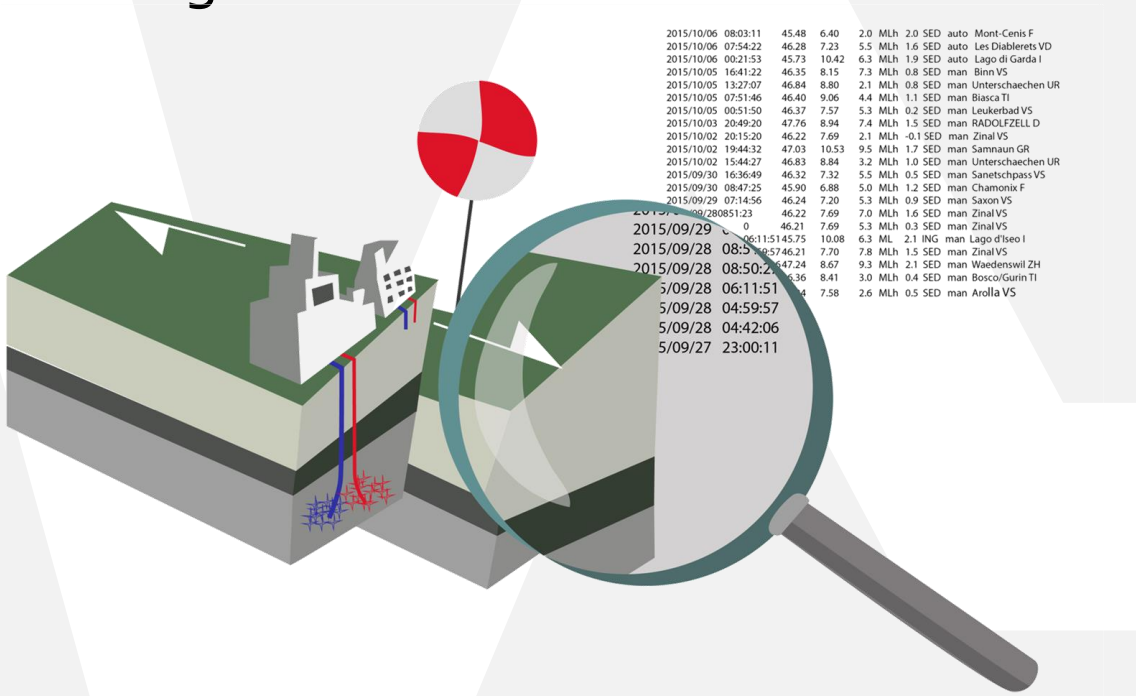
Schweizerischer Erdbebendienst
Service Sismologique Suisse
Servizio Sismico Svizzero
Swiss Seismological Service

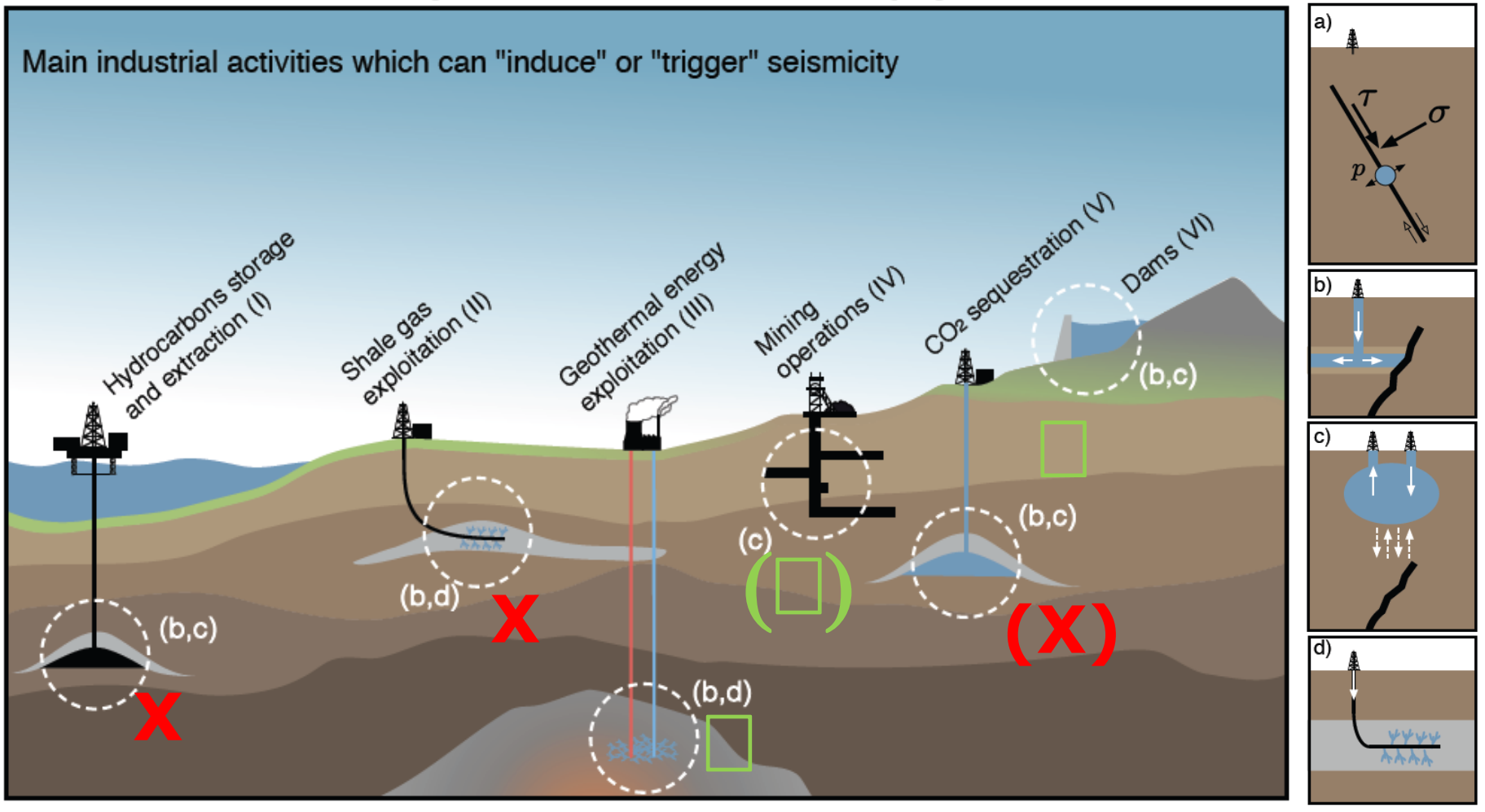
ETH zürich

Induced Seismicity in Switzerland: An update and outlook

Stefan Wiemer for the induced seismicity working group at the Swiss Seismological service

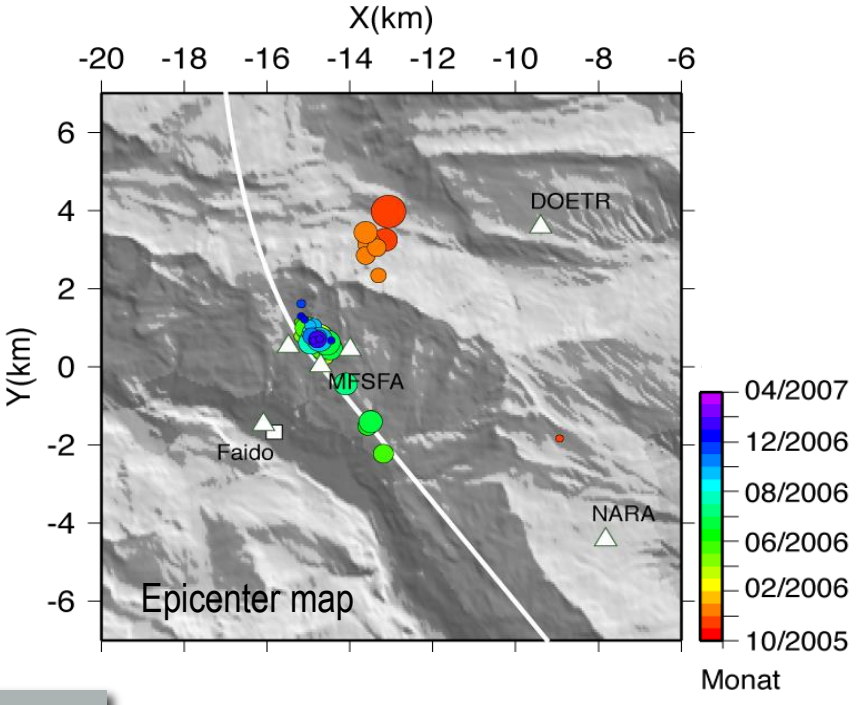


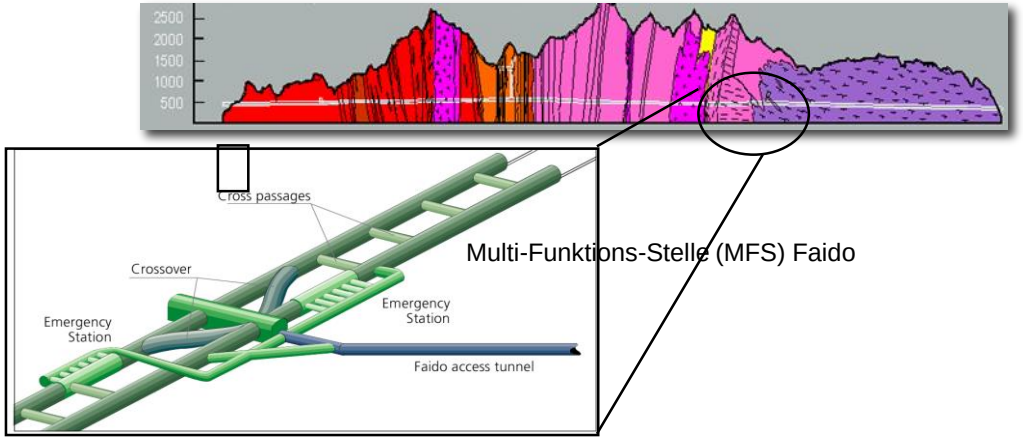
Induced Earthquakes in Switzerland



Grigoli et al., Rev. of Geoph., in press

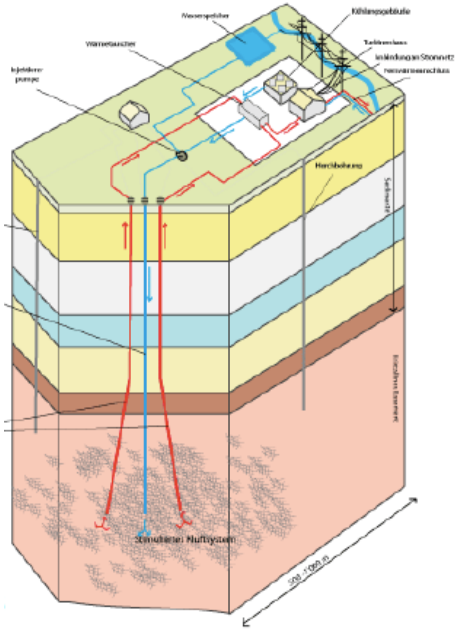
NEAT induced earthquakes (2005-2007)

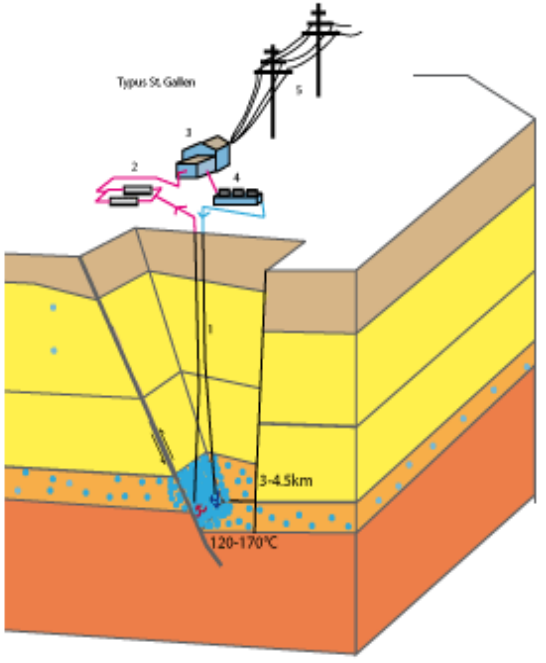




- NEAT tunneling activity near Faido created a burst of micro-earthquakes, some felt at the surface, coinciding with collapse of the tunnel walls over dozens of meters.

