Sensitivity of Alpine glaciers to anthropogenic atmospheric forcings

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Glacier of interest

Argentière glacier:

- Mont Blanc Range
- 2nd largest in France
- from 1550 to 3500m a.s.l.
- ~10km long
- many observations
- mean thickness loss = -25% since 1900

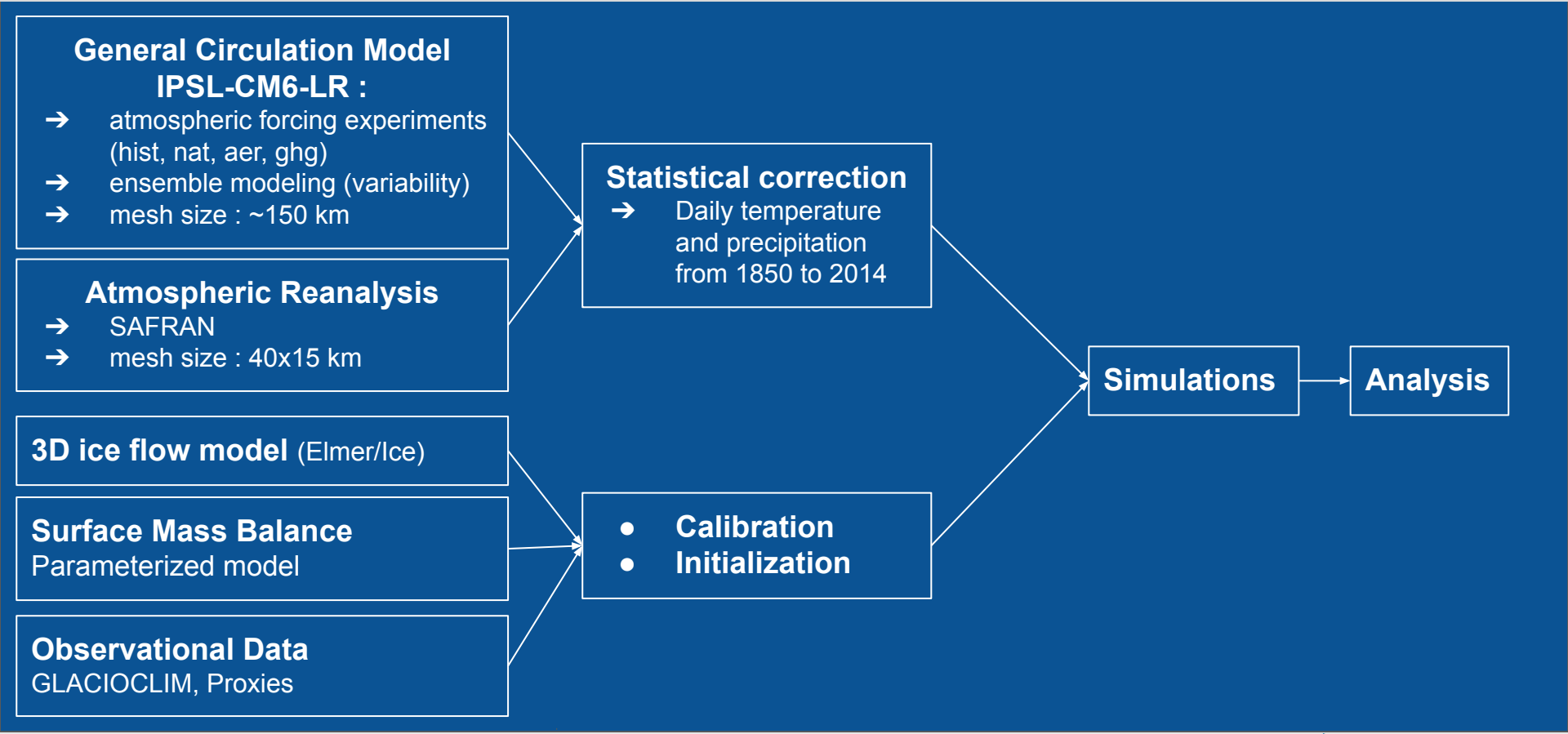
From there …

1860

… to there

2015

Study overview



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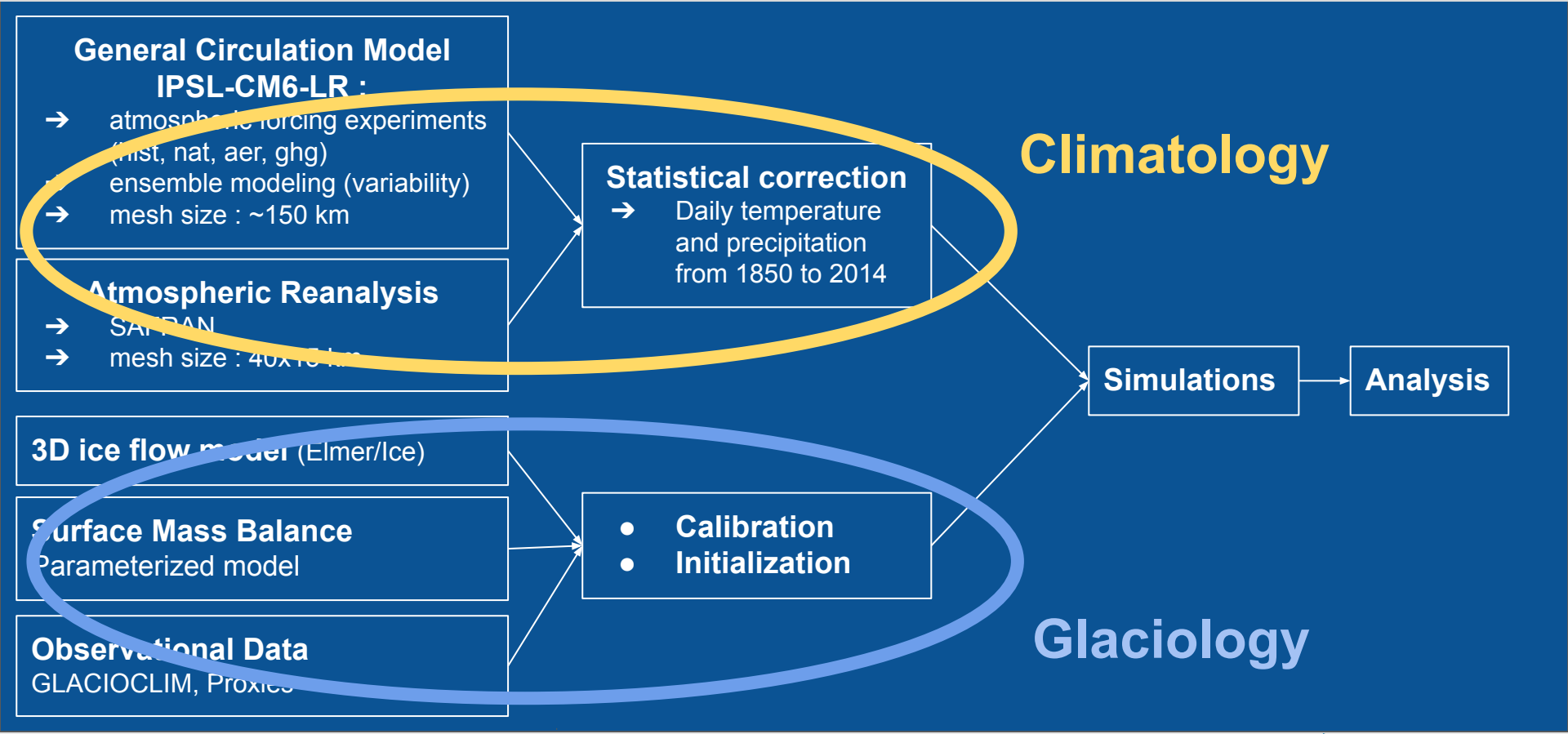


