GEM conference

Site-specific seismic hazard assessment for nuclear and hydropower facilities in France

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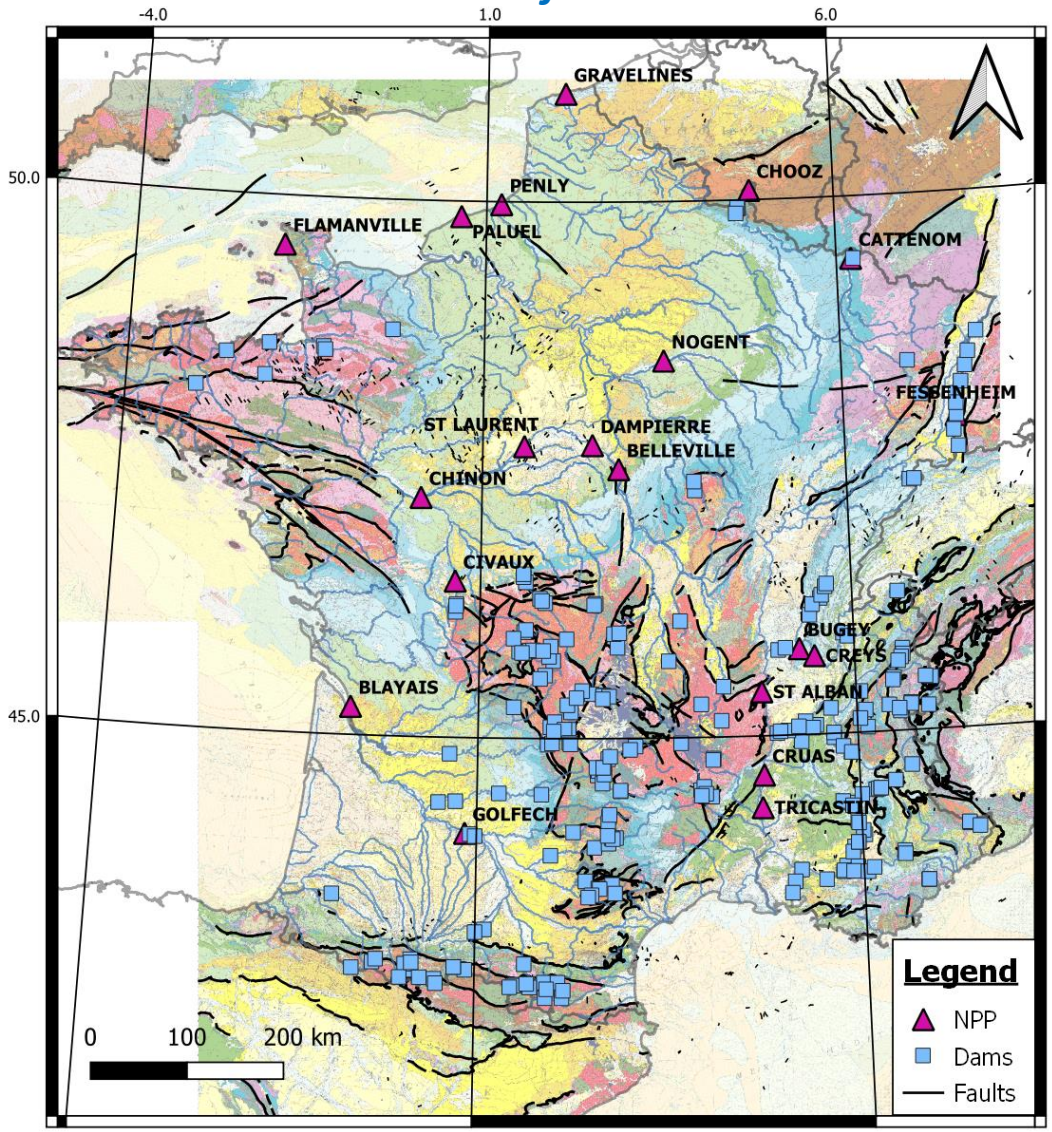
Outline

- Introduction
- Why OQ Engine?
- « How has it been used? »
  - PSHA at the national scale
  - Site-specific PSHA at EDF nuclear and hydro power facilities
  - Engineering applications
- Perspectives

Introduction

EDF critical facilities



- Energy operators are responsible for Seismic Hazard Assessment of their facilities (with Safety Authority, who guarantees compliance with the regulation + technical support)
- Nuclear regulation in France calls for Deterministic SHA approach, but international standards and guides (WENRA, IAEA) call for application of probabilistic approaches
- Dam regulation allows performing either, deterministic or probabilistic approach for SHA
- Critical facilities located all over the territory → variety of geological, seismotectonic, attenuation contexts

Need to perform PSHA at both, national and « site » scales

N.B. Ordinary building code, as well as “special risk facilities” based on probabilistic SHA

