NARSIS

New Approach to Reactor Safety ImprovementS

Modelling External Hazards: example of application of the French directive for Basic Nuclear Installations (BNI)

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IRSN

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Outlines

- Context
- Quantification of the Extreme Sea Levels in the French Guide (ASN Guide n°13)
- Focus on storm surges evaluation: the problem of outliers
- Conclusions & Perspectives

Nuclear Facilities in France

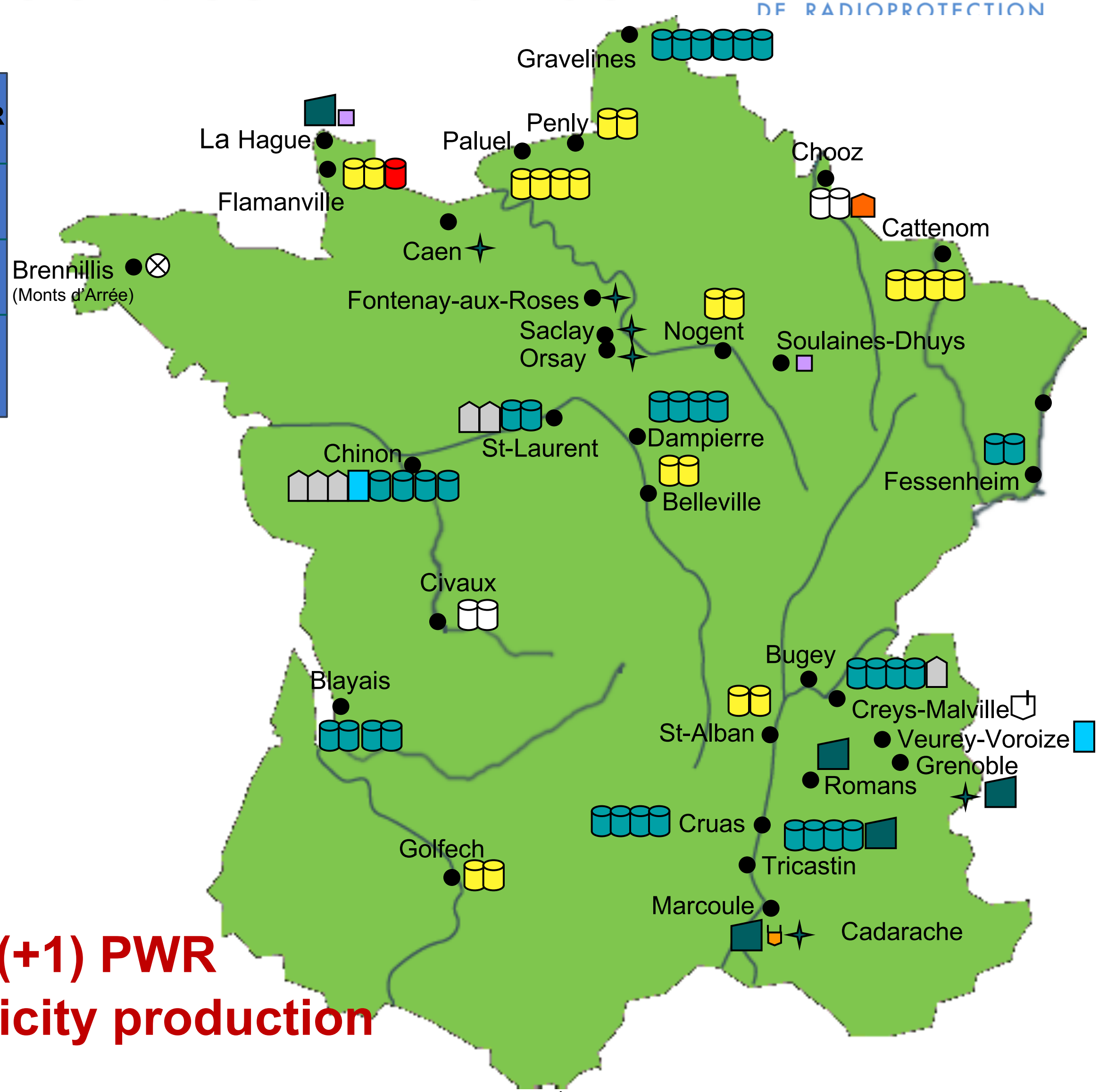
58 + 1PWR					Graphite Gaz	Gaz Eau lourde	1 FNR
300 MWe	900 MWe	1300 MWe	1450 MWe	1600 MWe			

Fuel cycle
(enrichment, fabrication, retreatment))

Waste disposal sites

Research centers

Laboratories



- **Whole cycle**
- **4 major operators**
- **1 manufacturer**
- **Standardized fleet of 58 (+1) PWR**
- **75% of the French electricity production**

