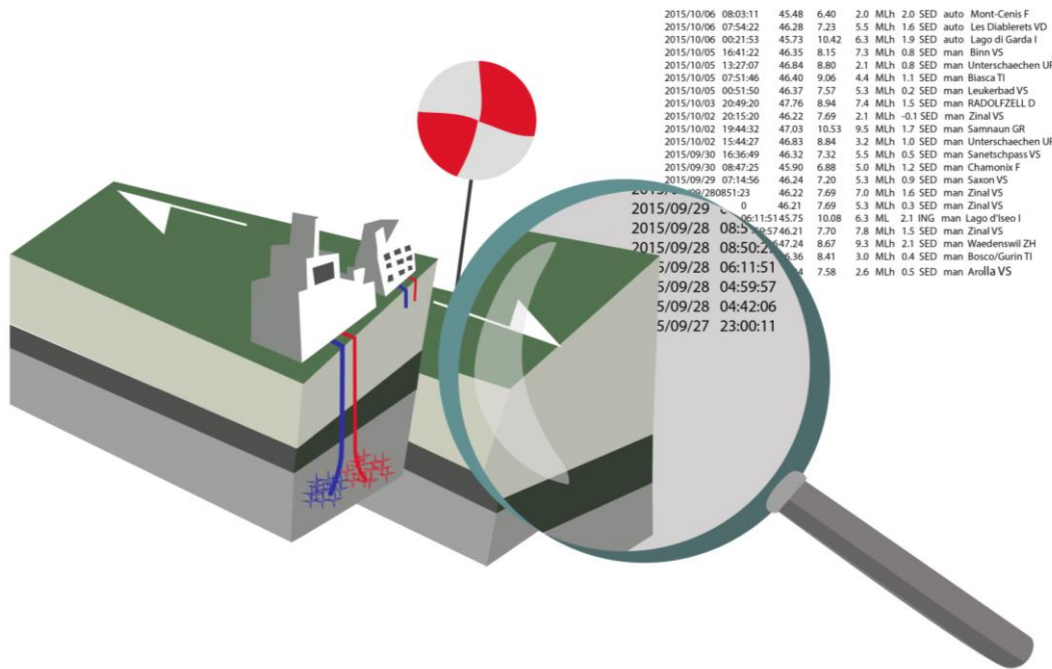


Challenges for limiting induced seismicity

Stefan Wiemer - with contributions by many others

Sion, 13.9.2016



SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY



Demonstration of soft stimulation treatments
of geothermal reservoirs



Energiewende
Nationales Forschungsprogramm

In cooperation with the CTI



Energy funding programme
Swiss Competence Centers for Energy Research



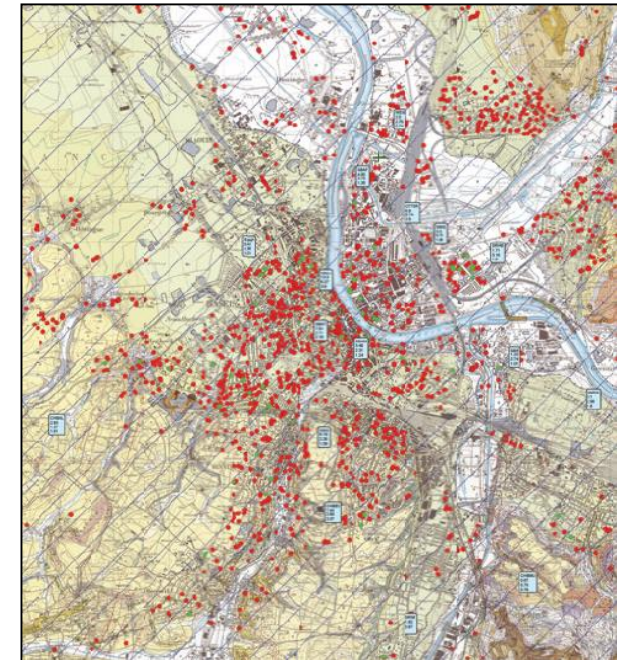
Schweizerische Eidgenossenschaft
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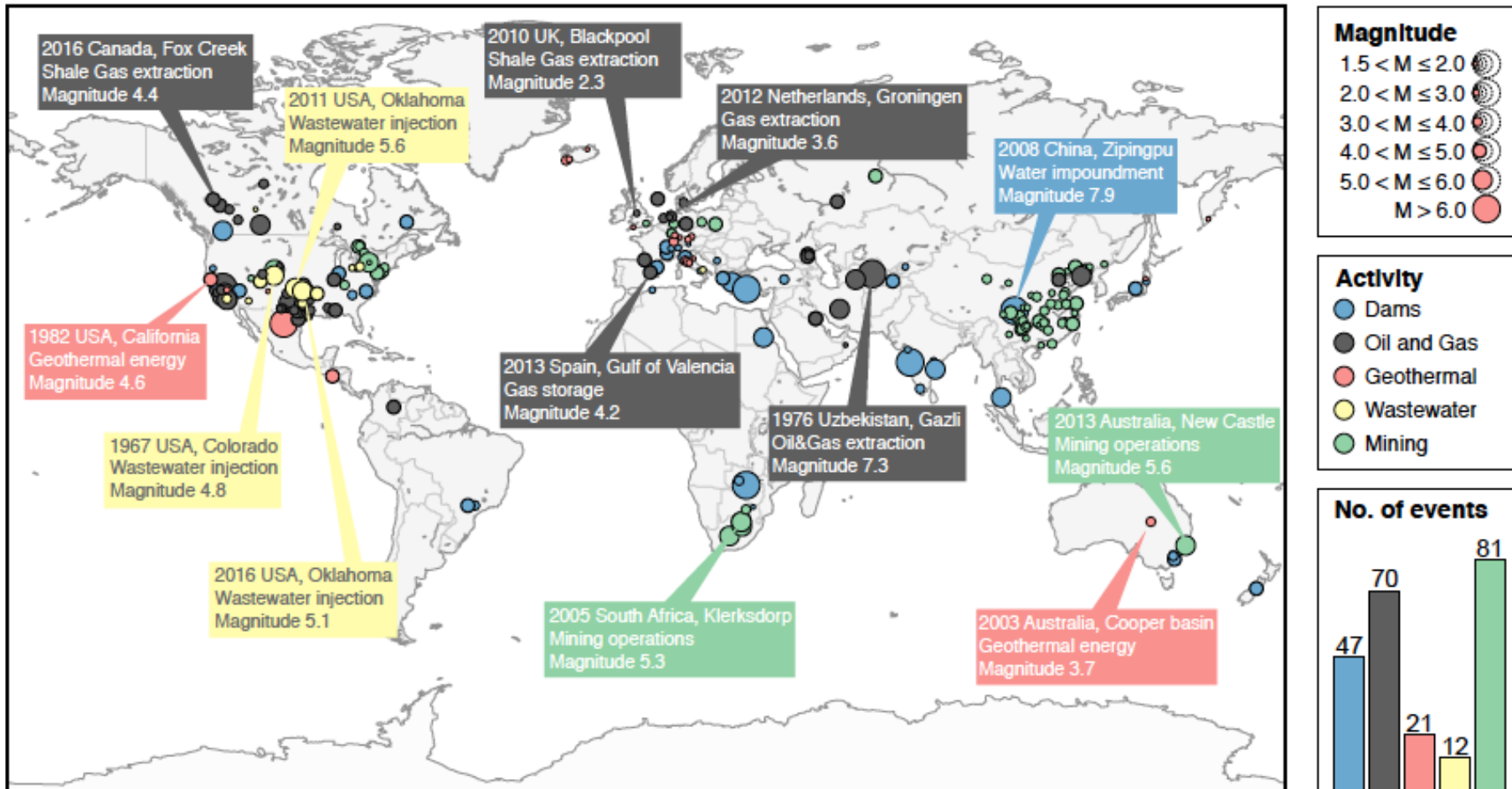
Commission for Technology and Innovation CTI

At least since Basel 2006 - we all know Induced Seismicity is a problem

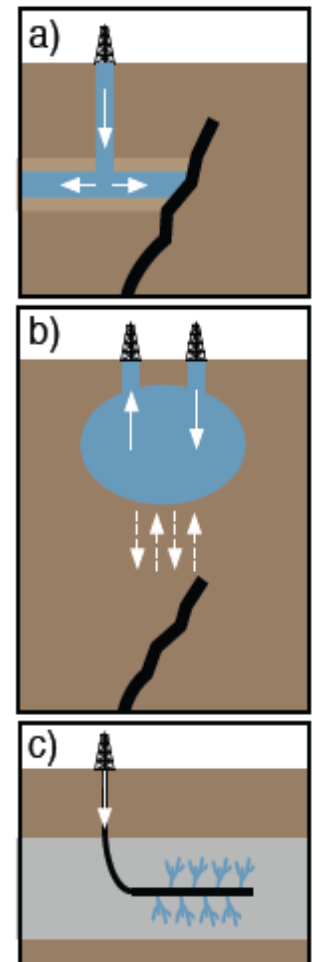
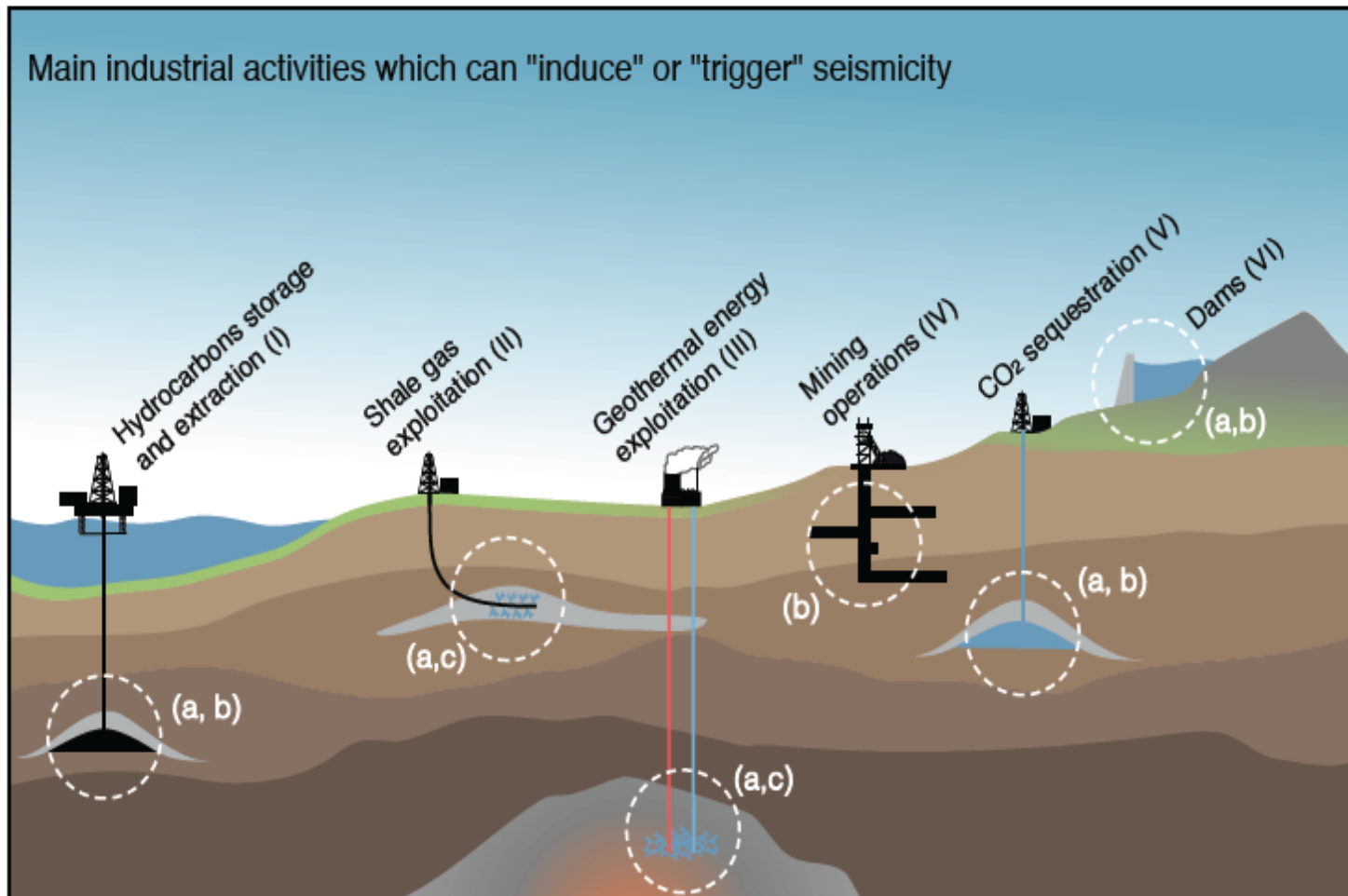
But it is 2016 – have we made progress - are we there yet?



