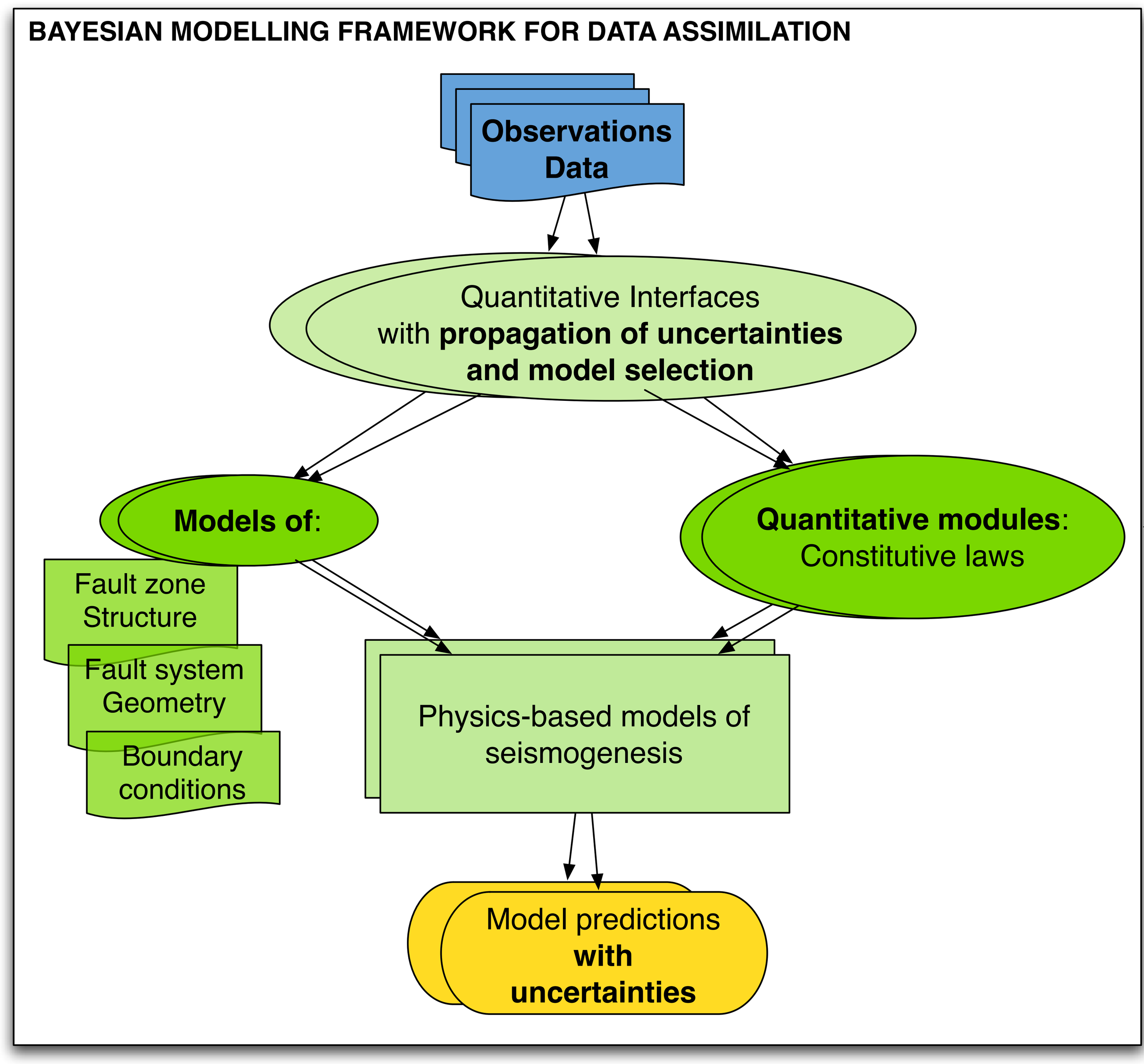
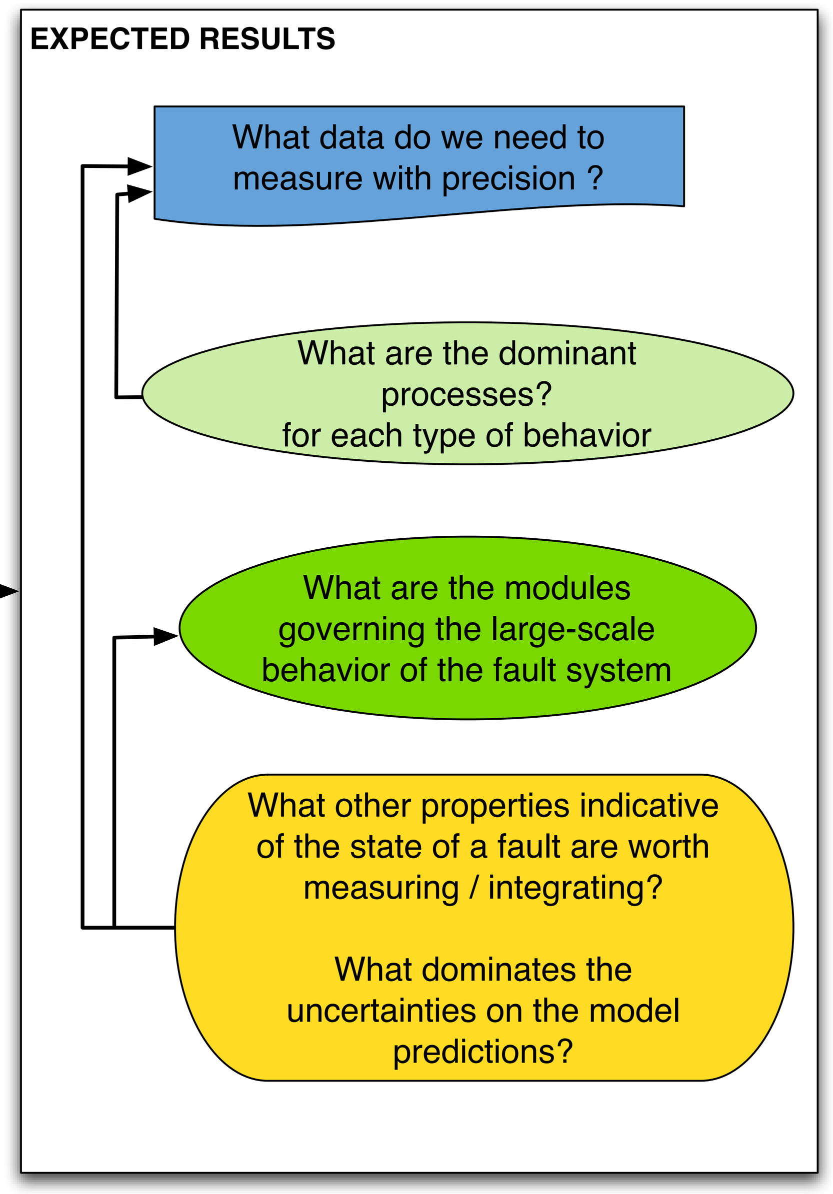
Probabilistic modeling of earthquake occurrence: first examples of data integration within a Bayesian framework.

