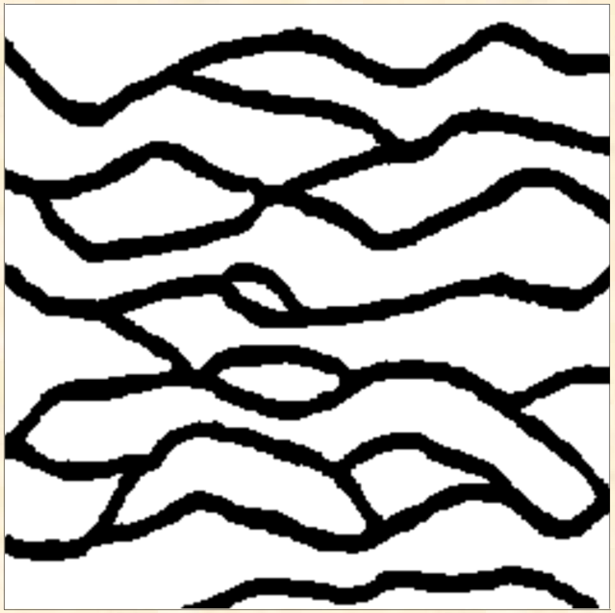
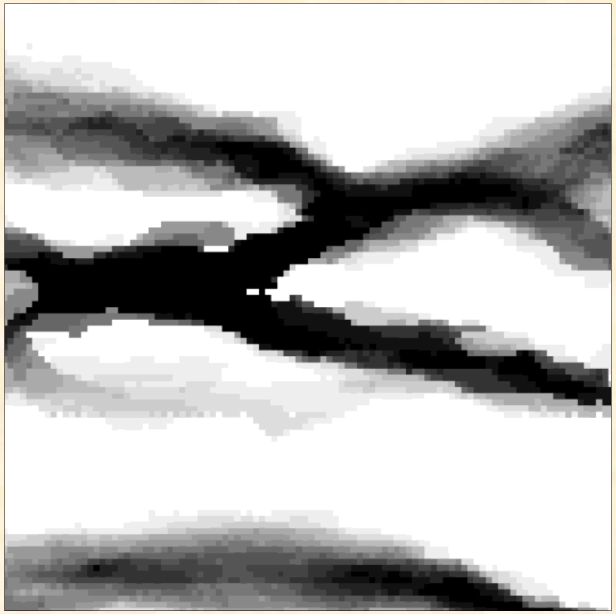
The Blocking Moving Window sampler. Conditioning MP simulations to non-local hydrogeological data

Andrés Alcolea & Philippe Renard
Stochastic Research Group
CHYN (Centre for Hydrogeology of Neuchâtel, Switzerland)

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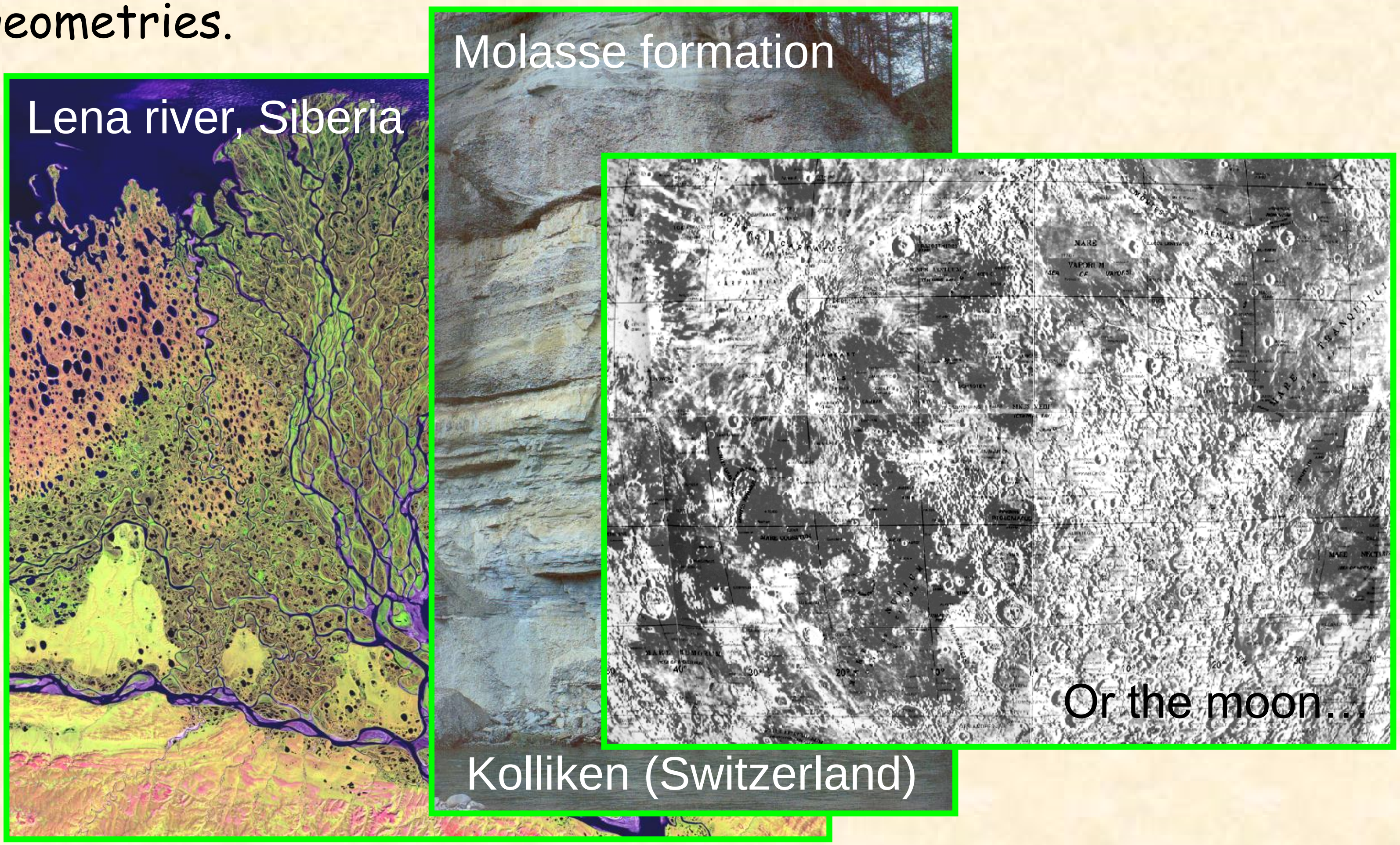
15-19 DECEMBER · SAN FRANCISCO
Université de Neuchâtel unine
chyn
FNSNF Swiss National Science Foundation

SCOPE

- ✓ MOTIVATION. THE NEED FOR MP
- ✓ MULTIPLE POINT GEOSTATISTICS
- ✓ THE BMW SAMPLER
- ✓ A TOY EXAMPLE.
- ✓ CONCLUSIONS. THE NEED FOR SPEED

MOTIVATION

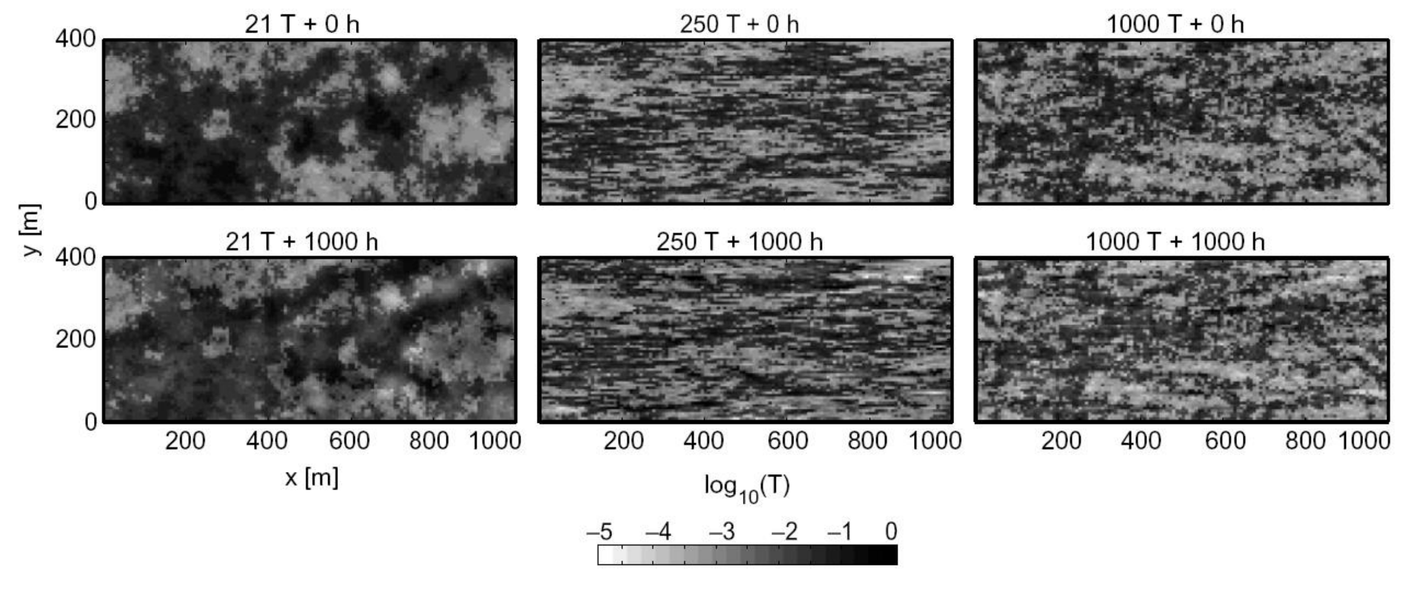
- ✓ Geological scenarios often present well connected lithofacies distributions with sophisticated 'crispy' geometries. Two-point statistical techniques (variogram) not capable of reproducing such geometries.