But our main challange: Earthquakes induced by geothermal energy

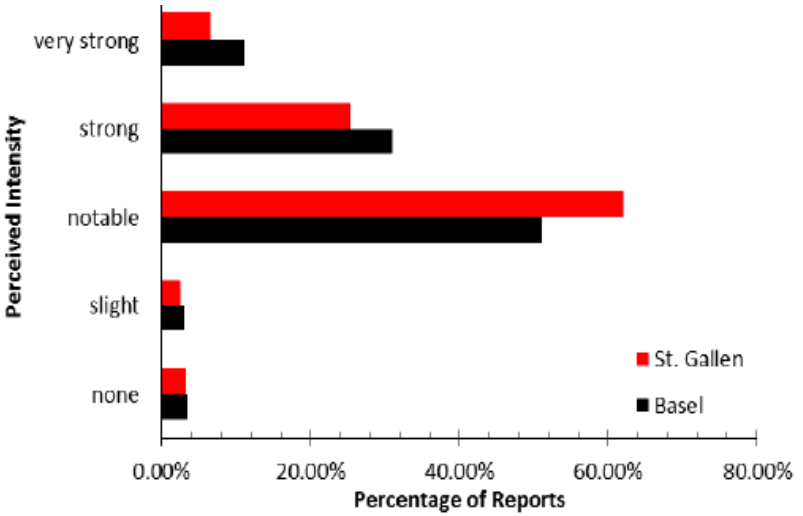


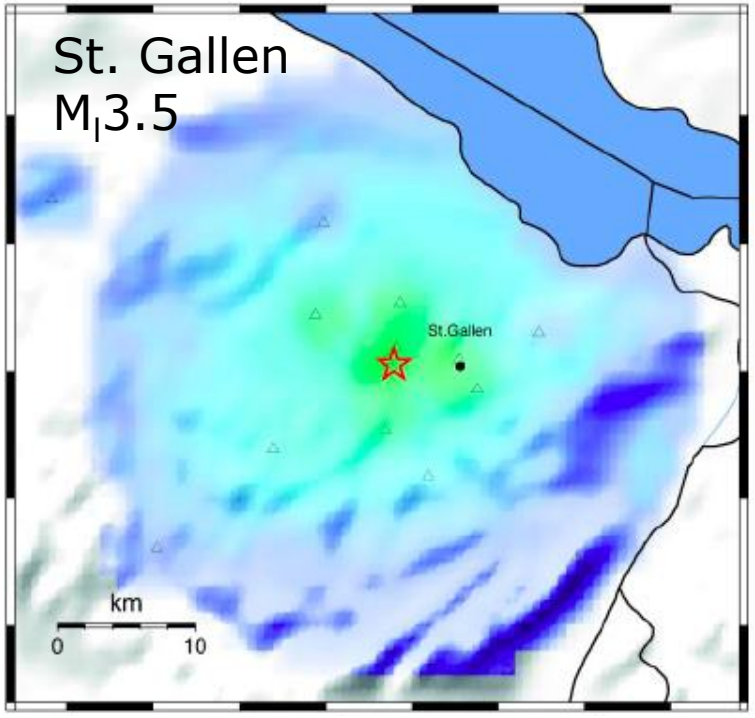


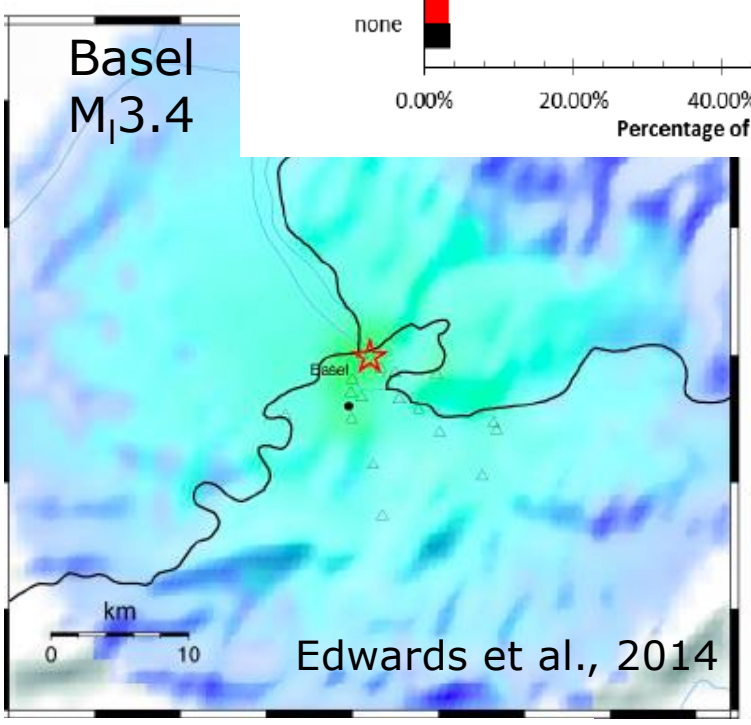
Basel (2006)
(EGS)

St. Gallen (2013)
(Hydrothermal)

ShakeMaps and perceived shaking





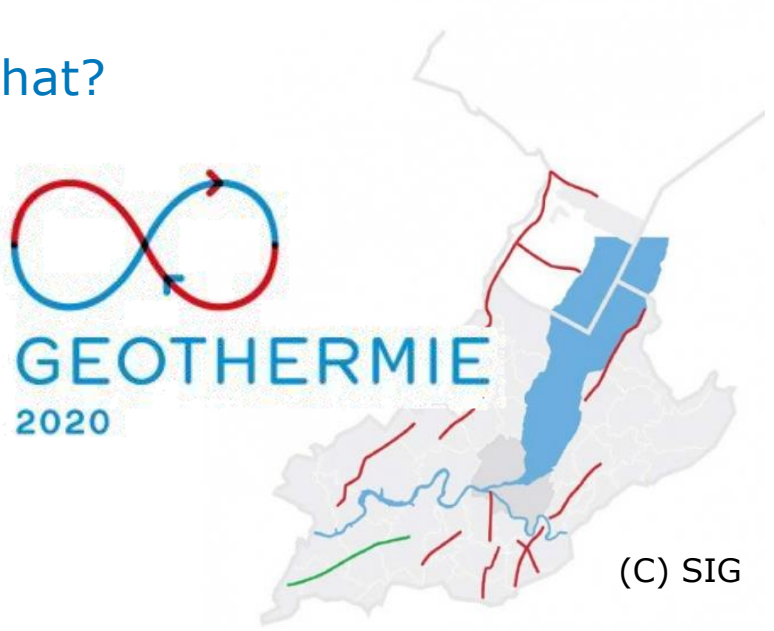


Two setbacks – 100 Mio CHF lost - now what?

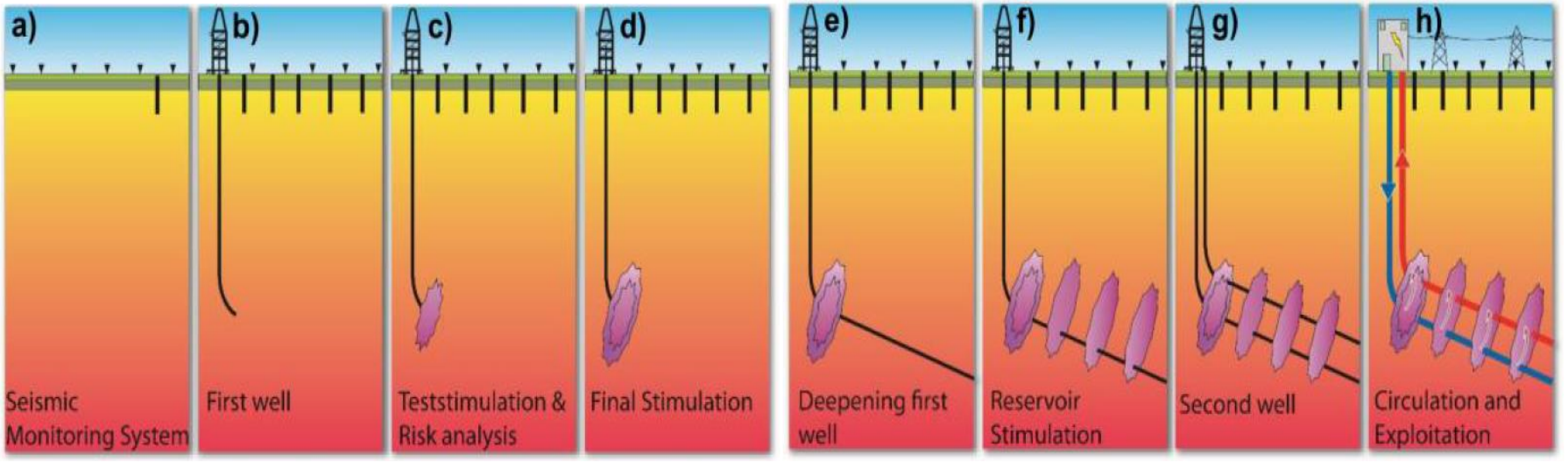
1. Give up, build more nuclear power plants or buy gas from Russia?

2. Try again, but smarter?

→ The federal office of energy wants to try again. The public will have the final say in May on the Energy Strategy 2050 (→ Gunter)



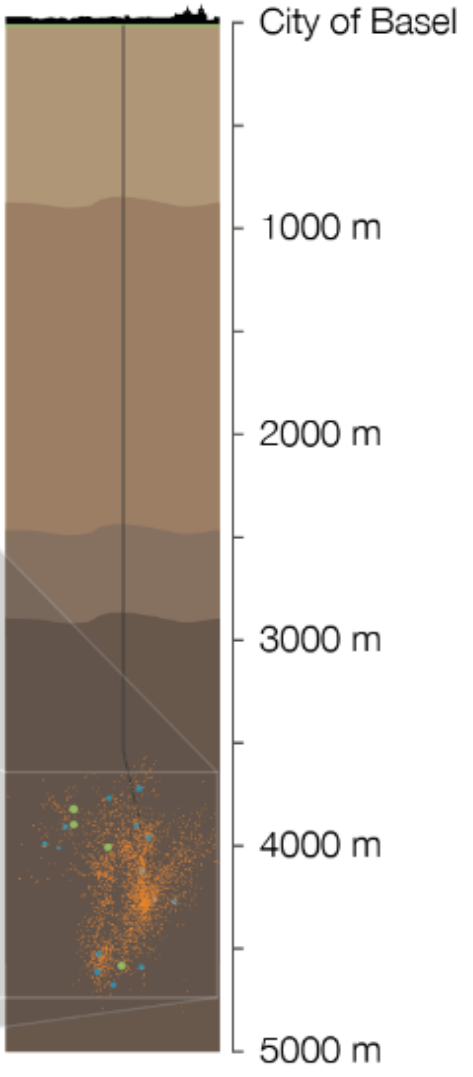
(C) SIG



(C) GeoEnergie Suisse AG

Implications for ETH and the Swiss Seismological Service

- Besides seeing induced seismicity as a fascinating and rewarding research topic, we must help to make the next geothermal projects a success.
- There is, in our view, no single measure that will ensure success. Needed are a wide variety of coordinated actions in many areas (interdisciplinary, multi-scale, holistic, etc.). We need to team up!
- This workshop is one of many direct consequences of our quest to understand, model and mitigate induced seismicity related to deep geothermal projects.
- At the workshop you will see many presentations and posters by the team that describe how far we have come.

