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Hydrological controlled HOT SPOT Generation Mechanisms within a Wetland with Micro-topography: A Modeling Approach

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OUTLINE

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1. *Background and Motivation*
2. *Synthetic Wetland Model*
   a) Micro-topography & Model Set Up
   b) Runoff Generation Mechanisms
   c) Subsurface Flow Patterns & Residence Times
3. *Biogeochemical Modelling*
   a) Stream Tube Approach
   b) Hot Spot Generation Mechanisms
4. *Problems and Limitation*
   a) Modelling Efficiency
   b) Alternatives: Rill Storage Height Variations
5. *Conclusions and Outlook*

BACKGROUND

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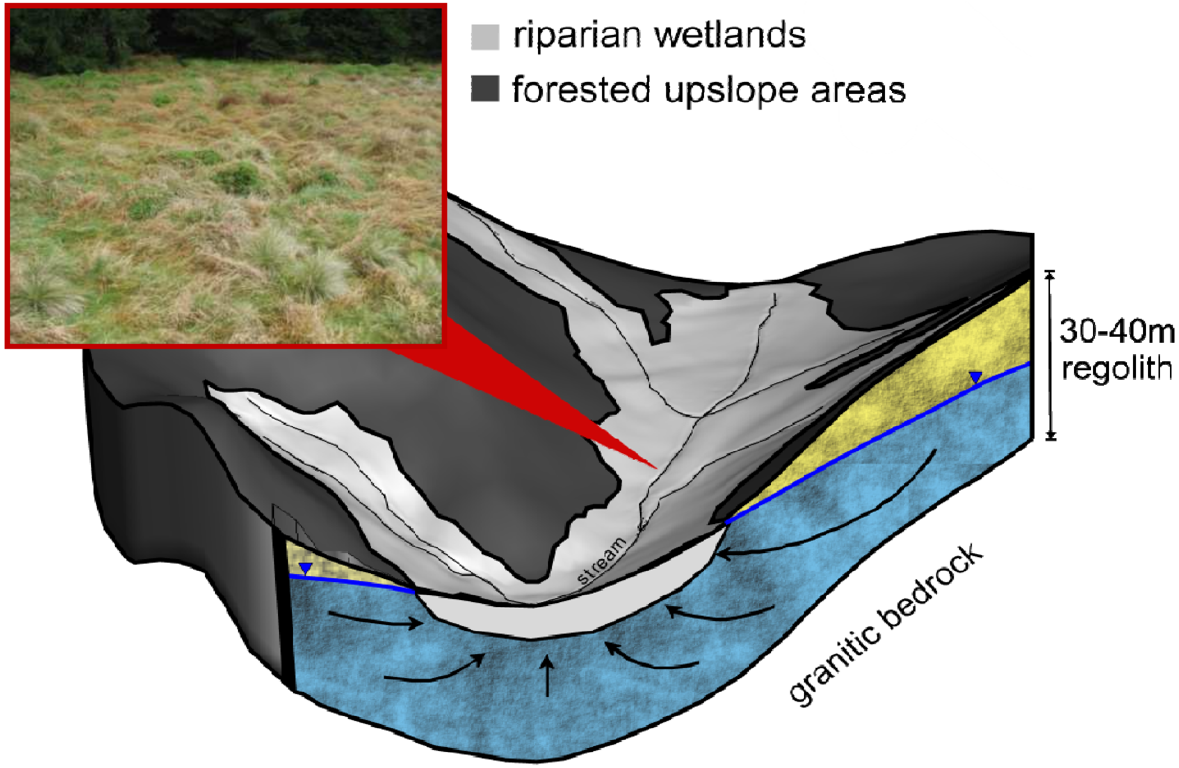
Lehstenbach Catchment:

- ~4.2 km²; located in North-Eastern Bavaria
- 1/3 of area: riparian wetlands
- areas control event runoff generation & water quality (earlier studies)
- wetlands show pronounced micro-topographical structures (***hollow*** & ***hummock*** structures)