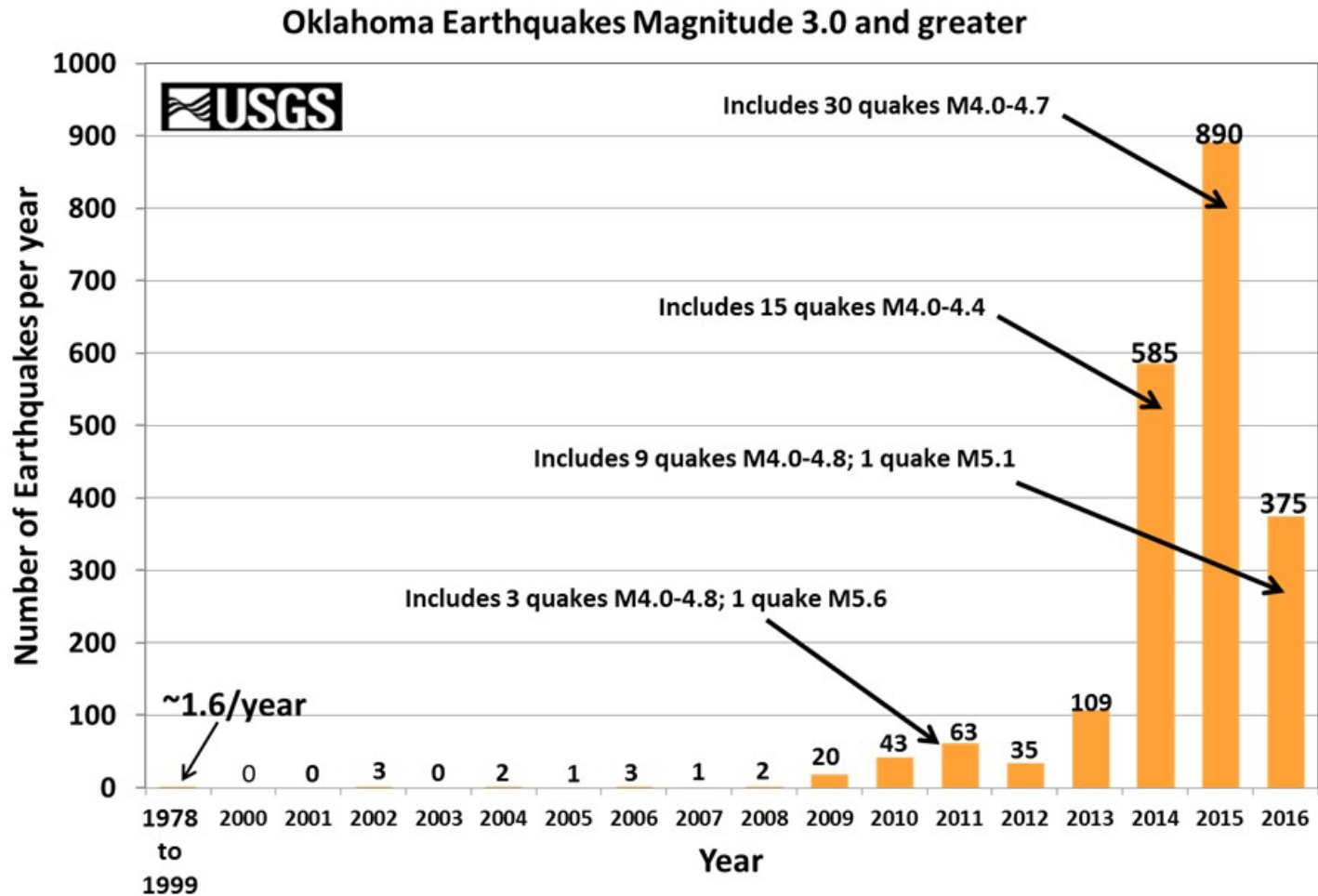
Induced Seismicity: A global challenge...



... with many causes ...

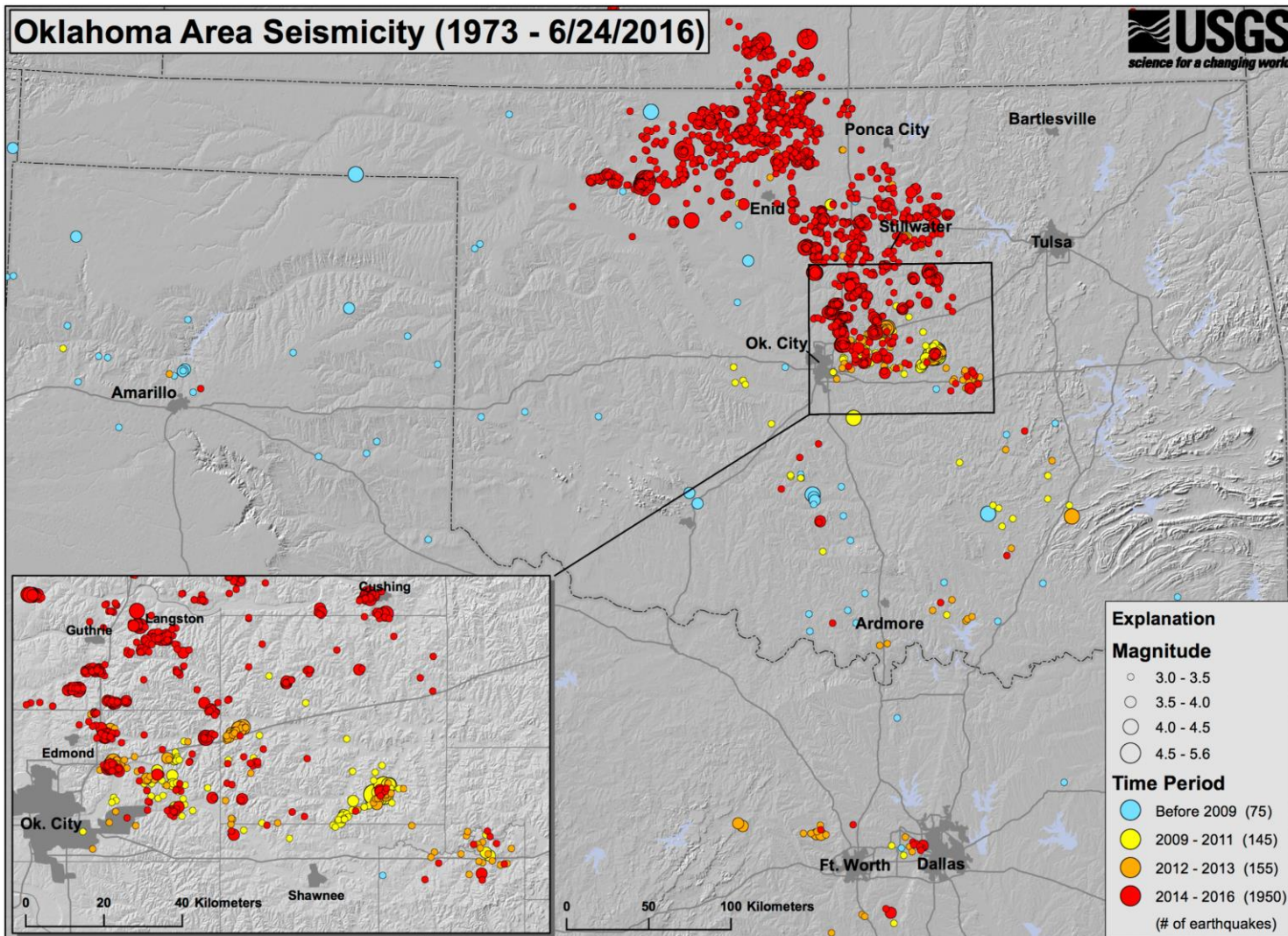


Are we there yet ? Not in the USA ...



Source: USGS-NEIC ComCat & Oklahoma Geological Survey; Preliminary as of June 22, 2016

Are we there yet ? Not in the USA ...



Are we there yet ? Not in the USA ...

U.S.

Oklahoma Orders Shutdown of Wells After Record-Tying Earthquake

By NIRAJ CHOKSHI and HENRY FOUNTAIN SEPT. 3, 2016



Stonework fell to the sidewalk at the corner of Sixth and Harrison Streets in Pawnee, Okla., after a 5.6-magnitude earthquake struck the area on Saturday morning. Lenzky Krehbiel-Burton/Reuters



Oklahoma officials on Saturday ordered oil and gas operators to shut down three dozen wastewater disposal wells following a 5.6-magnitude earthquake that tied a record as the strongest in state history.

The quake, centered near Pawnee, rattled the state just after 8 a.m. Eastern

The lawyers have arrived!

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- ✔ Damaged bricks, mortar joints and fascia
- ✔ Movement or cracking of the foundation

- ✔ Cabinets separating from walls
- ✔ Damaged doors and door casing
- ✔ Damage to door and window trim
- ✔ Cracked drywall

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Last Name *

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Are we there yet ? Not in the NL...

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NETHERLANDS

EARTHQUAKES DAMAGED AT LEAST 100,000 GRONINGEN HOMES

Posted on Sep 5, 2016 by Janene Pieters



Picture: Matt Katzenberger/Flickr

At least 100 thousand Groningen residents live in a home damaged by earthquakes caused by extraction in the province. A quarter of them reported damage more than once, according to a study by the University of Groningen, public health service GGD and the municipality of Groningen, NOS.

The researchers looked at NAM's data on damage reports as well as figures from Statistics Netherlands and the Land Registry. Since 2012 about 70 thousand earthquake damage claims were filed. Sixty thousand of these were handled and paid. The other 15 thousand are still in various stages of processing.

According to the researchers, the actual figures may be much higher as the damage in some homes has not yet to be discovered. They also point out that many damaged homes lie outside the so-called "earthquake zone" and are therefore not included in the figures.

A previous study showed that earthquake damage to home can lead to health problems for those affected, ranging from insomnia to heart problems. About 40 percent of Groningen residents do not feel safe in their homes, compared to 15 percent in all of the Netherlands. Among Groningen residents whose homes were hit by an earthquake more than once, only a third still feel safe in their homes.

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101 schools in Groningen need action because of earthquake risk

Education     June 7, 2016



Photo: Graham Dookery

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Shell and ExxonMobil regret Groningen earthquake problems

Business | September 8, 2016



A condemned and shored-up cafe. Photo: Graham Dockery

The two i
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Groninge
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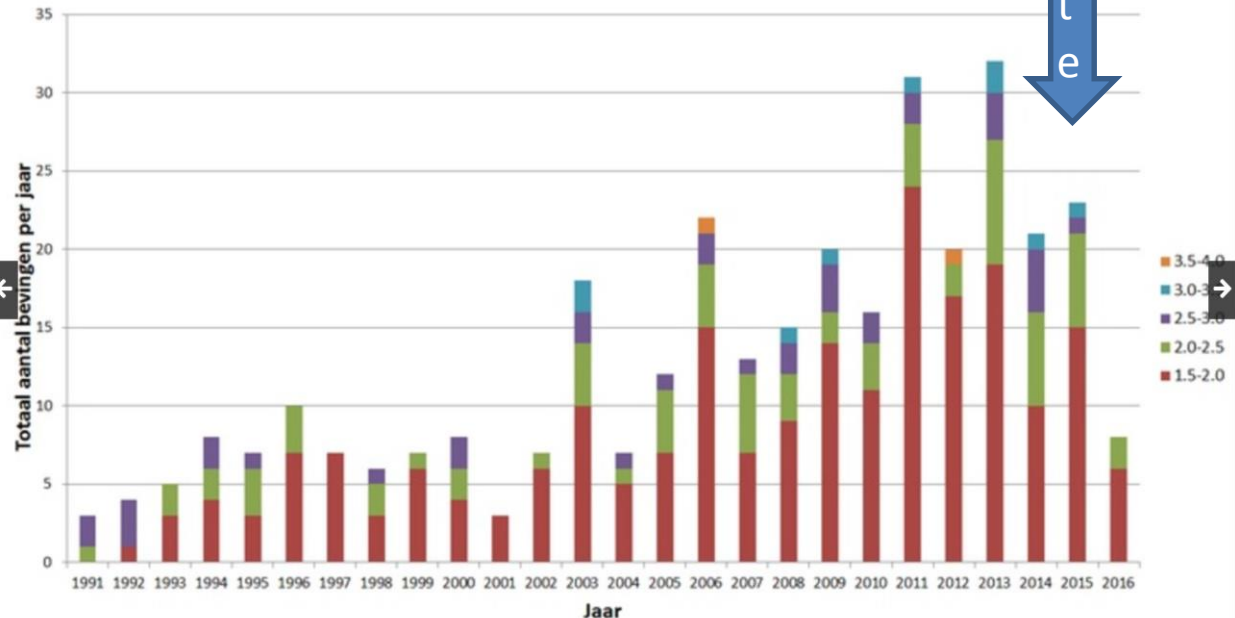
Officials r
parliamer
ExxonMo

challenged by GroenLinks MP Liesbeth van Tongeren

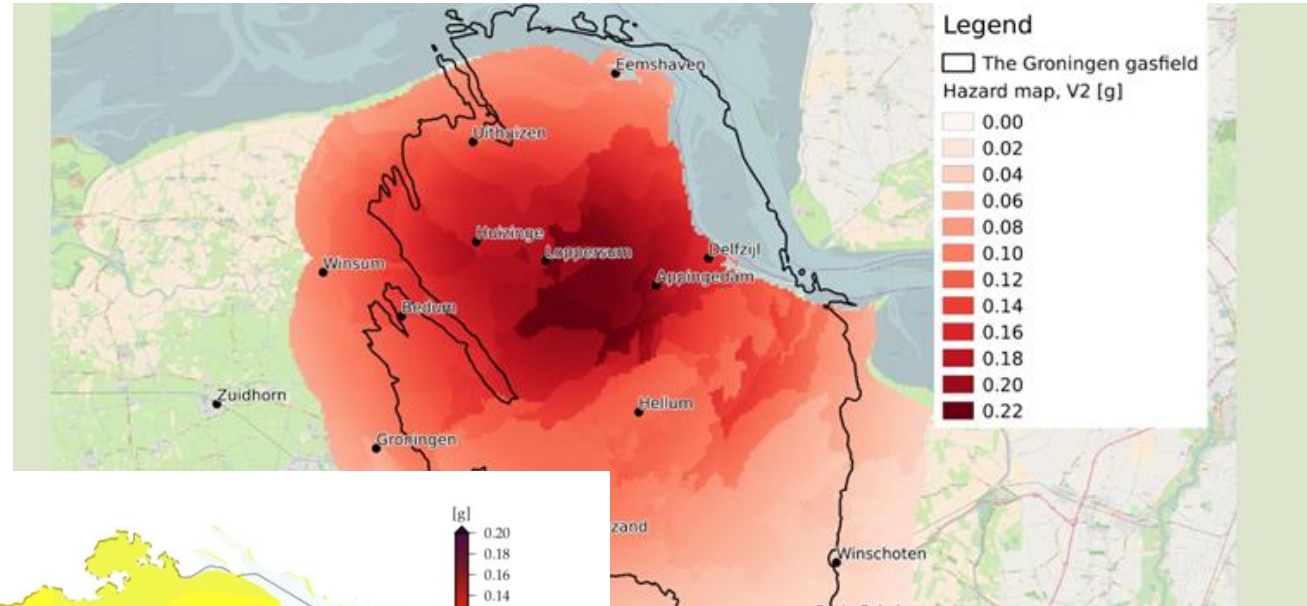
'We acknowledge that the people of Groningen are d
caused by gas extraction, which we in the Netherland
Shell Nederland president Marjan van Loon said.