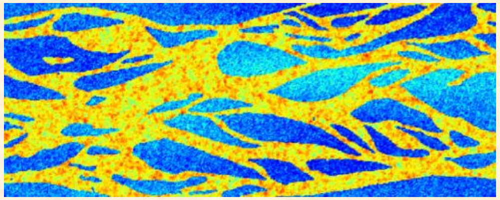


MOTIVATION. THE NEED FOR MP

- ✓ What if parameter fields are non-Multi-Gaussian?

"If anything can go wrong, it will " (Murphy's law)

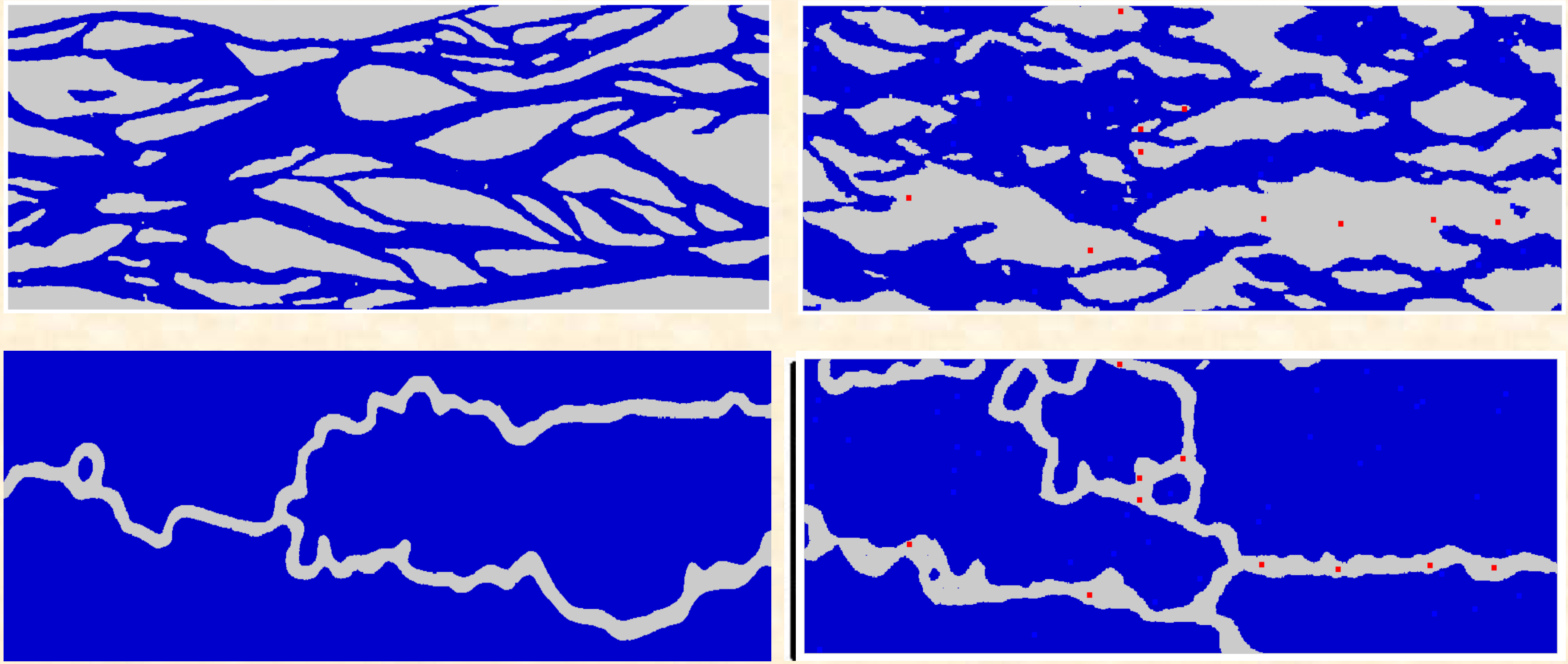




Kerrou, Renard, Hendricks-Franssen, Lunati, 2008, AWR, 31: 147-159

MP STATISTICS

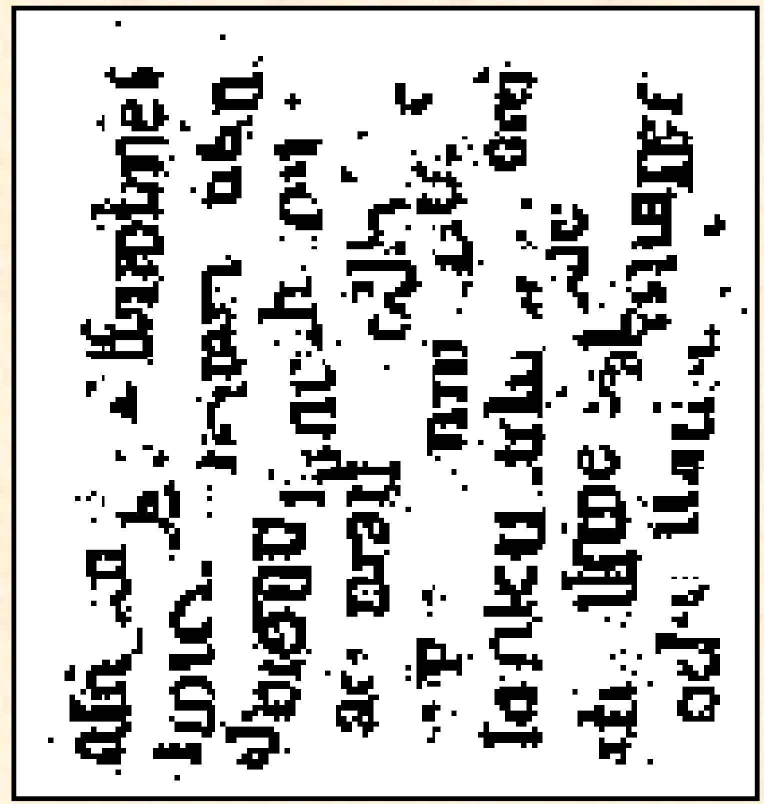
- ✓ MP techniques used successfully as simulator of such scenarios. They allow us to reproduce "crispy" geometries.
- ✓ MP techniques rely on 'training images' depicting a prior conceptualization of the system being modeled. Beyond variograms



MP STATISTICS

- ✓ MP can be used in multiple branches of science. Here, reconstruction of a journal's back issue.

Training image



Unconditional simulation

OBJECTIVES

- ✓ Conditioning data are local lithofacies & (sometimes) geophysics. MP used for raw geological modeling.
- ✓ Little attention to other hydrogeological data: connectivity, heads, concentrations, etc. (Hoffman, 2003; Caers & Hoffman, 2006 in the context of PPM; Ronayne et al., 2008).
- ✓ These data sets contain important information about patterns of heterogeneity and should be accounted for in meaningful models.

The Blocking Moving Window (BMW) sampler

1) Stochastic : stack of lithofacies distributions that
2) Honor geological data and non-local connectivity
3) Honor geological conceptual models (resemble training images)
4) Fit well available state variable data (e.g., heads)

THE BMW sampler

LOOP UNTIL "CONVERGENCE":

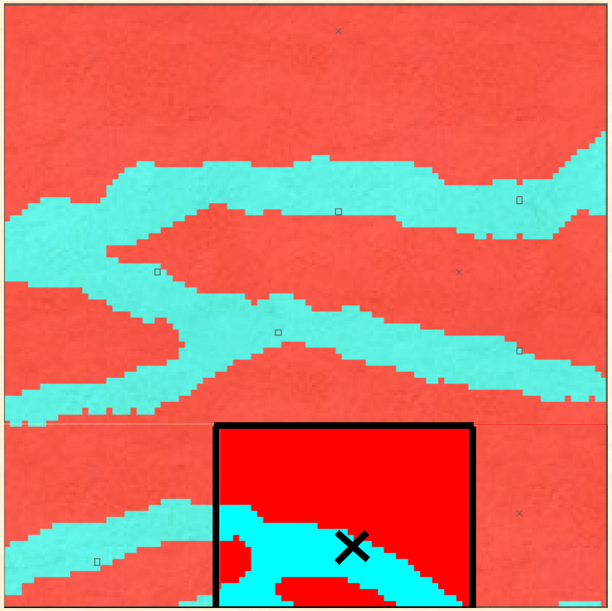
1) Perturb last accepted MP simulation

   1.1) Select randomly the centre of the (square) window

   1.2) Draw the Blocking Moving Window (size = user defined)