influence of micro-topography on

✓ runoff generation
✓ subsurface flow patterns
✓ biogeochemical settings

modeling studies

SYNTHETIC WETLAND

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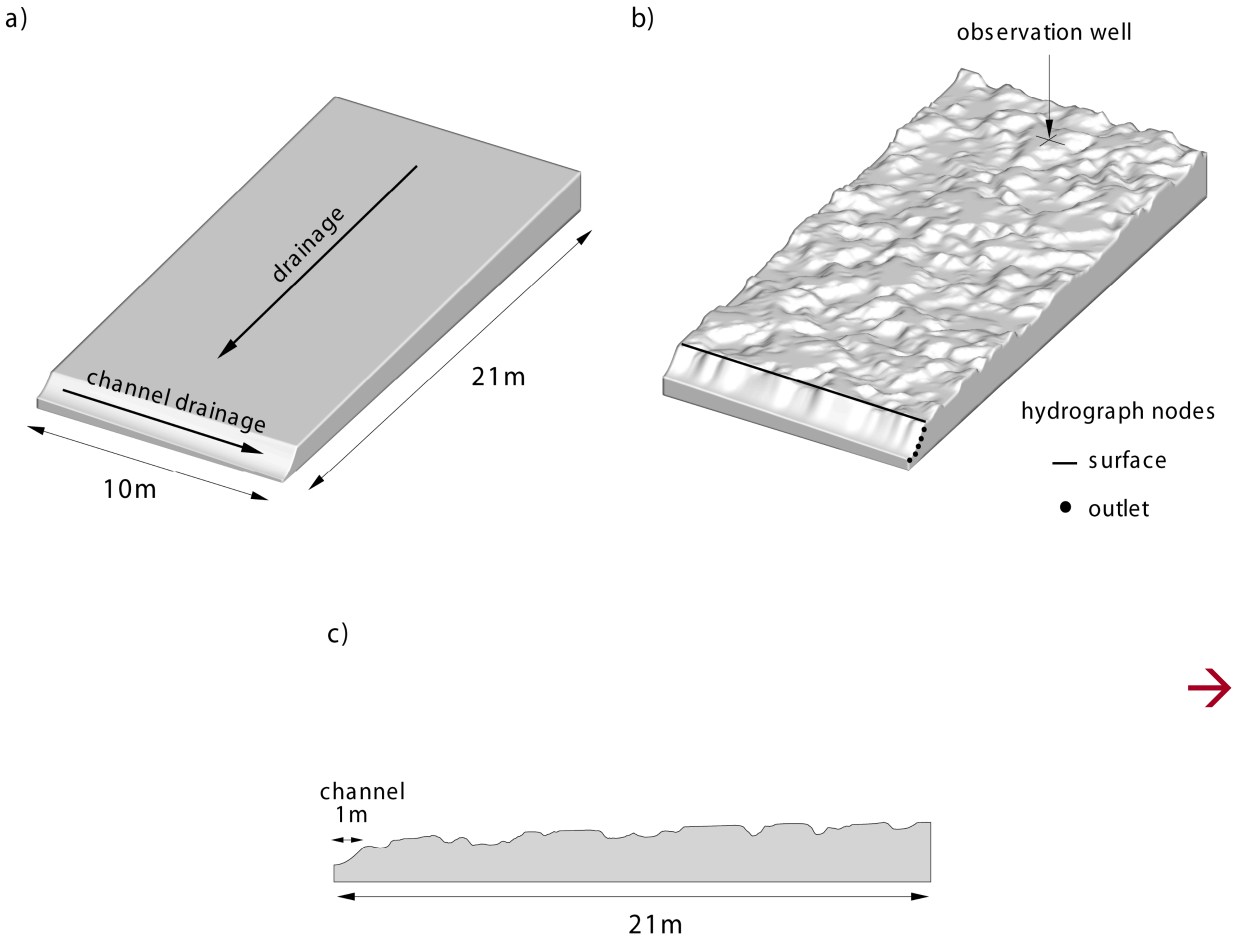
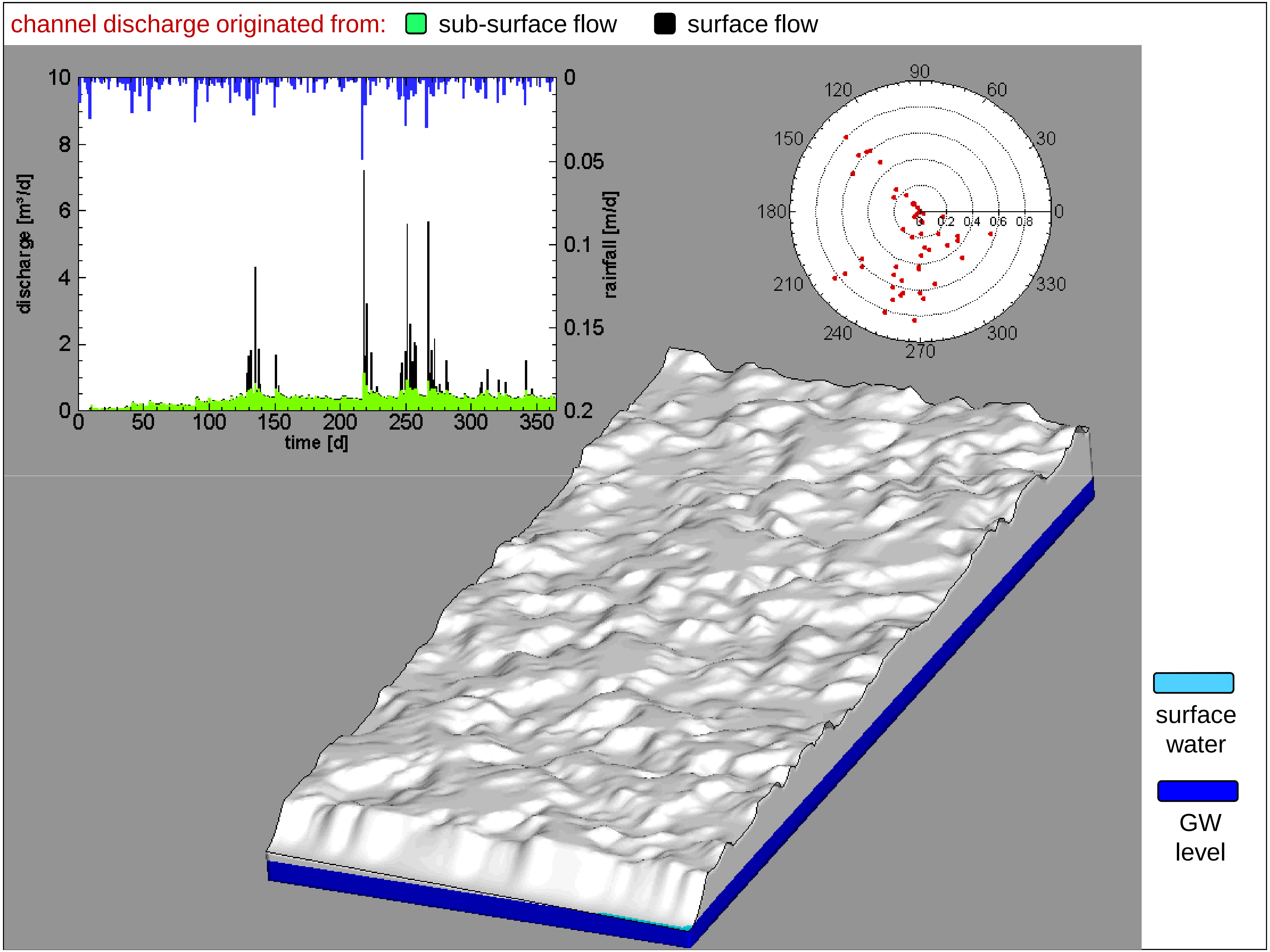


- *geostatistical generated micro-topography*
  - *indicator based geostatistics (TPROGS)*
- *numerical flow model (Hydreogeosphere):*
  - *variably saturated flow (3D Richards Eq.)*
  - *surface flow (diffusive wave approx.)*

→ only surface heterogeneity
no
material heterogeneity


channel discharge originated from:
sub-surface flow
surface flow
discharge [m³/d]
rainfall [m/d]
time [d]
0
50
100
150
200
250
300
350
0
2
4
6
8
10
0
0.05
0.1
0.15
0.2
90
60
30
0
330
300
270
240
210
180
150
120
0.2
0.4
0.6
0.8
surface water
GW level

EVENT - RUNOFF GENERATION

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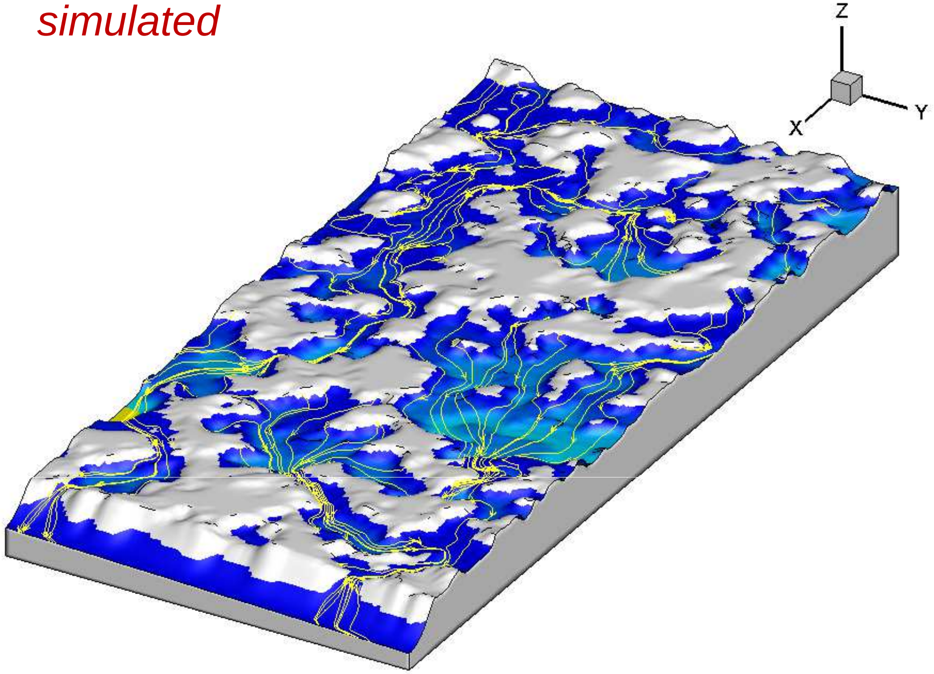
simulated