'That is why the people of Groningen deserve our sup
its regrets and I can fully support that. So I can say to

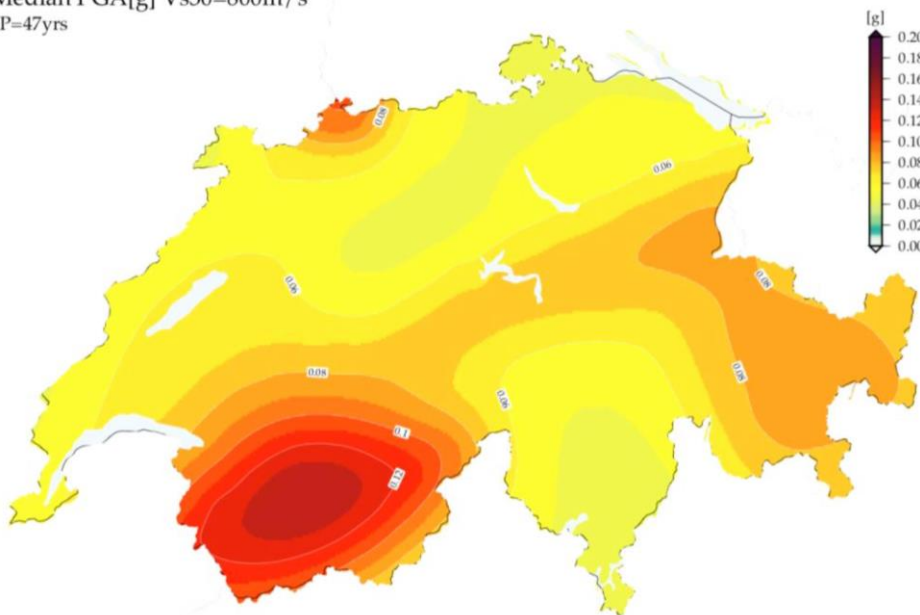
Jaarlijkse verdeling per magnitude in Groningen



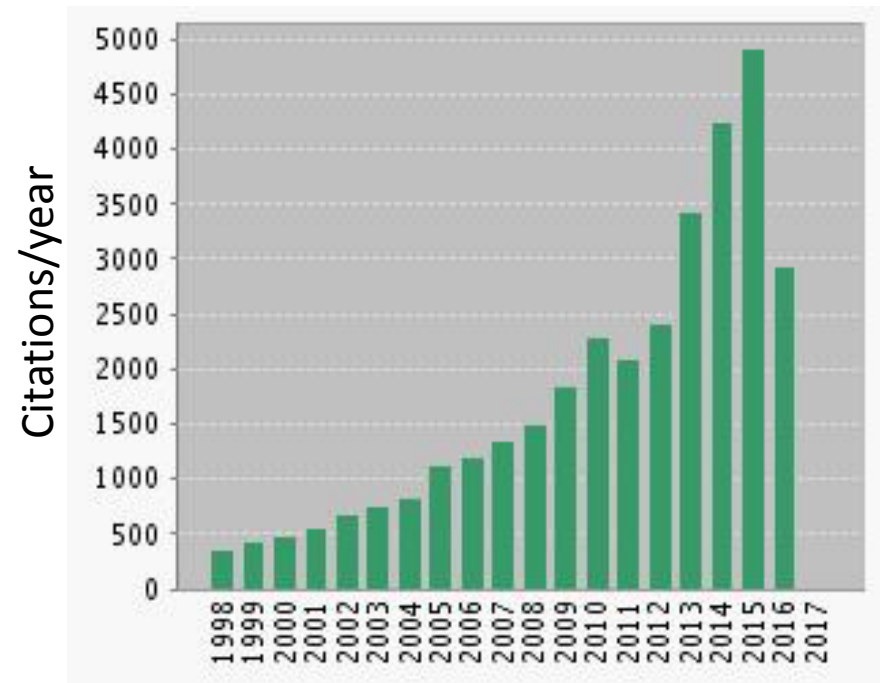
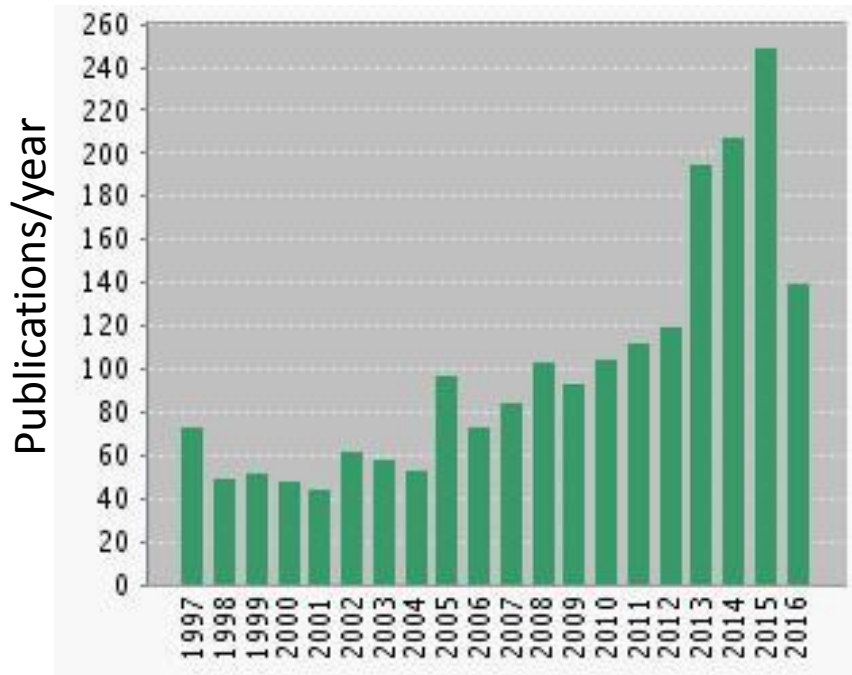
Beyond nuisance ...



Median PGA[g] Vs30=800m/s
RP=47yrs



Are we there yet ? The academic world is just getting started ... (citation '*induced seismicity*')



Some perspective

- Natural earthquakes matter more!
- Other topics may matter more ('climate change': 23'932 papers in 2015 alone...) .
- We are not powerless.



Are we there yet ? Status in Switzerland

4 **Blick**

Erdbeben-Simulation im Felslabor

Freitag, 9. September 2016

Dieser Forscher schlägt Wellen



Im Felslabor Grimsel: Florian Amann (41) mit einer Sonde für die Untersuchung der Bohrlöcher. An der Spitze ist eine Kamera.



Der Eingang: Das Felslabor befindet sich in 450 Metern Tiefe.

Artita Albert (Text) und Stefano Schroter (Fotograf)

In 450 Metern Tiefe am Grimselpass im Berner Oberland fühlen Wissenschaftler dem Berg den Puls. In einem Felslabor arbeiten sie an der Energie der Zukunft – und daran, **deren grösstes Risiko deutlich zu verringern: unerwünschte künstliche Erdbeben.**

Ein 3,30 Meter hoher Tunnel führt zum unterirdischen Labor. Der Boden ist feucht, denn **der Räterichsbodensee über uns presst das Wasser durch den Granit.**

15 Bohrungen hat das Team um Florian Amann (41) von der ETH Zürich in den Fels getrieben, bis zu 48 Meter tief. In ihnen stecken **Kameras, Glasfaserkabel und Sensoren**, welche Verschiebungen und Druckveränderungen registrieren.

«Wir forschen daran, die Geothermie effektiver zu machen und das Risiko von Beben in einem akzeptablen Rahmen zu halten», sagt er. Geothermie ist Energie aus heissem Tiefenwasser, diese soll in der Schweiz einen Teil des Atomstroms ersetzen. Um alle unsere Atomenergie abzulösen, bräuchte es 25 geothermische Kraftwerke.

110 Experten arbeiten für das Schweizer Kompetenzzentrum für Strombereitstellung. Sie prüfen, welche Wege sich das eingepresste Wasser im Fels sucht, **der In vier bis fünf Kilometern Tiefe bis zu 200 Grad heiss** ist, und welche Erschütterungen und Verschiebungen das heisse Wasser bis zur Rückkehr nach oben auslöst.

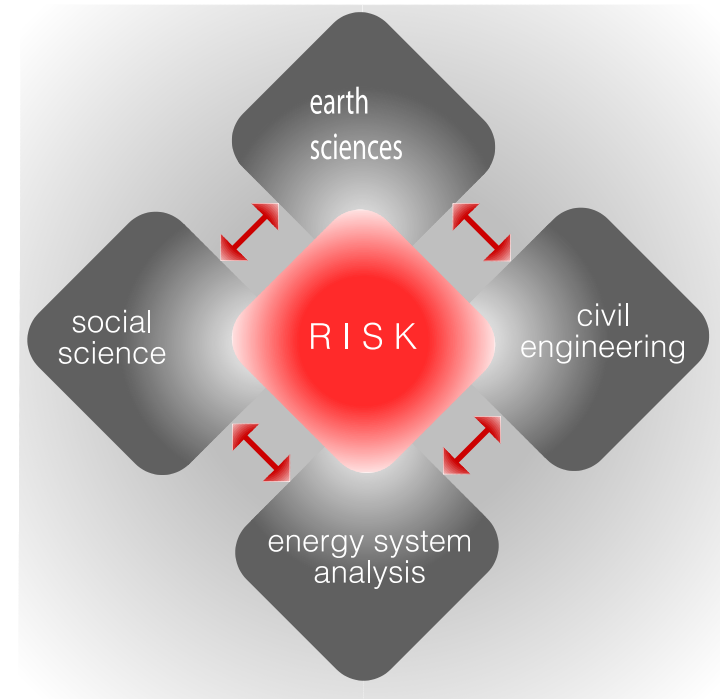
Ein Warnzeichen war eine Probebohrung 2006 in Basel: Das eingepumpte Wasser, das sich in der Tiefe erhitzen sollte, **löste 11 200 kleine Erdbeben aus. Mehrere davon mit einer Stärke von über 3,0 auf der Richterskala** verursachten kleinere Schäden. St. Gallen begrub 2014 ein Geothermieprojekt, weil das gefundene Wasservorkommen zu gering war. Aber auch im Siterobel war es ein Jahr zuvor bei einer Spülung zu einem Beben gekommen.

Im Felslabor Grimsel soll das Unvermeidbare beherrschbar werden. Experte Ueli Wieland (58): **«Das Ziel sind Beben einer Stärke von maximal 2,5. Sie sind an der Oberfläche kaum zu spüren.»**

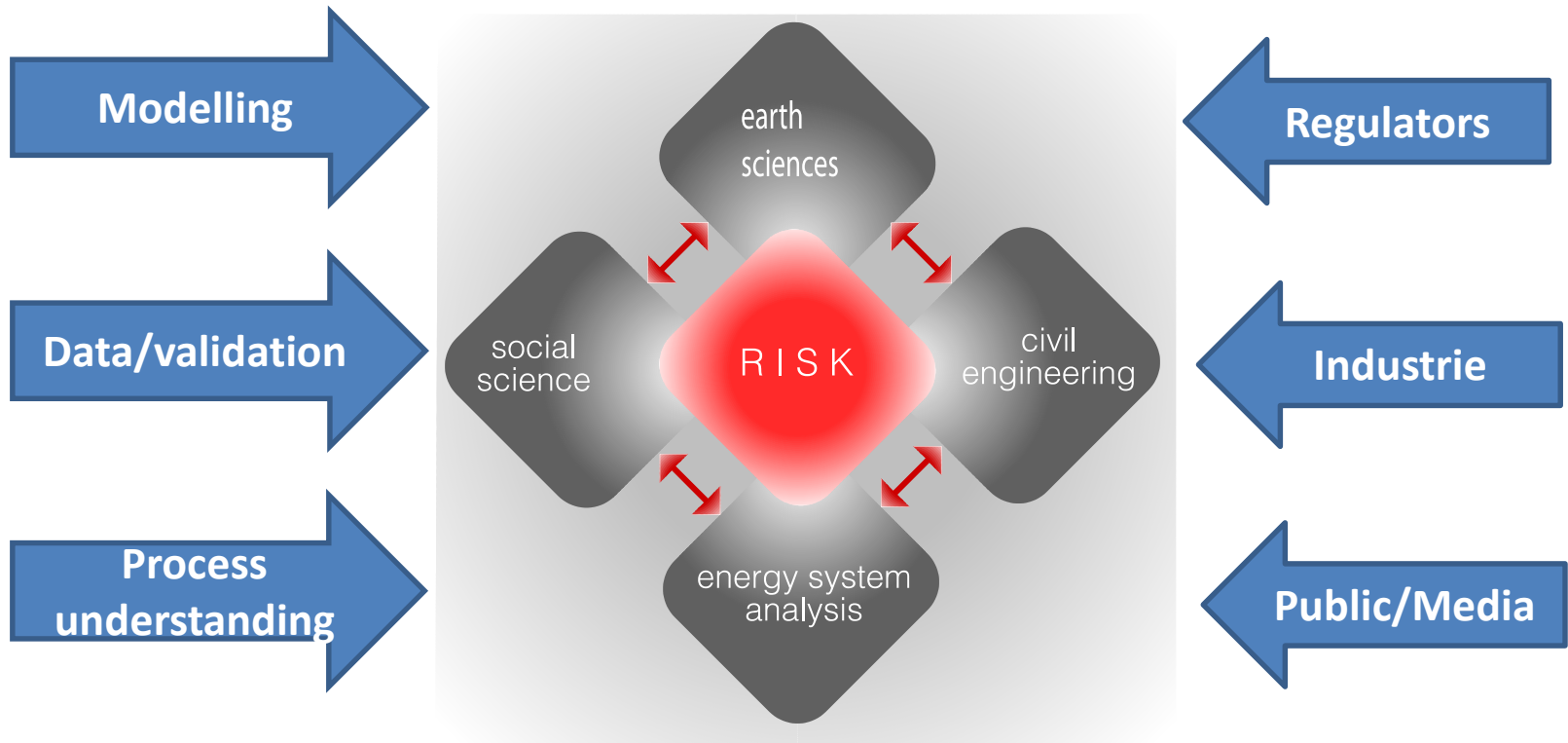
Informationen können die Felslabor Grimsel besichtigen, die Touren sind kostenlos. Informationen: Telefon 056 417 12 82.

