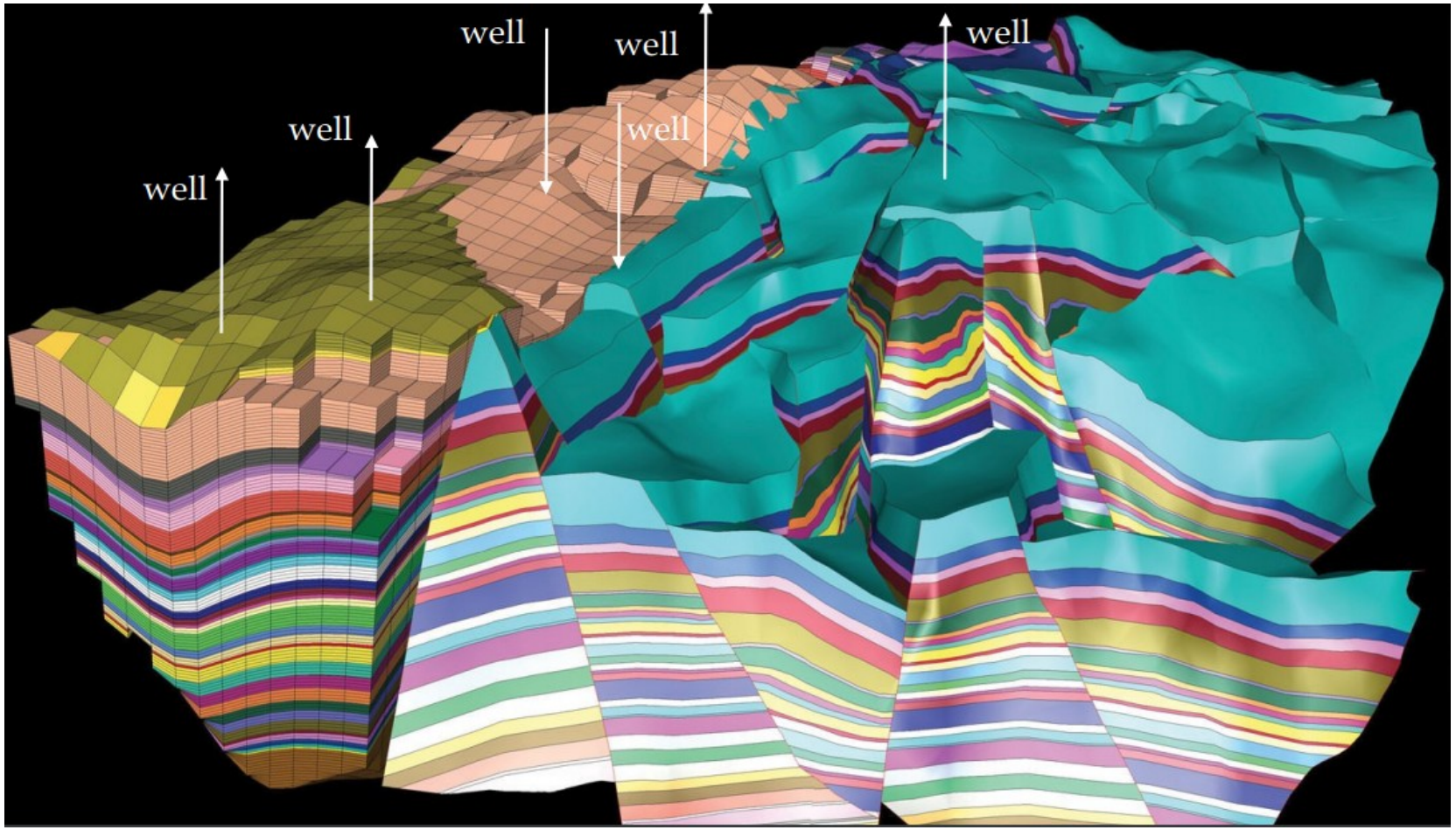
CWI

Transform-based Particle Filtering for Parameter Estimation in Reservoir Modeling

Sangeetika Ruchi

April 12th, 2019

Subsurface oil/gas reservoir



Subsurface flow

A simple 2D model for subsurface flow is a diffusion equation

$$-\nabla.(k(x)\nabla P(x))=g(x), \qquad x\in D\subseteq R^2$$

- k, the hydraulic conductivity of the subsurface,
- g, source/sink terms,
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Problem of Parameter estimation: Given limited observations of the pressure P(x), the aim is to estimate the unknown permeability k(x).

