Better modelling durations to better characterize heat spells - A new approach to estimate extreme temperatures in the nuclear safety field

IRSN
INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

Enhancing nuclear safety

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July, 26th 2018

PRESENTATION OF IRSN,
Institut de Radioprotection et de Sûreté Nucléaire

- **A public body with industrial and commercial activities**, is placed under the joint authority of the Ministries of **Defense**, **Environment**, **Energy**, **Research**, and **Health**.

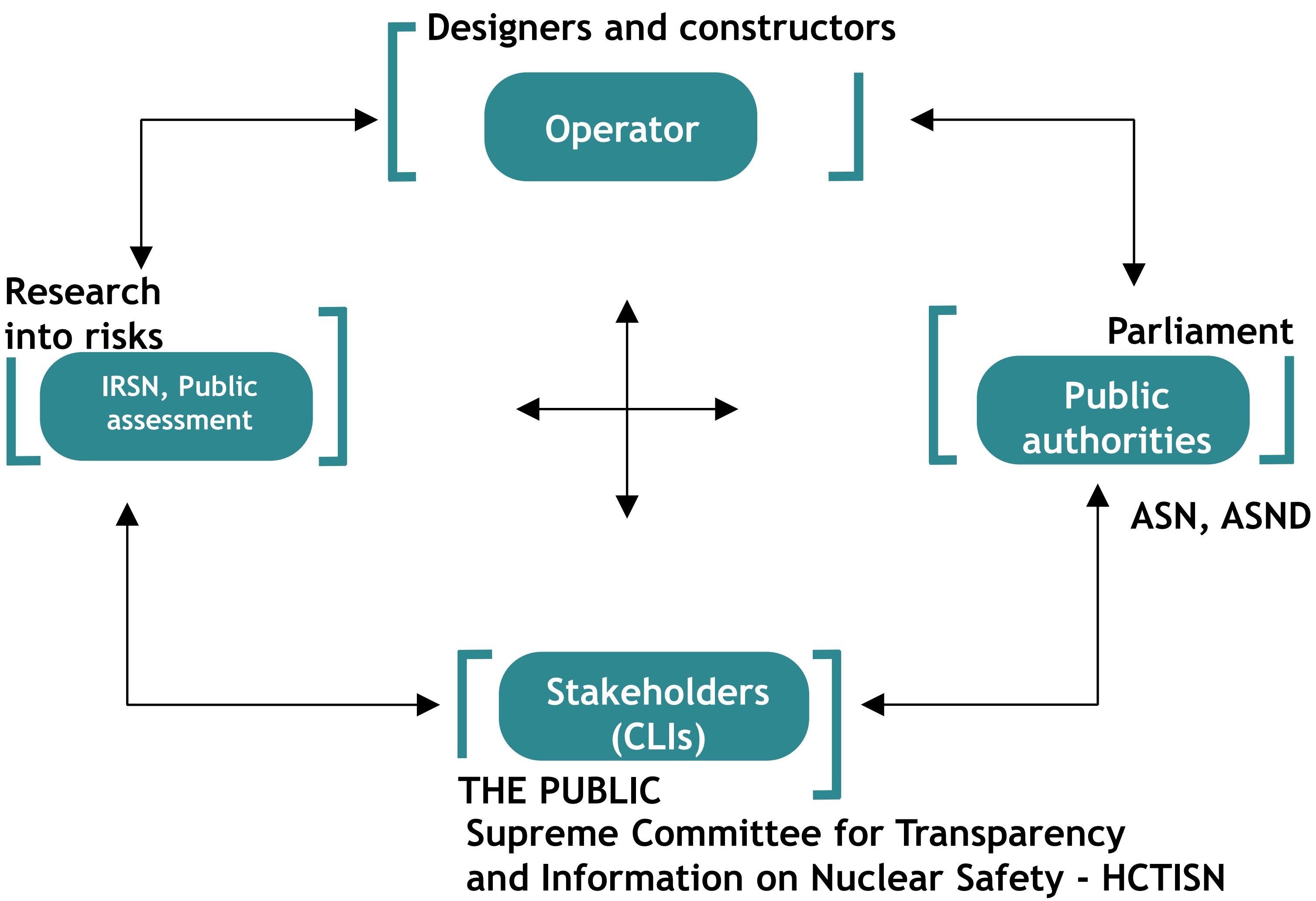
- National public **expert** for **research** and **technical support** on radiation protection and nuclear safety risks

- 1800 employees, including more than 1000 specialists: **researchers**, **Ph.D. students**, **post-docs** and **engineers**

- 8 establishments in France, including 3 major sites

- Our values : Knowledge, independence, proximity

Institutional environment



Fields of activity

- **Nuclear safety:** reactors, fuel cycle, waste, medical applications and transports

- **Protection** of
  - workers, population and environment against ionizing radiation risks
  - nuclear sensitive materials
  - nuclear facilities and transport of radioactive and fissile materials against malicious acts

- **Emergency** preparedness and post-accident operational support

Three main missions

1. Research and services of public interest, including public transparency: Research on nuclear safety and security and radiation protection
2. Support and technical assistance to the public authorities for civil or defense-related activities;
3. Contractual assessment, study and measurement services for public and private organizations, both French and foreign.

Missions . . . *enhancing nuclear safety*

1. Research and services of public interest, including public transparency

- Research on nuclear safety and security and radiation protection
- Contribution to national emergency preparedness and response planning
- . . . Monitoring of populations exposed to ionizing radiation; National accounting of nuclear materials; Management of the national database of radioactive sources; Contribution to training in radiation protection and safety

2. Support and technical assistance to the public authorities for civil or defense-related activities

- Safety of basic nuclear installations
- Safety of basic nuclear installations classified as secret and of nuclear defense systems
- Safety of nuclear transport; Protection of nuclear materials, facilities and transport against malicious acts

3. Contractual assessment, study and measurement services for public and private organizations, both French and foreign

- Safety assessments for the European Commission in Eastern Europe and developing countries (via Riskaudit), 180 cooperation agreements with 41 countries
- . . . Technological risk assessments; Environmental measurements; Dosimetry of workers : creation in Jan. 2010 of a business unit dedicated to passive dosimetry contractual assessment.

Activities, Multidisciplinary teams

IRSN: National expert in nuclear safety risks and radiation protection

- Researchers, general and specialist engineers and technicians ;
- … in biology, chemistry, geology, physics, thermodynamics, hydraulics, mechanics, neutronics, fluid mechanics, IT, statistics, radiation protection and electronics, etc.
- Physicians, agronomists, veterinarians;

Site & Natural Hazard Department :

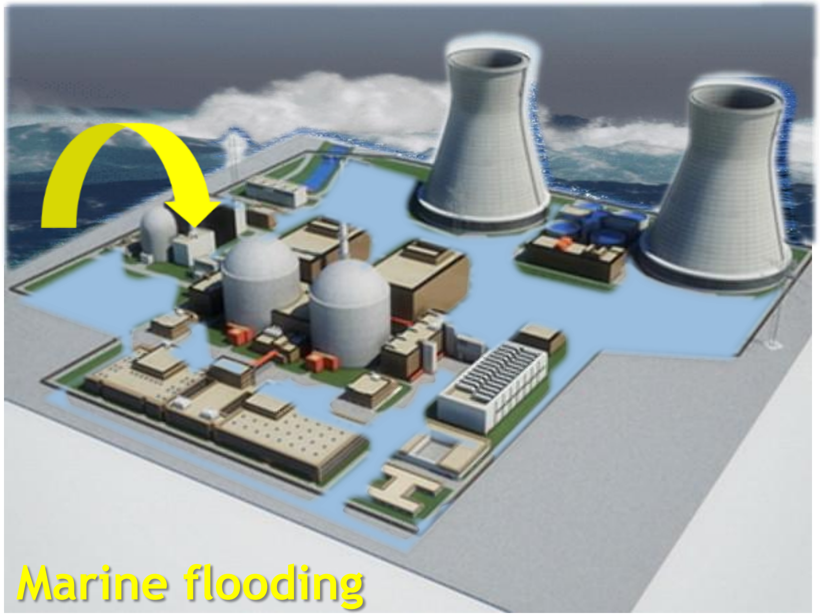
- Studies, assessments and research on natural hazards (earthquakes, revering and coastal flooding, geotechnical instabilities, extreme temperatures & heat waves, violent winds, etc.) potentially affecting the facility safety.

