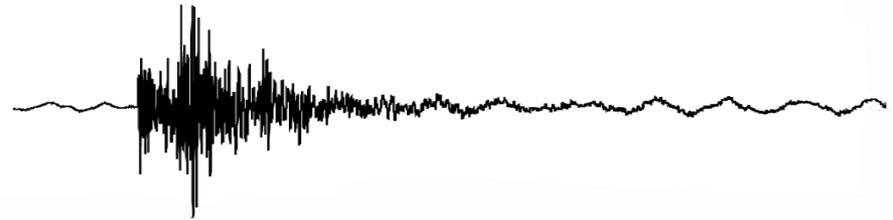


# Induced seismicity risk management for deep geothermal projects: Status and outlook

Prof. Dr. Stefan Wiemer

ETH-Zurich, Swiss Seismological Service  
(SED), Switzerland



With major contributions from many others

In cooperation with the CTI



**Energy funding programme**

Swiss Competence Centers for Energy Research



Schweizerische Eidgenossenschaft  
Confédération suisse  
Confederazione Svizzera  
Confederaziun svizra

Swiss Confederation

Commission for Technology and Innovation CTI

# Summary



# The question in 2013

“To secure a future for DGE in the energy mix of Switzerland, we need to **tackle two complementary challenges**. The first is a purely technical challenge:

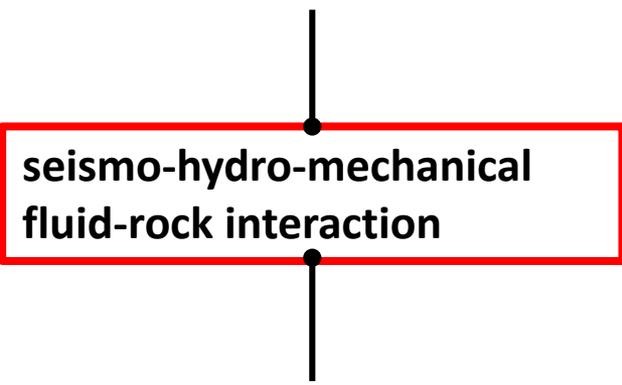
- *Is it possible to **engineer** in the Swiss underground a **productive heat exchanger** at depth (>3 km), with consistent flow of hot water (>50l/sec,  $T>180^\circ$ ), sustainable over 20 and more years without significant temperature decline, **seismically safe ( $M<3$ ) during stimulation and long-term operation**, in different tectonic and geological environments? “*

**National innovation roadmap for the development of Deep Geothermal Power in Switzerland**

Domenico Giardini, Keith Evans, Tony Kaiser, Peter Meier & Stefan Wiemer  
V2, June 11, 2013



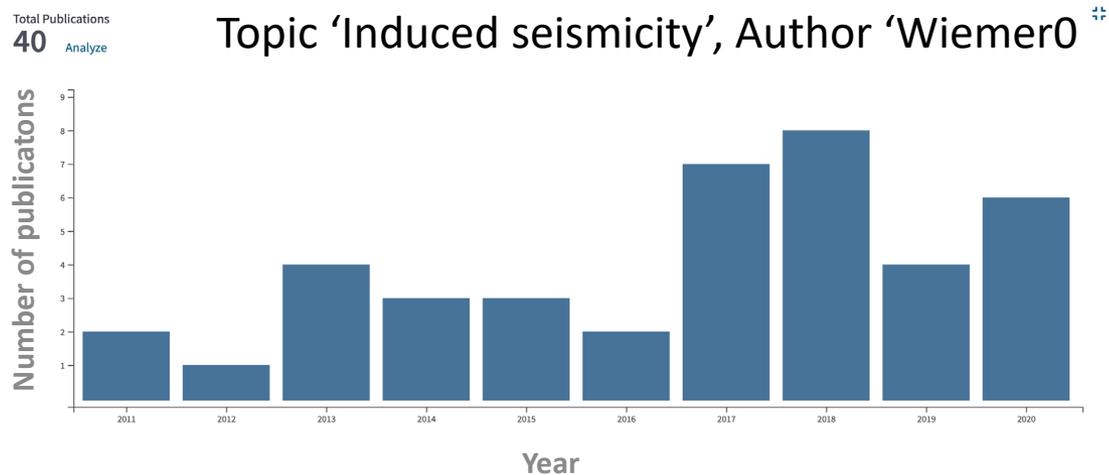
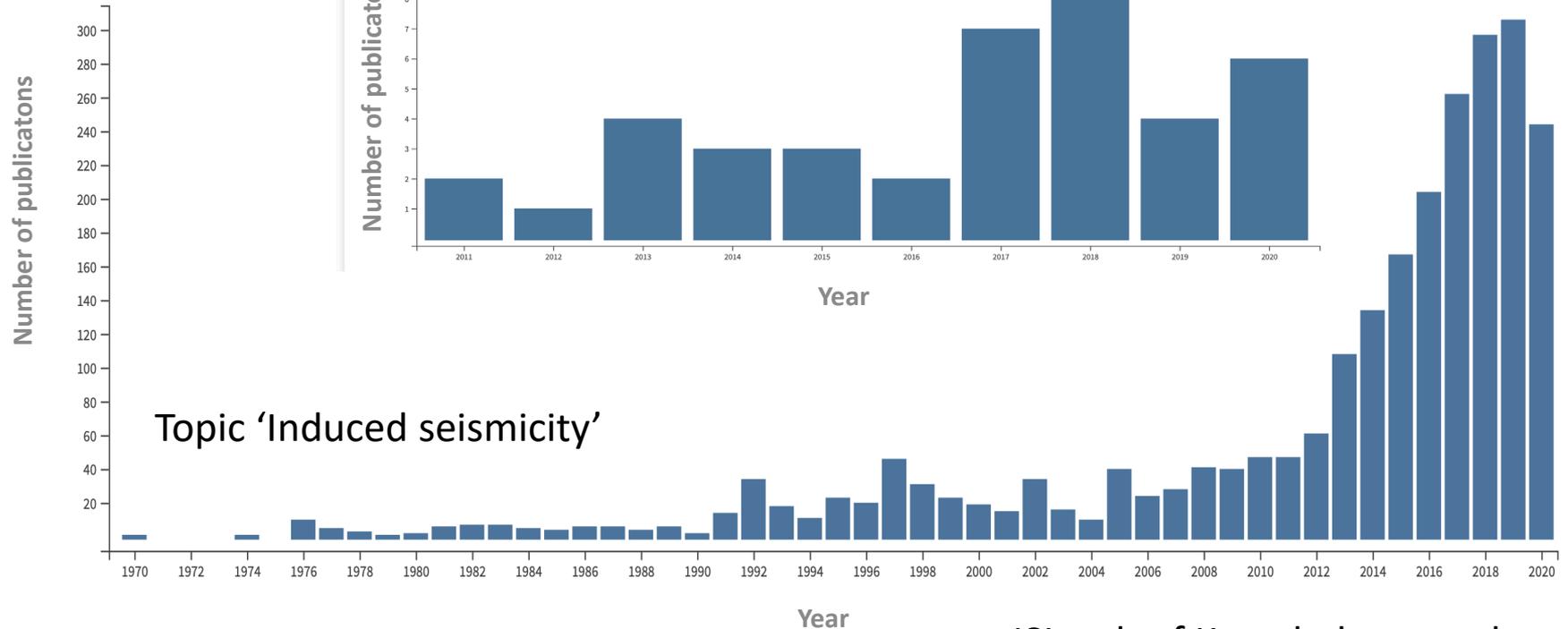
Fractures in building wall after the 3.4 mag. eq. in 2006 beneath Basel (source:www.bazonline.ch)



**seismo-hydro-mechanical  
fluid-rock interaction**

# Science (and I) did what it is supposed to do: Publish (not to perish)

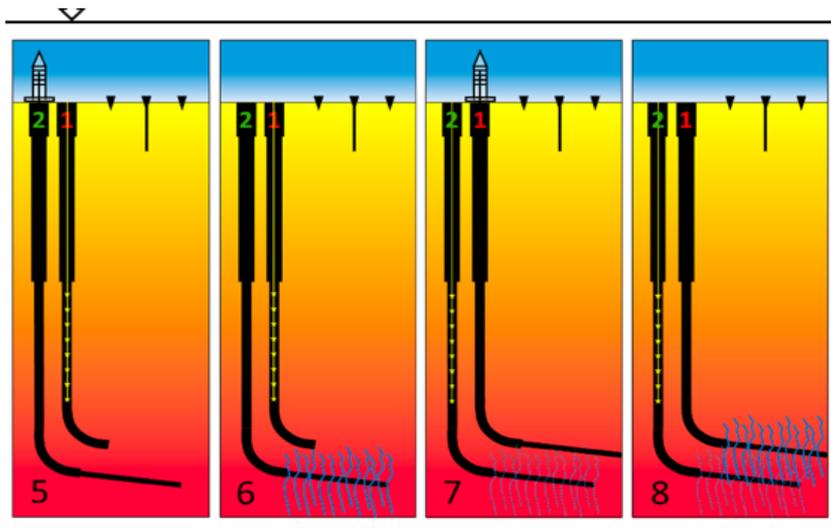
Total Publications  
**2,440** Analyze



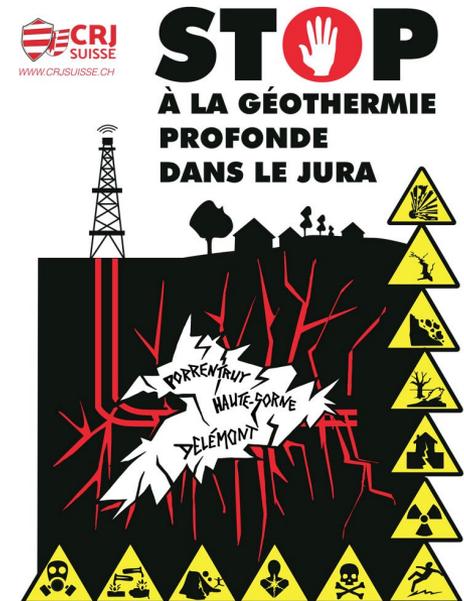
# So what is the status in 2020

*The question was : "Is it possible to engineer in the Swiss underground a heat exchanger without too many earthquakes ?"*

**The answer to date is: Maybe**, we do not know, because we have not had a chance to tried lately ....



Nice plan – but ... times have changed for geothermal in CH

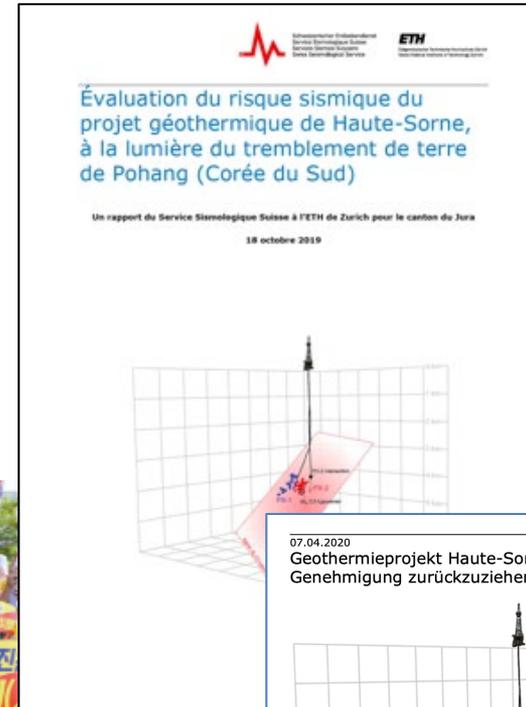


# The Mw 5.5 2017 South Korea Earthquake did not excately help...

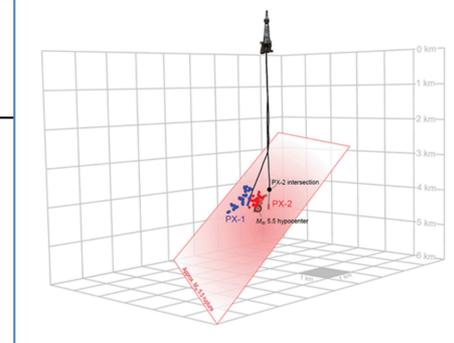
Due to its shallow focus (about 4.5 km depth) the earthquake caused extensive damage in and around the city of Pohang.