French Nuclear Actors

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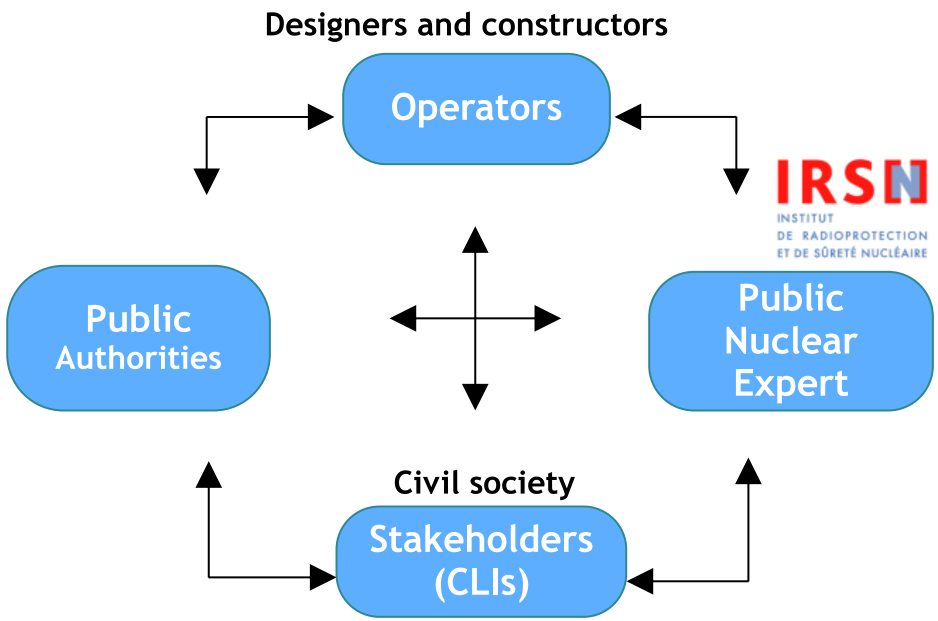
- **Operators** ensure the prime responsibility of the safety of their nuclear facilities. Operators receive authorization to continue the operation for 10 years at the end of which a thorough safety review has to be performed. EDF (single NPP operator), Areva/Framatome (fuel cycle installations), CEA (research

- **Public authorities (Ministries, ASN, ASND)** define nuclear safety, security and radiation protection policies.



The Public Expert conducts research to enhance nuclear safety and provide public authorities with an independent high-level expertise capacity. It works for benefit of 3 others

- **Local Information Committees (CLI) and the High Committee for Nuclear Transparency (HCTISN):** communication to public.

Flooding Hazard

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- Various flooding sources (oceans, rivers, estuaries,…)
  - 19 nuclear power plant
    - 14 river sites
    - 4 coastal sites
    - 1 estuary site

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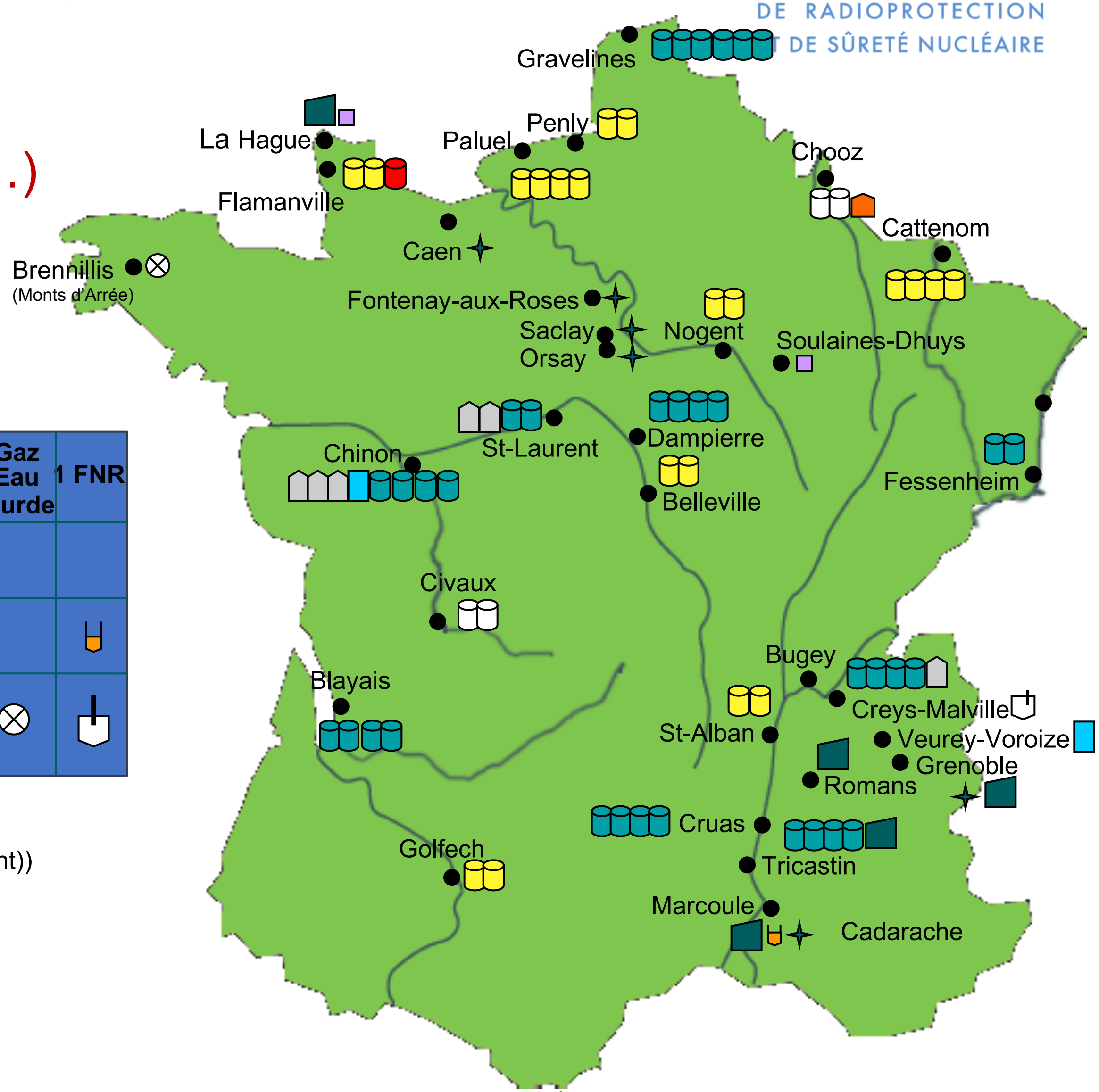

