USING STEADY-STATE TRANSPORT MODELS TO SIMULATE GROUNDWATER AGE AND AGE TRACER BREAKTHROUGH

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Background

- Climate change -> long term simulation
- Simulating solute and reactive transport to assess groundwater quality evolution relies on robust groundwater flow models
- Flow models that employ only hydraulic heads for model calibration suffer from non-uniqueness
- Environmental tracer data, i.e., groundwater age tracers can potentially reduce non-uniqueness and predictive uncertainty arising from « head-only » calibrations

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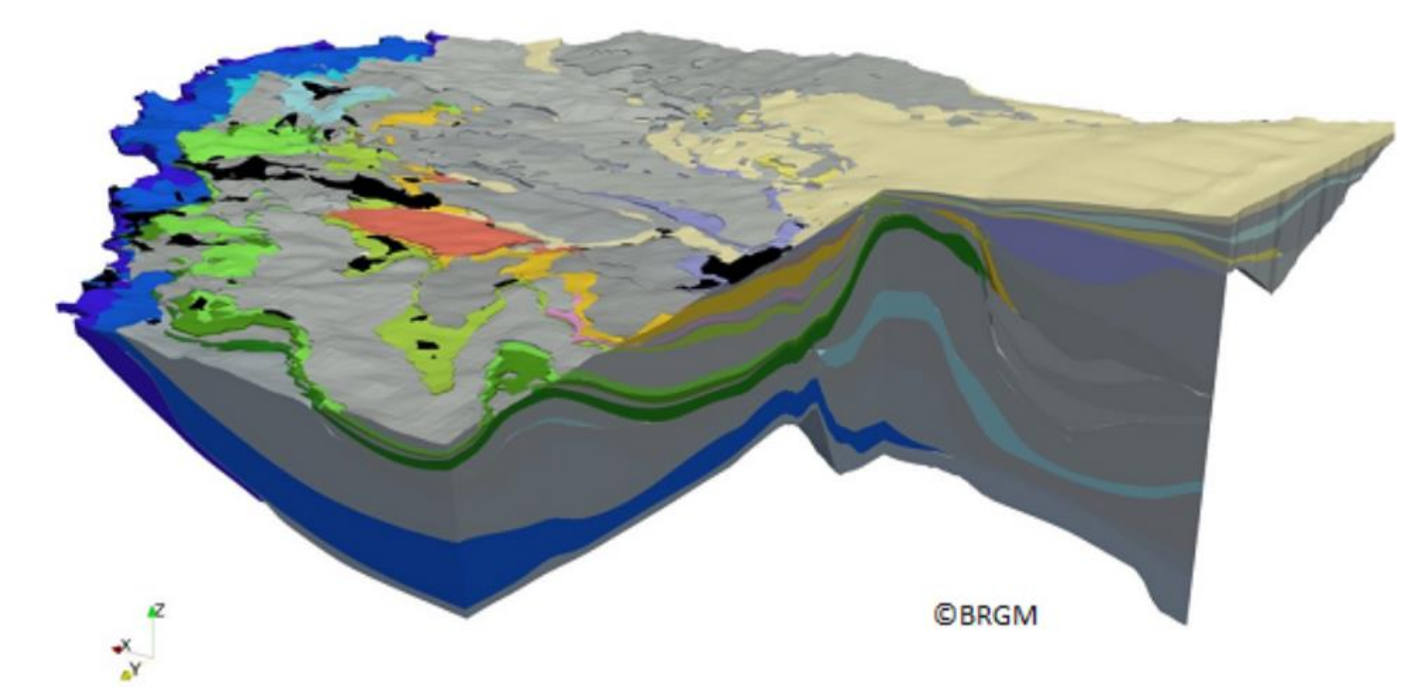
Flow and transport in large basins



- Flow simulations may take several hours
- Transport simulations may take several days

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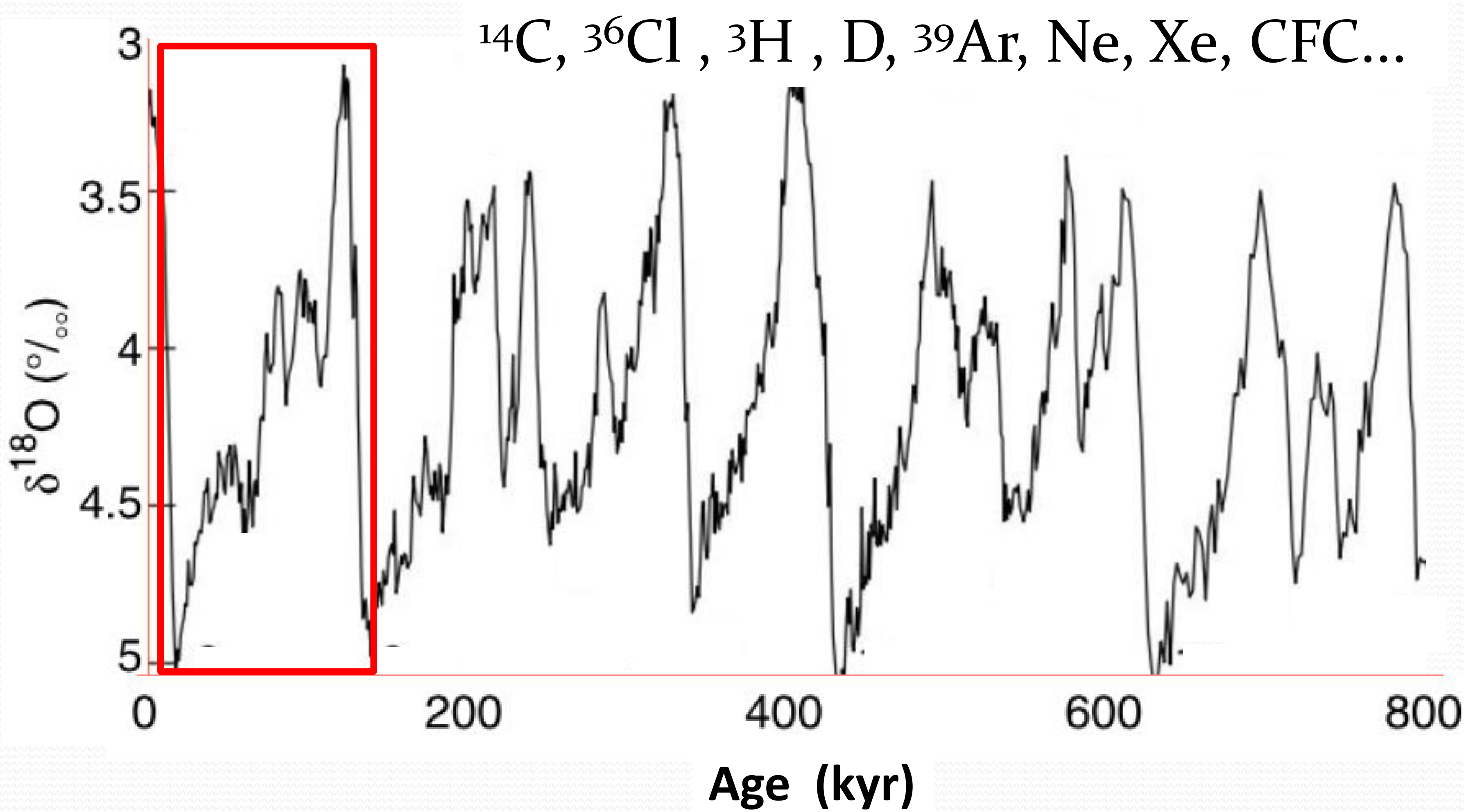
Temporal evolution of ^{18}O