What is Data Assimilation?

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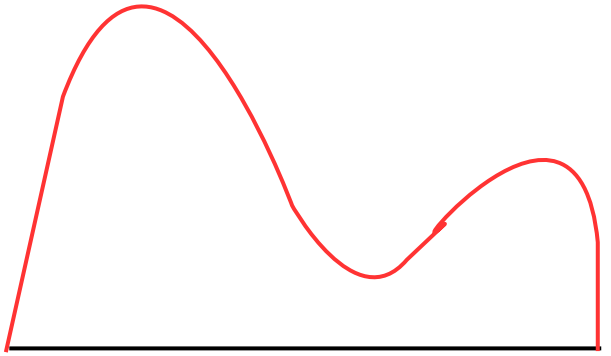

Mathematical model (Prior)

$$X = \mathrm{M}(x)$$

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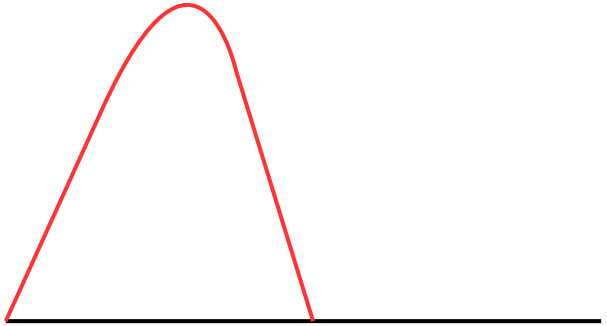
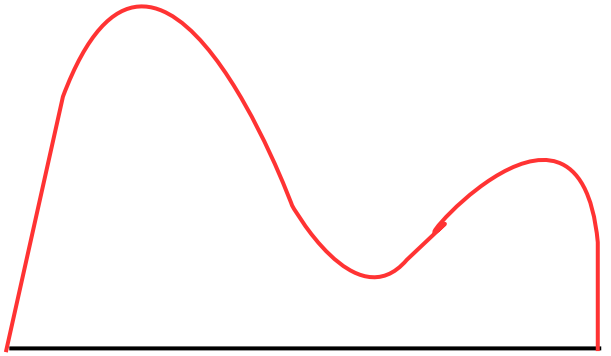


