SCCER SoE

Schweizerischer Erdbebendienst
Service Sismologique Suisse
Servizio Sismico Svizzero
Swiss Seismological Service

ETH zürich

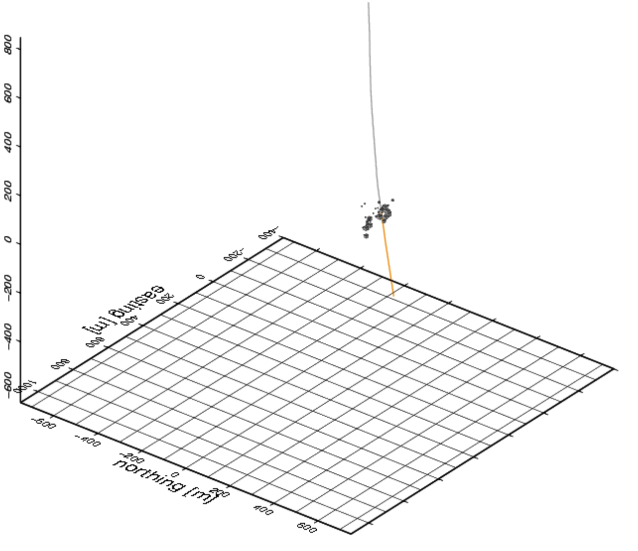
Towards (Real-Time) Risk Assessment and Mitigation Systems for Induced Seismicity

Stefan Wiemer

with contributions by many others!

Before I talk about **Risk**: Why I **Love** to work on Induced Earthquakes

- They are a great Laboratory: Just drill a hole, add water and you **can fast-forward** tectonic processes by a factor of 100’000 and more.
- So even places like Switzerland, or Kansas, can be a **research-seismologists heaven** (and an operational-seismologists hell).
- Also: In natural earthquake we can only observe and guess. In induced earthquakes we have (some) **control**!
- We can conduct and **repeat** experiment when and where we like → Great testing environment, hope to understand the physics at work.
- We often have **much better data** since we known the time and place of the experiments.



Last but not least: Interdisziplinar reserach at its best

- It will take Seismologist of all flavors, Engineers, Computer Scientist, Social Scientists and maybe even Geologists (!) to make progress.
- A great learning and collaboration opportunity[1]
- If we learn how to use earthquakes as a tool, we can do good for the world.

[1]*and yes, there are also funding opportunities*

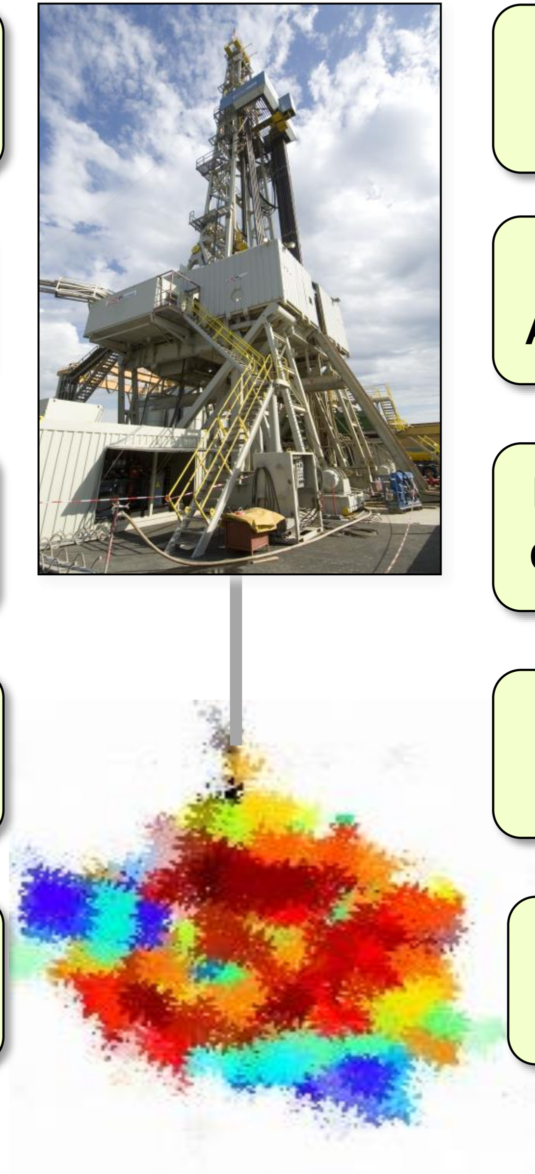
Seismology

Earthquake Physics

Fluid Dynamics

Numerical Modeling

Social Science



Geological Modeling

Risk Assessment

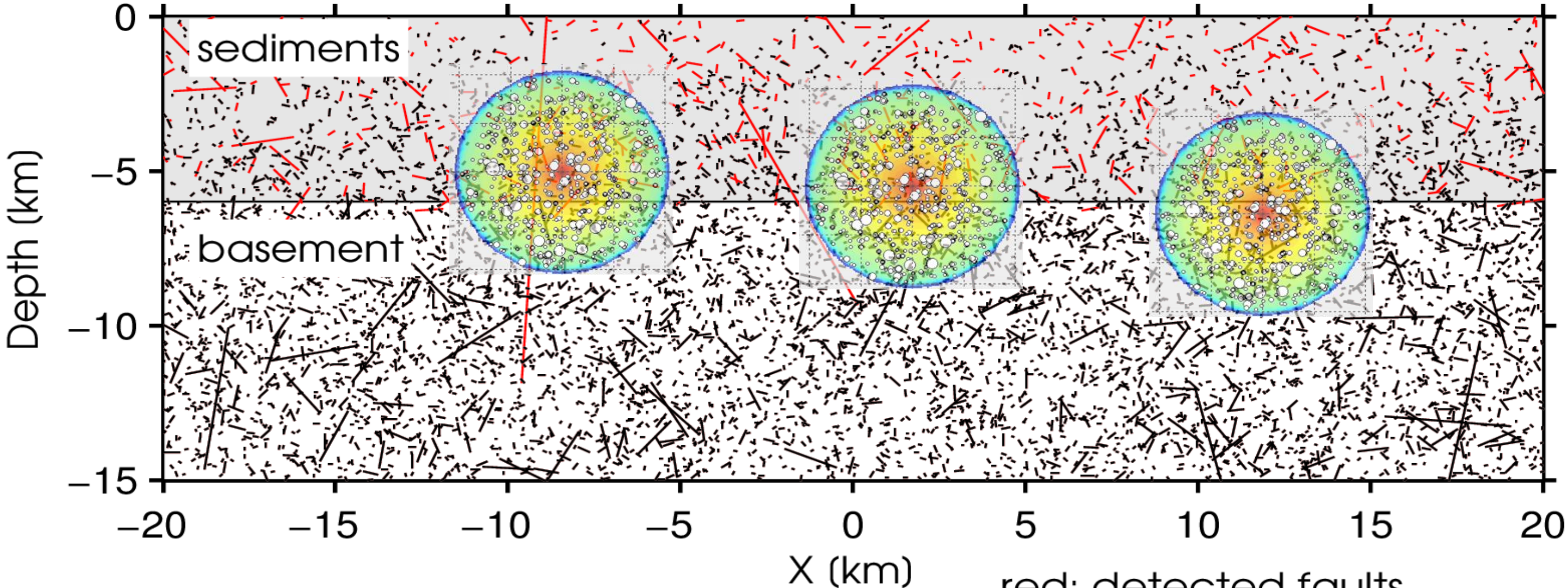
Exploration Geophysics

Rock Physics

Sensors

The challenge: In a critically stressed crust - there will be no easy answers ... Sorry

- We do not know where faults are in any sufficient detail, nor do we know the stress state of these faults in the areas of interest.
- We need to deal with uncertainty, we must think **probabilsitically**, not determistically!
- **No zero risk**

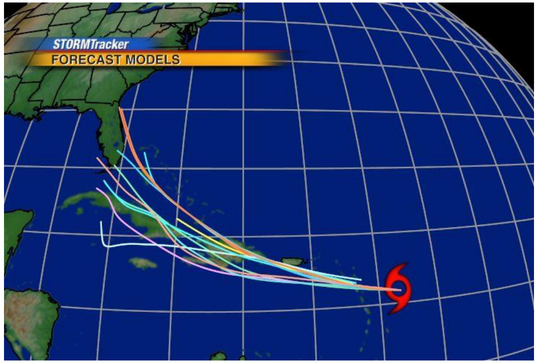


red: detected faults
black: overlooked faults

Weather ← → Earthquakes

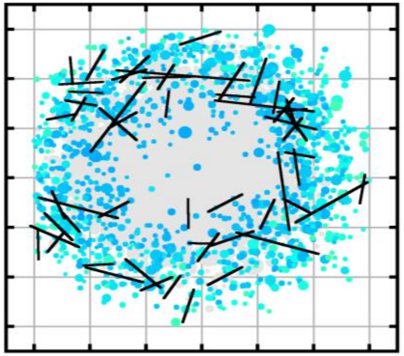
*„**Weather** forecasting is the classic inexact science, relying on the complex mutual interactions of **wind, currents, precipitation, tides, humidity and temperature** variations, and a million other variables (...) . To say forecasting the weather is tricky is putting it mildly indeed."*

(Mike Hammer, 2014)



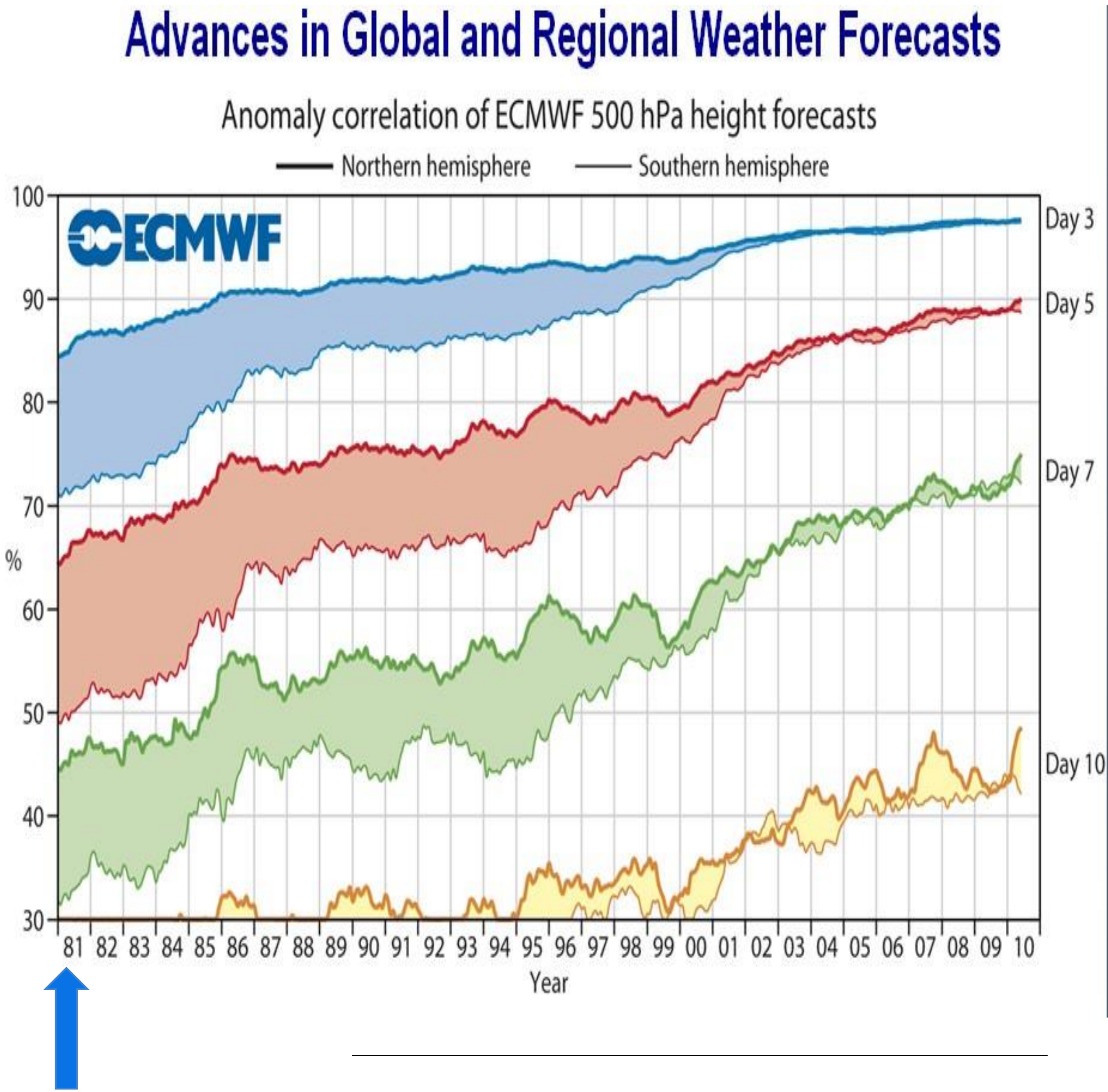
*„**Earthquake** forecasting is the classic inexact science, relying on the complex mutual interactions of **stress, fluids, tides, faults and temperature variations**, and a million other variables across the Earth Crust. To say forecasting earthquakes is tricky is putting it mildly indeed."*

(Stefan Wiemer, 2015)



But does that stop weather forecasting?