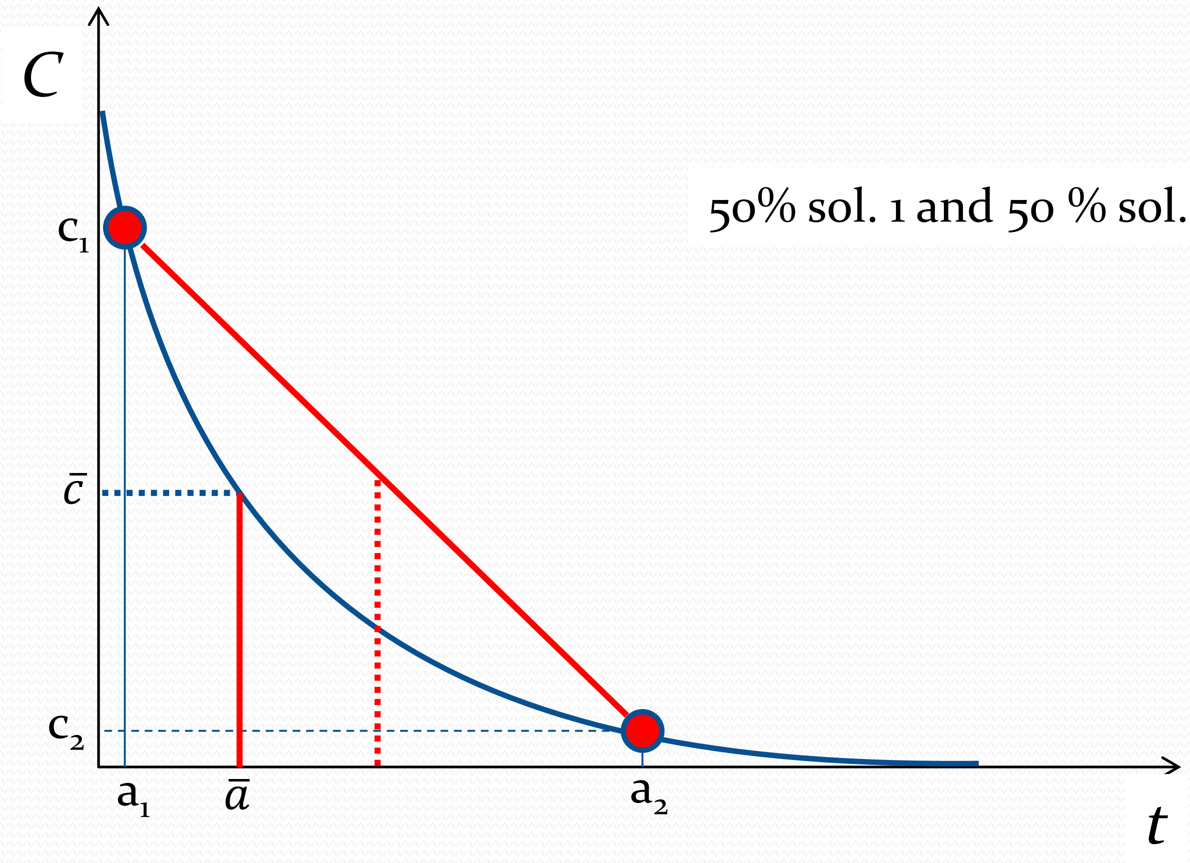


Objective and approach

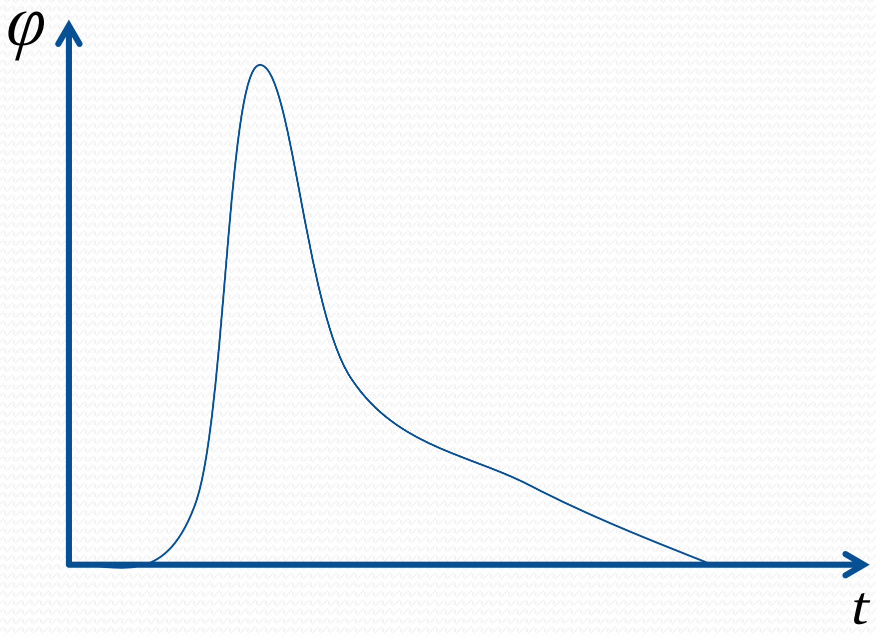
- Objectives
  - Develop an efficient method to simulate long term transport of noble gases or stable isotopes
  - To include this modelling in optimization process
- Approach
  - Use Mt3dms steady state solute transport simulation capability
  - Simulate several decaying substances
  - Invert it to get local age distribution

Age and mixing

- « Age » obtained from ^{14}C does not mix linearly



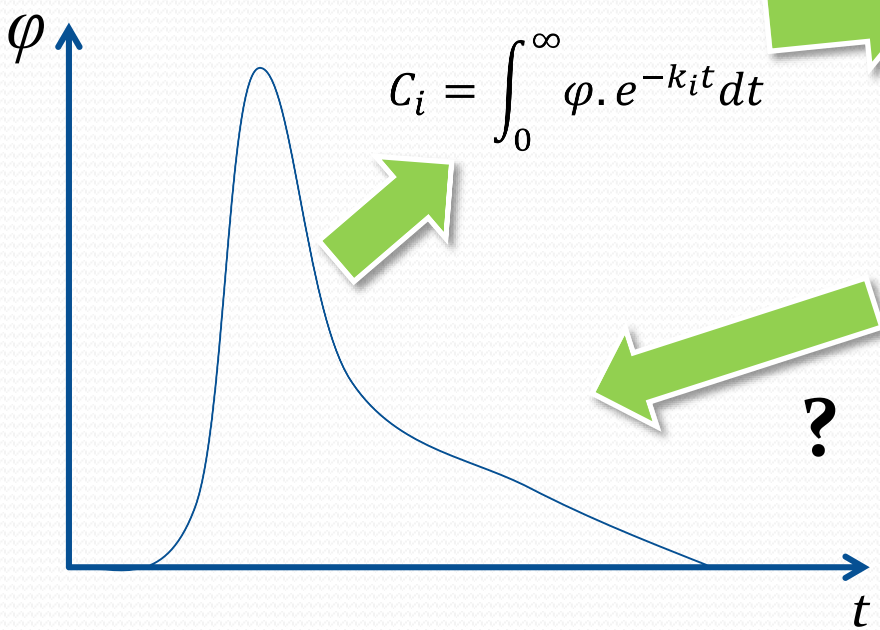
Age distribution and decay



Now, it is recognize that at each point, there is a distribution of the age of water