   REMARK : At first iteration, the whole domain is simulated

   1.3) Block all pixels outside the window = 'fake' measurements

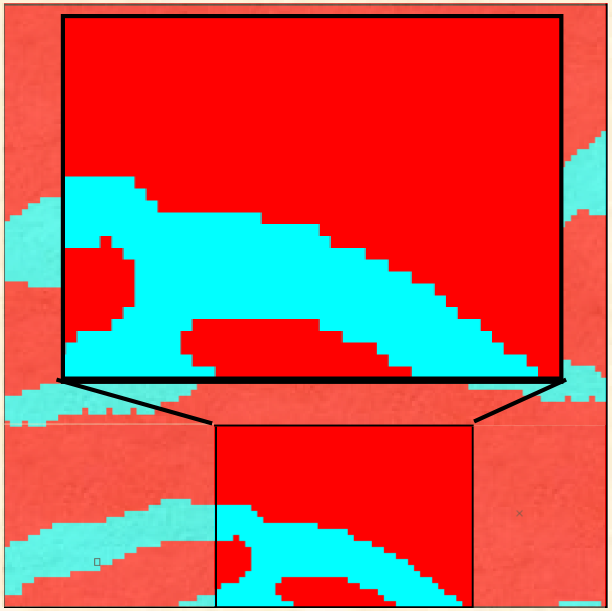


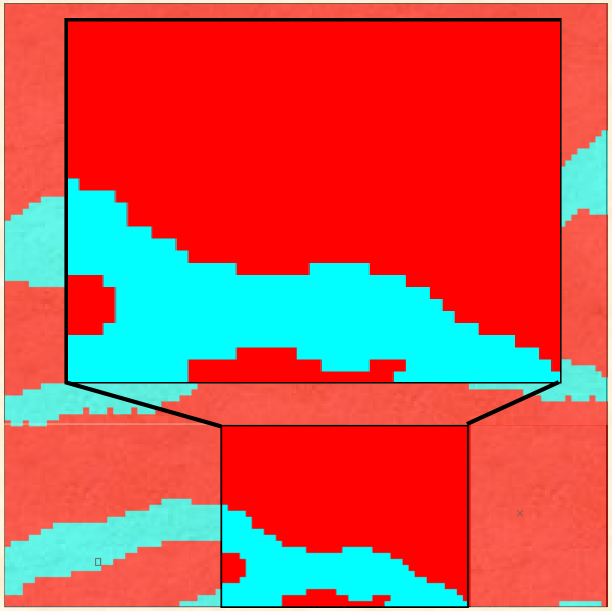
THE BMW sampler

LOOP UNTIL "CONVERGENCE":

1.4) Simulate using MP (cdList, Straubhaar, 2008) what is going on INSIDE the window only. Measurement set = actual conditioning data (lithofacies + geophysics + non-local connectivity) + all pixels outside the window.

BEFORE





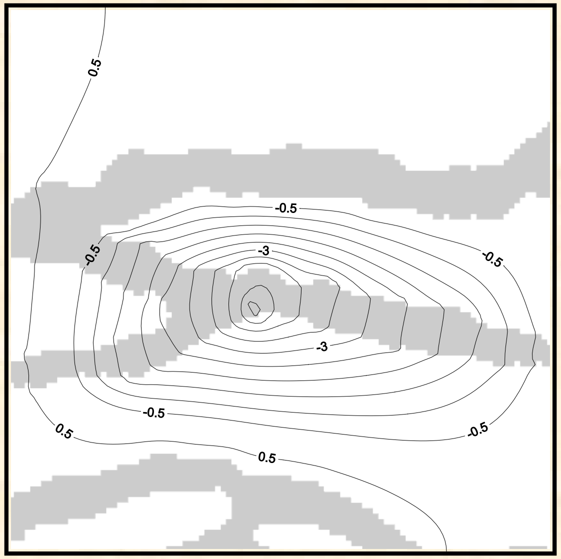
AFTER

THE BMW sampler

LOOP UNTIL "CONVERGENCE":

3) Populate hydraulic properties at the intrafacies (constant value is assigned here). Other options are 'double sequential simulation' or 'direct sampling' (Mariethoz and Renard, 200?).

4) Simulate groundwater flow / c. transport / heat / whatsoever…



5) Calculate objective function: $f = \sum_i \left(h_i - h_i^*\right)^2$

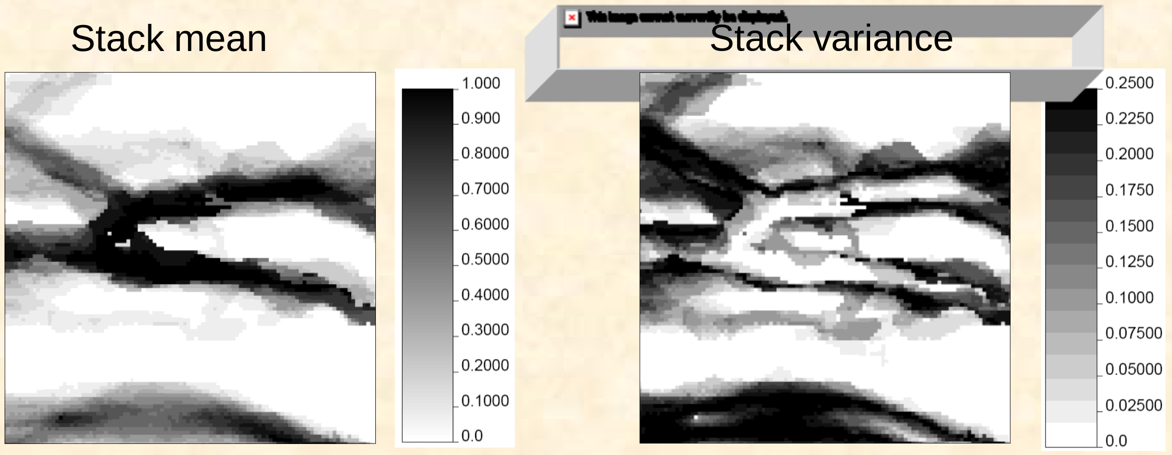
THE BMW sampler

LOOP UNTIL "CONVERGENCE":

6) Accept / reject by means of a simulated annealing type criterion. Accepted simulations are added to the stack if the objective function is below a certain threshold.

7) Check convergence and annealing temperature
- Maximum number of iterations / bad iterations
- Small value of the objective function
- Target stack size

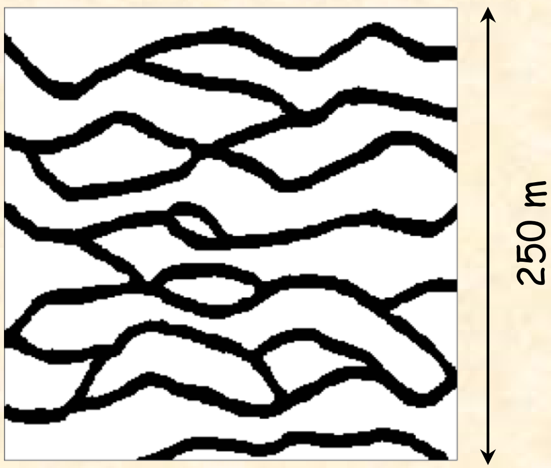
END LOOP



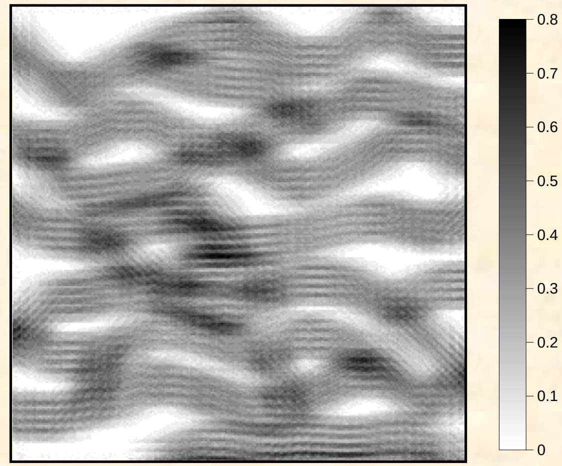
(probability of sand) (related uncertainty)

A TOY EXAMPLE. SETUP

Training image



Training image soft variable

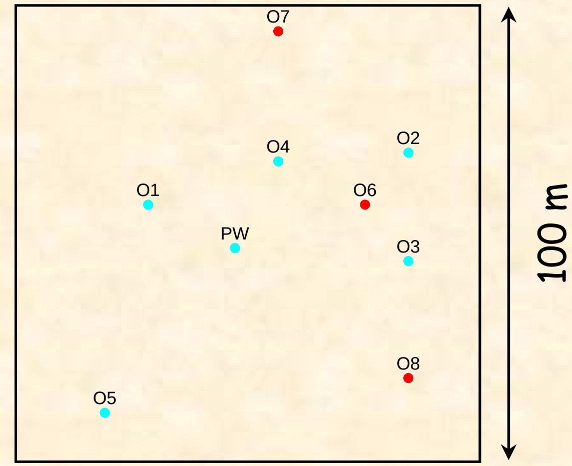


250 m

250 x 250 cells (1m x 1m)

250 m

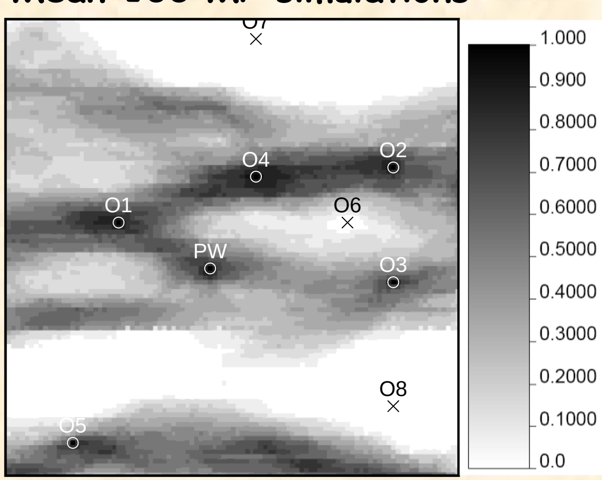
Domain and measurements



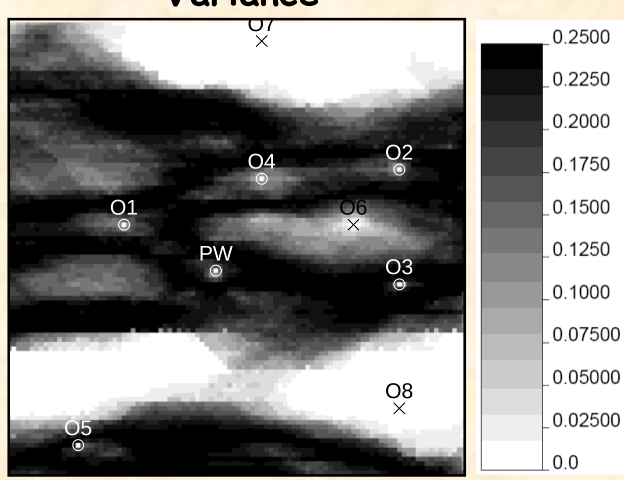
100 m

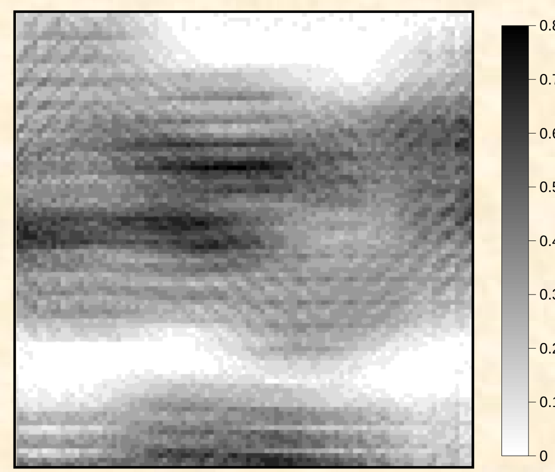
100 x 100 cells (1m x 1m)