- *"Between 1981 and 2010, the accuracy of 3-day weather forecasts in the northern hemisphere rose from about 70 percent to about 98 percent"*
- Steady evolution, hard, dedicated work and improvements in models, as well as data were needed.
- This, I think, is the path for induced earthquake research also.
- We need to agree on a metric and procedures to measure progress.



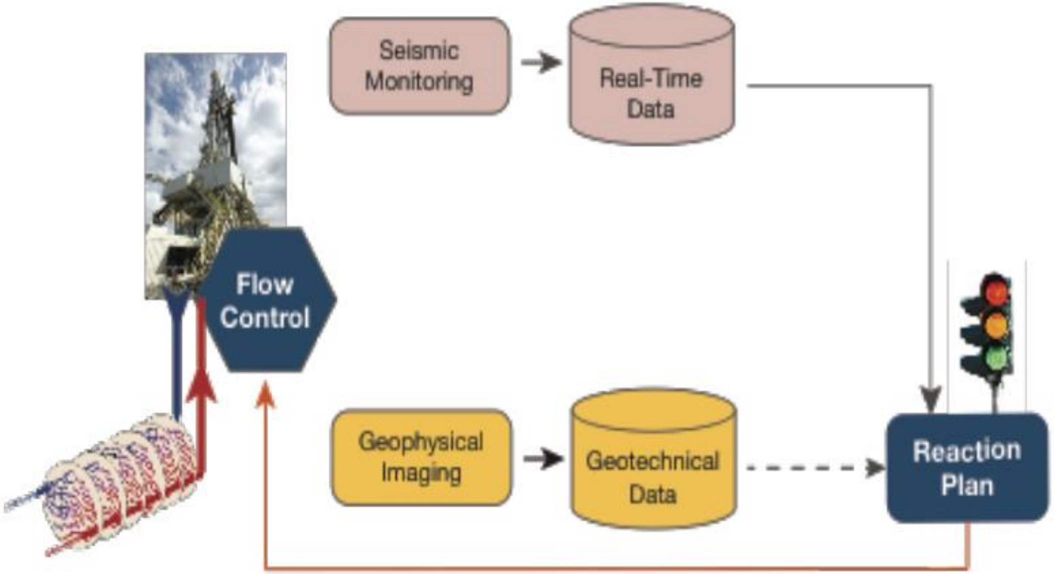
Risk assesment: Guiding principles

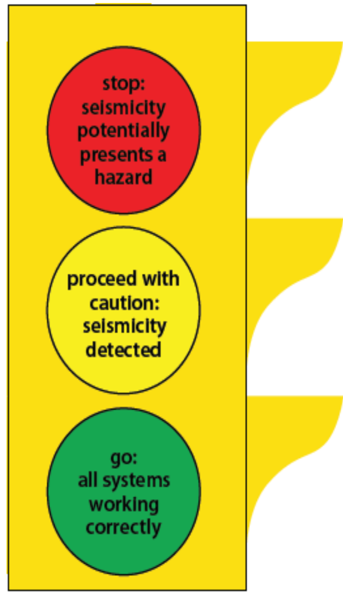
1. **Consider uncertainties** in our understanding and interpretation of the processes and in the relevant data.
2. **Risk based:** Societies decide based on cost and benefits, or risk and opportunities. Decisions should be based on the risk a project poses, not the hazard.
3. **Reproducible and quantitative.** It is science, after all.
4. **Comprehensive:** Monitoring, mitigation measures, interactions, natural events and unexpected events shall be considered consistently **during all project stages.**

Why PSHA ? PSHA is trying to...

- Allow societies to make educated decisions on earthquake safety.
- Attempt to rationalize the decision making process.
- Integrate all knowledge in a systematic way.
- Integrate the uncertainty in our knowledge in a formal way.
- PSHA is NOT trying to find the worst case scenario. The worst case will always be a large magnitude events with extreme ground motions, right underneath your feet – giving you several g of acceleration.
- As soon as you say that this scenario is too unlikely (how unlikely is too unlikely?; and if it is too unlikely to you, is it the same to me?), you are doing PSHA in your head (in other words, there is no such thing as deterministic hazard analysis).
- PSHA is well established, known to regulators and widely in hazard and risk assessment across the word and in all disciplines.

Implication for Induced Seismicity: From simple traffic lights....



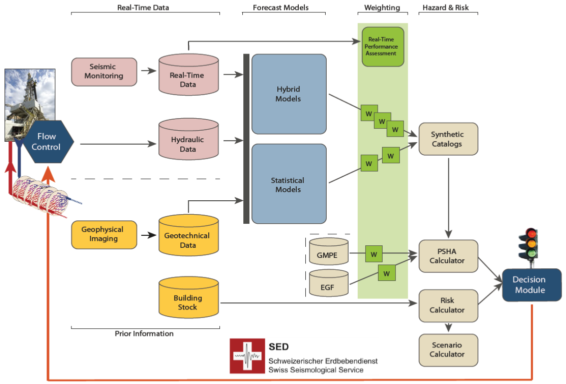


Zoback, April 2012, *Earth*

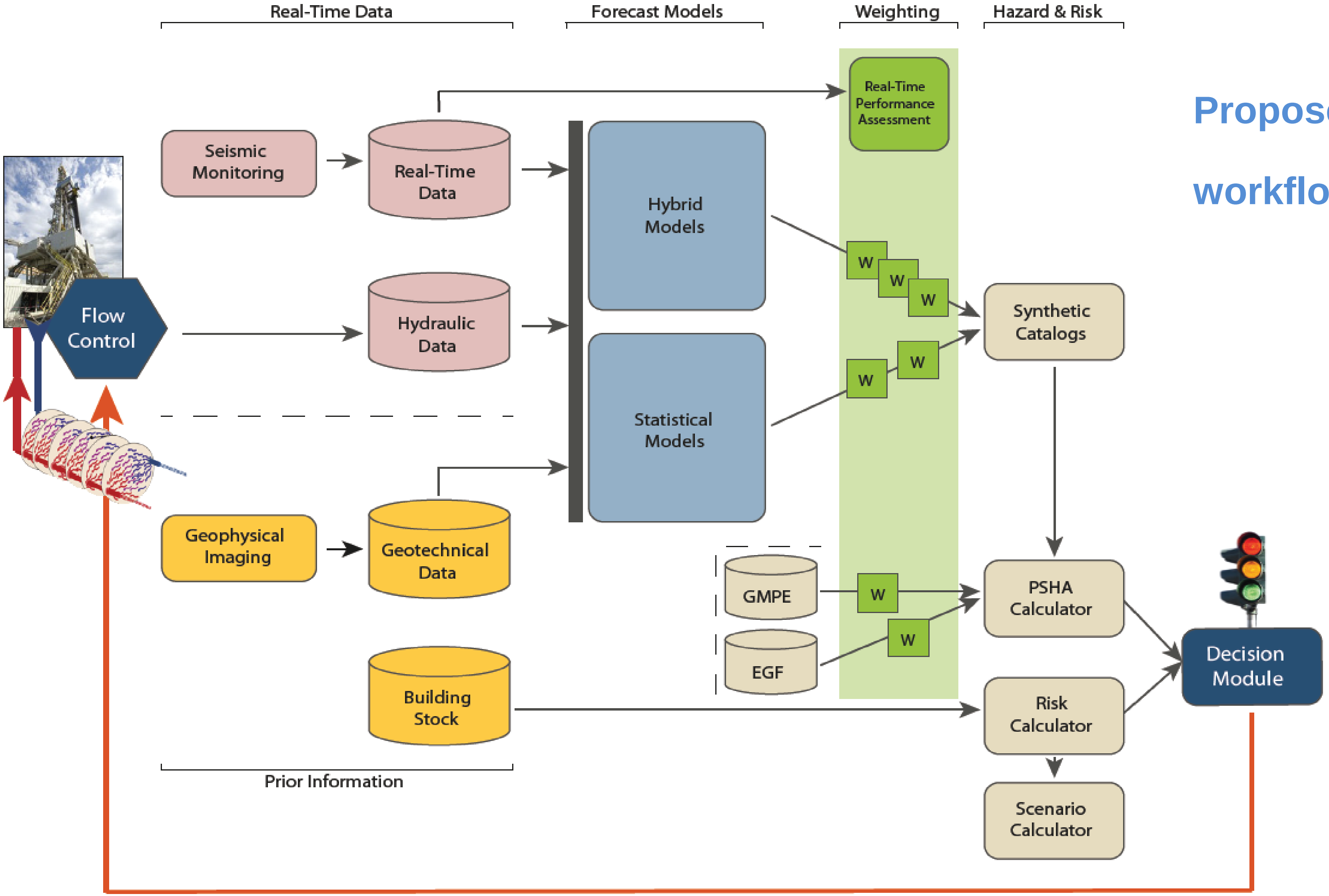
- No physical/reservoir model
- Uncertainties not accounted for
- Limited use for scenarios modeling
- Not risk based.
- Not learning
- …

... To (probabilistic) Real-Time Risk Assessment and Mitigation Systems for Induced Seismicity

- Rather than being reactive schemes, forecasts are **dynamically updated, forward-looking and fully probabilistic models** that forecast the future seismicity evolution based on a range of relevant key parameters (eq., K P, T, …), including uncertainties.
- They consider all possible scenarios, including ‘low probability-high consequence events’.
- Robustness through Bayesian principles and ensemble forecasting.
- Can be used also for scenario/planning purposes.
- Induced seismicity risk assessment is hence elevated to the quantitative analysis level common for earthquake risk analysis for other critical infrastructures.