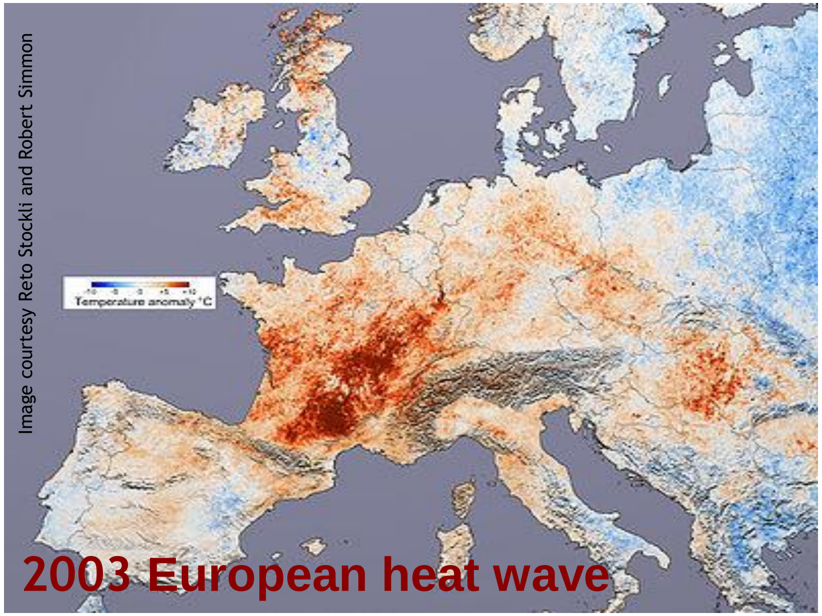
Hydrogeological, geotechnical, meteorological and flood hazards assessment section (BEHRIG)

- Technical support to the French nuclear safety authority
- Research on meteorological and flood hazards

Introduction

- Over 75% of electricity in France is from nuclear energy (19 Nuclear Power Plants (**NPPs**) in France with 55 reactors);
- NPPs and any other Infrastructures and facilities are exposed to either of these natural hazards (earthquakes; rivers and marine floods due to extreme precipitation and storm surges; heatwaves, violent winds, etc.).

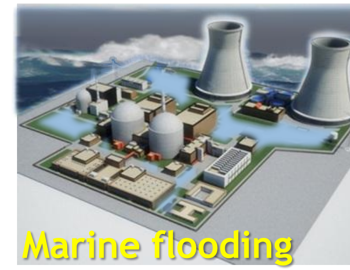


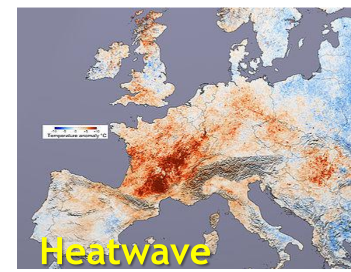


France has experienced many extreme meteo & climatic events in the last few decades:

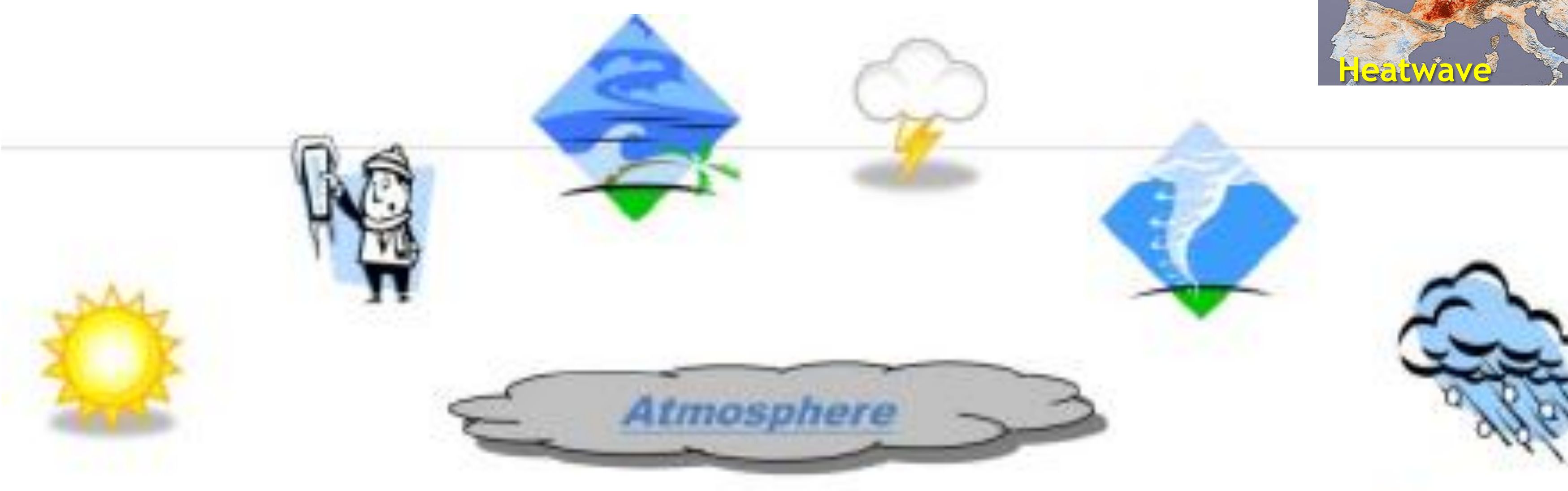
- Storms: 1953, 1987, Martin in 1999, Klaus in 2009 and Xynthia in 2010 (The Blayais NPP was partially flooded when storm Martin struck the French coast in 1999).
- France was hit especially hard during the 2003 European heat wave.