Mean 100 MP simulations



Variance



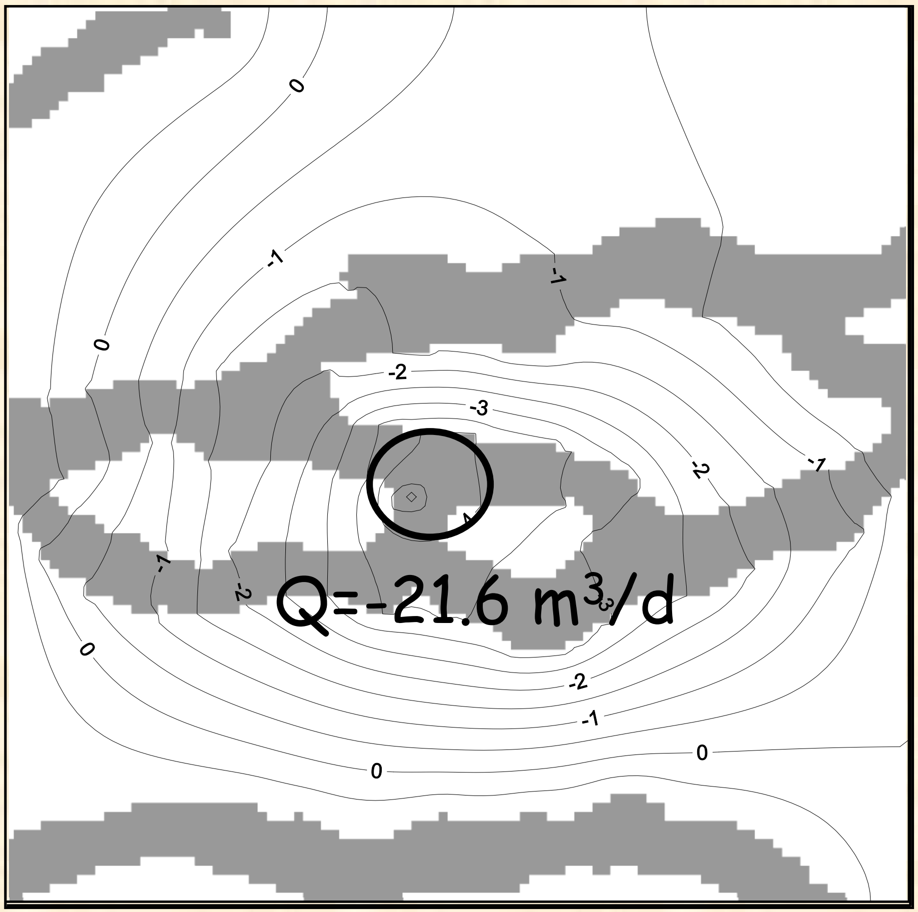


Seismic data

A TOY EXAMPLE. SETUP

Reference facies distribution

Q=0 m^3/d



H=1 m

H=0 m

Q=-21.6 m^3/d

Q=0 m^3/d

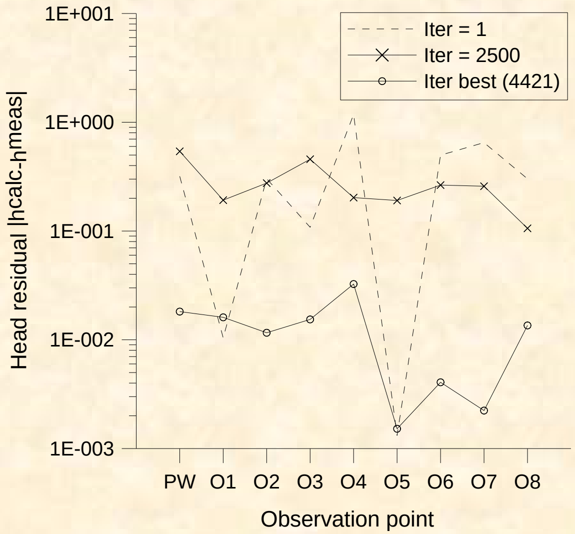
K_{sand} = 10 m/d

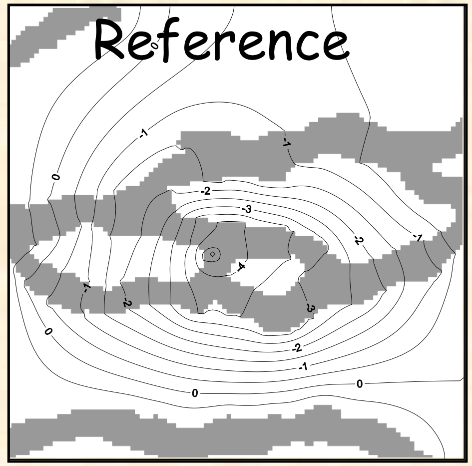
K_{clay} = 10^{-3} m/d

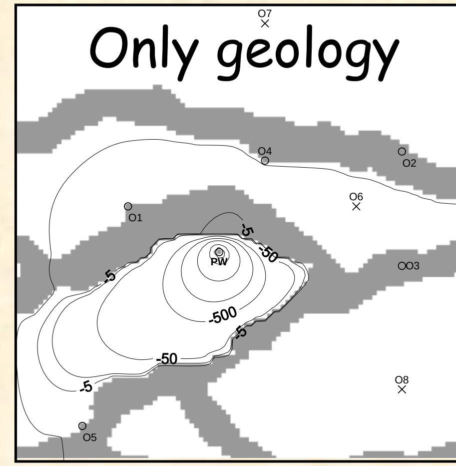
PW, O1 to O4 connected

9 head measurements

HEADS AND CONNECTIVITY





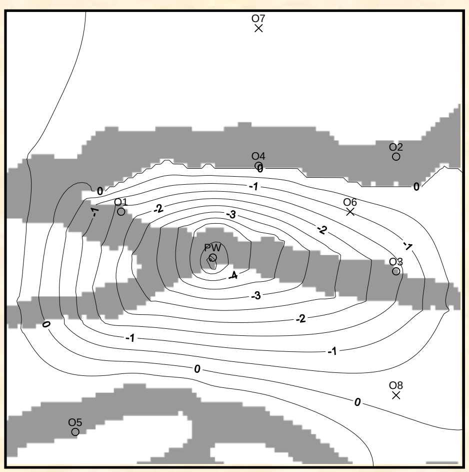


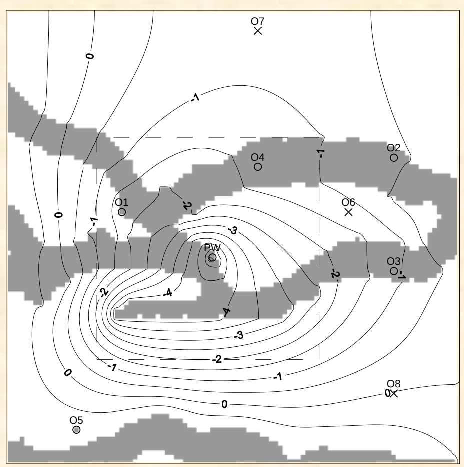
Initial

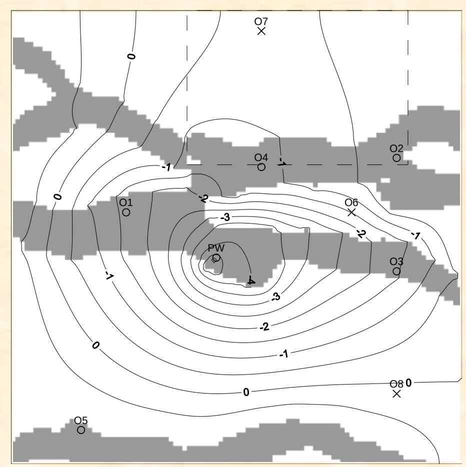
Iter = 2500

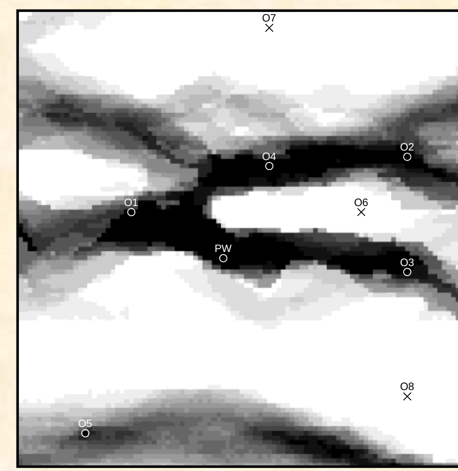
Iter ~ 5000 (best)

Stack mean (~450)