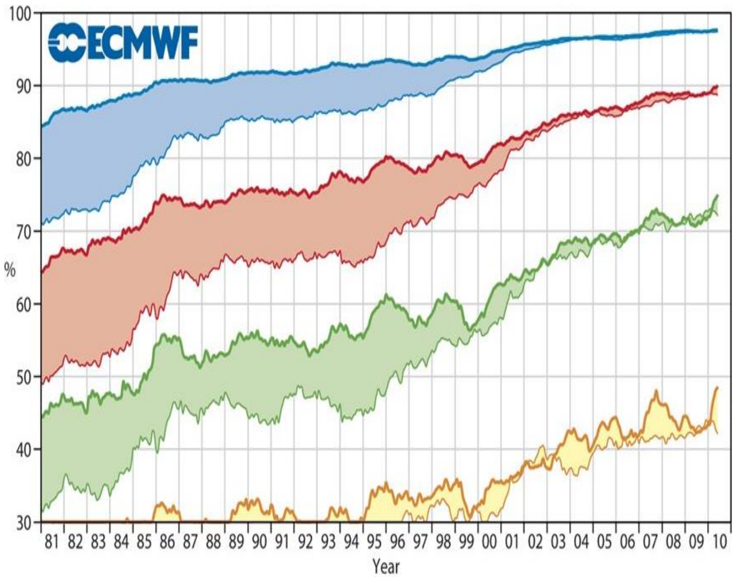
Proposed workflow



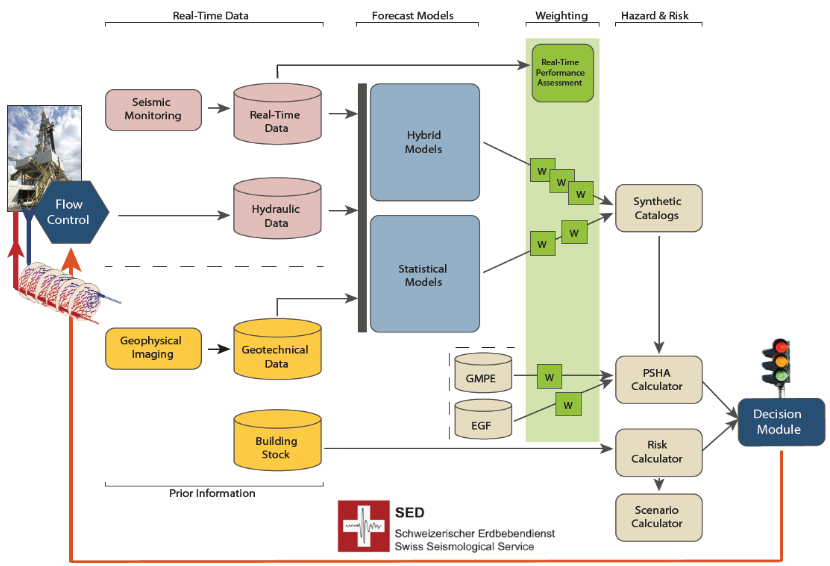
Next: Kaizen – start a „continual improvement process“

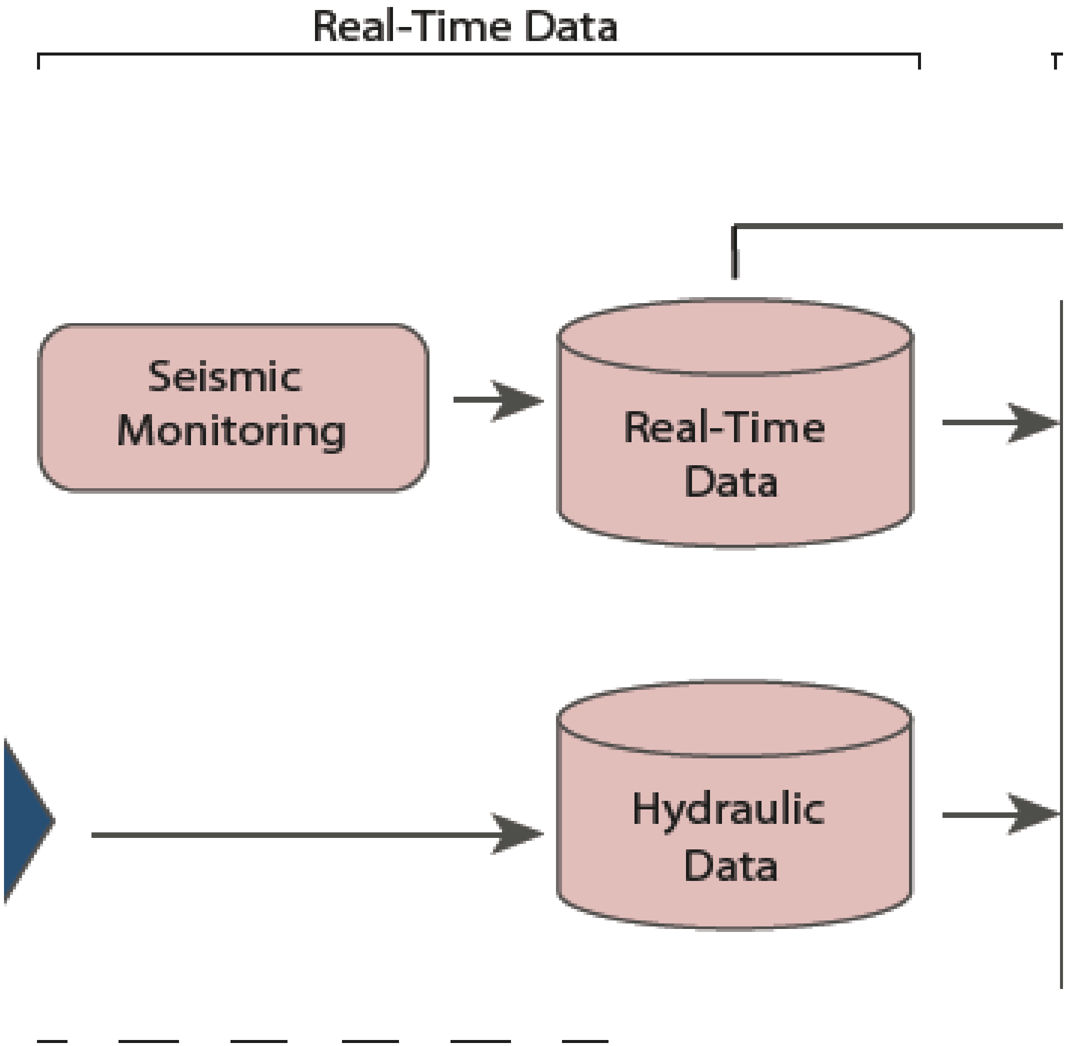
改善

Goal



Framework

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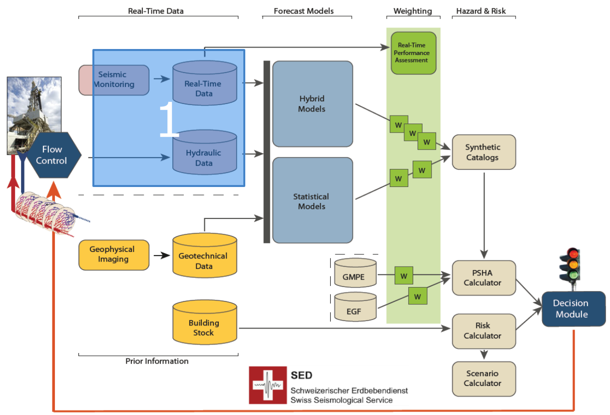
Seismic Monitoring
Real-Time Data
Hydraulic Data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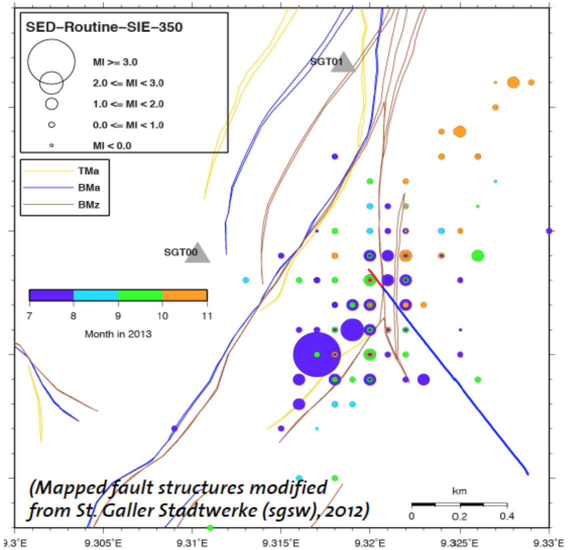
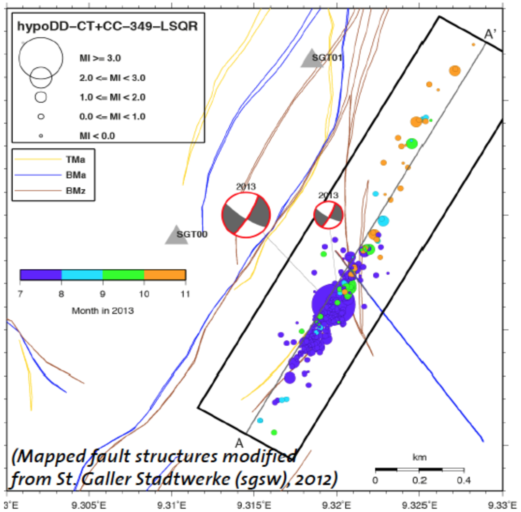
Scenario Calculator

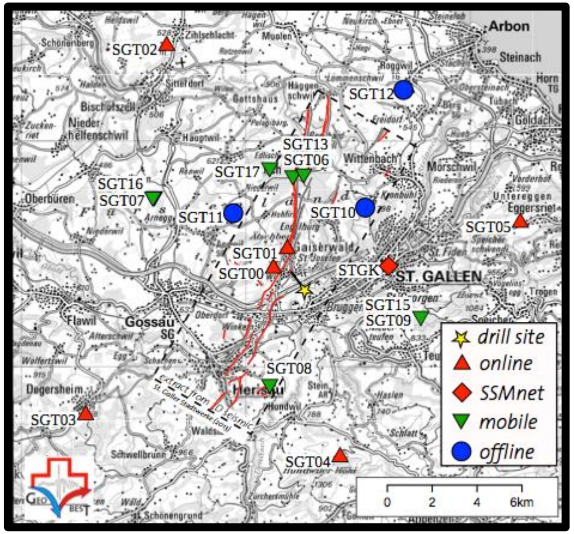
Accurate and near-real time Earthquake (re)location is key for process understanding

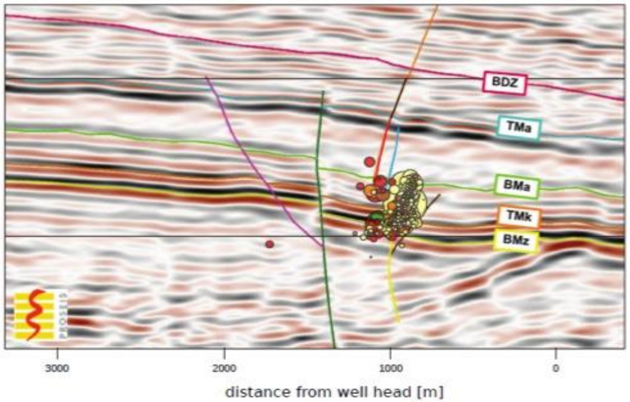


SED Routine Locations:
- Manual Picks (P+S)
- Grid-based location (NonLinLoc)
- 3D P-wave velocity model (+ const. Vp/Vs)