Hydro-meteorological hazards assessment: practices in nuclear safety field and scientific challenges





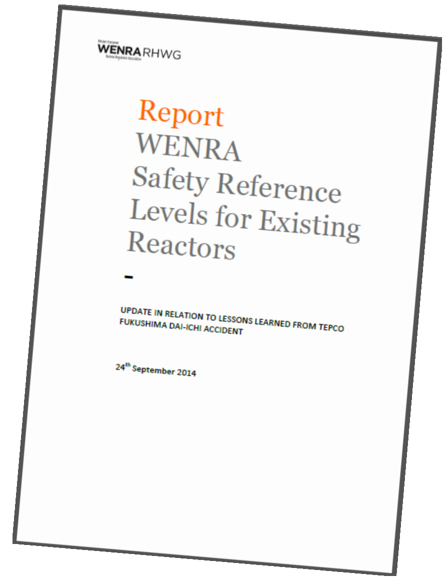
- Frequency analysis methods for extreme events
- Current scientific challenges



General approach for external hazards

- **Event usually defined by 2 typical parameters**
  - Intensity
  - Frequency

- **Main steps**
  - Characterization of an extreme hazard/event
  - Hazard characterization at location(s) of interest
  - Effects on structures/equipments



WENRA RHWG

Report
WENRA
Safety Reference
Levels for Existing
Reactors
-

UPDATE IN RELATION TO LESSONS LEARNED FROM TEPCO FUKUSHIMA DAI-ICHI ACCIDENT

24th September 2014

- **A very low target value of frequency**

"A common target value of frequency, not higher than 10^{-4} per annum, shall be used for each design basis event." according to Safety reference level for existing reactors (Wenra report, 2014)

General approach to characterize meteorological & hydrological hazards

Methods for assessment of the hazards

- **Deterministic**
  - Description of phenomena using models
  - Maximization of the inputs to account for uncertainties
  - For obtaining conservative outputs

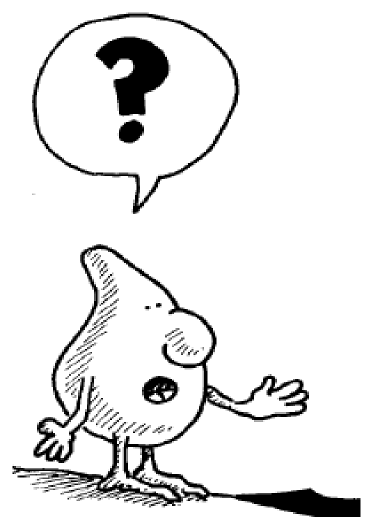
- **Probabilistic**
  - Description of phenomena using models
  - Probabilistic descriptions of all inputs to account for uncertainties
  - For obtaining output values associated with frequency of exceedence (1/return period)
  - In hydrology, used only for tsunami. On going R&D.

Uncertainties

statement from the IAEA safety guides (***IAEA Safety Standards - Specific Safety Guide No. SSG-18***):

IAEA
International Atomic Energy Agency

> « The assessment of the hazards implies the need for treatment of the uncertainties in the process… »
>
> International Atomic Energy Agency



Uncertainties

Need a stepwise approach for uncertainty analysis, reduction and estimation

- Sources… data quality, sampling methods, frequency models and projection into the future (i.e. errors in trend models) are major sources of uncertainty;
- Methods for calculating confidence intervals (CIs) have already been intensively studied in the literature. Nevertheless, theses methods were often used separately in a stationary context, without in-depth comparison …

thought of as a feature of nature and cannot be reduced

Uncertainty

Aleatory

stationary & non-stationary

Confidence intervals

Delta

Profile likelihood

Bootstrap

Epistemic

require more careful consideration

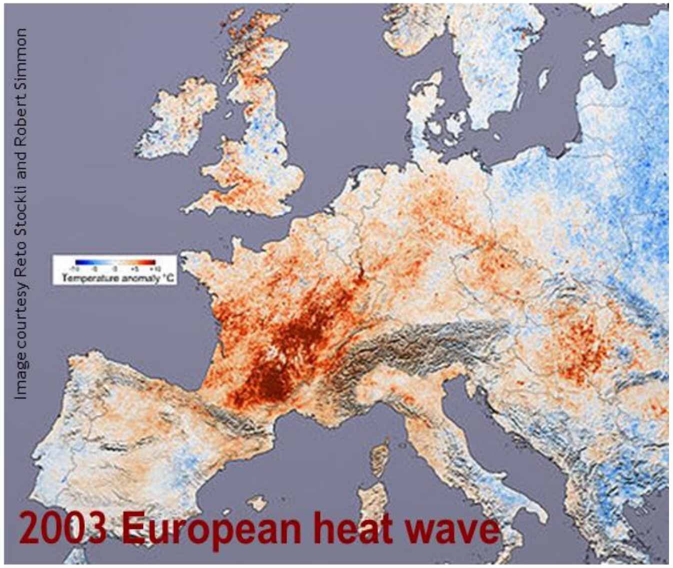
Improve models choices & assumptions

Use the likelihood ratio, *AIC* & *BIC* to:

- select the best distribution
- select the best trend model (non-stationary climate).

The hazard "high temperature" & "heatwave"

- Nuclear power plants (NPPs) are subject to extreme temperatures and heat waves
- France has experienced many extreme heat waves in the last few decades. It was hit especially hard during the 2003 European heat wave… 2015



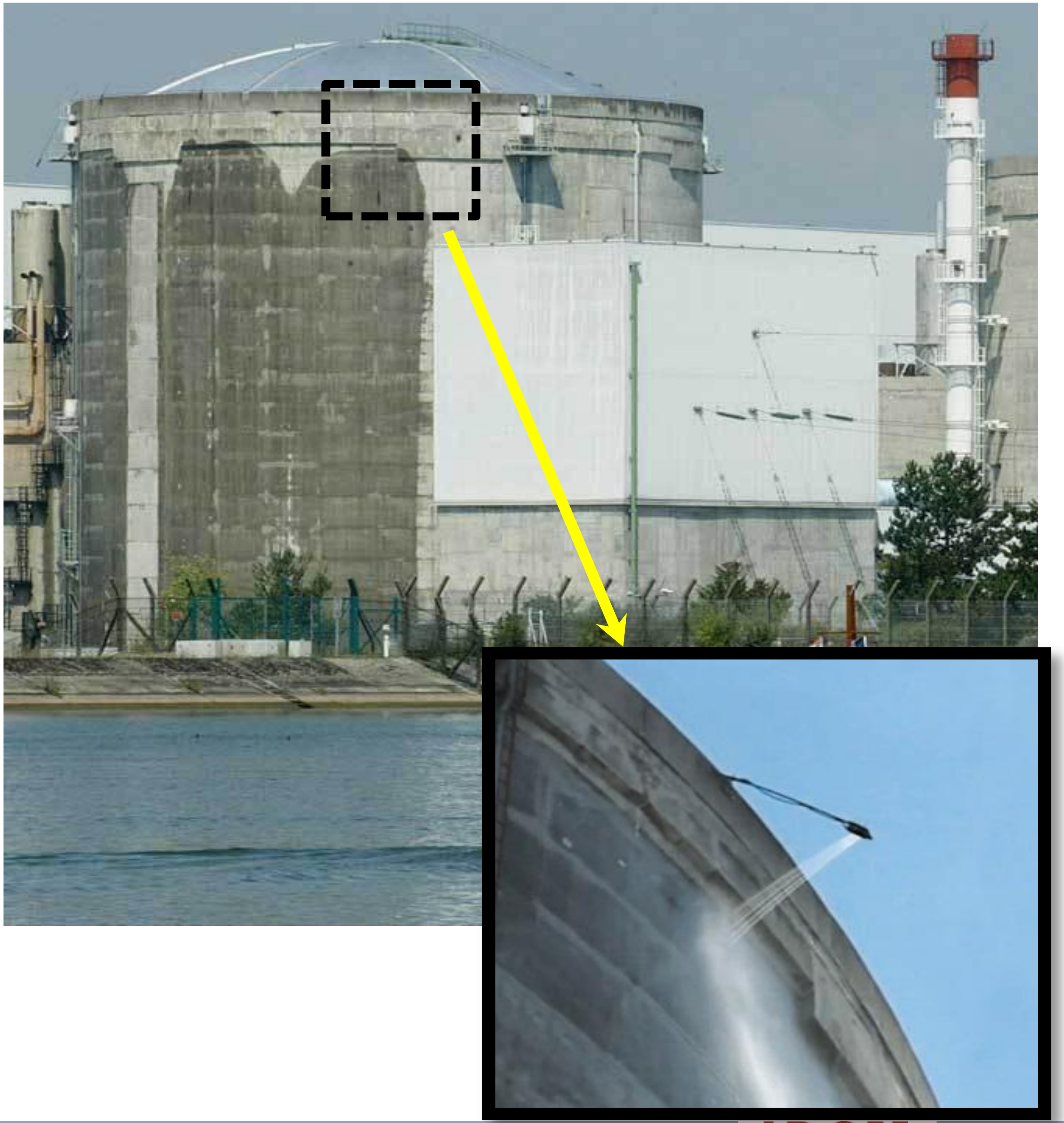
- According to the World Meteorological Organization, the 2003 European heat wave led to the hottest summer on record in Europe since at least 1540.
- The heat wave led to health crises in several countries and combined with drought to create a crop shortfall in parts of Southern Europe.
- In France, 14,802 heat-related deaths (mostly among the elderly) occurred during the heat wave, according to the French National Institute of Health.