People were pretty angry over there ...  
And for good reason if you ask me.

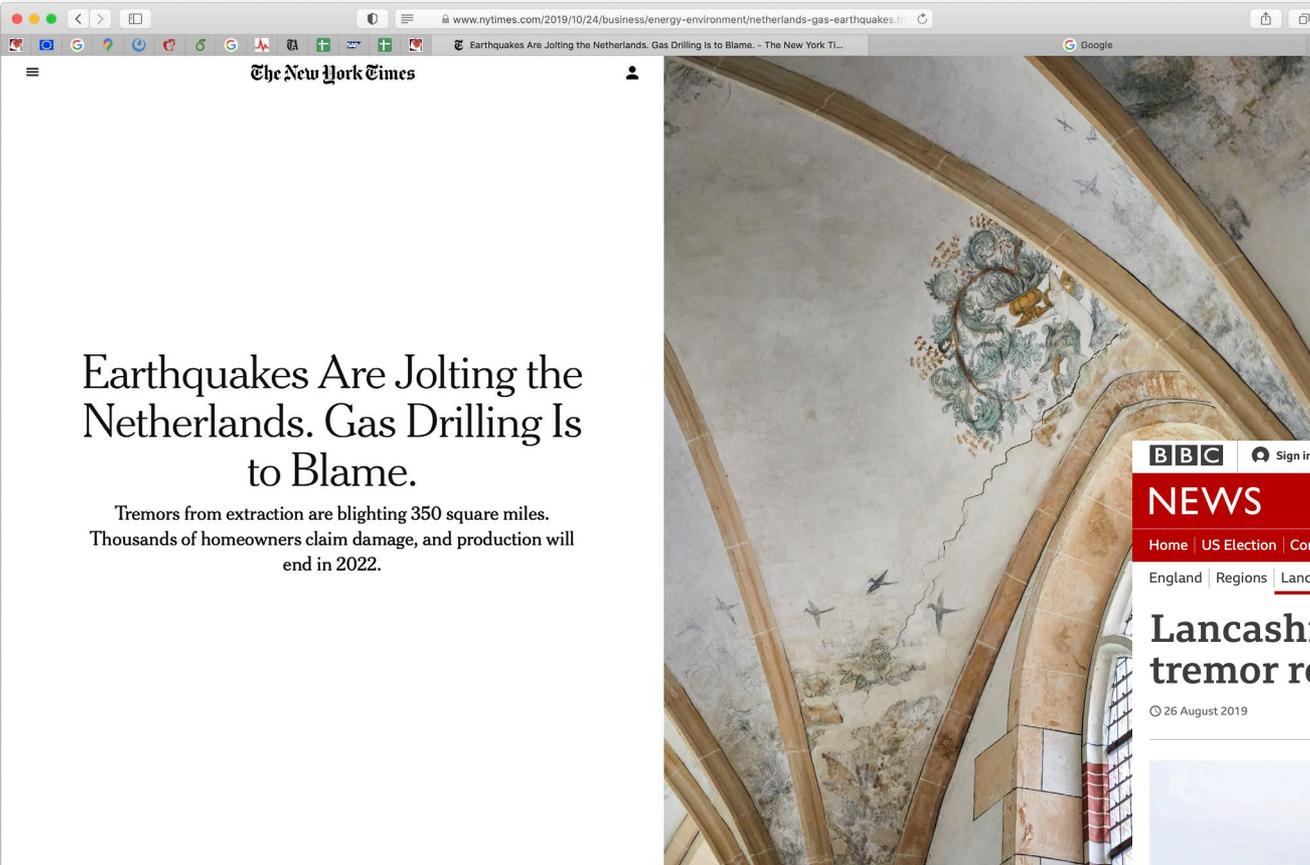


07.04.2020  
Geothermieprojekt Haute-Sorne – Kanton erwägt Genehmigung zurückzuziehen



In der jurassischen Gemeinde Haute-Sorne war vorgesehen, ein petrothermales Tiefengeothermieprojekt zur Stromerzeugung zu errichten. Die Frage nach dem mit dem Projekt verbundenen seismischen Risiko wurde vom Kanton erneut aufgeworfen, nachdem sich im November 2017 nahe der südkoreanischen Stadt Pohang ein Erdbeben mit einer Magnitude von 5.5 ereignet hat (siehe Aktualbeitrag vom 24.05.2019 für eine Übersicht). Auslöser des Bebens war ein petrothermales Tiefengeothermieprojekt in unmittelbarer Nähe. Die Geo-Service Suisva AG (GSG), welche das Projekt in Haute-Sorne plant und betreibt,

# News from other places: Not good



www.nytimes.com/2019/10/24/business/energy-environment/netherlands-gas-earthquakes...

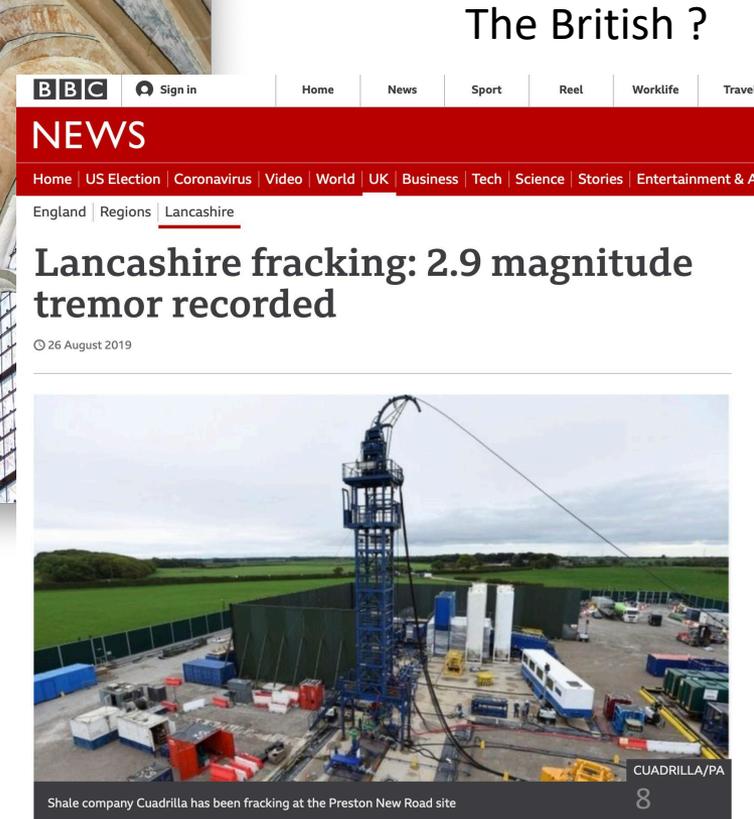
Earthquakes Are Jolting the Netherlands. Gas Drilling Is to Blame. - The New York Times

## Earthquakes Are Jolting the Netherlands. Gas Drilling Is to Blame.

Tremors from extraction are blighting 350 square miles. Thousands of homeowners claim damage, and production will end in 2022.

The Dutch are giving up

04.11.2020



## The British ?

NEWS

Home | US Election | Coronavirus | Video | World | UK | Business | Tech | Science | Stories | Entertainment & A

England | Regions | Lancashire

### Lancashire fracking: 2.9 magnitude tremor recorded

26 August 2019



CUADRILLA/PA

Shale company Cuadrilla has been fracking at the Preston New Road site

# A bit of hope from Finland

Finnish geothermal pilot project in Espoo on track to deliver heat in October 2020

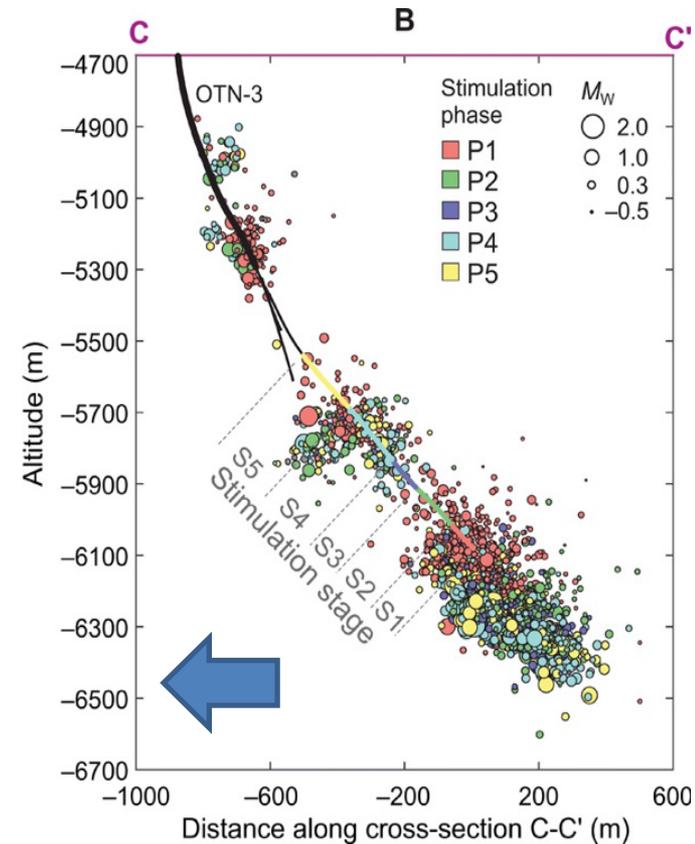


Drilling rig on project site in Otaniemi, Finland (source: St1)

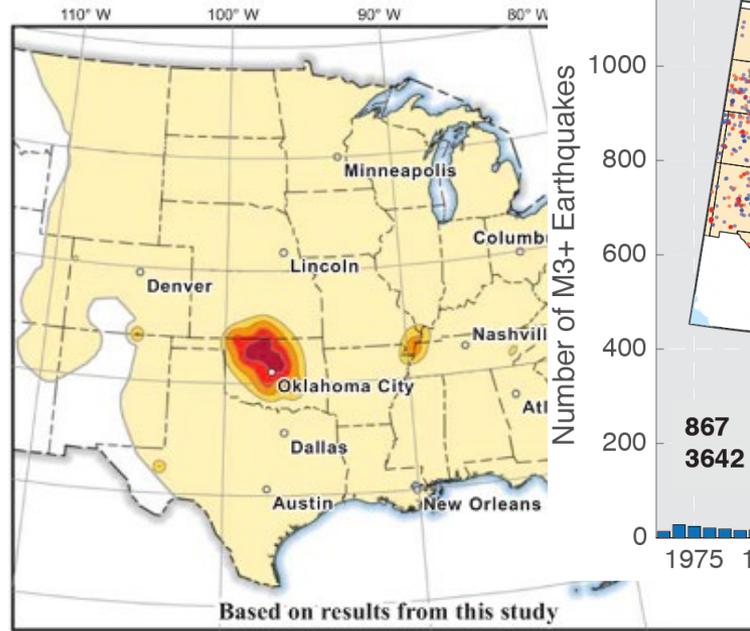


Alexander Richter  
23 Apr 2020

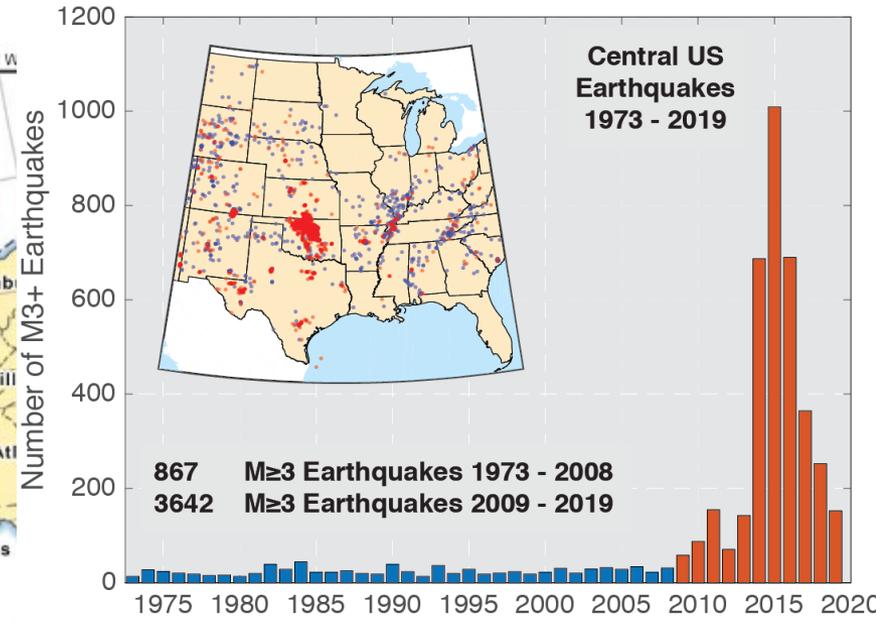
With the final drilling concluded, the St1 geothermal heating pilot project in Otaniemi, Espoo in Finland is on track to deliver sustainable geothermal heat to the district heating system in October 2020.