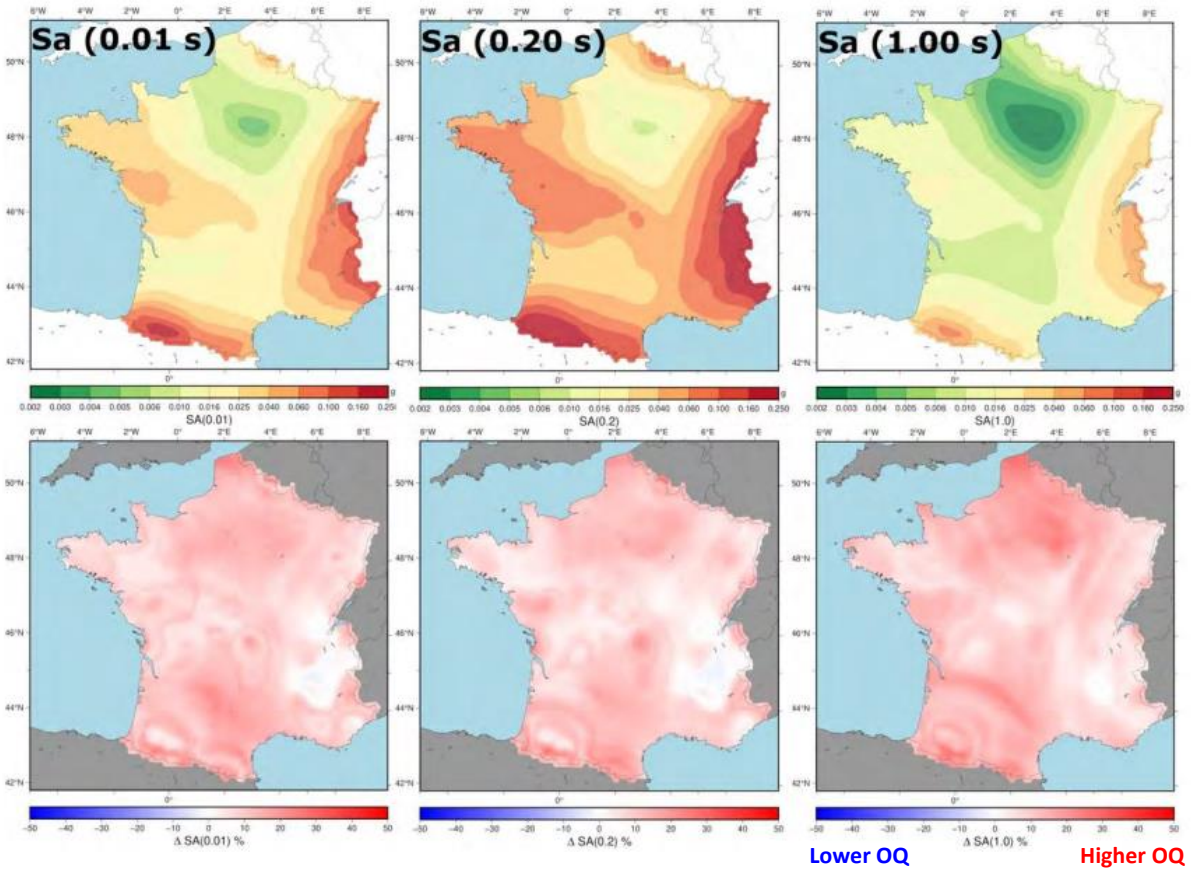
Why GEM and the OQ Engine?

- EDF selected GEM's Openquake Engine for the implementation of their PSHA calculations, based on:
  - Numerous features for SHA
  - Open-source code
  - Continuous development and active maintenance of the source code
  - Code-testing on a daily basis
  - Resources for support and toolkits
  - GEM's active participation in long-term R&D (academic & private) projects

National scale hazard maps

OQ Developments and model comparisons in France

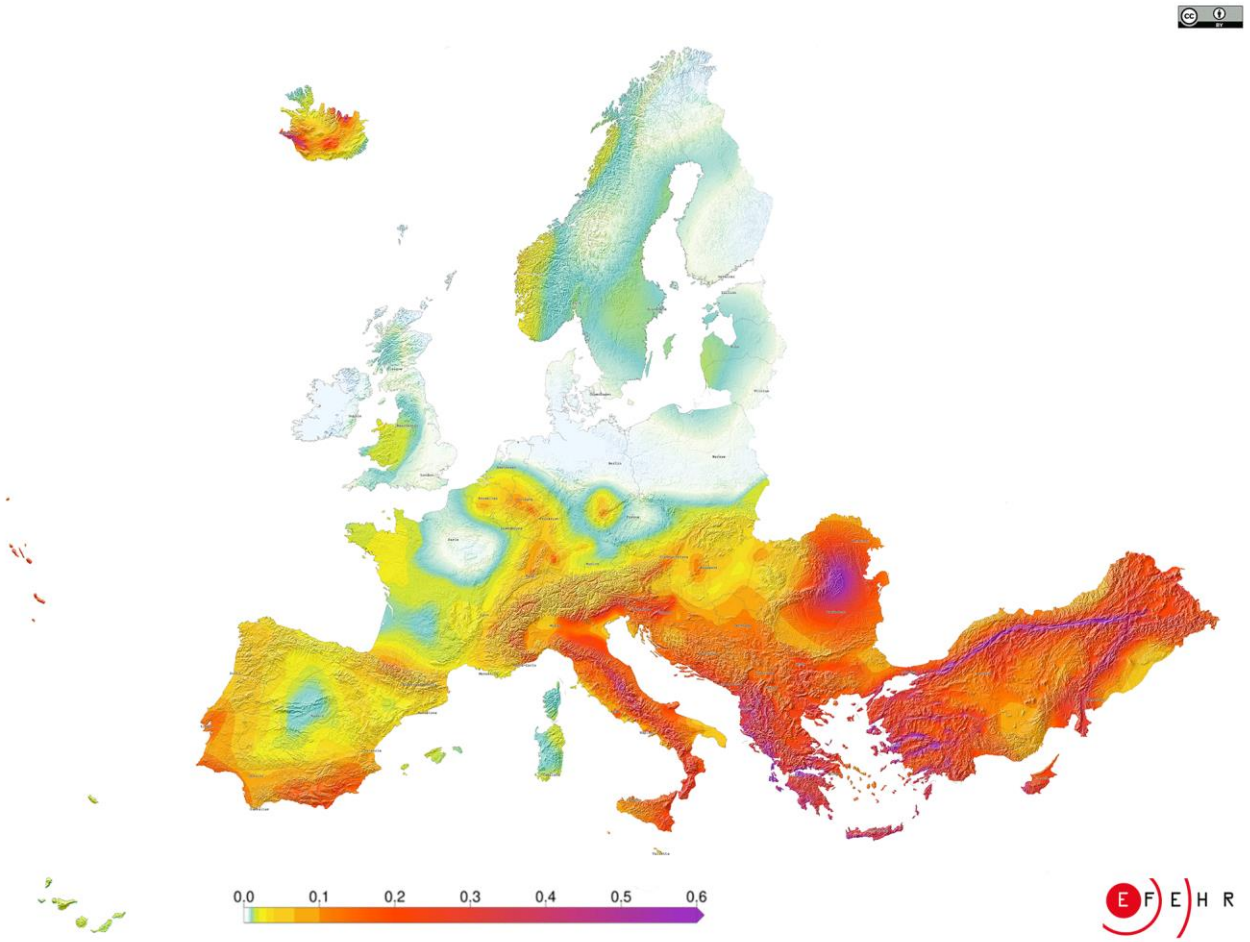
- Implementation in OQ Engine of new GMM useful in the French context
- Model Comparison with existing seismic hazard maps for France → implementation of the Drouet et al. (2020, 475 ys RP) model (Seister in-house code)
  - Complex SSC models built under same assumptions
  - Same multiple GM models
- Conclusion: Agreement between software can only be achieved when a substantial amount of detail about the model and the processes in the underlying software are provided.