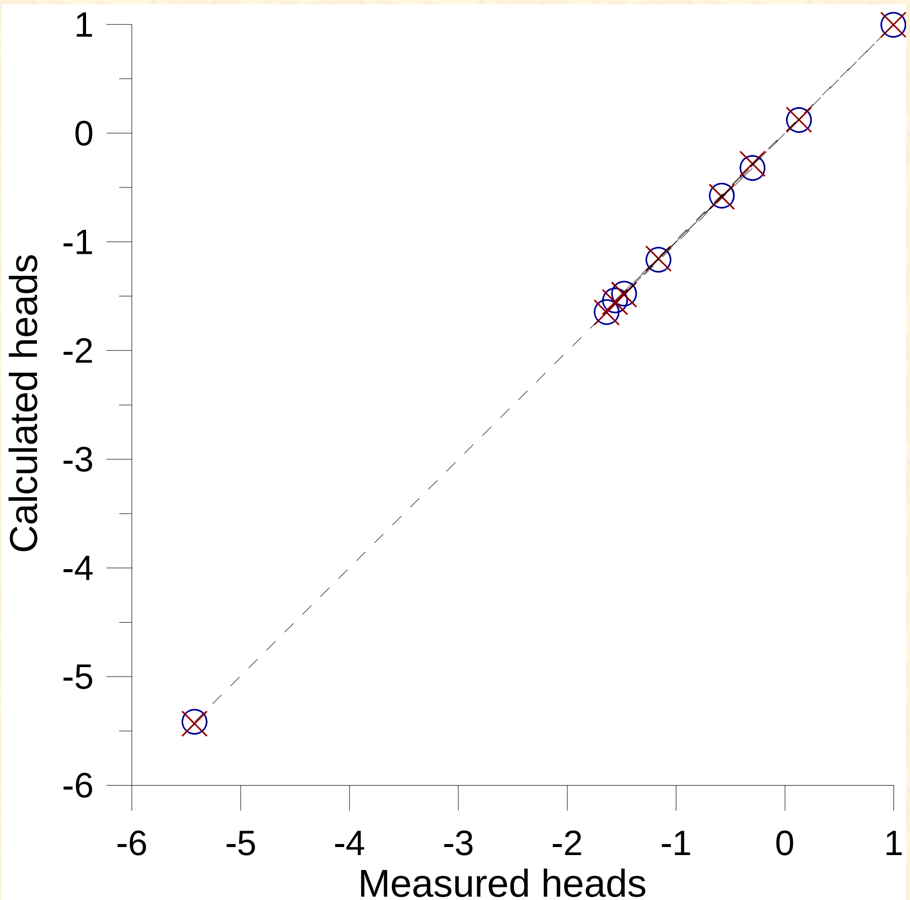


(geology only)

(geology + heads)

F < 0.1 (e_h < 0.1)

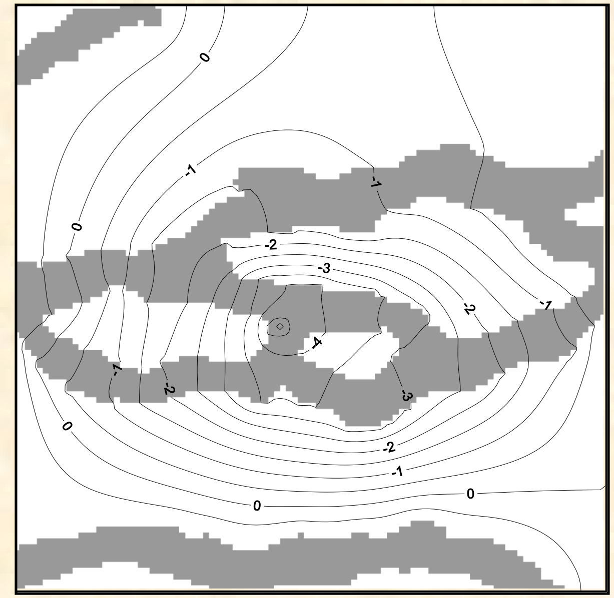
RESULTS. SOME FITS



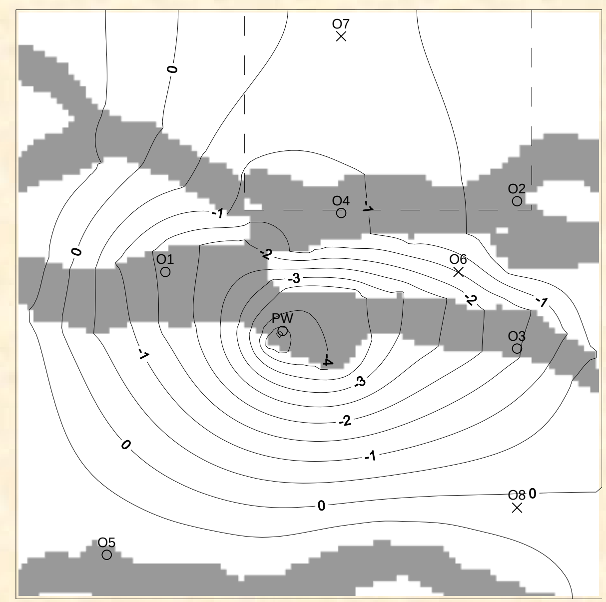
Just 9 head measurements !!!

One cannot get more information from that.