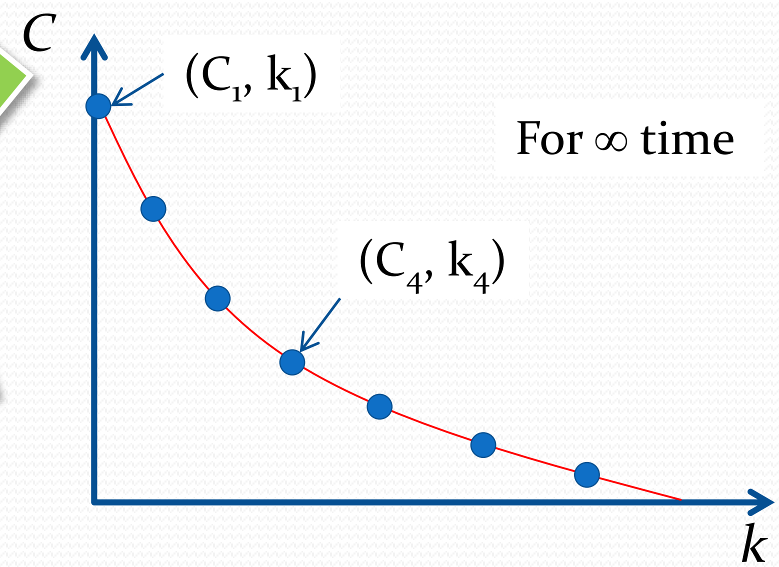
Age distribution and decay

Local age distribution shall lead to different concentrations of decaying substances



$$C_i = \int_0^{\infty} \varphi . e^{-k_i t} dt$$

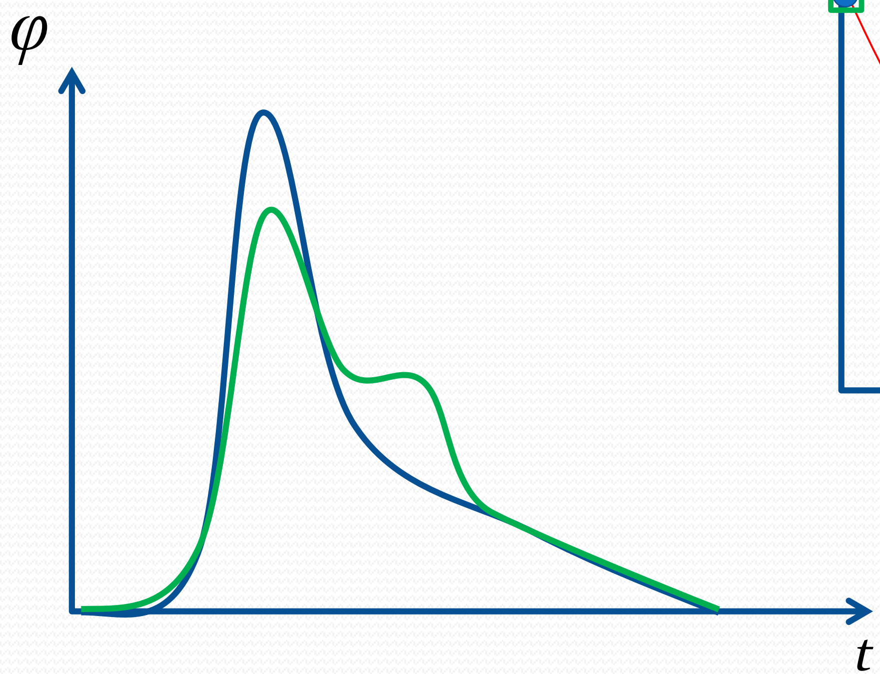
?

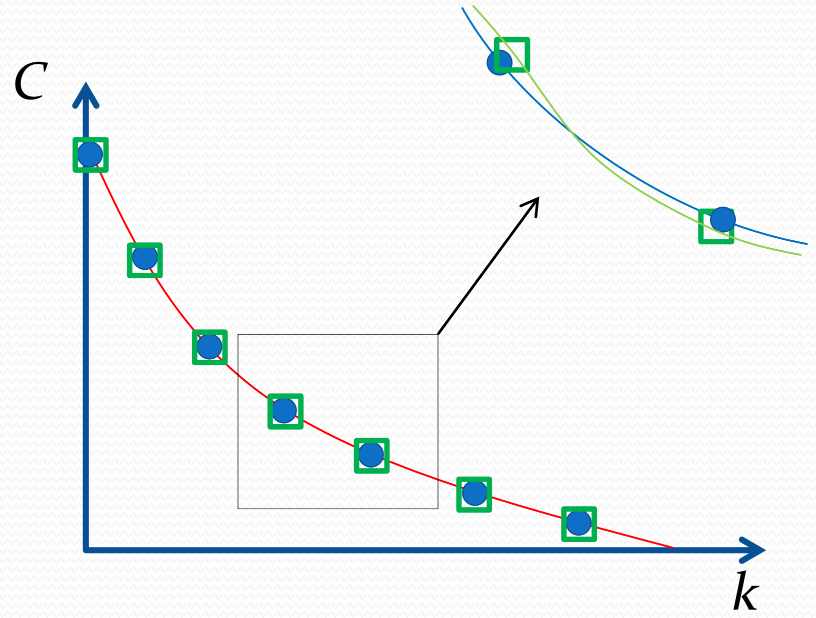


Close to non-uniqueness

Due to integral and exponential, different distributions can lead to very close C_i