Comparison of median hazard maps (475 yrs RP)

Report: *G. Weatherill et al., 2021, Implementation of the Drouet et al (2020) PSHA for France into OpenQuake: Comparisons and Modelling issues. SIGMA-2 report, SIGMA2-2021-D5-085*

European model: ESMH20



Recent European Hazard Map ESHM20 (Danciu et al. 2021)
http://www.efehr.org/earthquake-hazard/

Implemented using OQ Engine → possibility to perform

- Transparent model comparisons over the French territory
- Sensitivity Studies

Overall all this ensures transparency and robusteness in Seismic hazard assessment!!

http://hazard.efehr.org/en/Documentation/specific-hazard-models/europe/eshm2020-overview/eshm20-ground-motion-data-and-model/

Next release of seismic hazard maps

- Pre-existing seismic hazard maps for France (regulatory map developed in the early 2000 and Drouet et al. 2020 – 475 ys RP implemented using Seister's in-house PSHA code)
- Motivations for new release:
  - Moving towards GMC back-bone partially non-ergodic model, based on the Kotha et al. (2020-2022) GMM.
  - New source models (zoneless, faults, area sources)
  - Implementation using the OQ Engine
  - Delivery expected 2024-2025
  - Expanded capabilities for Epistemic Uncertainty Propagation recently developed in OQ