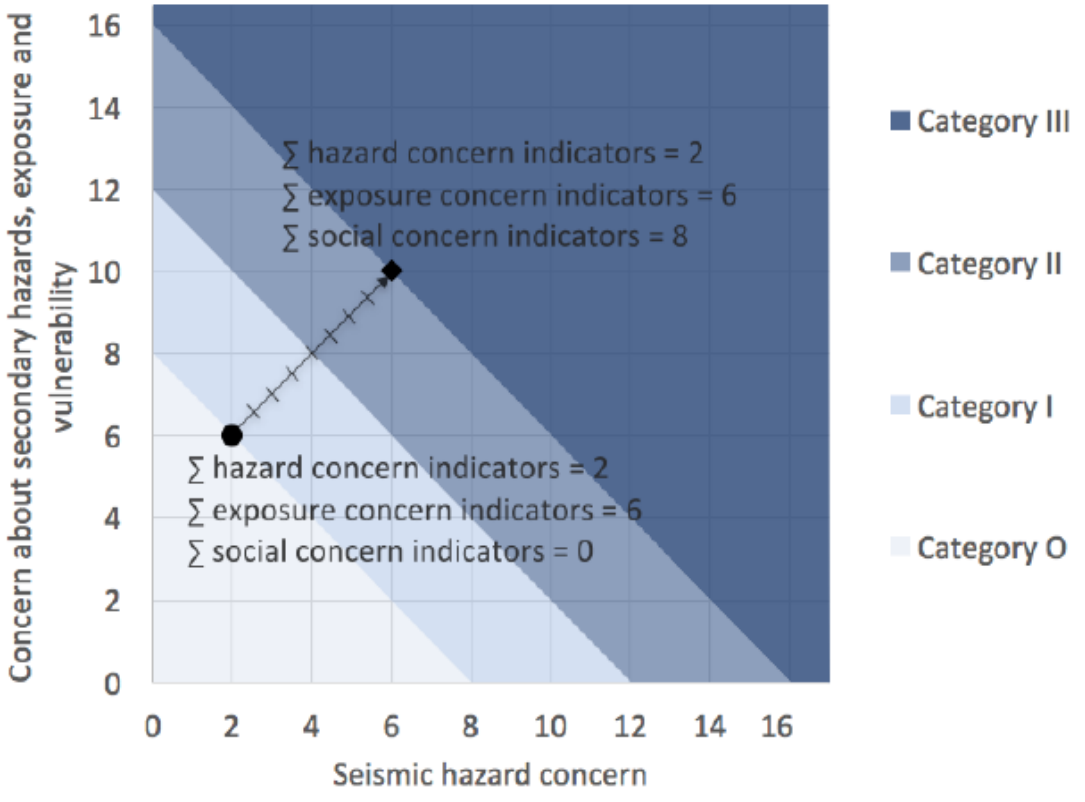


Major frontiers for us

1. Improving **data quality** at all steps (e.g., seismic monitoring and processing).
2. Improving **process understanding**, modelling and **validation** (e.g. Grimsel Lab).
3. Building **quantitative and data-driven** approaches to real-time forecasting (e.g., adaptive traffic lights).
4. Considering and quantifing **uncertainties** in all steps and build robustness through ensemble forecasting and Bayesian approaches.
5. Moving towards **risk based** decision making (in a risk-cost-benefit framework).

First things first – not all projects are born equal

- Based on a set of initial screening parameters, we propose tailor made risk governance workflows for different project categories.



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

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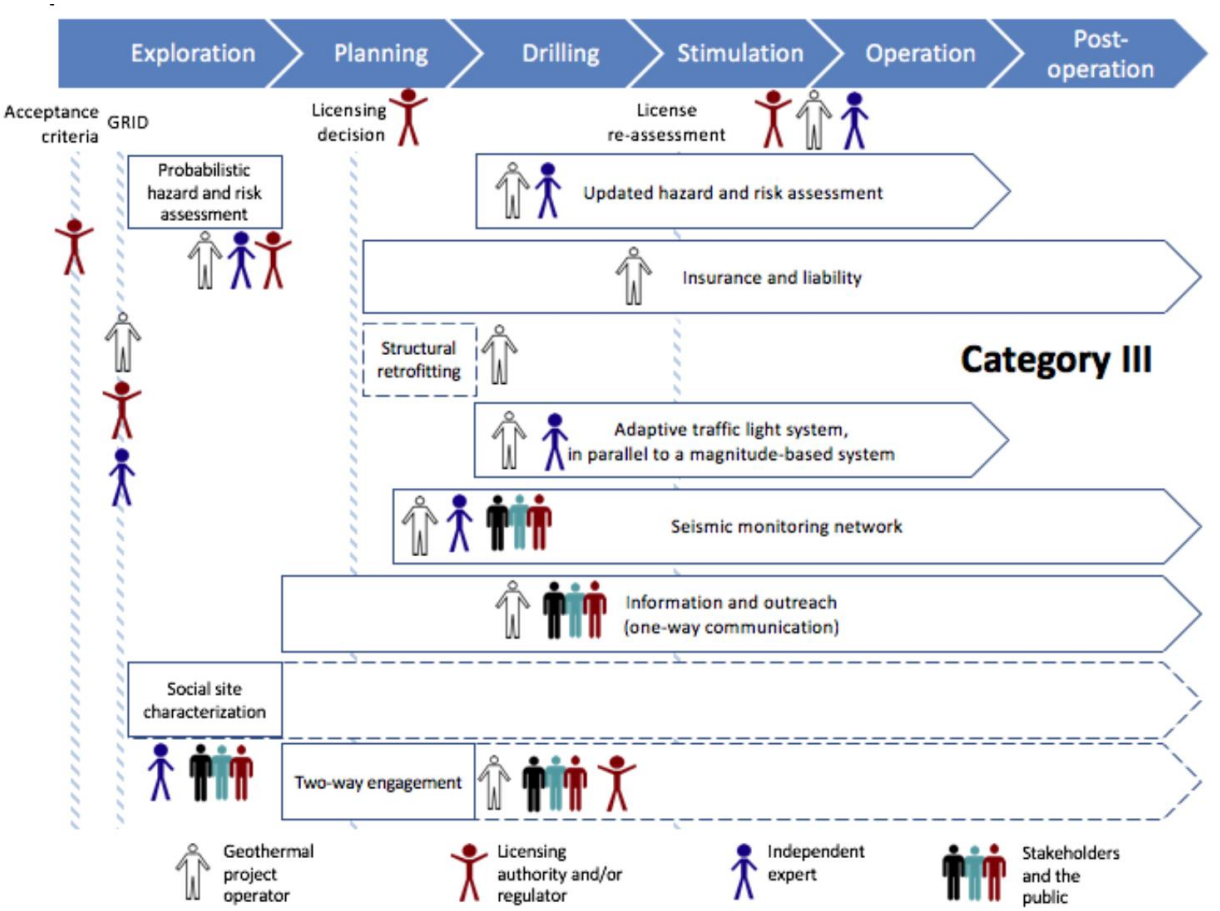
Holistic concept of risk governance & community resilience

- ✓ From **risk analysis**
  - Data analysis & statistics
  - Physical process understanding
  - Risk modeling
- ✓ To risk **management & governance**
  - Risk grading / stress tests
  - Traffic-light systems
  - Communication with industry, regulators & public.