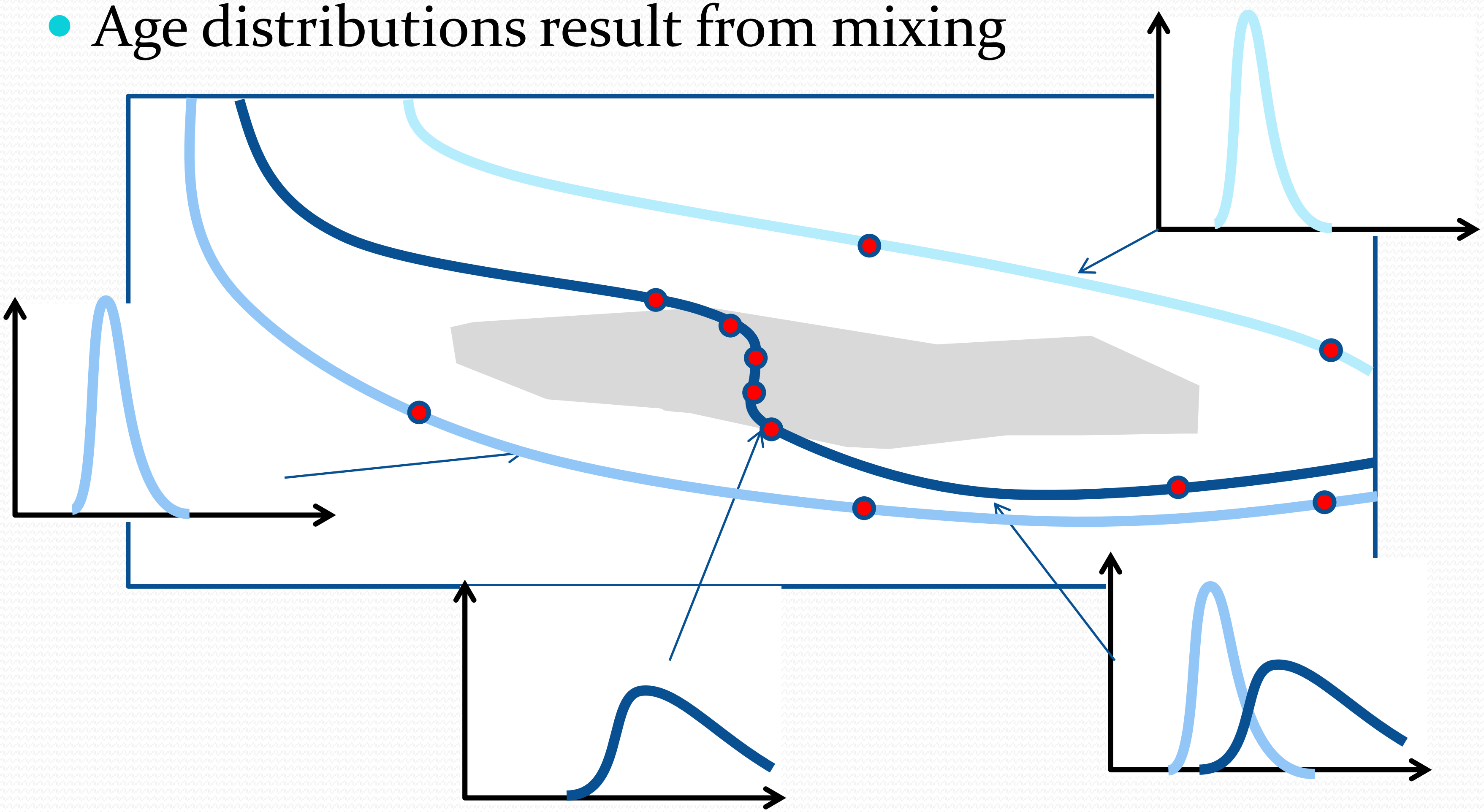
$$C = \int_0^{\infty} \varphi . e^{-kt} dt$$