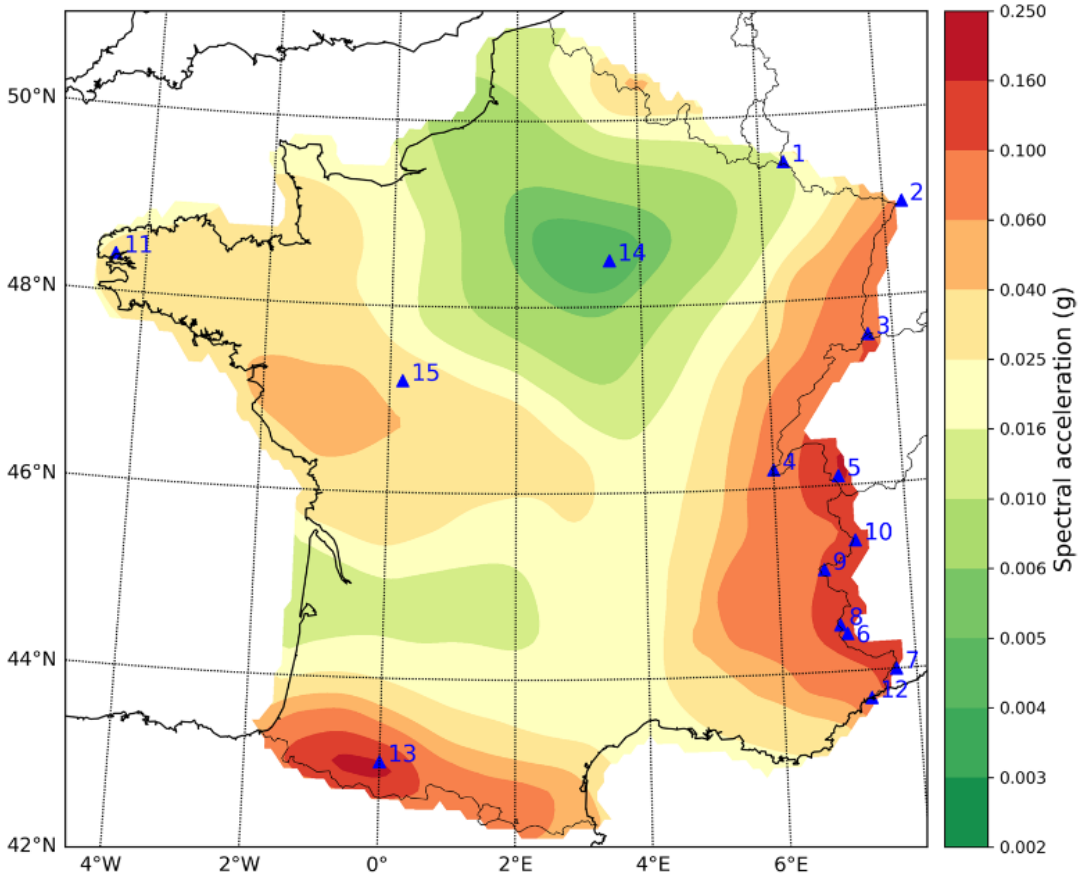
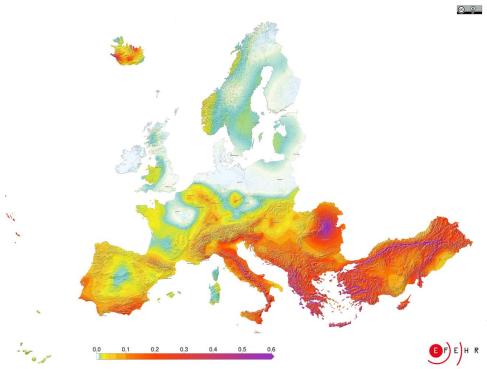
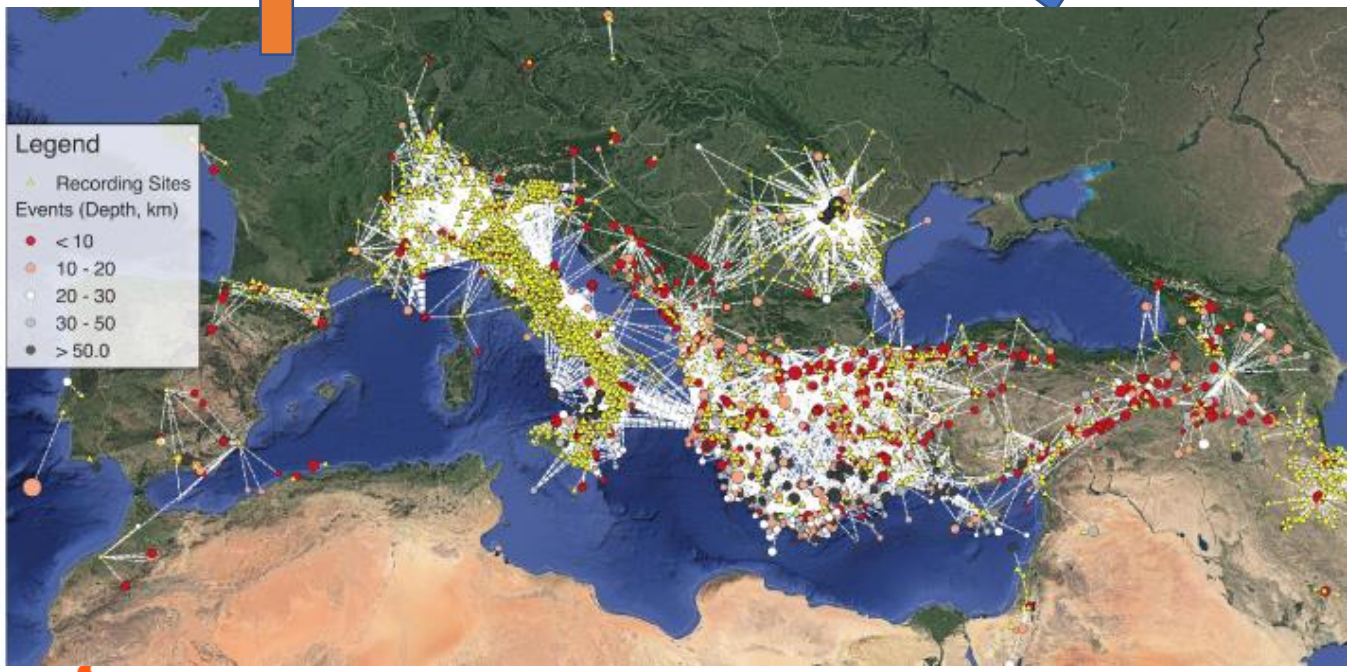


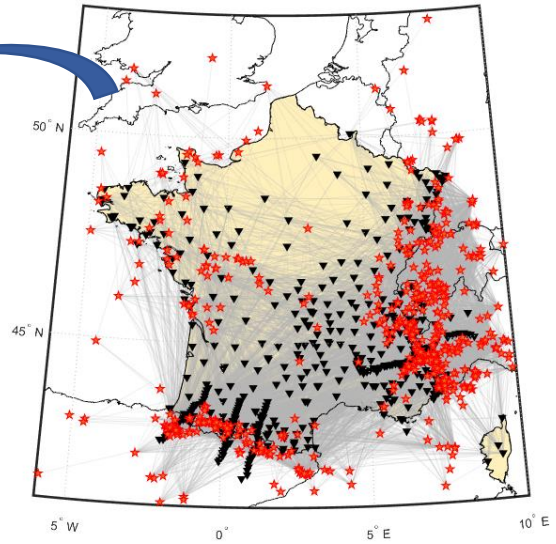
Fig. 20 Hazard map for median PGA at 475 years return period (10% probability of exceedance within 50 years). Blue triangles denote points where comparison with PSHA results from other studies are performed

Partially non-ergodic GMM



ESHM20 model based on a partially non-ergodic GMM, developed using the pan-European Engineering Strong-Motion (ESM) dataset, applicable for earthquakes of 3 < Mw < 7.4)





Traversa et al 2020, Buscetti et al in Prep.