Delphine D. Fitzenz (EOST Strasbourg, France), Steve H. Hickman (USGS Menlo Park, CA), Andre Jalobeanu (LSIIT Strasbourg, France), Chris Spiers (HPT Lab Utrecht University, The Netherlands)

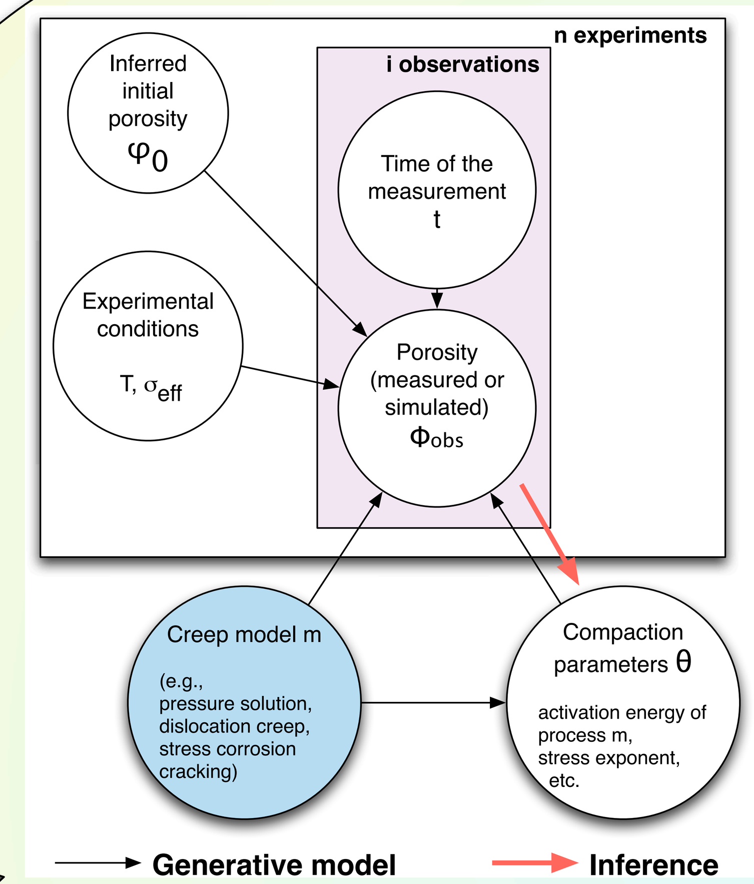
Building upon our recent experience in the analysis and integration of isotropic creep experiments into numerical models of interseismic fault processes, we study creep under deviatoric stresses, and then perform time-forward simulations of interseismic fault behaviour. Given a shear loading rate and a rupture criterion, our model provides probability density functions for the time to failure and fault zone physical properties at the onset of failure. The first step in the forward modeling is the point-source model, in which we evaluate the robustness of the modeling results in response to uncertainties in the input parameters and alternative models for the creep law.
Our modeling framework addresses two big issues in seismic hazard assessment: the evaluation of the aleatory uncertainties and the reduction of the epistemic uncertainties (via model selection).
Current efforts also include extending the approach to study the relative influence of more complex simulations (with 2D to 3D faults), to provide a modular probabilistic "synthetic earthquake simulator". This will allow us to test the impact of different sources of heterogeneity in fault zone physical properties and loading conditions on the statistics of time to failure.





Data analysis tool

Graphical model : a guide for the inference



The five steps of the inference

A: Choose the parametrization making the problem as linear as possible

B: When a factorization appears in the new Bayesian network, adopt a hierarchical inference scheme

C: Calculate the joint probability density function according to the graph structure (the joint pdf is proportional to the posterior pdf).

D: Eliminate the nuisance parameters (marginalization step)

E: Revert from the new parametrization to the original parameters θ_i *

Observations

Experimental or simulated porosity time series

Choice of the model m *

When the grain-size effects can be neglected, and we make no assumption on the mechanisms, we can choose a creep law of the type:

$$\frac{\partial \varphi}{\partial t} = \theta_0 \times \sigma_{\mathrm{eff}}^{\theta_1} \times \exp(-\theta_2/(RT)) \times \exp(\theta_3 \varphi)$$

Stress exponent (θ_1); Apparent activation energy (θ_2)

Prerequisite

- Integration of the creep law: we want to use the data, not a subproduct of it
- Reparametrization such that the problem is as linear as possible (work with Gaussians)

$$f(\varphi_0, t) = -\mu \log\left(t\, e^{-\lambda'/\mu} + e^{-\varphi_0/\mu}\right)$$

$$\Theta = F(\theta) = \{\log(-\theta_0)/\theta_3,\ \theta_1/\theta_3,\ \theta_2/\theta_3,\ 1/\theta_3\}$$