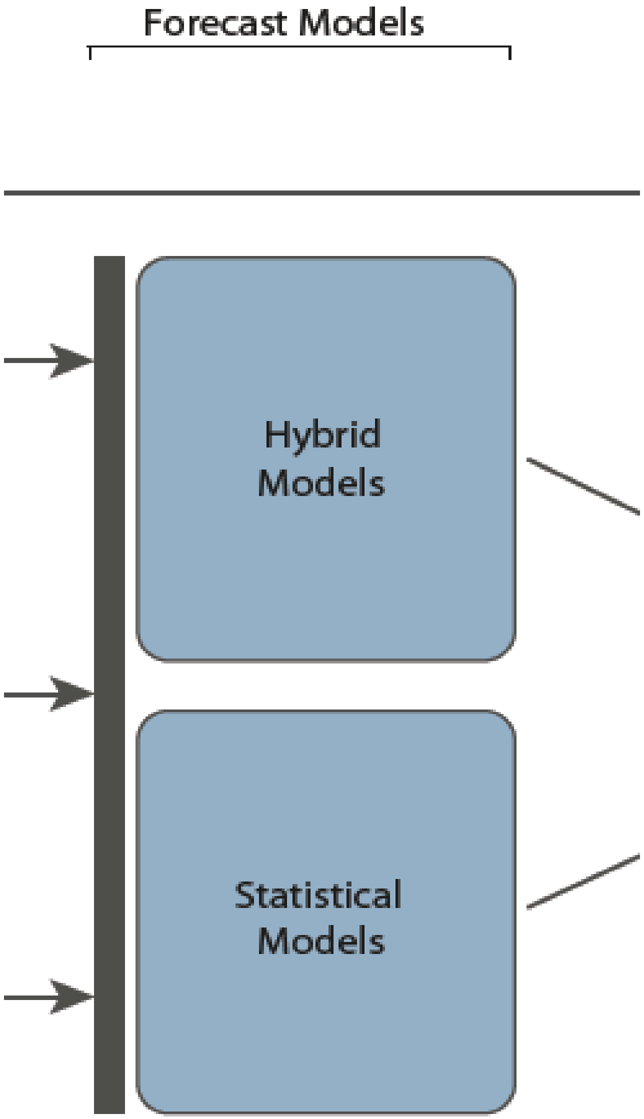


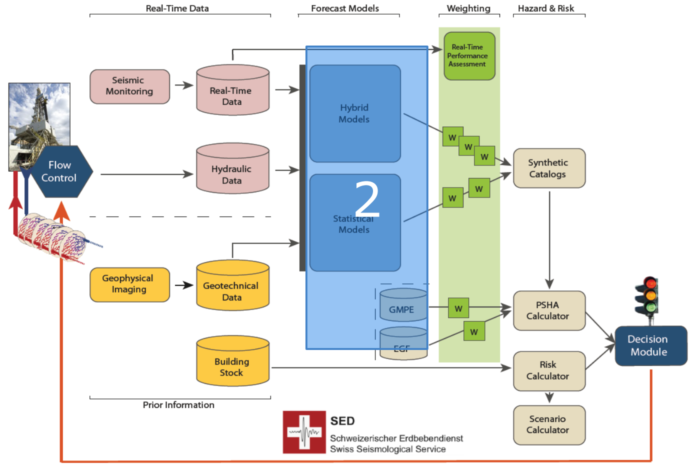
Double-Difference Relocations:
- Differential times from manual picks (P+S)
- Differential times from cross-correlation (P+S)
- hypoDD
- Initial locations from VELEST locations
- Minimum 1D P+S model





→ Diehl et al., 2014


Forecast Models
Hybrid Models
Statistical Models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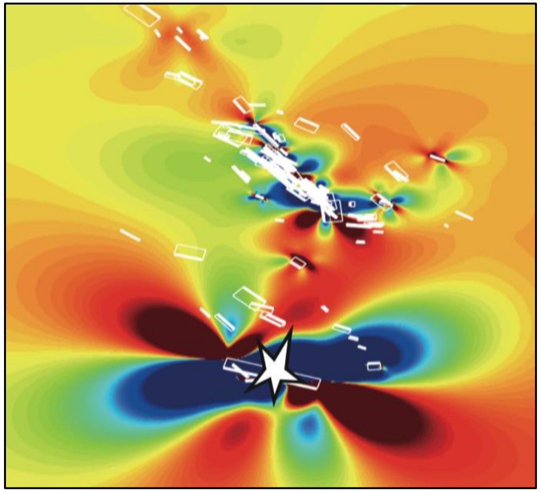
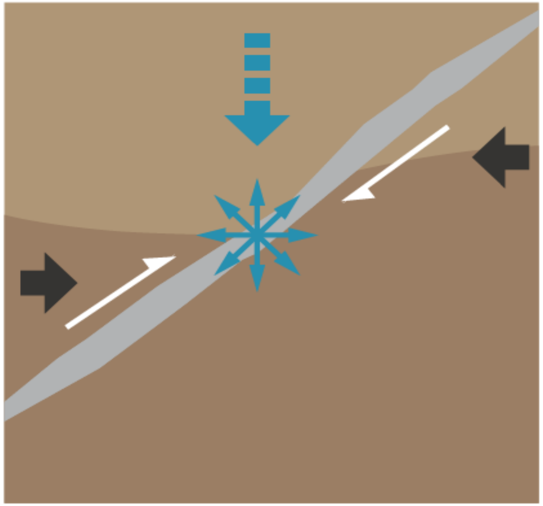
Challenges in Modelling

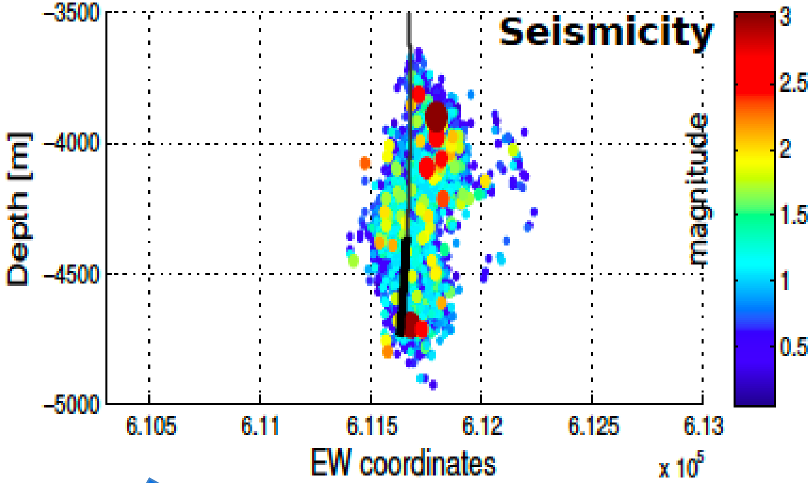
- Identify relevant physical processes for geo-mechanical coupling.
- Integration of uncertainties in modeling.
- Real-time application: Time constraints, robustness, automation.
- Calibration and model update, on the fly.
- Validation of models outside of data constrained areas.
- Joint optimization of induced seismicity for reservoir creation and thermal revenues.
- Use of pre-stimulation, test stimulation data to calibrate models.
- Use of well-log information for forecasting.
- Etc.

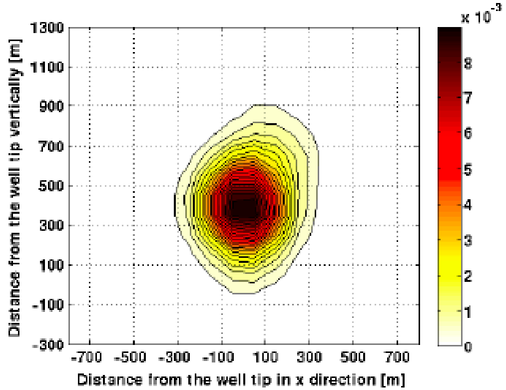


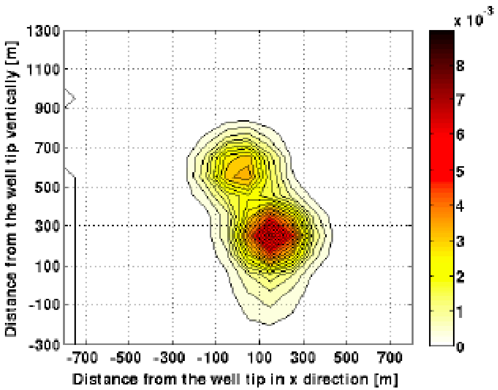


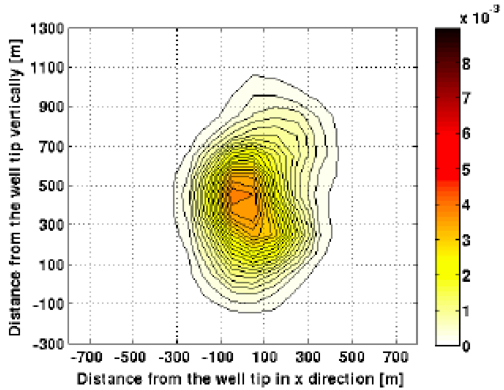
Simple models (statistical): Ezster and Jeremy

- Best for short-term forecasts?







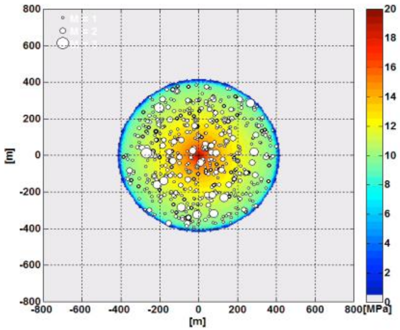


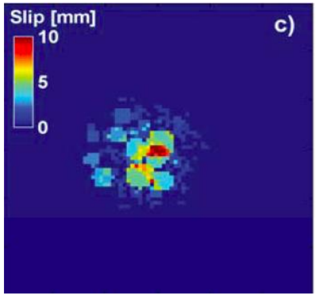
Hybrid Models

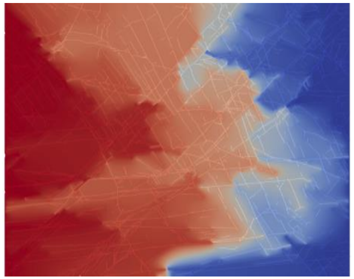


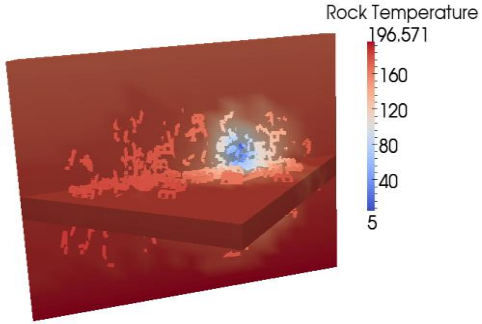

Model Complexity

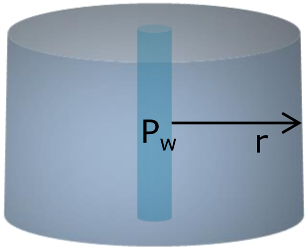
2012 | 2013a | 2013b | 2014a | ...