Observations

$$y = h(X) + \varepsilon$$



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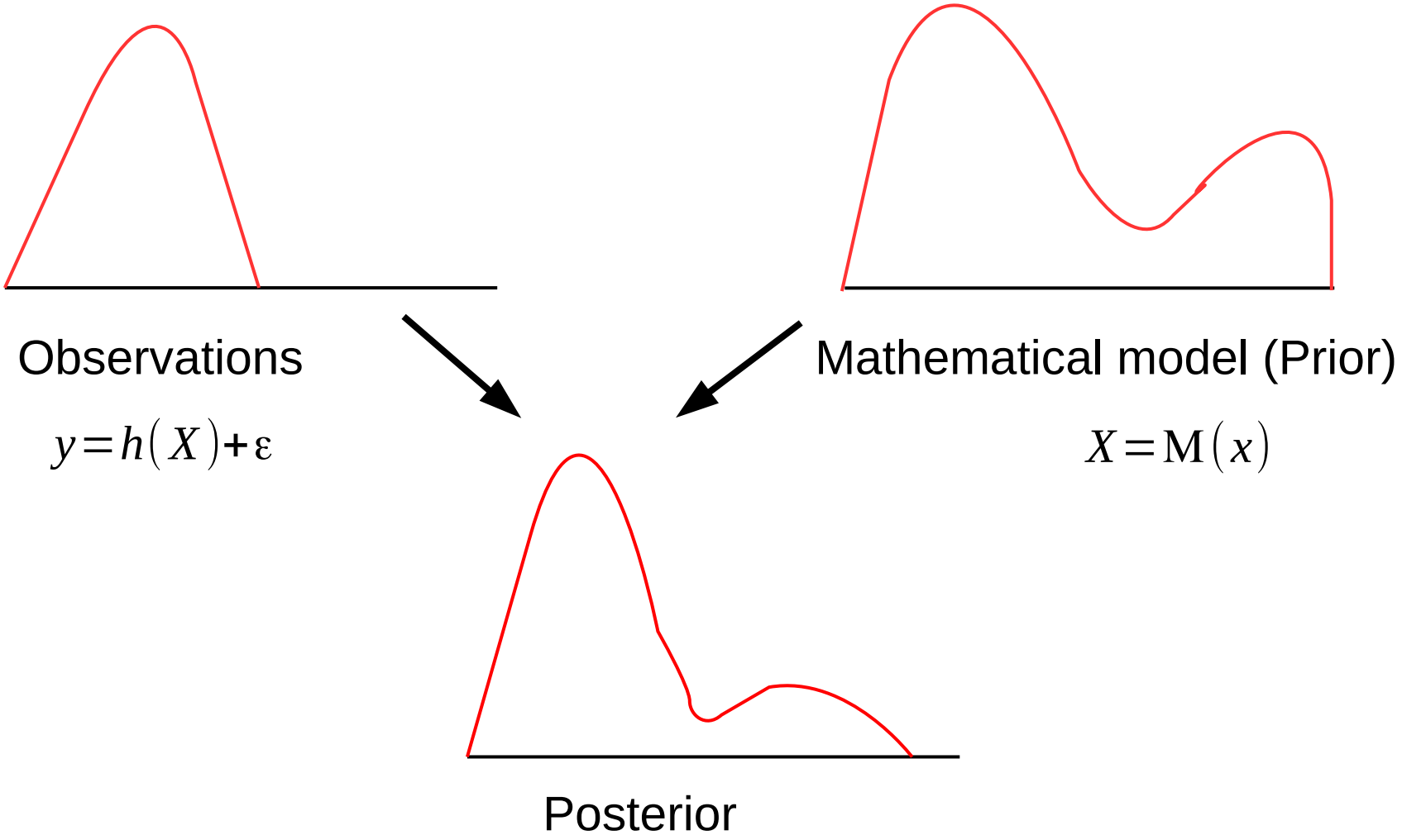

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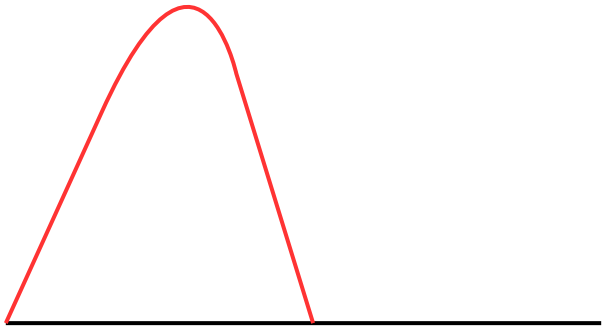

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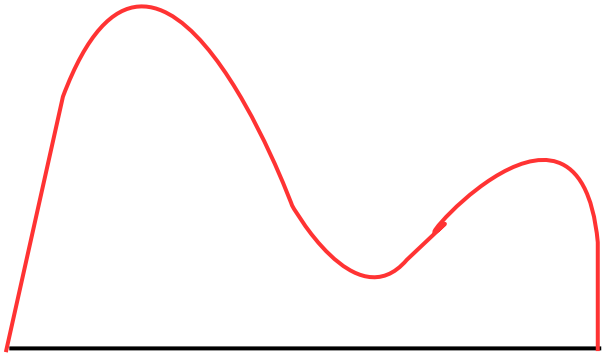

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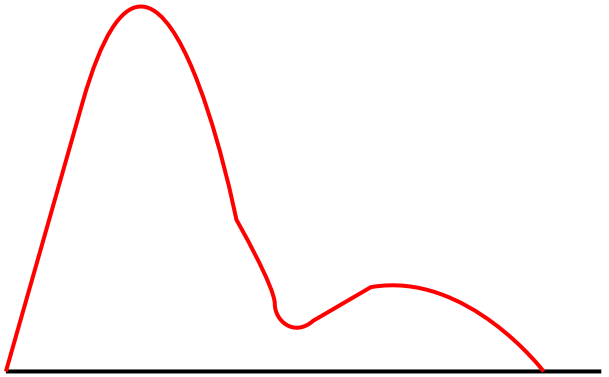

Posterior

Bayes' Theorem

$$p(x|y) = \frac{p(y|x)\,p(x)}{p(y)}$$

Data Assimilation

Markov Chain Monte Carlo (MCMC)

- Requires very large number of realizations of a model (samples /ensemble members), which is computationally unaffordable for high-dimensional systems.