The hazard "high temperature" & "heatwave"

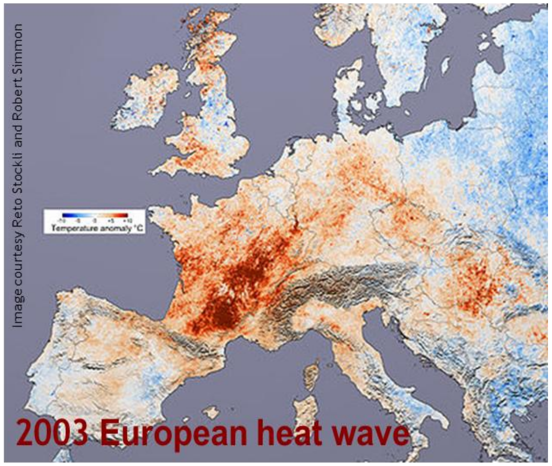
Fessenheim NPP (France) 2003

Here is how the cooling took place in **Fessenheim NPP** (in France) during the 2003 heat wave…

The cooling system is essential to safeguard and preserve a reasonable temperature in the reactor building.



The hazard “high temperature” & “heatwave”



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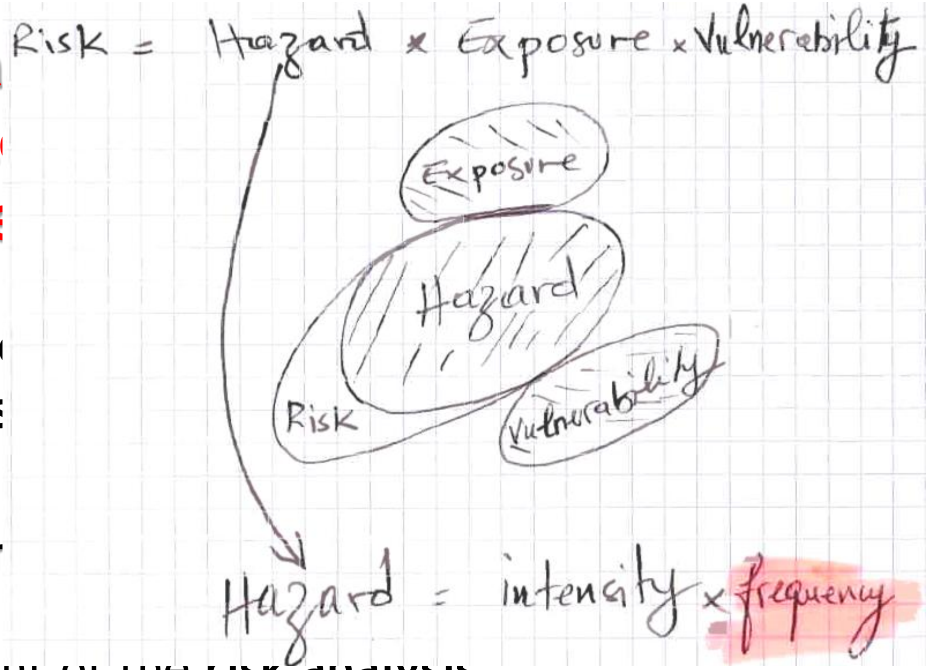
Need to ana
associated t
temperature



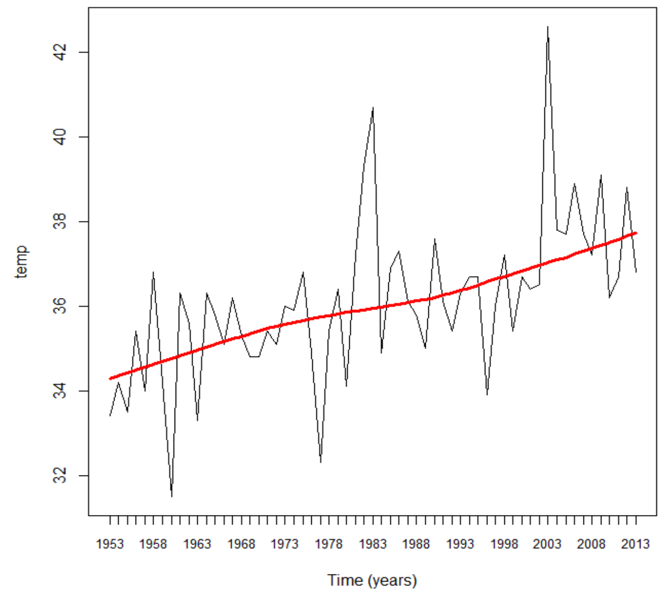
Characterizati
and risk analys

Frequer

key component of the **risk analysis**

Extreme temperature is non-stationary

- Climate and urbanization evolution
- Estimating temperature extremes and associated uncertainties under the **non-stationary assumption** is a key research question in several domains including the nuclear safety field
- In a **non-stationary context**, the notion of return period is not easily interpretable. For instance, to predict a high return level in a future year, time-varying distributions must be used and compared



Time-varying GEV distribution

$$F\left(x;\mu(t);\sigma(t),\xi\right) = exp\left\{-\left[1+\xi\,\frac{x-\mu(t)}{\sigma(t)}\right]^{-1/\xi}\right\}$$