# Tricky to sustain public opposition - Unless you have powerful friends (and the oil price drops)



Chance of potentially minor-damage\* ground shaking in 2018



Big News Network

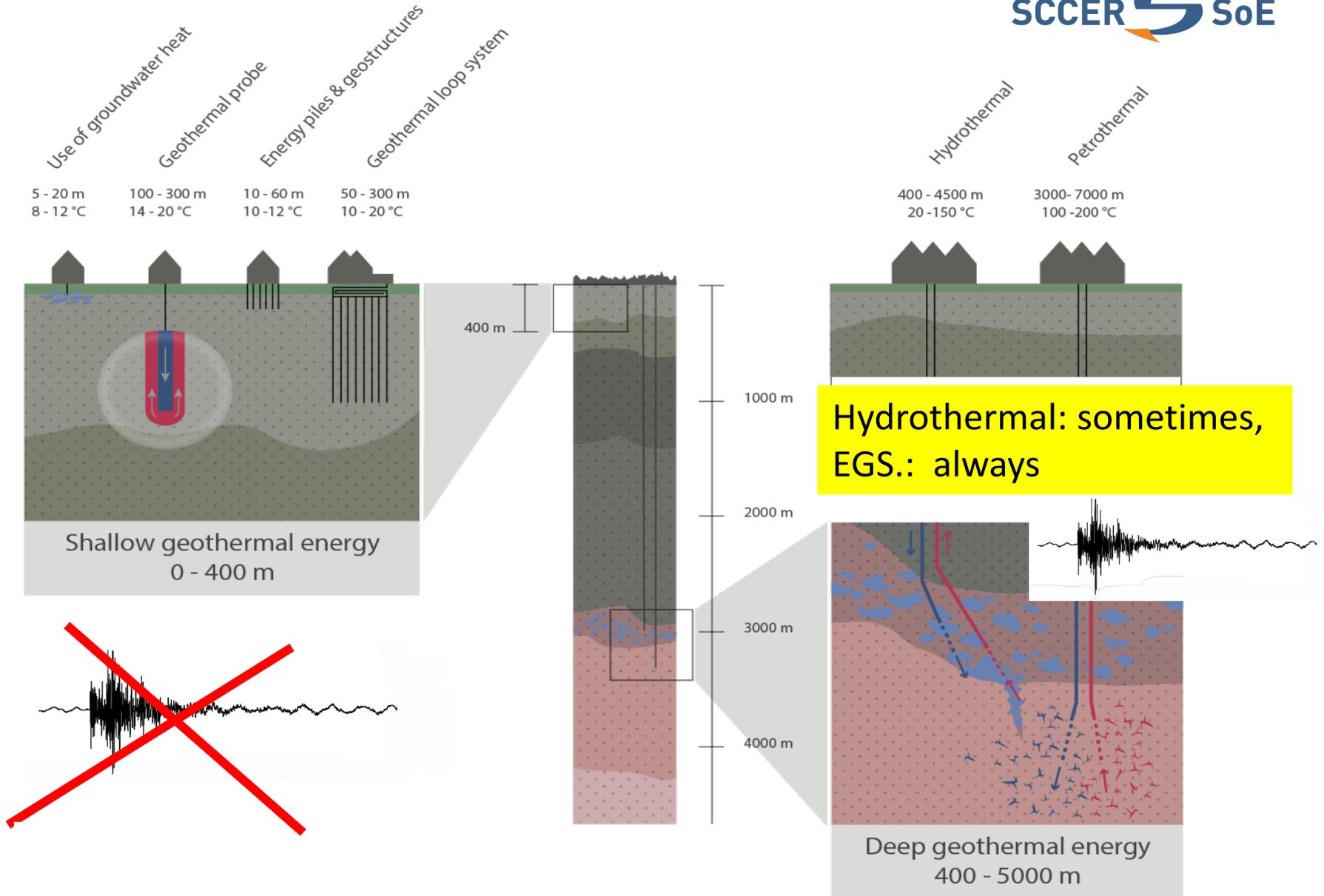
## Trump signs order to protect hydraulic fracking

Washington DC [US], November 1 (ANI): US President Donald ... "Just signed an order to protect fracking and the oil and gas industry. ... sources of inexpensive and reliable energy and producing more jobs for Americans.

18 hours ago



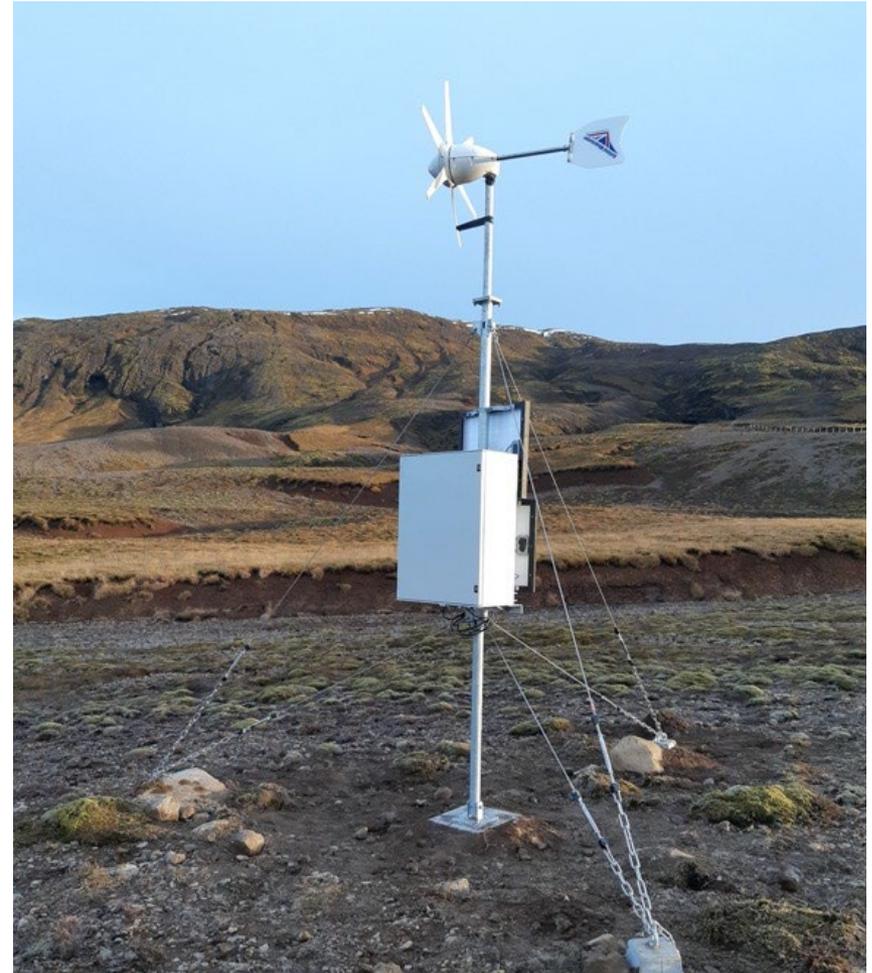
# To be certain to not be misunderstood



# Progress? Yes!

## Progress in 4 Dimensions:

1. Progress in the **fundamental science** of induced seismicity
2. Progress in **demonstrating** adaptive risk mitigation strategies
3. Progress in **supporting** cantonal authorities in monitoring, risk assessment and regulation.
4. Progress in **sustainable implementation and** acquiring future projects.



# 1. Progress in the fundamental science of induced seismicity

- Much better data & and enhance analysis tools.
- Experiments at all scales.
- Better models & model calibration.
- Interdisciplinary risk assessment in near-real time

ETH zürich



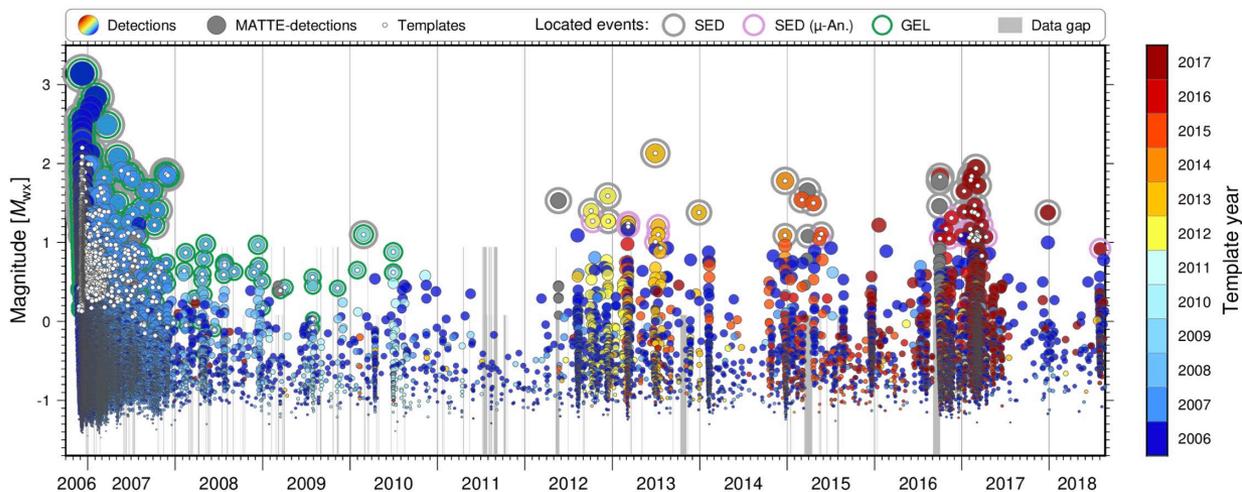
## Complexity, heterogeneity and scalability of injection induced seismicity from decameter-scale stimulation experiments

Doctoral Defense of Linus Villiger, 28.10.2020

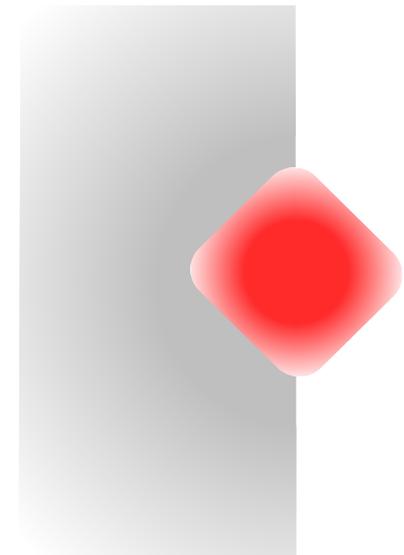
Committee: Prof. Dr. Stefan [Wiemer](#), Dr. Valentin [Gischig](#), Prof. Dr. Domenico [Giardini](#), Prof. Dr. Georg [Dresen](#)

Chair: Prof. Dr. Johan [Robertsson](#)