So why are we not there yet?

- Because induced earthquake risk governance is a very complex scientific/engineering/societal/ economical (etc.) problem.
- No quick fixes, no silver bullet, no single measure that will simply solve the problem. Instead: A brick by brick, long-term approach that gradually improves the sustainability and the resilience of projects.
- A transdisciplinary and holistic approach is needed, integrating various disciplines as well as spatial and temporal dimensions.
- This is what the SCCER-SoE is doing!



Induced seismicity risk governance is a process – and it requires interfaces!



Check our our posters!

List of posters:

- "Accident Risk Assessment for Deep Geothermal Energy Systems in Switzerland: An Update" by Matteo Spada, Emilie Sutra and Peter Burgherr
- "A Bayesian Hierarchical Model for Hydropower Dam Accident Risk" by Anna Kalinina, Matteo Spada and Peter Burgherr
- "Physical-Based Model of a Dam Failure Event" by Anna Kalinina, Matteo Spada and Peter Burgherr
- "ENSAD v2.0 Hydro: a new interactive, GIS-based database for historical hydropower accidents worldwide" by Peter Burgherr, Matteo Spada, Anna Kalinina and Kim Wansub
- "Risk GOveRnance of electricity pOrtfolioS (RIGOROUs): Cross-technology and spatial tradeoffs of multiple risks" by Trutnevte E., Berntsen P., Knoblauch T., Volken S.
- "Long-term decay and possible reactivation of induced seismicity at the Basel EGS site", by Herrmann M. (other authors?)
- "Controlling induced seismicity in EGS projects by a model-driven traffic light system", by A. Mignan, M. Broccardo and S. Wiemer
- "Multi-risk in the Swiss landscape: The case of earthquake-triggered landslides", by A. Jafarimanesh, A. Mignan and D. Giardini
- "Social discourses on deep geothermal energy" by Olivier Ejderjan and Michael Stauffacher
- "Induced seismicity risk analysis in OpenQuake. Basel case, validation and GIS integration", by Marco Broccardo, Laurentiu Danciu, Arnaud Mignan, Stefan Wiemer
- "Impact of combined wind and solar energy on the Swiss electricity system", by Jérôme Dujardin, Annelen Kahl, Bert Kruyt, Michael Lehning
- "Seasonal and Diurnal Wind Power", by Bert Kruyt and Michael Lehning
- "Nonstructural Damage Tests on Masonry Building Walls: First Phase", by Max Didier, Marco Broccardo, Giuseppe Abbiati, Christoph Jost, Laurentiu Danciu, Bozidar Stojadinovic, Domenico Giardini
- "Accounting for uncertainty in the propagation of dam break flood waves in the Rhone River: from hazards to risks", by A. Darcourt, J. P. Matos and A. J. Schleiss

Abstract

The stimulation phase of Enhanced Geothermal Systems (EGS) induces earthquakes, hence posing problems to the feasibility of geo-energy projects. Although traffic light systems (TLS) exist to mitigate the risk of anthropogenic seismicity, they are on-the-fly tools with so far no forecasting capability. We show in 6 stimulation experiments that a piecewise model describes the observed data with a good degree of confidence. The model is driven first by the injection profile followed by post-injection normal diffusion, and completely defined by a three-parameter set $\theta = [b, a_{fb}, \tau]$ (earthquake size ratio, activation feedback and mean relaxation time, respectively). This allows defining as TLS the magnitude threshold m_{th} at which injection must be stopped to respect a given probabilistic safety target. The proposed model can be used during project planning to estimate the likelihood of failing based on an *a priori* θ and during stimulation phase to respect the safety target.

Induced Seismicity Model

We propose the following piecewise induced seismicity temporal rate $\mu(t)$ model:

$$\mu(t) = \begin{cases} \mu(t) = 10^{a_{fb}/b} 10^{-bM} \Delta V(t) & ; t \leq t_{shut-in} \\ \mu(t) = \mu(t_{shut-in}) \exp\left(-\frac{t - t_{shut-in}}{\tau}\right) & ; t > t_{shut-in} \end{cases} \quad (1)$$

where the injection phase (before shut-in time $t_{shut-in}$) is described by a linear relationship between $\mu(t)$ and the injected flow rate $\Delta V(t)$, in agreement with previous observations (Dinske and Shapiro, 2013; Mignan, 2016; van der Elst et al., 2016), and where the post-injection phase is described by a pure exponential decay representative of a normal diffusion process (Mignan, 2015; 2016) (Fig. 1).

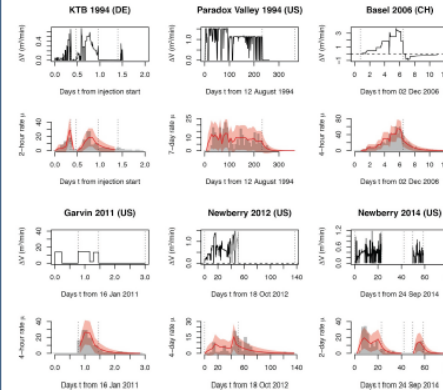


Fig. 1: Induced seismicity model fitting of six stimulation experiments (all publicly available): Kontinentale Tiefbohrung (KTB), Germany, 1994; Paradox Valley, United States, 1994; Basel, Switzerland, 2006; Garvin, United States, 2011; Newberry, United States, 2012 and 2014. For both KTB and 2014 Newberry, experiments are broken down into two separate stimulations, each with its own post-injection tail. The model (Eq. 1) is represented by the red curves on the induced seismicity time series with the $\pm 3\sigma$ uncertainty envelope shown in light red. Vertical lines indicate the shut-in time and the sub-stimulation separations. The model uses as input the induced seismicity time series and the injection profile characterized by the flow rate ΔV .

TLS use during EGS project planning

A safety criterion is recommended that defines acceptable levels of probabilities of exceedance Y , for a prescribed safety threshold X (e.g., magnitude threshold m_{th}). Assuming a non-homogeneous Poisson process, we have $\Pr(m \geq m_{th}, T) = 1 - \exp(-\Lambda_{m_{th}}(T)) = Y$ with $\Lambda_{m_{th}}(T)$ the mean cumulative number of events obtained by integrating Eq. 1. It finally yields:

$$\Lambda_{m_{th}}(T) = 10^{a_{fb}/b} 10^{-b m_{th}} [V(t_{shut-in}) + \tau V'(t_{shut-in})] \quad (2)$$

where V is the total fluid volume injected during the project. Hence, for a given set θ (e.g., previous experiments like Fig. 1) and a planned injection profile, one can determine if the project would *a priori* pass or fail the fixed safety threshold (Fig. 2).

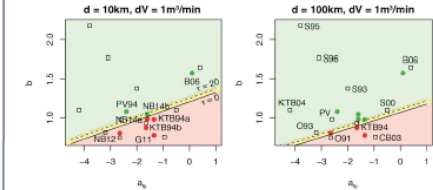


Fig. 2: Acceptable domain for a fixed limit state function with $V = 10,000 \text{ m}^3$, $\Delta V = 1 \text{ m}^3/\text{min}$, 2 building distances d from borehole (10 or 100 km) & $\Pr(\text{building collapse}) = 10^{-6}$ (see Mignan et al. (2015) for damage to m_{th} conversion), considering the set θ obtained in previous projects (circles: this study; squares: Dinske and Shapiro, 2013). NB: Preliminary results, subject to changes.

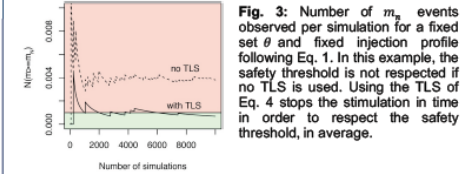
TLS use during EGS stimulation phase

Once the project has the green tag, one can define the TLS using the operational magnitude threshold m_{th} at which the injection is stopped in order to meet the safety target. From

$$\begin{cases} 10^{a_{fb}/b} 10^{-b m_{th}} [V(t_{shut-in}) + \tau \Delta V'(t_{shut-in})] \sim Y \\ 10^{a_{fb}/b} 10^{-b m_{th}} V(t_{shut-in}) = 1 \end{cases} \quad (3)$$

we get $m_{th} = \frac{1}{b} \log_{10} [Y - 10^{a_{fb}/b} 10^{-b m_{th}} \tau \Delta V'(t_{shut-in})] + m_{th}$ (4)

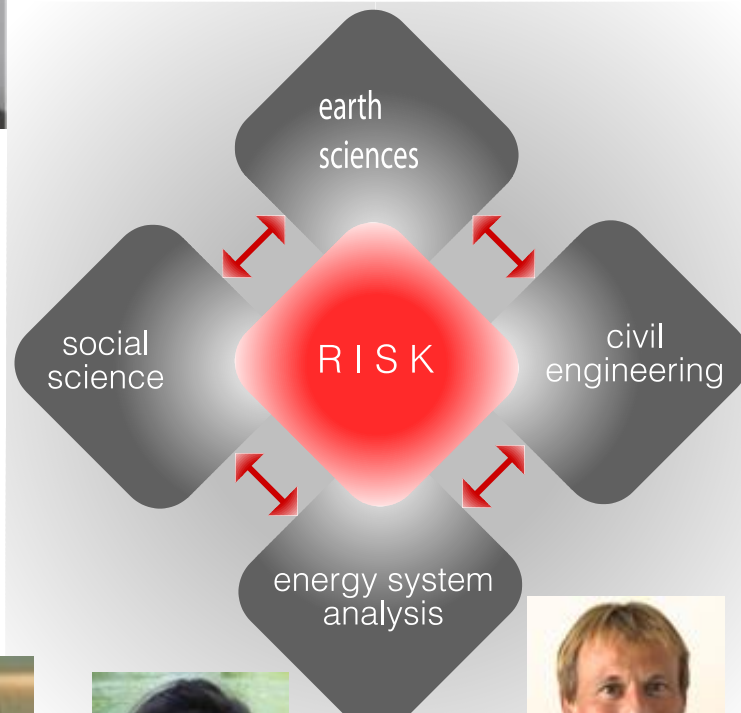
which validity is verified in Fig. 3.







References

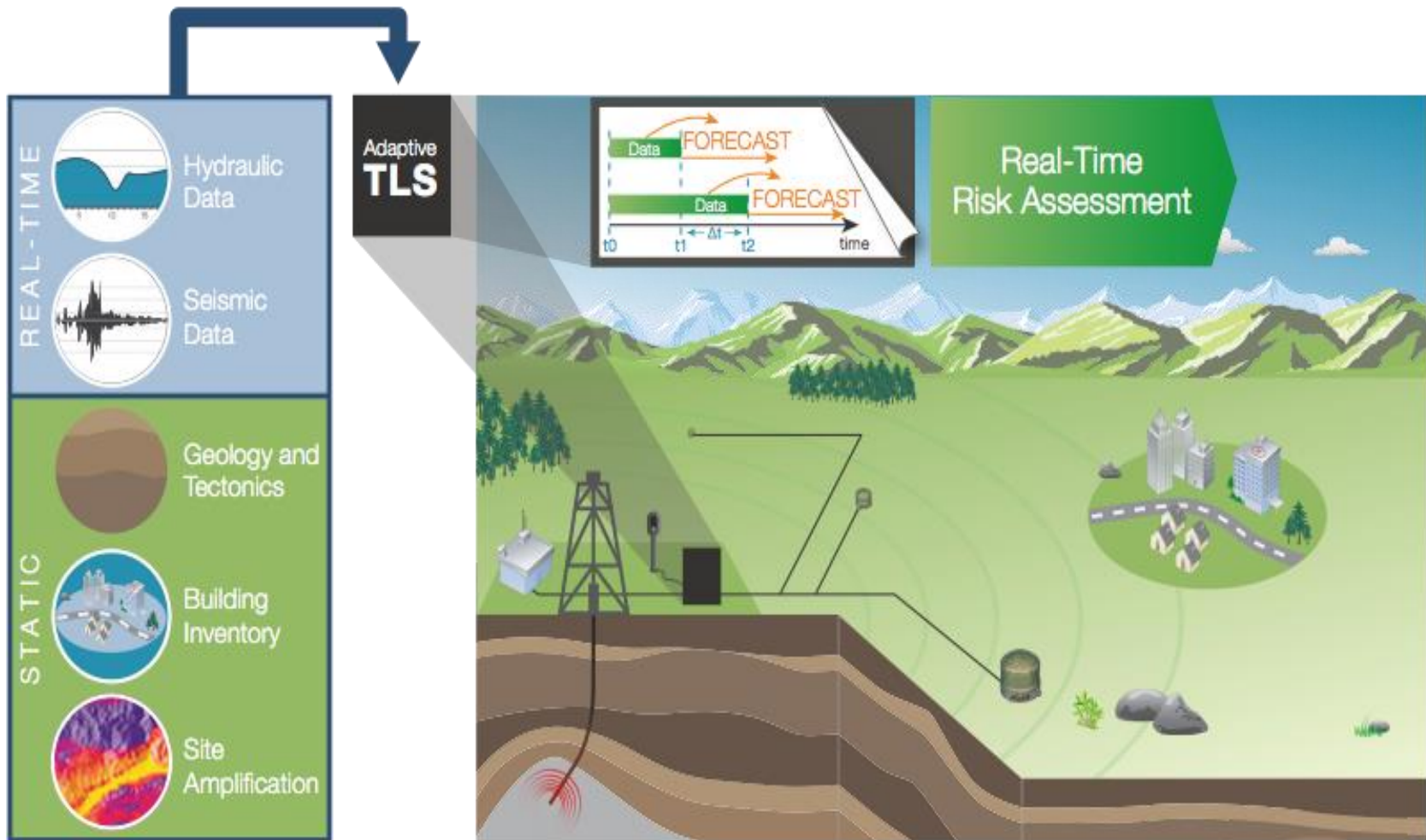
Dinske, C. and S. A. Shapiro (2013), *J. Seismol.* 17
Mignan, A. et al. (2015), *Geothermics* 53
Mignan, A. (2016), *Geophys. Res. Lett.* 42
Mignan, A. (2016), *Nonlin. Processes Geophys.* 23
van der Elst, N. et al. (2016), *J. Geophys. Res.* in press