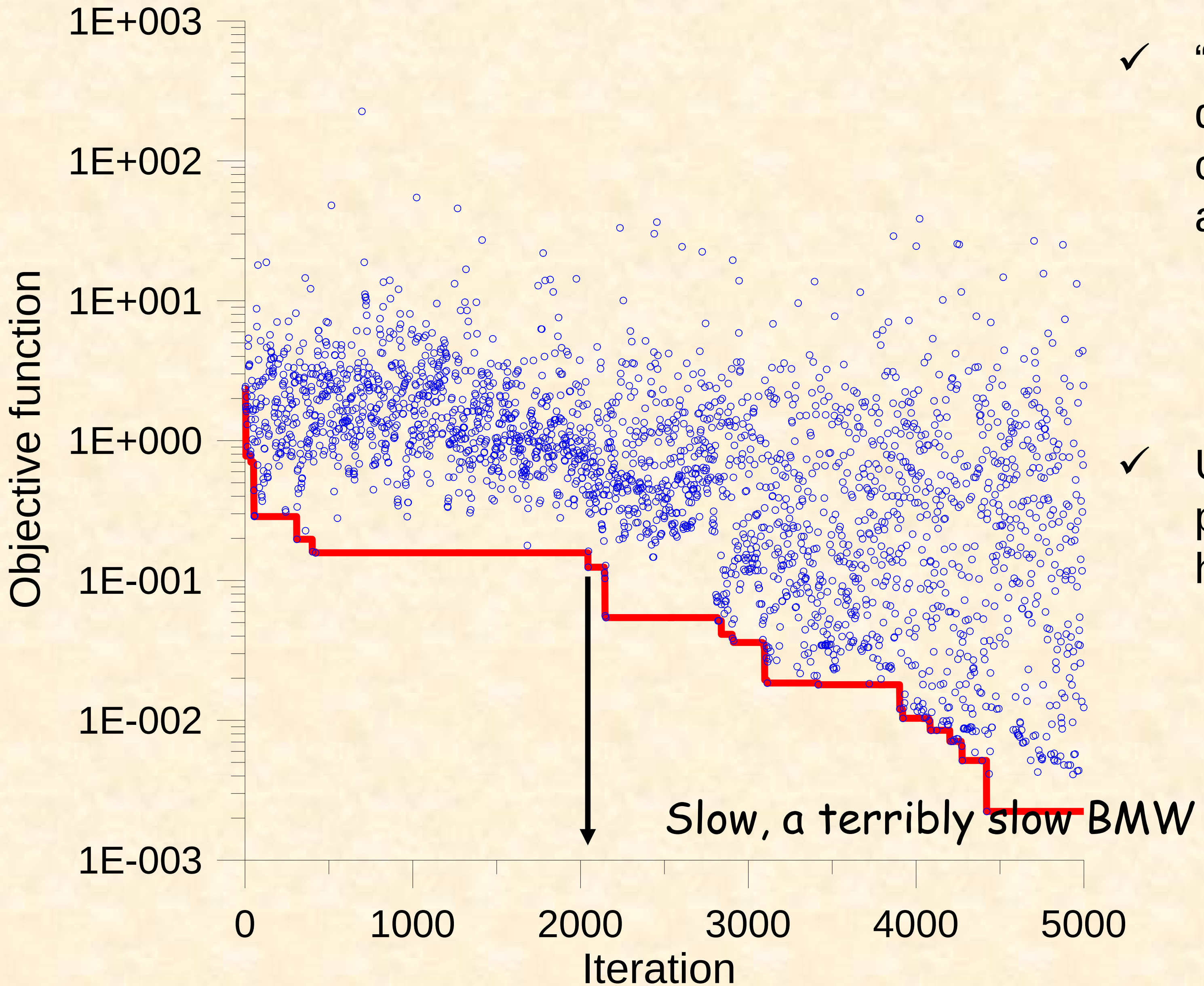
REFERENCE



CALCULATED

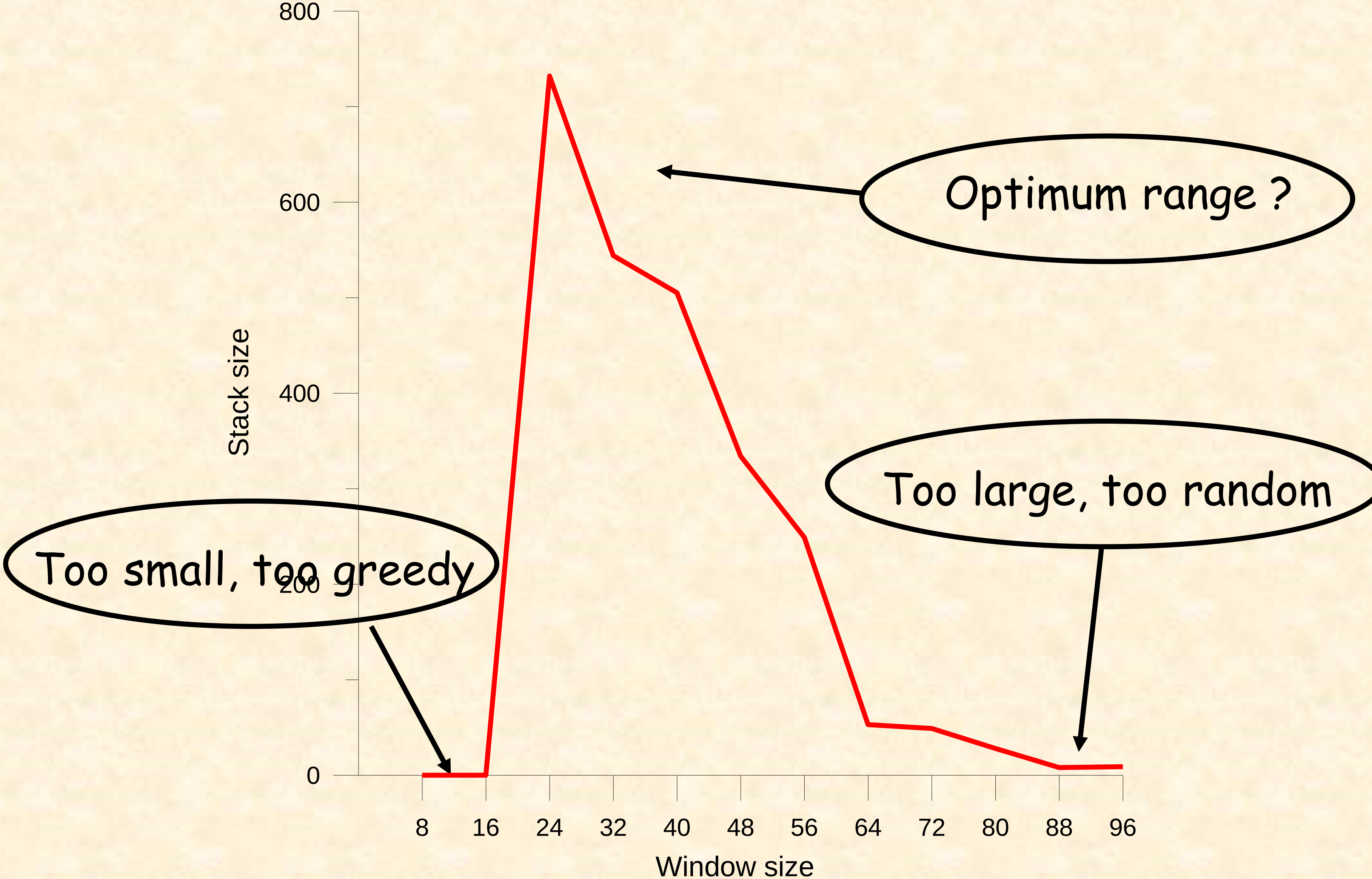


HEADS AND CONNECTIVITY

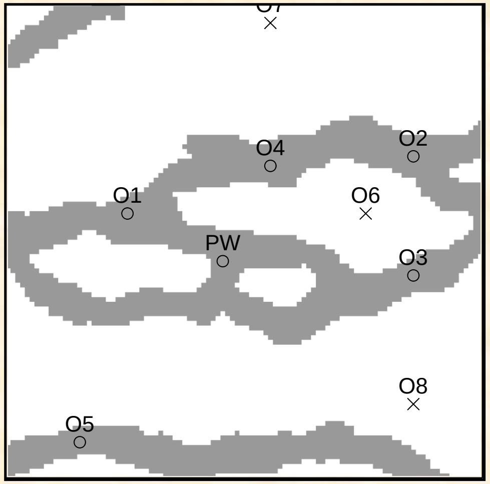


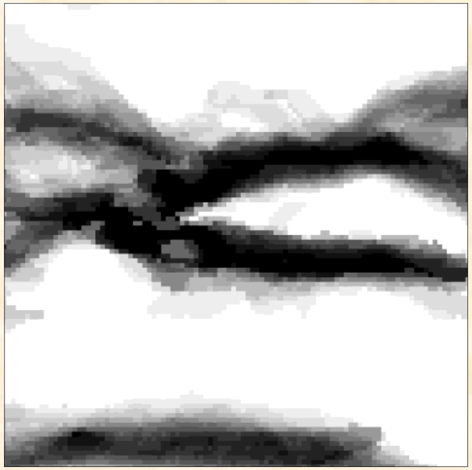
- ✓ "Bad" distributions can appear at any stage
- ✓ Use of proxies could help

RESULTS. THE WINDOW SIZE

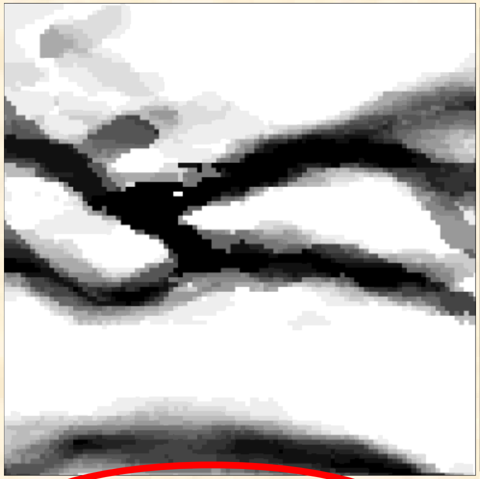


RESULTS. THE WINDOW SIZE

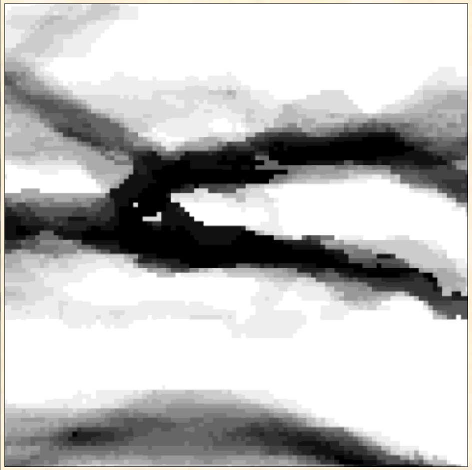




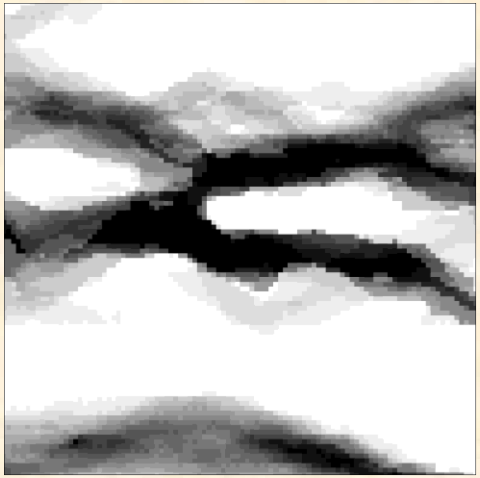
Size = 24



Size = 32

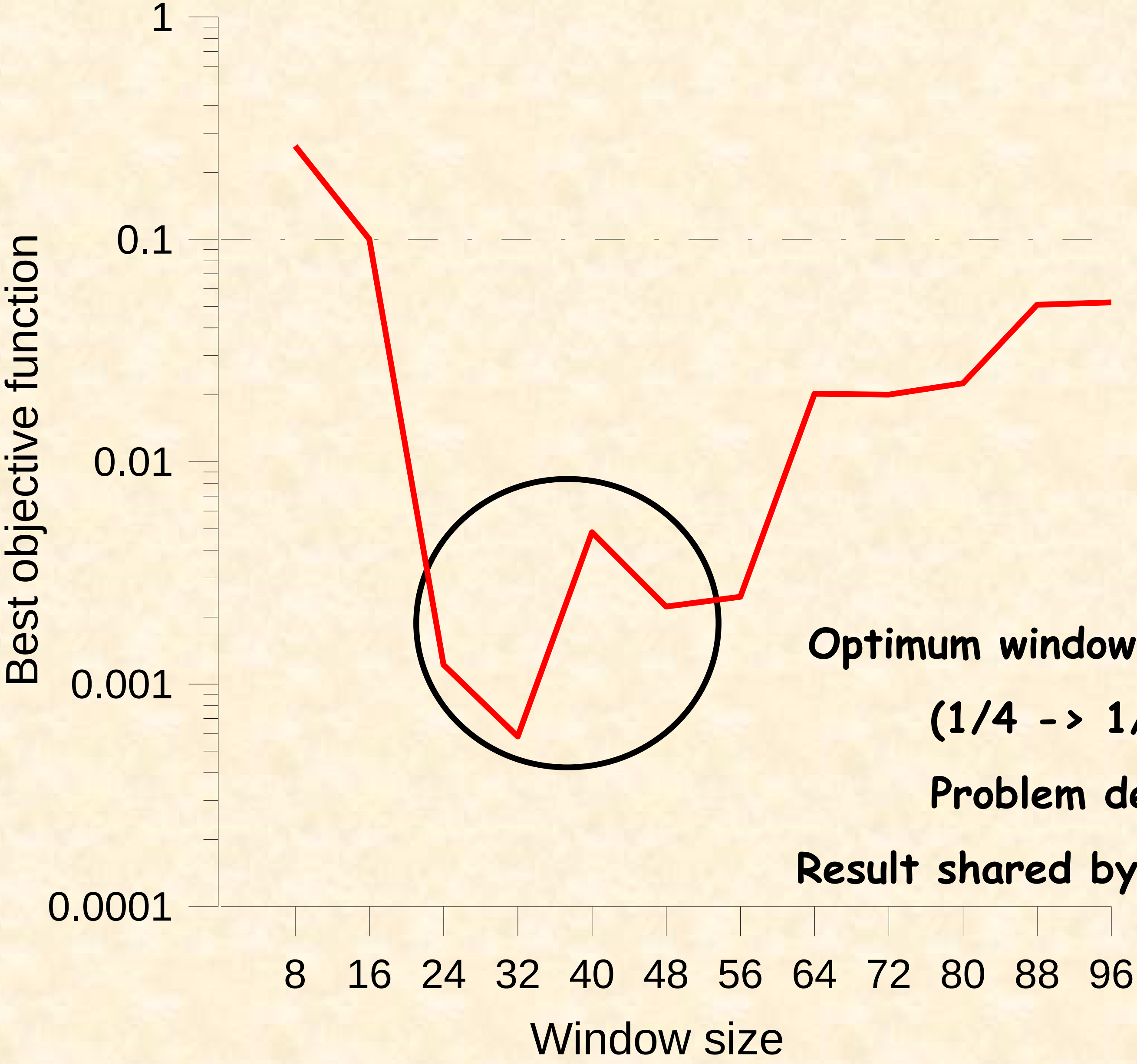


Size = 40



Size = 48

RESULTS. THE WINDOW SIZE



Optimum window size = 24 – 48

(1/4 -> 1/2 domain)

Problem dependent.