The French ASN Guide n°13

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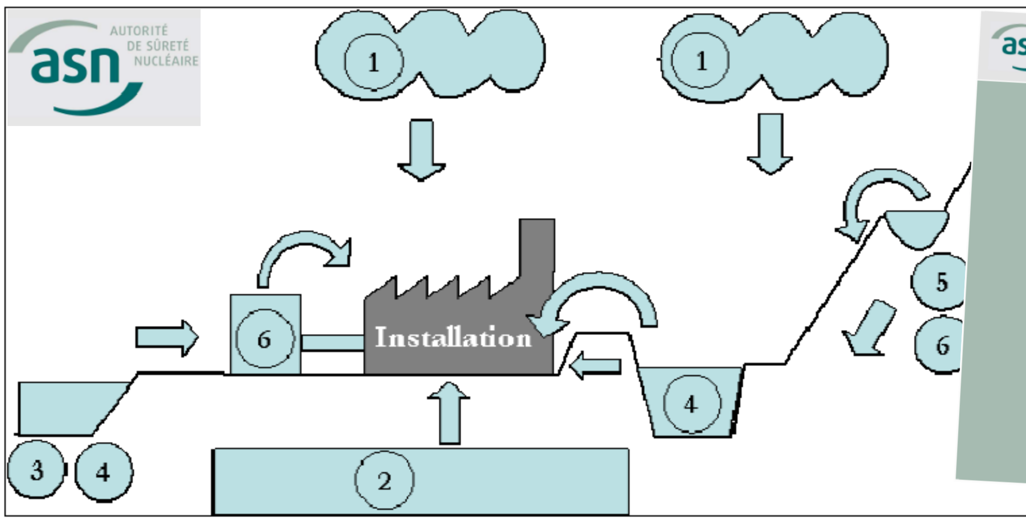
- ➢ Reference Flood Situations (RFS) defined in the flooding guide (ASN, 2013)
  - ❑ Deterministic approach with statistics of extreme used in several situations



RFS
PLU: Local rainfall
CPB: Small watershled flooding
CGB: Large watershed flooding
DDOCE: Malfunctioning of structures, circuits or equipment
INT: Mechanically induced wave
RNP: High groundwater level
ROR: Failure of a water-retaining structure
CLA: Local wind waves
NMA: Sea level
VAG: Ocean waves
SEI: Seiche

- ❑ The target value frequency « 10-4/year » is generally lower than the state of art available with statistics of extremes
  - Addition of margins / combination of events (dependent, independent or partially dependent)
  - Penalisation of influencing parameter

The Extreme Sea Level

- Extreme *Sea Level "NMA"* (ASN, 2013)
- Agreed sum of:
  - The maximum level of the theoretical tide,
  - The change in mean sea level extrapolated until the next safety review,
  - The 1000 year return period storm surge (upper bound of the 70% confidence interval)
    - + 1 m to take account of the "outliers"
    - Or statistic model for "outliers" (extreme event)

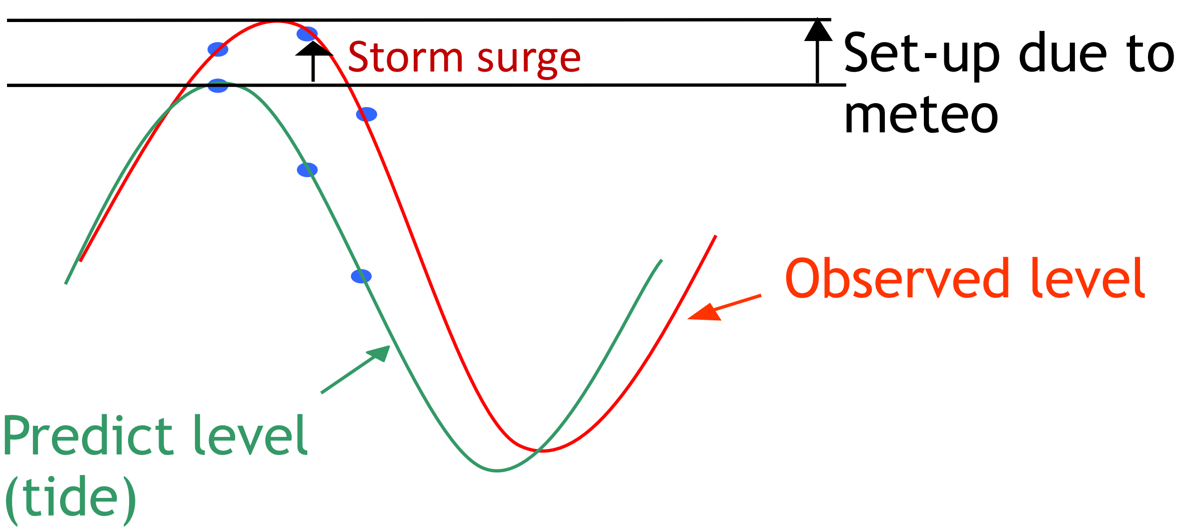
	Probabilistic objective: 10^{-4} / year, with uncertainties		
RFS	**Basis Hazard**	**Increase / combination of events**	
NMA: Sea level	maximum level of the theoretical tide + expectable climatic evolution	1,000-yr storm surge (UB of the 70% CI)	+ 1 meter (to take account the "outliers") *Or* statistic model for "outliers" (extreme event)

- Focus on storm surge evaluation: the problem of outliers !!!