SCCER SoE *induSED* seismicity



04.11.2020



# Example: Mont Terri Experiment (CO<sub>2</sub> storage)

## Fault sealing and caprock integrity for CO<sub>2</sub> storage: an in-situ injection experiment

**Review status**  
This preprint is currently under review for the journal SE.

Alba Zappone<sup>1,2</sup>, Antonio Pio Rinaldi<sup>1,5</sup>, Melchior Grab<sup>1,3</sup>, Quinn Wenning<sup>1,3</sup>, Clément Roques<sup>1,3,4</sup>, Claudio Madonna<sup>2</sup>, Anne Obermann<sup>1,3</sup>, Stefano M. Bernasconi<sup>1,3</sup>, Florian Soom<sup>5</sup>, Paul Cook<sup>5</sup>, Yves Guglielmi<sup>5</sup>, Christophe Nussbaum<sup>5</sup>, Domenico Giardini<sup>1,3</sup>, and Stefan Wiemer<sup>1</sup>

<sup>1</sup>Swiss Seismological Service, ETHZ, Zurich, 8092, Switzerland

<sup>2</sup>Department of Mechanical Engineering, ETHZ, Zurich, 8092, Switzerland

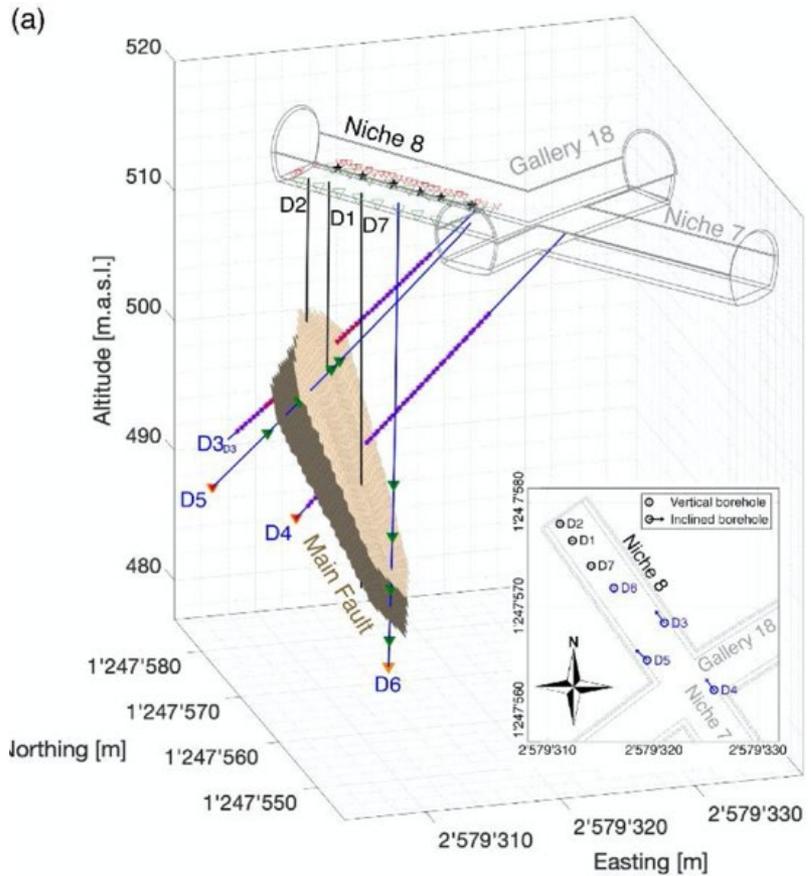
<sup>3</sup>Department of Earth Sciences, ETHZ, Zurich, 8092, Switzerland

<sup>4</sup>Géosciences Rennes, University of Rennes 1, Rennes, 35000, France

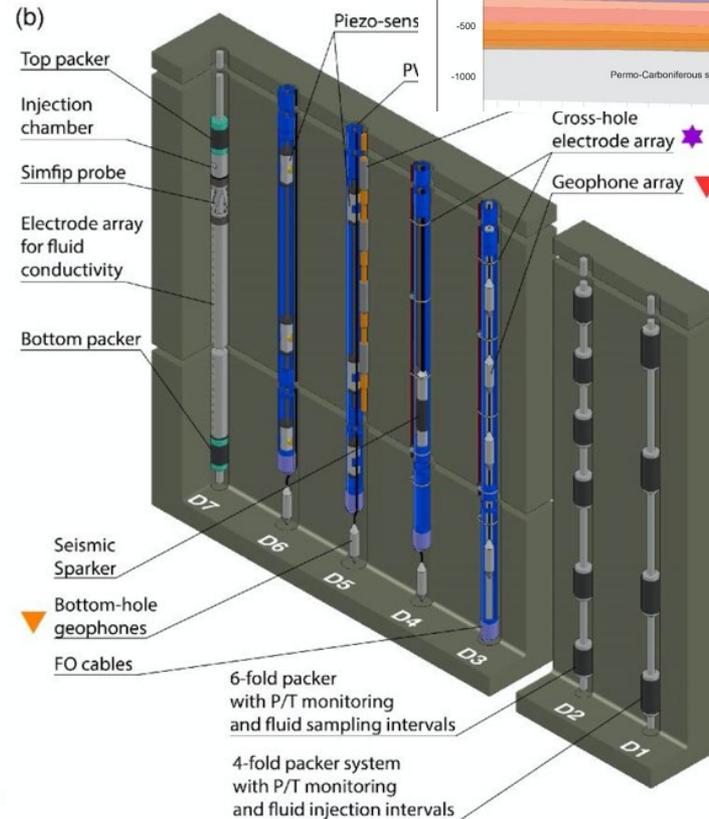
<sup>5</sup>Energy Geosciences Division, LBNL Berkeley, CA 94720, USA

<sup>6</sup>Swiss Geological Survey, swisstopo, Wabern, 3084, Switzerland

Received: 04 Jun 2020 – Accepted for review: 09 Aug 2020



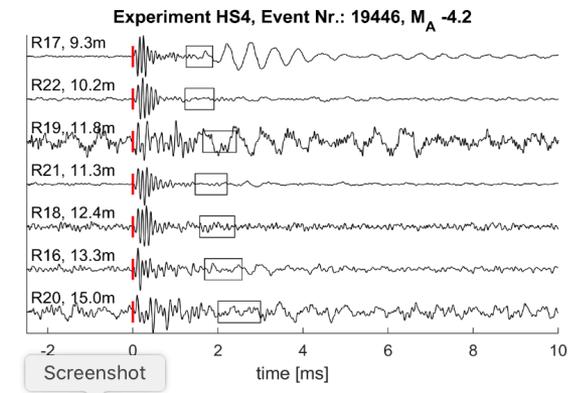
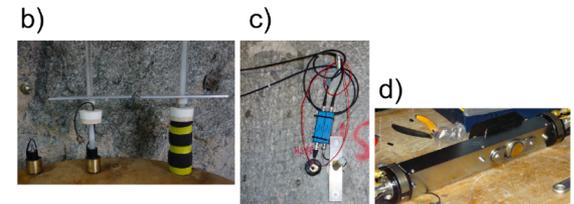
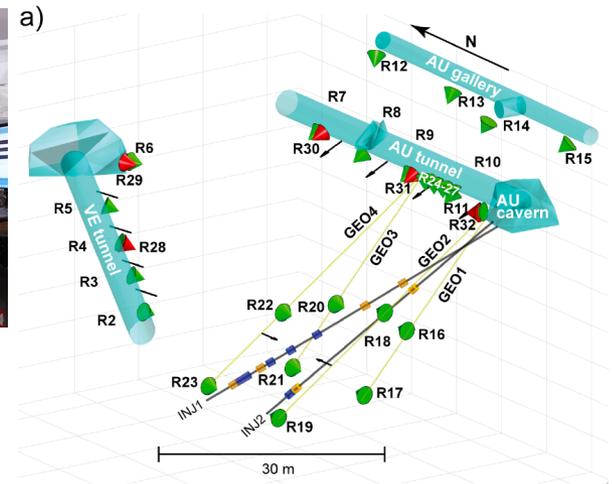
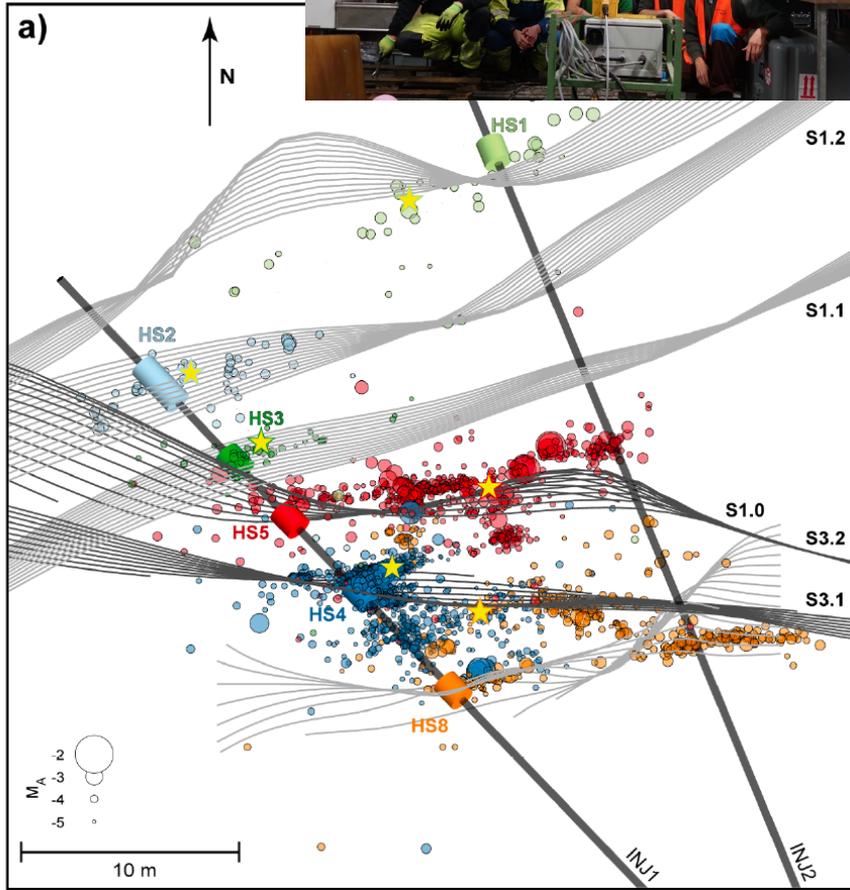
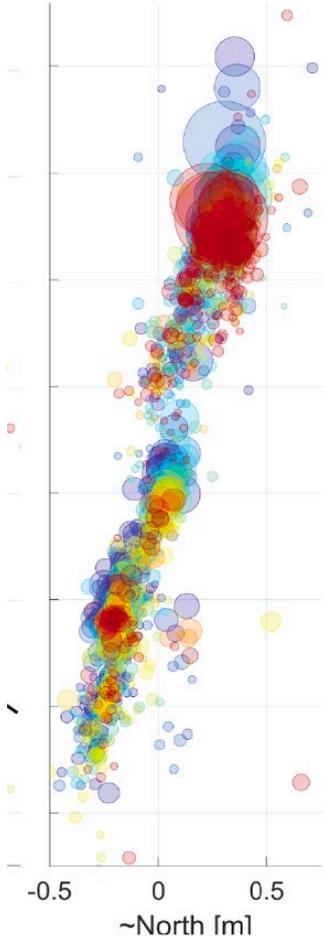
★ Hammer sources    ▼ Piezo-sensors in niche    ▼ Geophones in niche