μ : location
σ : scale
ξ : shape

Time-varying GEV distribution

- **Time evolution parameters are detected and estimated.**
  - Regression structures allowing up to quadratic dependence on time could be considered for m and s parameters. The simplest case with a linear regression is considered for the location parameter:

$$\mu(t) = \mu_0 + \mu_1 t$$

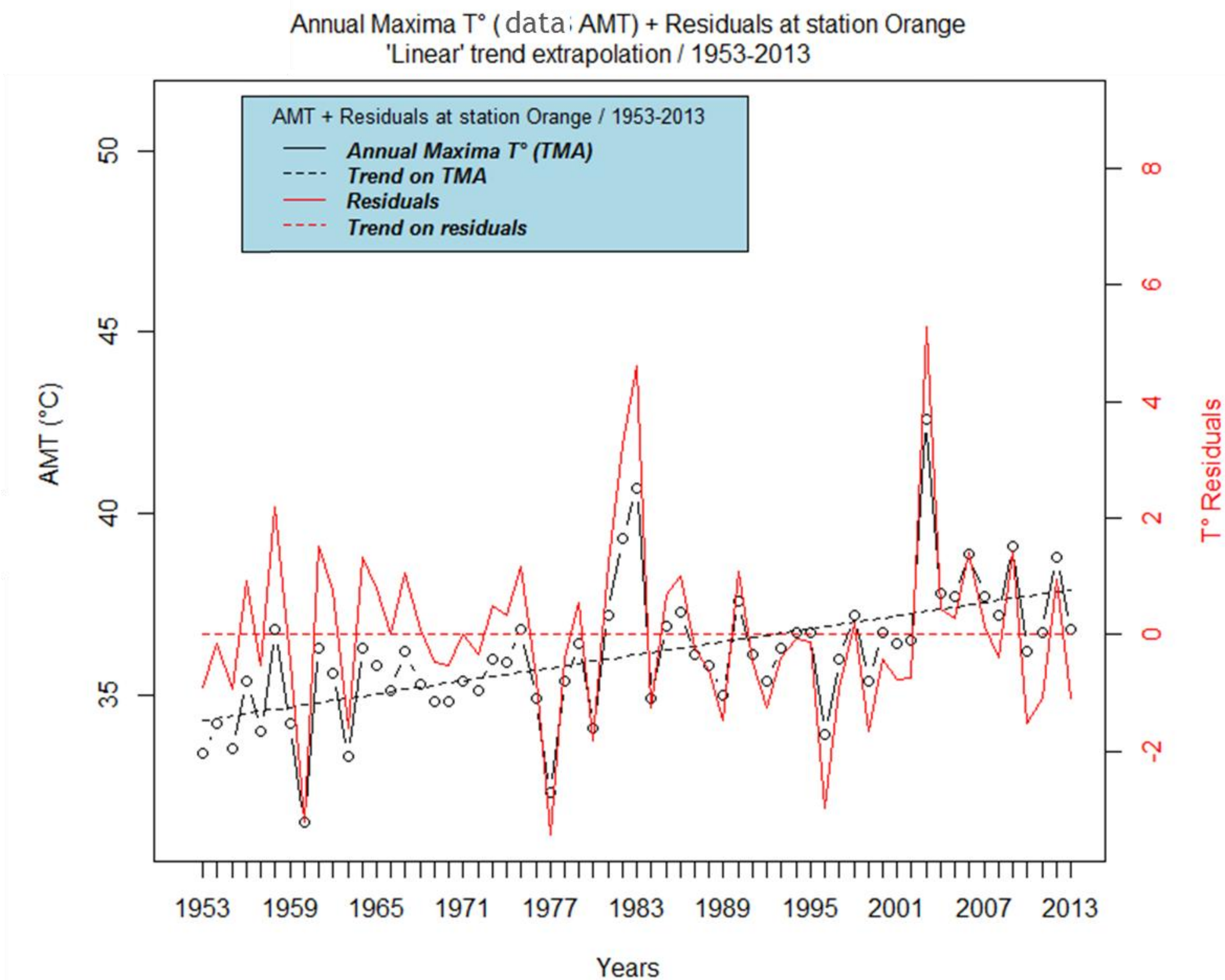
  - Model the time series with multiple linear trends and locate the times of significant changes (Break dates)
  - To select the best time-varying model, we compare criteria (AIC, BIC and the likelihood ratio).