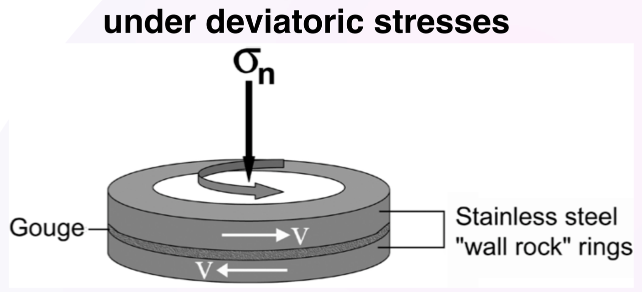
$$\lambda' = h(\Theta) = -\Theta_0 - k_1\Theta_1 + k_2\Theta_2 + \Theta_3 \log\Theta_3$$

$$\mu \equiv \Theta_3$$

Advantages of integrating
- no need to define explicitely the notion of state
- no need to compute strain or compaction rates
- we can **analyse all data simultaneously**

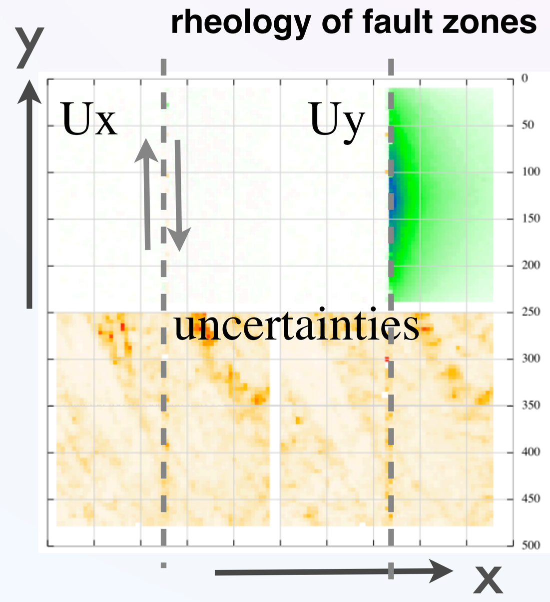
Future directions

Interseismic porosity and friction evolution under deviatoric stresses



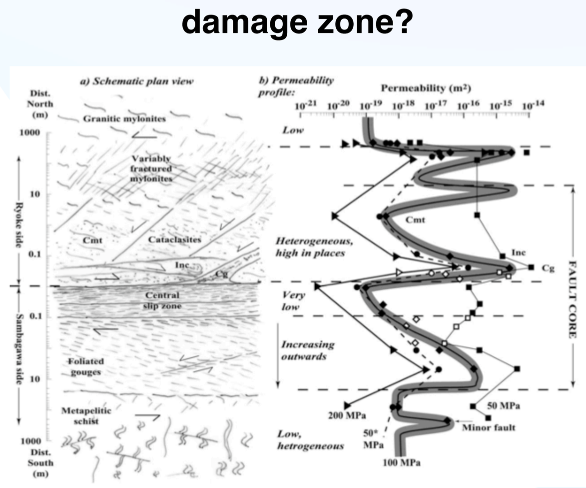
Rotary shear experiments at the HPT Lab, Utrecht

From surface deformation to the geometry and rheology of fault zones



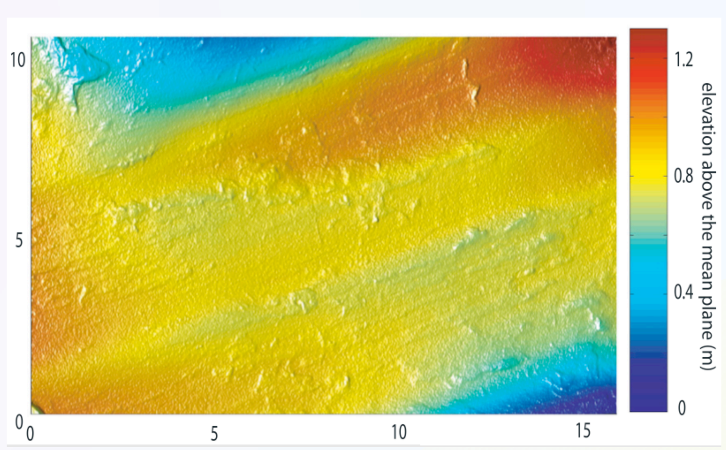
Deformation field along x and y axes inferred from a simulation

How well do we need to characterize the damage zone?