And an some of the faces behind the names



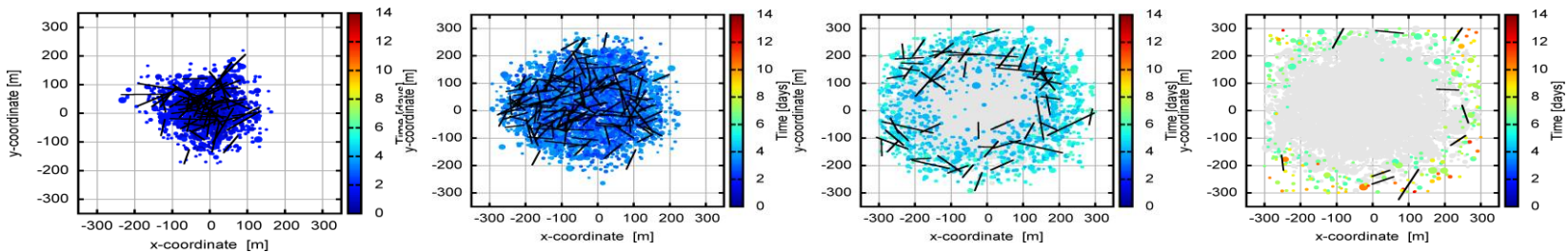
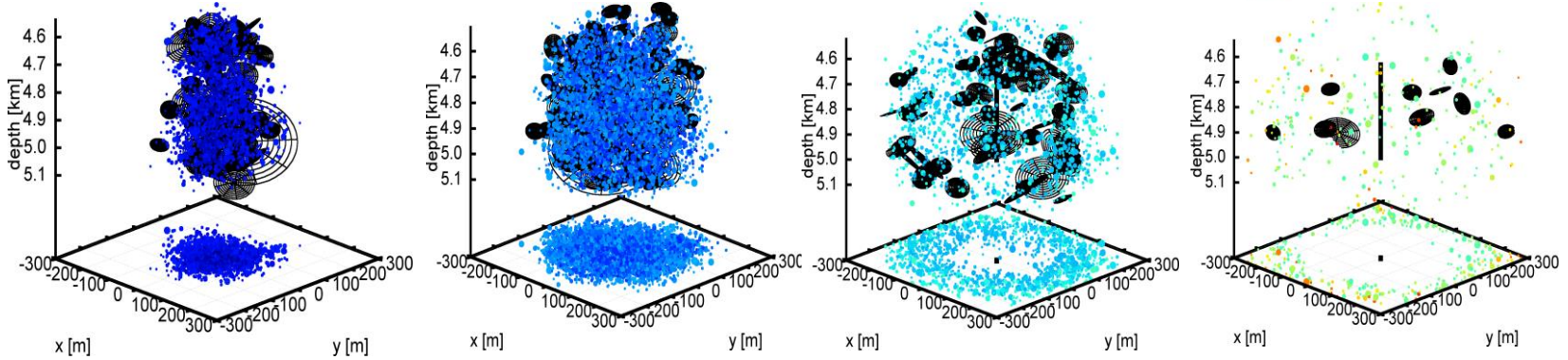
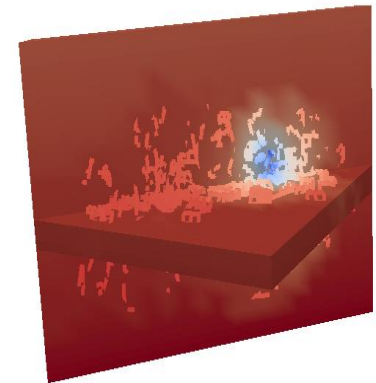
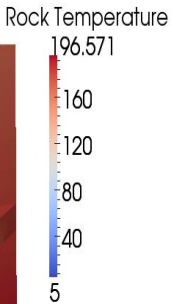
-  Coordinator
-  PI's
-  SCCER T4.1
-  NFP70 PhD

Our vision: Smarter systems for managing Induced Seismicity



(Selected) ongoing activities (1)

- Numerical Model development for understanding and forecasting the coupled problem of permeability creation \leftrightarrow seismicity evolution.



0-2 days

2-4 days

4-6 days

6-14 days

(Selected) ongoing activities (1)

The importance of earthquake interactions for injection-induced seismicity: Retrospective modeling of the Basel Enhanced Geothermal System

Article in *Geophysical Research Letters* 43(10) · May 2016

DOI: 10.1002/2016GL068932



1st **Flaminia Catalli**

19.12 · Helmholtz-Zentrum Potsdam - Deuts...



2nd **Antonio Pio Rinaldi**

24.17 · ETH Zurich



3rd **Valentin Gischig**

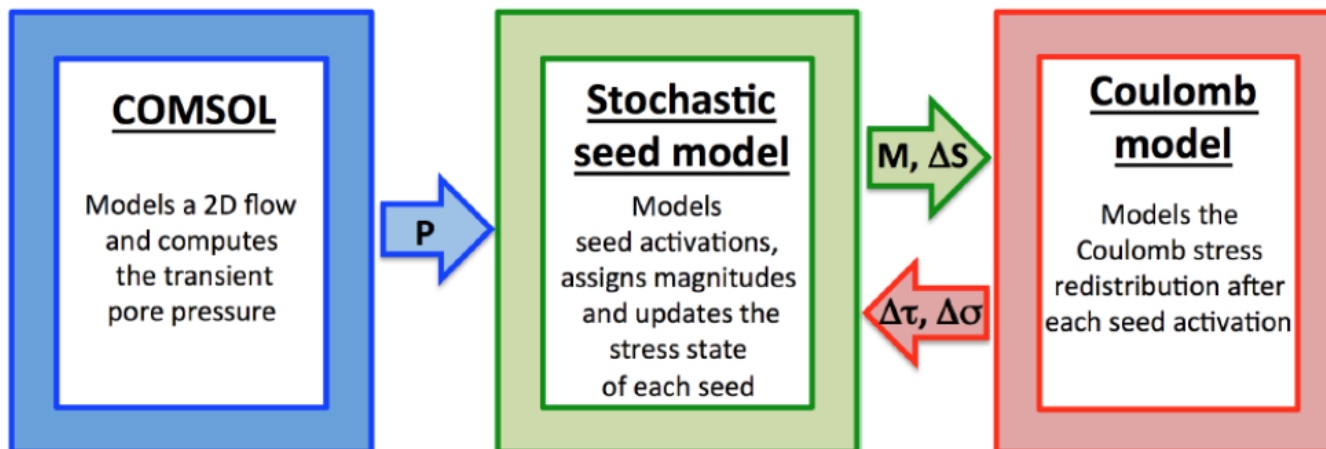
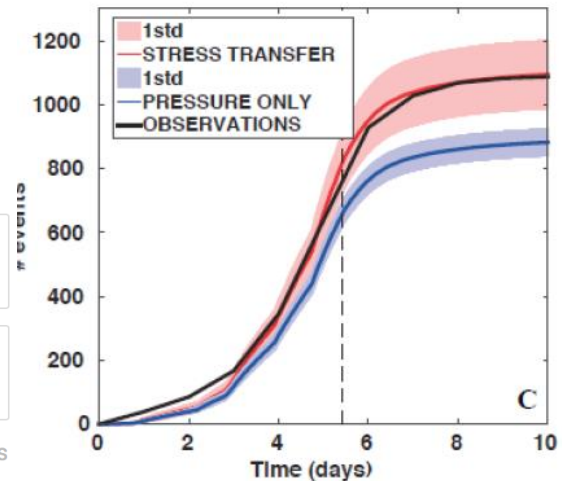
24.83 · ETH Zurich



Last **Stefan Wiemer**

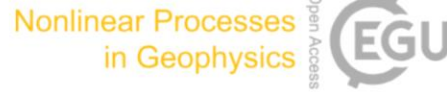
39.13 · ETH Zurich

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NC PAST Postulate also explains linear relationship $\mu \approx \Delta V$ & parabolic spatial front

Nonlin. Processes Geophys., 23, 107–113, 2016
 www.nonlin-processes-geophys.net/23/107/2016/
 doi:10.5194/npg-23-107-2016
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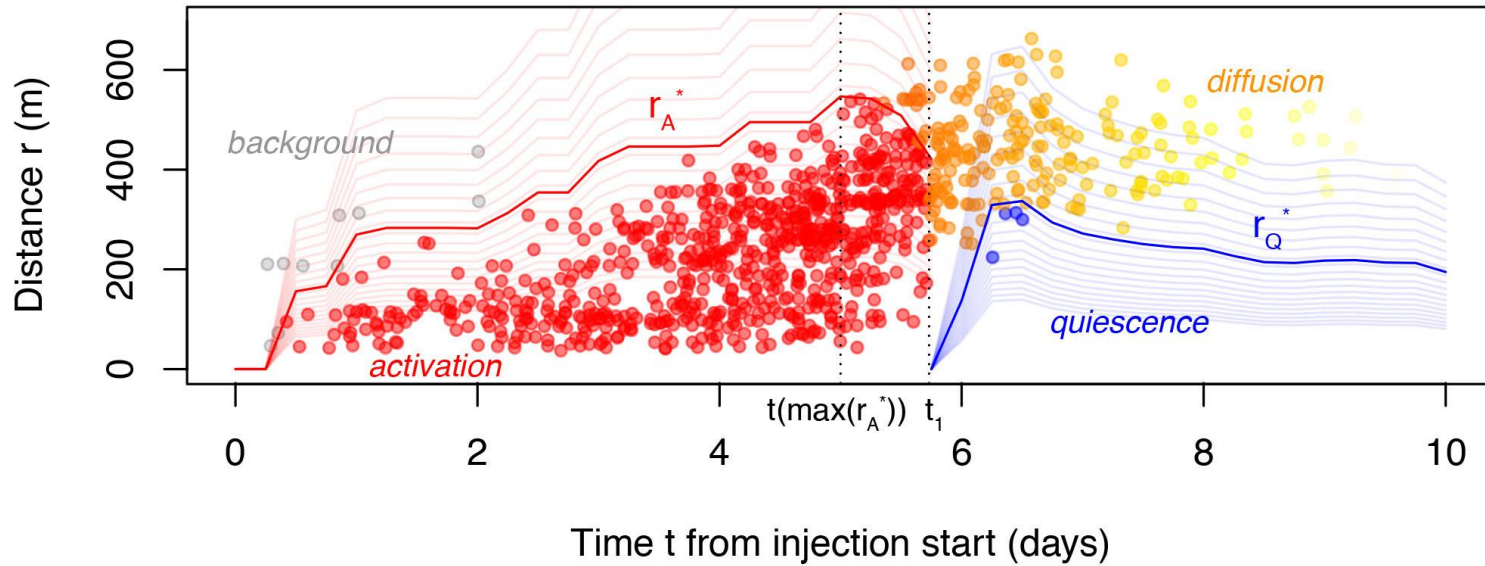


Static behaviour of induced seismicity

Arnaud Mignan

Institute of Geophysics, ETH Zurich, Zurich, Switzerland

with k being a geometric parameter and d the spatial dimension. For the tectonic case in which $r_{\max} \gg h$, the volume is assumed to be a cylinder with $k = \pi$, $d = 2$, and δ being the density of epicentres in space (Fig. 1c). It should



power law behaviour observed prior to some large mainshocks (Fig. 1d) (see the review by Sammis and Sornette (2002) for different physical processes yielding a temporal power law)

with t_0 being the starting time of the injection. The volume change rate is then defined as

$$\Delta V(t, \Delta t) = \frac{V(t) - V(t - \Delta t)}{\Delta t}, \quad (8)$$

with Δt being a time increment.

In the EGS case, $r \cong h$, with h being the borehole depth and induced seismicity defined as hypocentres. The spatio-temporal stress field $\sigma(r, t)$ becomes

$$\sigma(r, t) = \begin{cases} \sigma_0^*, & t < t_0 \\ \frac{r_0^n}{(r + r_0)^n} P(t, r = 0) + \sigma_0^*, & t \geq t_0 \end{cases} \quad (9)$$

with r being the distance along the stress field gradient from the borehole. The diffusion exponent for static seismicity is $n = 3$ for a borehole radius of volume $V_0 = \pi r_0^2 h$. The parameter r_0 is the characteristic radius of volume V_0 in the static case when fluids are injected (bleed-off), or, in the dynamic case when the pressure change is negative, respectively. It follows

$$\left(\frac{V(t)}{V_0} \right)^{1/n} - r_0 = \Delta V(t) \quad (10)$$

temporal shape of the injection profile $Q(t)$ on the n th root of the

flow rate profile $Q(t)$ (with $n = 3$ in the static stress case). This parabolic relationship is similar to the generalised form $r(t) \propto m(t)^{1/d}$ derived from non-linear poroelasticity in a

(Selected) ongoing activities (2)

- Model verification/calibration/validation experiments. Benchmarking, ensemble models etc.