The case study

Application

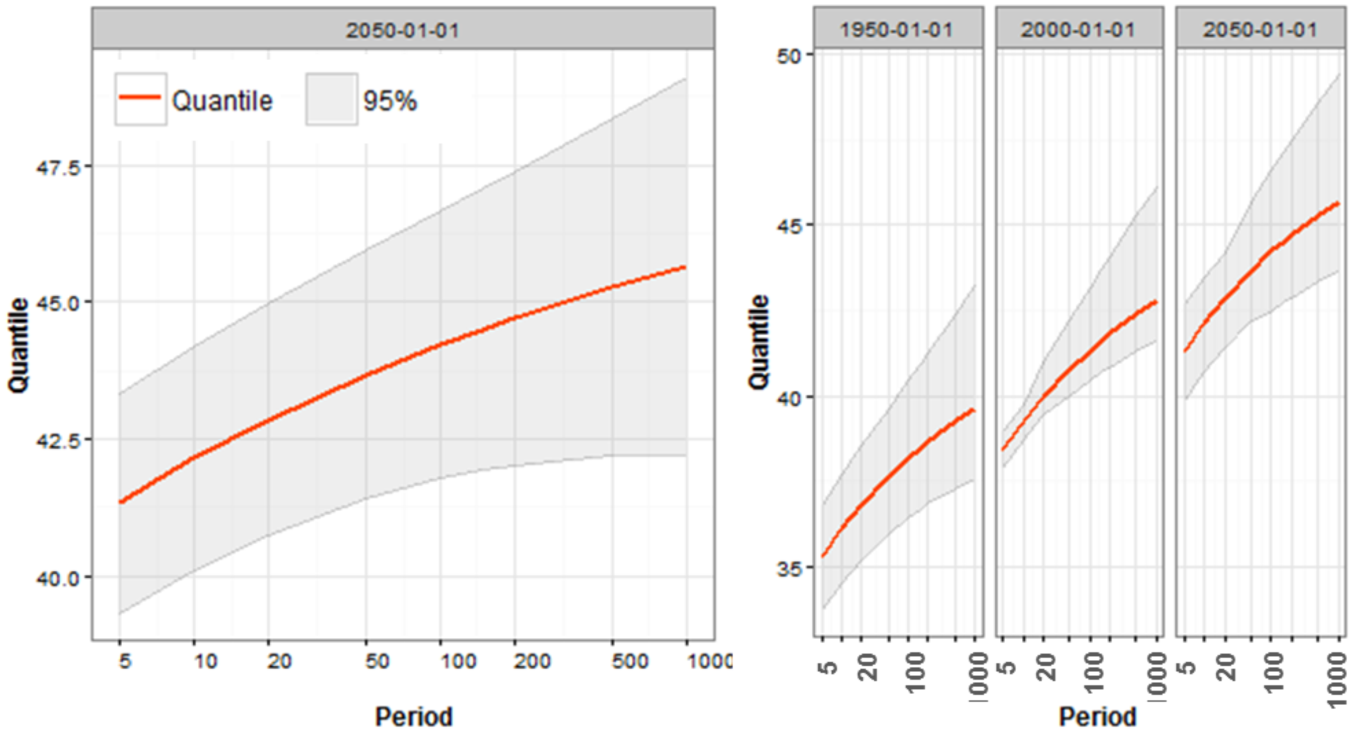
Orange station in southern France

Extreme temperature & residuals

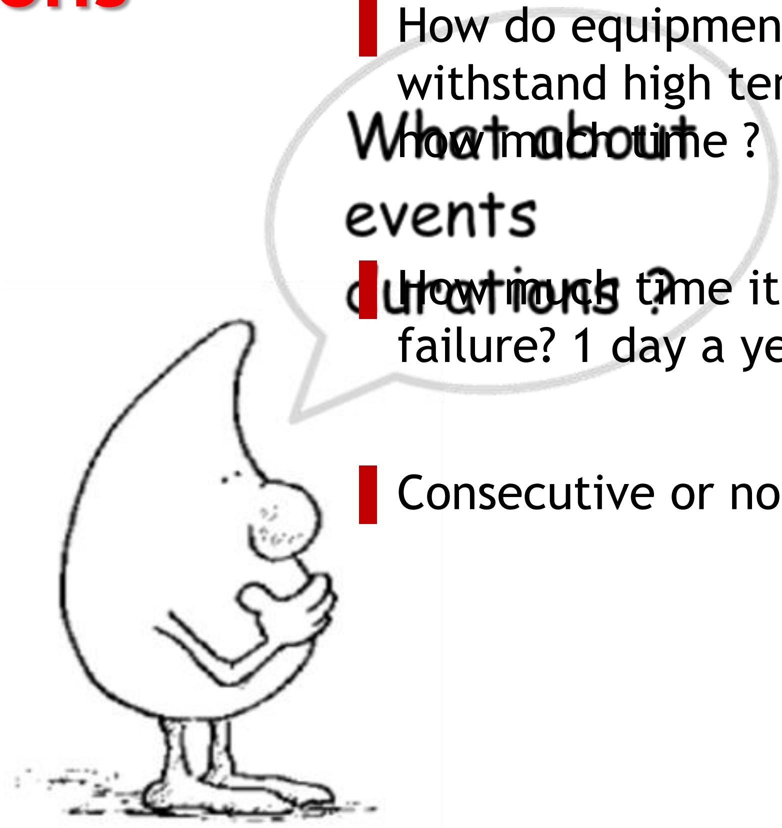


Prediction of the extreme temperature for the year 2050

- Return levels (>100 years) has reached 44°C.
- The CIs were calculated with the delta method in the left panel of the figure and for 3 different dates (1950, 2000 & 2050) with the likelihood profile (to the right).



Events durations



- How do equipments (sensitive ones!) withstand high temperatures ? And for how much time ?
- How much time it will take until failure? 1 day a year, 2 days … or more ?
- Consecutive or non-consecutive days ?

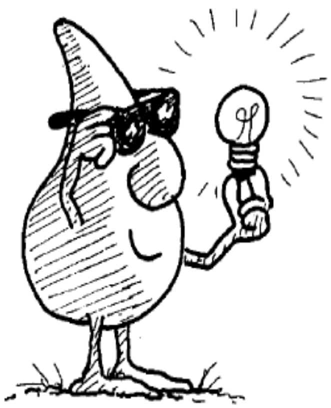
Events durations

- The thermal inertia of buildings that can heat up very quickly (in metal frame) or more slowly (concrete buildings)
- In buildings: material and equipment more or less sensitive to high temperatures (electronics, engines, ...)
- The temperature of the reactor's primary heat sink (rivers, bodies of water, etc.) is also a significant safety issue (thermal efficiency and discharge).

Events durations

- Characterizing extreme temperatures and heat waves were often performed with the extreme value theory **but rarely with duration modeling**.

- For a modern risk-based approach, knowledge of the magnitude and frequency of occurrence **for a given duration** and **number of exceedances** are prerequisites.



- The notion of duration is not easily interpretable in a frequency analysis and can even be subtle.

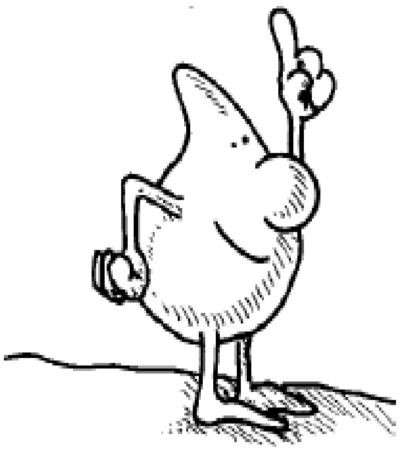
- Few methods have been proposed in the literature to tackle this issue. The most important contributions propose the **Temperature-Duration-Frequency** (**TDF**) concept.

- **For systems more susceptible to extreme temperatures, we estimate a relatively high temperature associated to a sum of non consecutive days.**

Material & Methods

- As a matter of fact, the non-consecutive exceedances are nothing else than the annually ***r*-Largest-Order-Statistics** (**r-LOS**).

- A new and more rational approach to estimate a design temperature considering events durations is presented herein. The approach is based on the set of **Temperature-rLOS-Frequency (TrF) curves**.



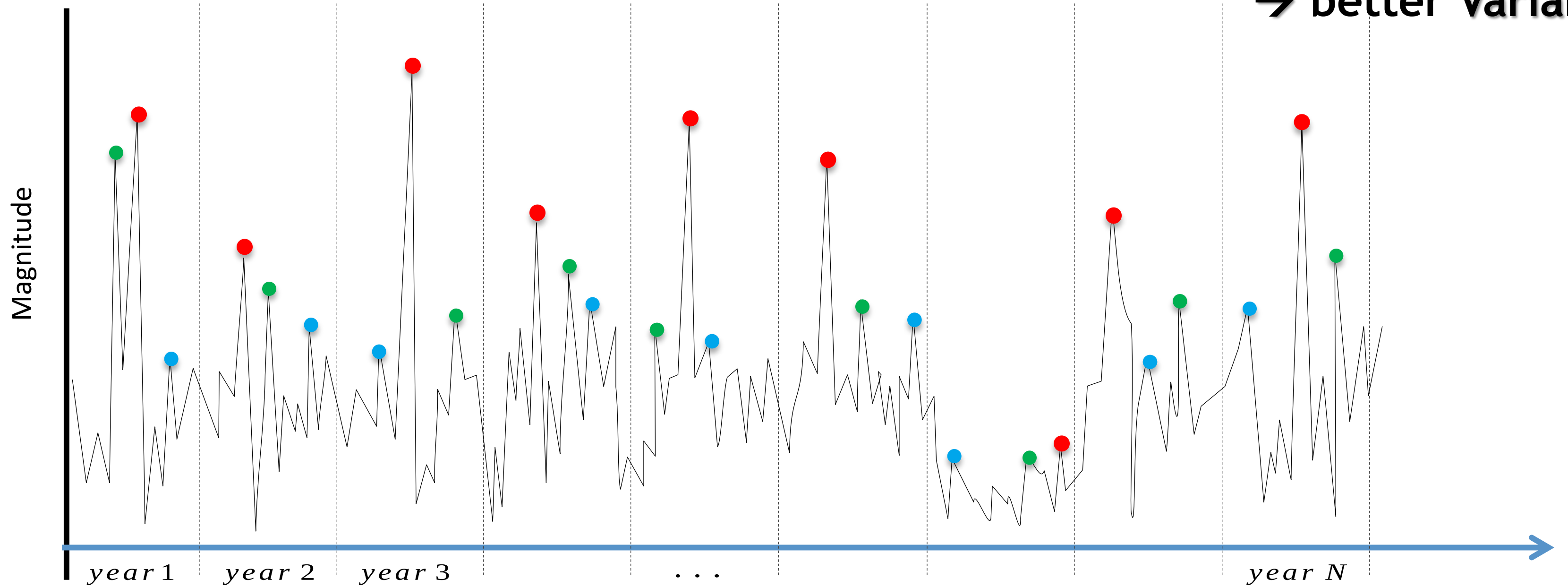
- Annual extreme temperatures of duration r=1,…,10 non-consecutive-days are used and 10:100-years Return periods are used.