Result shared by McMC methods

CONCLUSIONS

1) Connectivity and heads help. The marriage between geology/geophysics and hydrology is a necessary step towards meaningful modeling.

2) The Blocking Moving Window sampler allows conditioning MP simulations (geology / geophysics) to non-local connectivity and state variable data (hydrology).

3) The BMW couples two "black boxes": an MP simulator for drawing lithofacies with a simulator of dependent variables. Flexible.

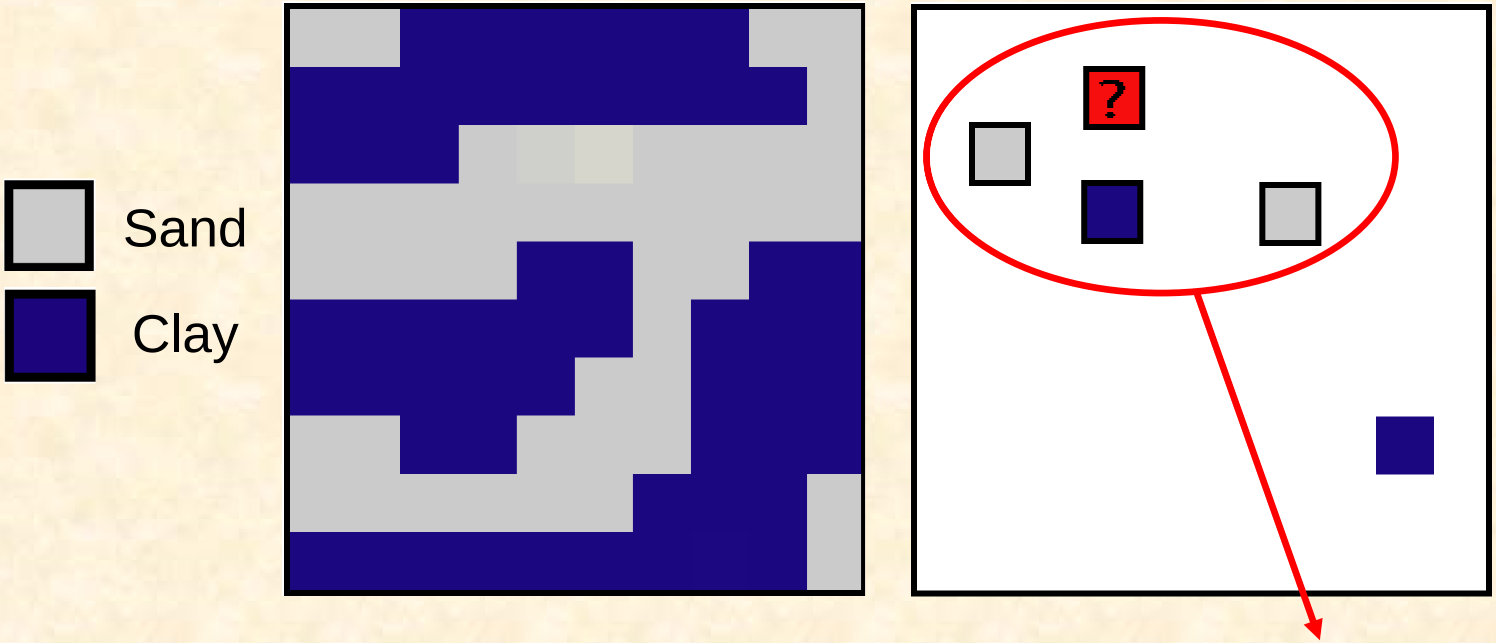
4) Size of Moving Window critical. Too small, too greedy search. Too big, too random & inefficient. Optimum size non-identifiable a priori and, most likely, problem dependent.

5) A large number of iterations (~2000) is required to start populating the stack. Not a real BMW… Use of proxies !

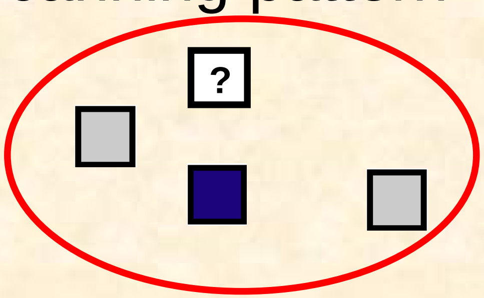
MP. HOW DOES IT WORK?

Training image.

Simulated image.



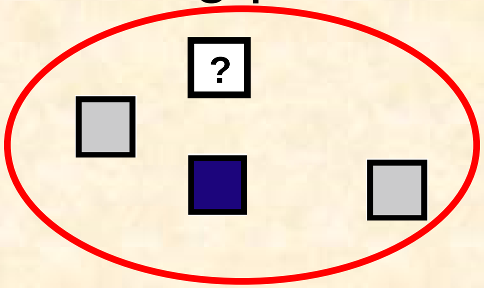
Scanning pattern

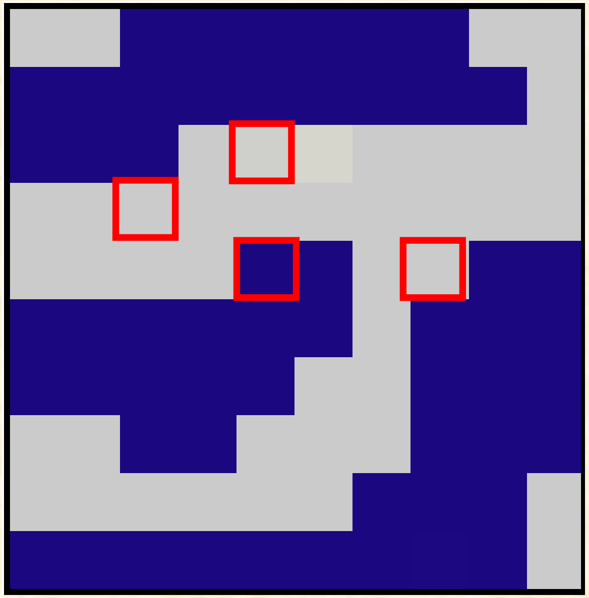


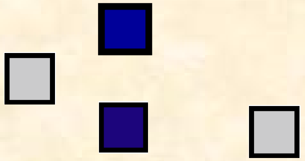
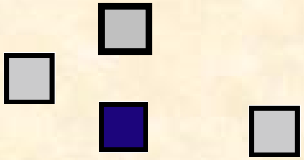
1) We have a set of measurements
2) Random selection of point to be simulated
3) Search measurements nearby
4) Is it sand or is it clay? Map the probability of sand within the training image

MP. HOW DOES IT WORK?

Scanning pattern

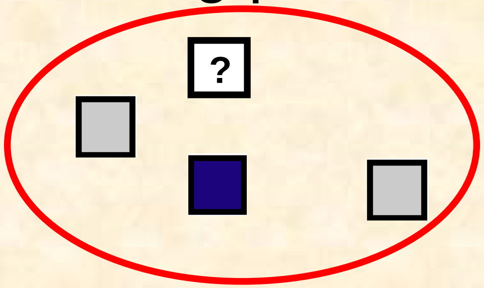


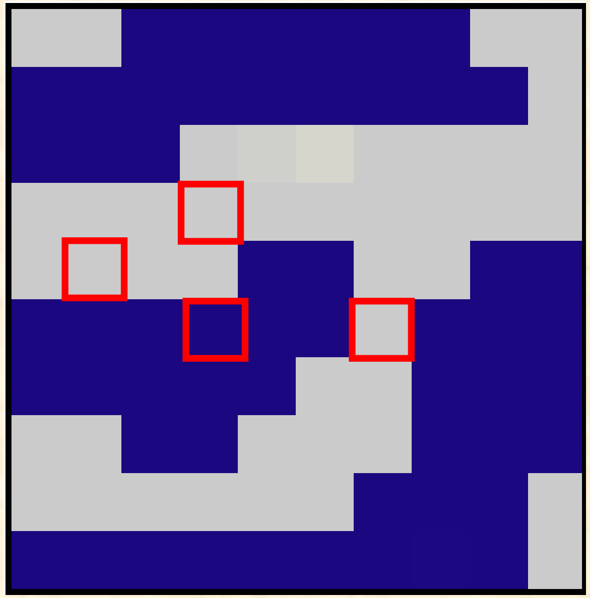


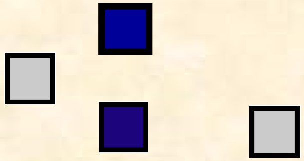
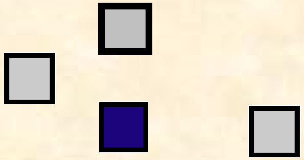
	Clay	Sand
		
Counts	0	1

MP. HOW DOES IT WORK?

