Establishment of a climatological frame of reference of cold weather for gas TSOs

Marie CASSAS[1], Agathe DROUIN[1], Florian GIBIER[1], Valérie LAFONT[2], Raphaël LEGRAND[1], Yann MICHEL[1], Marketa PICHLOVA LALLEMENTOVA[2], Aurélien RIBES[1]

[1]METEO-FRANCE, Toulouse, FRANCE [2]GRTgaz, Bois-Colombes, FRANCE

ICEM 2023*, Padova, ITALY, 27-29th June 2023*

Gas transmission in France

- Two actors in France: GRTgaz and Teréga

- **Continuity and safety of gas supply** in the country:
  - Development, maintenance and safety of the network
  - Dispatching to the local and national distribution operators
  - Storage and LNG terminals interfaces management
  - International transit of gas
  - Support to renewable and sustainable gases development

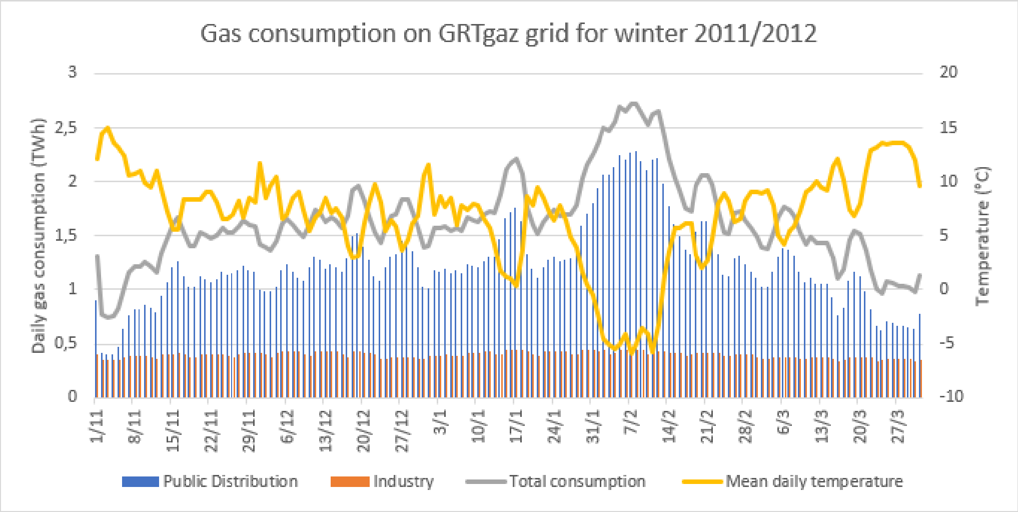
Credits: GRTgaz

Need for climate services

- Each winter in France, high energy demand for heating
  - Operational decision making to guarantee the balance of the system
  - Depends on meteorological conditions

► Need for a **climatological reference** to contextualise each real time situation

→ *historical values and return times associated*



Credits: GRTgaz

- In the long term, provide enough energy for heating during severe cold spells
  - Dimensioning of pipelines, underground storages, etc.
  - While carrying out the partial conversion of the network to H_2 or CO_2

► Need for an **estimation of the magnitude of severe cold spells** in current (and future) climate

→ *2, 10, 20, 50-year return levels*

Methodology overview

1 **Data extraction**, handling of missing values, computing of derived variables of main interest

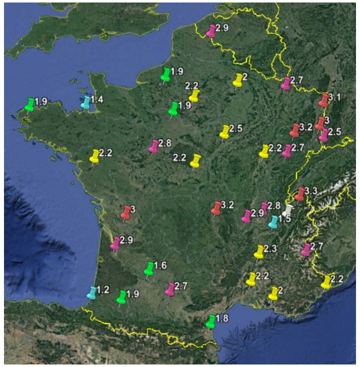
2 **Statistical modelling** of the distribution of the variables, fitting of the parameters on the dataset

3 Trying different models, checking their quality and **selecting the most adequate** and reliable

4 **Computing the return levels or periods** using the selected model with associated **confidence intervals**