The r-LOS sample

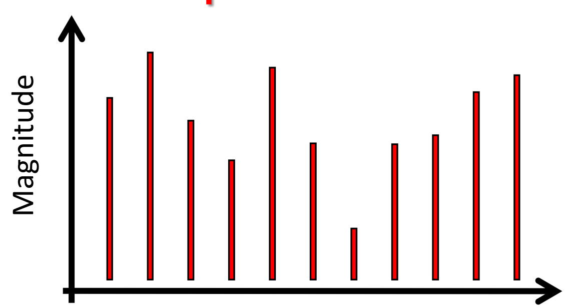
Data available for N years → **r largest observations each year**

- **better sample siz**

→ better Variance

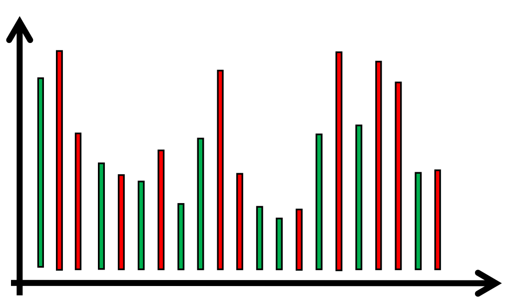


AM sample



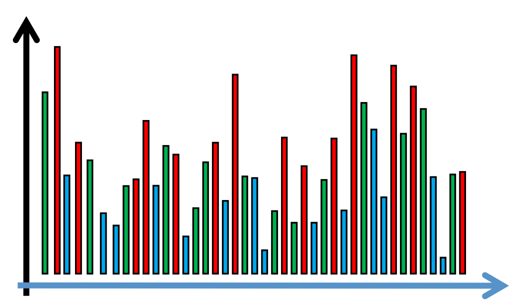
r=1 event/year

r-LOS sample



r=2 events/year

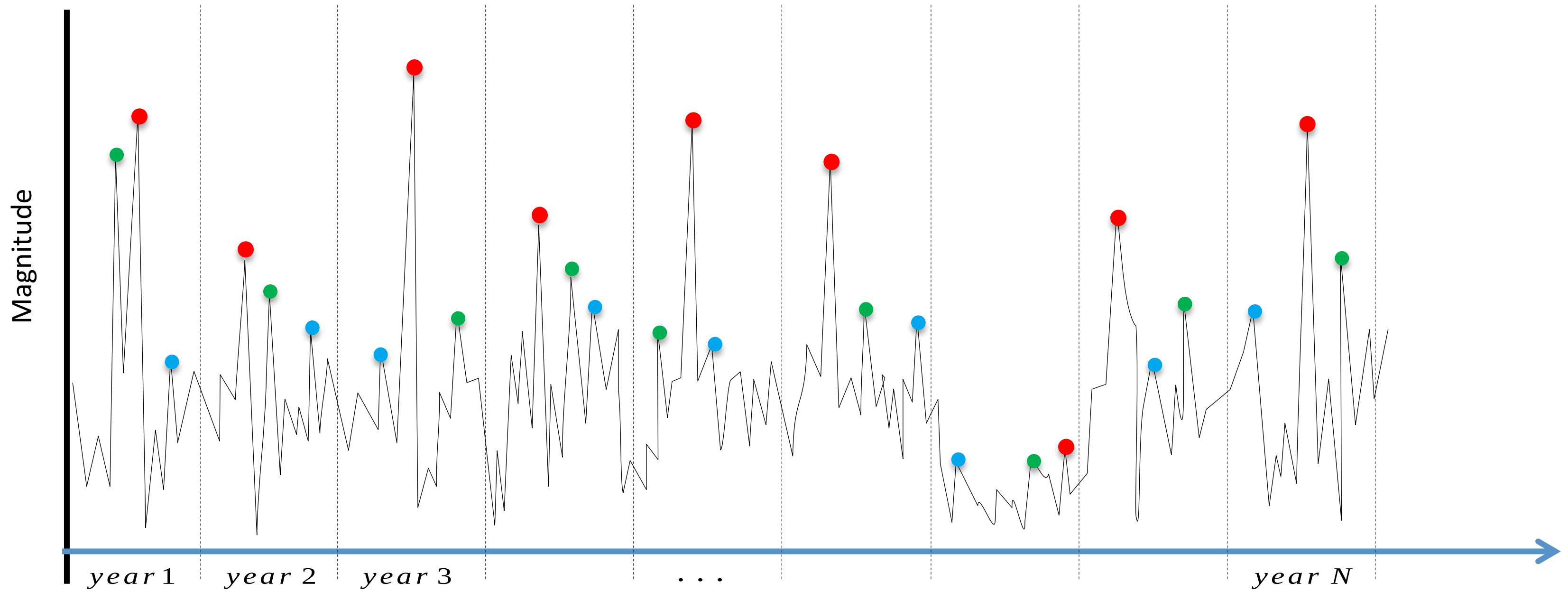
r-LOS sample



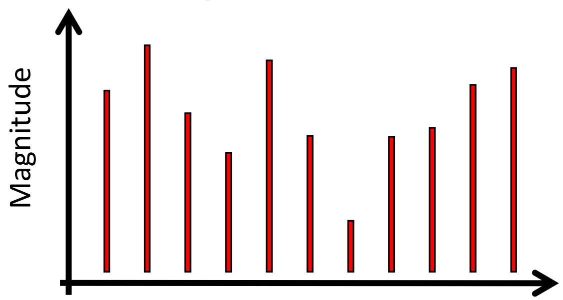
r=3 events/year

The r-LOS sample

Data available for N years → **r largest observations each year**



AM sample

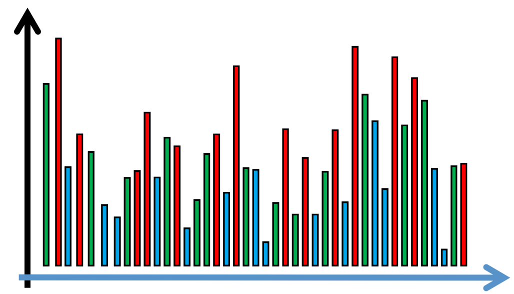


r=1 event/year

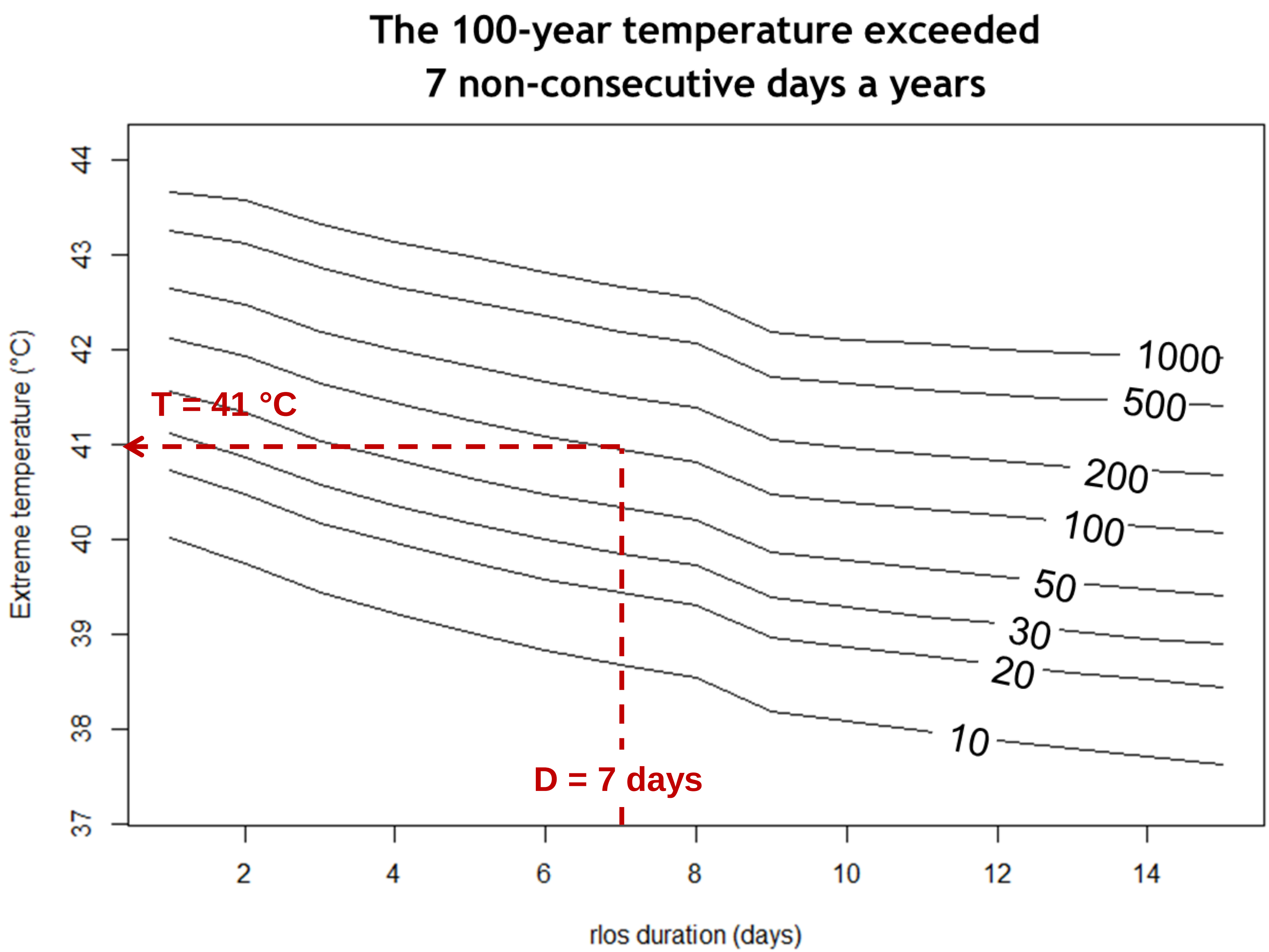