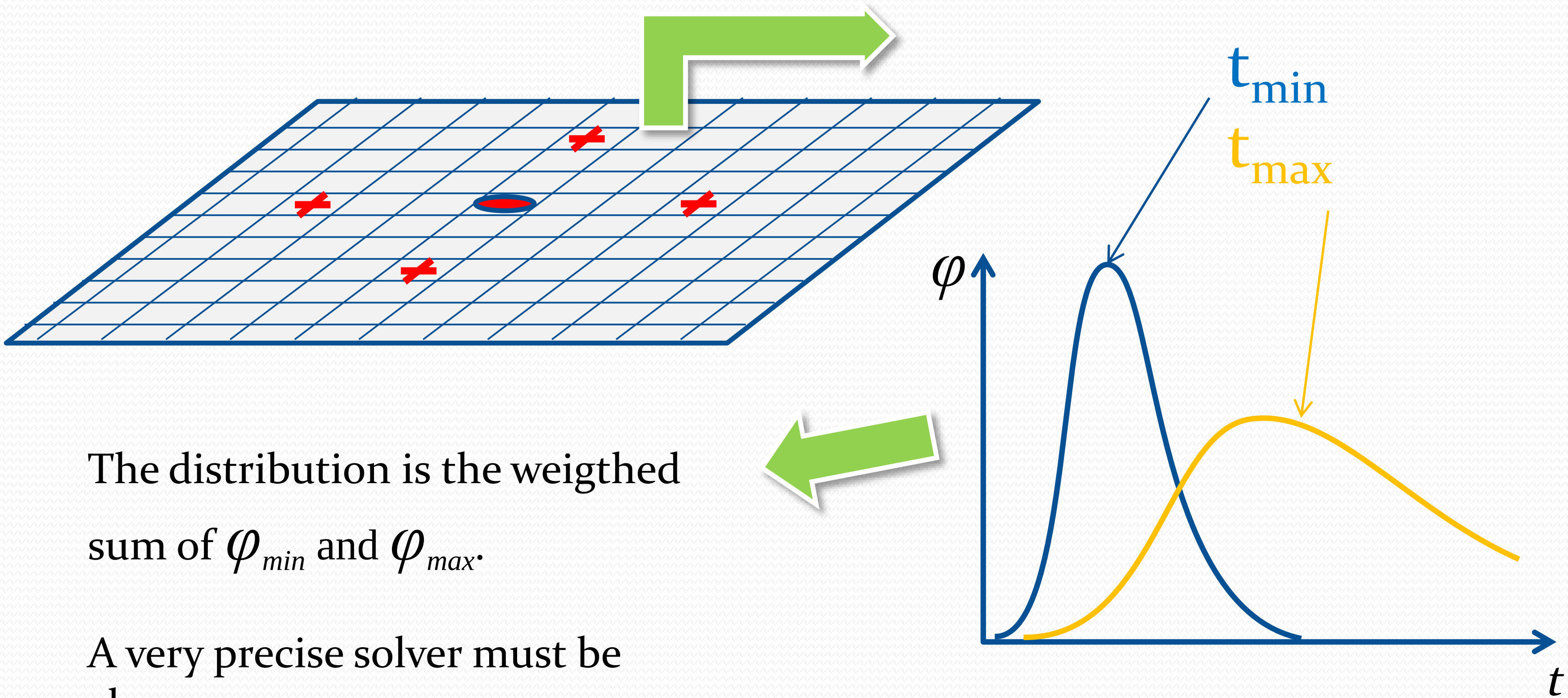


How age distributions occur

- Age distributions result from mixing



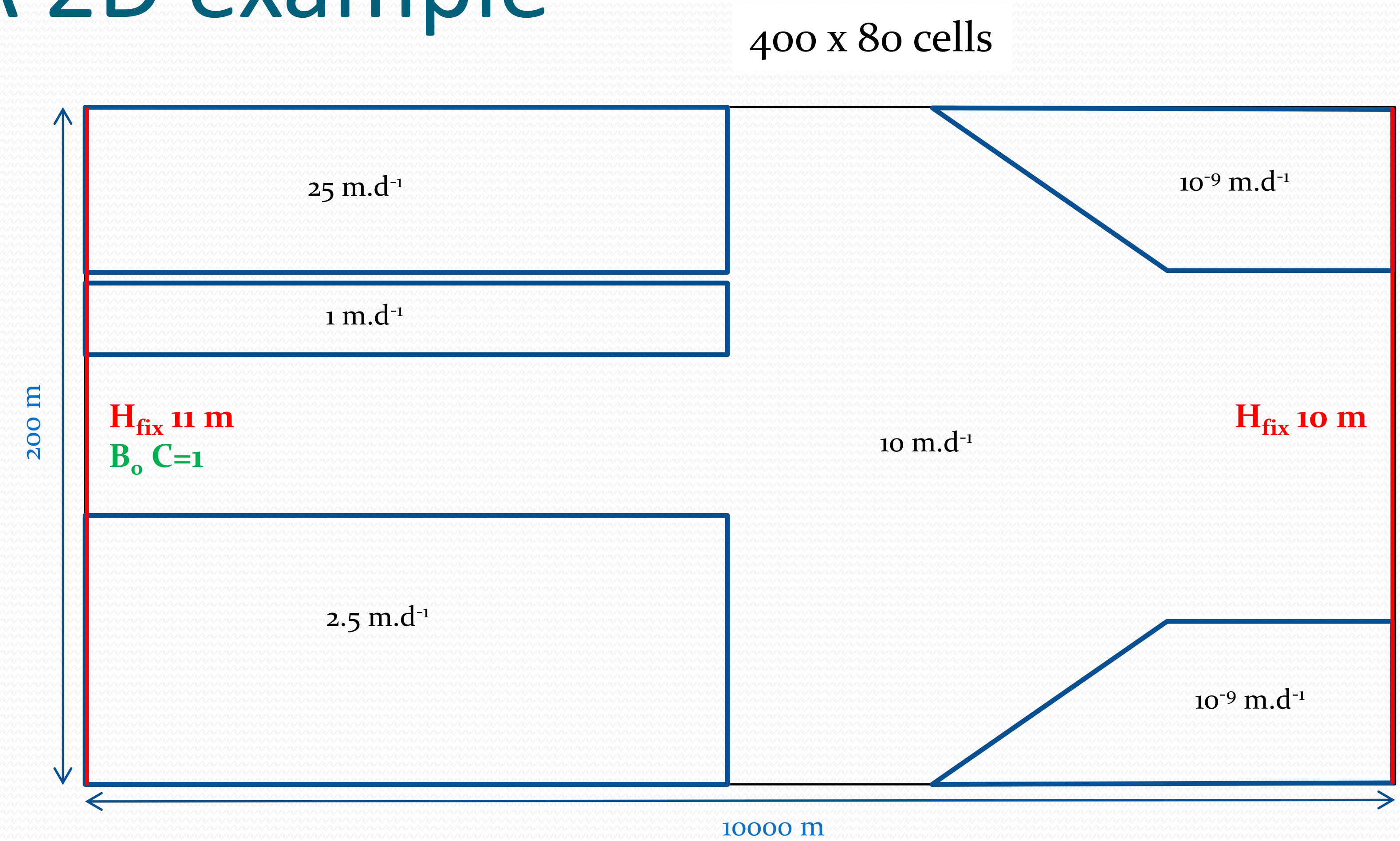
Using neighbors to solve non-uniqueness



The distribution is the weigthed sum of φ_{min} and φ_{max}.

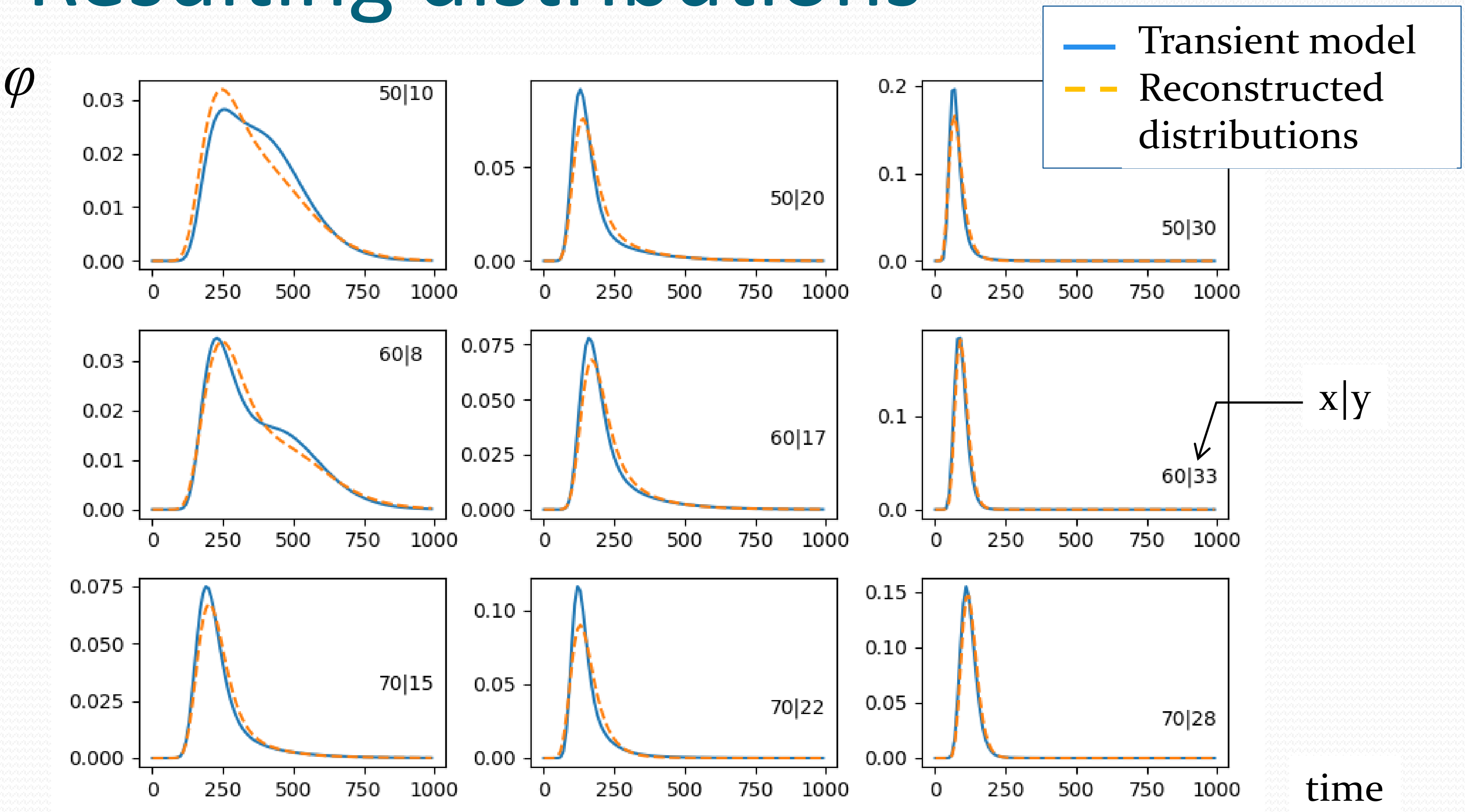
A very precise solver must be chosen

A 2D example



400 x 80 cells
25 m.d-1
1 m.d-1
2.5 m.d-1
10 m.d-1
10-9 m.d-1
10-9 m.d-1
H_{fix} 11 m
B_o C=1
H_{fix} 10 m
200 m
10000 m