high flow → formation of surface flow networks

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Effects of micro-topography on surface–subsurface exchange and runoff generation in a virtual riparian wetland — A modeling study

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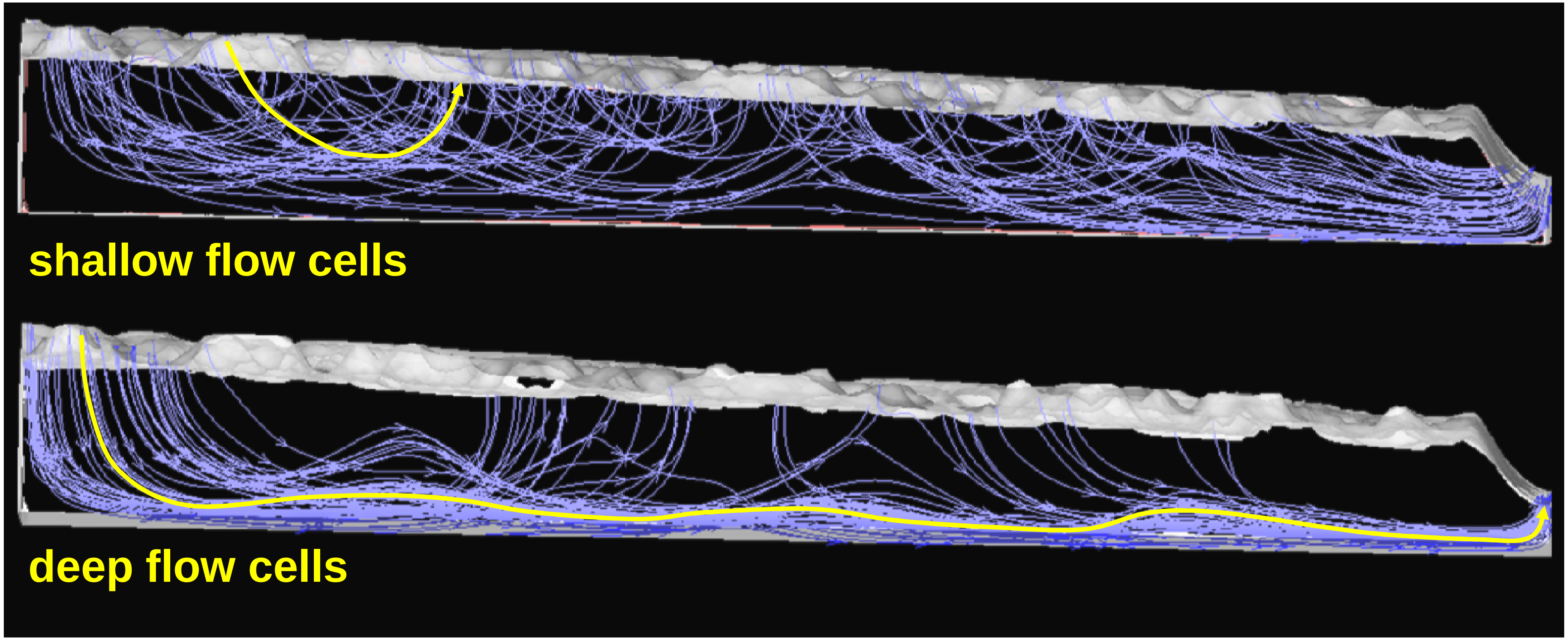
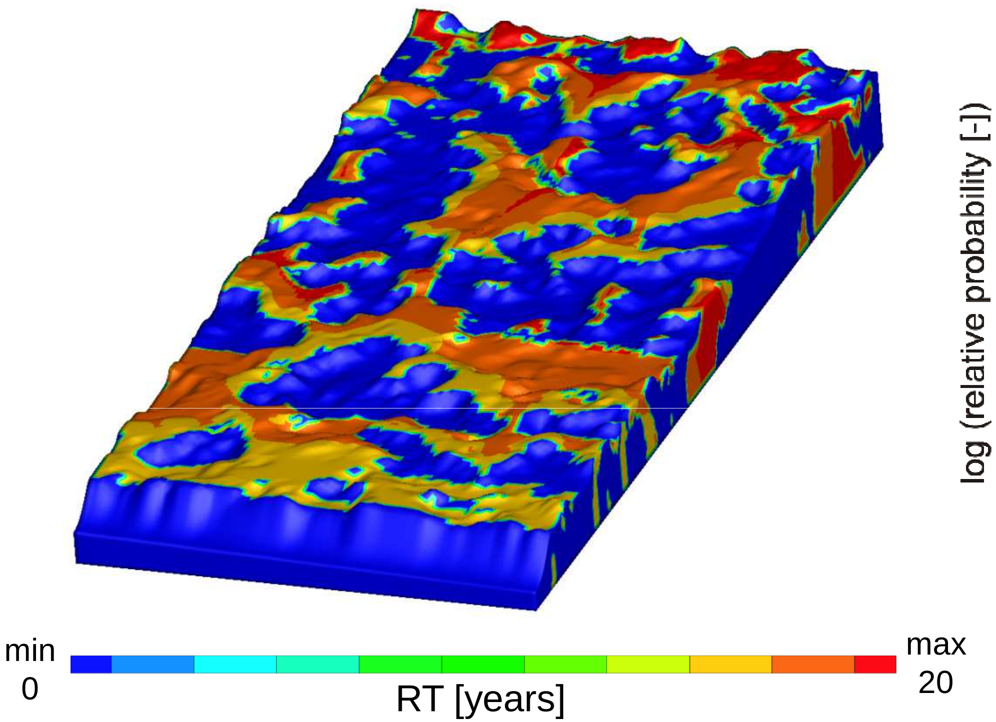
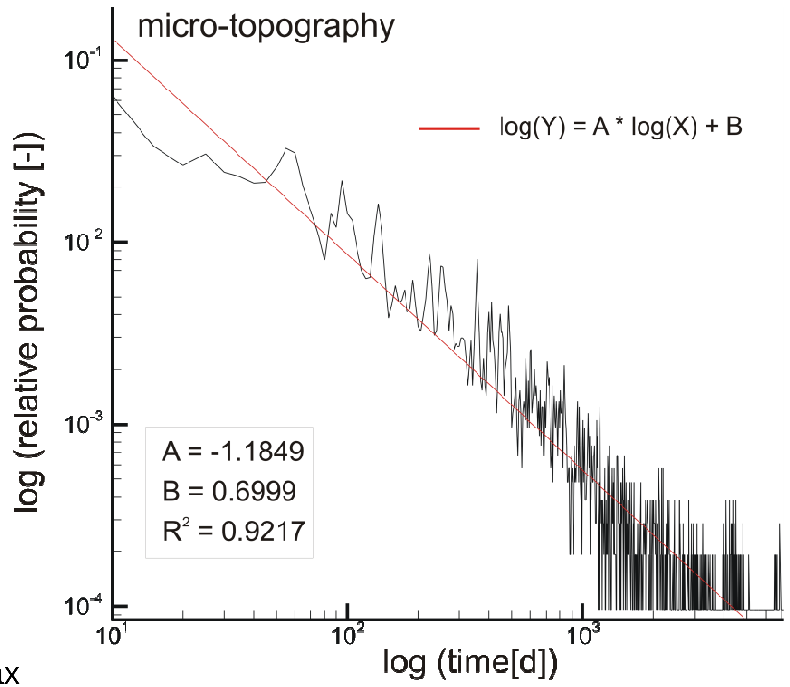
SUBSURFACE FLOW PATTERNS