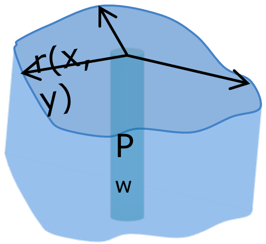






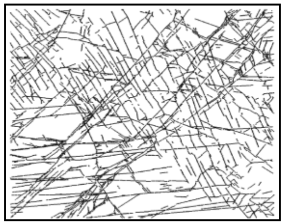
COMSOL

Gischig & Wiemer, 2013
Goertz-Allmann & Wiemer, 2013



SUTRA

Gischig et al, 2014



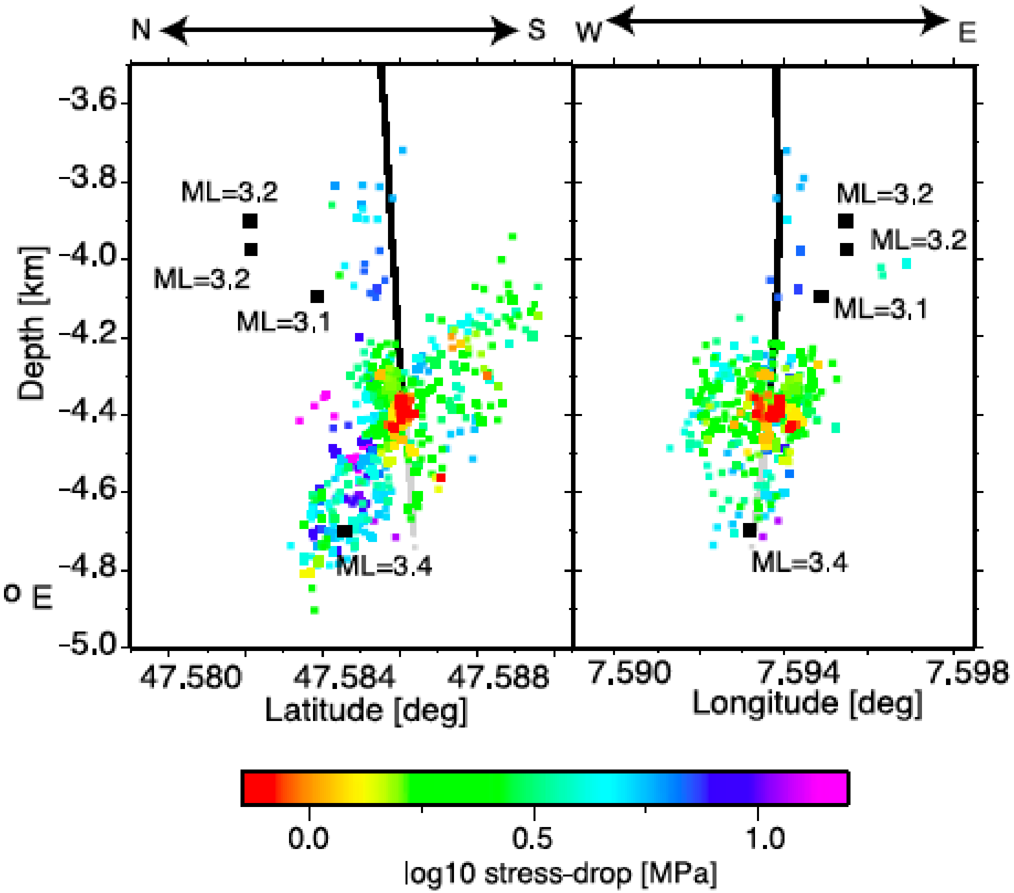
HFR-Sim

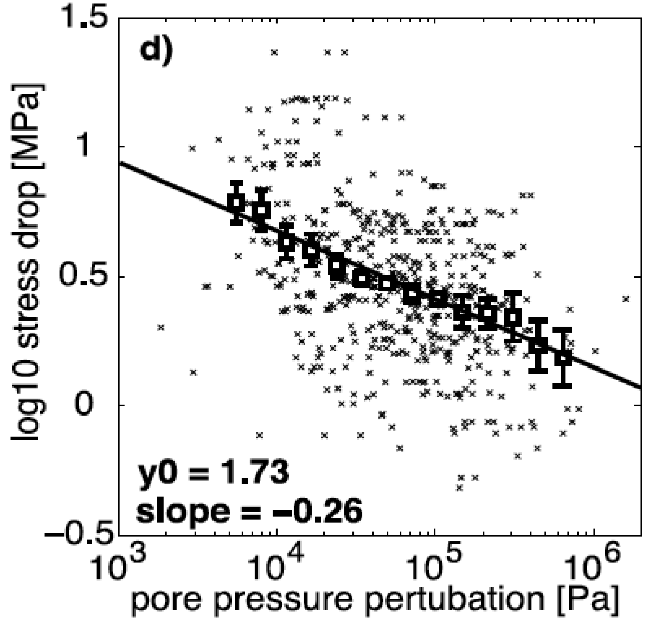
Karvounis et al., 2013

HFR-Sim+

Karvounis and Wiemer, 2014

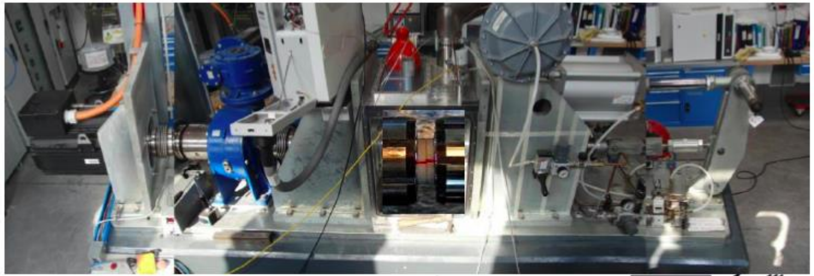
Better models through using observations and analysis.

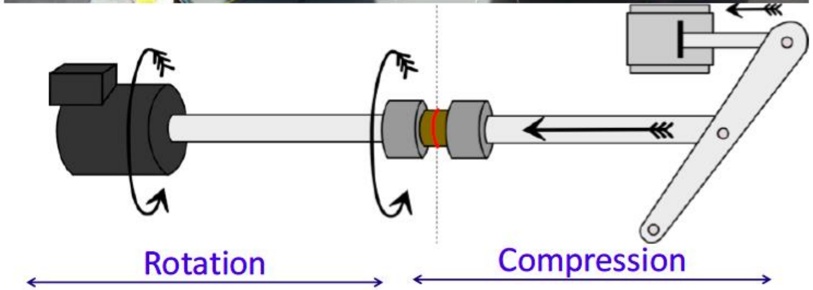


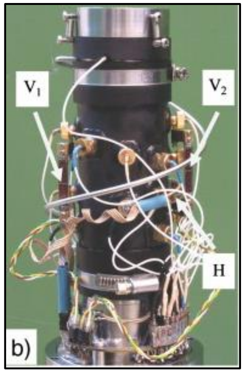


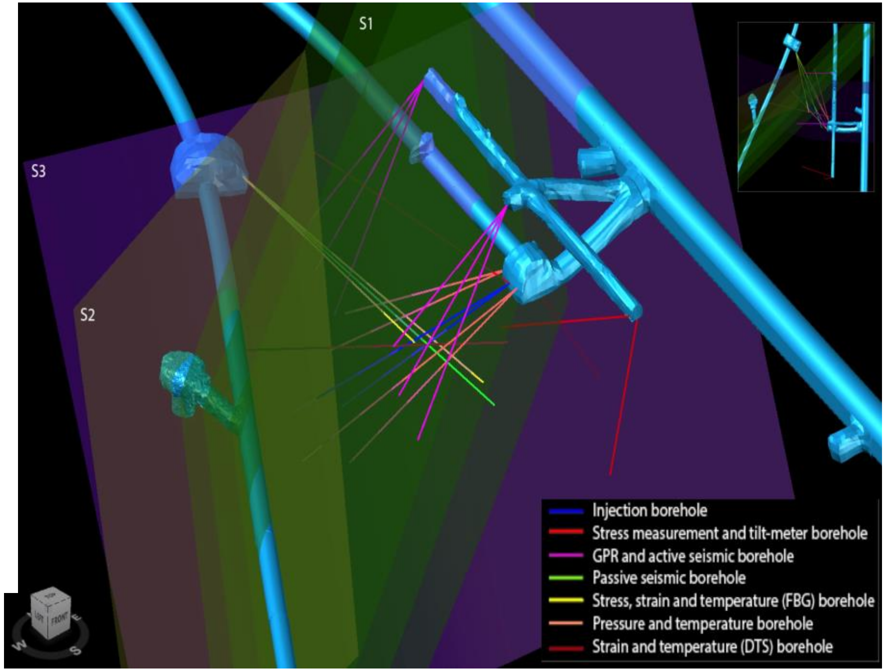
→ Goertz-Allmann et al, 2011 → Goertz-Allmann et al, 2013

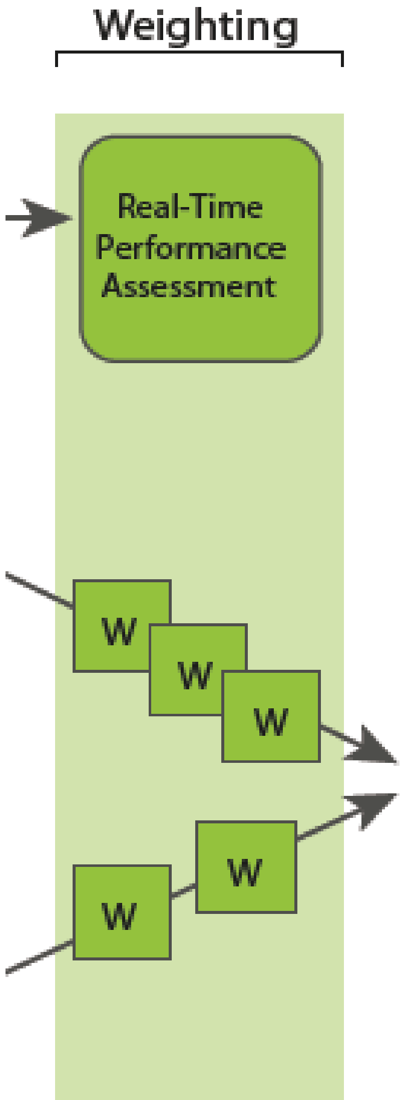
Model development and calibration: Rock Labs und UG-Labs