Ongoing Bayesian update of the Kotha et al (2020, 2022) partially NE model using French data (EDF-ISTerre collaboration)

Next release of seismic hazard maps for France

Weatherill et al., 2018, 2020a,b, Kotha et al 2020

Optimized implementation of partially non-ergodic GMM in OQ

- Partially non-ergodic GMM → take into account regional and/or site, source or path differences in ground motion scaling (classically neglected when the ergodic assumption was used). Significant impact on predictions and on standard deviation.

- In OQ : optimized implementation of partially non-ergodic GMM (regional scaling effects associated to the source and the site location)
  → automatic selection of the regional adjustments depending on the location of the source and of the site:
  - Default: full Kotha 20-22 GMM (vs the simplified version already implemented for the ESHM20 computations).
  - User-defined geo-database, providing attenuation regionalization polygons, source location polygons, associated adjustments and standard errors

- Ongoing work in the framework of the next release of seismic hazard maps in France.

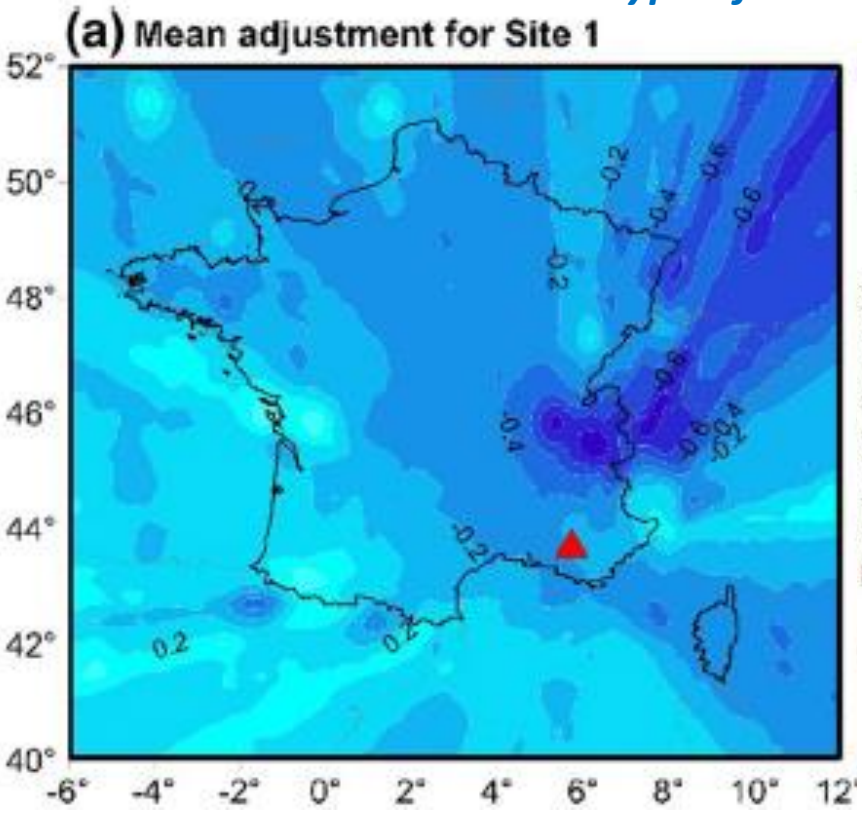
Chandrasekhar et al 2022

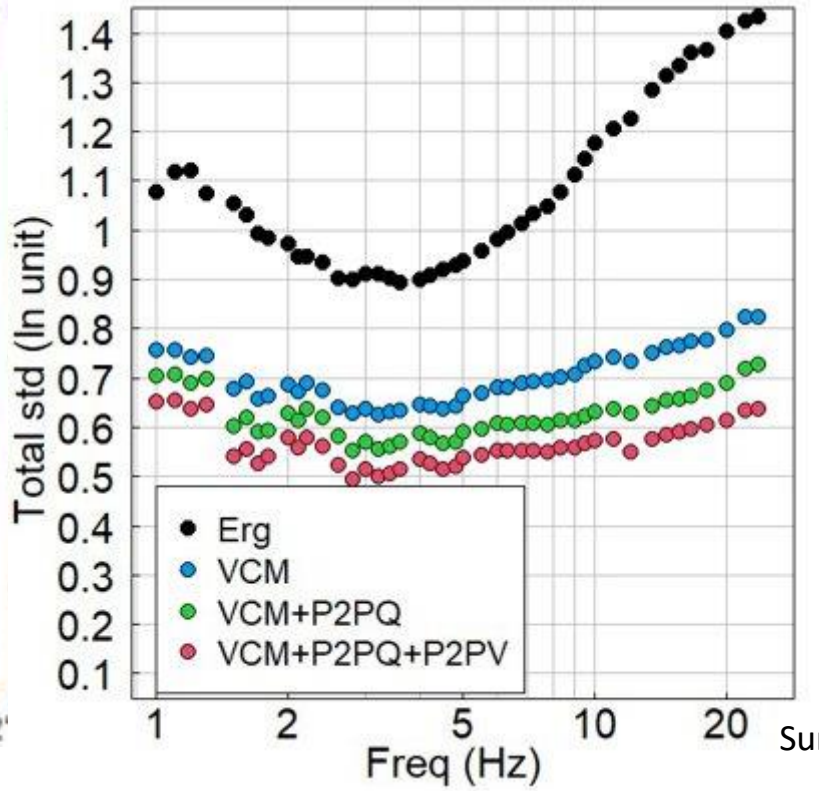
Site-Specific PSHA at critical facilities

