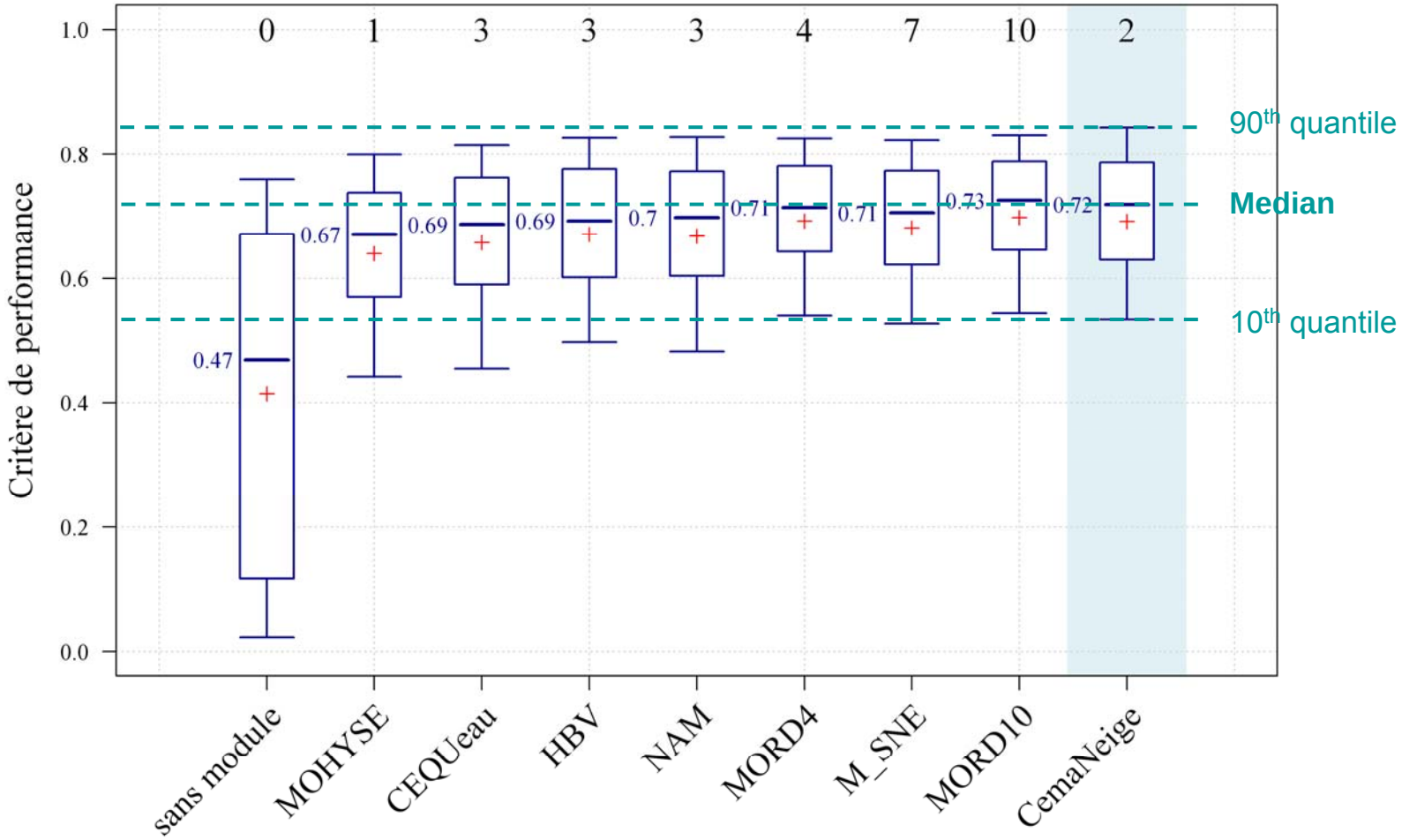
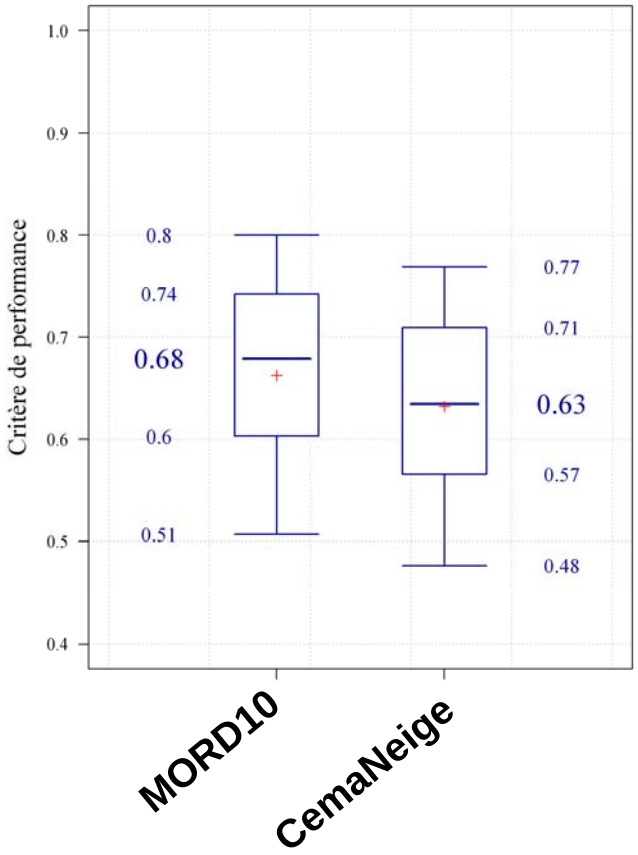


