RECENT AND FUTURE CHANGES IN WATER RESOURCES IN THE ALPS

RESULTS OF A SPATIALLY DISTRIBUTED HYDROLOGICAL MODEL ON THE ISERE CATCHMENT

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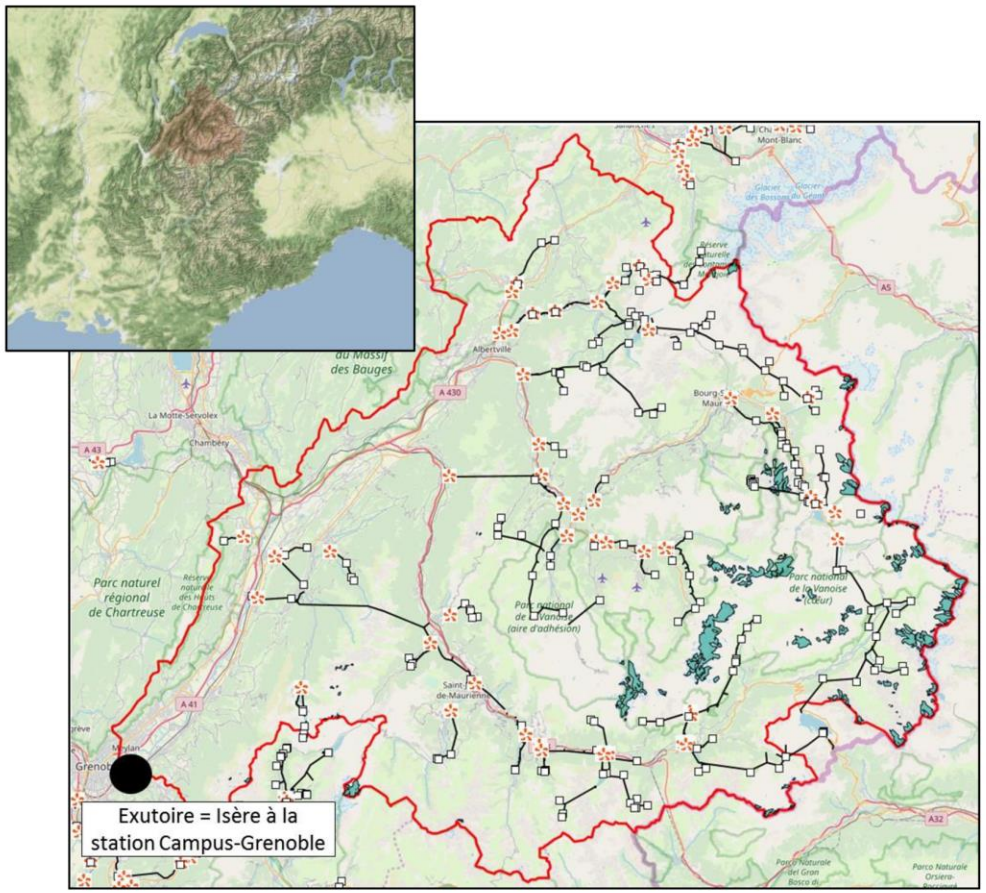
Water resources issues in the Alps

- The Alps, recognised as the *Water towers of Europe*, play a crucial role in acccumulating and supplying water to the continent.
- They provide the indispensable water resources for industrial water supply, irrigation, hydropower, tourism,...
- However, the Alpine climate has changed significantly during the recent decades, with a rapid increase in temperature.
- Impacts on the alpine hydrosystems are already widely visible, with a significant decrease in snow and glacier cover, and changes in the runoff regimes.
- Projected climate changes, both in precipitation and temperature, will deeply alter runoff regimes and water resources in the Alps.

Isere@Grenoble catchment

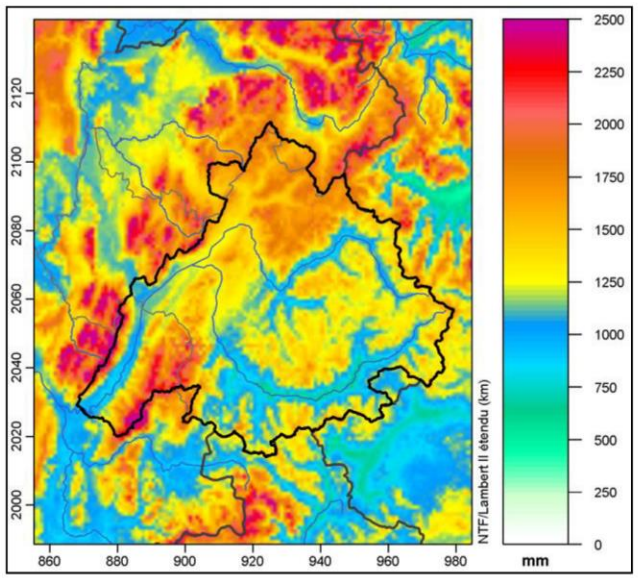
- A large (5700 km²) and representative catchment of alpine hydrology
- Caracterised by complex natural snow and glacier processes
  - Altitudes ranging from 200 to 3800m
  - More than 200 glaciers (~2% of the basin area)
- Affected by major anthropogenic influences, mainly hydro-power :
  - 14 Dams (Tignes, Mont-Cenis, Bissorte, Roselend,…)
  - 800 Mm3 storage
  - Strong seasonal influences (storage in spring, destocking in winter)



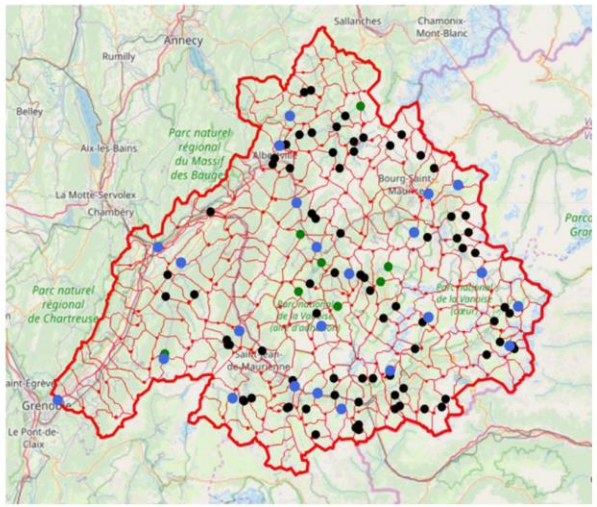
Hydro-climatic data

- **Precipitations & Températures** : SPAZM reanalysis (1948-2017) *[Gottardi et al. 2012]*
- **Streamflow :** 23 series (7 natural discharge, 17 de-influenced discharge)
- **Snow Cover:** MODIS Fractional Snow Cover Product (MOD10A1) *[Hall et al. 2006]*
- **Glaciers :** glacier inventory *[Gardent et al. 2014] and glacier-wide mass balance [Rabatel et al. 2016]*