Site-specific PSHA at critical facilities

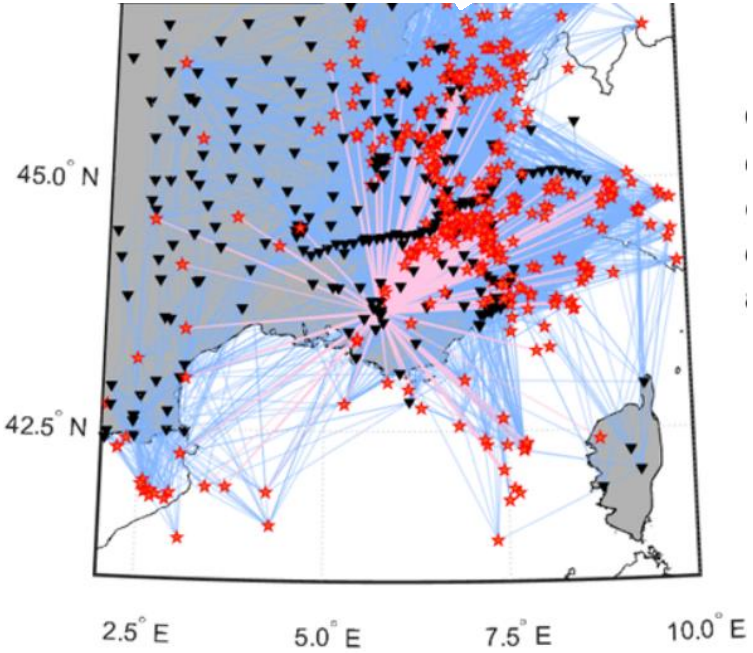
- Developments in OQ Engine: fully non-ergodic GMM implementation and methods, ongoing HAZ45 code implementation comparisons

Prototype of Non-ergodic GMM for France





Sung et al. (2022)

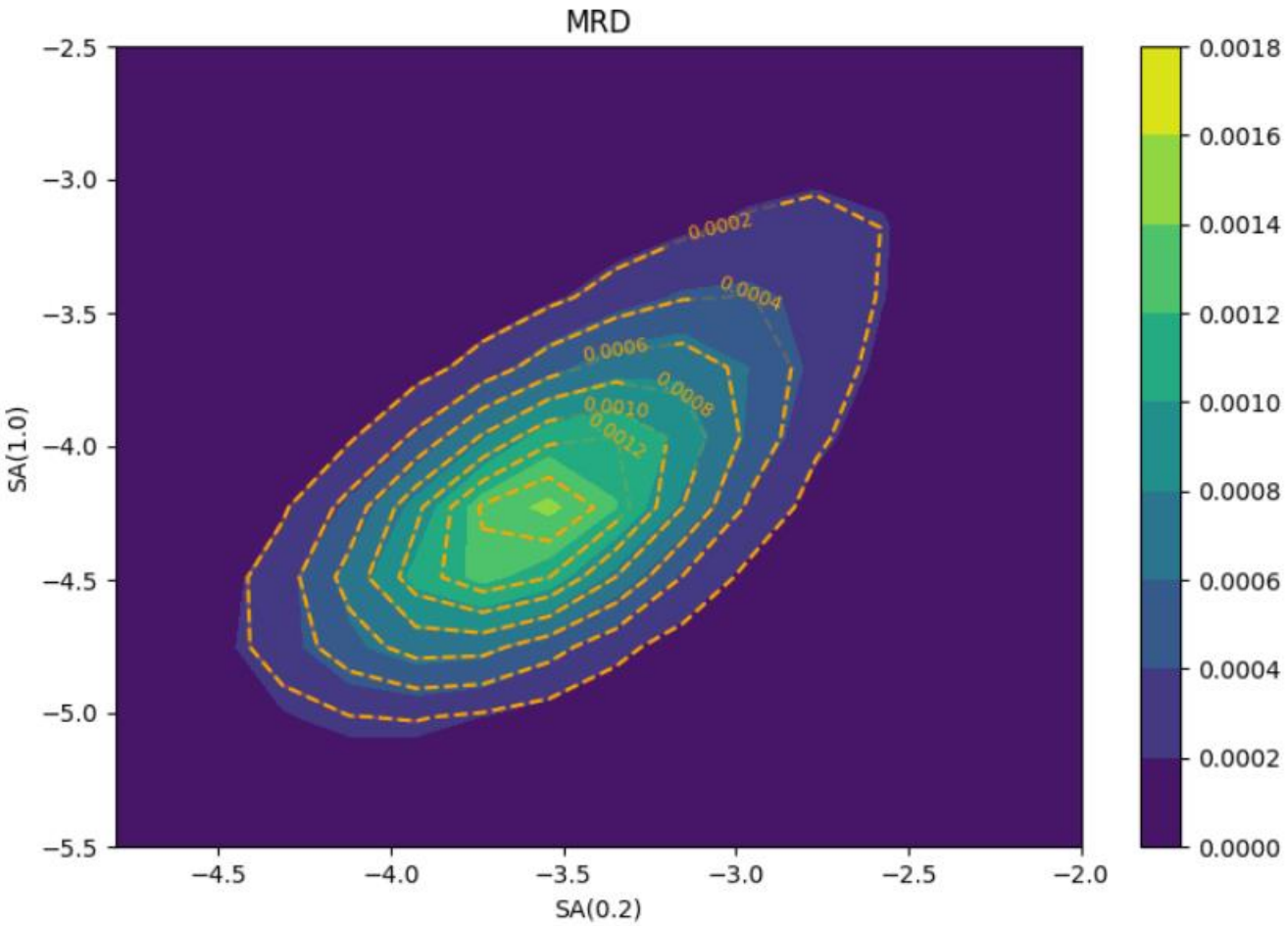


Traversa et al. (2020), Buscetti et al. (in prep.)