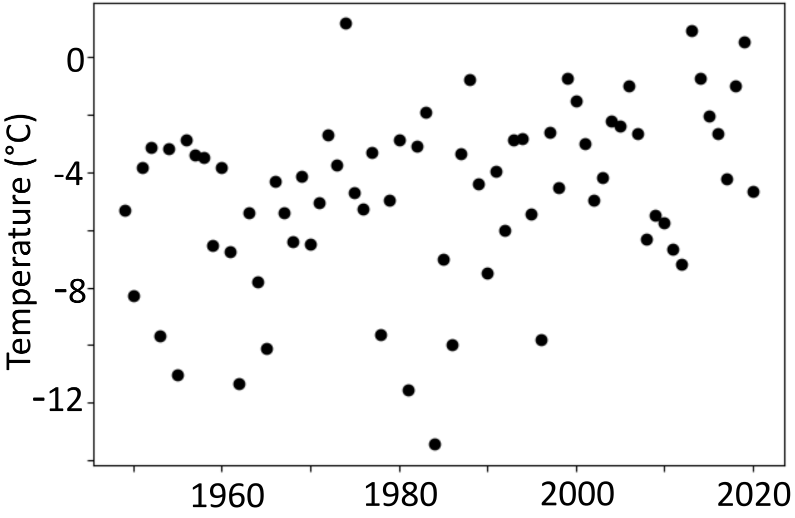
Dataset of the study

- Current climate: study on the past period **1949-2021** with **historical data** in France
- 2-meter air temperature measured by ground weather stations from MF’s national network



Locations of the stations of the study

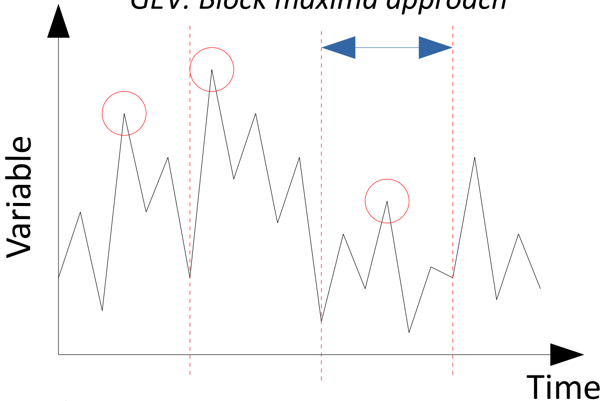
Yearly minimums of smoothed daily temp., Lille



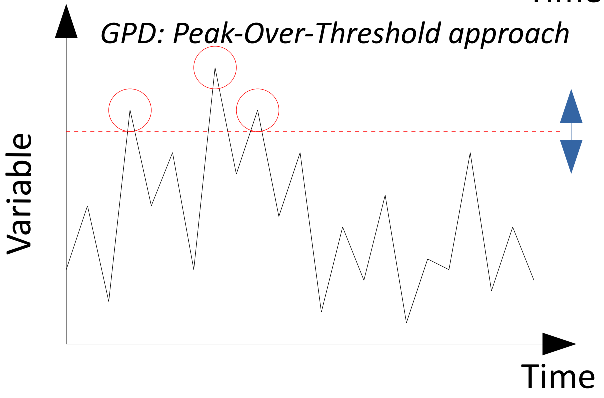
- Climatological reference: **heating degree days** cumulated over different periods (3, 7, 14 days, monthly, whole winter) and over all stations
- Risk of extreme cold spells: **daily mean temperature** smoothed over 3 days for each station
- Missing measurements, relocations: hard to get complete, continuous, homogeneous series

Statistical models

- Statistical modelling to represent distribution of variables:
  - **Generalized Extreme Value** (GEV) distribution for **cold spells** (3 to 14 days):
    - Block maxima approach (width = 1 year / 1 or 2 months)
    - Peak-Over-Threshold (GPD) approach tested for degree days
    - 3 parameters:
      - Shape **ξ**
      - Location **μ**
      - Scale **σ**
  - **Gaussian distribution** for monthly and winterly **cumulated degree days**
    - Best-suited for cumulated variables (central limit theorem)
    - 2 parameters:
      - Mean **μ**
      - Variance **σ^2**



GEV: Block maxima approach



GPD: Peak-Over-Threshold approach

Taking into account the climate tendency

- Previous models will only work for *homogeneous time series*, which is not the case due to climate change caused by human activities: this tendency needs to be taken into account
- Robin and Ribes, 2020: covariate X_T, proxy of the average tendency on the period