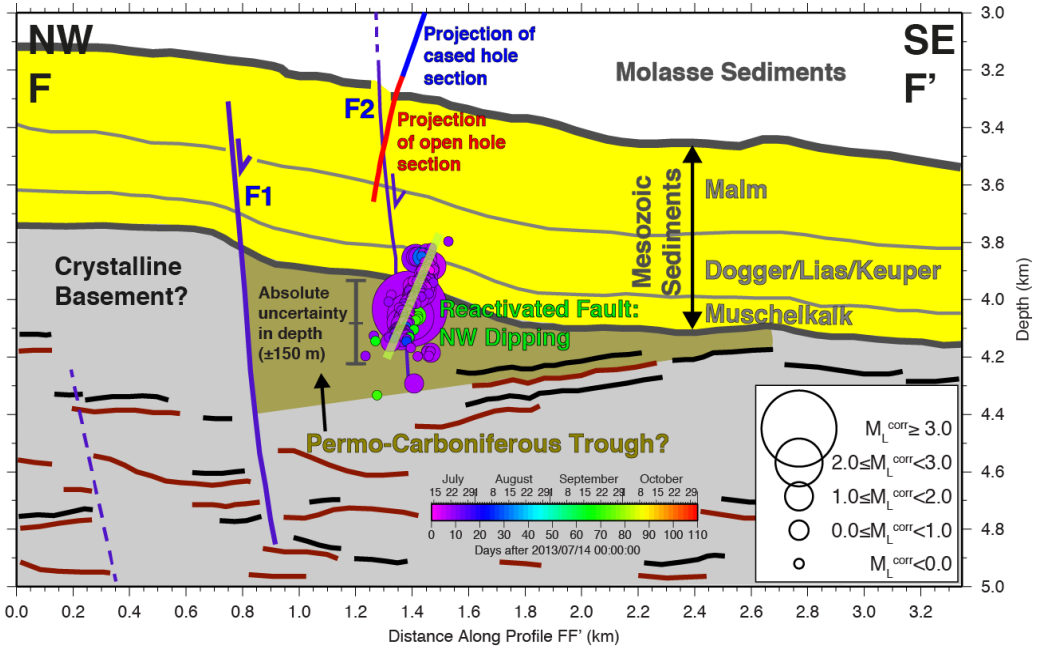


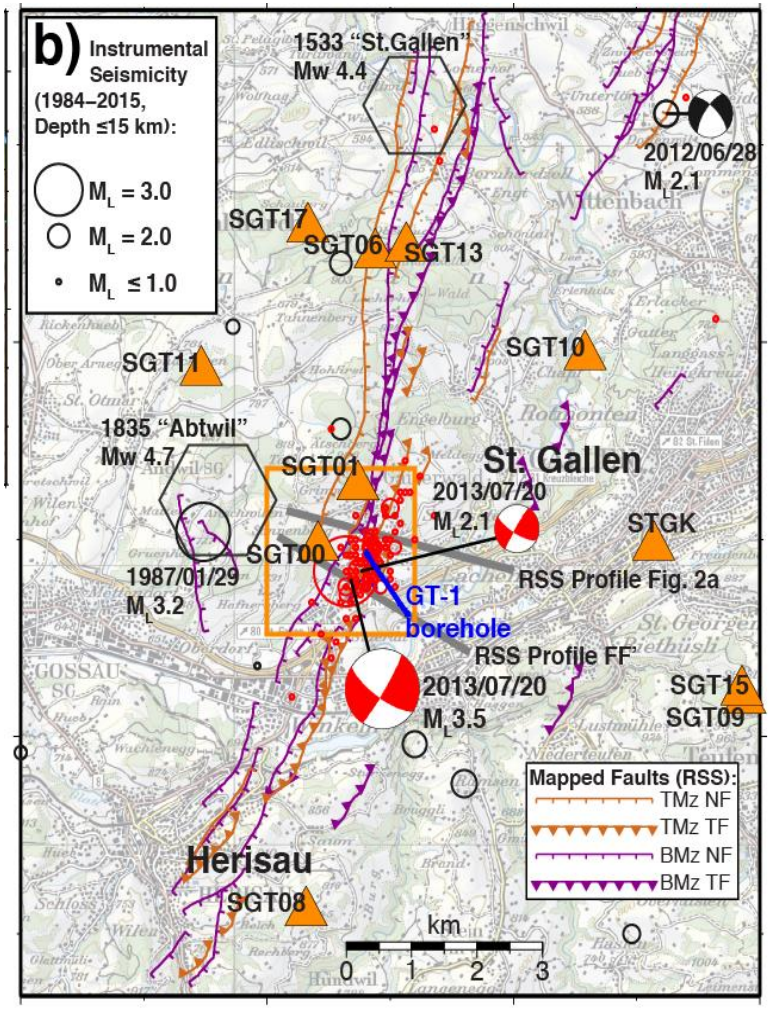
Trutnevyte & Wiemer, 2017

Understanding induced seismicity in Sankt Gallen

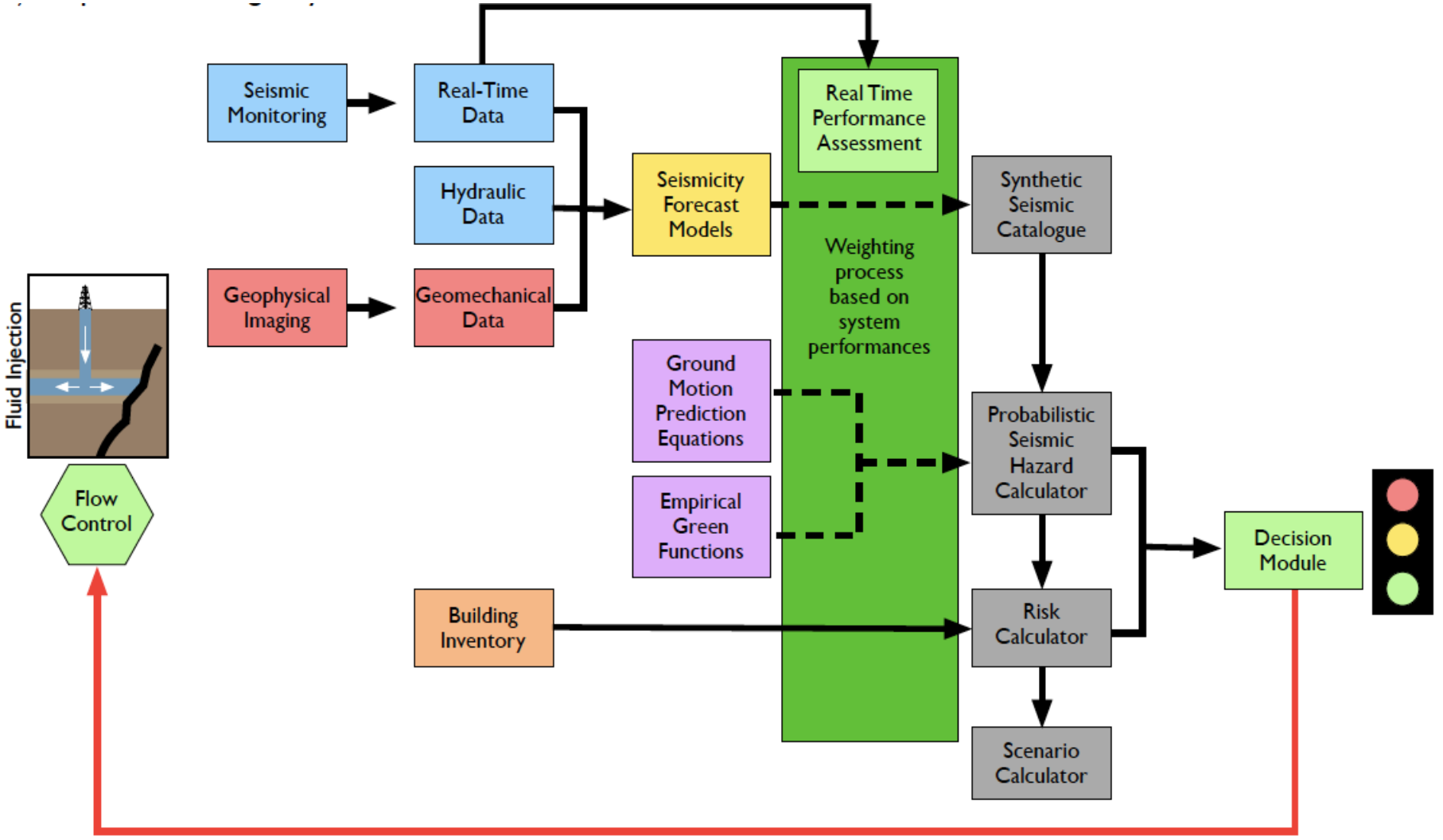
→ Talk by T. Diehl

→ Poster by Domink Zbinden.





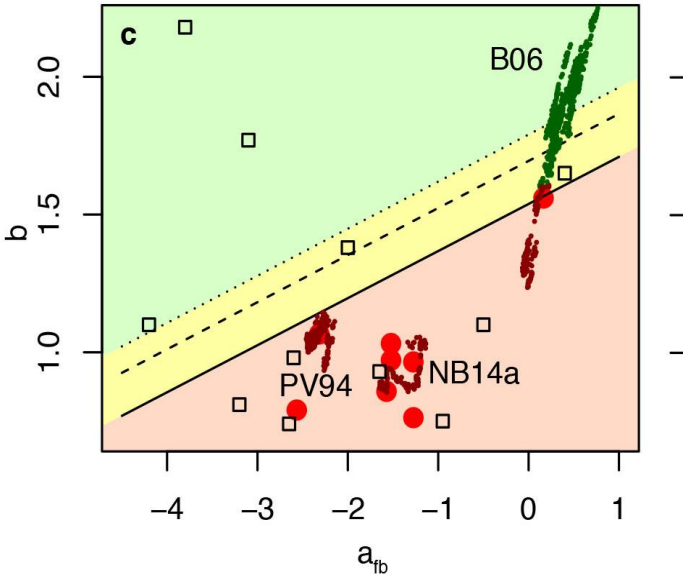
Adaptive Traffic Light Systems

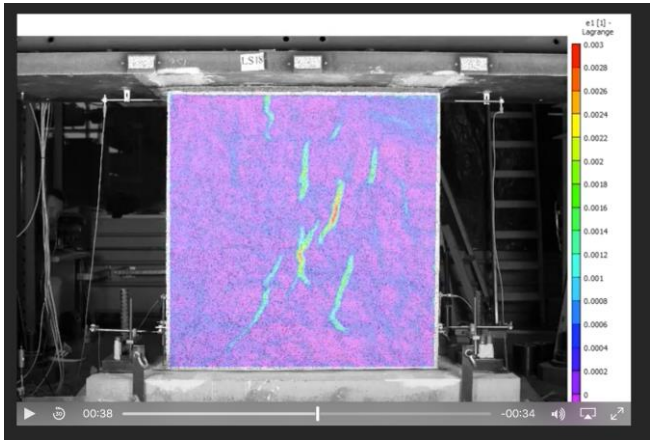


Grigoli et al., Rev. of Geoph., in press

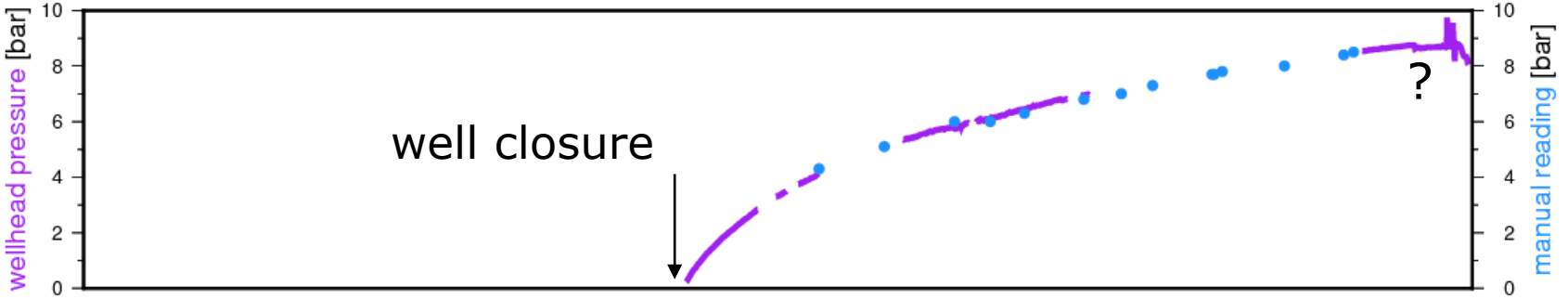
And much more ... also here at the meeting

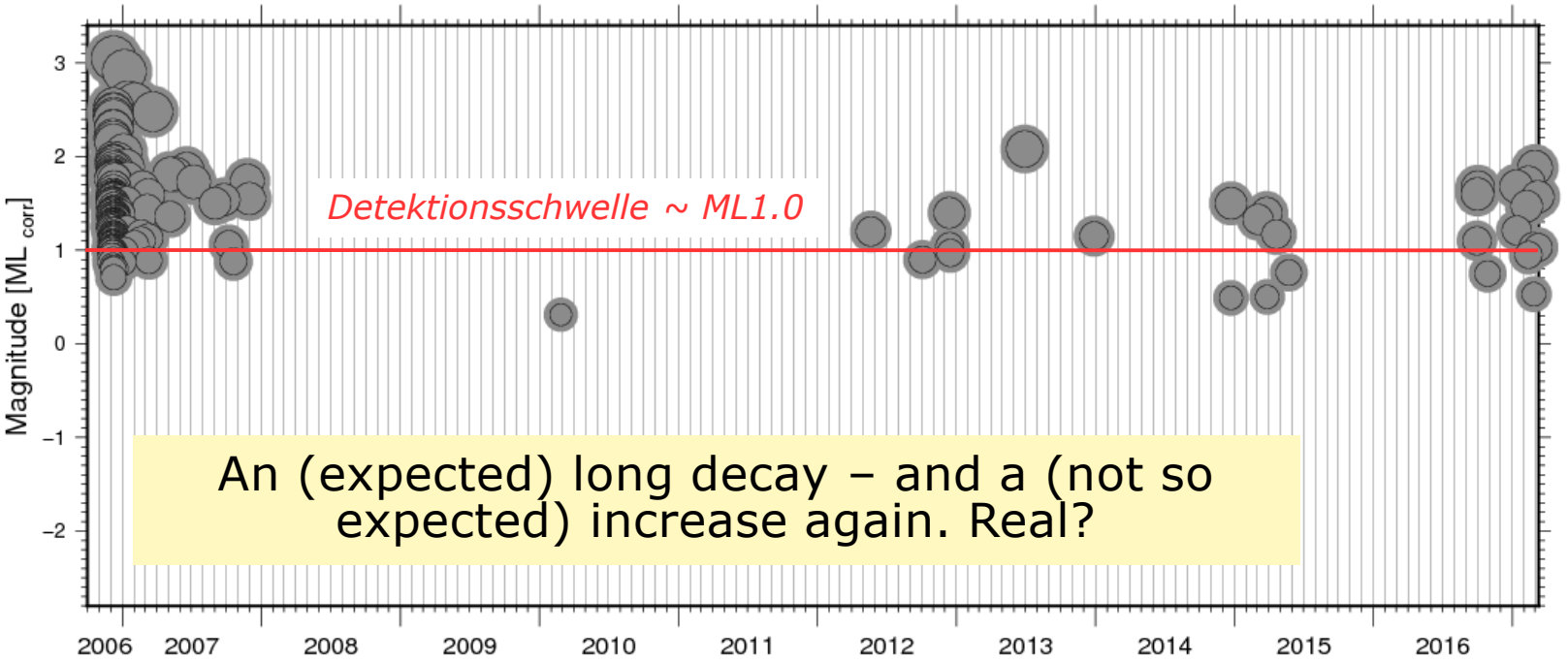
- **Seismicity Analysis:** Clinton et al., Deichmann, Grigoli et al., Diehl et al., Kraft et al.)
- **Modelling**: (Rinaldi et al., Mignan et al, Karvounis, Kiràly et al., Urpi et al., Zbinden et al.)
- **Validation and Experimation** (e.g., Grimsel, Giardini, Dotesch.
- **Hazard and Risk**: Broccardi et al.,





But what I really like to talk in the remaining minutes: Basel!