Statistical correction

Main goals:

- ➔ Downscaling
- ➔ Bias removing
- ➔ Mean climatology and daily variability adjustment

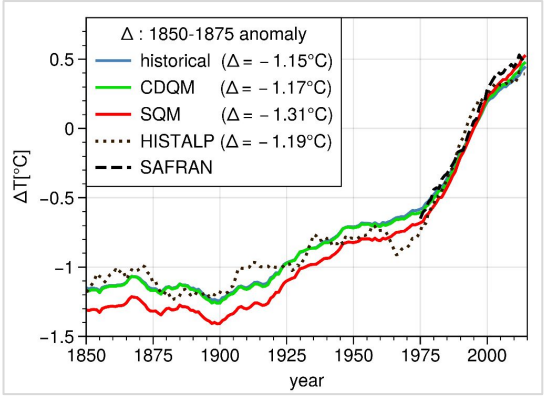
Principle:

- monthly basis
- difference GCM vs. reanalysis
- calibration with **historical mean** over **1975-2014**
- applied for all experiments and the whole period (1850-2014)

Tested methods :

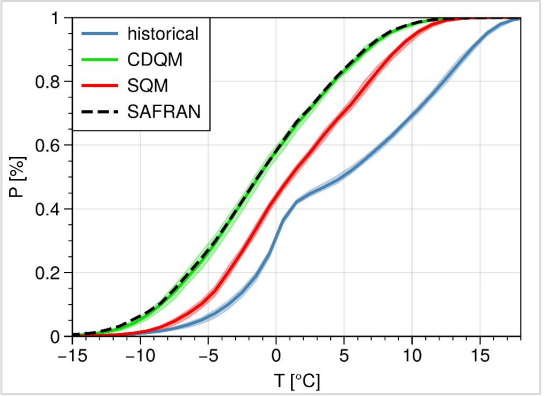
- ★ Simple Quantile Mapping (SQM)
- ★ Coupled Delta Quantile Mapping (CDQM)

Long-term tendencies overestimation



30-year rolling mean of temperature anomaly, reference is the 1975-2014 average, Δ is the 1850-1875 mean anomaly

Precipitation-temperature consistency : snowpack understated



Precipitation cumulative distributive function relatively to 1°C-width temperature quantiles, solid line corresponds to the member mean and shade area to the member range

CDQM = **delta quantile mapping for T** (Cannon et al., 2015) **+** **2D conditional approach for P** (Piani et al., 2012)

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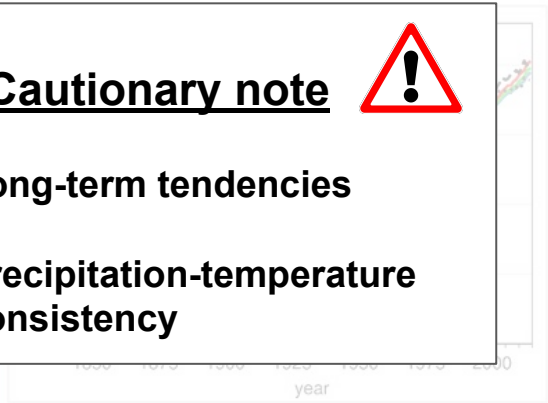
⚠ **Cautionary note** ⚠

- ➔ **Long-term tendencies**
- ➔ **Precipitation-temperature consistency**



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Climate data correction results

Statistical significance test :