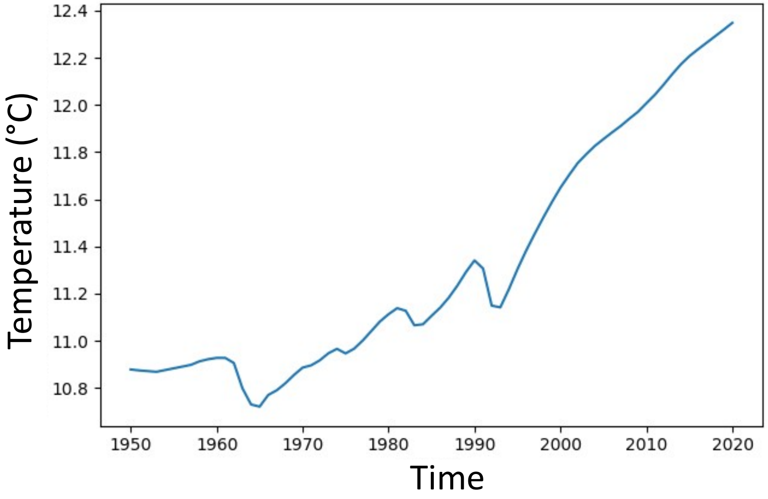
  → **parameters of the distributions vary depending on year / climate state**

- GEV / Gaussian distribution:
  - GEV: constant shape ξ
  - Location / mean: linear dependence
  - Scale / variance: linear + exponential link (positivity)

$$\mu(T)=\mu_0+X_T*\mu_1 \qquad \sigma(T)=\exp(\sigma_0+X_T*\sigma_1)$$

- Choosing (arbitrarily) an adequate covariate X_T:

► Ribes et al., 2022: **yearly mean temperature over France** on the 1850-2100 period using **GCMs constrained by regional observations** (also used for IPCC AR6)



Covariate X_T: French mean yearly temperature 1949-2021 (GCM + observational constraint)

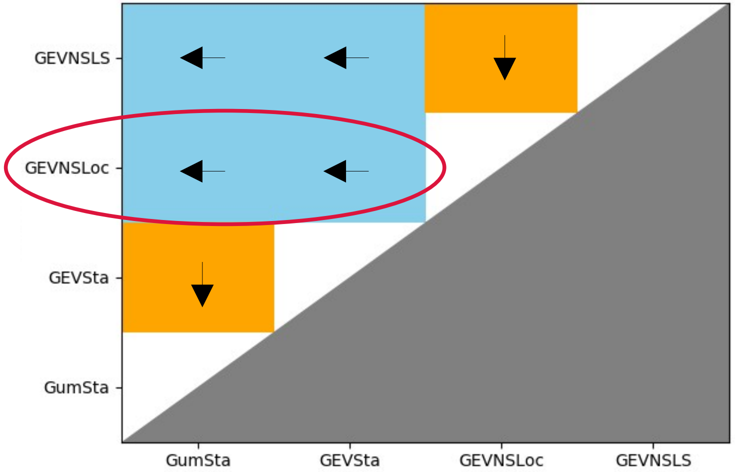
Selecting the best models

- Validate the relevance of the non-stationary formulation
- Checking which parameters really need to vary with X_T
- Avoiding useless complexity which could deteriorate reliability

► **Likelihood ratio test**

e. g. GEV distribution:

- ▸ Stationary Gumbel (ξ = 0, constant μ and σ)
- ▸ Stationary GEV (constant ξ ≠ 0, μ and σ)
- ▸ Non-stationary GEV Loc (constant ξ ≠ 0 and σ, μ(T))
- ▸ Non-stationary GEV Loc+Scale (constant ξ ≠ 0, μ(T), σ(T))



Likelihood ratio test results for Paris, smoothed daily mean, 1-year blocks (95 % tolerance)
Blue = the more complex the better
Orange = the simpler the better

- Results (same formulation for all stations and time blocks for homogeneity):

→ **Non-stationary** formulation is **necessary**

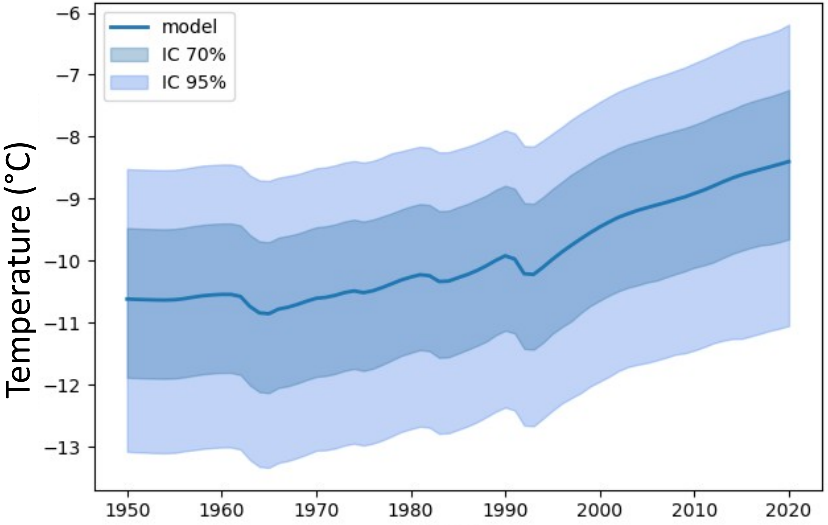
→ **Only on location / mean** (non-stationarity on scale /variance = non-profitable complexity)