coexisting flow systems (deep/shallow)
→ induced by micro-topography

SUBSURFACE RESIDENCE TIMES





micro-topography → power law distributed RT
→ significance for biogeochemistry???

COUPLING HYDROLOGY & BIOGEOCHEMISTRY

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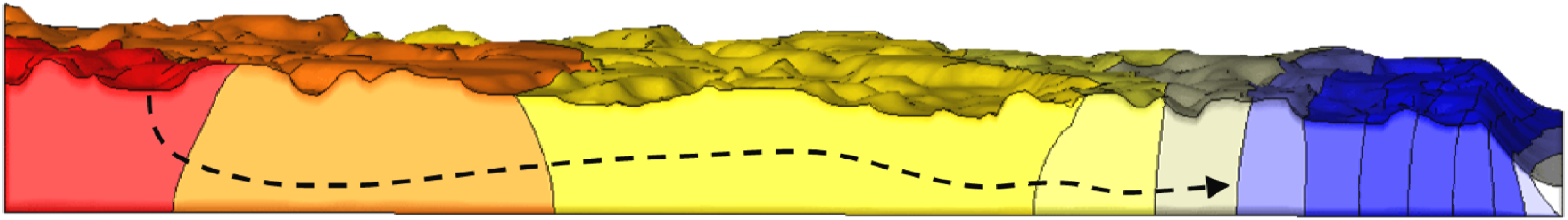
3D transient head field