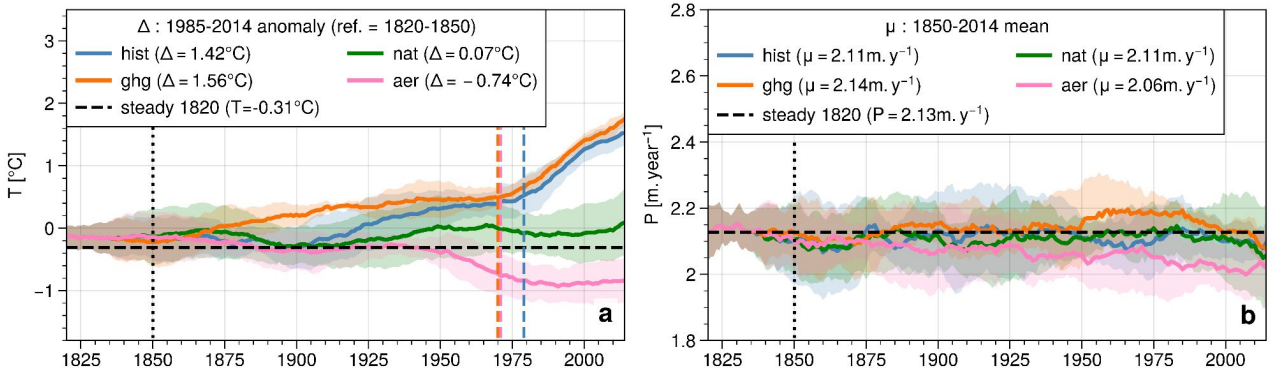
1. Yearly bootstrap resampling (1000 samples)
2. Empirical probability

Precipitation :

➔ no clear tendency
➔ variability dominates

Temperature:

➔ signals stronger than variability
➔ *AER* cooler than *NAT* by 1971
➔ *GHG* hotter than *NAT* by 1971
➔ *HIST* hotter than *NAT* by 1979



30-year rolling mean of (a) temperature and (b) precipitation. Solid lines are 6-member means, shades correspond to the 1-σ member range, vertical black lines show the spin up end, vertical coloured dashed lines indicate the year by which it is very likely (>90%) or unlikely (<10%) to have a lower value than in the natural forcings only experiment

Glaciological model

3D ice flow model:

- ➔ Full-Stokes finite element solvers
- ➔ Refining meshing in front position
- ➔ Digital Elevation Model for bedrocks

Surface Mass Balance model:

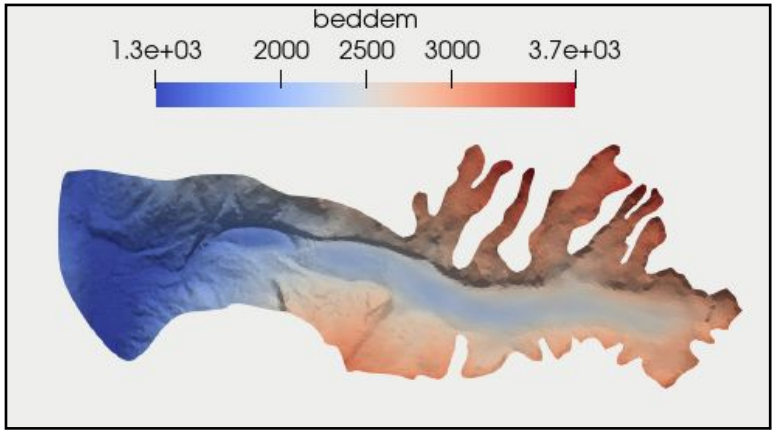
- ➔ parameterized model (temperature-index)
- ➔ spatialization of T and P (each node)
- ➔ Accumulation : ***A=P if T<1°C***
- ➔ Melt derived from energy (*Oerlemans, 2001*)

Calibration :

- ➔ period 1975-2014
- ➔ observational data (*GLACIOCLIM*)