Weighting
Real-Time Performance Assessment
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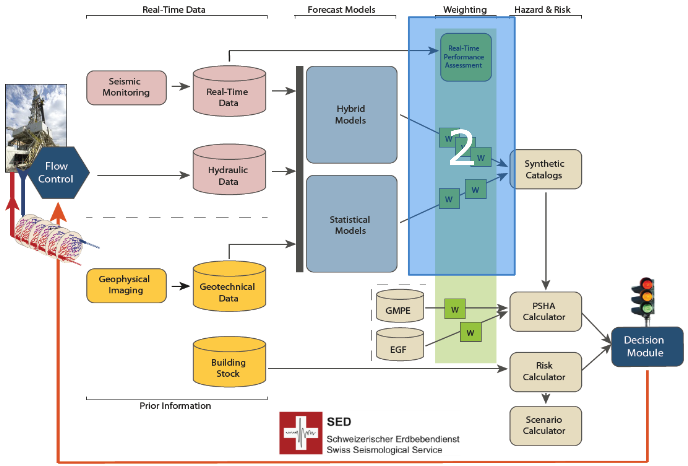
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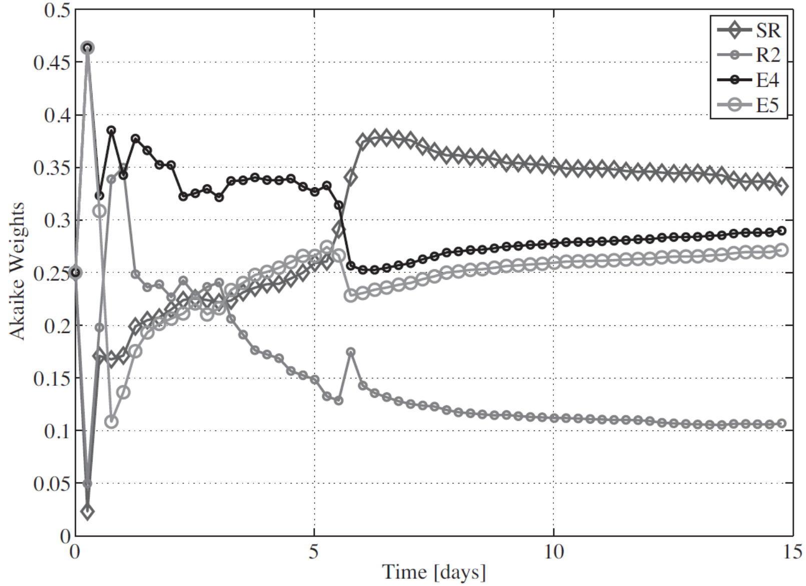
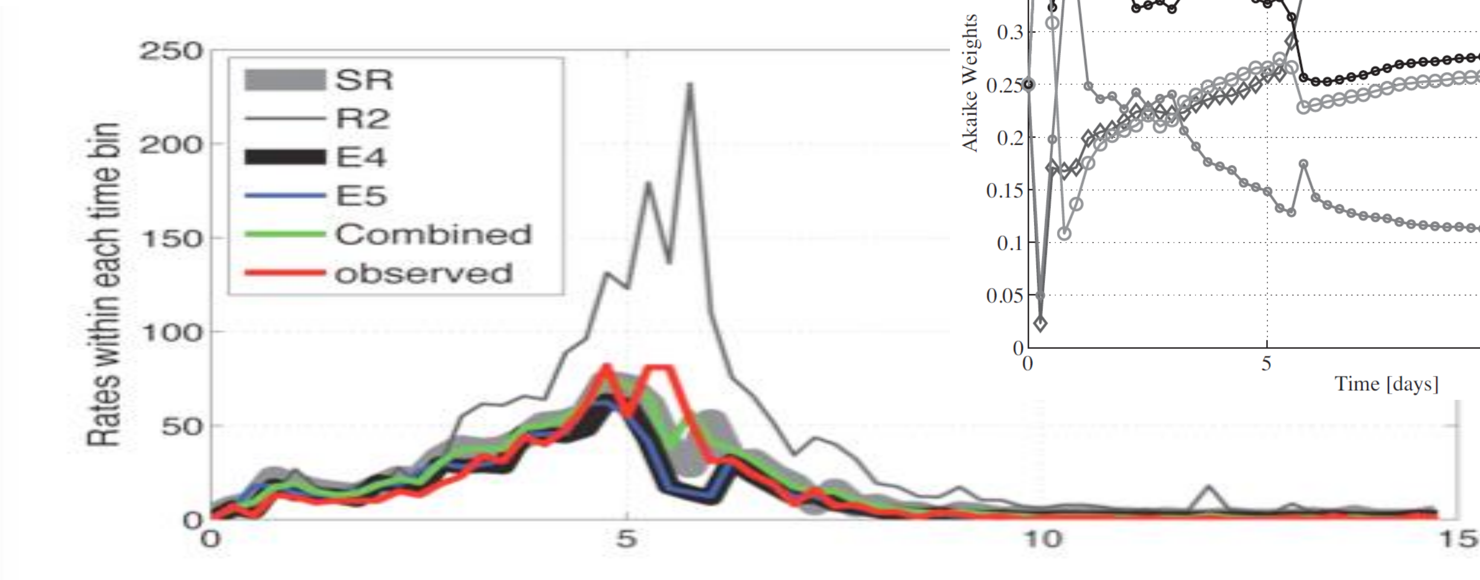
Challenges: Model Validation and Ensemble Modeling

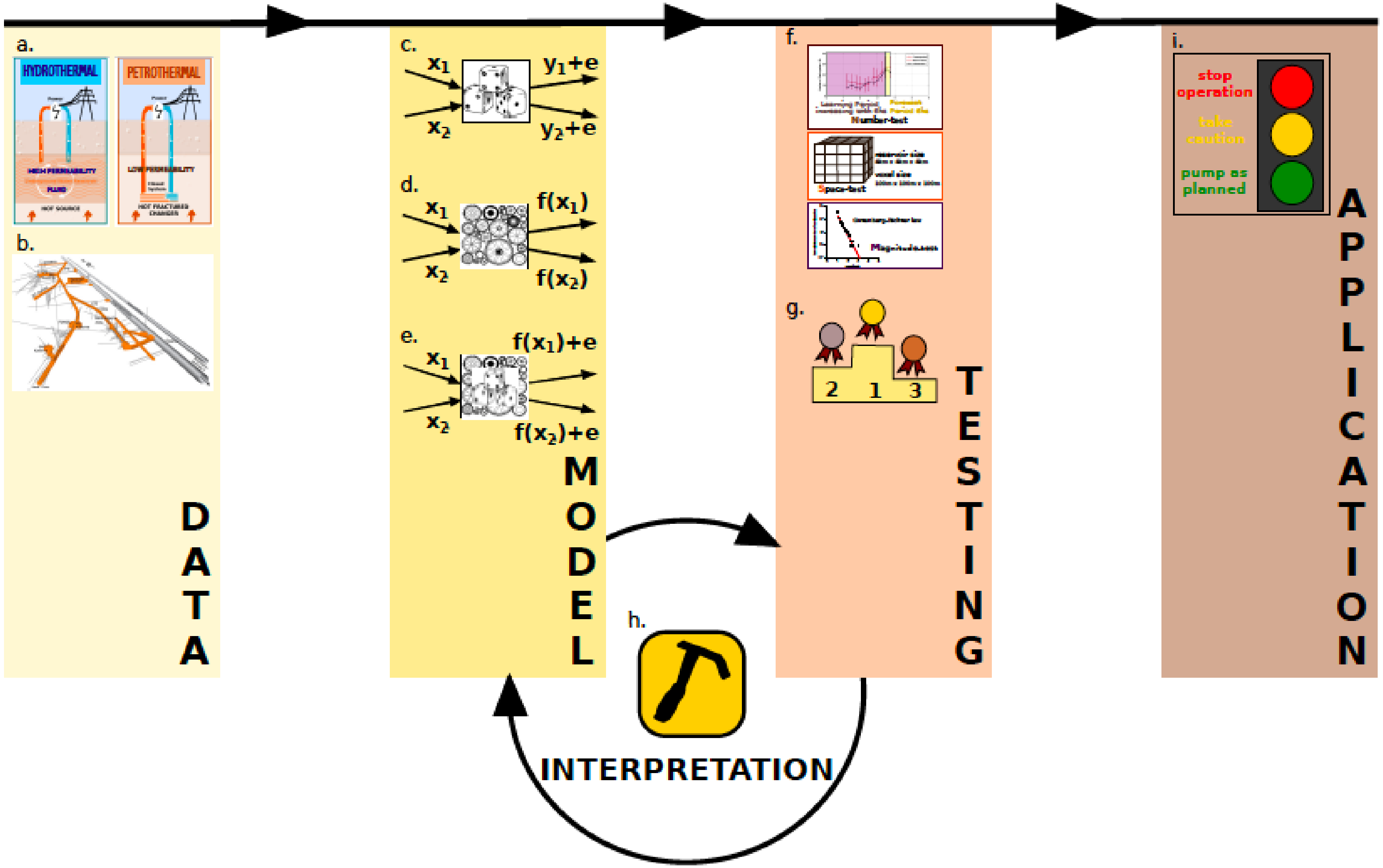
- Model Performance assessment in (pseudo-) real time.
- Maximizing performance and robustness through ensemble Models
- Validation of models
- Systematic model improvements
- Measuring progress, identifying gaps.

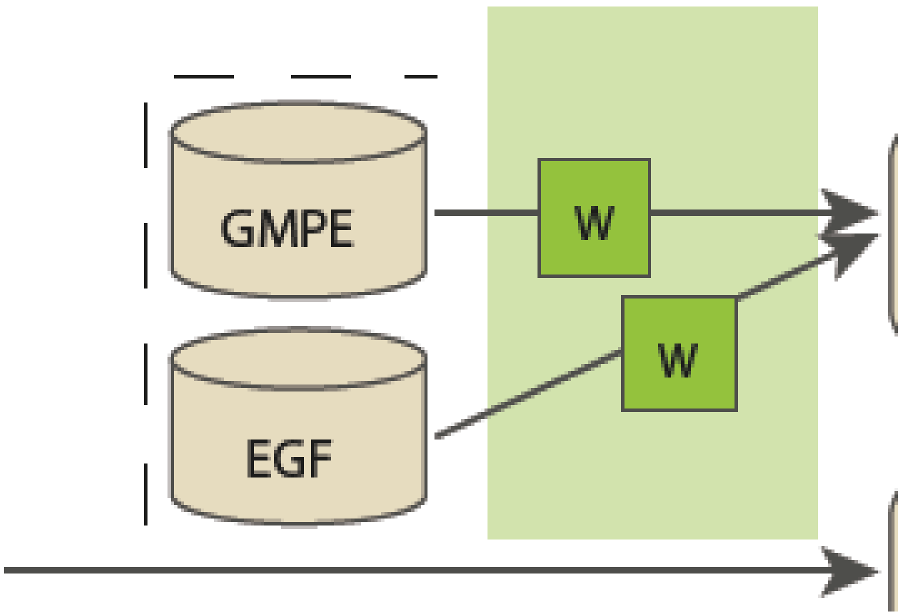




Mena et al., 2012

INDUCED SEISMICITY MODELING TEST BENCH




GMPE
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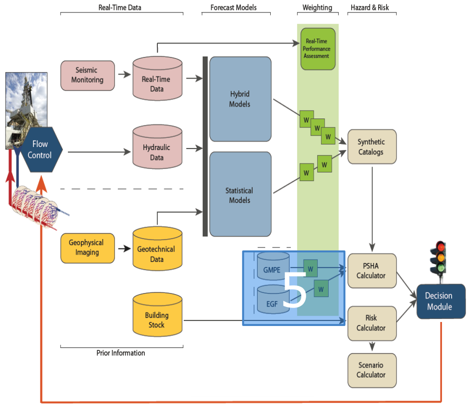
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PSHA Calculator
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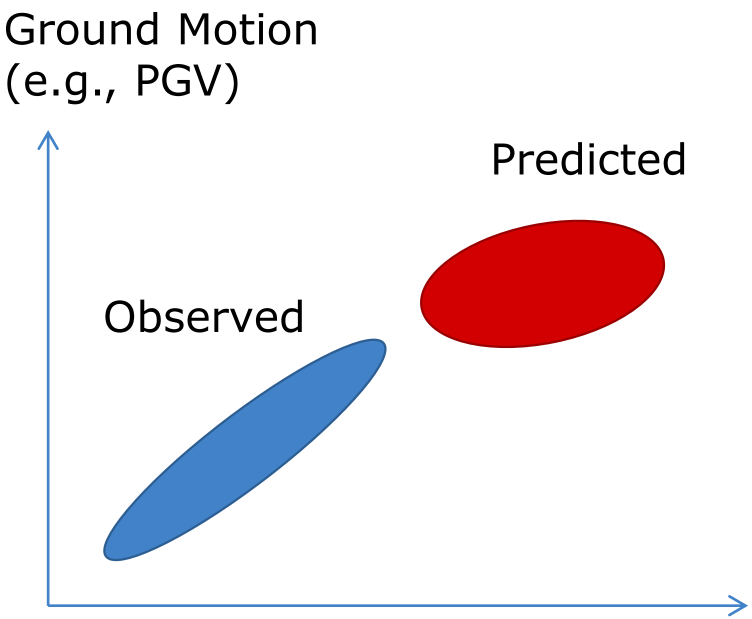
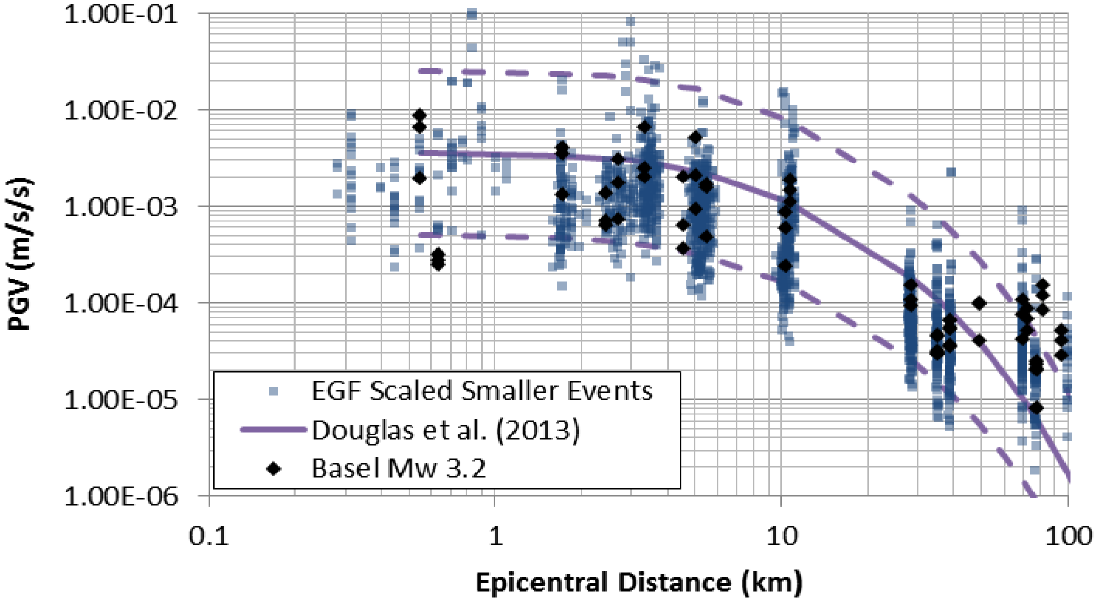
Prior Information