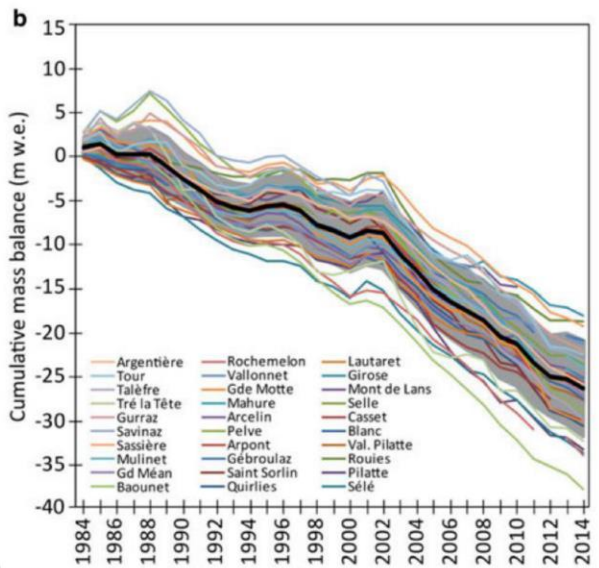
Precipitations [1948-2017 module]



Streamflow data location (in blue)



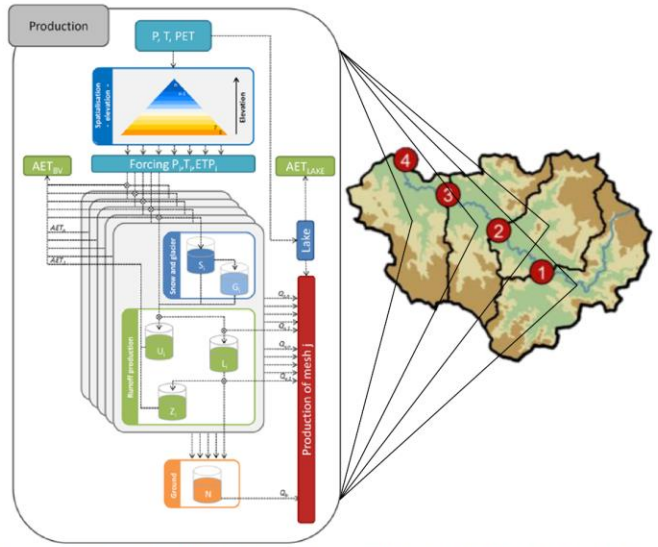
Glacier-wide mass-balance for 30 glaciers in the French Alps (Rabatel et al. 2016)



Hydrological modelling

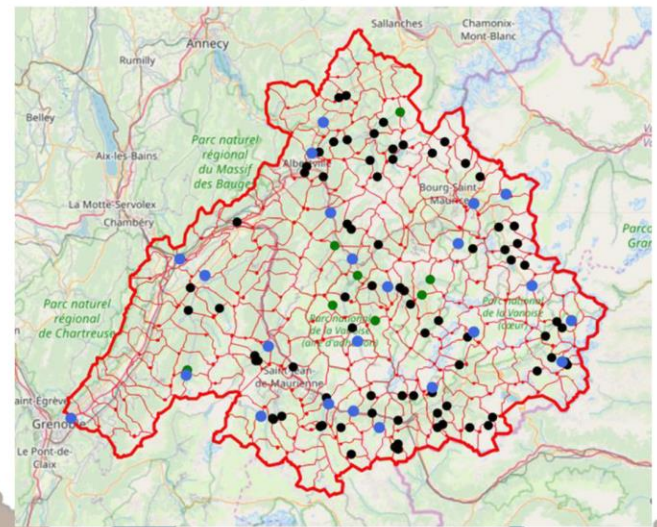
The MORDOR-TS model

- The MORDOR modelling system widely used at EDF [Garavaglia et al. 2017] for operational applications, in its spatially distributed version [Rouhier et al. 2017,2018]
- A spatial discretization based on a hydrological meshes and orographic zones
- Daily simulations, including snow and glacier components

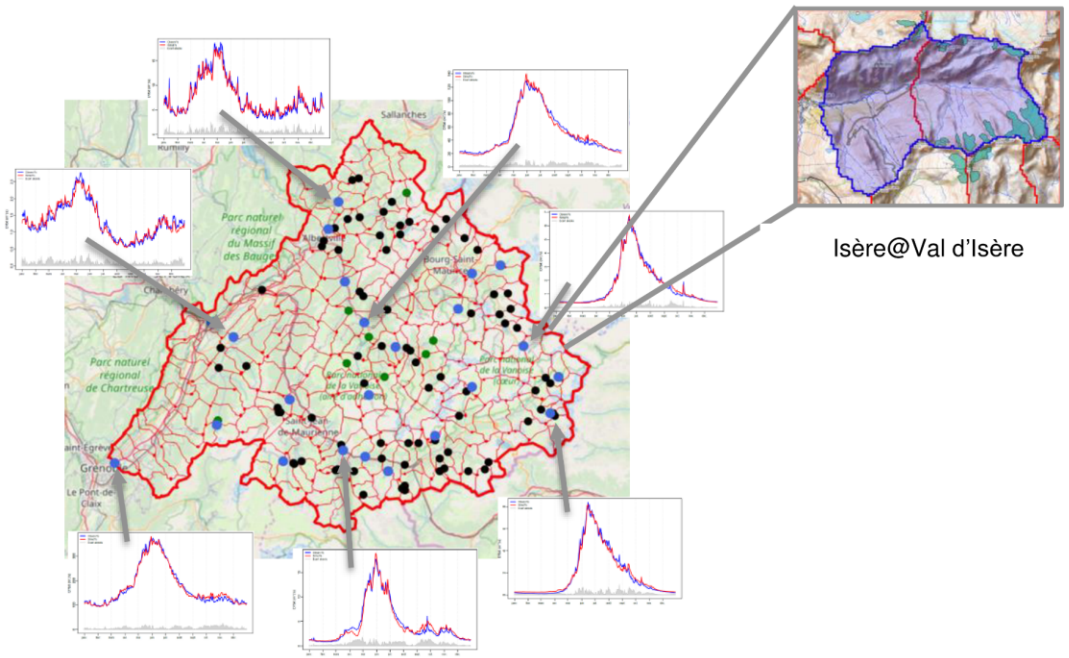


The Isere@Grenoble model

- 245 meshes (~30 km², 4 orographic zones)
- A multi-objective and spatialized calibration scheme *[Rouhier et al. 2018]* that values:
  - All available hydrometric data on the 1986-2017 period
  - Snow Cover data
  - Glacier mass-balance
- Spatially distributed hydrological simulations of natural hydrology