Wibberley and Shimamoto

Spatial heterogeneities: do we have to know the values at each point?



Roughness of a slip surface, Renard et al.

Spatial heterogeneities: how do they contribute to the a-periodicity of the seismicity?

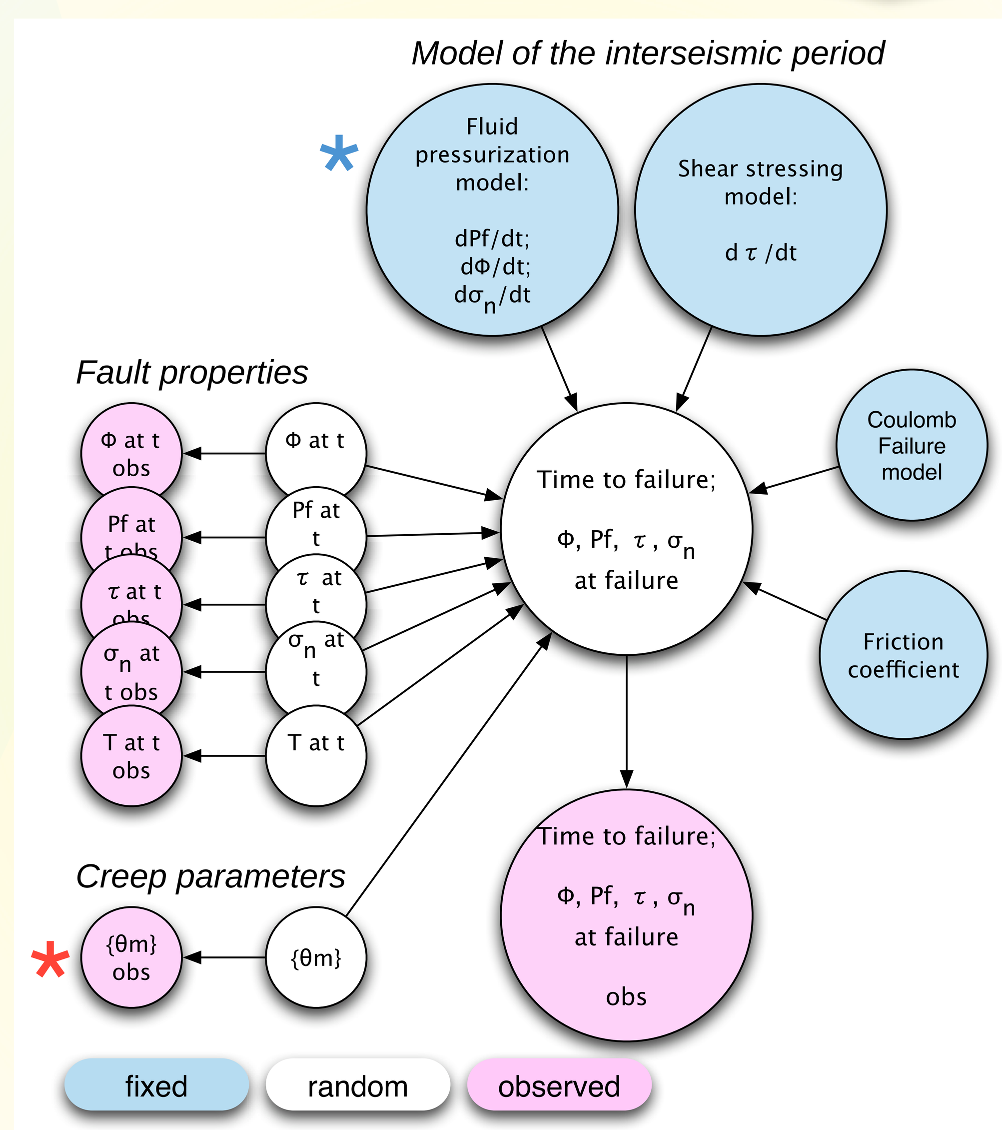
Slip characterization for given distributions of contacts (salt sample), Voisin et al.