Zappone et al., 2020

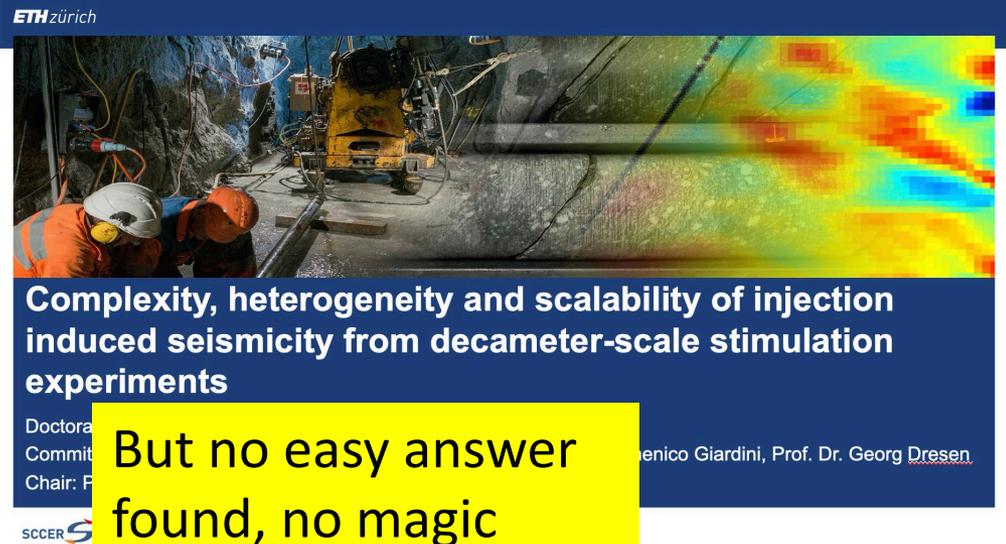
# Example: Understanding Fluid-rock interaction at Deca-meter scale (Grimsel, Bedretto)

side view

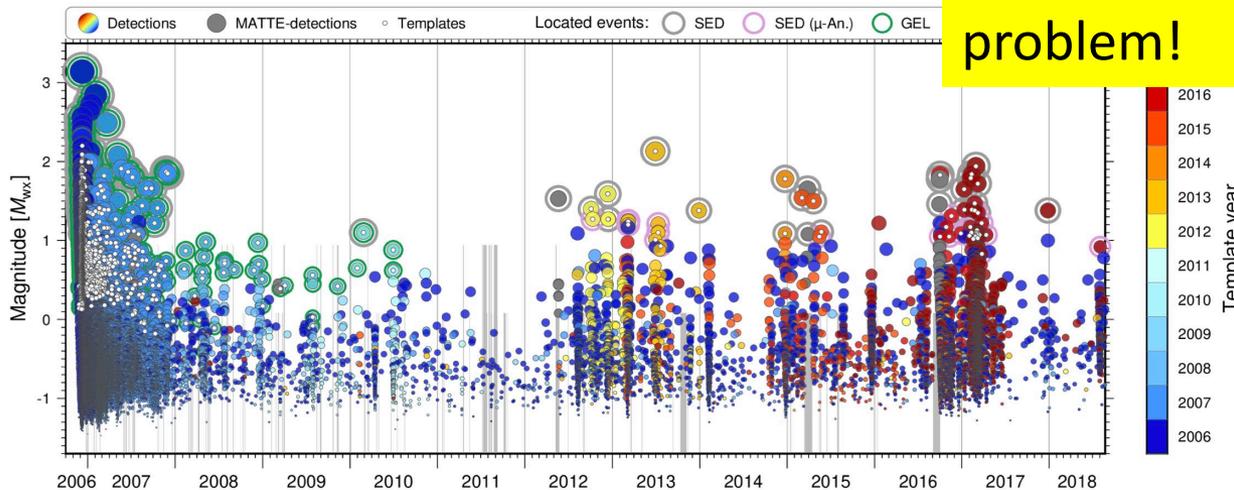


# 1. Progress in the fundamental science of induced seismicity

- Much better data & and enhance analysis tools.
- Experiments at all scales.
- Better models & model calibration.
- Interdisciplinary risk assessment in near-real time



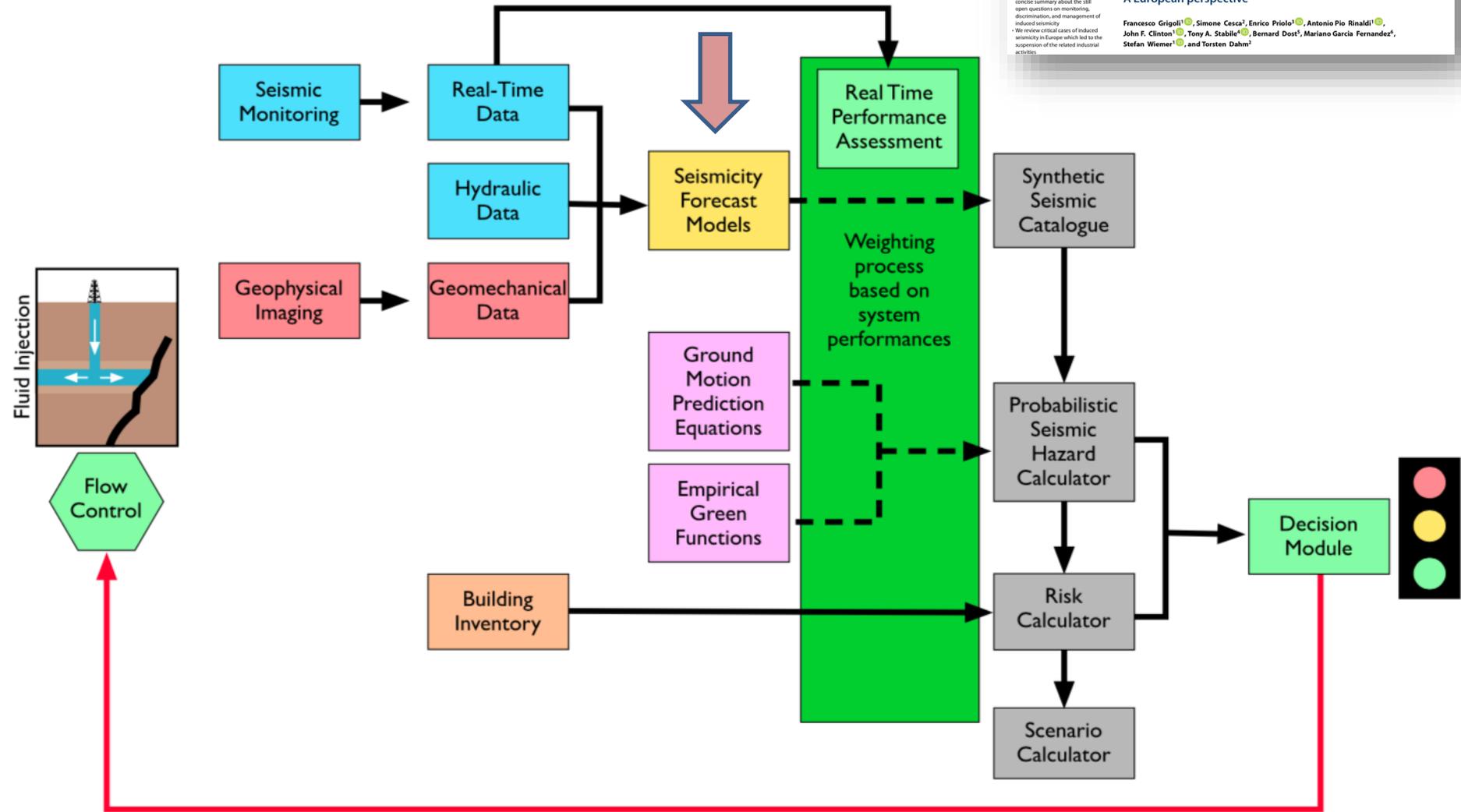
But no easy answer found, no magic bullet, it is a hard problem!



Best hope:  
Quantitative Risk assessment update in near-real time

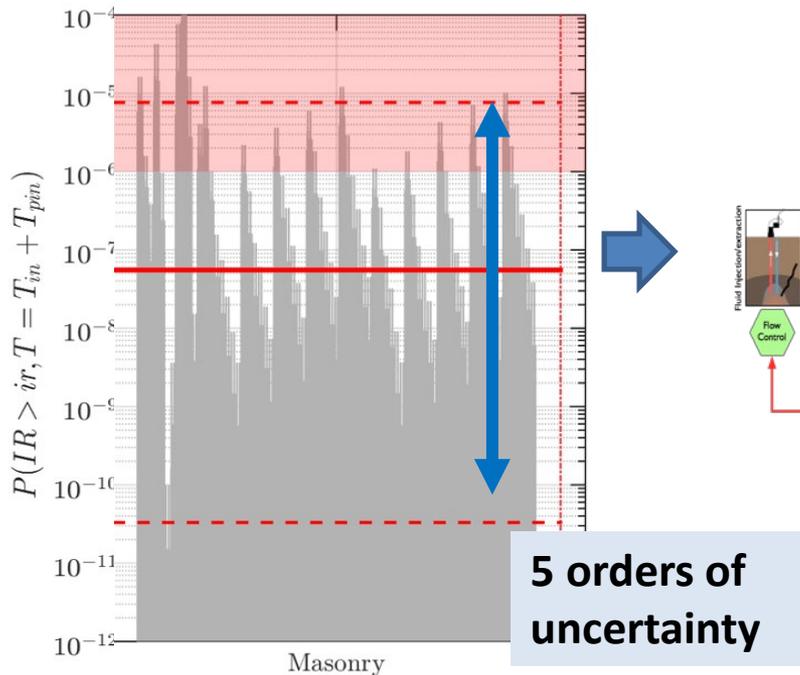


# Our approach: Adaptive Traffic Light System (ATLS)

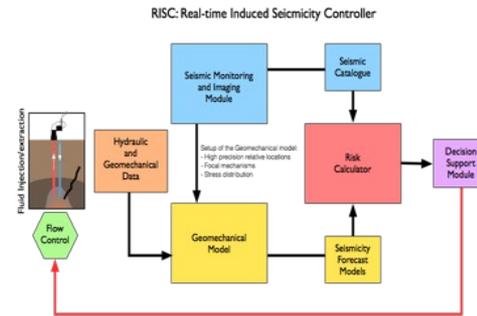


**Huge a-priori risk uncertainty due to heterogeneity and lack of local knowledge. The only way to reduce it is in-situ, through data assimilation (?)**

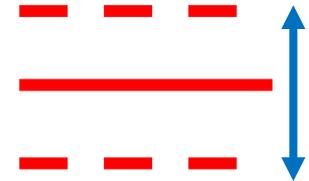
### A-priori risk study



### ATLS



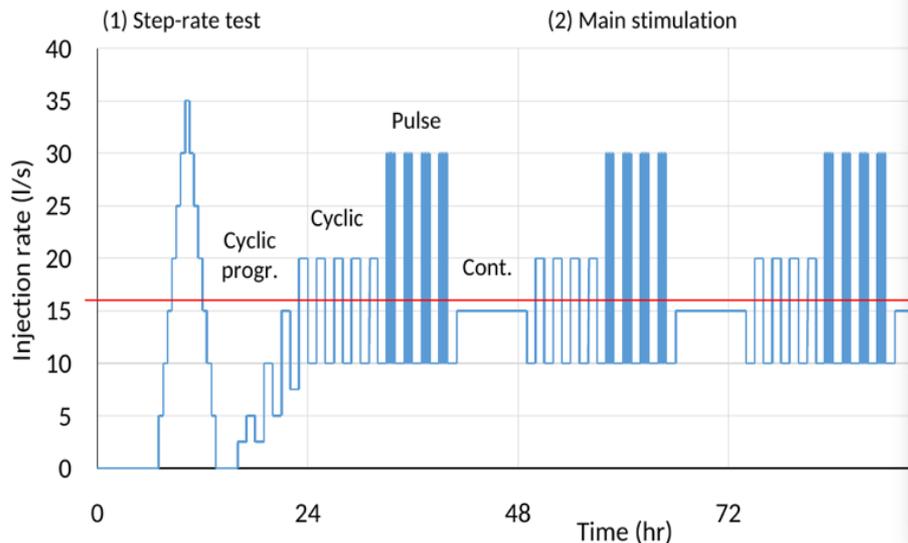
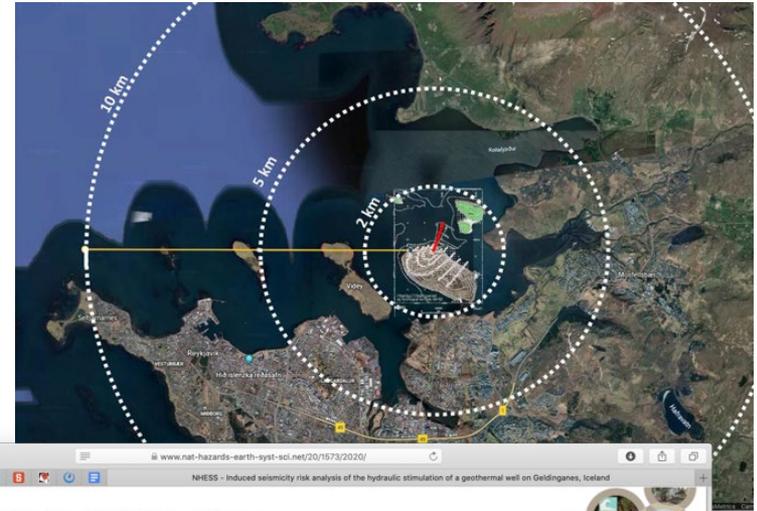
### Real time update