Challenges in Ground Motions Prediction

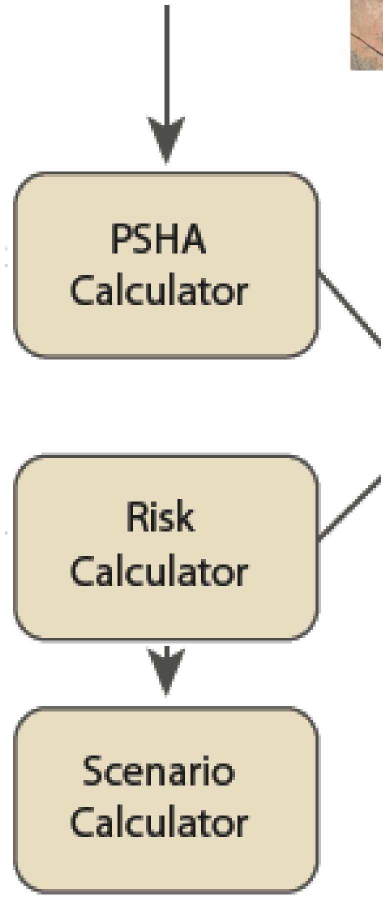
- Suitable GMPE's for induced seismicity plays
- Use of prior information
- Real-time updating.
- Reduction of uncertainties
- Coupling to building responses





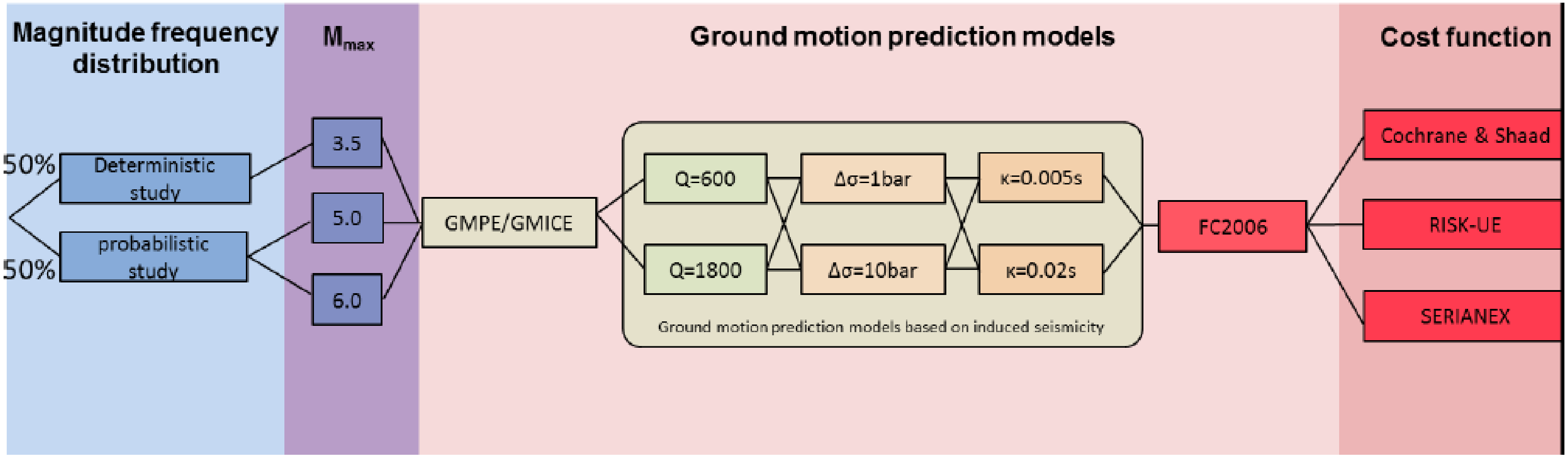
Many Challenges in Hazard/Risk Assessment

- Uncertainty treatment
- Real-time updating strategies and computational constraints
- Metric for decision making
- Validation of hazard results
- Communication of probabilistic results
- Low probability/high consequence events (tails)
- Coupling to site responses, reference rock.
- Suitable exposure models.
- Suitable vulnerability models for cosmetic damage and for CH conditions.



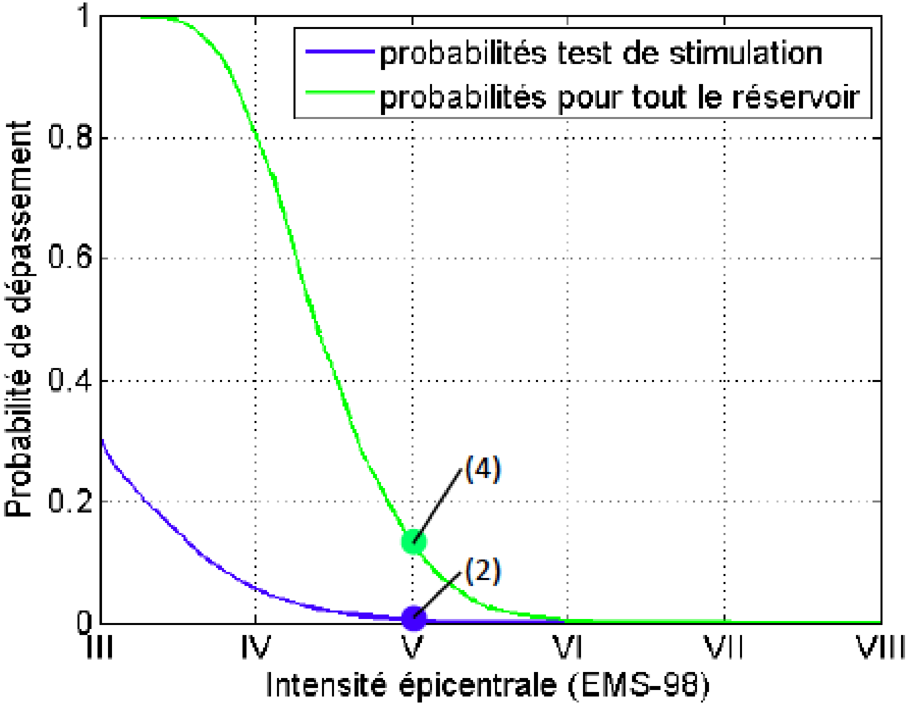
OPENQUAKE

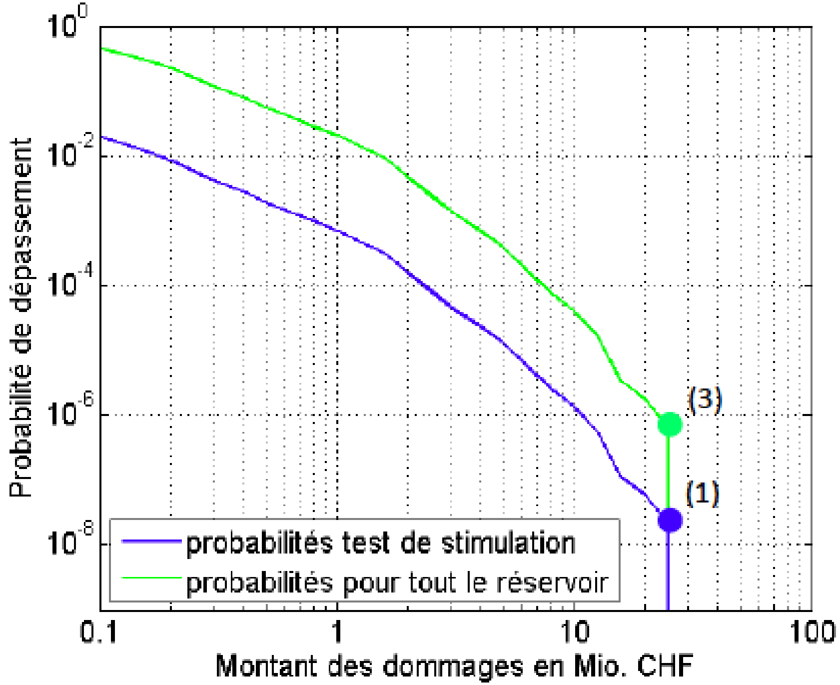
Logis tree tocapture uncertainty and expert elicitation