particle tracking

infiltration

aerob. respiration

denitrification

Fe-reduction

SO_4-reduction

nitrification

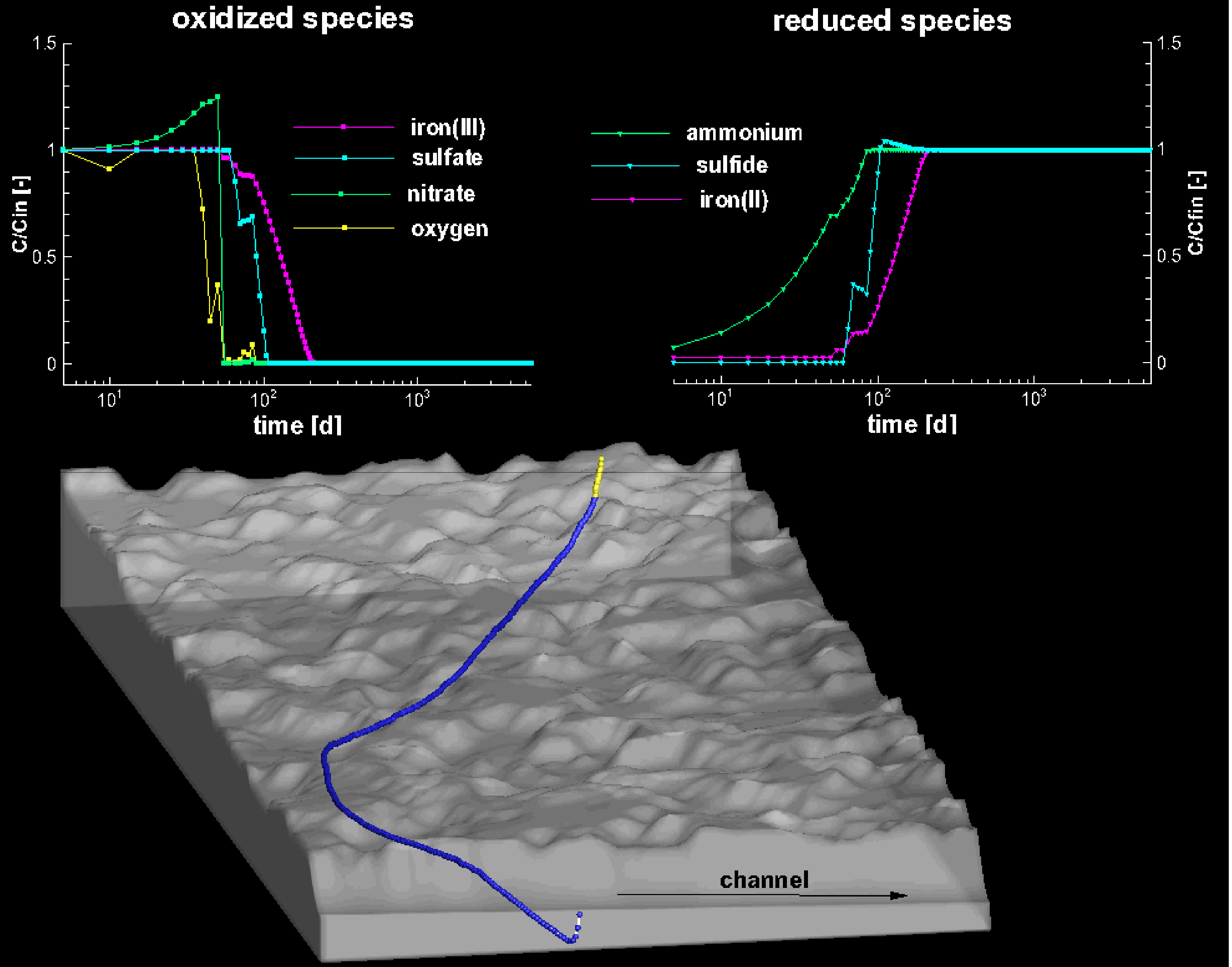
Fe II oxidation

sulfid oxidation

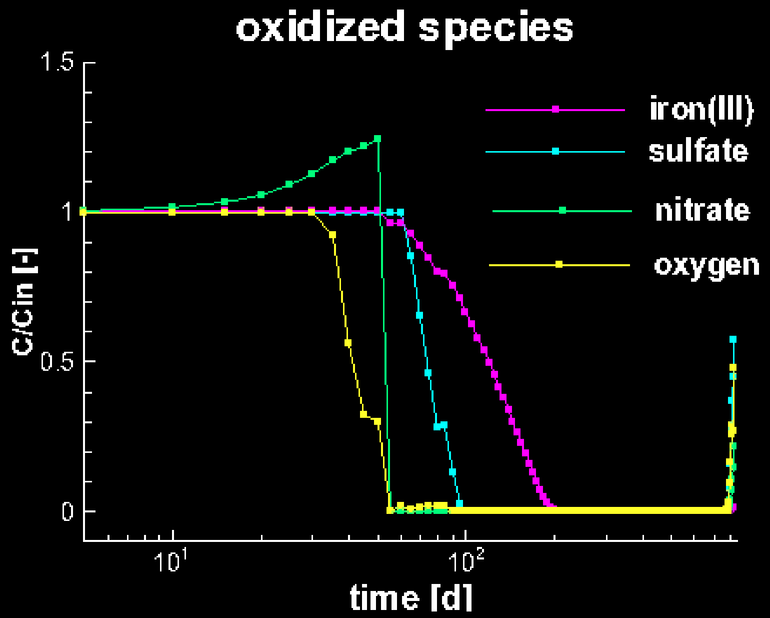
exfiltration

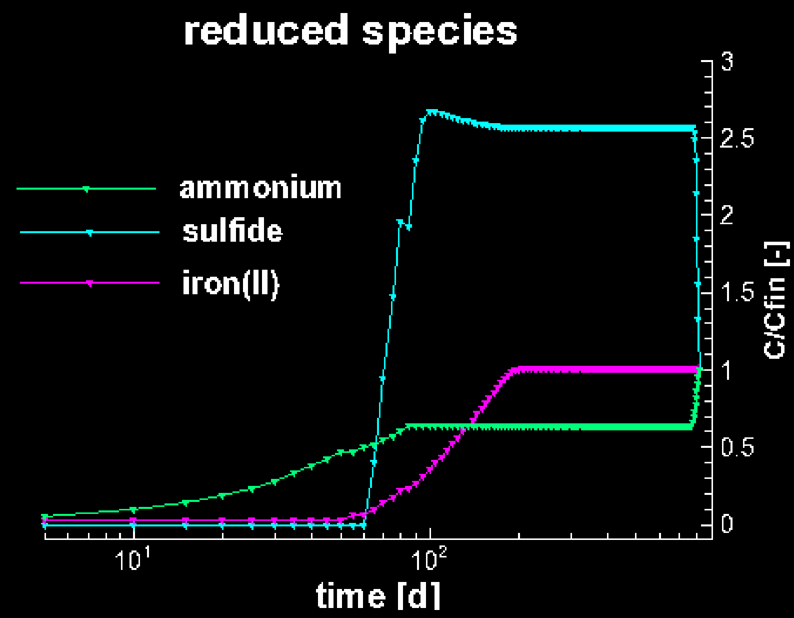
reduction	oxidation

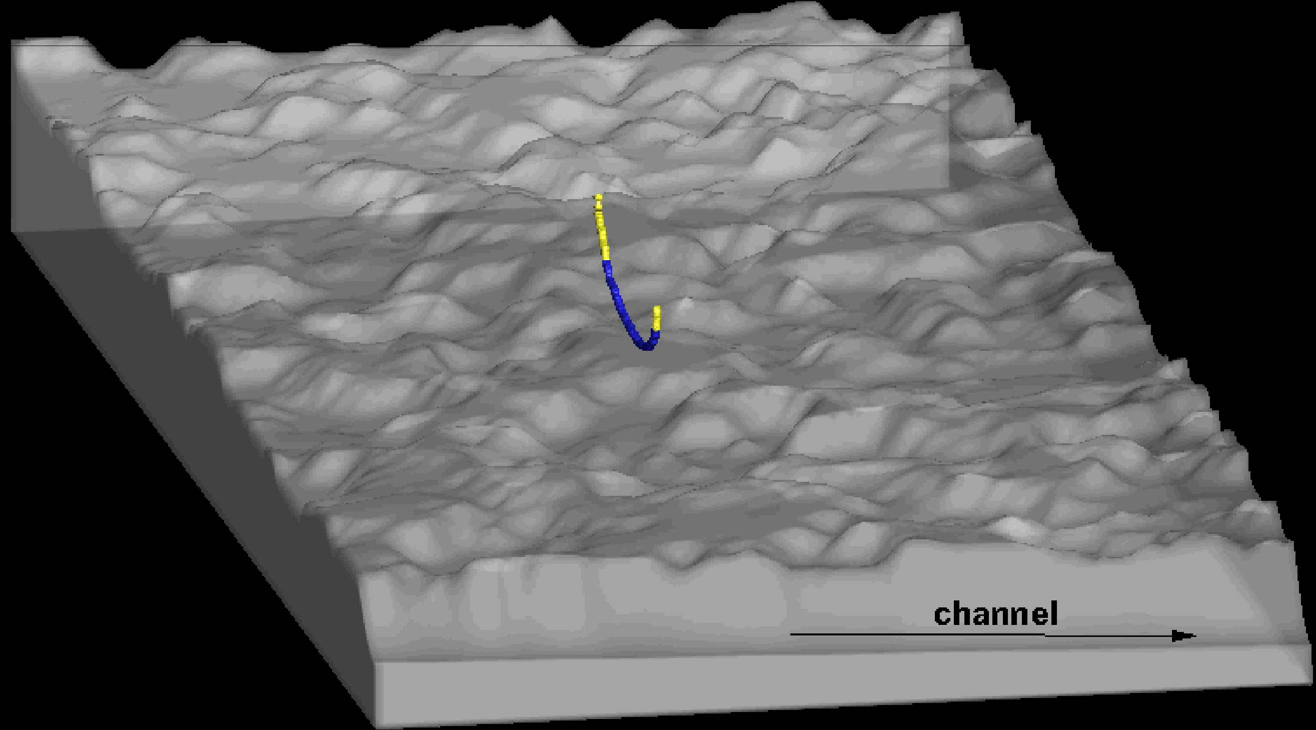
→ *wetland typical redox processes represented in PhreeqC*