Brooks, S., Gelman, A., Jones, G. L. and Meng, X.-L., eds. (2011). Handbook of Markov Chain Monte Carlo. CRC Press, Boca Raton, FL.

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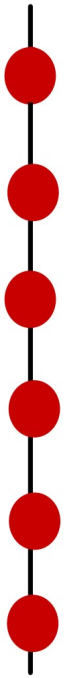
Ensemble Kalman Filter (EnKF)

- EnKF became a standard data assimilation method in inverse modeling, though it assumes Gaussian probabilities which might not be always the case.

Evensen, G. (2006). Data Assimilation: The Ensemble Kalman Filter. Springer

Particle Filters



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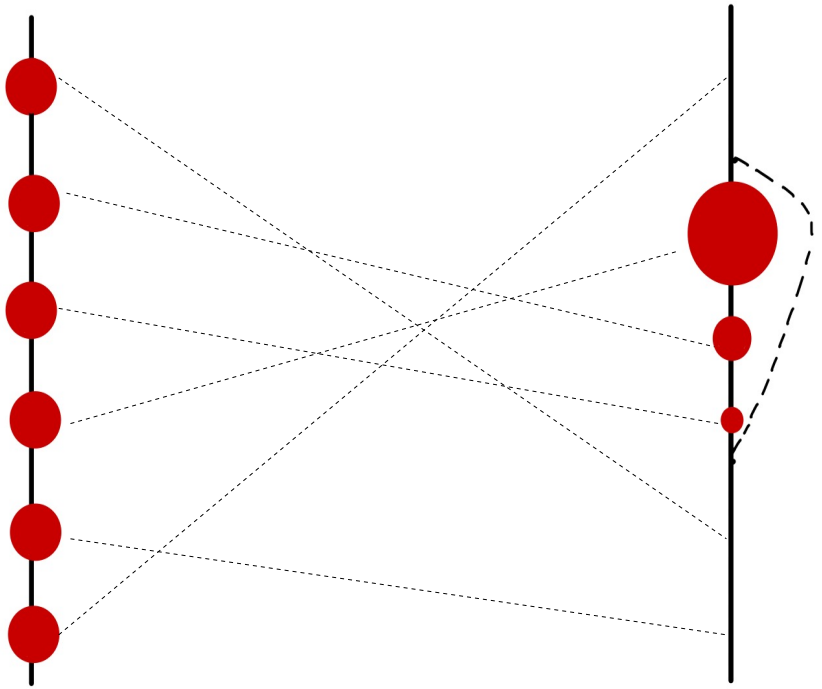

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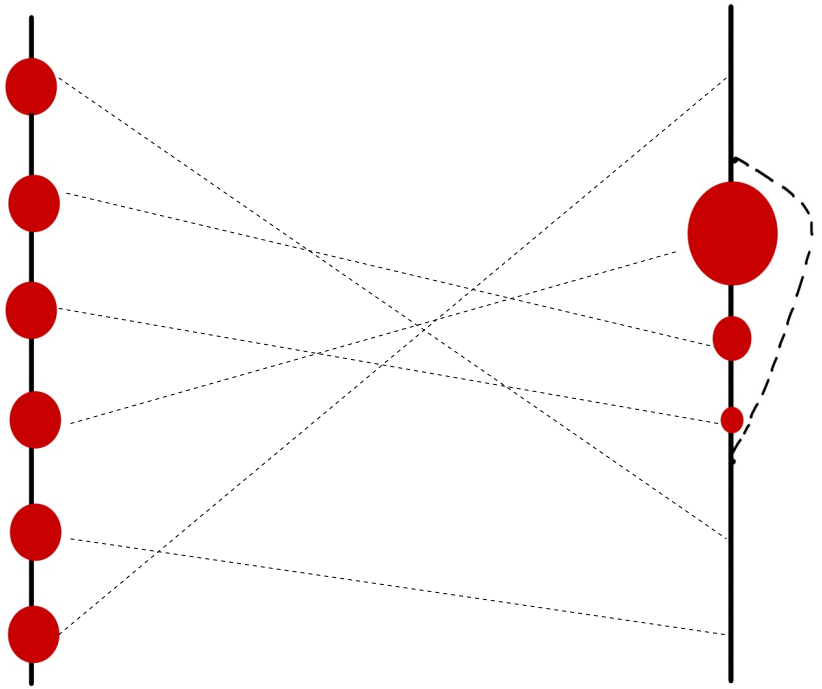