The Extreme Sea Level

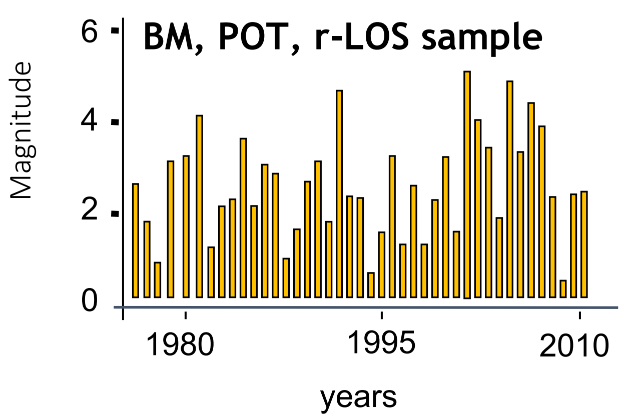
➢ Methodologies for storm surge quantification

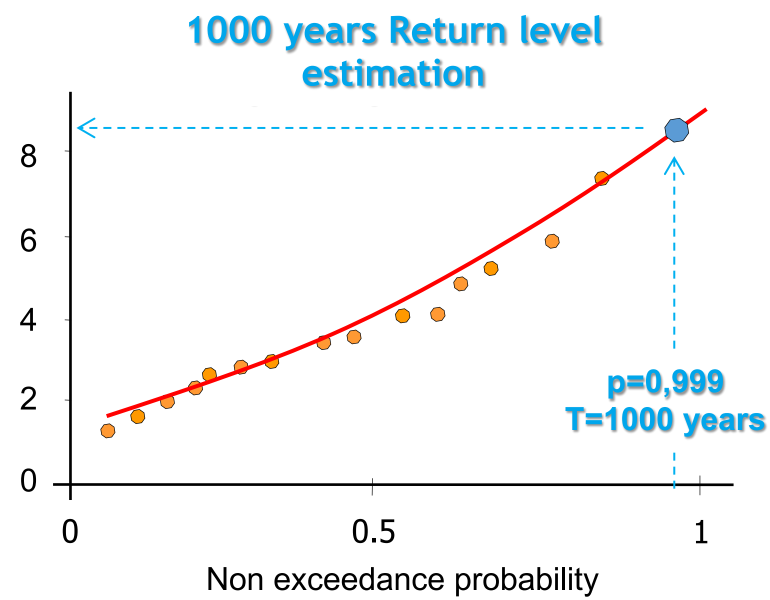
- The storm surge is defined as the difference between the observed water level and the predicted water level at high tide
- The value can be assed through classical *local* Frequency Analysis (FA)
- Alternatively, Regional Frequency Analysis “RFA” can be used (for instance)
- Historical information “HI” can improve results from both methods



The Extreme Sea Level

- Methodologies for storm surge quantification: local FA
  - Raw data & Hypothesis testing (stationary, independent & homogenous)
  - Frequency model selection, empirical probability computation, distribution selection & fitting
  - Adequacy criteria & tests, uncertainty estimation (confidence interval)
  - Extrapolation (1000-yr return level for example)





The Extreme Sea Level

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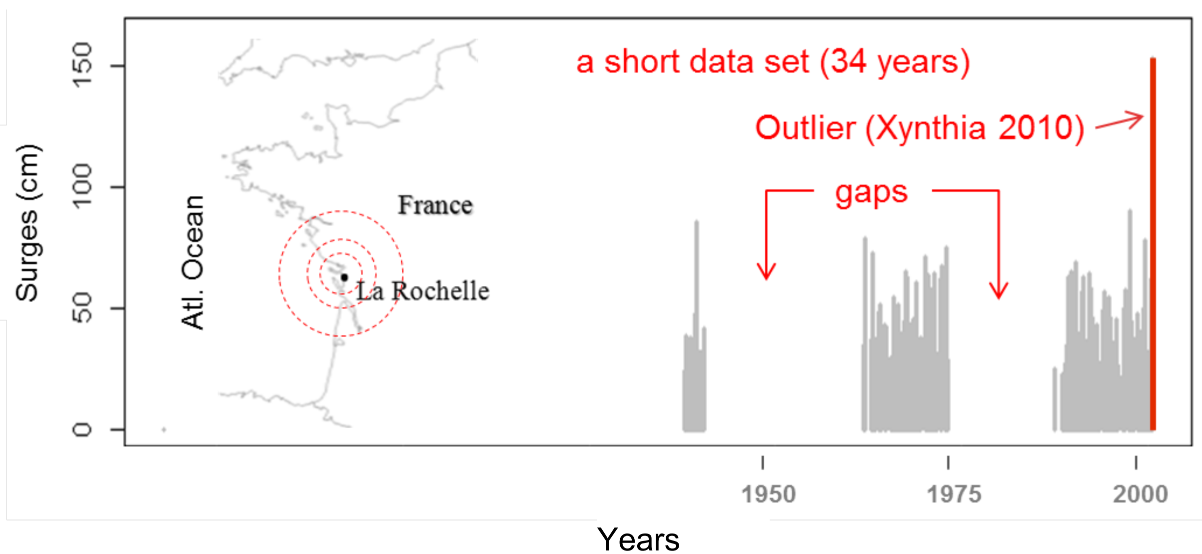
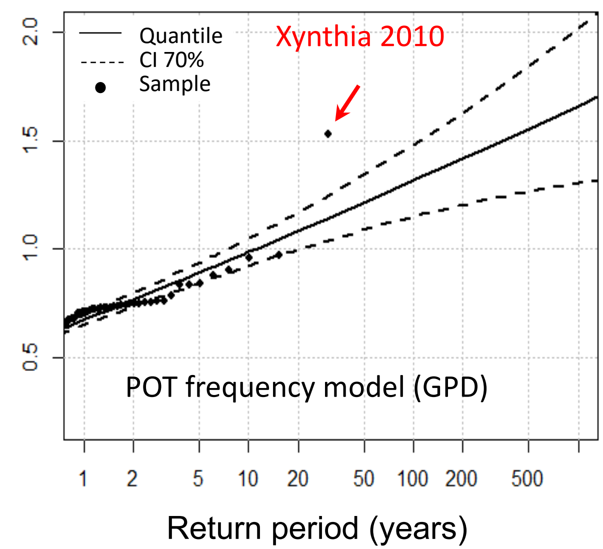
- Storm surges quantification with local FA: the impact of “outliers”
  - Results with classical local FA do not permit to have a good fit of outlier,
  - Short data set,
  - Gaps in time series.