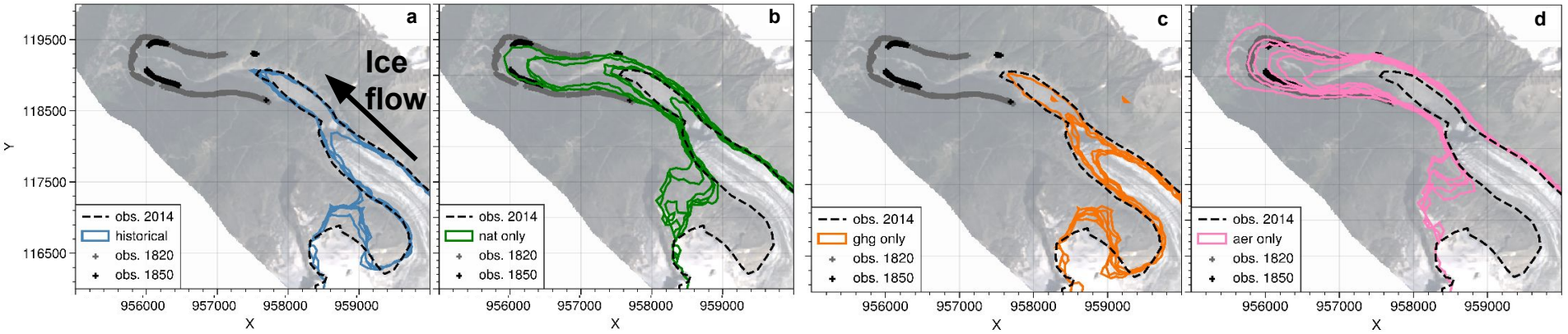
Initialization

- ➔ 1820 : stable state (*Protin et al., 2019*)
- ➔ 1820-1850 spin-up : initialize dynamics



Digital Elevation Model of Argentière glacier catchment

Simulation results



(a) Glacier extent for the individual (a) hist, (b) nat, (c) ghg and (d) aer members in 2014. Coordinates are given in meters in Lambert Centre France coordinates (EPSG:27562). Background picture is a Landsat 8 (band L1) georeferenced photograph taken on 03/09/2014, black dashed line is the corresponding glacier extent. 1820 and 1850 observations are from Protin et al. (2019)

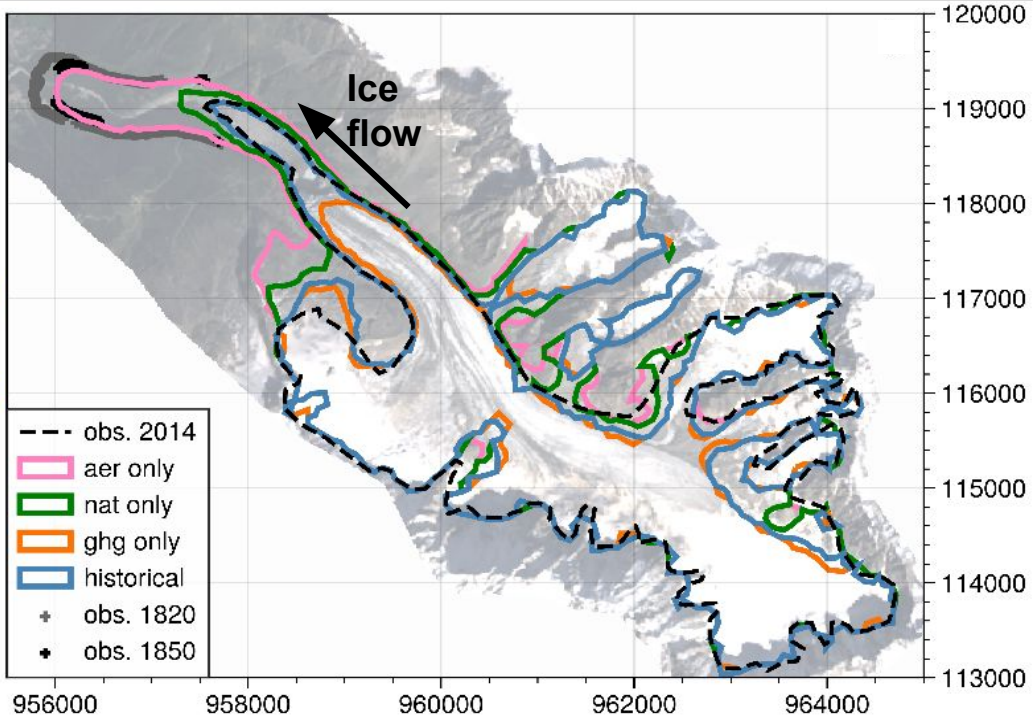
➔ ***HIST***
- close to 2014 observations
- strong retreat