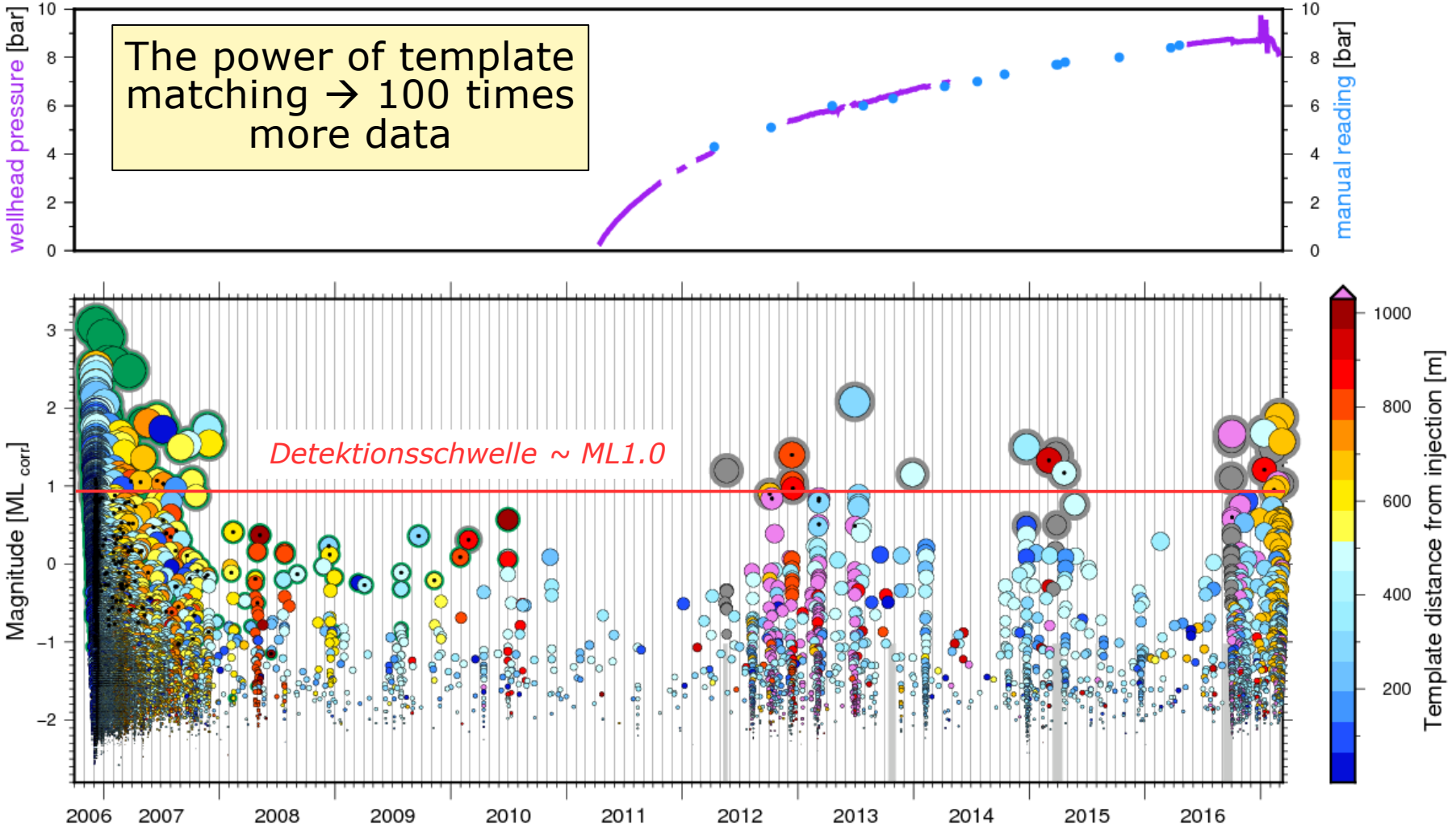




An (expected) long decay – and a (not so expected) increase again. Real?