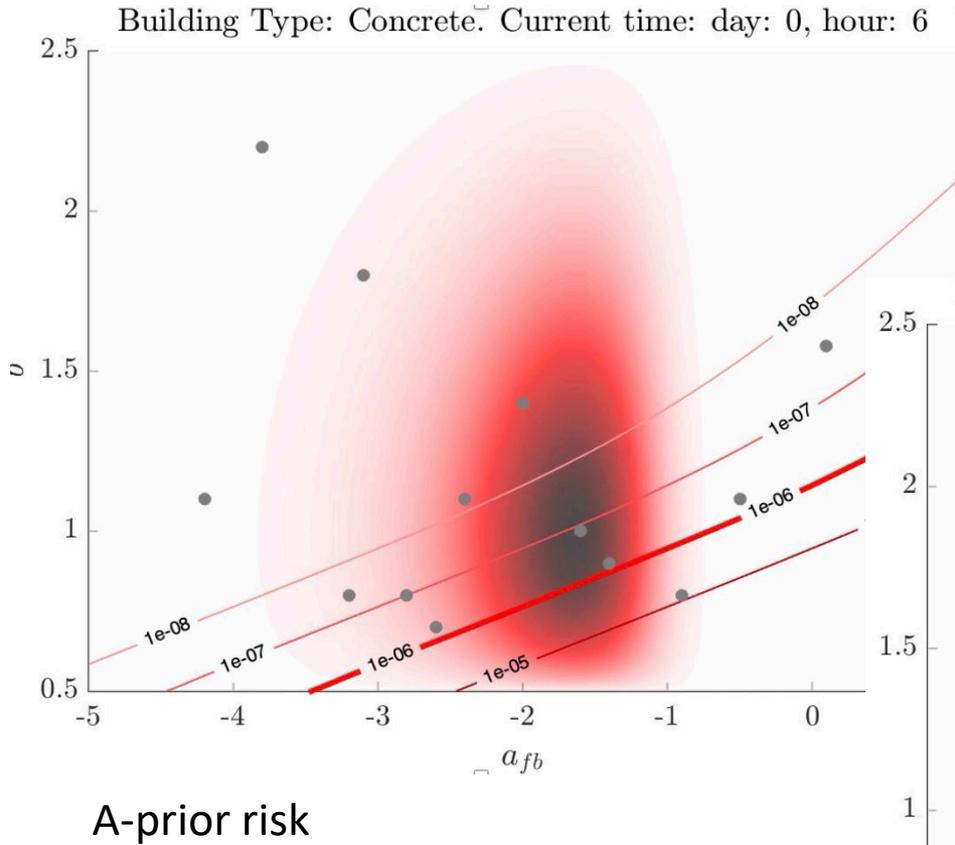
**2-3 orders of uncertainty?**

## 2. Progress in demonstrating adaptive risk mitigation strategies

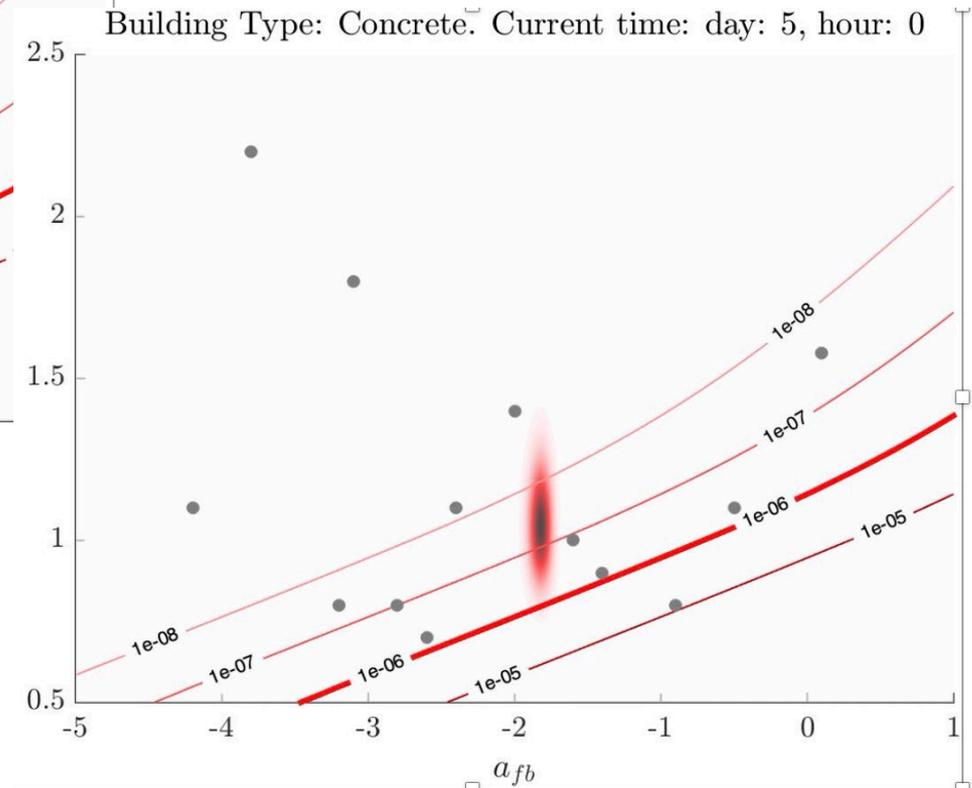
- For example, demonstrating adaptive traffic light system and cyclic stimulation in the Geldinganes project (together with DESTRESS).
- Next step: Application Bedretto (starting Nov 3 2020).



# Real-time risk assessment in Geldinganes: Worked OK.

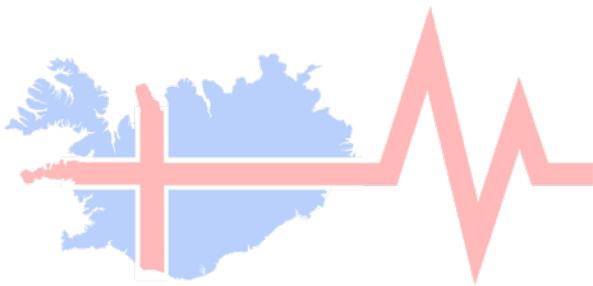
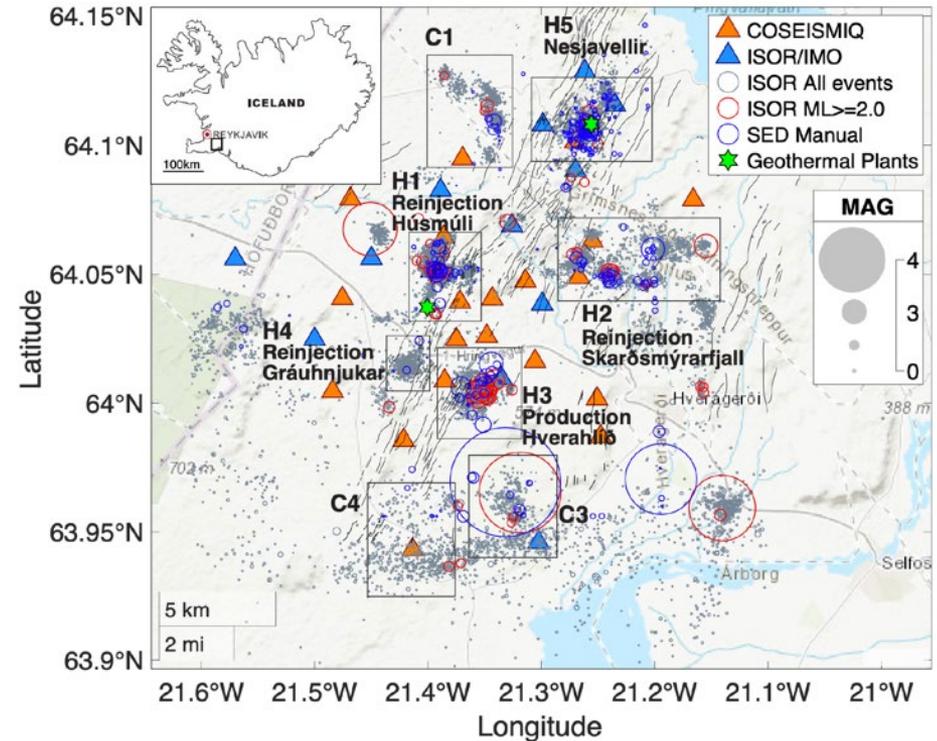


Note the reduction in uncertainty



# Island: 3 large projects by now

- EC GEOTHERMICA COSEIMIQ
- EC GEOTHERMICA DEEPEN
- EC FP7 DESTRESS
- → Iceland is a great test bed



# Spring in Island in 2020

Wet soil on the way to THJ07



Snow around BLK22



Water in BLK22

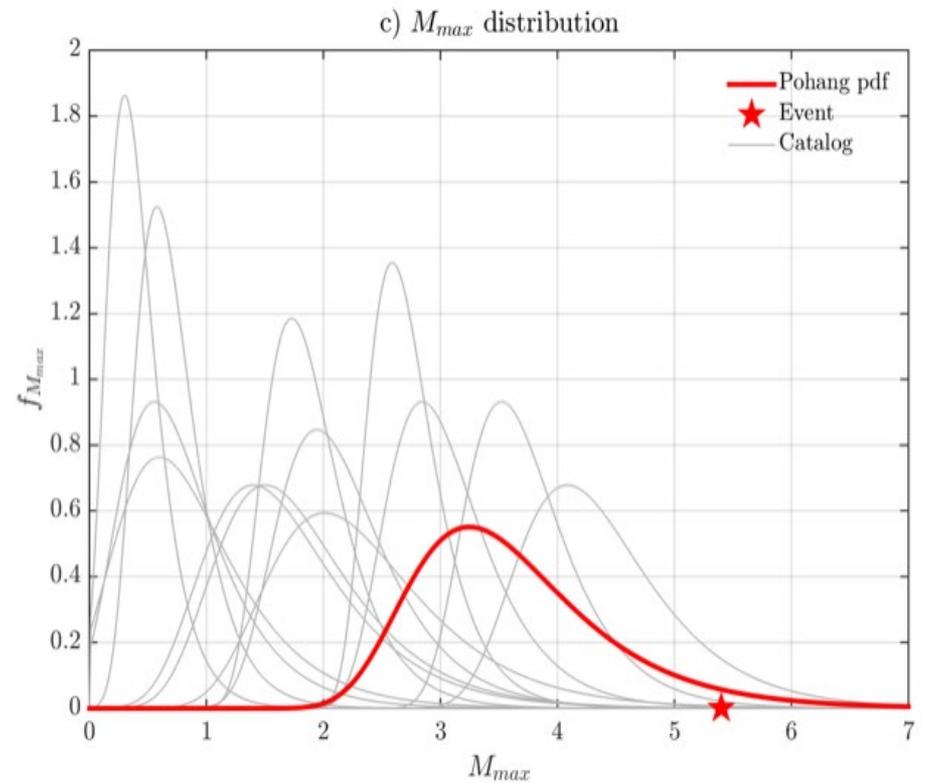
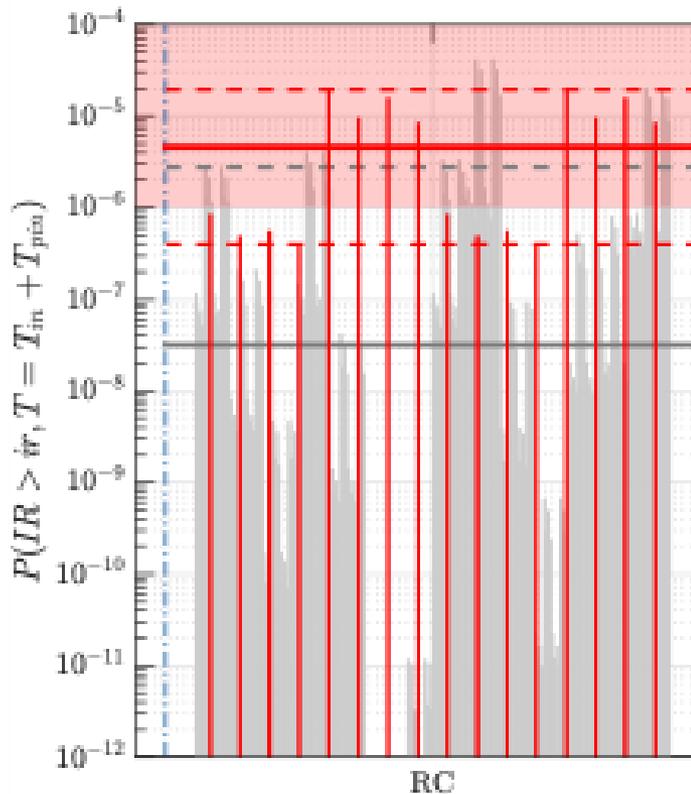