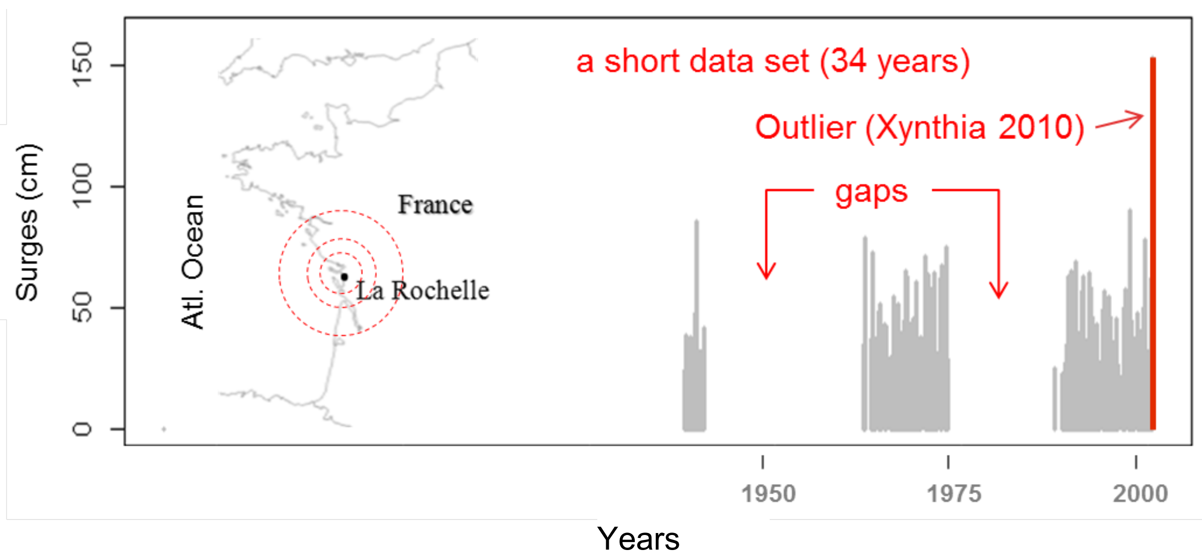
- Several observations of exceptional surges along the Northern and Western French coasts : Feb 1953, dec 1979, oct 1987, dec 1999, feb 2010 …
- According to the guide on flooding (ASN, 2013), an option to deal with outliers is to increase the extrapolated 1000-yr storm surge by 1m

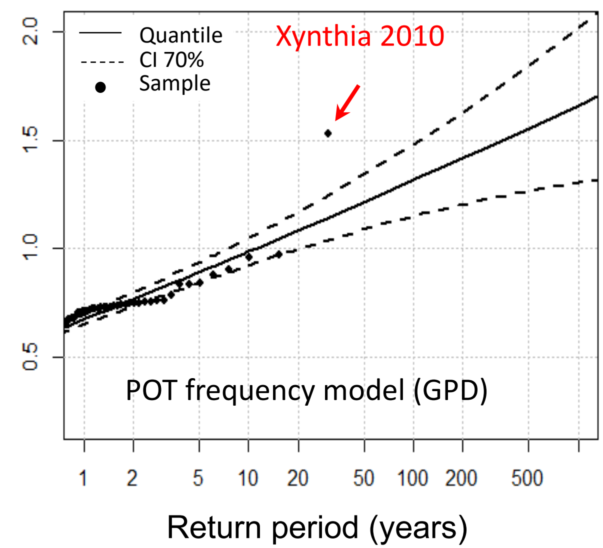
The Extreme Sea Level

➢ Storm surges quantification with local FA: the impact of “outliers”

➢ How to address more properly the FA?

- ❑ How to deal with gaps and how to enlarge the sample?
- ❑ How to increase the representativeness of the outlier in this sample?