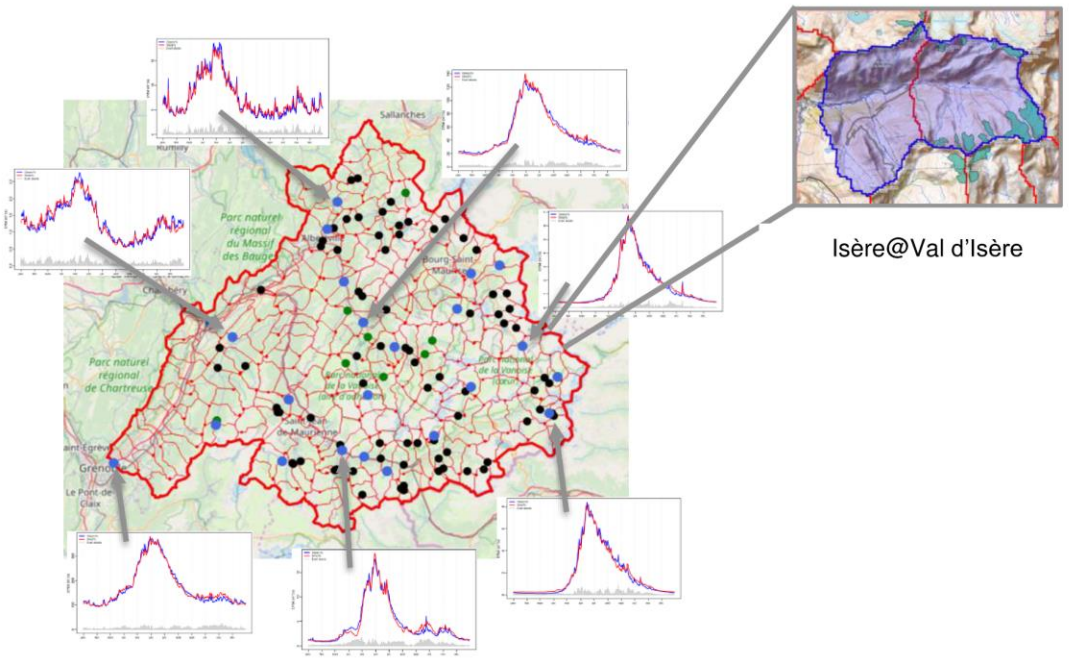


Hydrological modelling



Isère@Val d'Isère

Hydrological modelling



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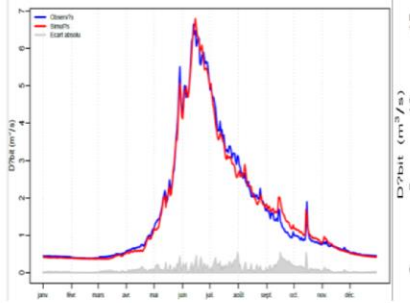
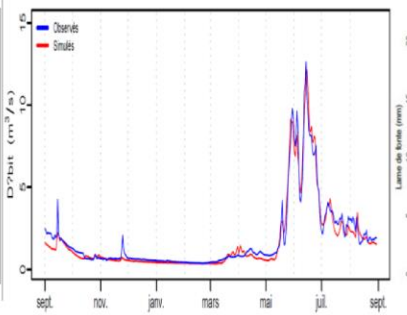
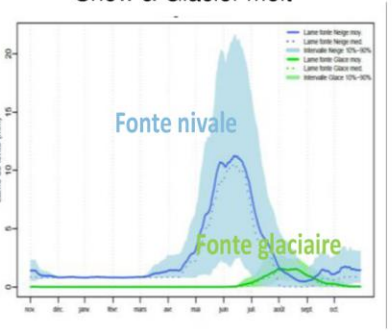
Streamflow Regime [1987-2017]



Streamflow



Snow & Glacier melt



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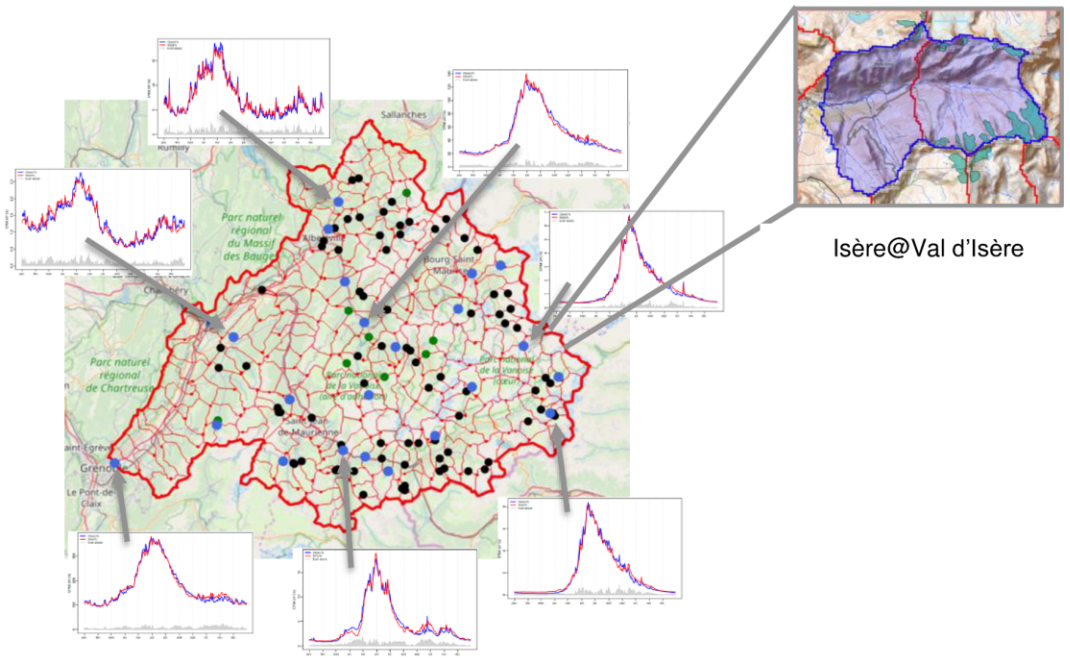

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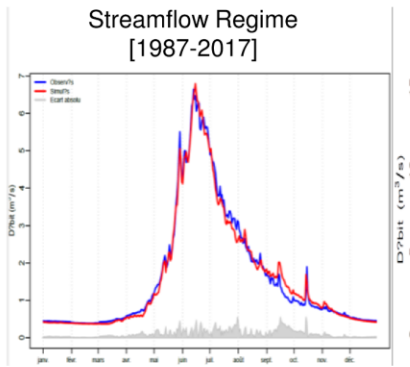
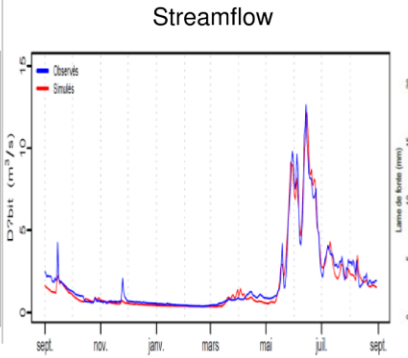
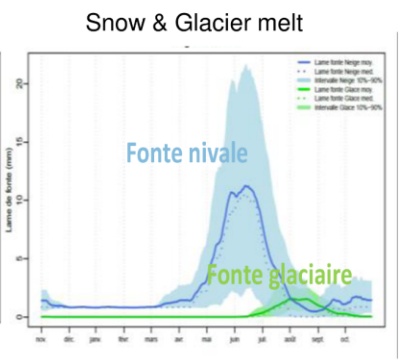
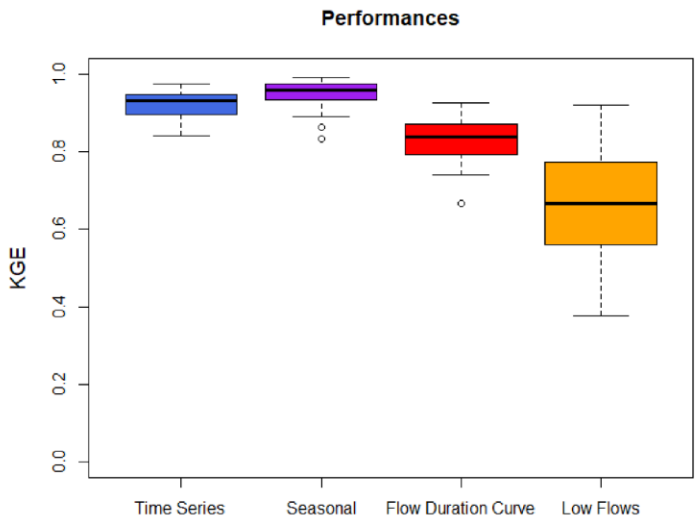