deep
flow
cells







shallow
flow
cells

Subsurface Flow Paths

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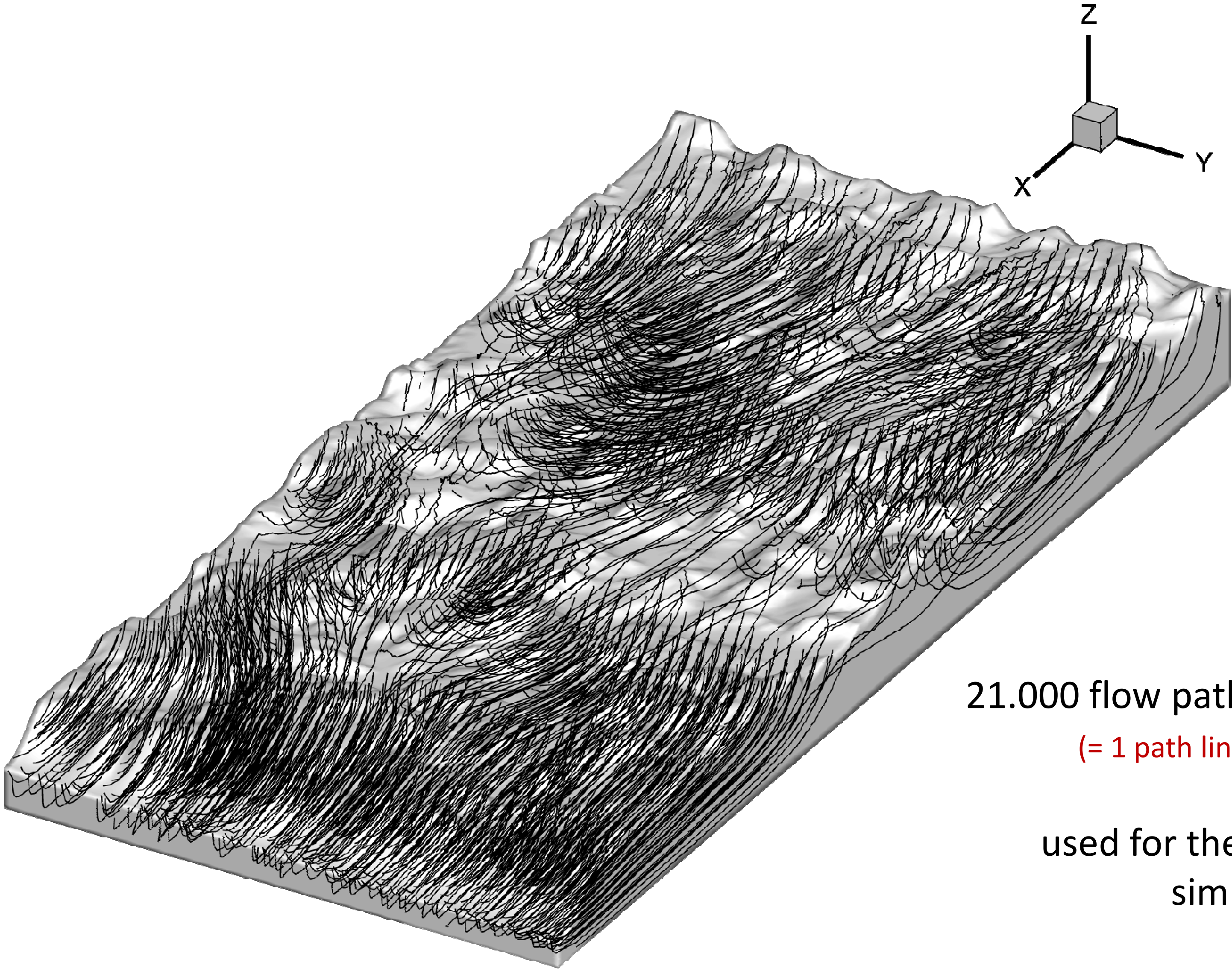

21.000 flow path lines were isolated

(= 1 path line per surface node)

and

used for the biogeochmical simulations

Sulfate – Reduction: $SO_4^{2-} + C_{org} \rightarrow S^{2-}$

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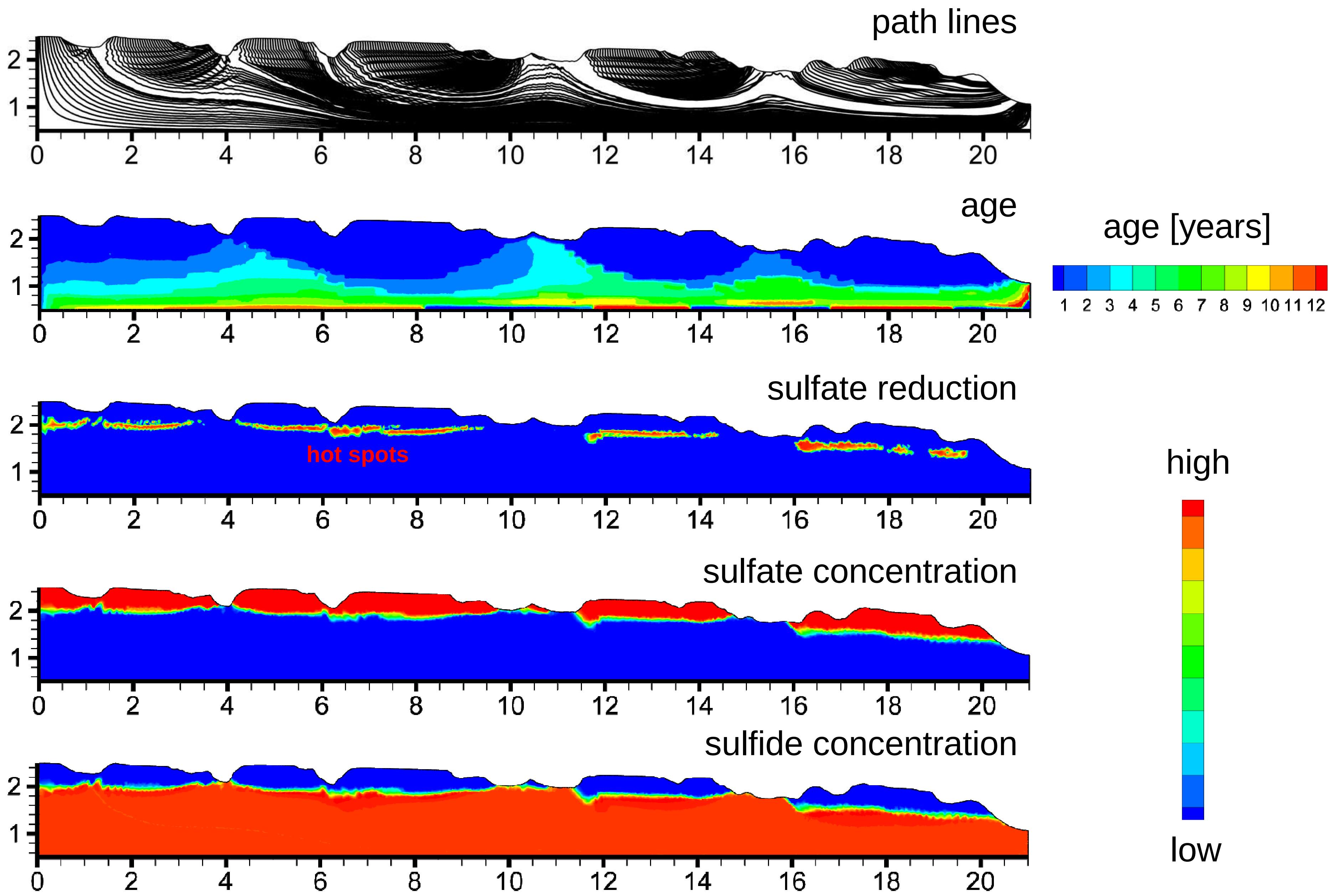