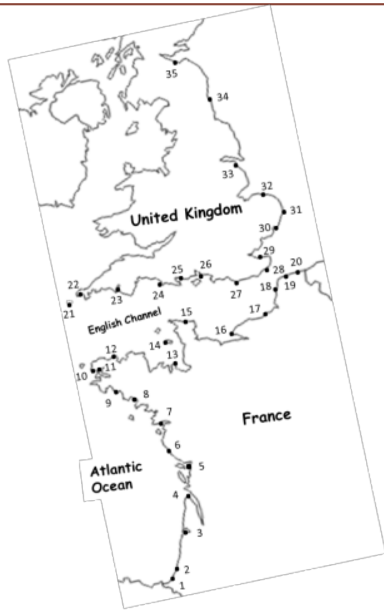
➢ Additional information (more extremes):

- ❑ Spatial information (Regional Frequency Analysis – RFA)
- ❑ Temporal information (Historical Information – HI)

The Extreme Sea Level

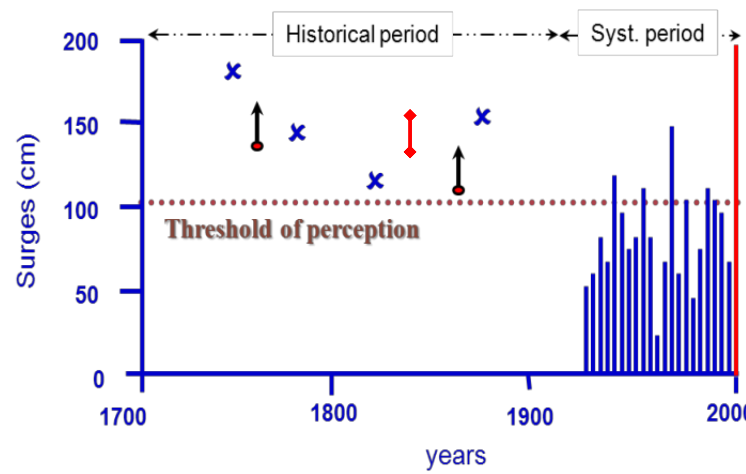
➢ With additional exceptional events, the outlier will no longer be an outlier !

Regional data



- Homogenous regions;
- One regional dist. for all sites;
- Go back to local estimates with local index.

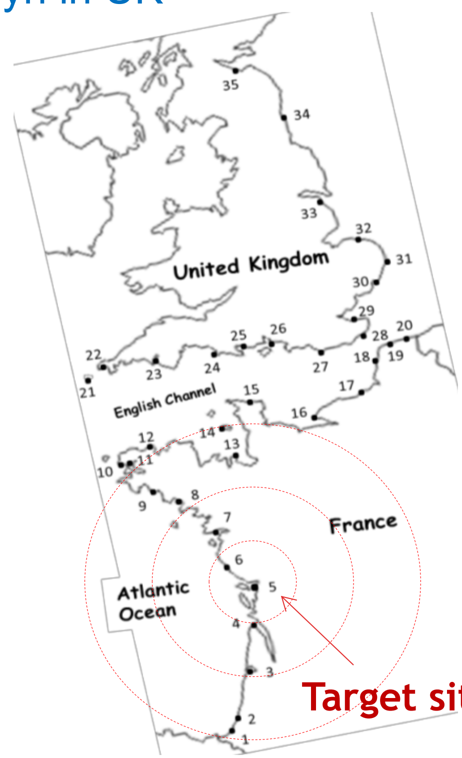
Historical Information (archives, sedimentology, …)



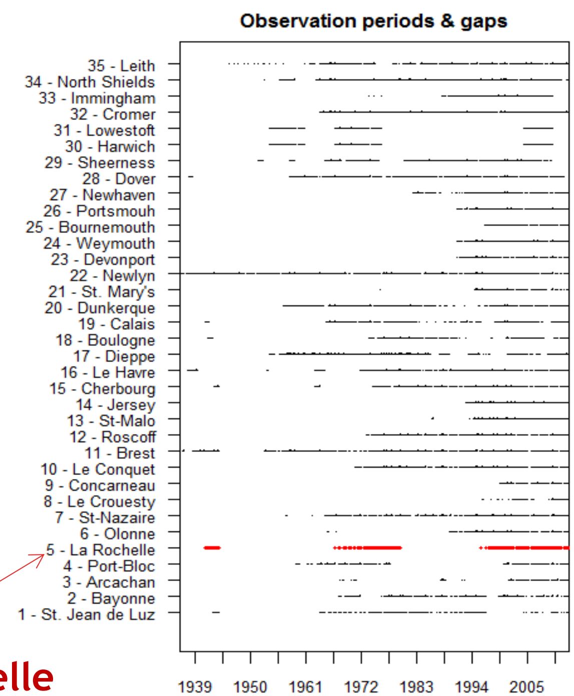
- Exact values (×)
- Lower bounds (↑),
- Range (↕)
- Threshold of perception (······)

The Extreme Sea Level

- Storm surges quantification: example of an application IRSN at La Rochelle (France)
  - The whole region: 35 harbors on the French (Atl & Eng. Channel) & British coasts
  - Whole region relatively poorly gauged, except fro sites 11 & 22: Brest in France and Newlyn in UK



Target site: La Rochelle

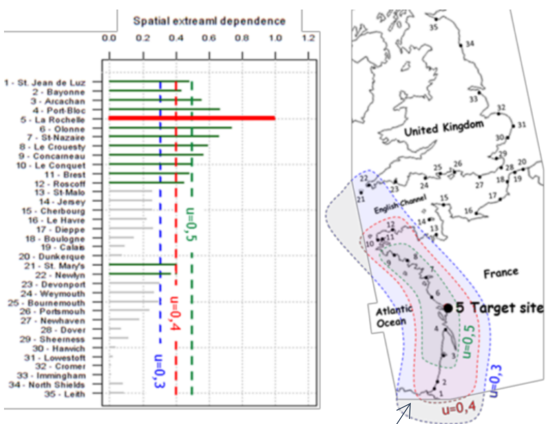


The Extreme Sea Level

➢ Storm surges quantification: RFA and HI

Regional info.