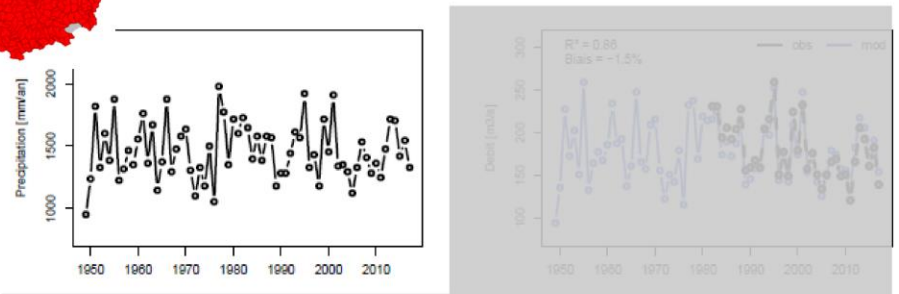




- Good performances
- Local issues, due to :
  - poor meteo forcing or poor hydrometric data
  - Complex snow and glacier processes

Recent interannual hydro-climatic variability

Isère@Grenoble [1948-2017]



- **Precipitation -** strong variability & no significative trend

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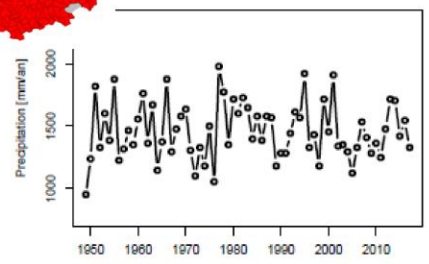

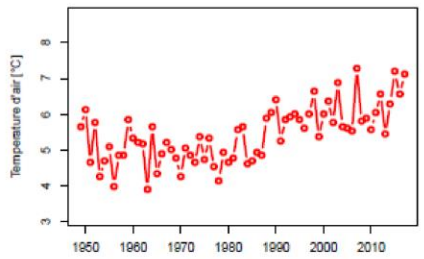

- **Precipitation -** strong variability & no significative trend
- **Temperature -** ~+0.5°C /decade from 80's

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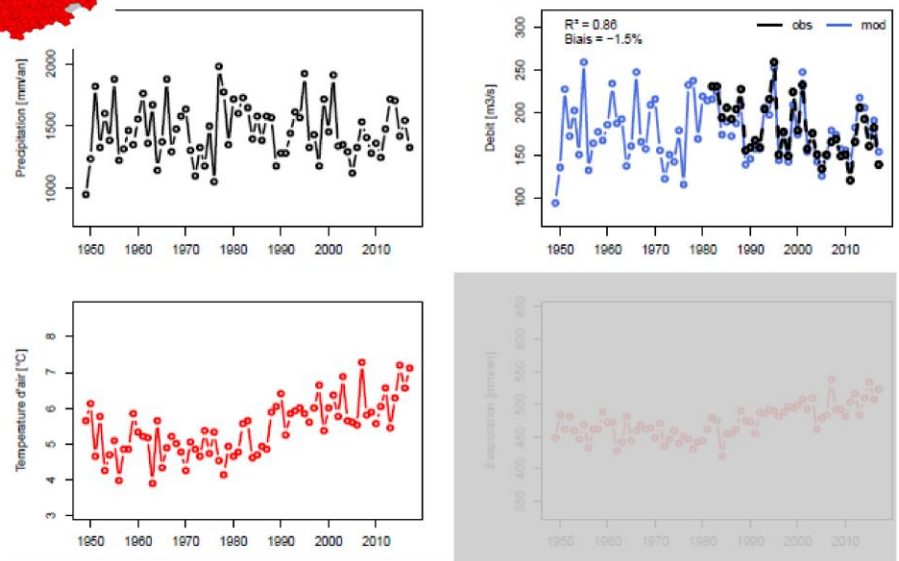

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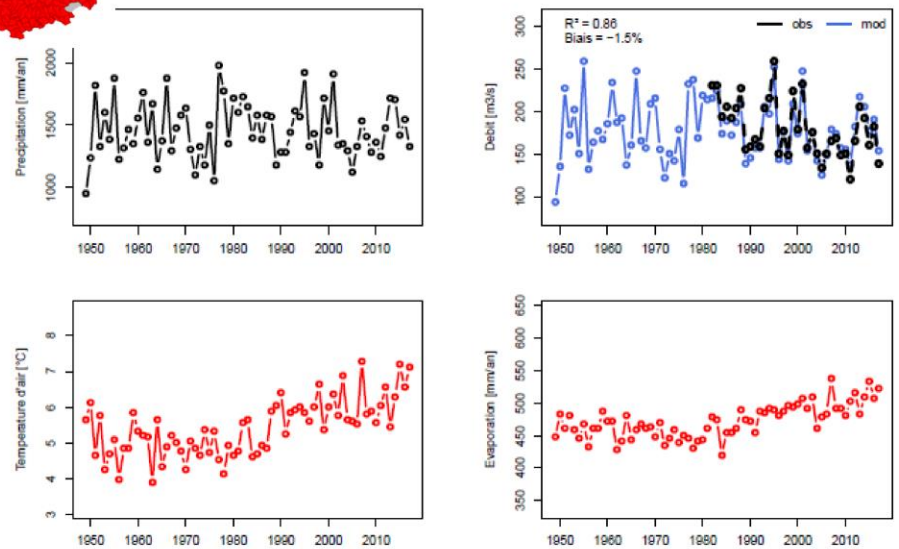