$$p(x|y)=\sum_{i=1}^{M} w_i \delta(x-x_i)$$

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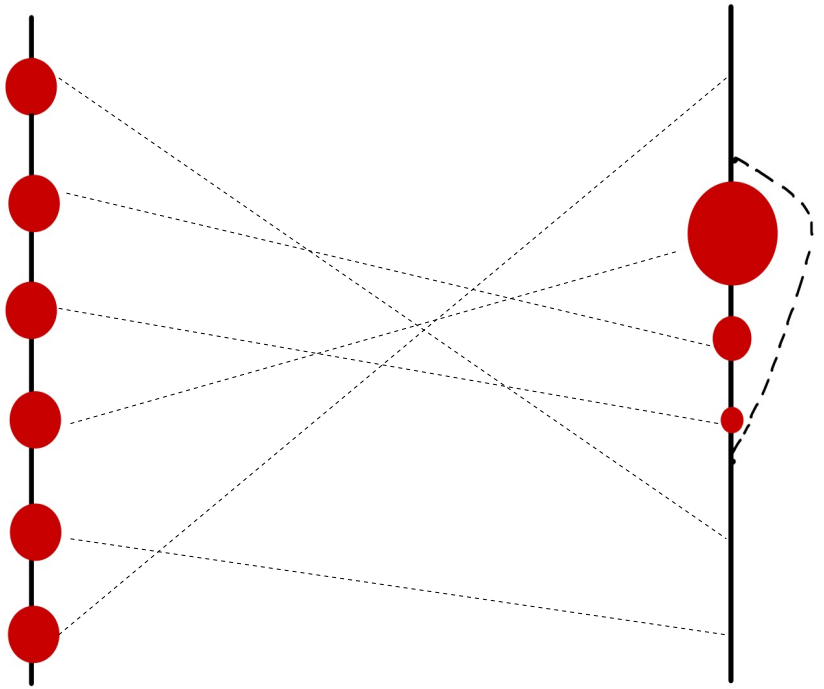
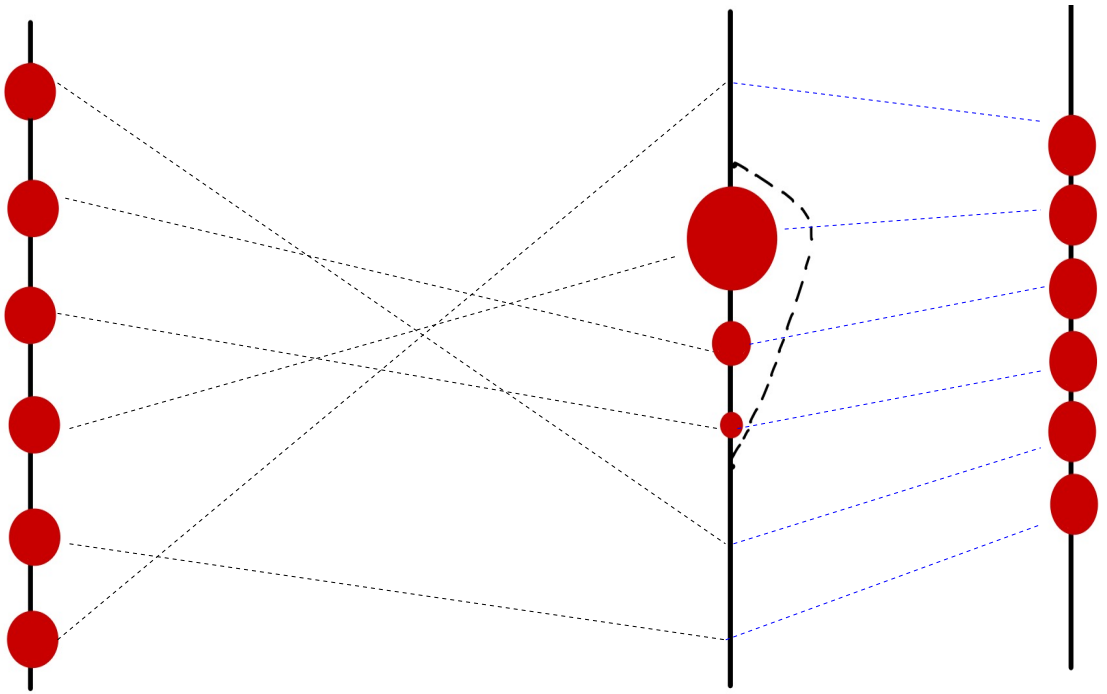


$$p(x|y)=\sum_{i=1}^{M} w_i \delta(x-x_i)$$

$$w_i=\frac{p(y|x_i)}{\sum_{j=1}^{M} p(y|x_j)}$$

Ensemble Transform Particle Filters (ETPF)