Engineering needs

Needs for the engineers

- Standard (scalar) PSHA provide annual probability of exceedence of <u>each</u> selected IM → hazard curves, UHS (representation of all SA having the same APE, taken individually) →
  - Return Period associated to an UHS taken as a whole is larger than the target RP
  - no one-to-one link of the PSHA results with an earthquake of well defined characteristics
- But, for site response and structural dynamic calculations, waveforms related to a seismic scenarios are needed → Recent develoments in OQ Engine:
  - V-PSHA
  - Conditional Spectrum



Joint mean rate density of two IMs

→ Link with risk evaluations

Collaborations and Perspectives

Working group on the use of OQ Engine for PSHA at nuclear and hydro power facilities in France

- Participants: EDF, CEA, GEM: collaborations, uniformisation of practices, feedback on the use of OQ for site-specific applications at nuclear sites (complex logic trees, long return periods…) → 1 annual meeting per year
- Training on the OQ Engine use in 2019 provided by GEM

Perspectives

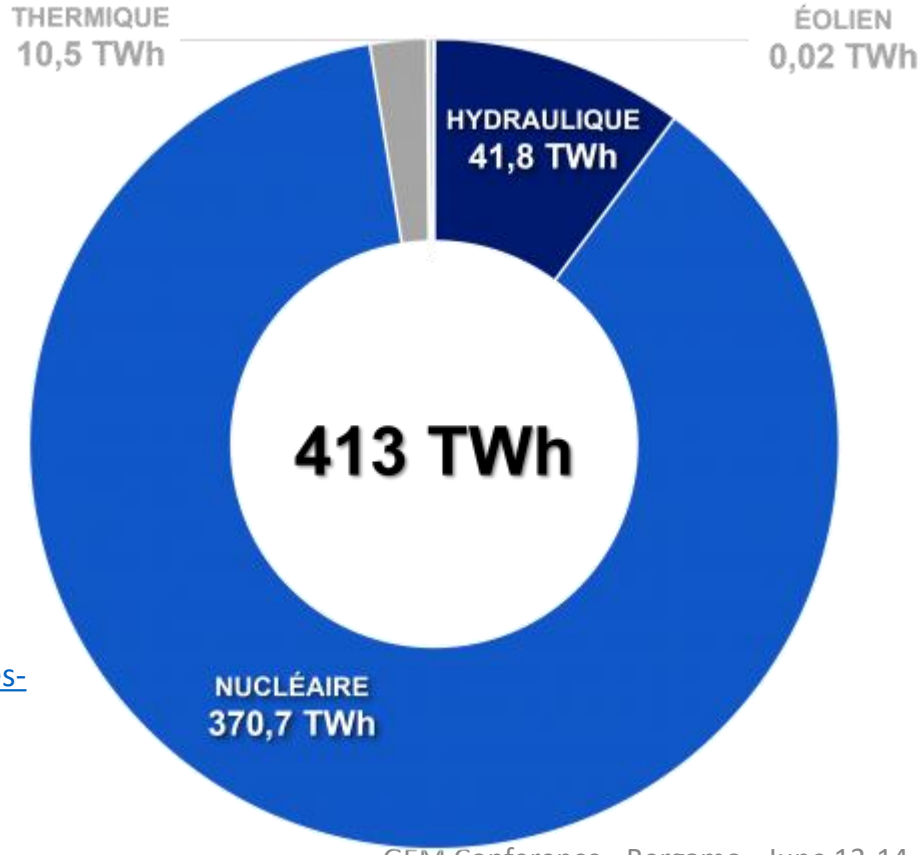
- Pursuing the implementation of non-ergodic methods and models in OQ Engine
- Site-specific PSHA combining results of different site response assessment approaches → sound epistemic uncertainty propagation
- « Scenario approaches », pursuing the develoments on CS and V-PSHA
- …

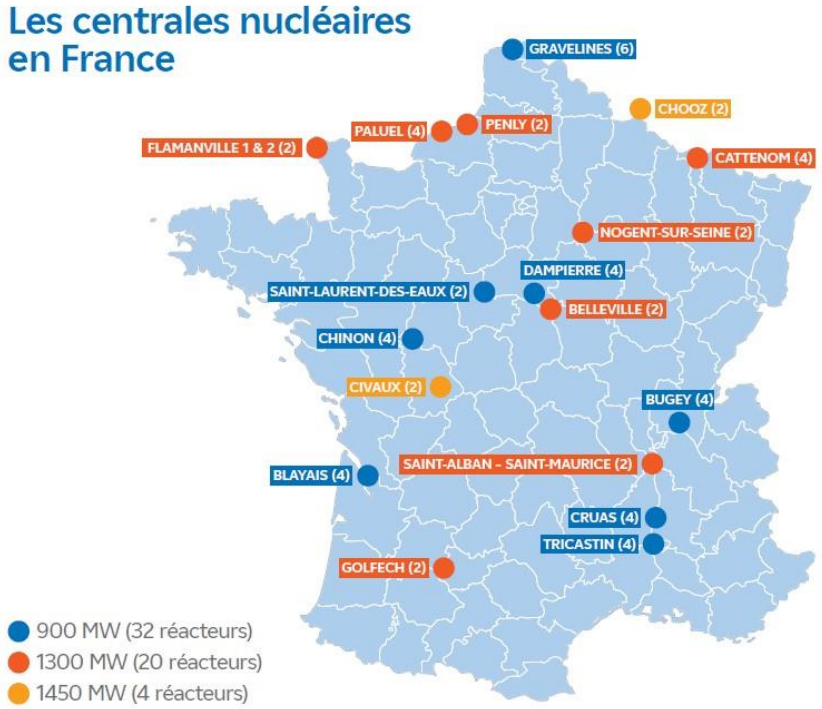
Thank you !