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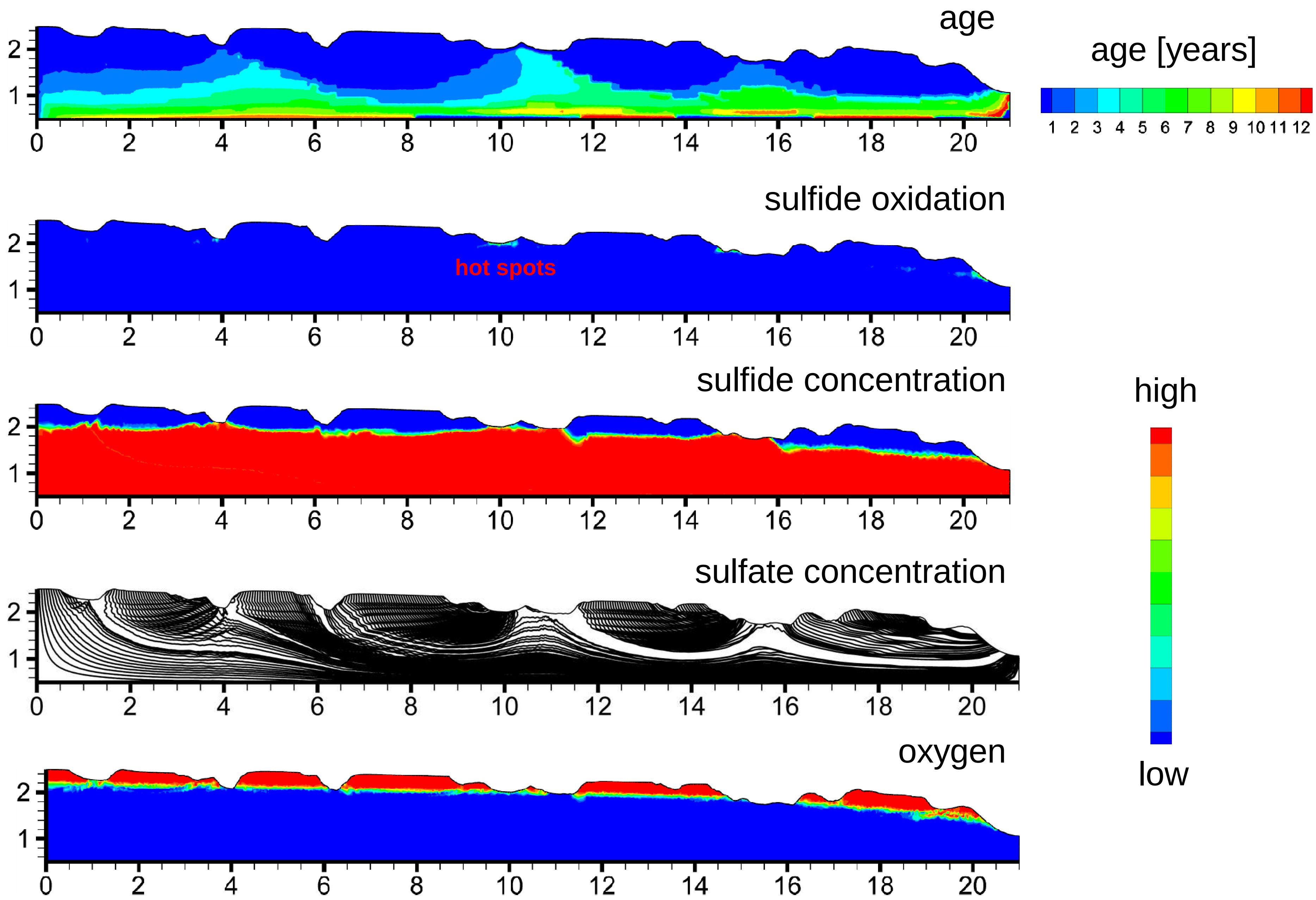
Sulfide – Oxidation: $S^{2-} + O_2 \rightarrow SO_4^{2-}$