Main results

- Return levels of cold spells and winterly cumulated degree days follow the same kind of evolution as the covariate:
  - **relatively stable until 1970** (high aerosol emissions compensate warming effect)
  - **increasingly steeper from 1980 to present** (as the aerosol emissions decrease)

- *Magnitude of severe cold spells decreases* over the period (+0.4°C/dec in 1980, +0.6°C/dec in 2020)
- Similar evolution for the degree days cumulated over the whole winter
- *Month by month* results have *similar* characteristics but show *some discrepancies*

  e. g.: Cumulated degree days decrease slower in December, January and February (7-8% between 1990-2020) than in November / March (10%)



Evolution of the yearly defined 50-year return level of smoothed daily mean temperature in Paris (with 70 and 95% confidence intervals)

Confidence intervals, uncertainty and limits

- Confidence intervals computed by bootstraping
  - **The higher the return level, the larger the confidence interval**
  - The width of the intervals remains relatively constant (high return levels, 1-year and winter)
  - Width more variable for smaller return levels and summer months

- Small dataset (73 years): relatively **high uncertainty for 50-year return levels**
  → **confidence intervals are large but need to be exploited**

- **Month by month results are less reliable** (EV theory limits), especially in summer
  → better to consider larger blocks (1-year)

- Some stations opened more recently: smaller dataset, higher uncertainty
  → station by station results *might show geographical patterns that are not reliable*

Take-away messages

- **Hard to get continuous and homogeneous measured time series**: need for a high resolution unbiaised reanalysis to complete missing data, especially on complex terrain

- **Extreme event studying requires a large dataset** to be reliable: 70 years is short to compute 50-year return levels

- **Taking into account the tendency induced by climate change** in the time series is crucial (at least on the mean / location parameter)

- **Severe cold spells and cold winters are becoming less intense** for a same return time, at a faster rate than the mean temperature

- Uncertainty remains high: **confidence intervals are essential** and results still need to be handled carefully

Thank you for your attention

References

- GABDA Darmesah, TAWN Jonathan et BROWN Simon, 2019: *A step towards efficient inference for trends in UK extreme temperatures through distributional linkage between observations and climate model data*. Nat Hazards 98**,** 1135–1154. (https://doi.org/10.1007/s11069-018-3504-8)
- GROSS Mia H., DONAT Markus G., ALEXANDER Lisa V., et SHERWOOD Steven C., 2020: *Amplified warming of seasonal cold extremes relative to the mean in the Northern Hemisphere extratropics*. Earth Syst. Dynam., 11, 97–111, (https://doi.org/10.5194/esd-11-97-2020)
- GULEV Sergey K. et al., 2021: *Changing State of the Climate System. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 287–422, (doi :10.1017/9781009157896.004, https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter02.pdf)

References

- RIBES Aurelien, QASMI Said, and GILLETT Nathan P., 2021: *Making climate projections conditional on historical observations*, Science Advances, 7, eabc0671, publisher: American Association for the Advancement of Science (https://doi.org/10.1126/sciadv.abc0671)
- RIBES Aurelien et. al, 2022: *An updated assessment of past and future warming over France based on a regional observational constraint*, Earth Syst. Dynam., 13, 1397–1415 (https://doi.org/10.5194/esd-13-1397-2022)
- ROBIN Yoann, 2019: Librairie SDFC v0.6 : https://github.com/yrobink/SDFC
- ROBIN Yoann and RIBES Aurelien, 2020: *Nonstationary extreme value analysis for event attribution combining climate models and observations.* Adv. Stat. Clim. Meteorol. Oceanogr., 6, 205–221 (https://doi.org/10.5194/ascmo-6-205-2020)
- SCARROTT Carl J. and MACDONALD Anna, 2012: *A review of extreme value threshold estimation and uncertainty quantification.* Revstat Statistical Journal, 10, 33-60 (https://doi.org/10.57805/revstat.v10i1.110)