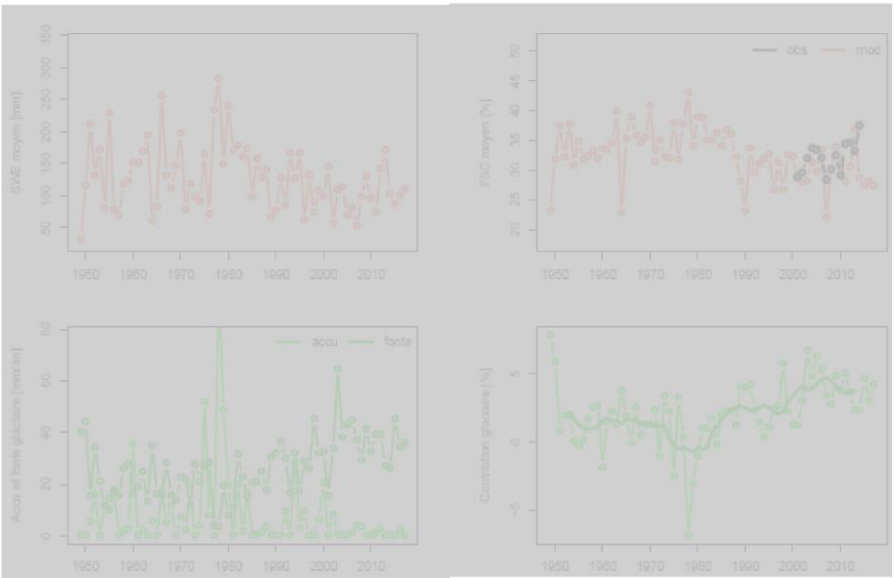

- **Precipitation -** strong variability & no significative trend
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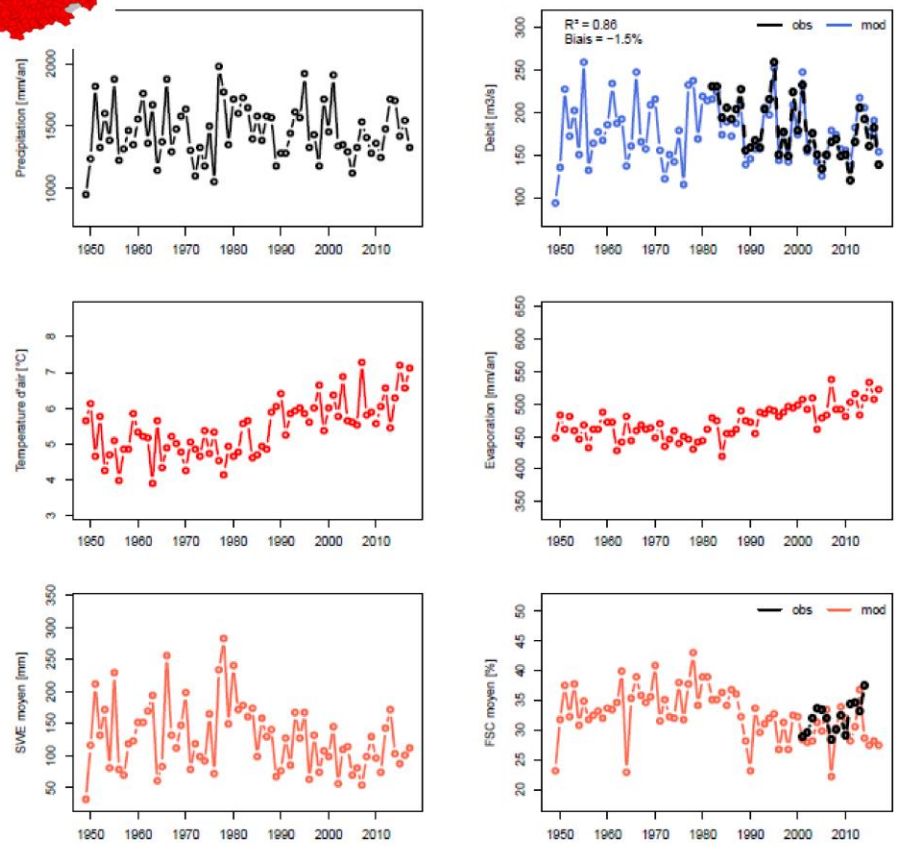

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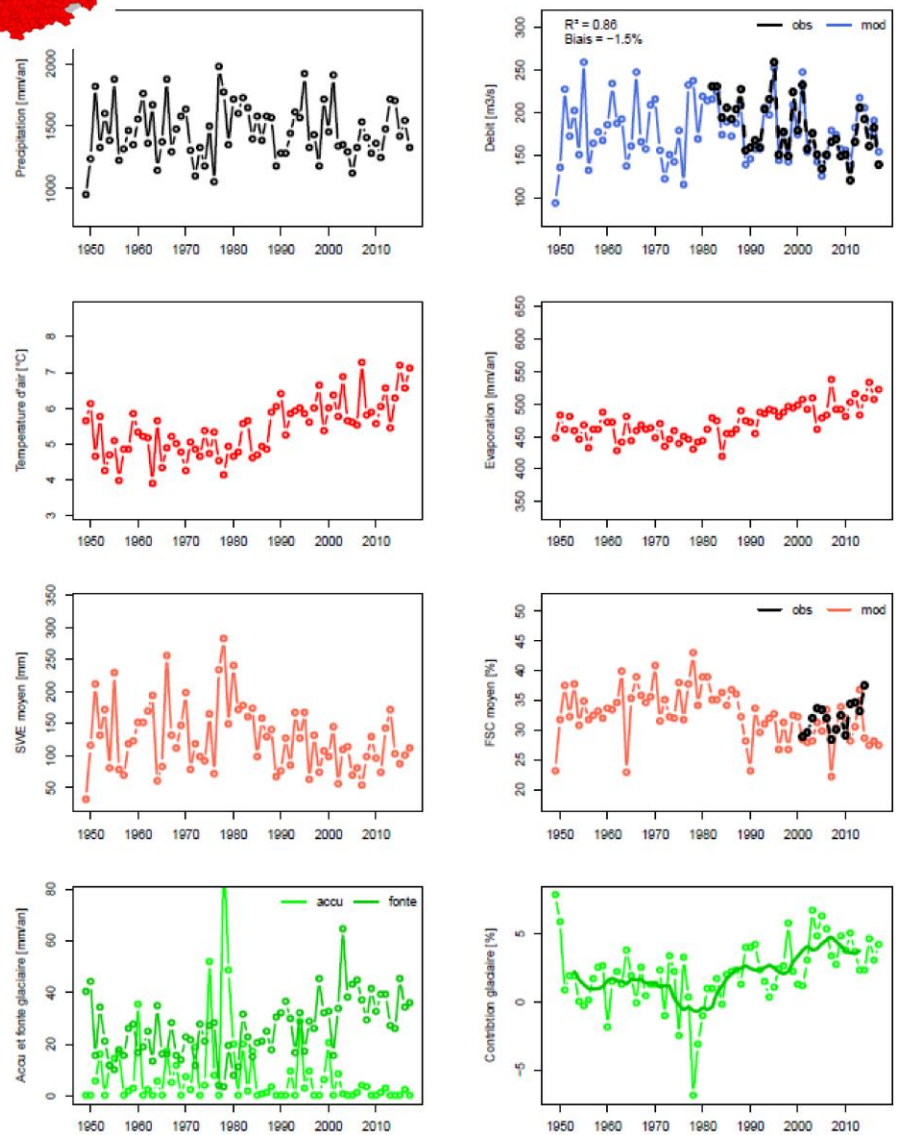

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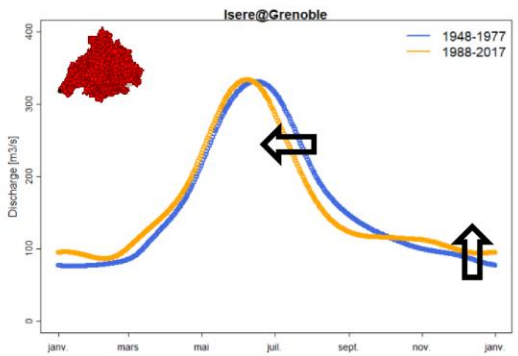
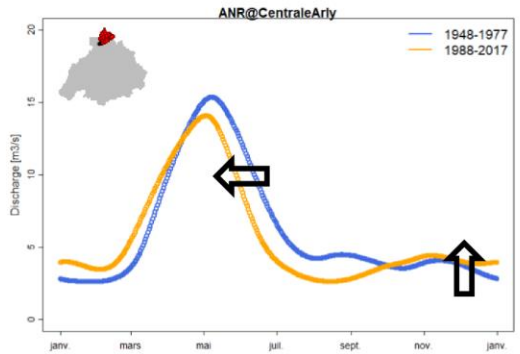
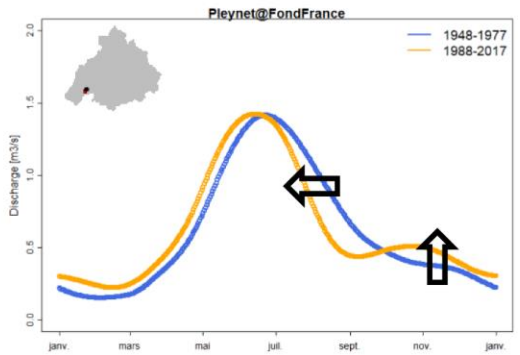
- **Evapotranspiration -** ~+4%/decade from 80's
- **Snow –** decrease, both in snowpack and extension
- **Glacier –** an increase of glacier melt contribution to streamflow (from ~2 to 4%)