Scanning pattern

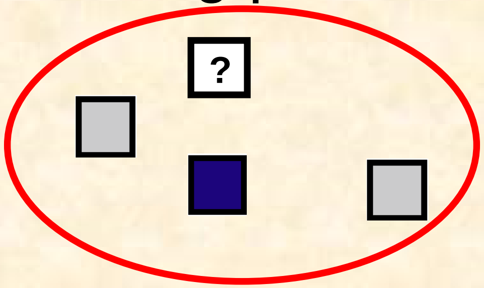


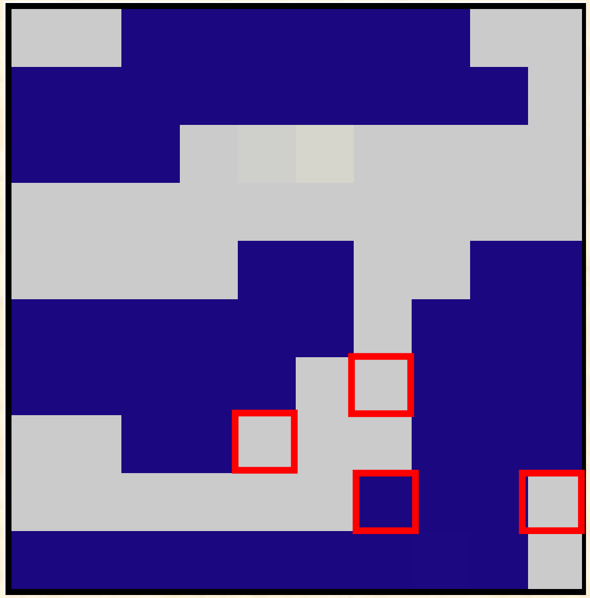


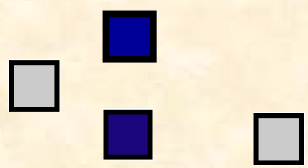
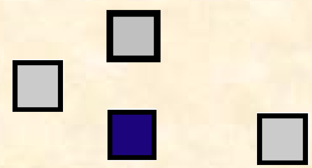
	Clay	Sand
		
Counts	0	2

MP. HOW DOES IT WORK?

Scanning pattern

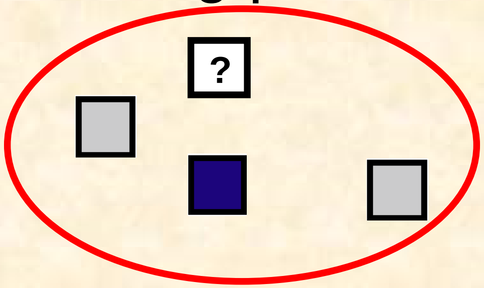


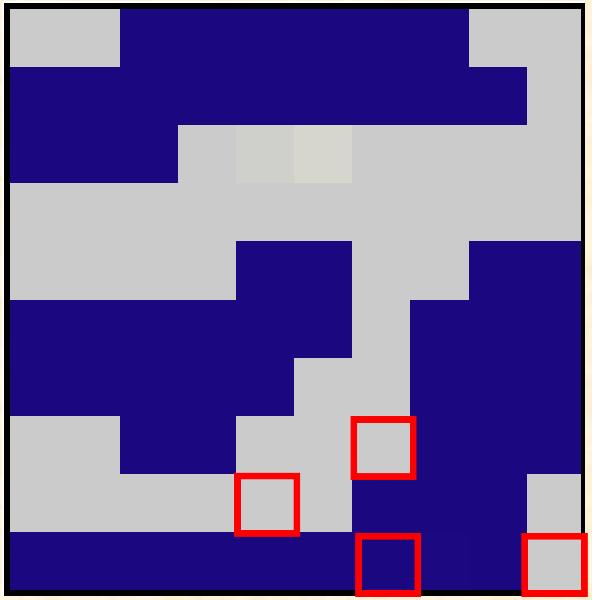


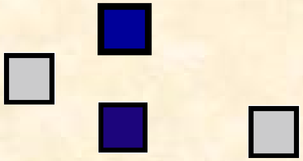
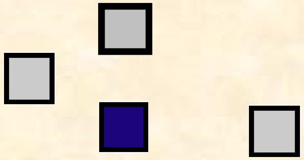
	Clay	Sand
		
Counts	0	3

MP. HOW DOES IT WORK?

Scanning pattern

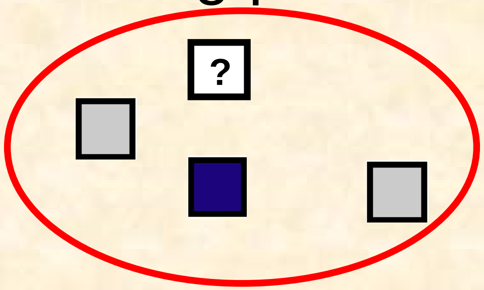


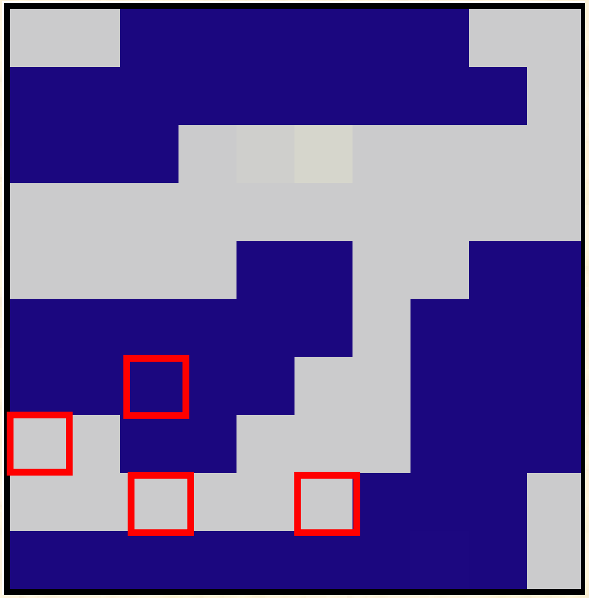


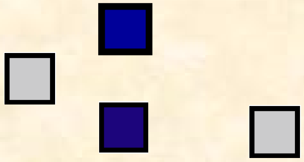
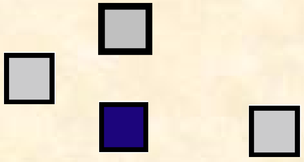
	Clay	Sand
		
Counts	0	4

MP. HOW DOES IT WORK?

Scanning pattern

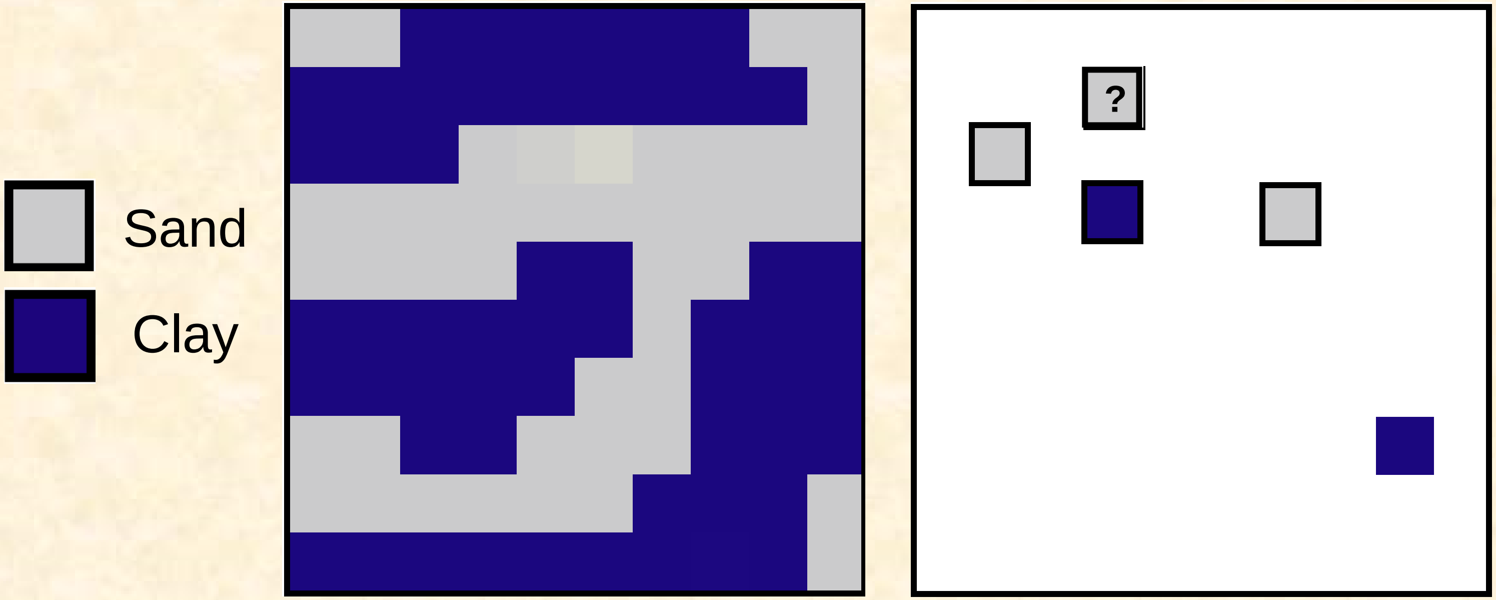




	Clay	Sand
		
Counts	1	4
Probability	1/5	4/5

MP. HOW DOES IT WORK?

Training image. Simulated image.



5) Generate random number α

6) α < p(sand) = 4 / 5 then sand.

7) Go to next point