SED-Lokationen Dez 2006 – 11.Mar 2017

Basel seismicity increase

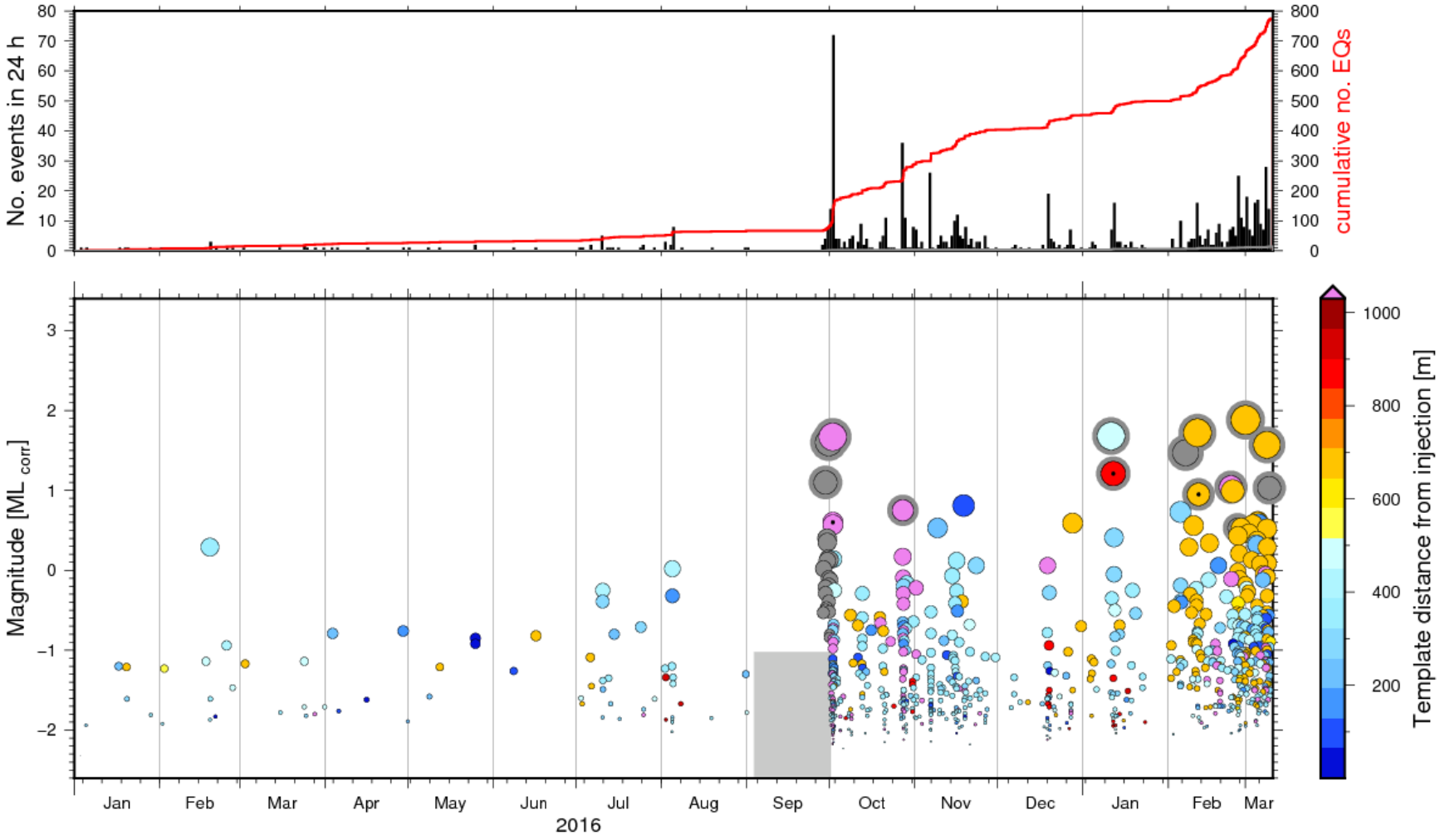


Detections Dez 2006 – 11.Mar 2017

Graue Balken: Gap an OTER2 durch MATTE aufgefüllt

→ M. Herrmann

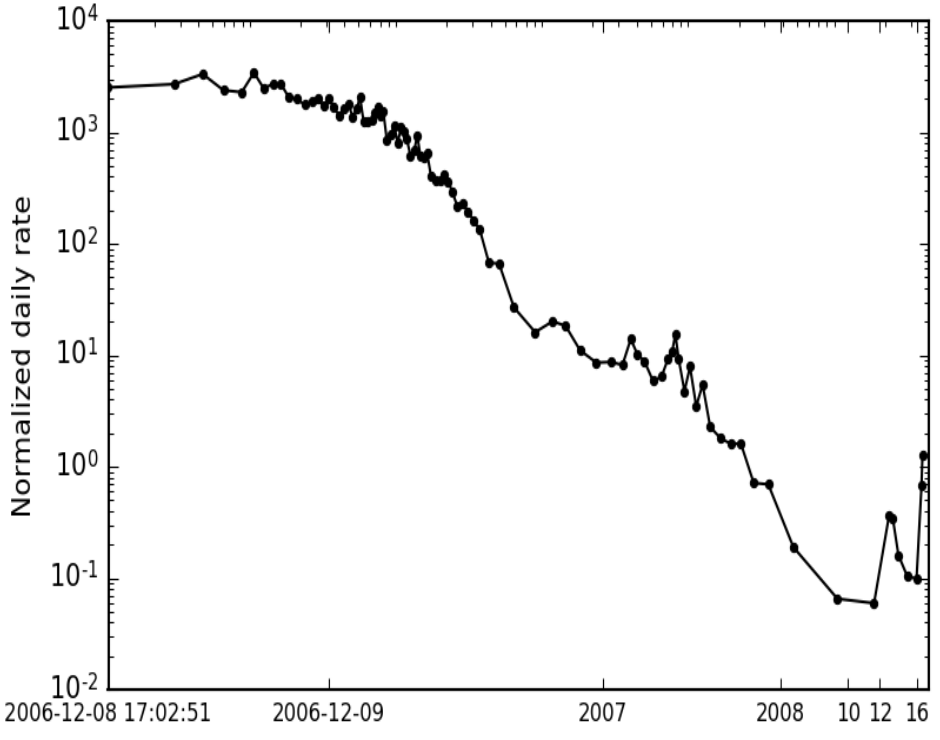
Zoom since 2016

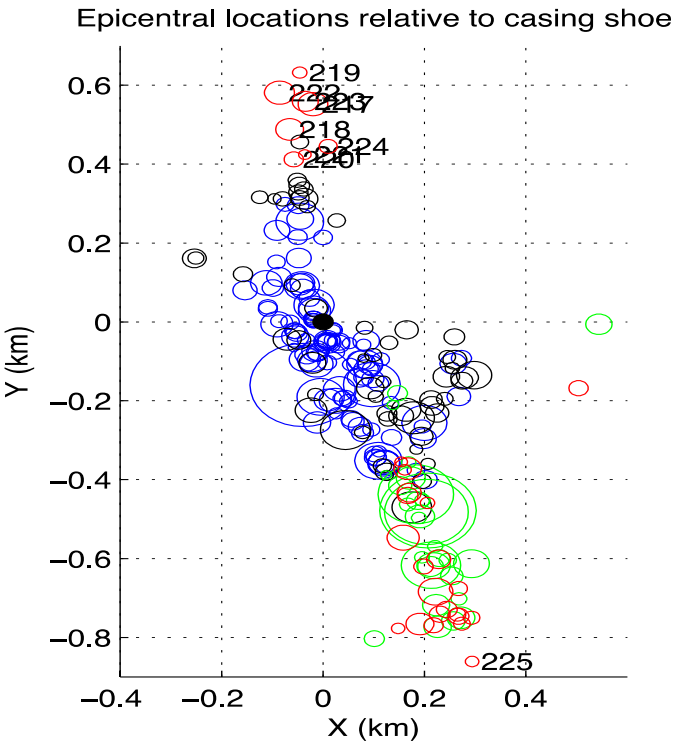


→ M. Herrmann

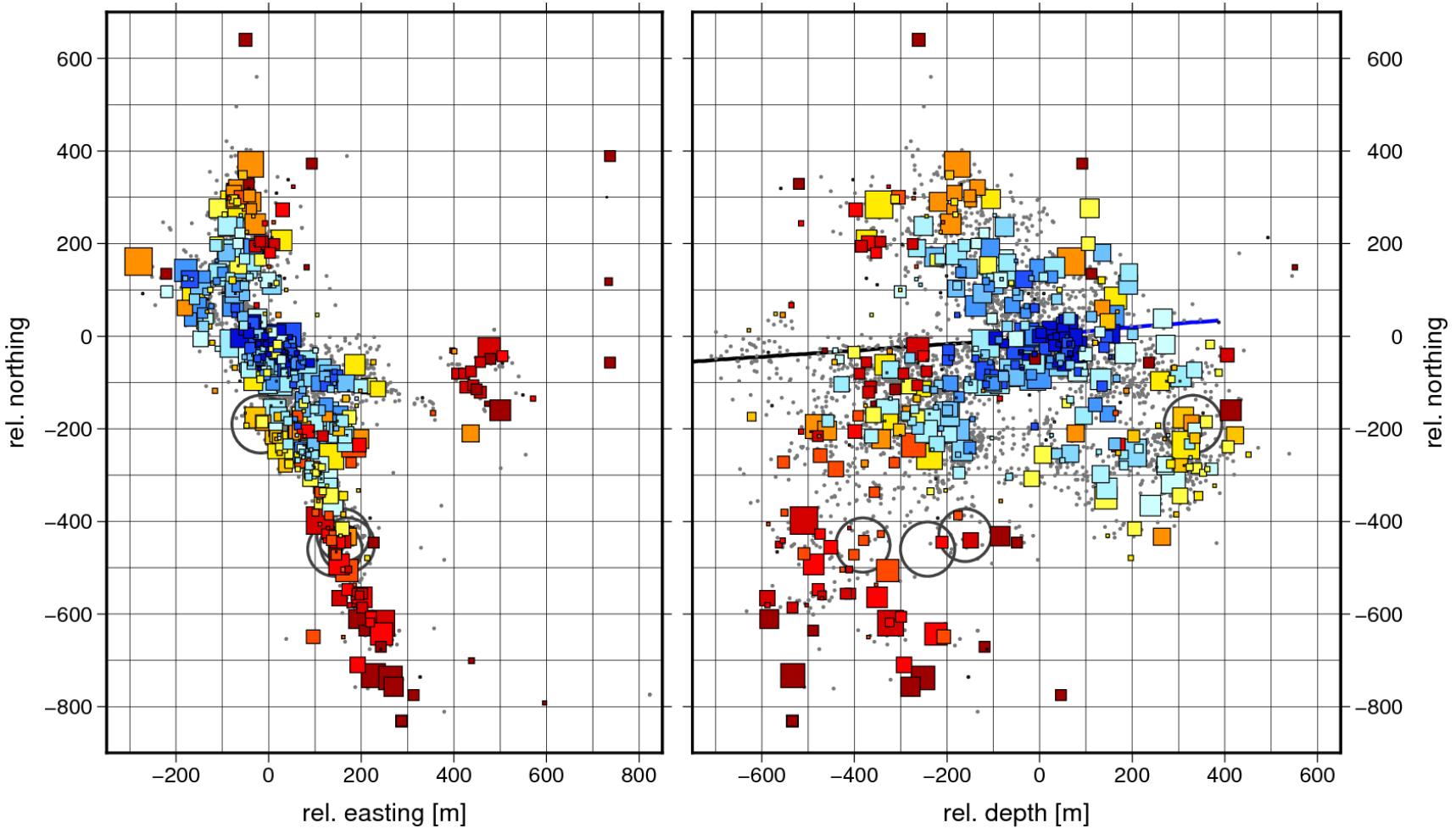
First order: The reservoir stimulation is followed by a decay just like aftershocks – and in a tight reservoir, it takes along time (we estimated in 2007 15 years or so) .

Second order: Closing of the well caused an increase in the seismicity, everywhere, but lately also migrating outwards to the north, and, since Monday, to the south...





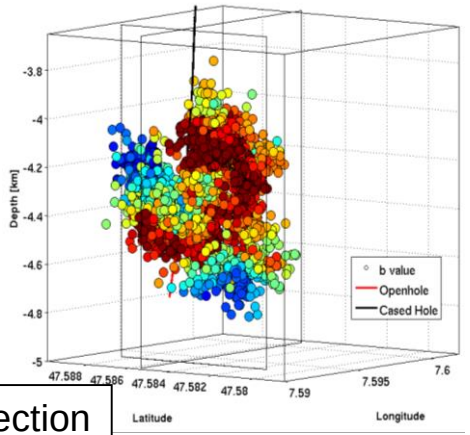
Locations – color-coded by template number



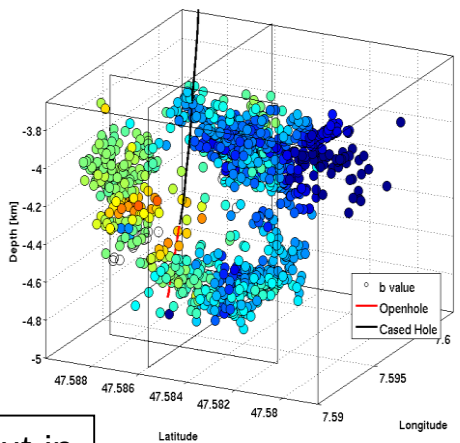
→ M. Herrmann

The size distribution changes

- After the well shut in, b-values decrease again.

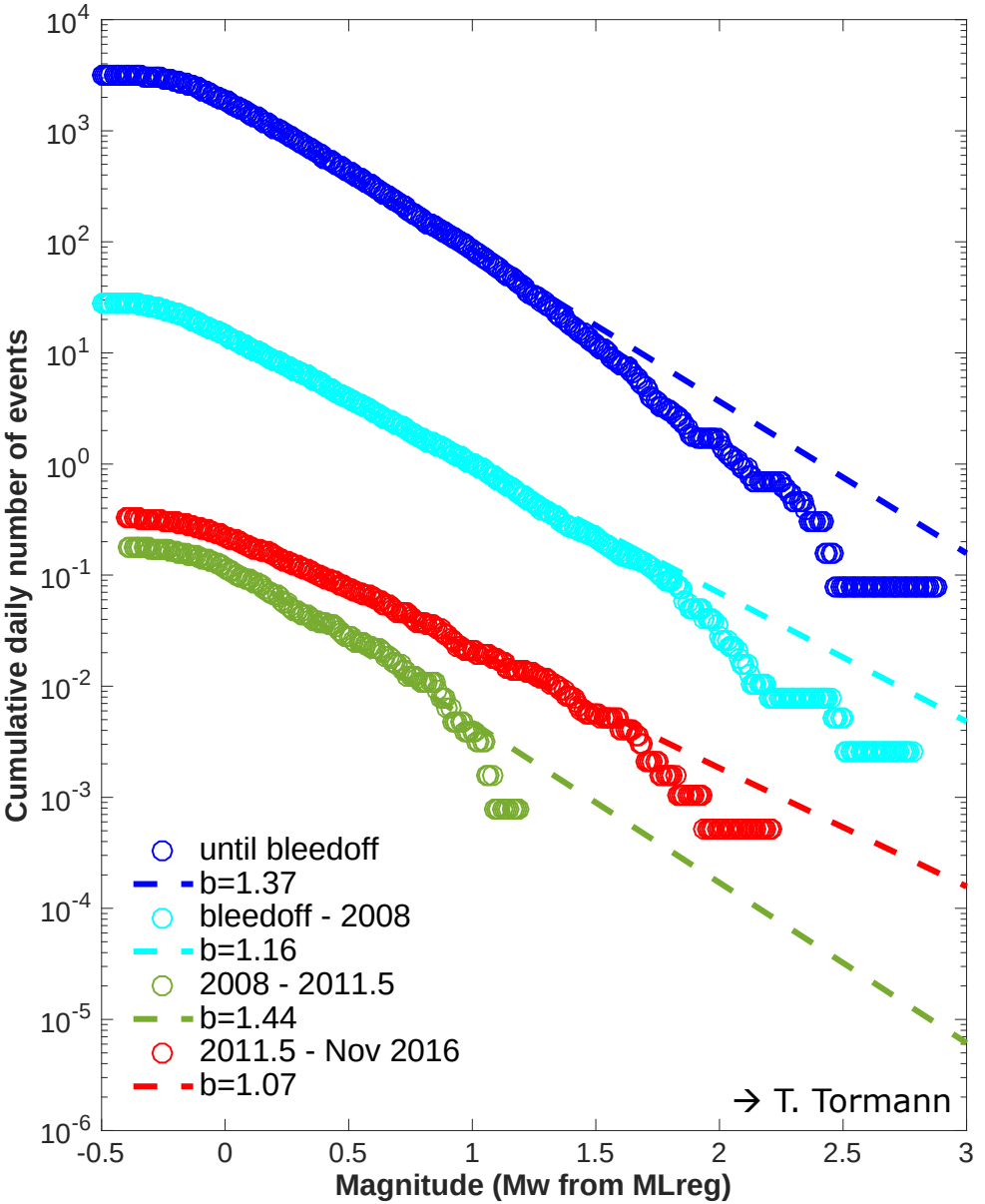


During Injection

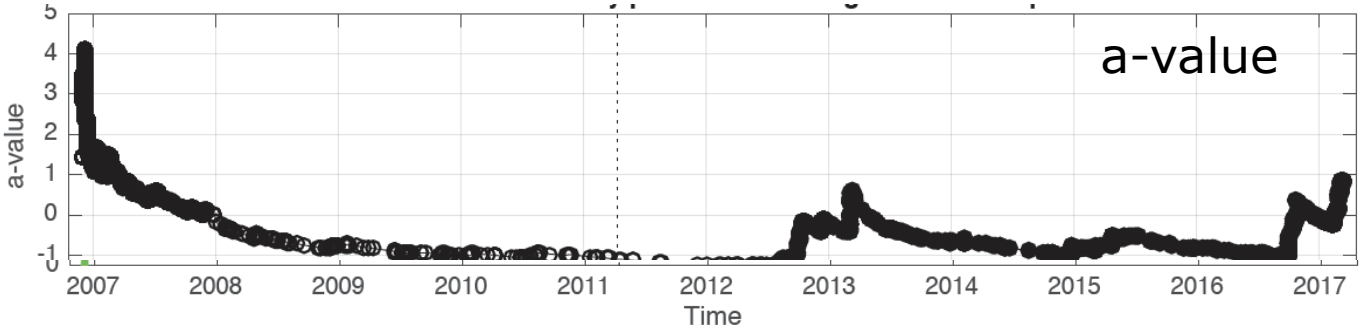


After Shut-in

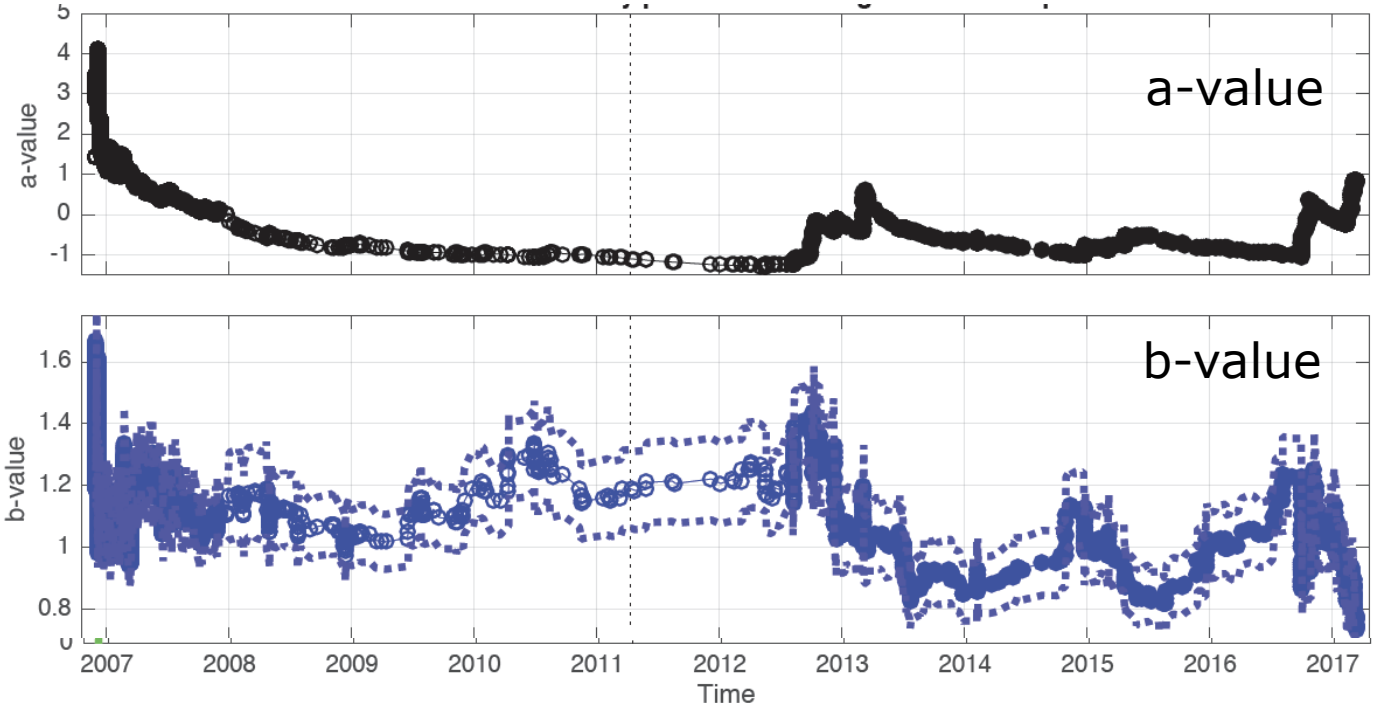
Bachmann et al., 2012



Hazard?


a-value
a-value
5
4
3
2
1
0
-1
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
Time