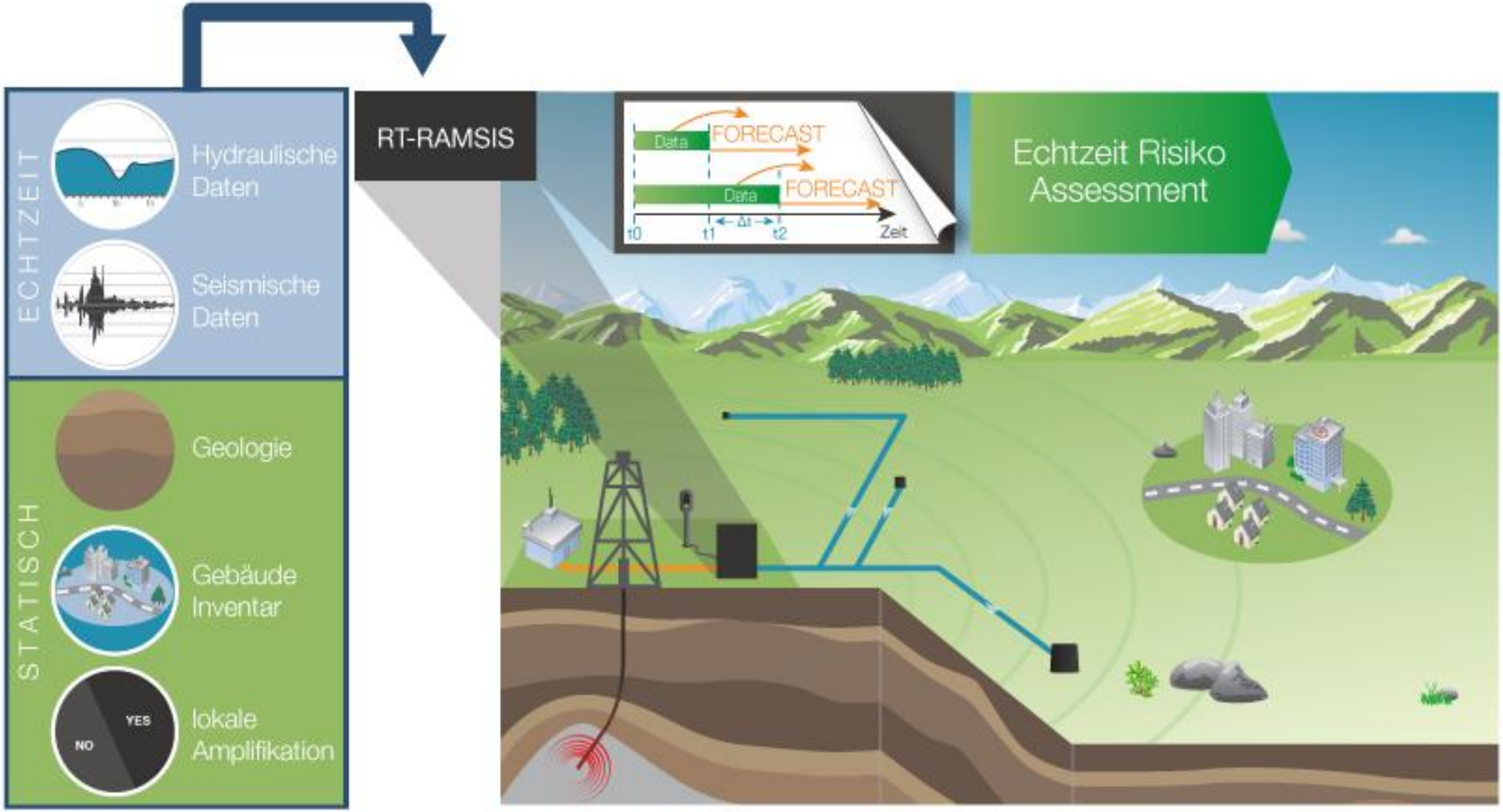
Logic tree approach, Mignan, 2015

Typical outcome: Hazard and Risk curves

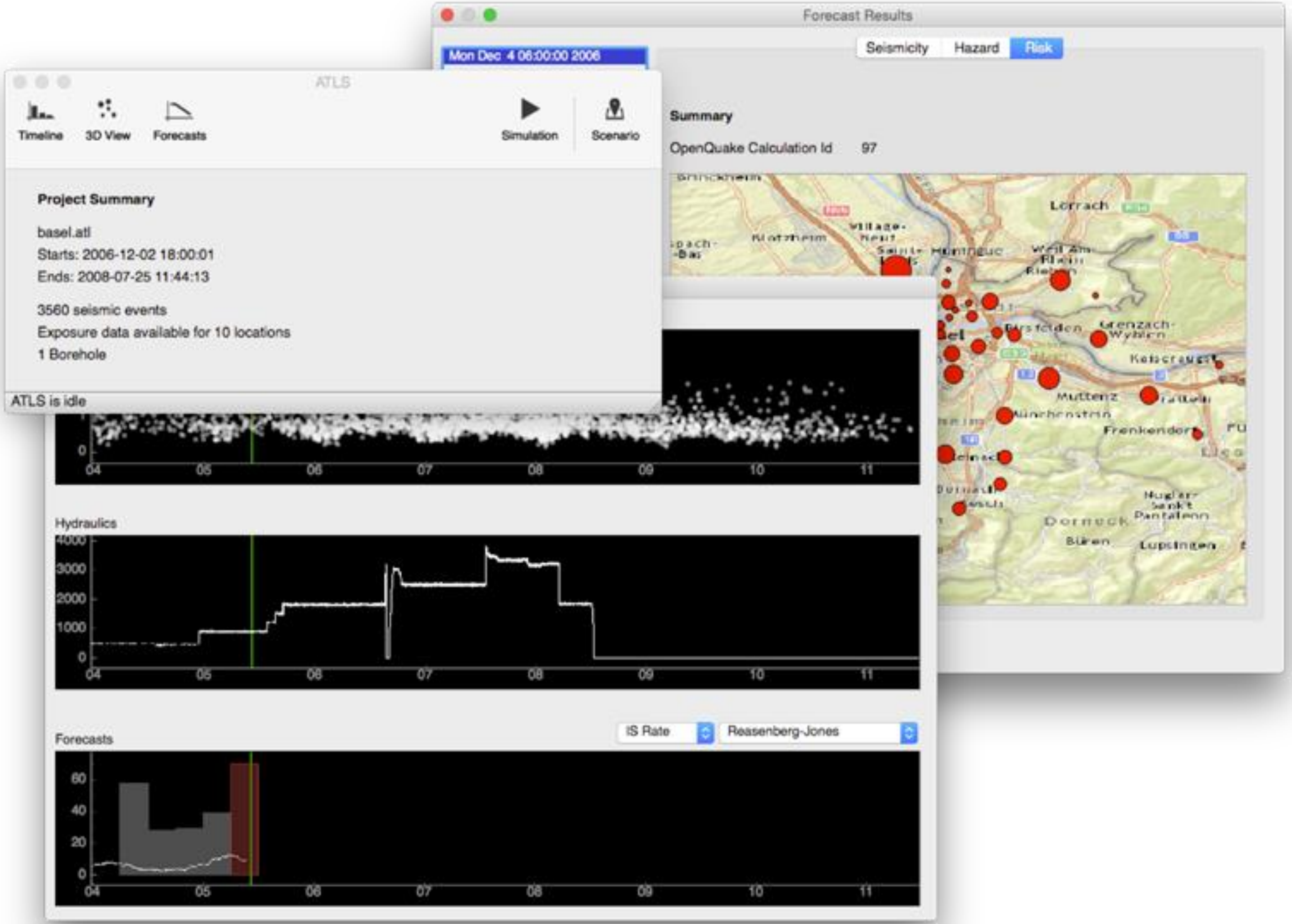




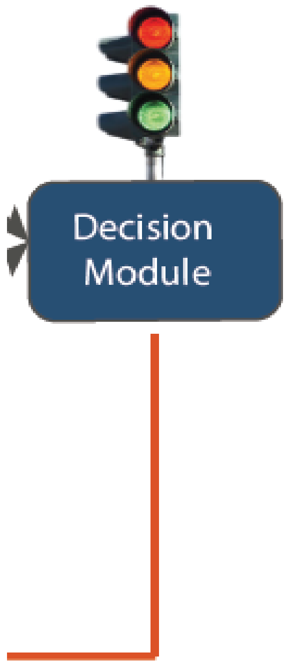
Real-time Implementation Framework

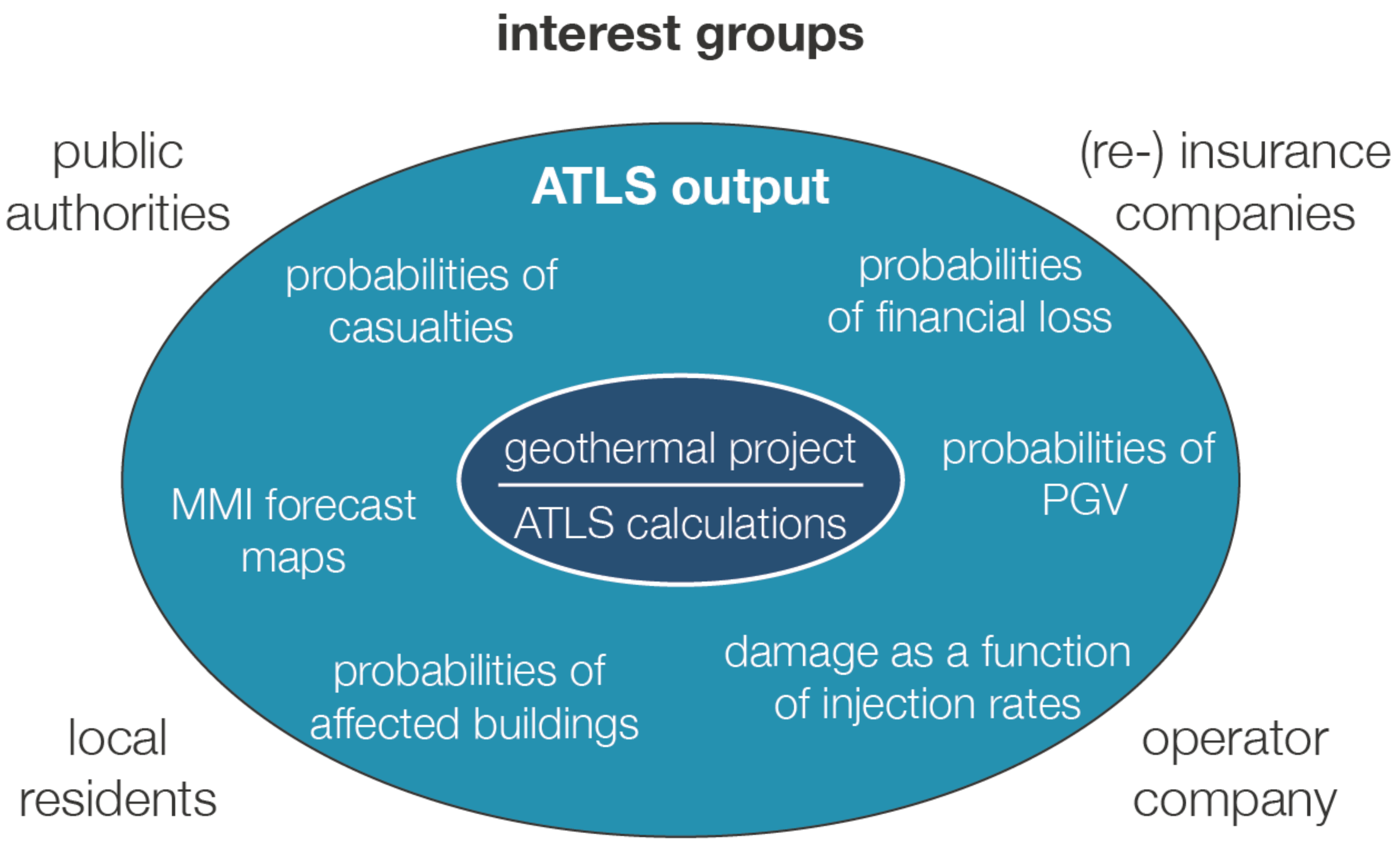


Software: Phyton based, Qt Gui

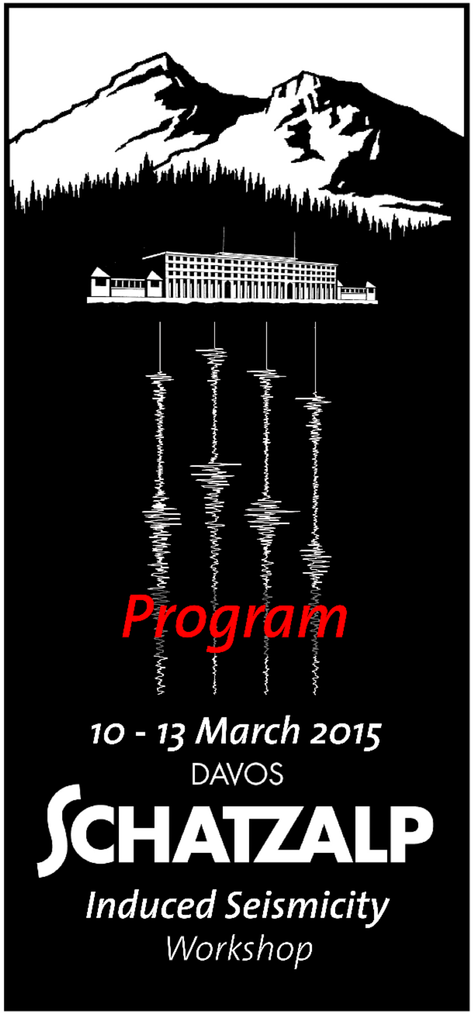


How much risk? Somebody elses job ...





Thank you


Program
10 - 13 March 2015
DAVOS
SCHATZALP
Induced Seismicity
Workshop