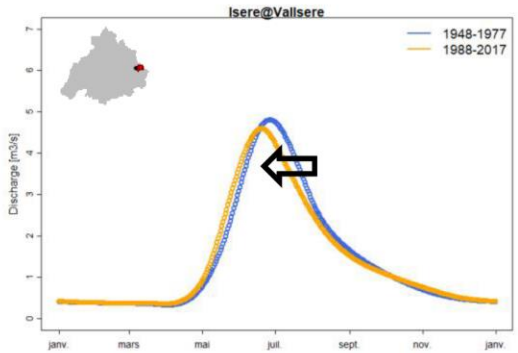
Impacts of observed warming on hydrological regimes

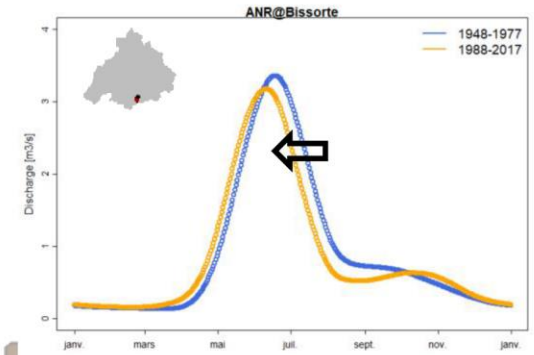
- **Between 1948-1977 & 1988-2017 (from model simulations)**
  - An earlier snowmelt (~10 to 20 days)
  - A decrease of summer flows, except on glacierized upstreams
  - An increase of winter flows on medium elevation catchments

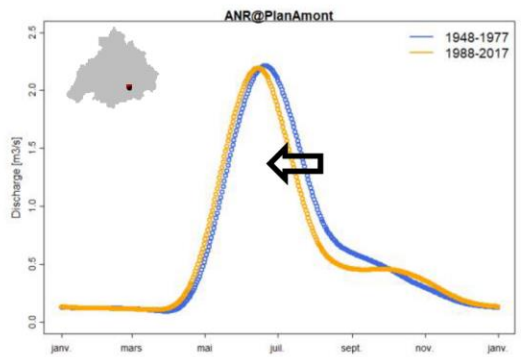






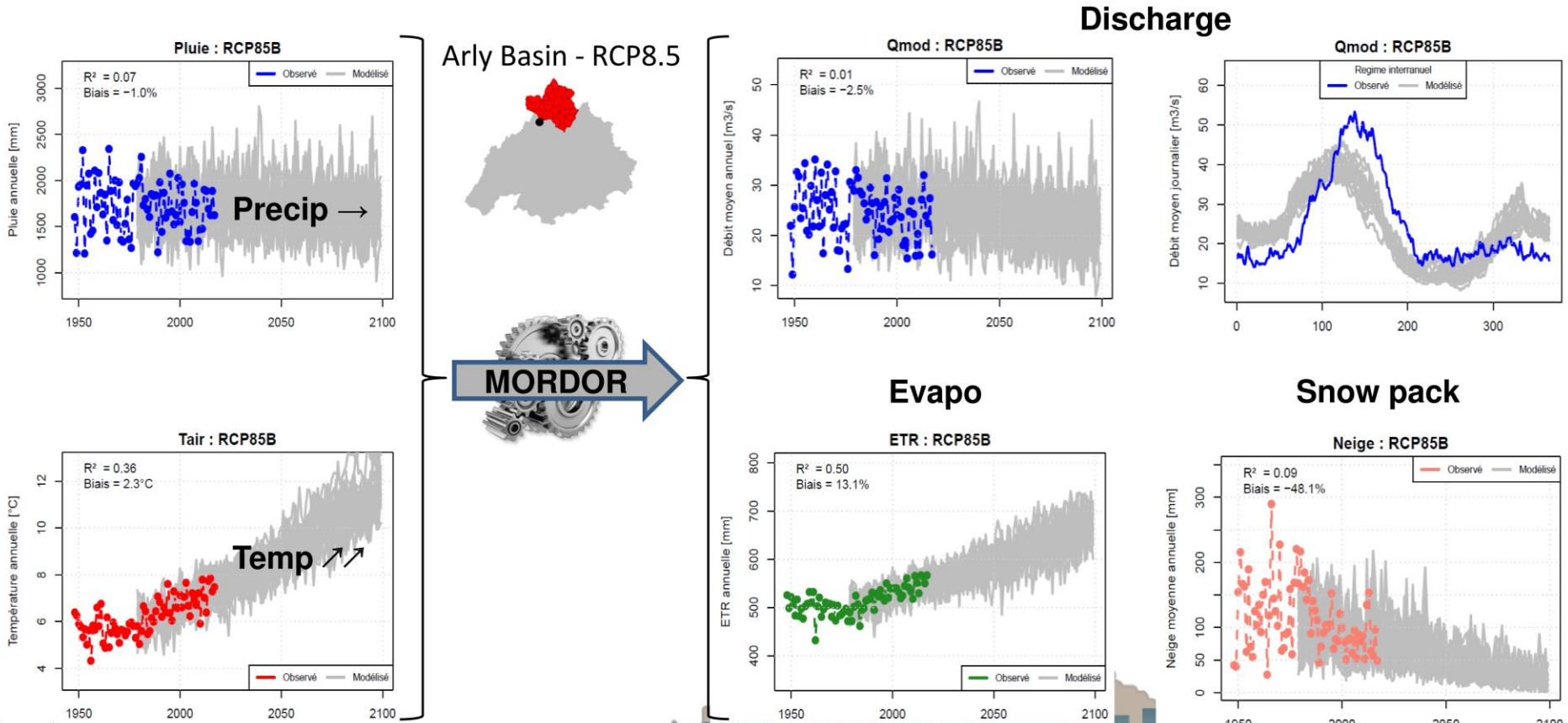






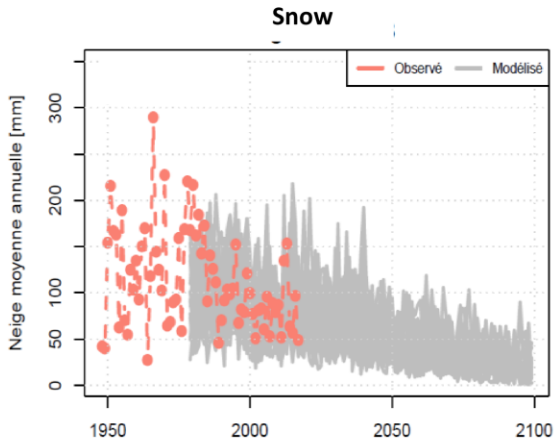
Hydrological projections

- Climatic projections: CMIP5 RCP 4.5 & 8.5 scenarii, 17 downscaled GCM outputs
- Hydrological modelling including a dynamic glacier area evolution parametrization