➔ ***NAT***
- strong variability

➔ ***GHG***
- warming effect
- stronger decline than HIST

➔ ***AER***
- cooling effect
- close to 1850 observations
- variability

Simulation results



Glacier extent for each experiment 6-member mean in 2014. Coordinates are given in meters in Lambert Centre France coordinates (EPSG:27562). Background picture is a Landsat 8 (band L1) georeferenced photograph taken on 03/09/2014, black dashed line is the corresponding glacier extent. 1820 and 1850 observations are from Protin et al. (2019)

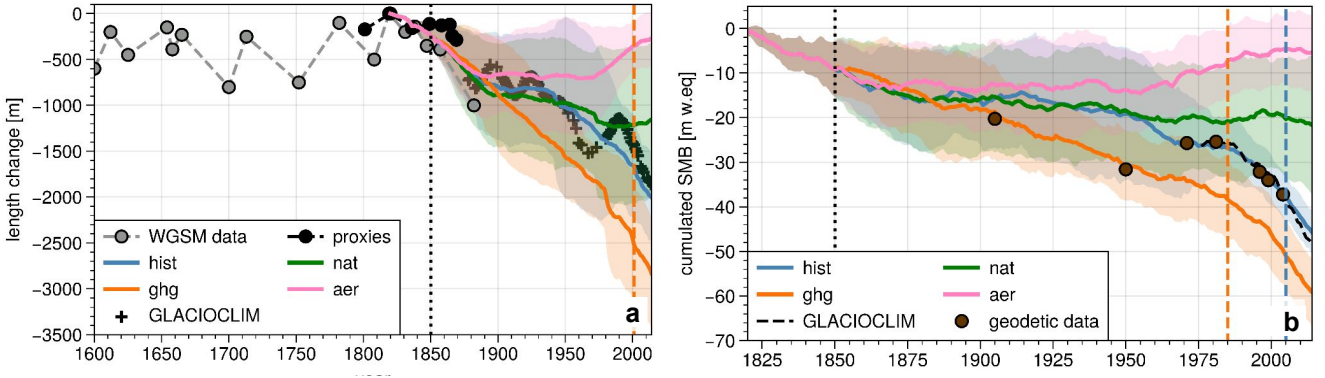
Simulation results

Length change:

- ➔ Topography dependence
- ➔ Strong variability
- ➔ ***GHG*** retreat greater than ***NAT*** by 2001

Cumulated Mass Balance (~volume):

- ➔ Topography independence
- ➔ Lower response-time and variability
- ➔ ***GHG*** lower than ***NAT*** by 1987
- ➔ ***HIST*** lower than ***NAT*** by 1987



Length change (a) and cumulated SMB (b). Solid lines are 6-member means, shades correspond to the 1-σ member range, vertical black lines show the spin up end, vertical coloured dashed lines indicate the year by which it is very likely (>90%) or unlikely (<10%) to have a lower value than in the natural forcings only experiment

Conclusions

Results:

- ➔ High sensitivity to atmospheric forcings (temperature and glacier volume)
- ➔ Strong influence of climate variability at this time scale
- ➔ The worst is yet to come ? (response time)

Discussion:

- ➔ Topography dependence : non-generalizable to other glaciers for length change, more likely for mass loss
- ➔ aerosol effect on snow/ice albedo not considered
- ➔ hypothesis on the statistical correction :
  - ◆ stationarity
  - ◆ precipitation trends negligible compared to temperature

Perspectives:

- ➔ multi-model approach (other CMIP6 global model)
- ➔ dynamical downscaling with Regional Climate Model
- ➔ application to other glaciers

Thanks for your attention !

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