Validating induced seismicity forecast models – Induced Seismicity Test Bench: INDUCED SEISMICITY TEST BENCH

Article in Journal of Geophysical Research: Solid Earth · August 2016

DOI: 10.1002/2016JB013236



1st **Eszter Kiraly**
iD 13.63 · ETH Zurich



2nd **J. Douglas Zechar**



3rd **Valentin Gischig**
iD 24.83 · ETH Zurich

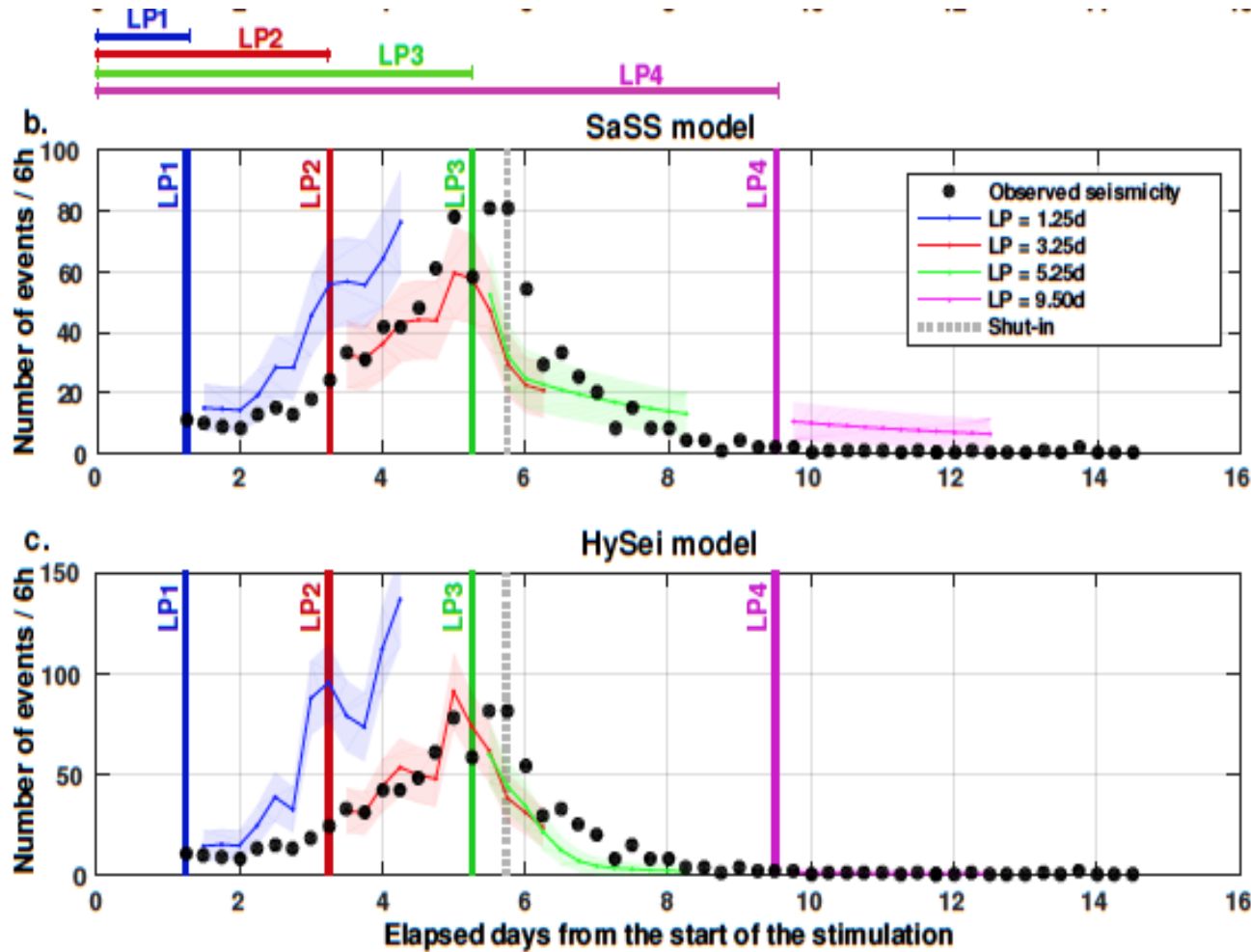


Last **Joseph Doetsch**
iD 26.51 · ETH Zurich

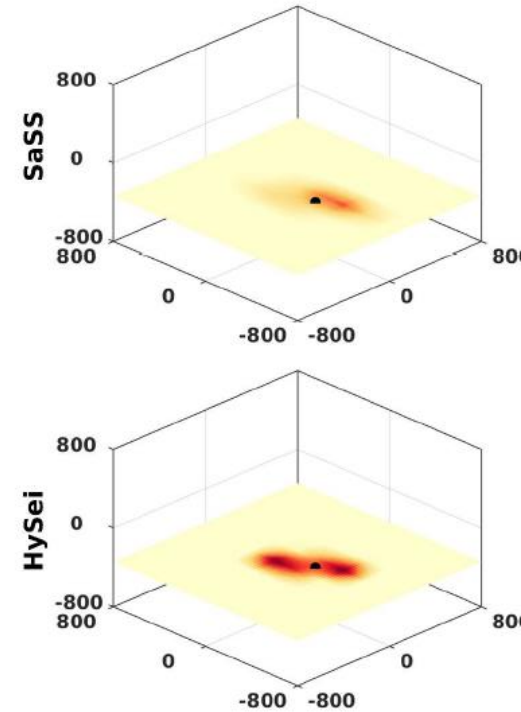
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Model
Development

(Selected) ongoing activities (2)



Horizontal cross section

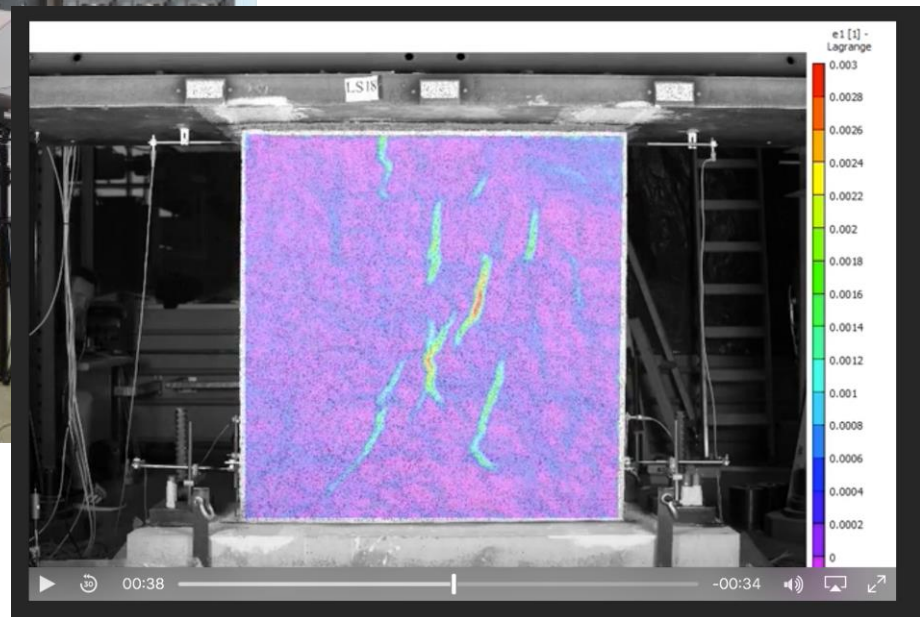


(Selected) ongoing activities (3)

- Understanding cracks in buildings using experiments



http://www.seismo.ethz.ch/static/sccer-soe/videos/sources/wall_test.mp4

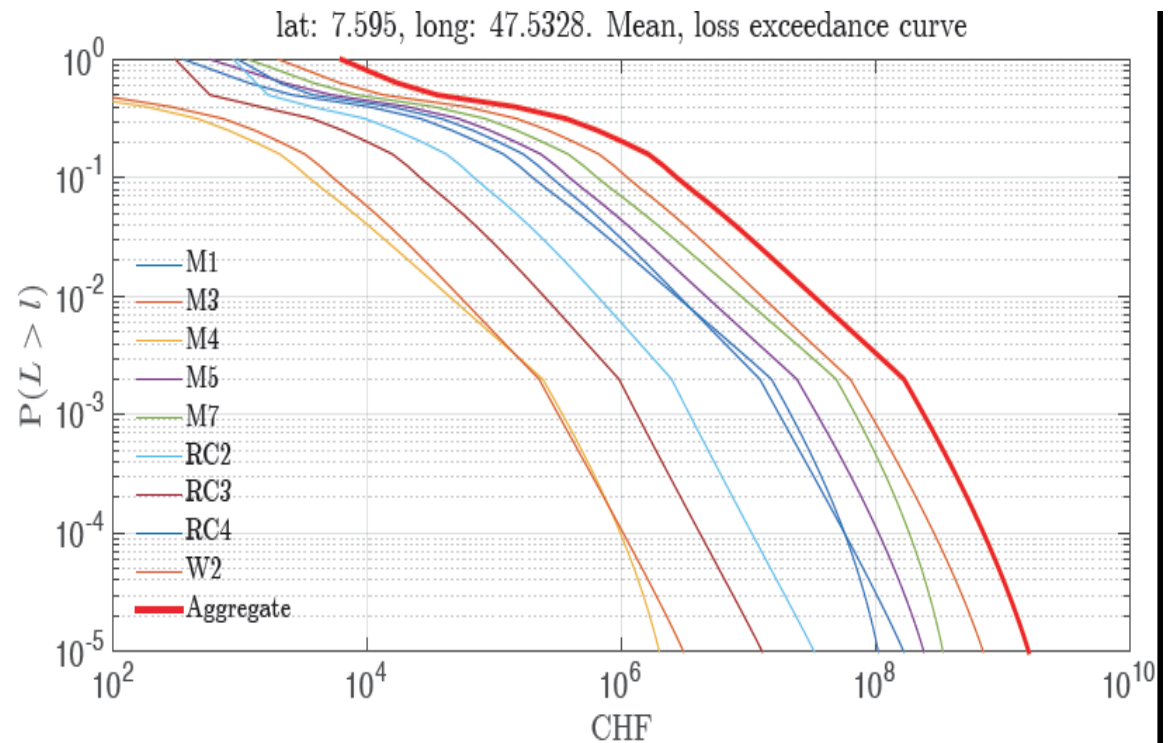
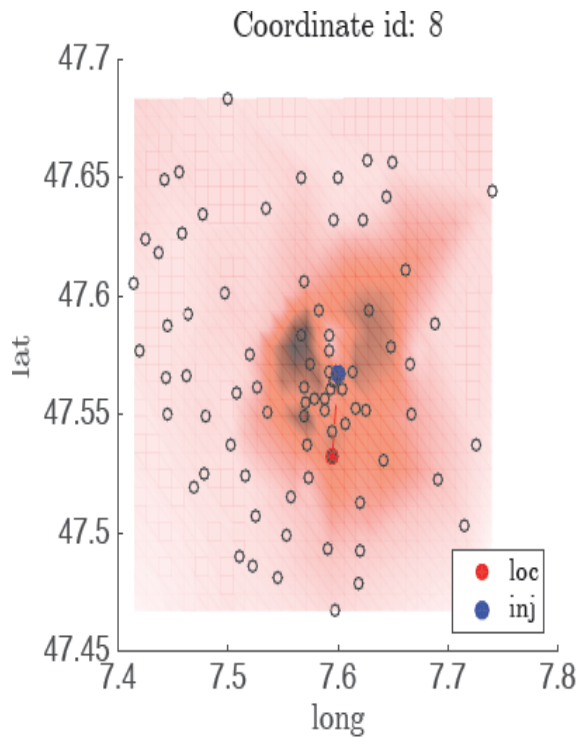




Individual and societal risk metrics as parts of a risk governance framework for induce seismicity

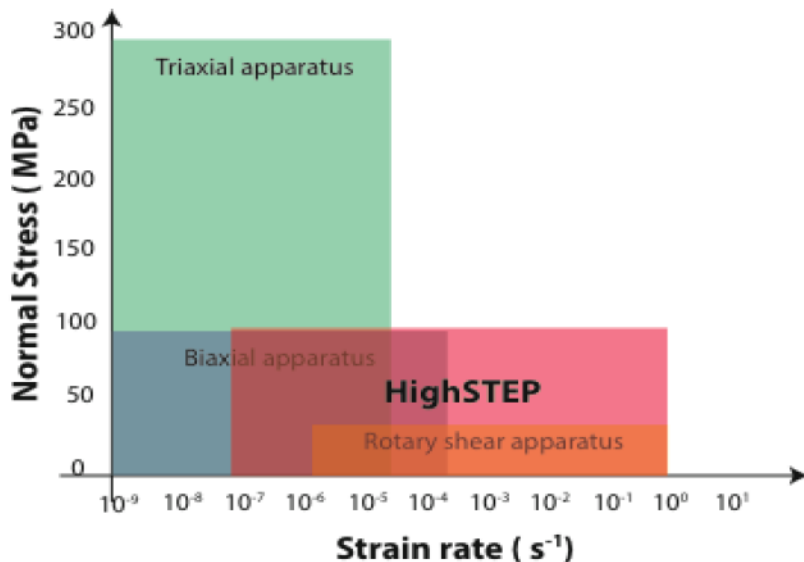
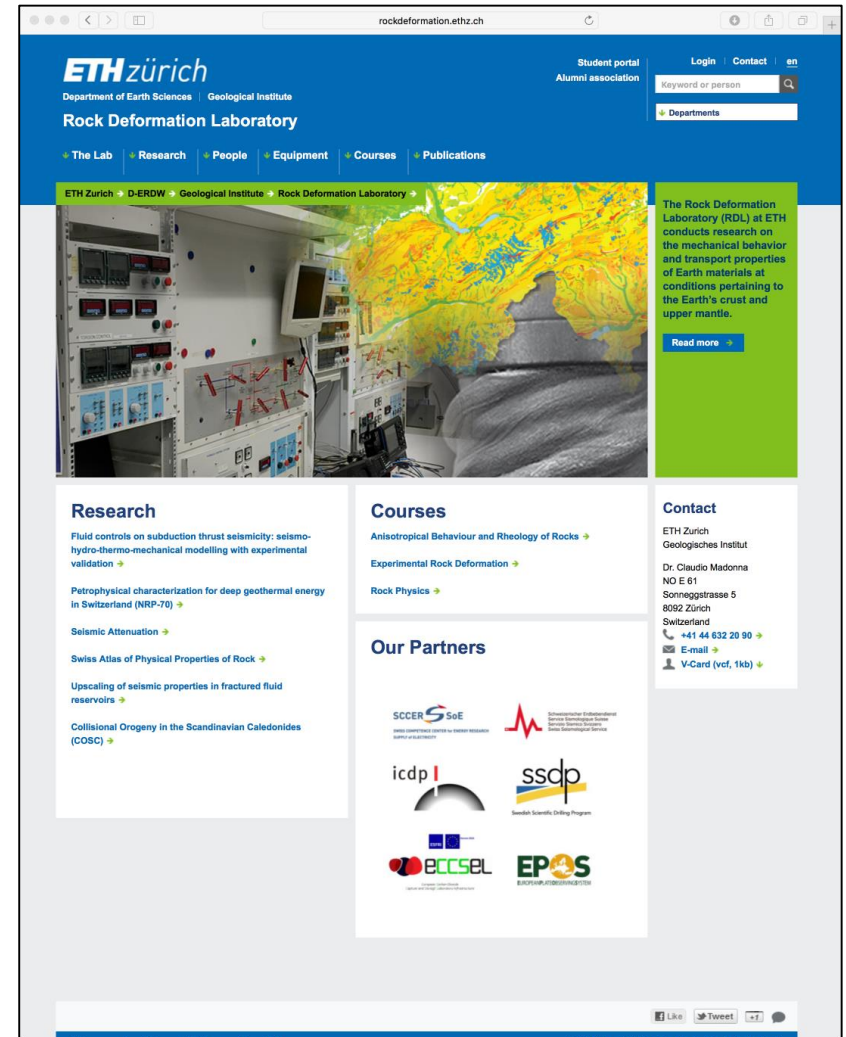
Marco Broccardo⁽¹⁾, Laurentiu Danciu⁽²⁾, Bozidar Stojadinovic⁽⁴⁾, Stefan Wiemer⁽⁵⁾