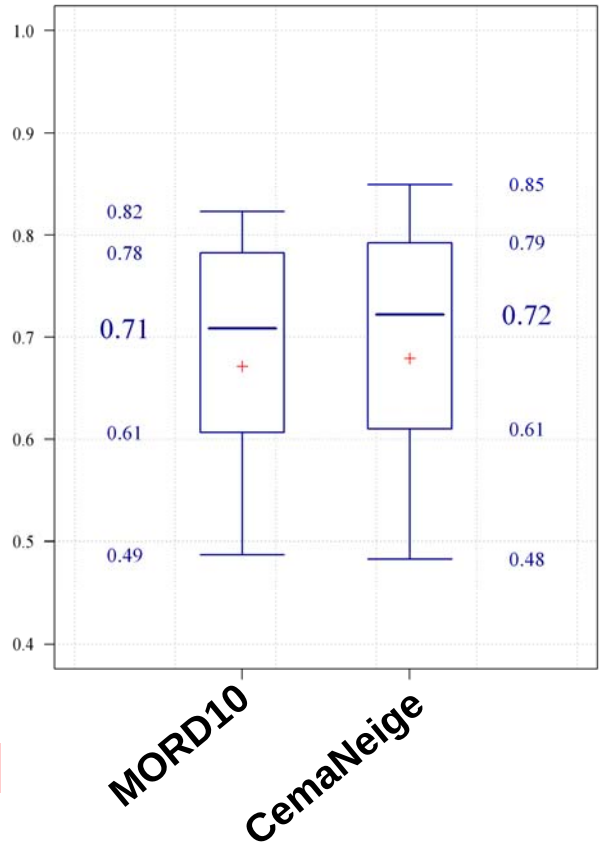
Comparative results

Hydrological model : GR4J

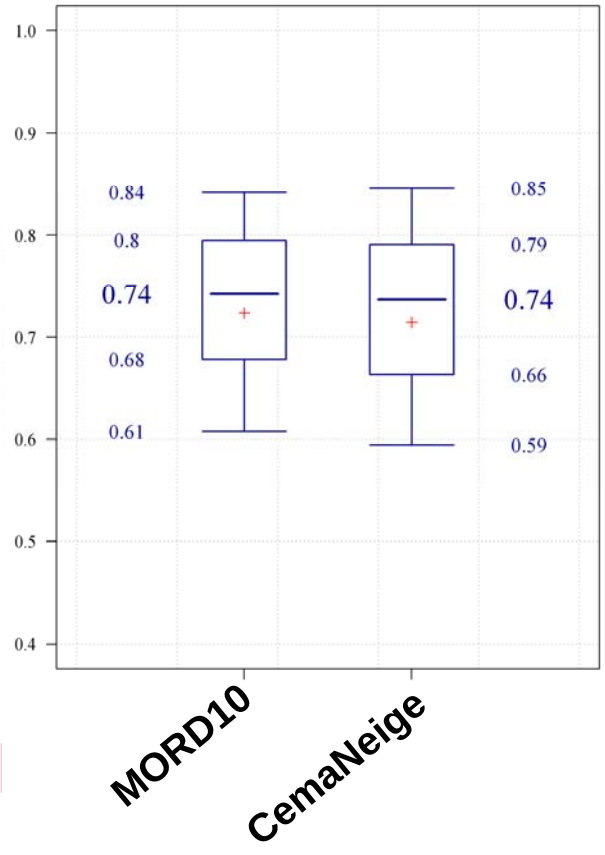
STRONG RELIEFS
50 catchments