Historical Info.



Homogeneous region centered on the target site **obtained with the** [empirical spatial extremogram](#)

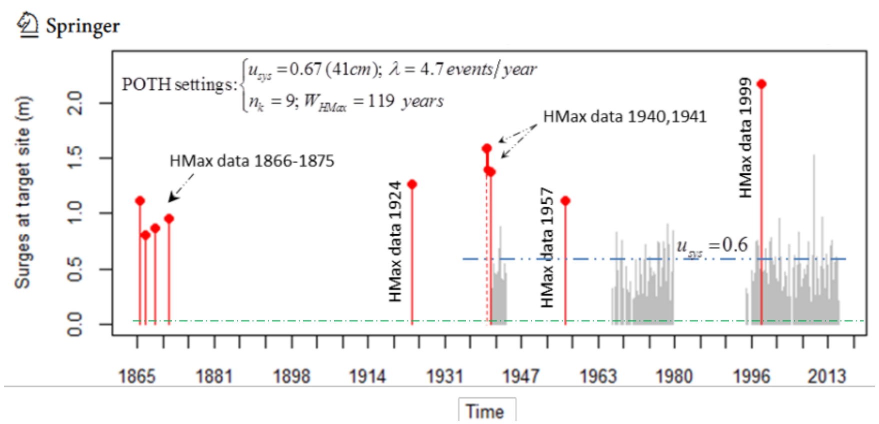
(Hamdi et al., 2018)

Regional info. is used in a local frequency analysis

A multiple linear regression is used to reconstruct local missed data using regional info.

Year	1866	1867	1869	1872	1924	1940	1941	1957	1999
Surge (cm)	111	80	87	96	127	139–159	137	111	217

Springer



"… historical information is particularly valuable in a local context." (Hosking and Wallis, 1986,1987; Tasker and Stedinger, 1987, Jin & Stedinger, 1989)

The Extreme Sea Level

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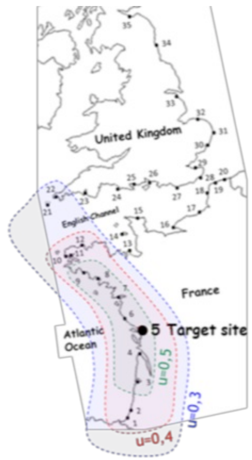
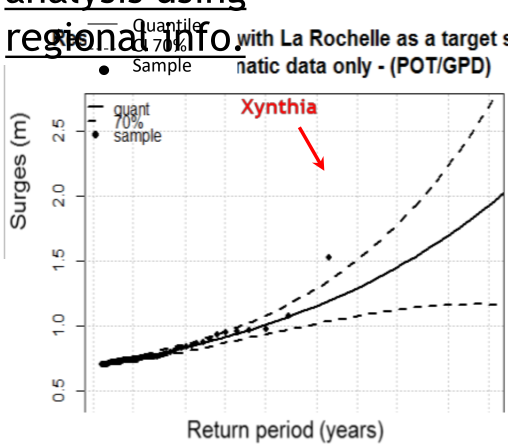
➢ Additional information: use of regional info. & historical info. separately

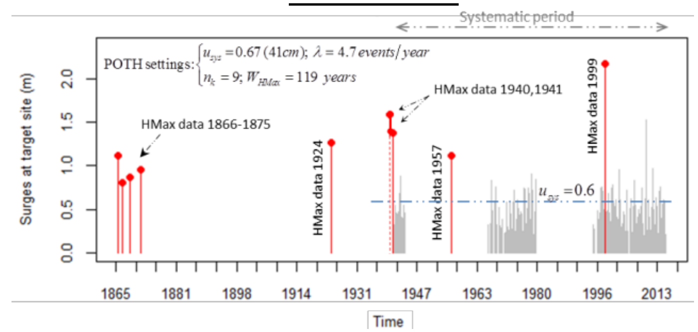
Regional info.



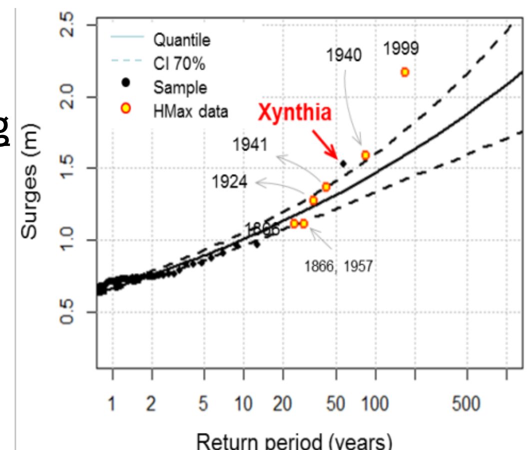
Local frequency analysis using regional info.



Historical



Local frequency analysis using historical info.