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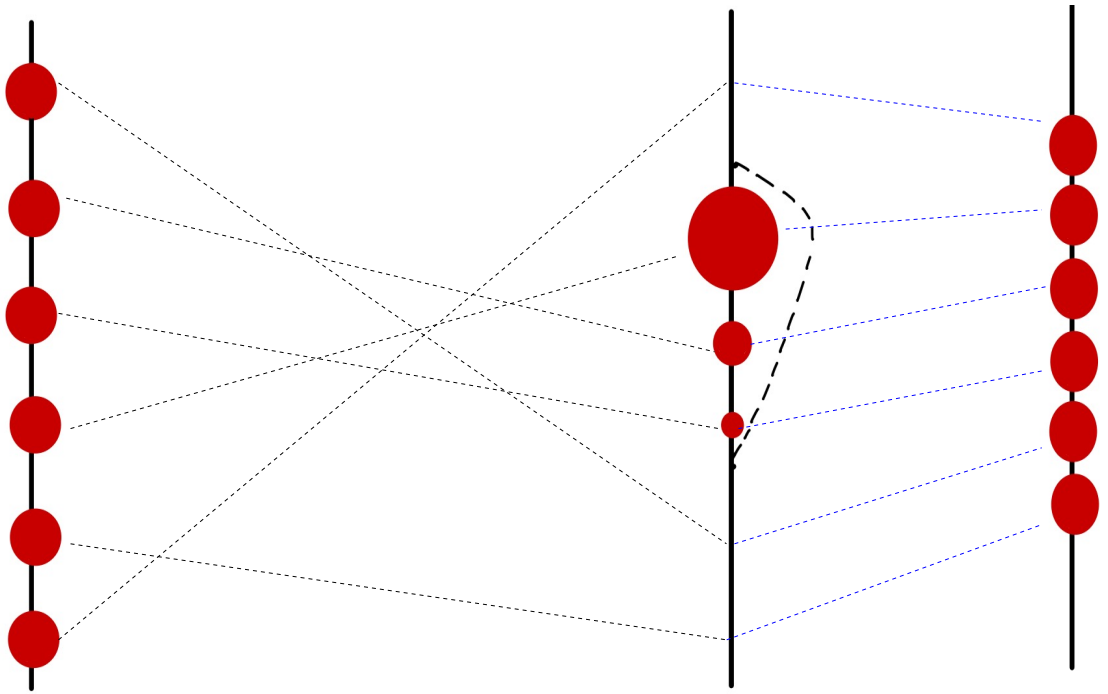

$$\min J\left(\{t_{ij}^{*}\}\right)=\sum_{i,j=1}^{M} t_{ij}\, d_{ij}$$

$$d_{ij}=\left\|x_i-x_j\right\|^2$$

S. Reich & C. Cotter. (2015). Probabilistic forecasting and data assimilation, Cambridge University Press.

Tempered Ensemble Transform Particle Filters (TETPF)

- Instead of jumping directly from prior to posterior, a smooth transition among the distribution can lead to stabilization of weights.