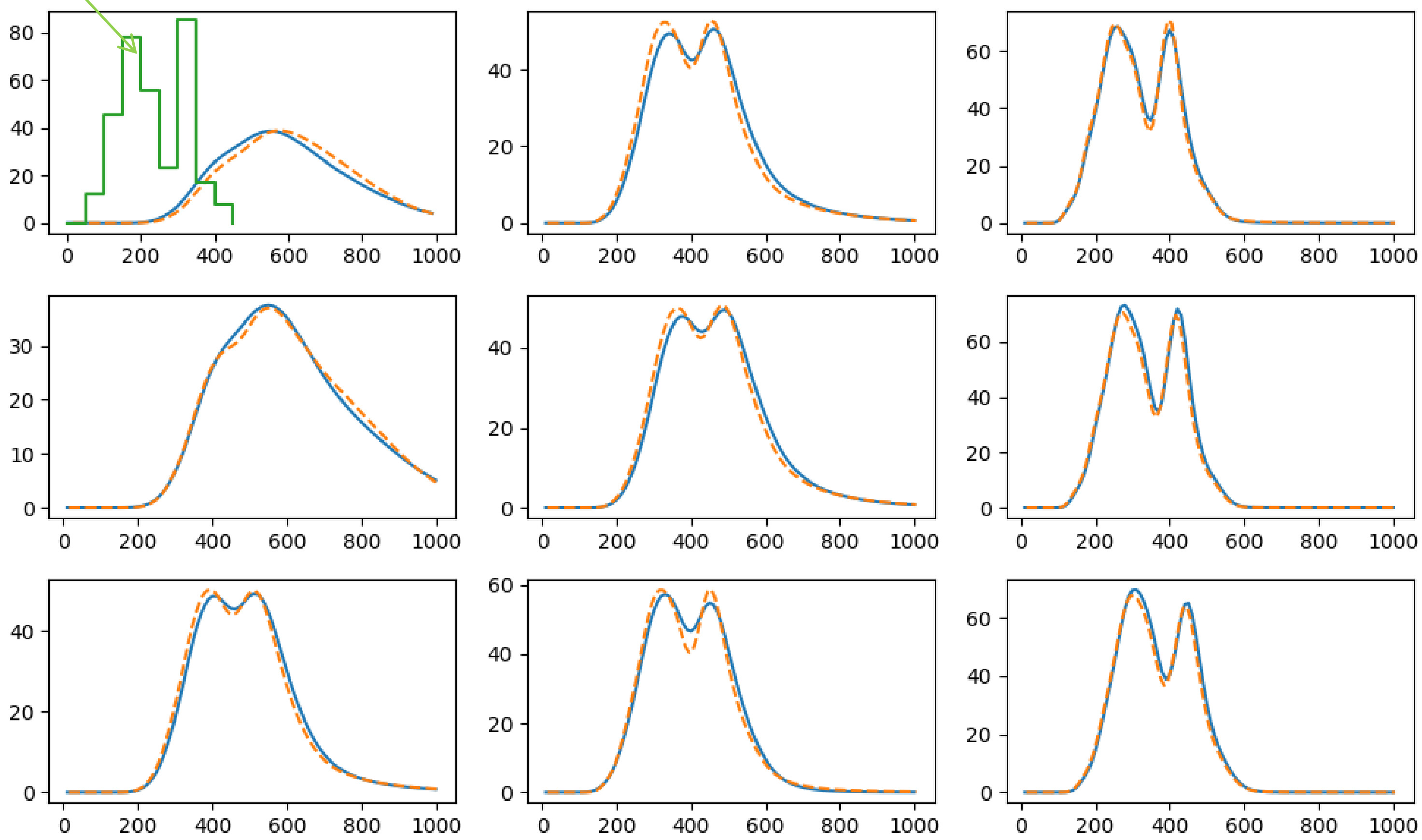
Resulting distributions



Tracer breakthrough by convolution

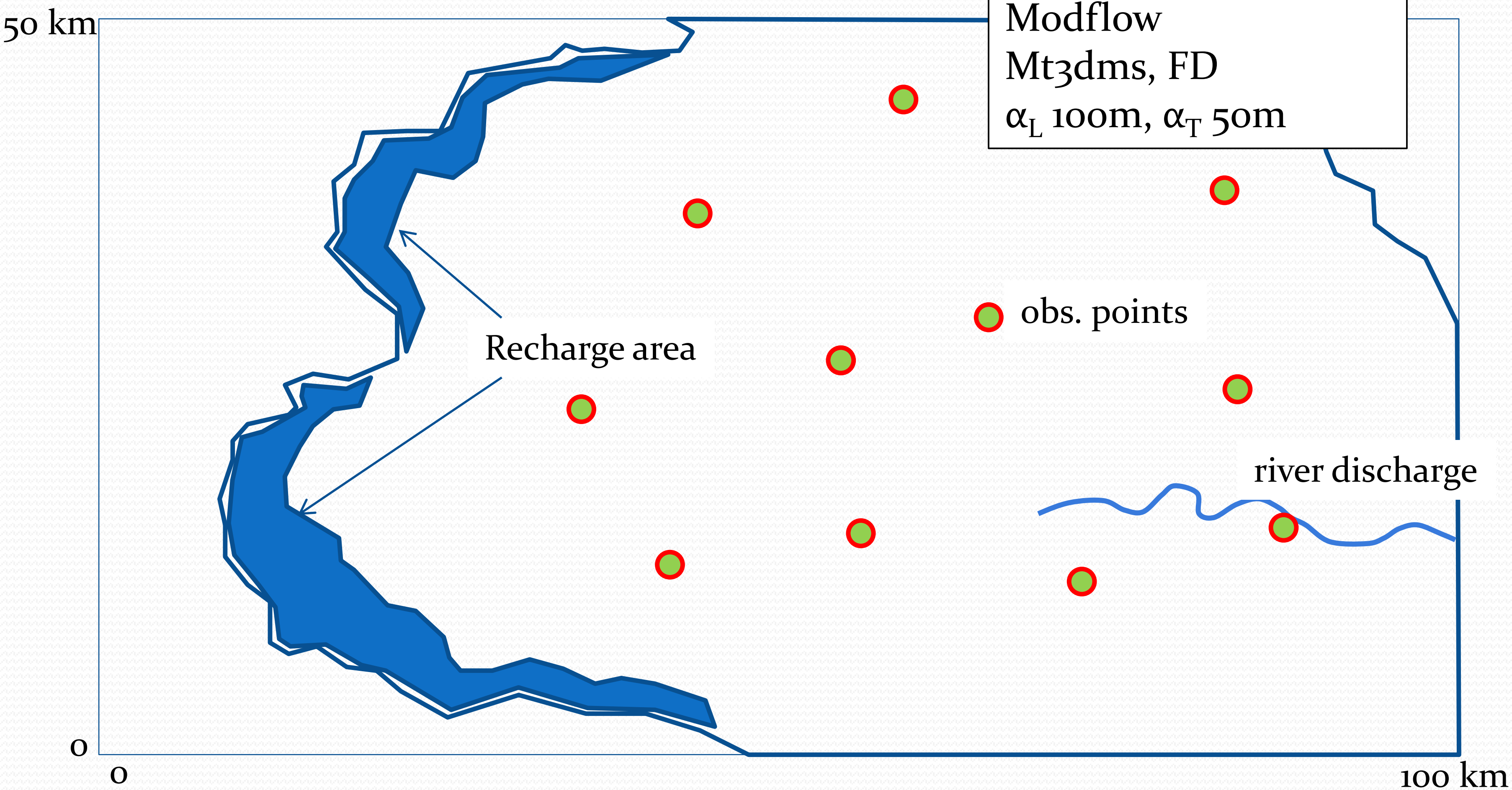
$$C(x,t)=\int_{0}^{t} C_{in}(\tau)\varphi(t-\tau)d\tau$$