Hydrological projections

- Nival catchments : A shift to pluvio-nival regime *[Arly, RCP85]*



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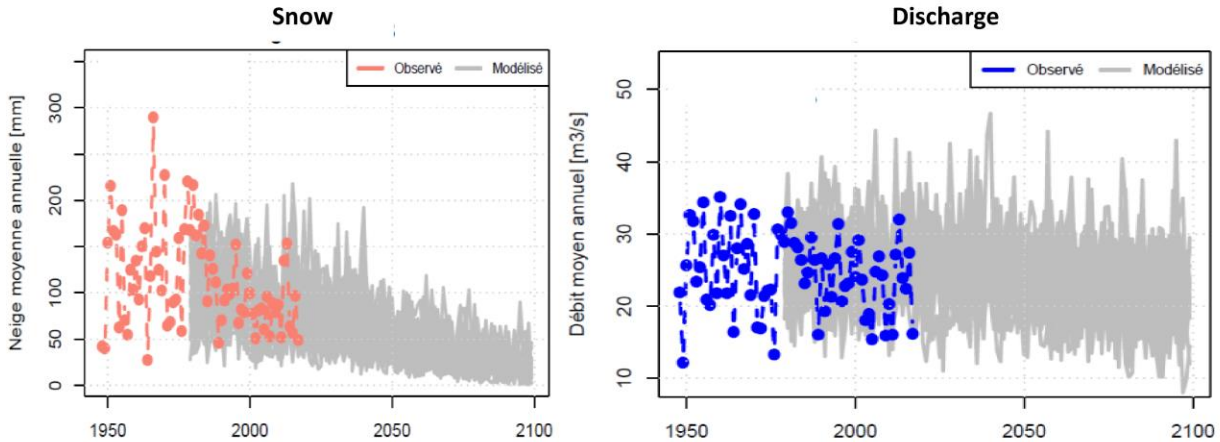

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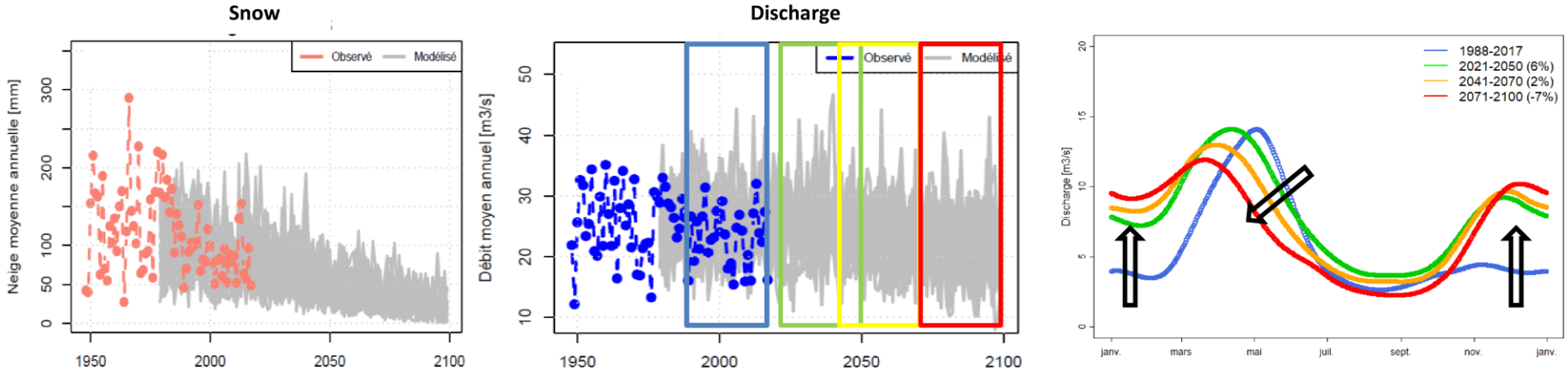

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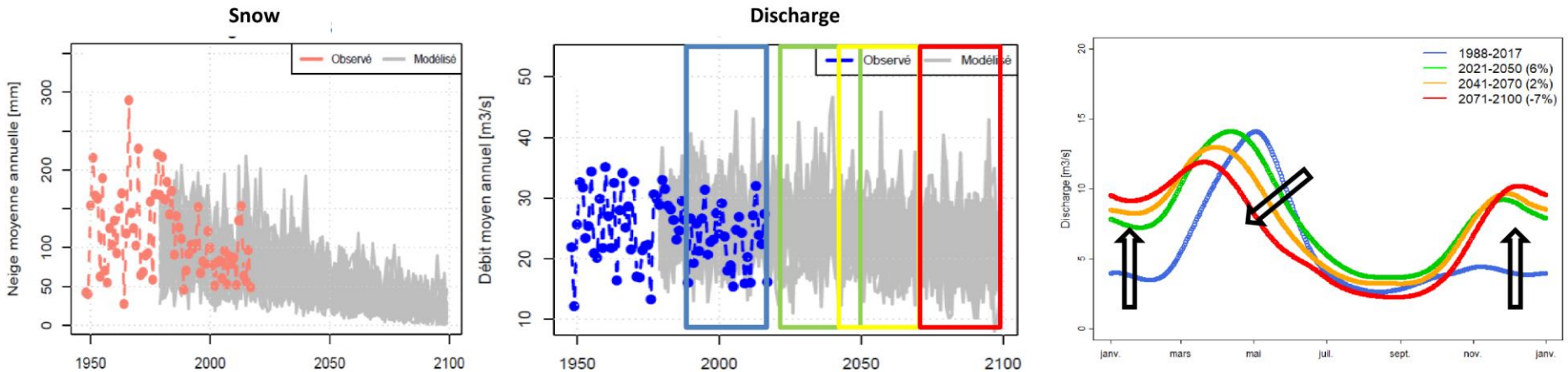
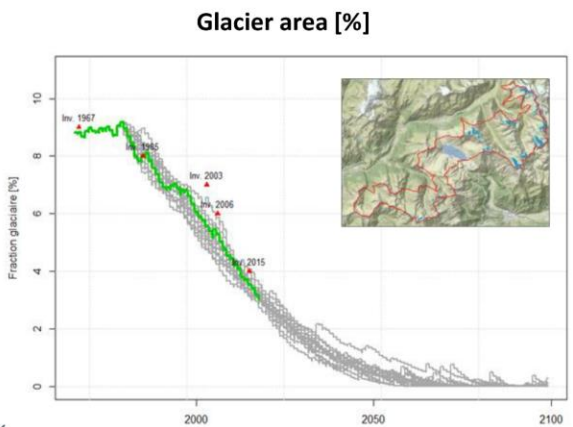