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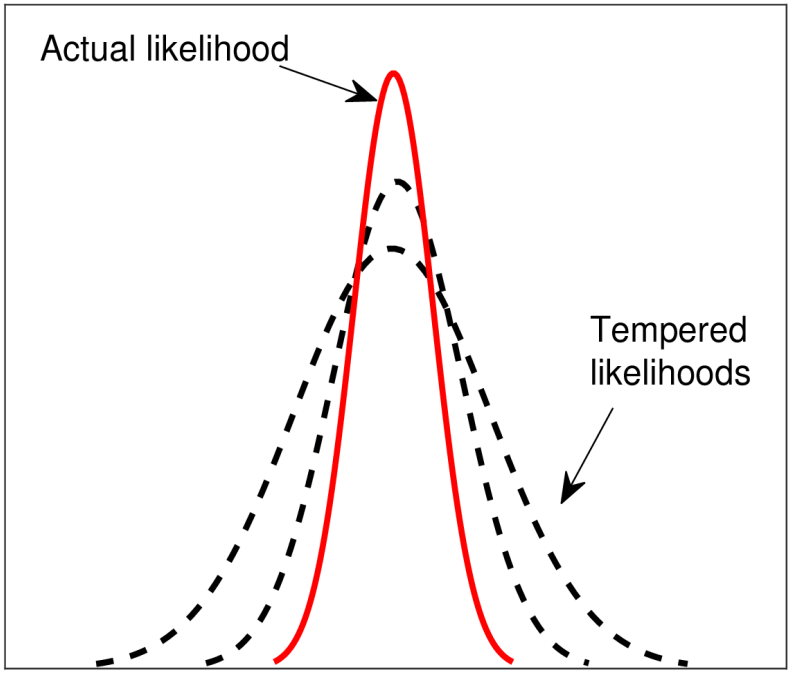
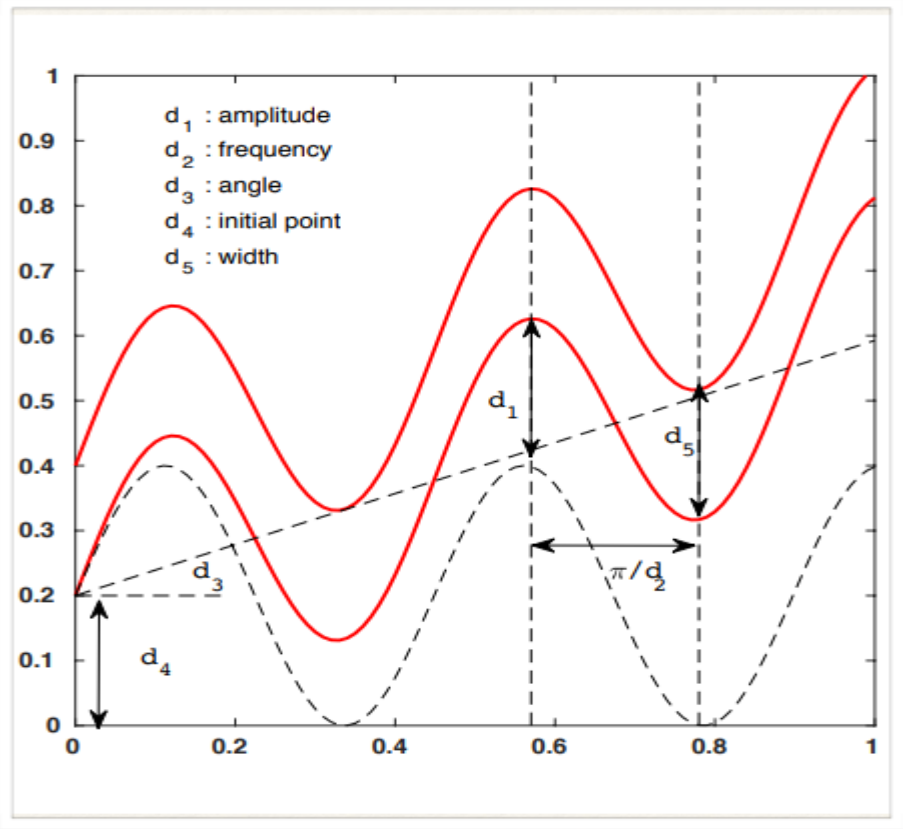


S.Ruchi & S.Dubinkina (2018), S. Dubinkina & S. Ruchi (2018) and S. Ruchi, S. Dubinkina & M. Iglesias (2018)

Test Case: Bimodal probability



- We consider a channelized domain: a channel with different permeability is situated in the domain.