GAN02

Station is  
under 1-2 m  
of snow

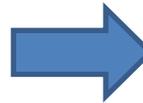
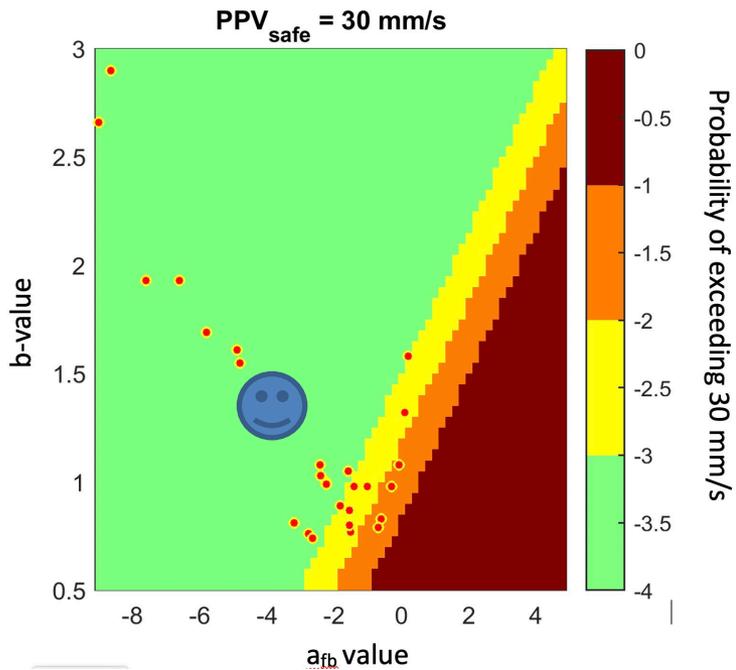
# Pohang ?

Easy to say with hindsight .. But we claim that if you had done Real-time risk assessment, the project would have been in the red area much before the M5.5.

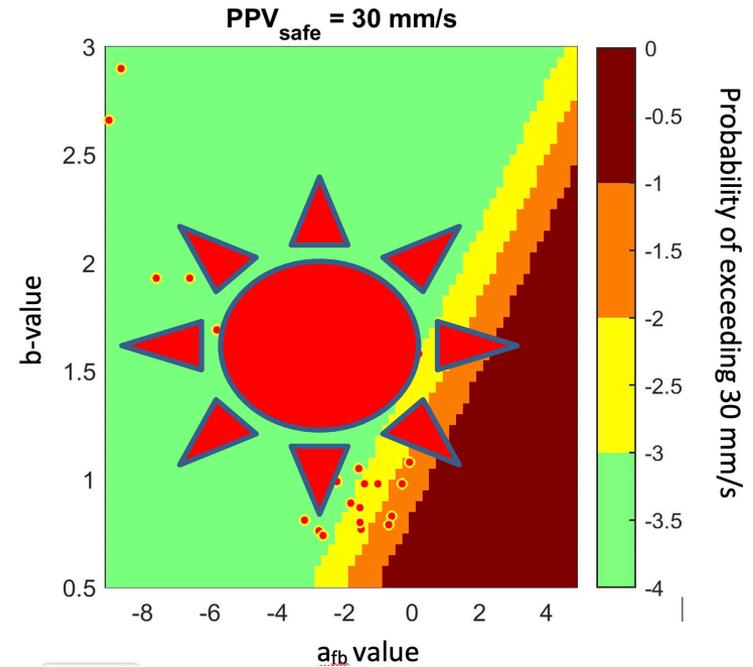


# Next stop (from Tomorrow): Bedretto

A-priori risk – well in the green



Updated risk ??

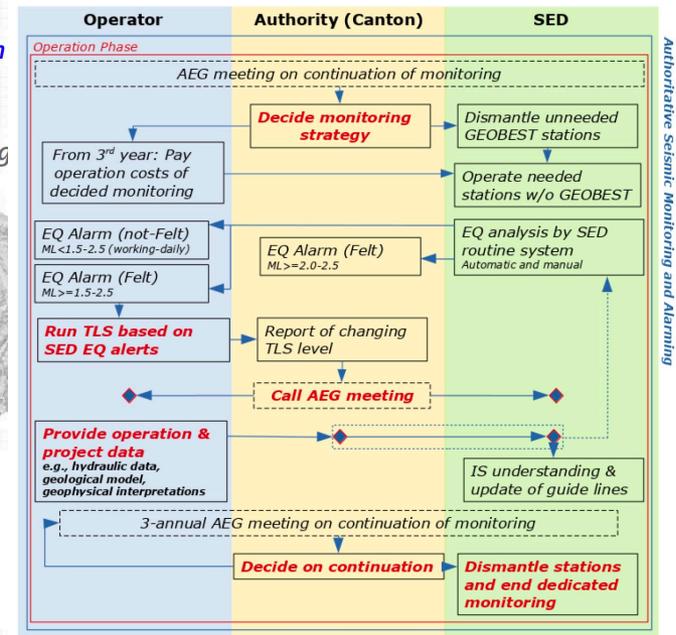
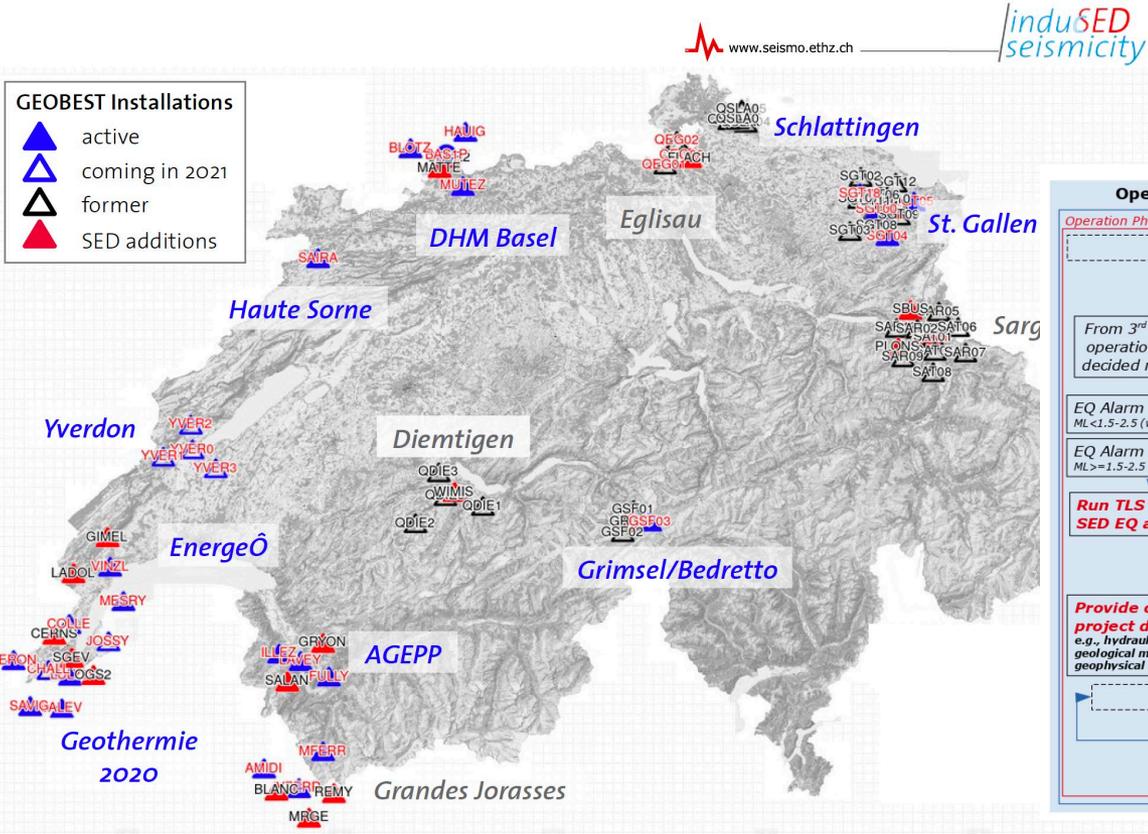


# 3. Progress on supporting cantonal authorities in monitoring, risk assessment and regulation

Based in parts on the progress achieved during the SCCER-SoE, the BFE funded framework GEOBEST2020+ supports cantons in upcoming hydrothermal projects (i.e. seismic monitoring, alerting, review of risk studies, workflows,, communication etc.).

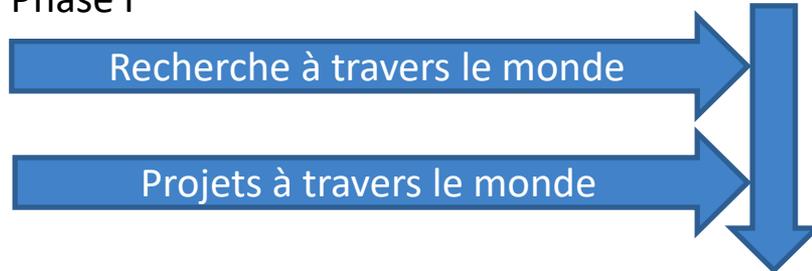
GEOBEST2020+ Seismic Safety Workflow for deep geothermal projects of hydrothermal type

Draft, Version 5.3, 18.05.2020  
Toni Kraft, Philippe Roth, and Stefan Wiemer  
Swiss Seismological Service @ ETH Zurich  
Contact: geobest@seis.ethz.ch



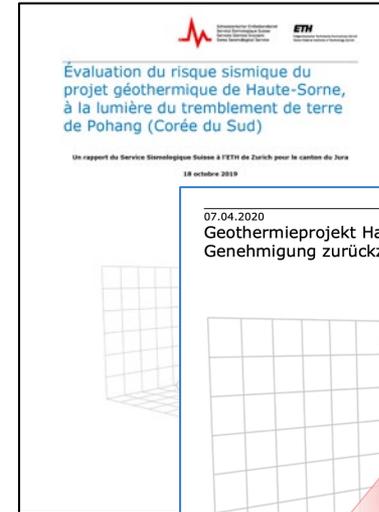
# Example: Recommendations SED to the Canton Jura Haute Sorne Project

Phase I



Attribution du permis?