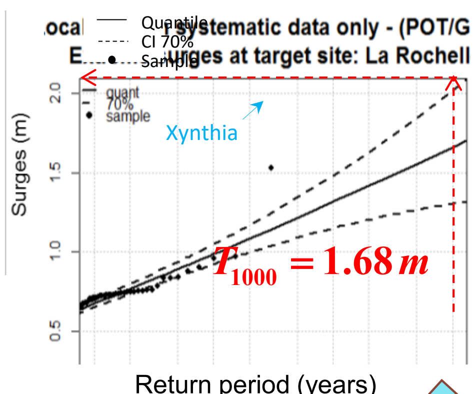


- **Better representativeness of the outlier;**
- **The fitting remains poor !**

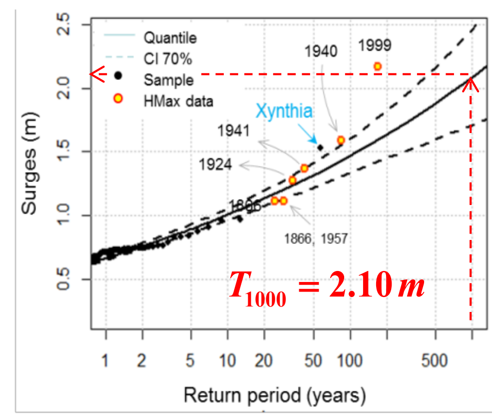
The Extreme Sea Level

➢ With historical events: with and with no regional data included

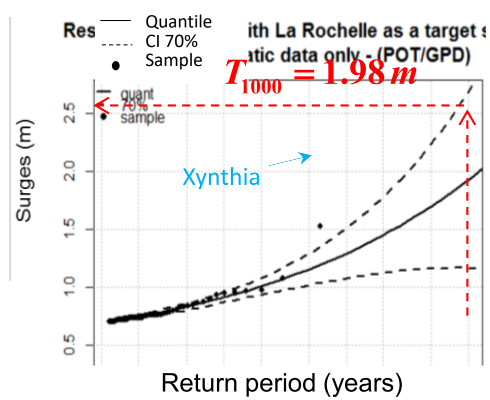
- “The outlier is no longer an outlier” in the two cases.
- Better fitting with regional data included.

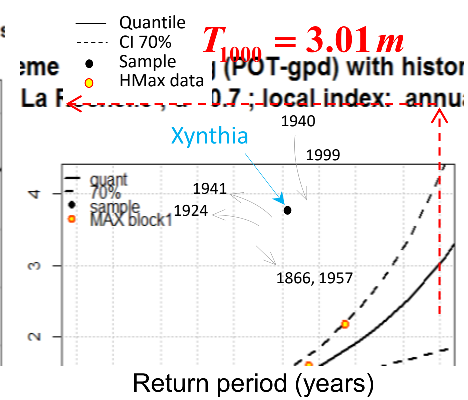


Without regional data



With regional data





The Extreme Sea Level

- These analysis were performed in the context of nuclear safety on some nuclear power plants

- Different methodologies were compared (i.e. Bardet et al., 2011; Hamdi et al., 2018; Weiss et al., 2014; Frau et al., 2018)

- The use of regional analysis and of historical information lead to an increase of the reference Sea Level up to 0,75 m at Gravelines:

  - Strong differences according to the methodology employed

  - Strong impact of historical data

- In general, increasing the available "information" permit to better fit outliers

Conclusions & Perspectives

- Three major challenges for storm surges evaluation
  - The huge mismatch between the probability target (10-4/yr) and the length of the available records,
  - The presence of many gaps in the data set,
  - The presence of an outlier in the data set.
- The classical local FA method without historical information does not insure a good fit of the probability distribution
  - Adding +1 m to results from classical FA seems adapted respects to the RFA method
- Data from HI and RFA (and their combinations) strongly improve the statistical regression
- Main challenges:
  - Develop, adapt and spread the practice of statistics models dealing with both historic information (sometimes imprecise) and regional information (in particular Bayesian approaches)
  - Work on data:
    - Collect additional information (historical, regional) and quantify uncertainties
    - Consolidate homogenous series (especially when time-varying models are used)

IRSN publications on extreme surges

- Bardet, L., Duluc, C.-M., Rebour, V., and L'Her, J. (2011). Regional frequency analysis of extreme storm surges along the French coast, Nat. Hazards Earth Syst. Sci., 11, 1627–1639, https://doi.org/10.5194/nhess-11-1627-2011.
- Bardet, L. and Duluc, C.-M.: Apport et limites d'une analyse statistique régionale pour l'estimation de surcotes extrêmes en France, Congrès de la SHF, Paris, 1–2 février 2012 (in French).
- Giloy, N., Hamdi, Y., Bardet, L., Garnier, E., Duluc C-M (2018).Quantifying historic skew surges: an example for the Dunkirk Area, France. Natural Hazards. https://doi.org/10.1007/s11069-018-3527-1.
- Hamdi, Y., Bardet, L., Duluc, C.-M., and Rebour, V. (2015). Use of historical information in extreme-surge frequency estimation: the case of marine flooding on the La Rochelle site in France. Nat. Hazards Earth Syst. Sci., 15, 1515–1531, https://doi.org/10.5194/nhess-15-1515-2015.
- Hamdi Y, Duluc C-M, Bardet L, Rebour V (2016) Use of the spatial extremogram to form a homogeneous region centered on a target site for the regional frequency analysis of extreme storm surges. J Saf Secur Eng 6(4):777–781. https://doi.org/10.2495/SAFE-V6-N4-777-781.
- Hamdi Y, Garnier, E, Giloy, N., Duluc C-M, Rebour V (2018a) Analysis of the risk associated with coastal flooding hazards: a new historical extreme storm surges dataset for Dunkirk, France. Nat. Hazards Earth Syst. Sci., 18, 3383–3402, 2018. https://doi.org/10.5194/nhess-18-3383-2018.
- Hamdi Y, Duluc C-M, Bardet L, Rebour V (2018b) Development of a target-site-based regional frequency model using historical information. Nat Hazards. https://doi.org/10.1007/s11069-018-3237-8.