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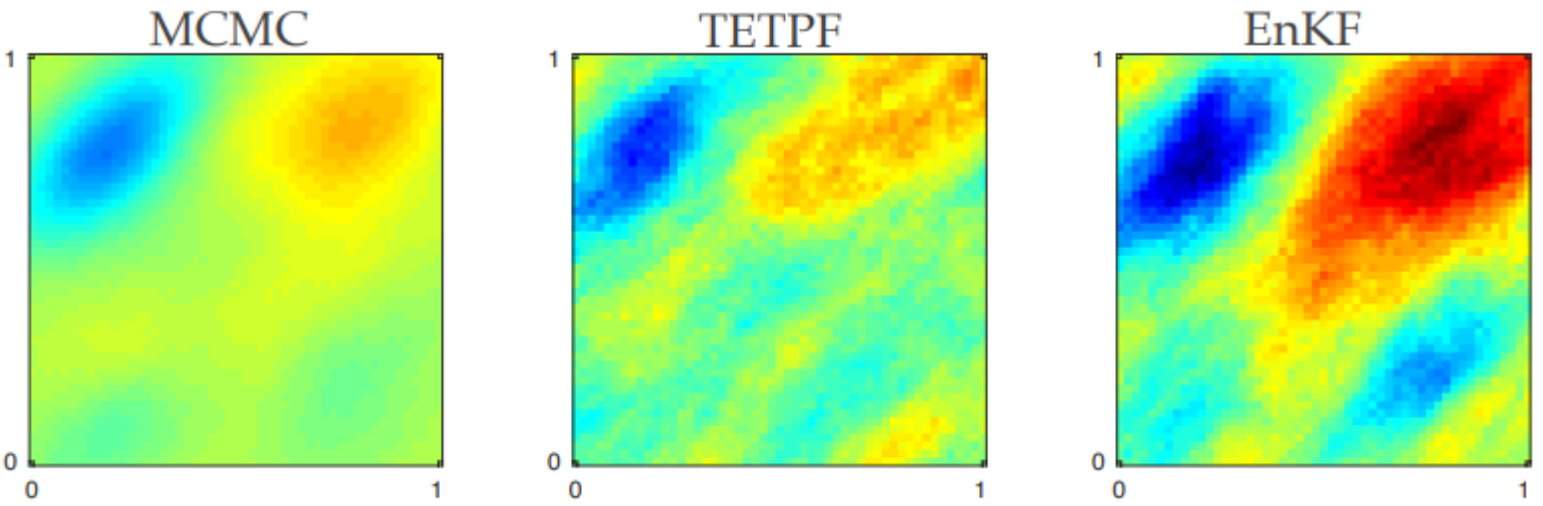

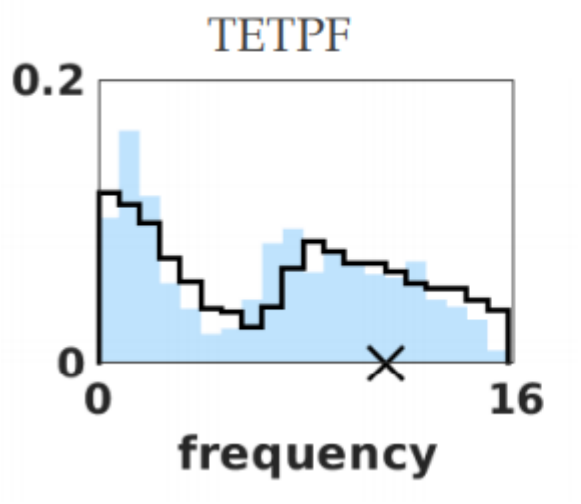

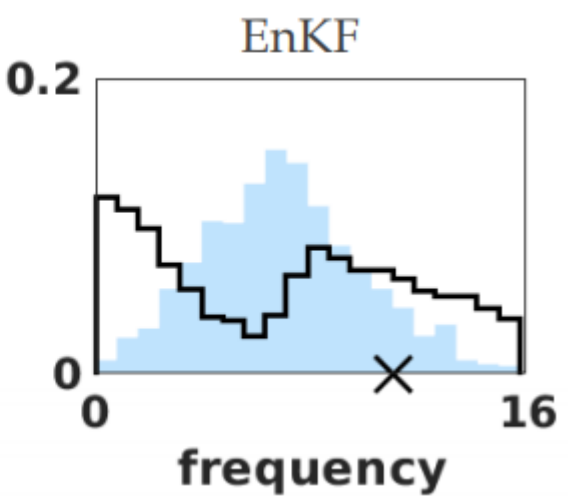

Conclusions

Accurate estimations can be obtained by

- EnKF, when everything is Gaussian;
- MCMC, when everything is low-dimensional.
- TETPF, when everything is high-dimensional and non-Gaussian.

Questions?