Suggestions are welcome!!

Data integration tool

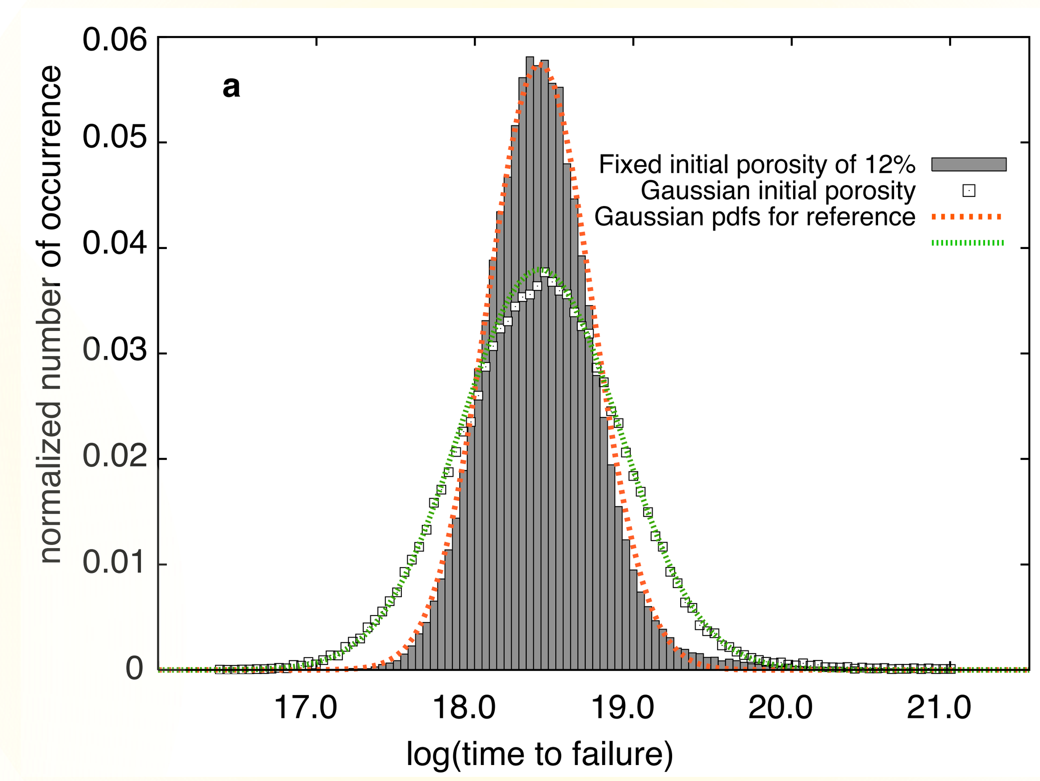
Generative model

Monte Carlo sampling through



- undrained
- 1 fault element
- t=0, 12% porosity
- z=3km
- {θj} from previous inversion
- (static) friction=0.6
- $d\tau/dt$=2.5 bar/year
- $d\sigma_n/dt$=0
- Coulomb failure: $\tau \geq$ friction$*(\sigma_n - P_f)$

Results in terms of time to failure



- Uncorrelated stress exponent and apparent activation energy lead to lognormal time to failure close to the optimum value.
- Random variations in post EQ porosity leads to increased variability in time to failure, and stable mean.

Ref.:Fitzenz et al., MaxEnt 2005
Fitzenz et al., JGR 2007 in press