- (1,3,4,5) Swiss Competence Centers for Energy Research, SCCER, ETH Zürich.
- (2,5) Swiss Seismological Service, SED, ETH Zürich
- (3) Institute of Geophysics, ETH Zürich
- (1,4) Chair of Structural Dynamics & Earthquake Engineering, ETH Zürich



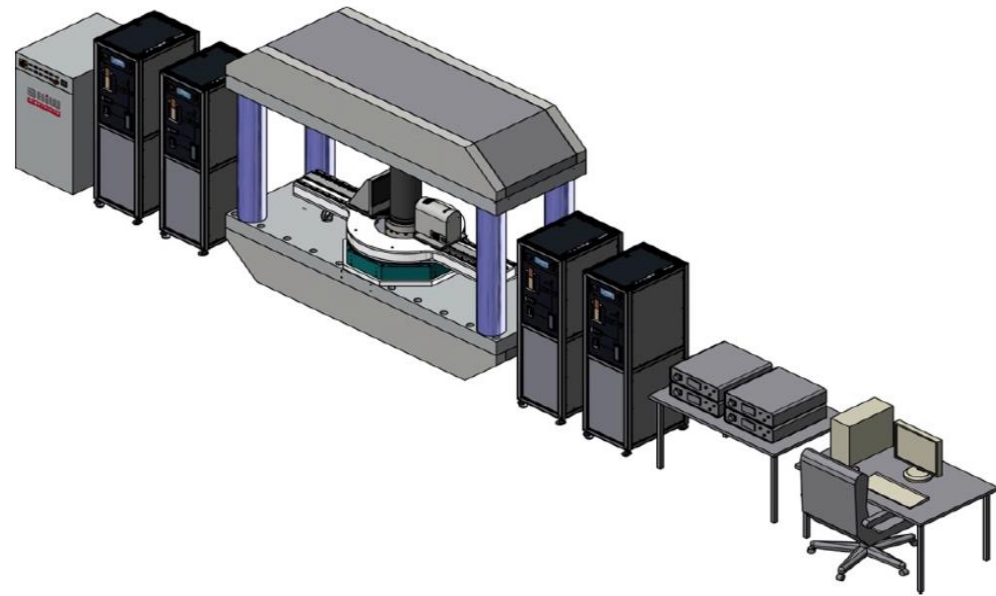
(Selected) ongoing activities (4)

- **Lab-scale experiments to study earthquake physics**
 - **HighSTEP**, a machine jointly owned by ETH and EPFL now being built at EPFL (Marie Violy/Claudio Madonna).
 - **LabQuake** triaxial apparatus for ETH (Rock Def Lab) request from SNF R'Equip.

The screenshot shows the website for the Rock Deformation Laboratory at ETH Zurich. The header includes the ETH Zurich logo, the Department of Earth Sciences and Geological Institute, and the Rock Deformation Laboratory name. Navigation links include 'The Lab', 'Research', 'People', 'Equipment', 'Courses', and 'Publications'. A search bar and a 'Departments' dropdown are also visible. The main content area features a large image of the laboratory equipment and a text box describing the RDL's research on Earth materials. Below this, there are sections for 'Research' (listing topics like fluid controls on subduction thrust seismicity, petrophysical characterization, seismic attenuation, etc.), 'Courses' (listing 'Anisotropic Behaviour and Rheology of Rocks', 'Experimental Rock Deformation', 'Rock Physics'), 'Contact' (providing address, phone, and email), and 'Our Partners' (listing various research institutions like SCCER SoE, icdp, sssp, eccsel, and EPOS).

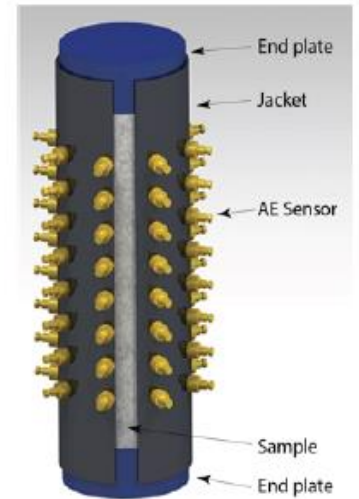
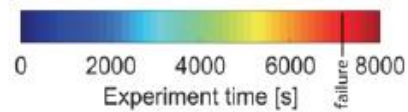
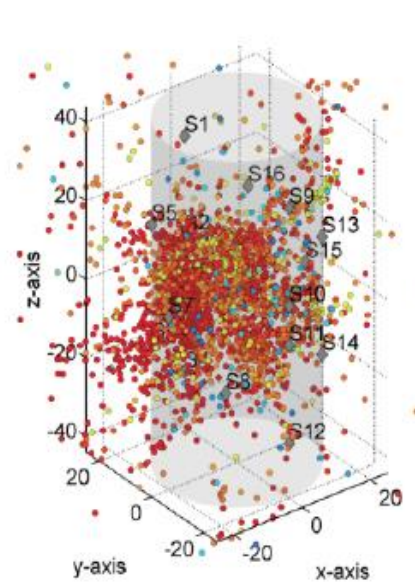
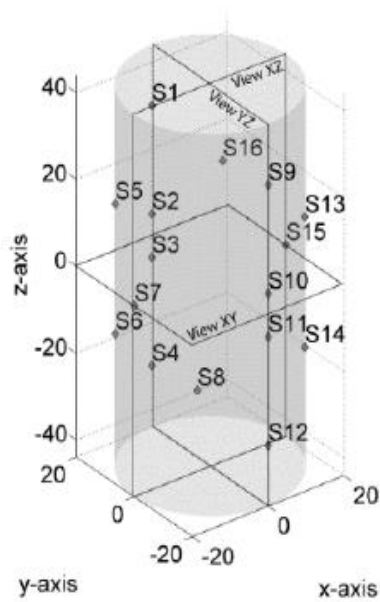
(Selected) ongoing activities (4)



a)

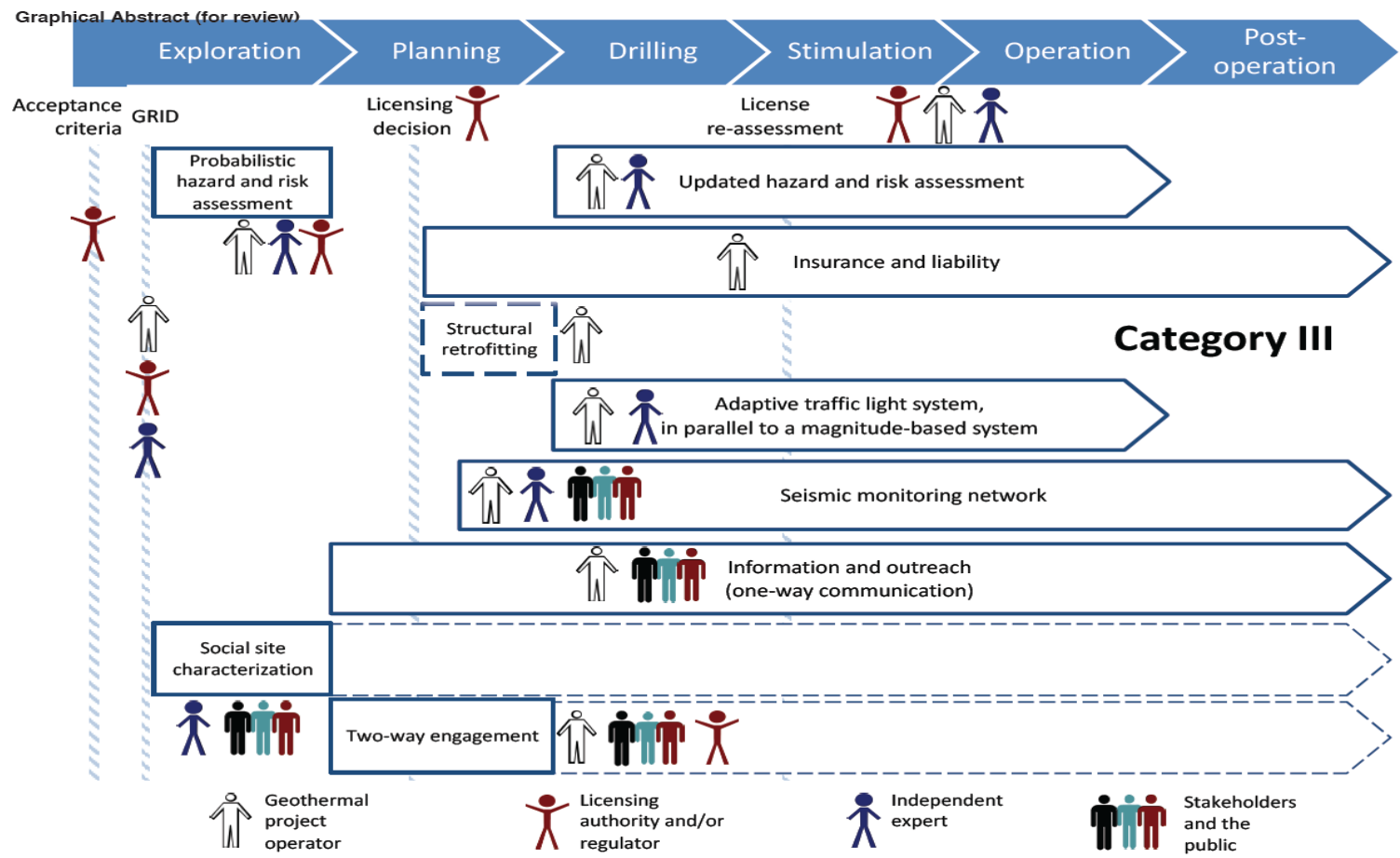


b)

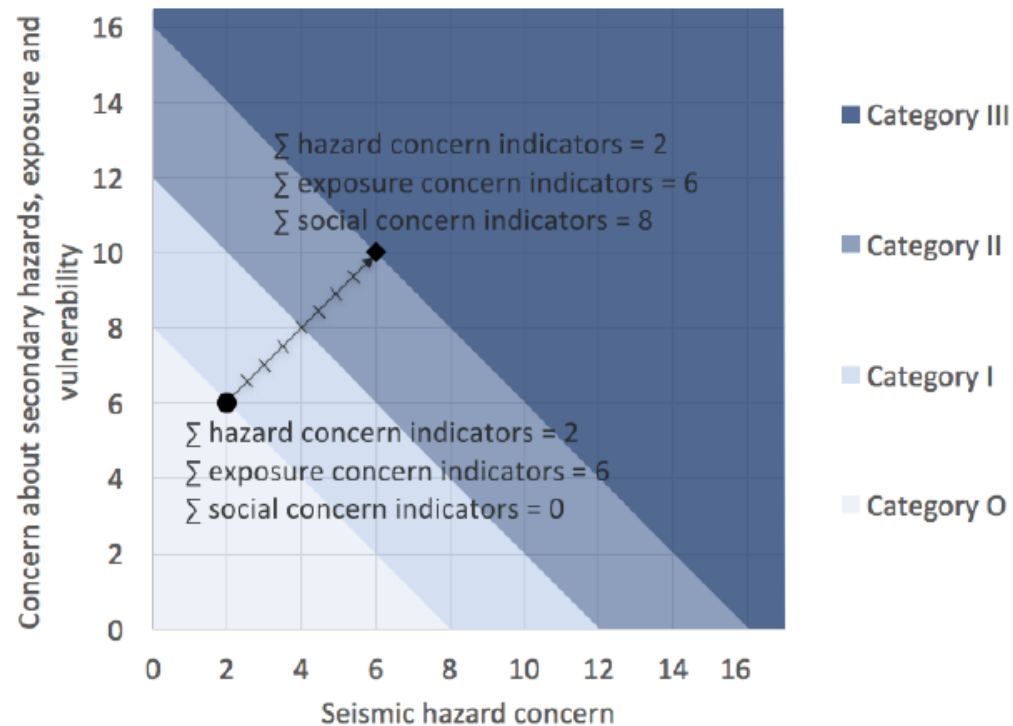


(Selected) ongoing activities (5)

- Tailor made risk governance for Switzerland



(Selected) ongoing activities (5)



1 Tailor-made risk governance for induced seismicity of geothermal 2 energy projects: An application to Switzerland

3
4 **Author:** Evelina Trutnevyte^{1,3*}, Stefan Wiemer^{2,3}

5 * Corresponding author, evelina.trutnevyte@alumni.ethz.ch, phone +41 44 633 87 05

6
7 ¹ ETH Zurich, Department of Environmental Systems Science (D-USYS), USYS
8 Transdisciplinarity Laboratory, Universitatstrasse 16, 8092 Zurich, Switzerland