Input curve (^3H?)

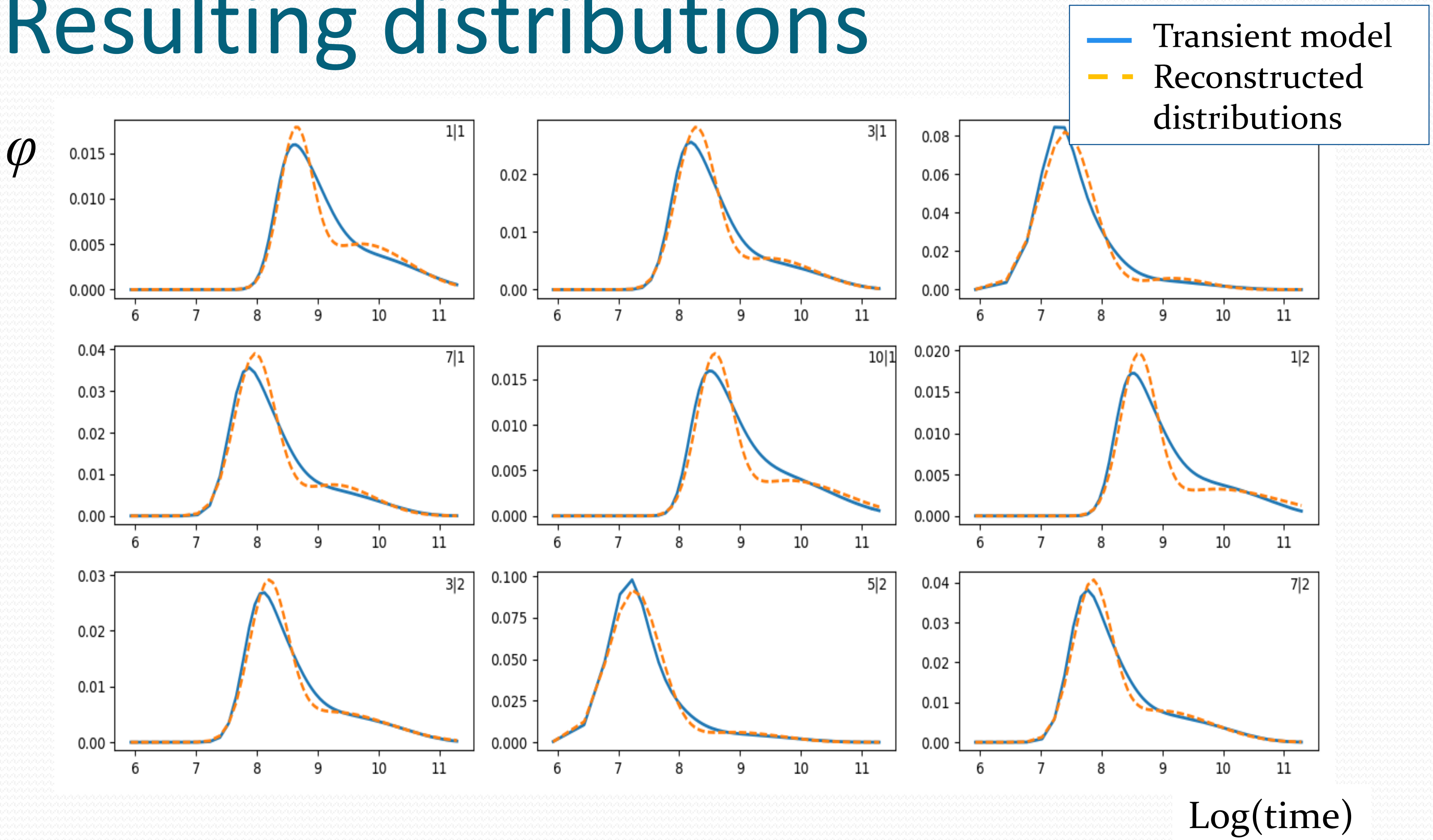


3D model

100 x 100 cells, 5 layers
80 000 years
Modflow
Mt3dms, FD
α_L 100m, α_T 50m

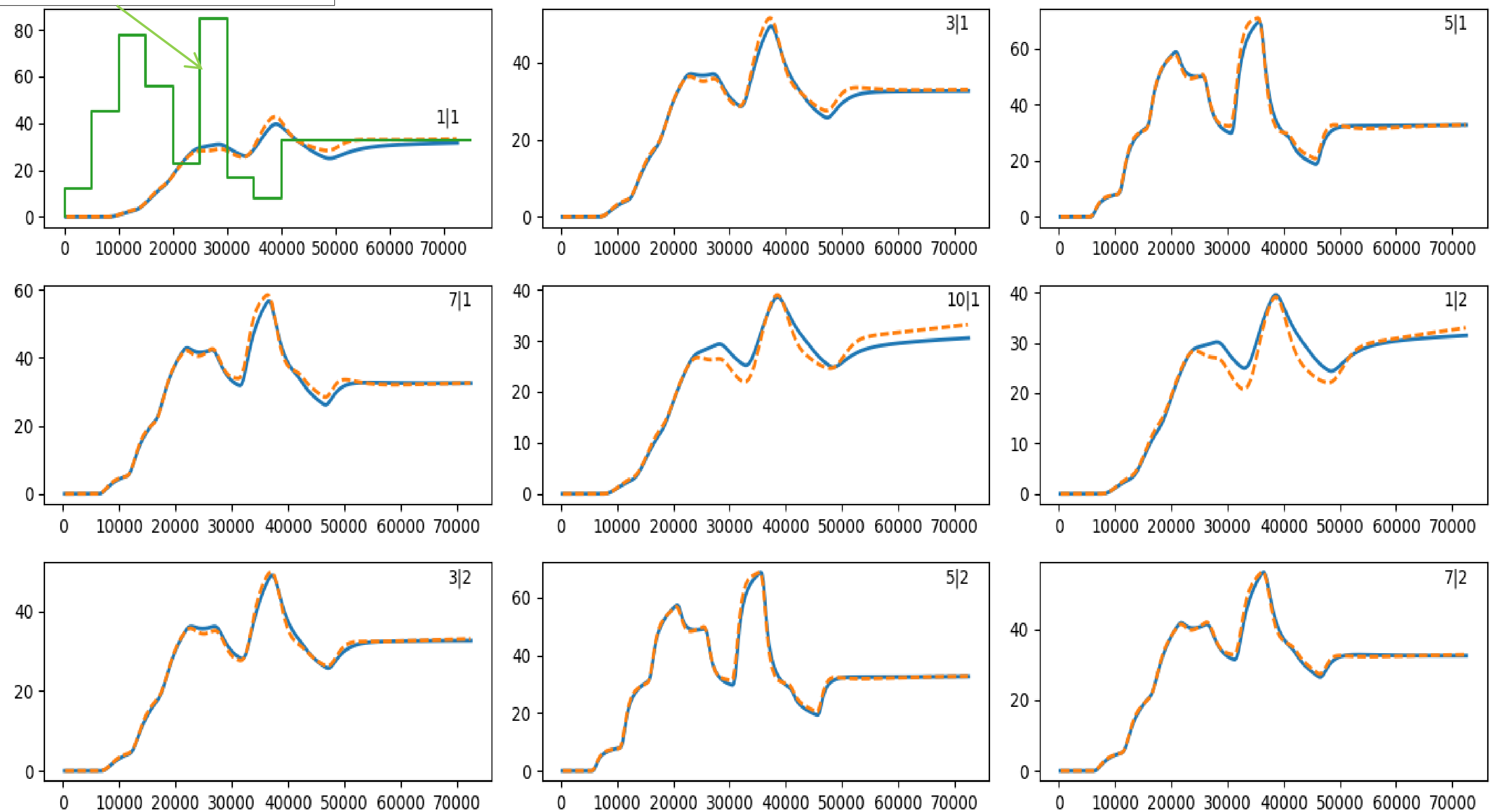


Resulting distributions



Tracer breakthrough by convolution

Input curve (^{18}O?)



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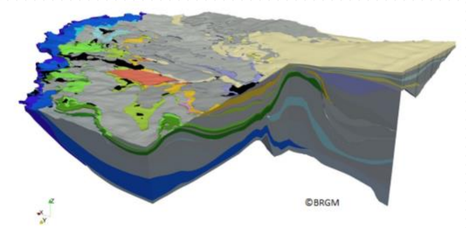
Calculation time

	2D fine	3D medium	3D fine
Nb of cells	64 000	50 000	1 250 000
Run time (min)			
Modflow transient	0.5	1.5	12
Modflow steady	0.1	0.3	1
Mt3dms transient	45	62	1100
Mt3dms steady	0.04	0.04	1.3
Curve fitting (10 pts)	0.02	0.02	0.02

Overall suggested process

Large flow model

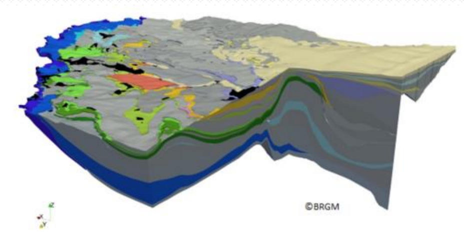


Large Transport model

Run steady state Transport

Overall suggested process

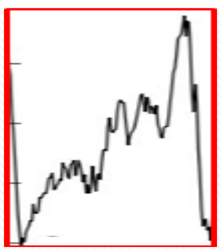
Large flow model



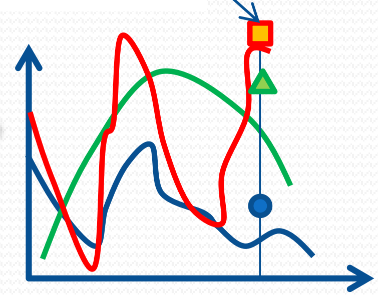
Large Transport model

Run steady state Transport

Input ${}^{18}O$, Ne, Xe… curve