As a bonus, we have a better sample size

→ better Variance

r-LOS sample



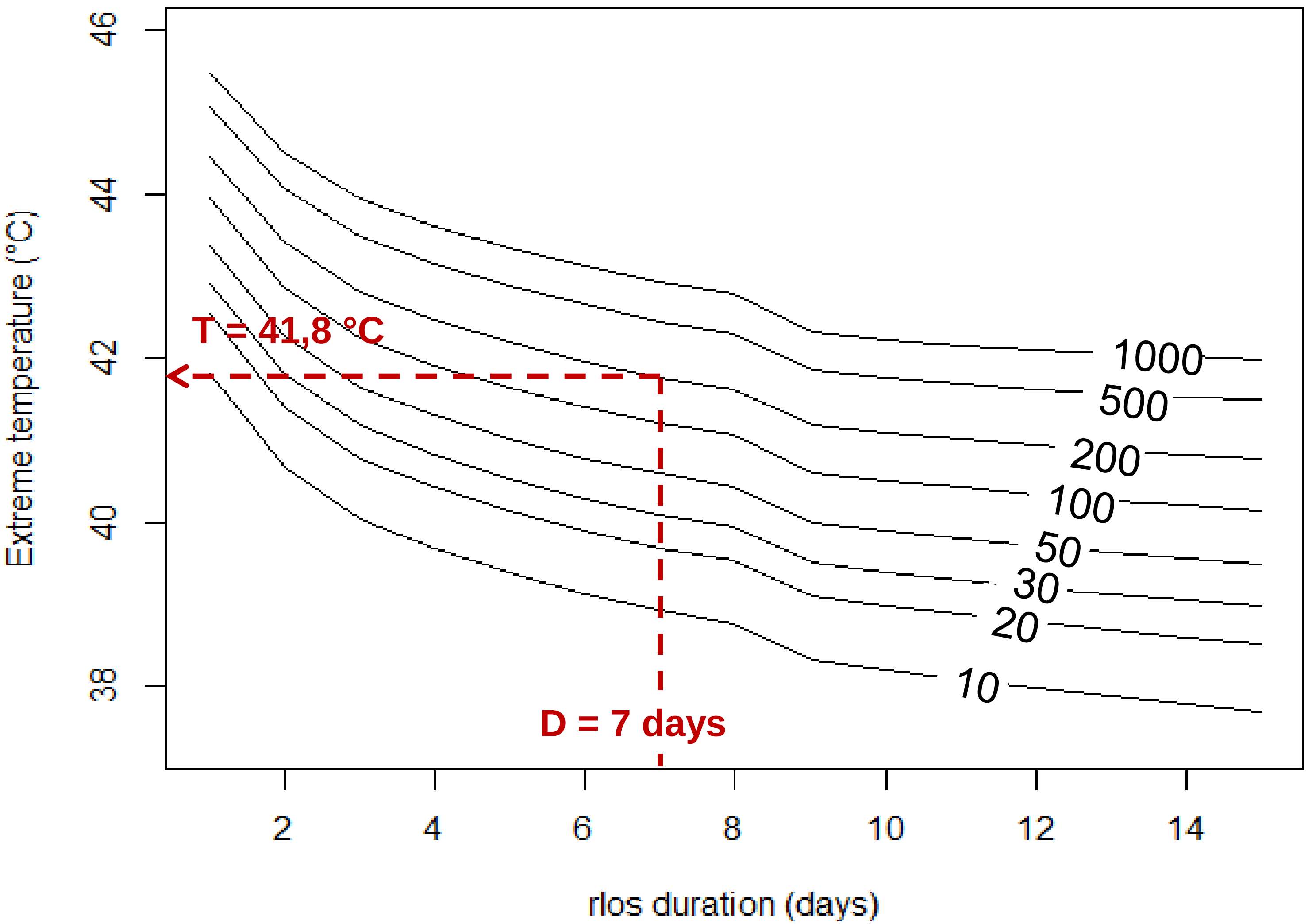
r=3 events/year


The 100-year temperature exceeded
7 non-consecutive days a years
Extreme temperature (°C)
37
38
39
40
41
42
43
44
2
4
6
8
10
12
14
rlos duration (days)
1000
500
200
100
50
30
20
10
T = 41 °C
D = 7 days

Results

The 100-year temperature exceeded 7 non-consecutive days a years

(in a future year : 2047 !!)



On going R&D

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Thank you for your attention

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