Hazard?


a-value
b-value
a-value
b-value
Time
2007
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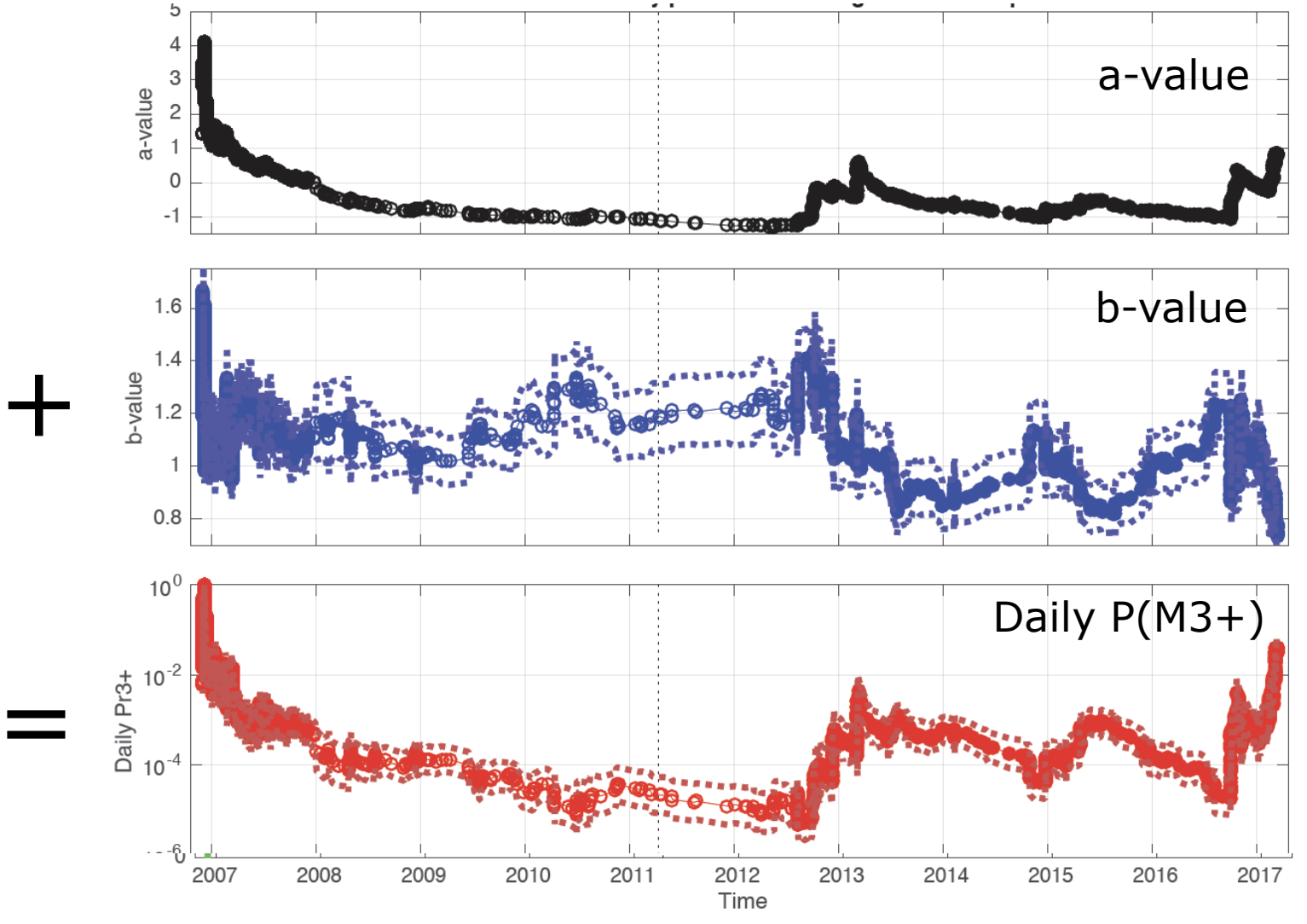
2016
2017

Hazard?



→ T. Tormann

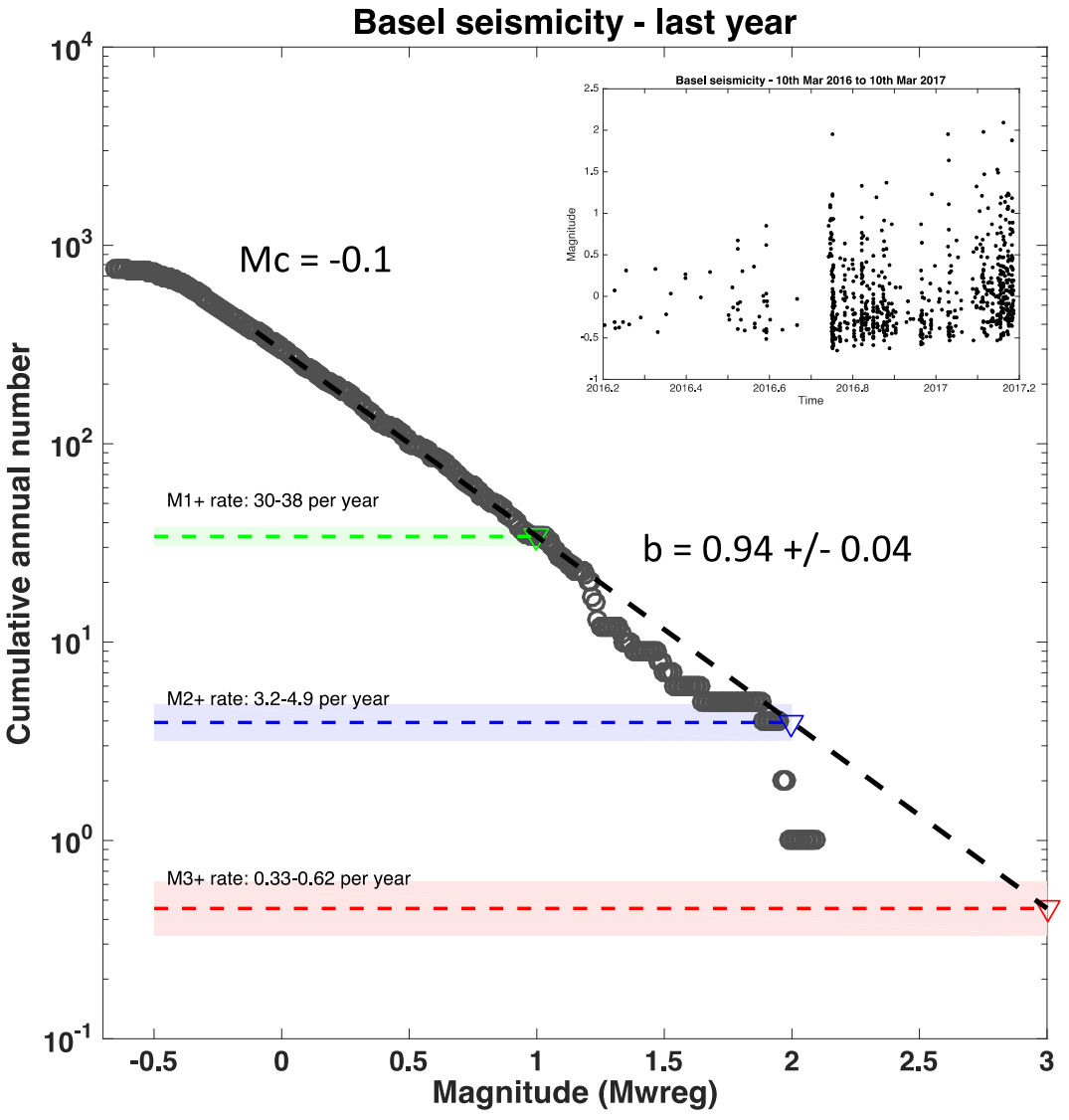
If the past is the key to the future ...

Another felt event is likely. A damaging one possible.

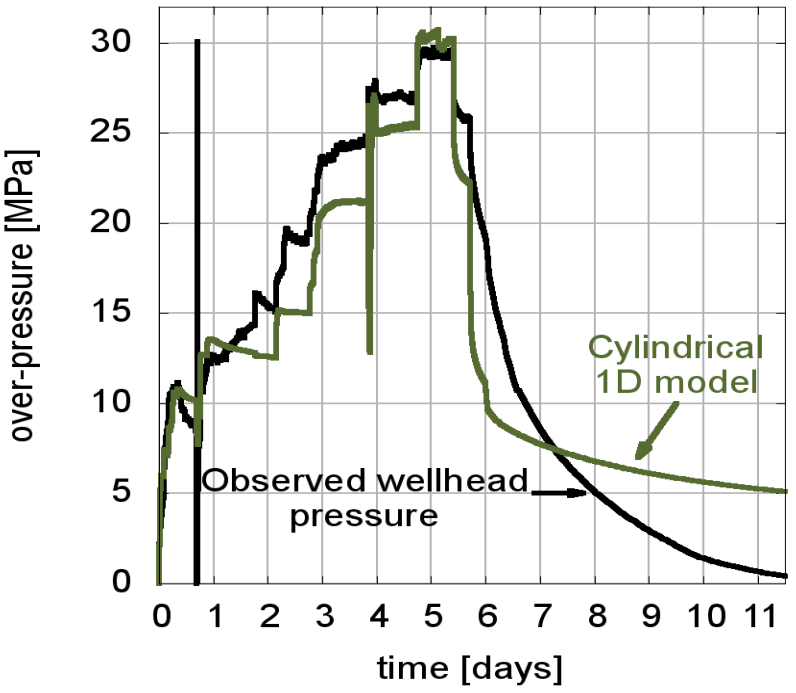
Question: Should one re-open the well?

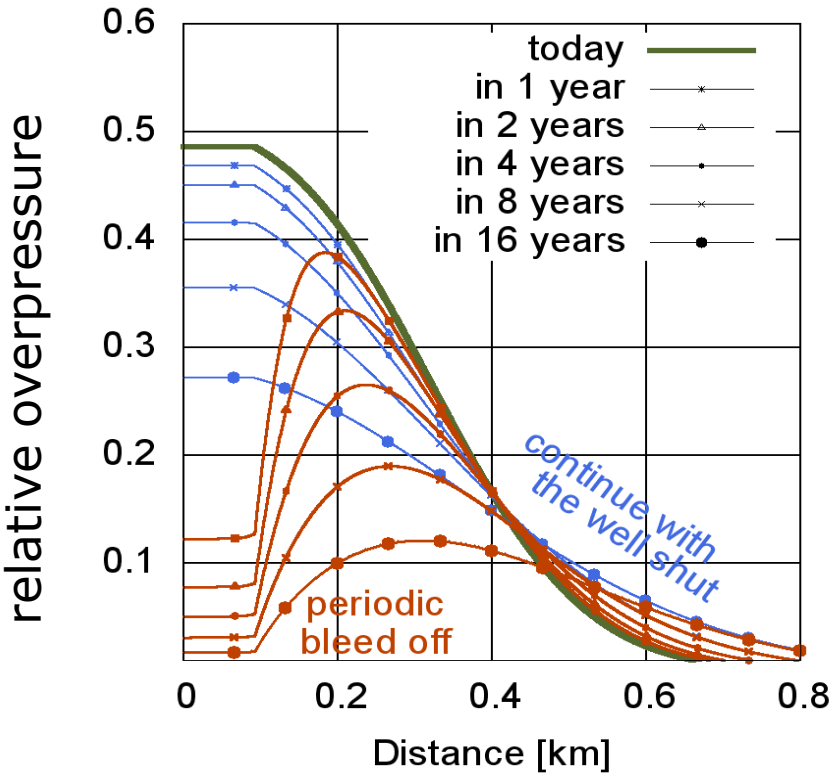
→ Reservoir modelling (Dimitrios Karvounis)