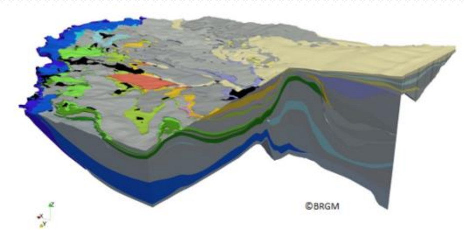


measured



Overall suggested process

Large flow model

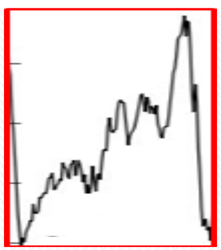


Large Transport model

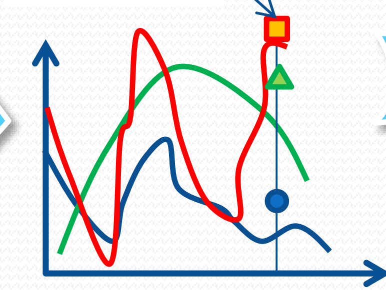
Run steady state Transport

Run steady state Flow

Input ^{18}O, Ne, Xe… curve



measured

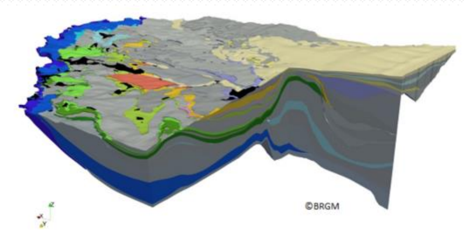


K field

PEST

Overall suggested process

Large flow model



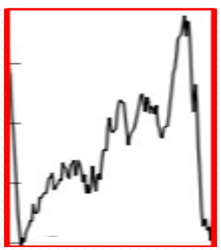
Large Transport model

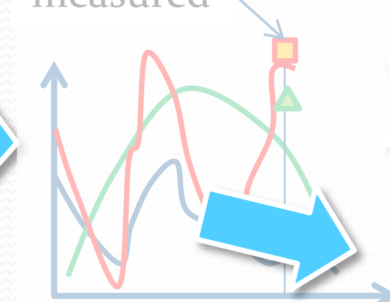
Run steady state Transport

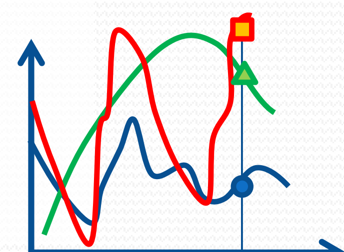
Run steady state Flow

PEST

Input ^{18}O, Ne, Xe... curve







Conclusions

- Steady state Mt3dms simulations can be used to retrieve age distributions
- Convolution of distribution provides local tracer transient curve
- Overall calculation < 1 min
- Can be used as a quite precise surrogate model for optimization
- Extension to kinetic reactions in dissolved phase possible
- Will soon be available as a plugin in Orti3d