- Glacio-nival catchments : A shift to nival regime *[Mont-Cenis, RCP85]*



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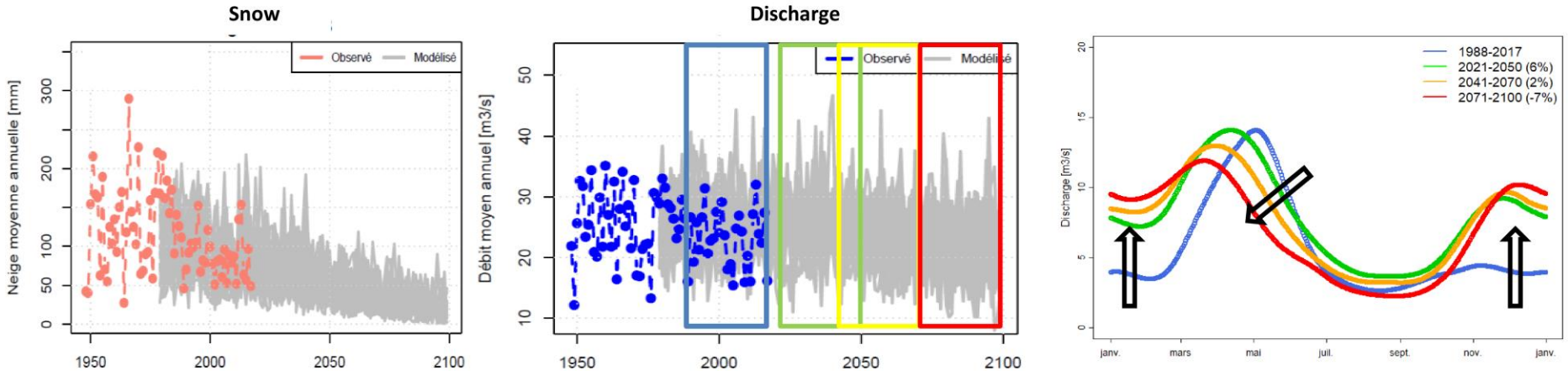

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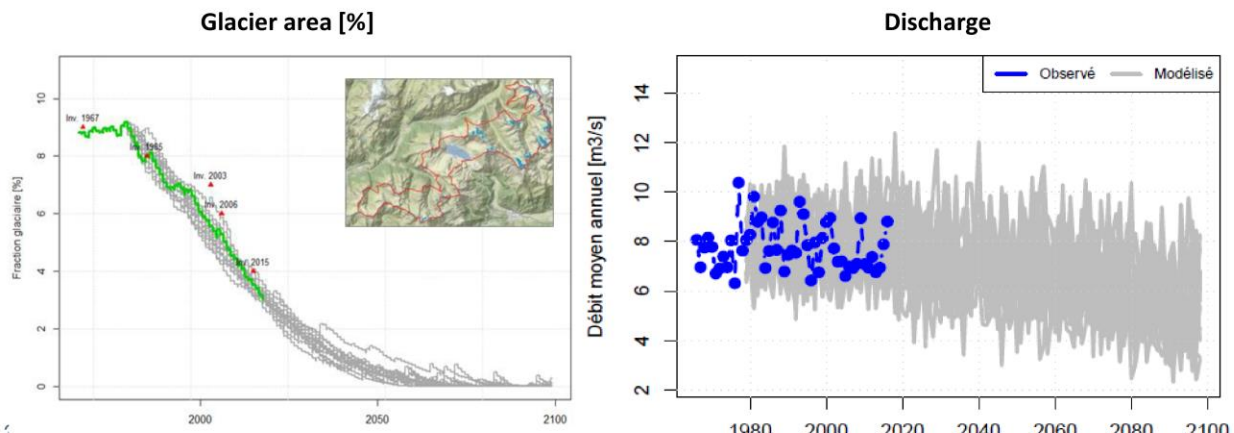

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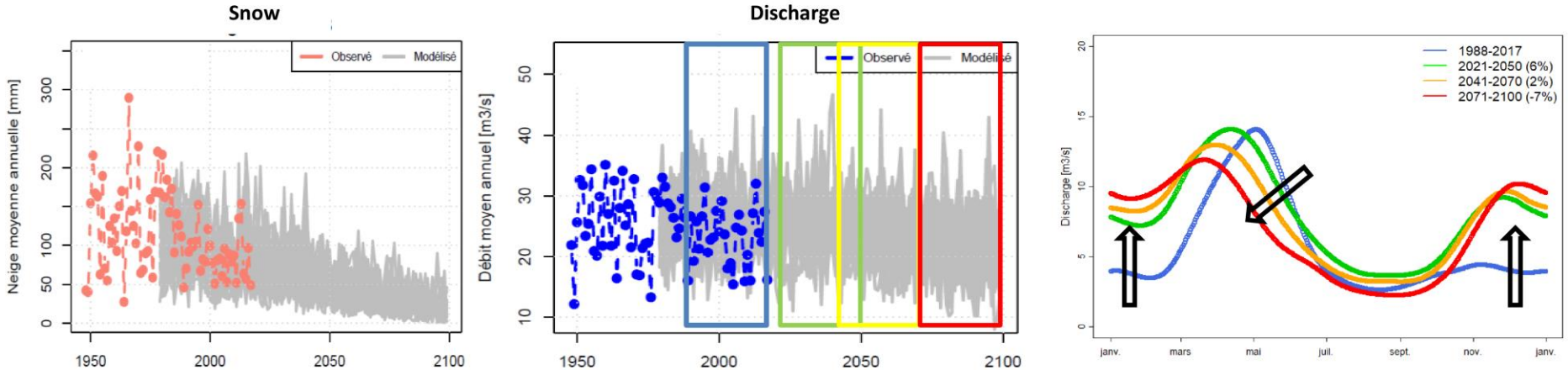

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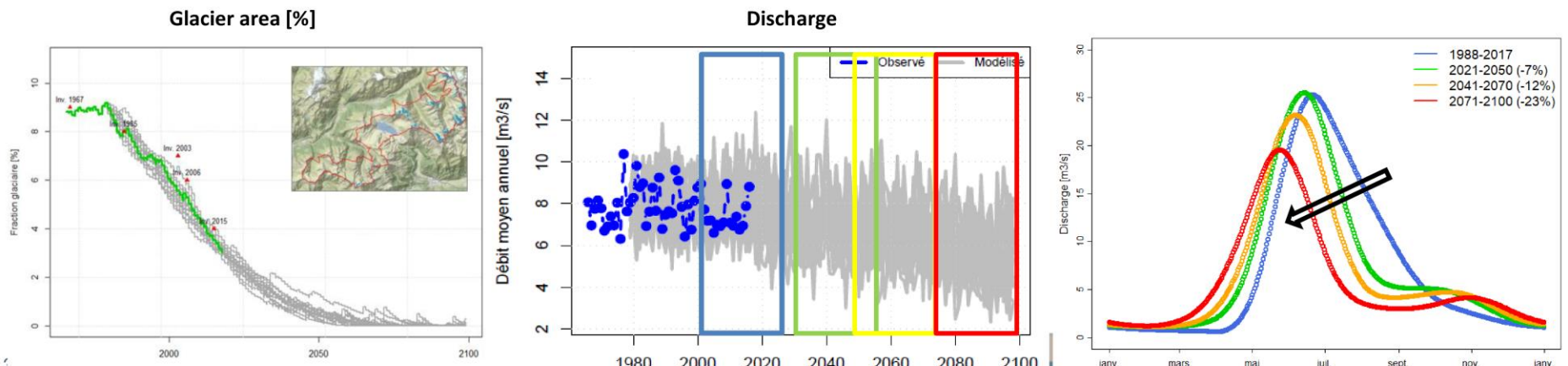

Conclusions

- A need for understanding the hydrological behaviour and evolution of complex mountainous catchments to anticipate impacts of climate change on water resources and multi-purpose issues.

- In this study, we illustrate the use of a spatially distributed model to provide information about the hydroelectric generation exploitation of the Isere river basin.

- The observed recent climate evolution already strongly impact hydrology, with an earlier snowmelt, lower summer flows, increasing glacier melt and increasing evaporation losses.

- Hydrological projections for the XXIth century exacerbate these ongoing changes, with a strong decrease of the snow and glacier contribution to streamflow.

Thanks for your attention