→ T. Tormann



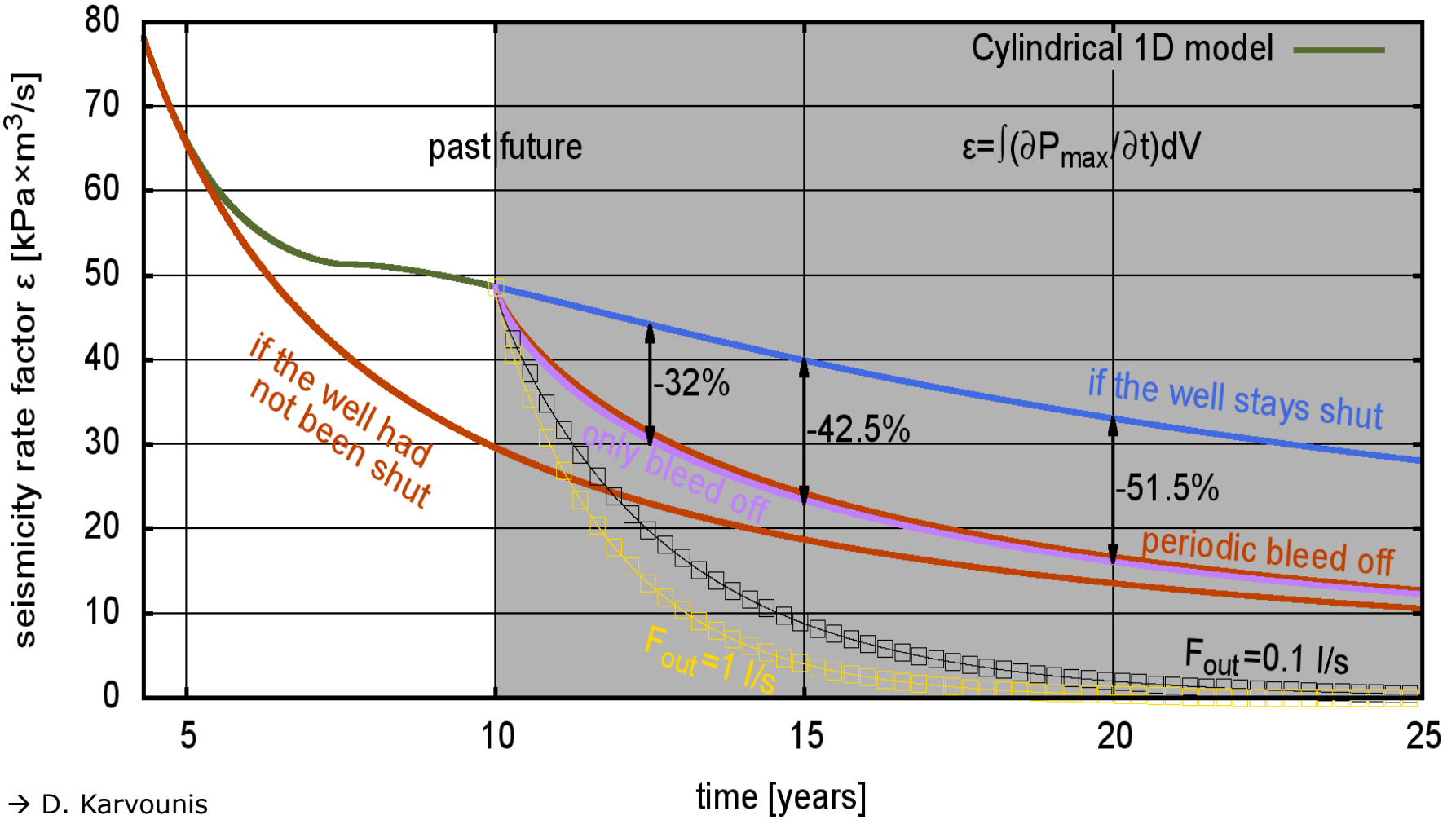
Reservoir modeling in 1D





→ D. Karvounis

1D model results translated to seismicity rates

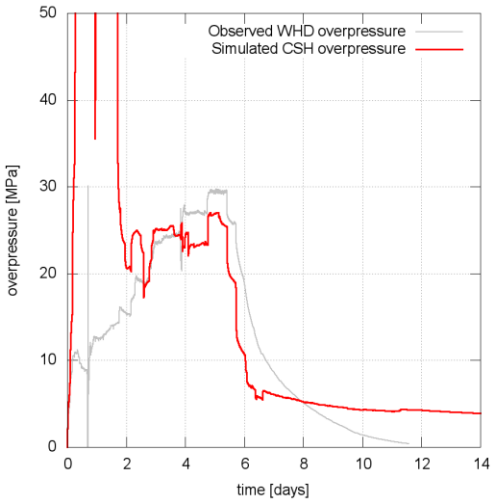


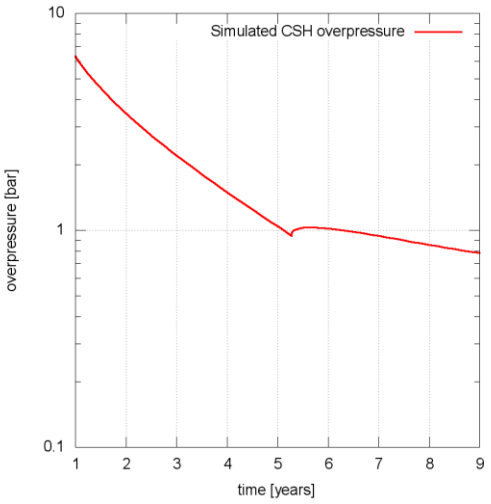
→ D. Karvounis

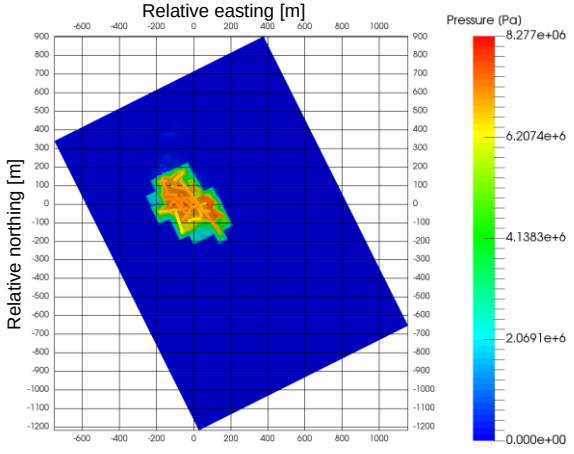
3D Modelling

Observations considered:

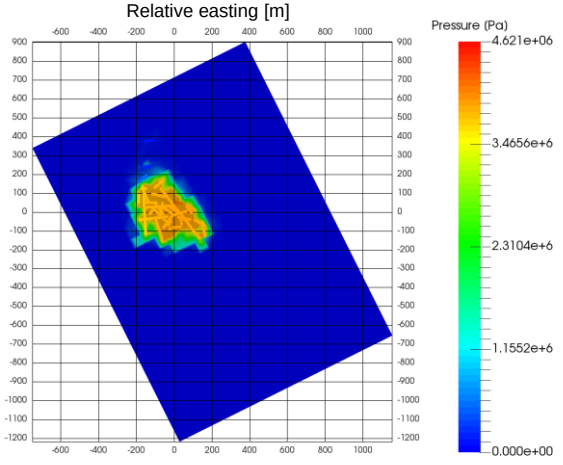
- Cumulative volume of produced fluids,
- Observed hypocenters and magnitudes (Kraft et al., 2015),
- Focal plane solutions and principal stresses (Terakawa et al., 2014), and
- Cluster analysis (Deichman et al., 2015).



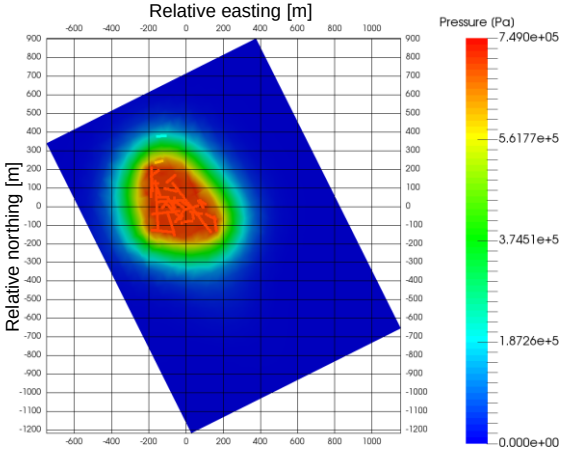




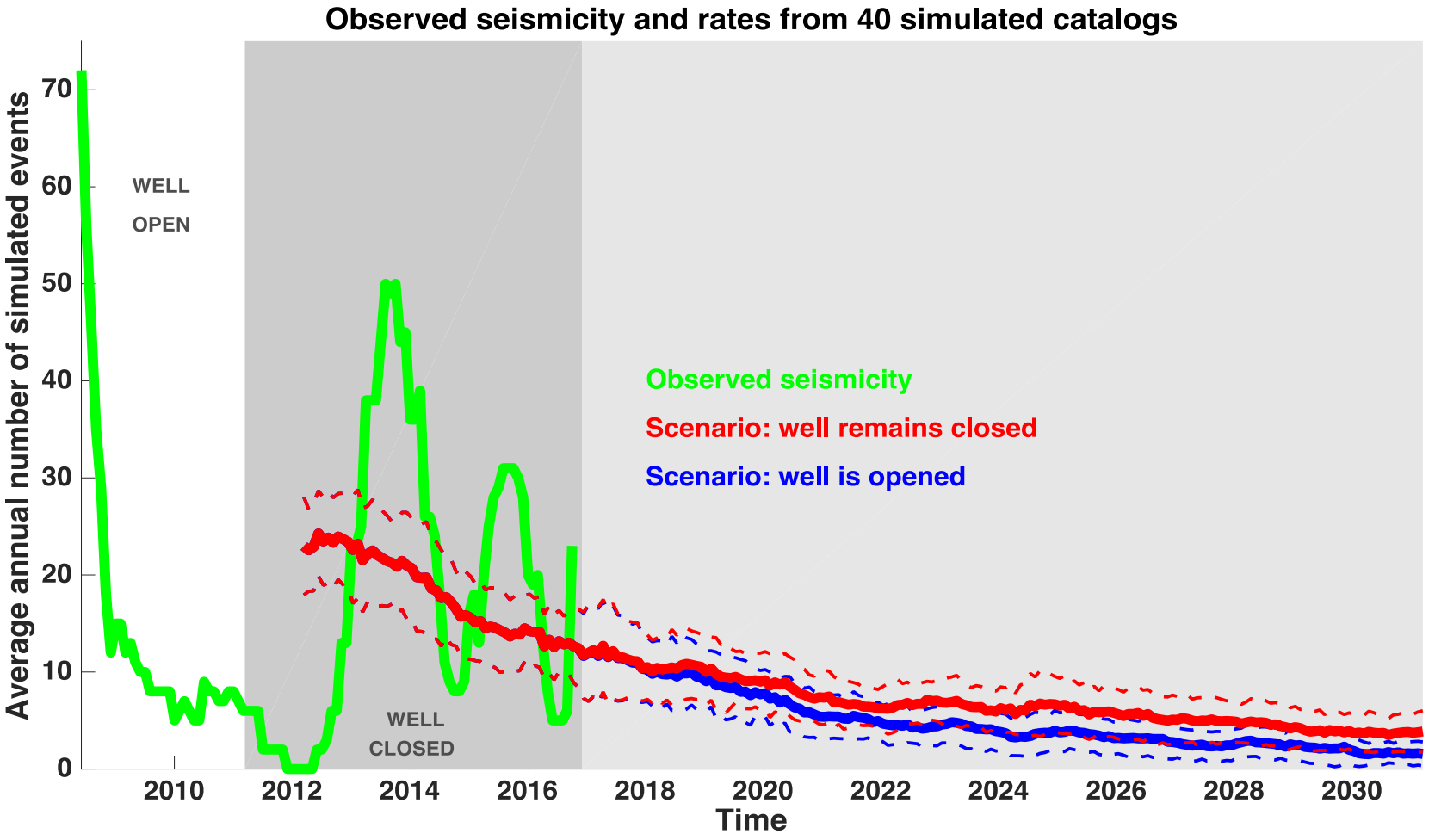
7 days since injection



14 days since injection



1 year since injection


Observed seismicity and rates from 40 simulated catalogs
Average annual number of simulated events
0
10
20
30
40
50
60
70
WELL
OPEN
WELL
CLOSED
Observed seismicity
Scenario: well remains closed
Scenario: well is opened
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
Time

Your turn! Would you:

1. Keep the well shut.
2. Reopen it (slowly)
3. Reopen and actively pump out