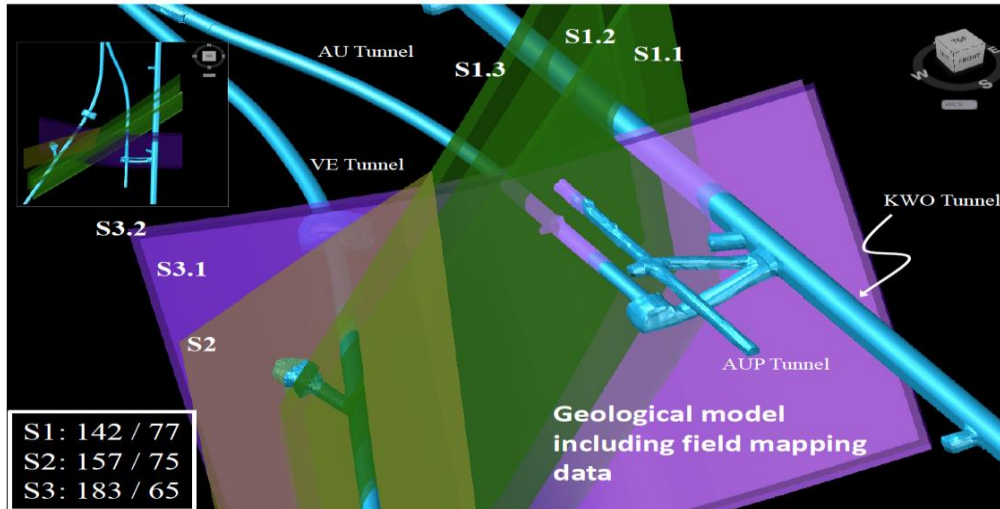
9
10 ² ETH Zurich, Swiss Seismological Service, Sonneggstrasse 5, 8092 Zurich, Switzerland

11
12 ³ Swiss Competence Center for Energy Research – Supply of Electricity, Sonneggstrasse 5,
13 8092 Zurich, Switzerland

14

(Selected) ongoing activities (6): Grimsel

- A great collaborative effort.
- A chance to study fundamental science questions – including induced seismicity.



International Continental Drilling Programme (ICDP): DSEIS

- Deep gold mines actively progressing (> 3 km) offer an interesting very high strain rate environment to study earthquakes and faulting.
- We are part of an international ICDP team to investigate processes related to natural and anthropogenic earthquakes (just funded at 1 Mio. \$)

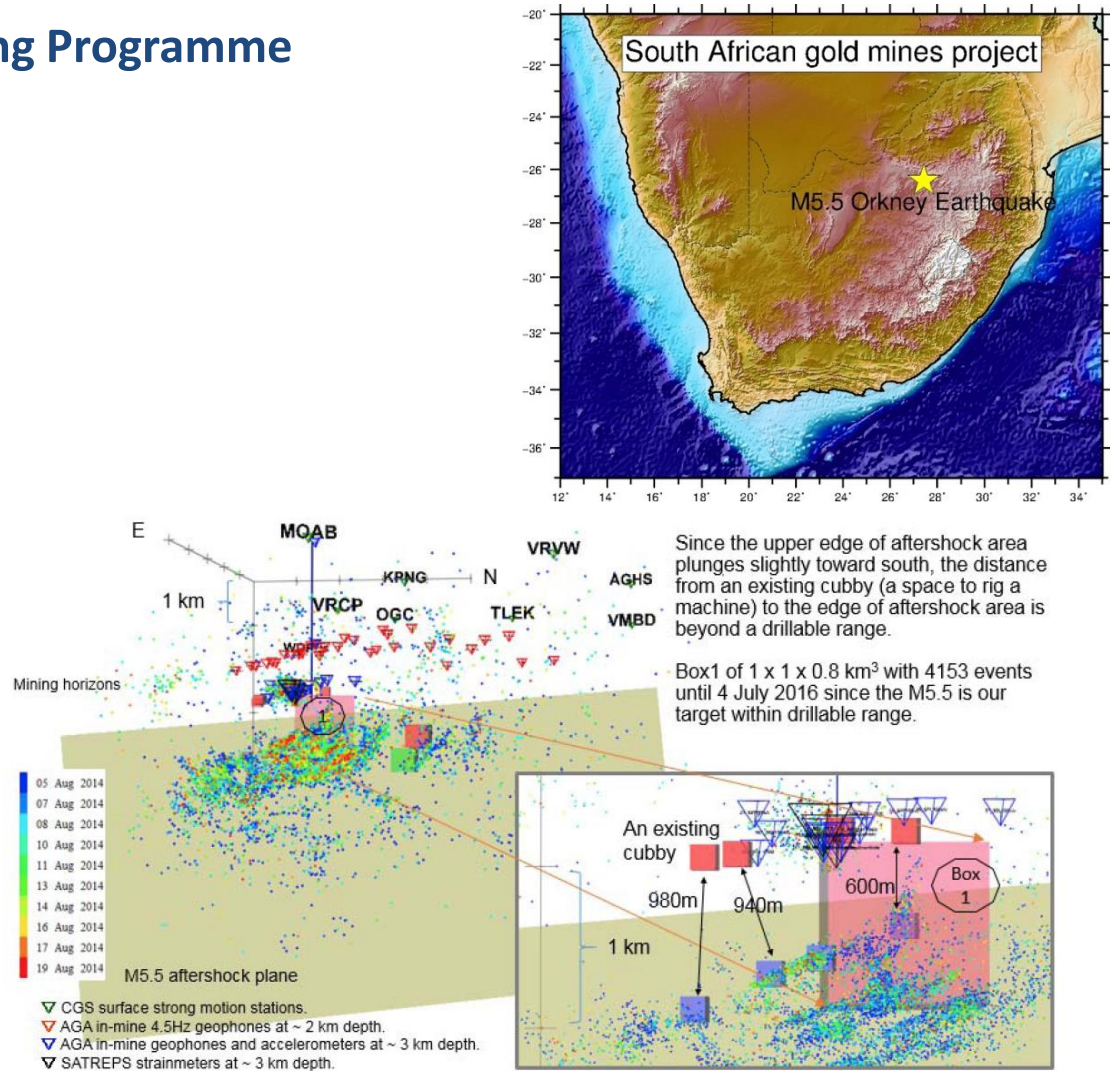


Figure 1. Seismicity in a 14-day period following the M5.5. Box 1 is a drilling target at MK within a drillable range. First, we have to identify a geological structure responsible for the 2014 M5.5 and calibrate the seismic velocity to refine seismicity location. The 2nd hole will be dedicated to geomicrobiology research.

GEOBEST-CH

- Support cantons in all matters related to geothermal projects (monitoring, hazard and risk assessment, best practice etc.).
- First workshop with cantonal authorities: spring 2016.

SED - Géothermie et séismes

Schweizerischer Erdbebendienst
Service Sismologique Suisse
Servizio Sismico Svizzero
Swiss Seismological Service

Le SED | Séismes récents | Séismes Suisse | Surveillance | Recherche

Home > Séismes en Suisse > Géothermie et séismes

Cause des séismes

Cause séismes Suisse

Atlas sismique
Risque sismique
Outil risque sismique
Fréquence
Effets
Les tremblements de terre historiques
Prévention
Que faire?
Scénario

Géothermie et séismes

Formes de la géothermie
La géothermie et les séismes induits
Mesures d'endossement de la sismicité induite
La géothermie en Suisse
La géothermie et le SED
Fracturation

On entend par énergie géothermique l'énergie emmagasinée sous terre. Les quantités d'énergie qui sont importantes. Cette énergie provient d'isotopes naturellement radioactifs du manteau terrestre.

Règle de base: plus on progresse dans la Terre, plus il fait chaud. En moyenne, la température augmente de 3°C par 100 mètres de profondeur à partir de la surface. Au gradient géothermique normal (2°C/100m), un processus très long: entre 100 et 200 mètres de profondeur, la surface de la Terre n'est plus de consistance solide. A 5'000 mètres de profondeur, la température de la roche est comprise entre 150°C et 200°C [1]. Compte tenu des connaissances actuelles, on estime que la température du noyau terrestre dépasse 6'000°C et que celle du manteau supérieur s'élève à 1'400°C.

Croute océanique 5 km
Croute continentale 35 km
Manteau supérieur (lithosphère) 100 km
Manteau inférieur (asthénosphère) 410 km
Noyau externe (liquide) 5100 km
Noyau interne (solide) 6371 km

"Best Practice" Guide for Managing Induced Seismicity in Geothermal Energy Projects in Switzerland

Dr. Toni Kraft
Dr. Evelina Trutnevyte
Prof. Dr. Stefan Warner

Planning → Drilling/Logging → Construction → Operation → Post-Closure

Seismic Monitoring (green arrow)

Risk Studies (red arrow)

Schweizerischer Erdbebendienst
Service Sismologique Suisse
Servizio Sismico Svizzero
Swiss Seismological Service

ETH zürich

GEOBEST-CH

Kompetente seismologische
Beratung bei
Tiefengeothermieprojekten

Stadt Basel

0-1000 m
1000 m
2000 m
3000 m
4000 m
5000 m

1000 m

● Nicht spürbar (Magnitude < 2)
● Kaum spürbar
● Spürbar (Magnitude > 3)

Manteau supérieur (lithosphère)
Manteau inférieur (asthénosphère)
Noyau externe (liquide)
Noyau interne (solide)

Croute océanique 5 km
Croute continentale 35 km
Lithosphère 100 km
Asthénosphère

100°C
200°C
400°C
600°C

0-400 m
400-4000 m

Géothermie peu profonde
Géothermie profonde

A plusieurs endroits de la planète, dans les zones volcaniques en particulier, on constate néanmoins des anomalies thermiques: des zones qui présentent un gradient géothermique bien plus élevé. C'est par exemple le cas en Islande, en Italie, en Indonésie ou en Nouvelle-Zélande. Dans certains lieux de ces pays, la nature fournit elle-même le système de circulation nécessaire pour capter et faire remonter cette chaleur (sous la forme de sources chaudes, de geysers, etc.) Ailleurs, exploiter l'énergie géothermique requiert des forages et la mise en place de pompes à chaleur, ou des sondes géothermiques couplées à des pompes de circulation pour pouvoir utiliser la chaleur. Plusieurs technologies sont disponibles pour cela. On distingue la géothermie peu profonde (jusqu'à environ 400 mètres) et la géothermie profonde.

Mit Unterstützung von

energieschweiz
Unser Engagement: unsere Zukunft.



Demonstration of soft stimulation treatments of geothermal reservoirs



www.destress-h2020.eu



- [Helmholtz Zentrum Potsdam \(GFZ\), Germany](#)
- [Energie Baden-Württemberg AG \(EnBW\), Germany](#)
- [és-Géothermie \(ESG\), France](#)
- [University of Glasgow, United Kingdom](#)
- [Geo-Energie Suisse AG, Switzerland](#)
- [TNO, The Netherlands](#)
- [Eidgenössische Technische Hochschule Zürich \(ETH\), Switzerland](#)
- [Geothermie Neubrandenburg GmbH \(GTN\), Germany](#)
- [Geoterma UAB, Lithuania](#)
- [Université de Strasbourg, France](#)
- [Delft University of Technology \(TU Delft\), The Netherlands](#)
- [NexGeo Incorporated, Korea](#)
- [Seoul National University \(SNU\), Korea](#)
- [Korea Institute of Civil Engineering and Building Technology \(KICT\), Korea](#)
- [ECW Geomanagement BV \(ECW\), The Netherlands](#)
- [Trias Westland B.V., The Netherlands](#)

The screenshot shows the homepage of the DESTRESS website. At the top, there is a navigation menu with links for Home, Who We Are, What We Do, Learn More, Demonstration Sites, and Stay informed. Below the navigation is a large banner image of the DESTRESS facility with the text 'Demonstration of soft stimulation treatments of geothermal reservoirs'. Underneath the banner are five buttons: Objectives, Partners, Sites, Stakeholders, and Newsletter. The Newsletter button includes a text input field for an email address and a 'Subscribe' button. Below the buttons is a 'News and Events' section featuring a calendar for September 22, 2016, and three news items with 'read more' links. To the right of the news items is a 'Welcome to DESTRESS' section with a paragraph of text and a 'Learn more' link. Below that is a 'Visit our Demonstration Sites' section with another paragraph and a 'Learn more' link. At the bottom left of the news section, there is a link for 'All news and events'.

Schatzalp workshop 2017



Save the date!

March 14 - 17, 2017
DAVOS

SCHATZALP
2nd induced seismicity
workshop

www.seismo.ethz.ch/schatzalp



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ETH zürich



energie schweiz
Clean Engagement. smere Zukunft.

SCCER  SoE

SWISS COOPERATION COURSE FOR ENERGY & ENERGY
SUPPLY & DEMAND



Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Bundesamt für Energie BFE
Office fédéral de l'énergie OFEN
Ufficio federale dell'energia UFE

Thank you!



Focus Topics

The workshop will cover eight thematic areas, each introduced by 2 to 3 invited keynote speakers, followed by 2 to 3 solicited presentations. There will be a moderated discussion at the end of each session and at the end of the workshop.

- Case Studies
- Modeling of Induced Seismicity
- Scaled Experiments
- Monitoring and Analysis of Induced Seismicity
- Risk Governance, Societal Acceptance and License to Operate
- Industry Projects & Perspective
- Pilot and Demonstration Sites & Future Initiatives



Conference Venue

Davos is located within the beautiful Swiss Alpine mountains of Graubünden. It's a city of culture, sports, and nature. It takes a 2:30 hours train ride from Zurich airport to go to Davos.

The conference venue «Schatzalp» is 300 m above Davos, at an altitude of 1861 m. A cable car takes you there in four minutes from Davos-Platz. The nostalgic Art Nouveau style building with its Belle Époque atmosphere opened its doors in 1900 as a luxury sanatorium. The soul of the house, its architecture, has been preserved in its original form until today. A night-lighted sledge trail down to Davos, and the skiing region Schatzalp-Strela are nearby.