Energy production in France

- Nuclear electrical power : ~70% of the total production.
- Hydroelectric power : 12% of the total production, 53% of renewable energy production.

2021 energy production

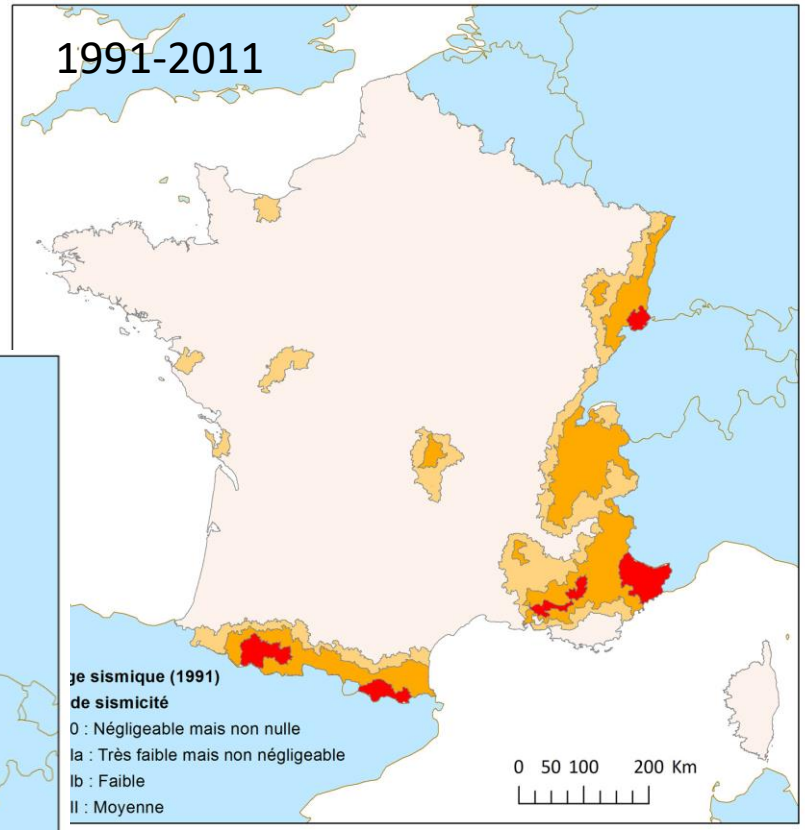




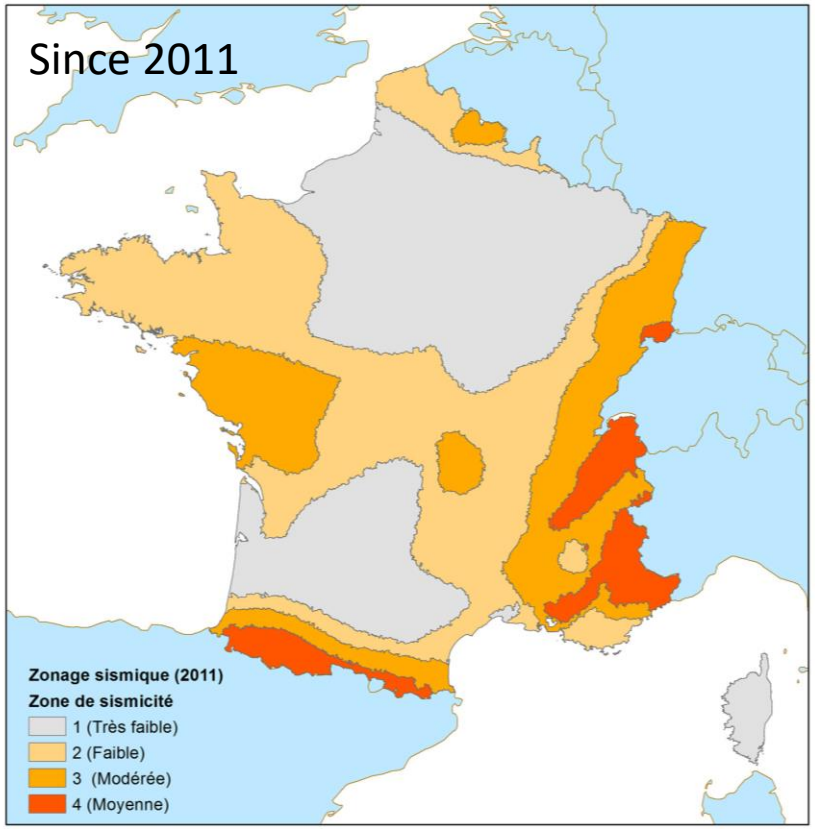
Source: EDF (https://www.edf.fr/groupe-edf/espaces-dedies/l-energie-de-a-a-z/tout-sur-l-energie/produire-de-l-electricite)

Regulatory seismic map for ordinary buildings

Carte du zonage sismique de la France métropolitaine établi en 1991
- Zone 0 : sismicité négligeable, mais non nulle.
- Zone Ia : sismicité très faible.
- Zone Ib : sismicité faible
- Zone II : sismicité moyenne.
- Zone III : sismicité forte (aux Antilles).



Carte du zonage sismique de la France métropolitaine en vigueur depuis le 1er mai 2011
- Zone 1 : aléa très faible.
- Zone 2 : aléa faible.
- Zone 3 : aléa modéré.
- Zone 4 : aléa moyen.
- Zone 5 : aléa fort (aux Antilles).



Source: IRSN (https://www.irsn.fr/savoir-comprendre/surete/zonage-sismique-france)