COLD CLIMATE
130 catchments



LIMITED INFLUENCE
200 catchments



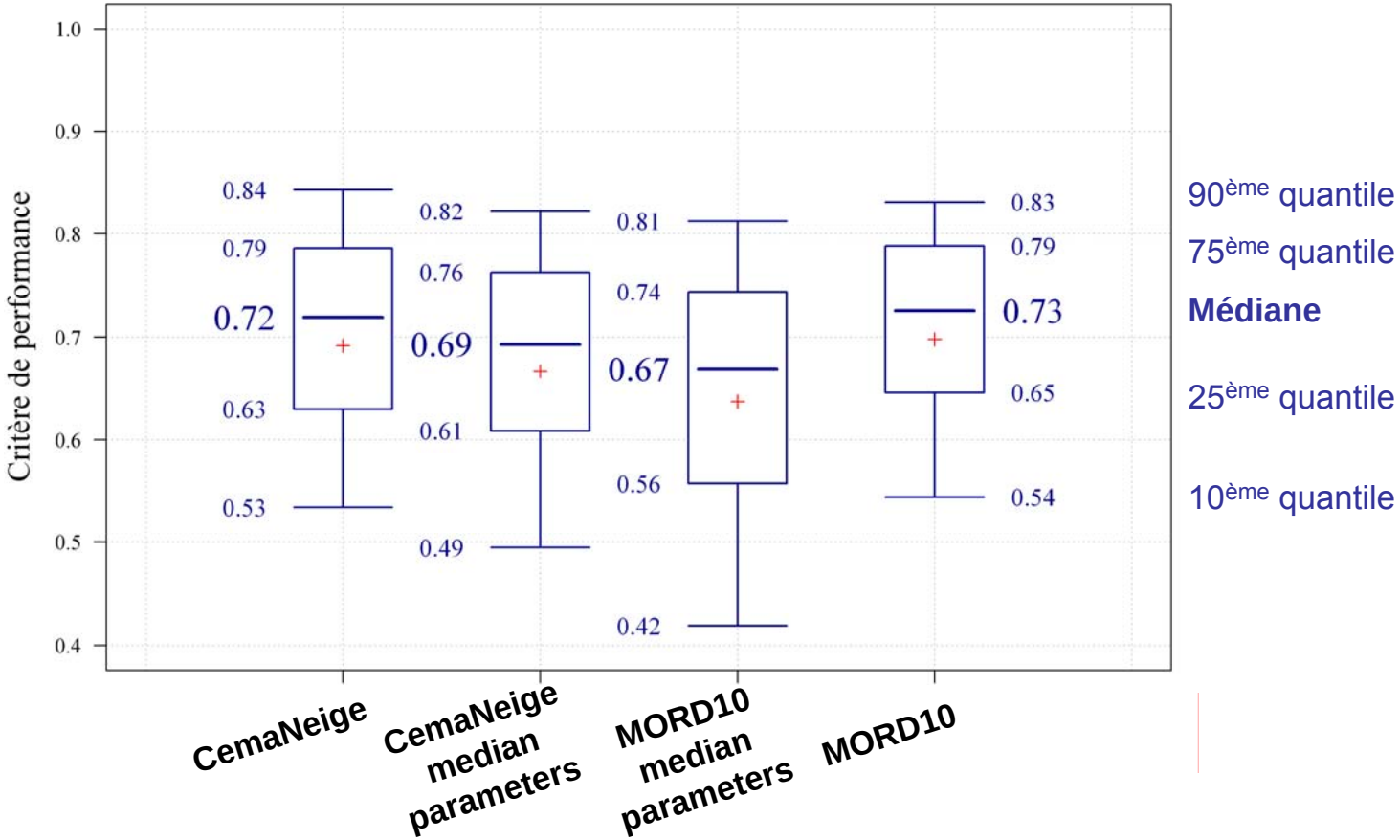
Results using CemaNeige

- Ungaged catchments:

  → The module also gives acceptable results with fixed parameters

Hydrological model: GR4J

Dataset : 380 catchments

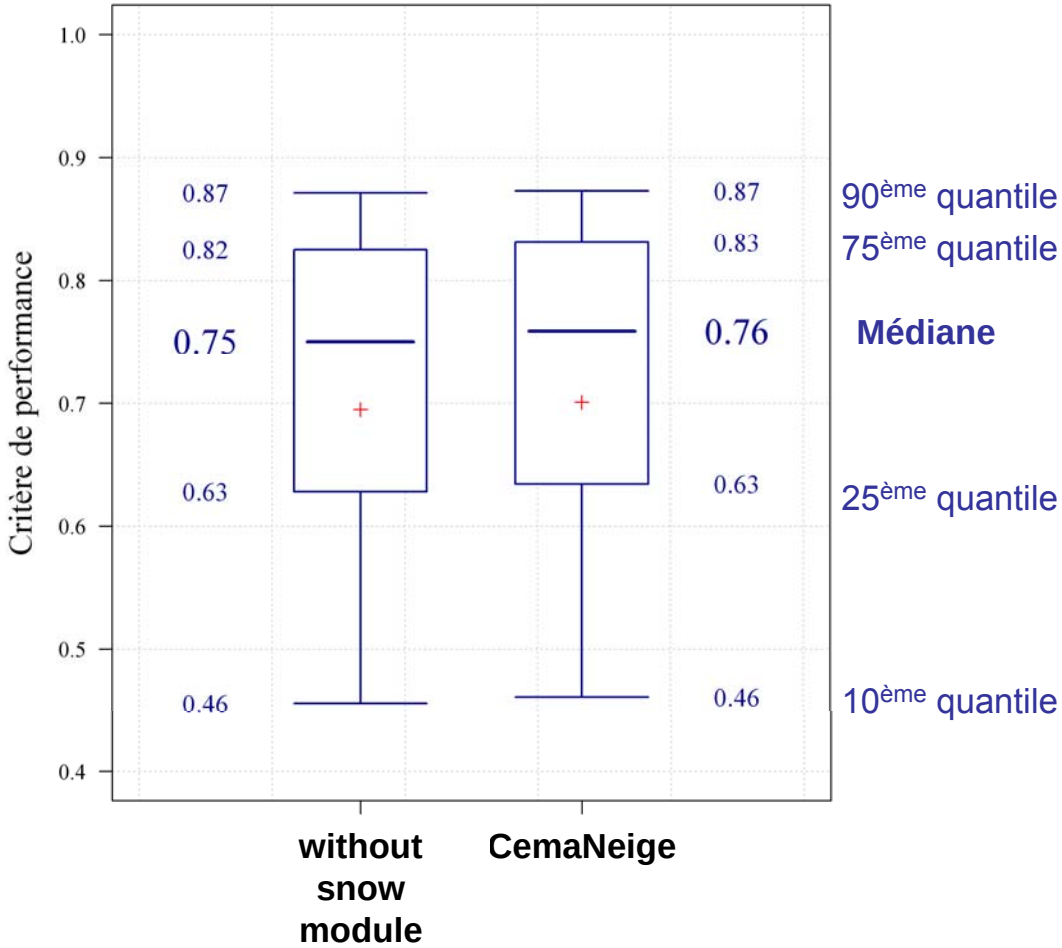


Results using CemaNeige

- The snow module does not disturb the calibration on catchments where snow is rare

Hydrological model: GR4J

Dataset: 873 French catchments with very little snow



Summary

- How much complexity is warranted in a snowmelt-snow accumulation routine?

- Our answer is: two free parameters are enough for a generic module

- The generic structure we identified is:
  - Statistically equivalent or better than the alternative modules
  - Transposable to a variety of catchments
  - Adaptable to different hydrological models
  - Parsimonious: only two free parameters

Is this the best possible snow module?

- NO

- This is only what we consider to be the best ‘one-size-fits-all’ module
- For many catchment, one can identify a better tailored solution
- As hydrologists, we would recommend starting from the identified module, and not rebuilding each time a model from scrap

Thank you for your attention
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