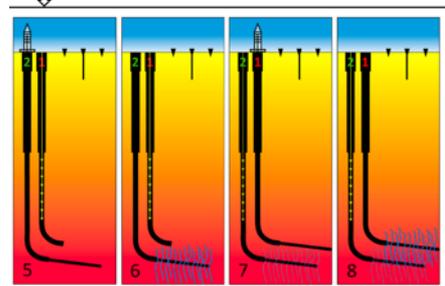
Phase II



07.04.2020  
Geothermieprojekt Haute-Sorne – Kanton erwägt Genehmigung zurückzuziehen

In der jurassischen Gemeinde Haute-Sorne war vorgesehen, ein petrothermales Tiefengeothermieprojekt zur Stromerzeugung zu errichten. Die Frage nach dem mit dem Projekt verbundenen seismischen Risiko wurde vom Kanton erneut aufgeworfen, nachdem sich im November 2017 nahe der südkoreanischen Stadt Pohang ein Erdbeben mit einer Magnitude von 5.5 ereignet hat (siehe Aktualisiertrag vom 24.05.2019 für eine Übersicht). Auslöser des Bebens war ein petrothermales Tiefengeothermieprojekt in unmittelbarer Nähe. Die Geo-Energie Suisse AG (GES) wolle das Projekt in Haute-Sorne abtun und betoni

ATLS (Risque en temps réel)



Canton

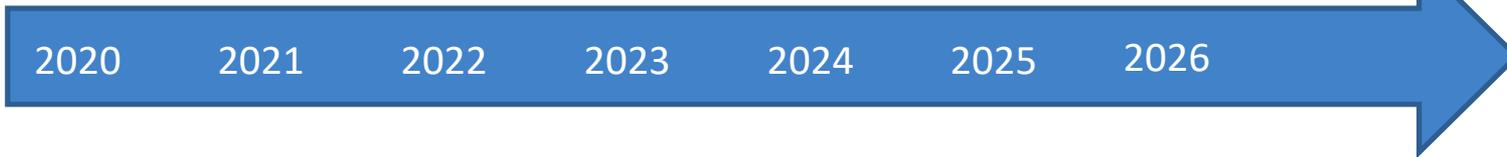
GO/NO

Sismique 3D

Étude de risque

Canton

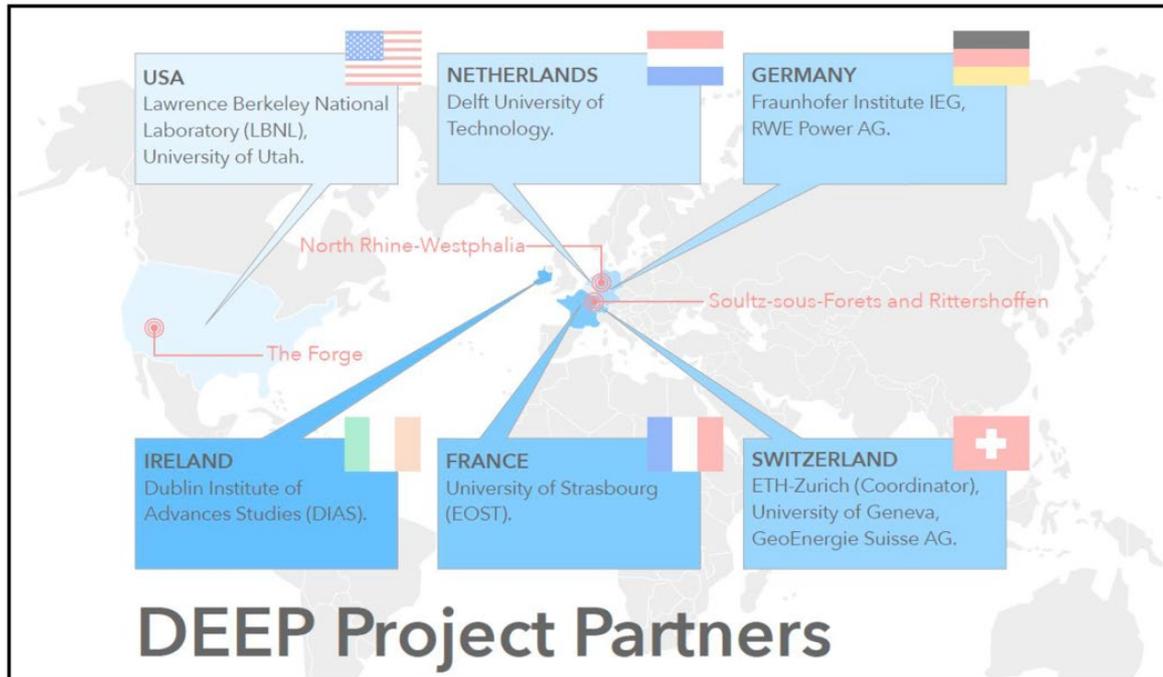
GO/NO



## 4. Progress in sustainable implementation and acquiring future projects

The EC Geothermica project DEEP (2020-2023, funding 5.7M EUR) bring together academic and industry partners (including ETH, UniGe and GES) in demonstrating innovative approaches to de-risking EGS projects.

BFE also funds GES to to bring innovation to Haute-Sorne



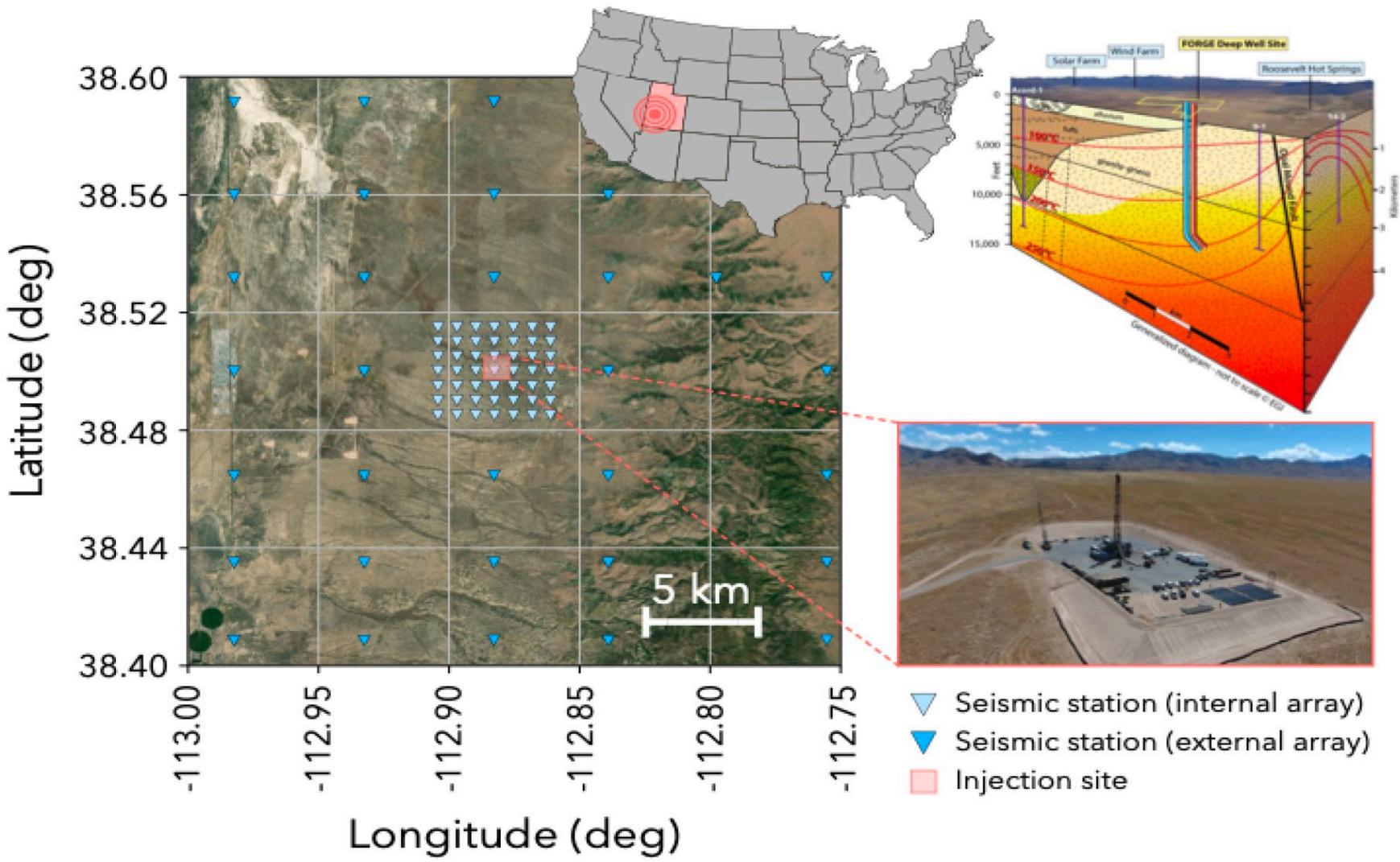
### DEEP: Innovation for De-Risking Enhanced Geothermal Energy Projects

A proposal to the 2<sup>nd</sup> call of GEOTHERMICA presented by ETH, LBNL, IEG, GES, EOST, DIAS, UNIGE, TUD, UUTAH, DAGO and RWE

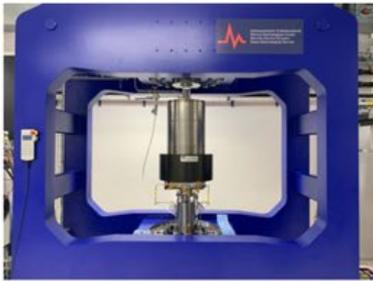
Stage II proposal, submitted January 31 2020

Screenshot

# UTAH Forge: A full scale EGS field laboratory – and Switzerland is an important partner – fantastic opportunity!



# The future: Working across scales



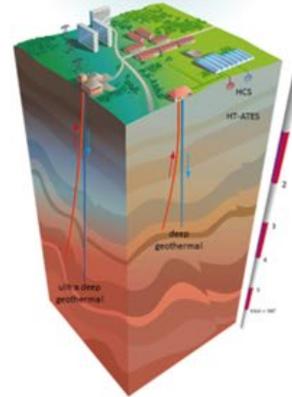
0.01- 100 mm

-9 to -6



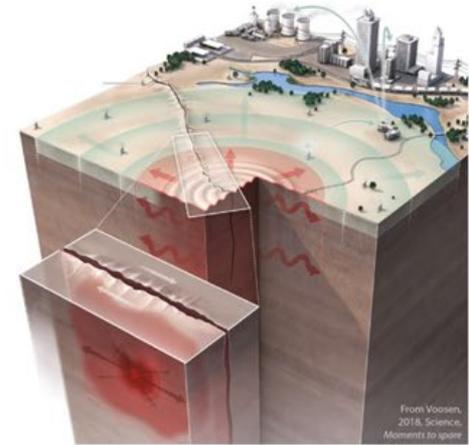
0.01 – 100 m

-5 to 0



0.1 – 1 km

-1 to 5

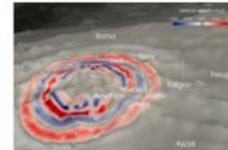


1 - >100 km

1 to 9

Length scales →

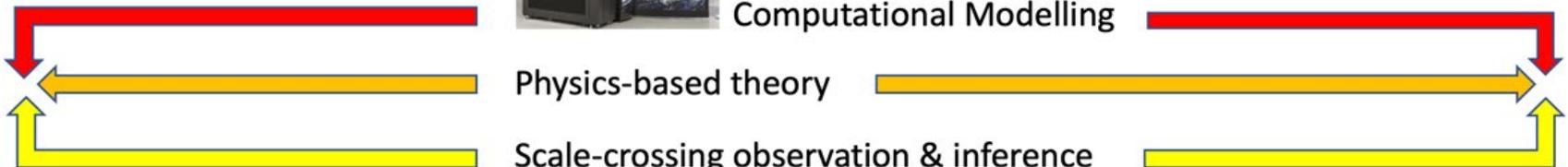
Magnitudes (Mw)



Computational Modelling

Physics-based theory

Scale-crossing observation & inference



# So, where are we in managing induced seismicity? It depends on your point of view ...