Sulfate – Reduction: $SO_4^{2-} + C_{org} \rightarrow S^{2-}$

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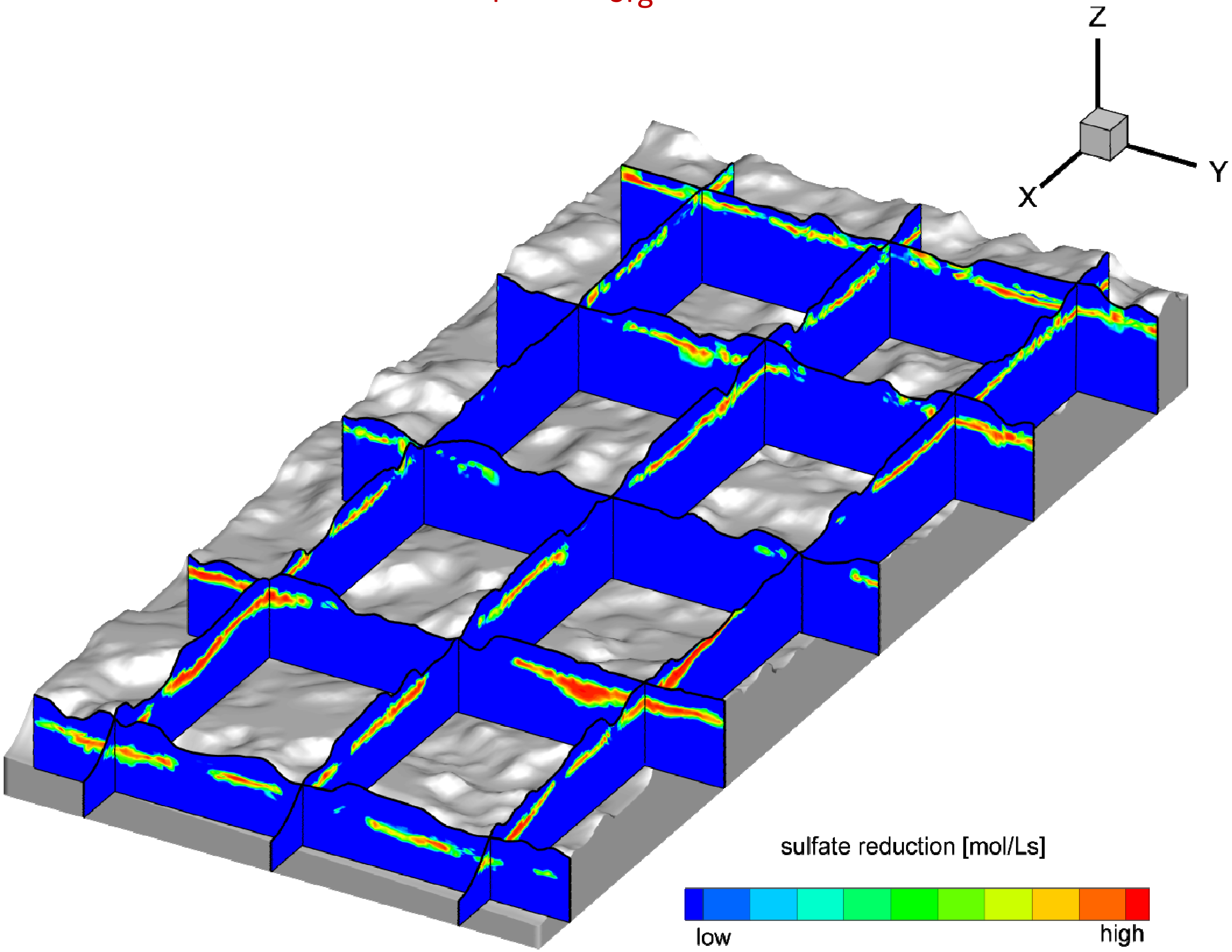
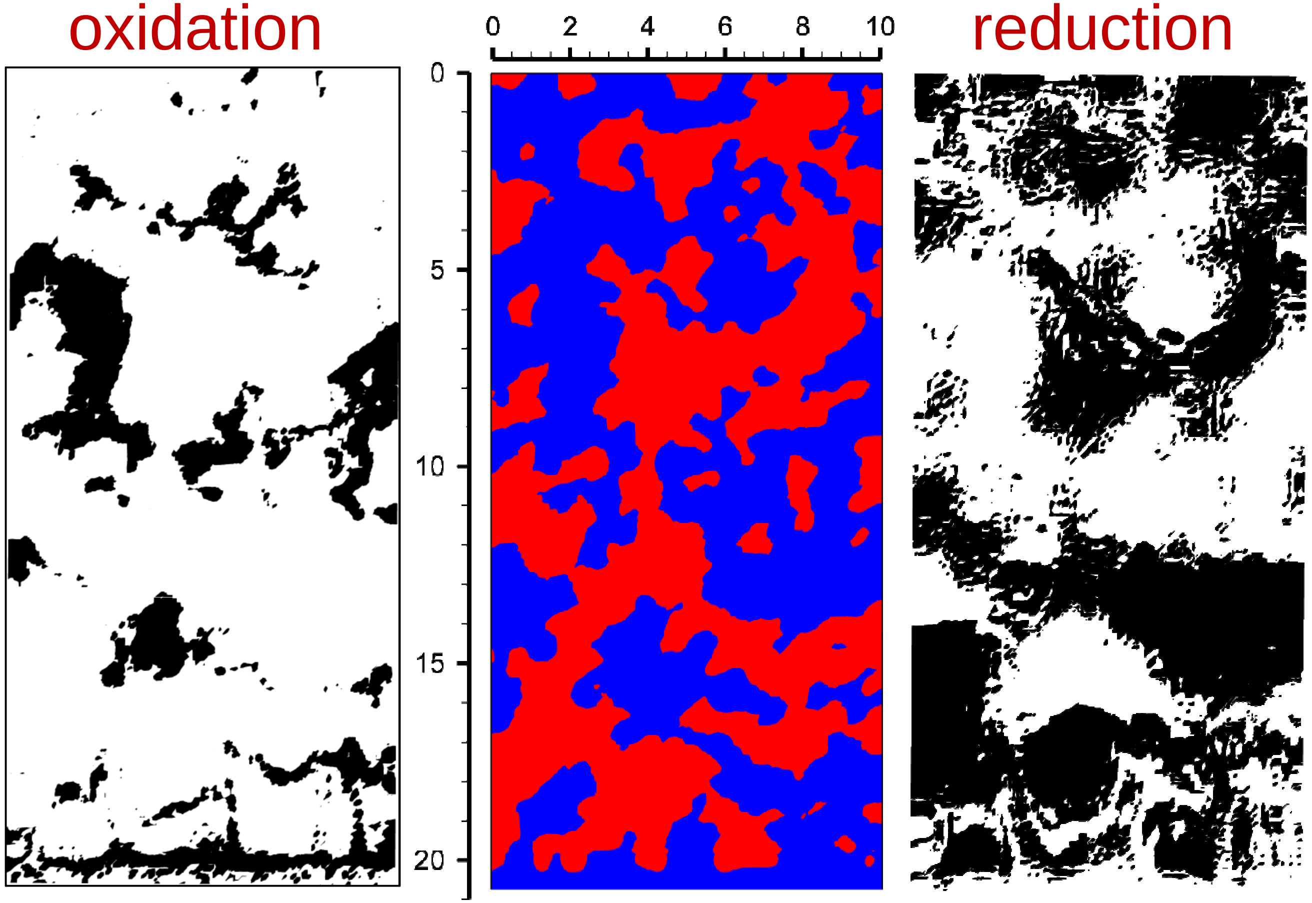


oxidation | reduction



hollows

hummock - structures

hot spots
process activity

→hot spots below depressions

→hot spots below hummocks

Fe(II)-Profiles:

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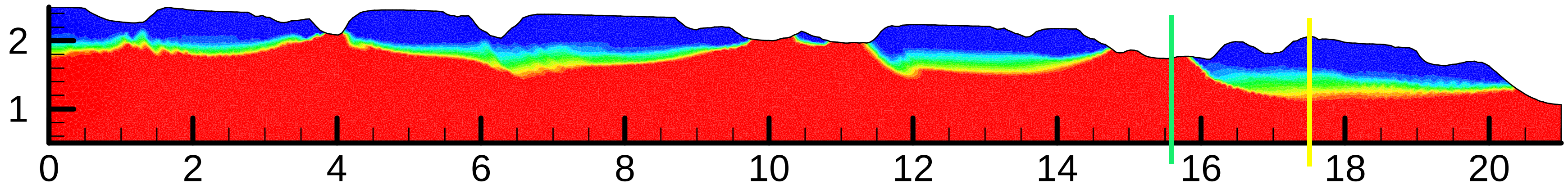

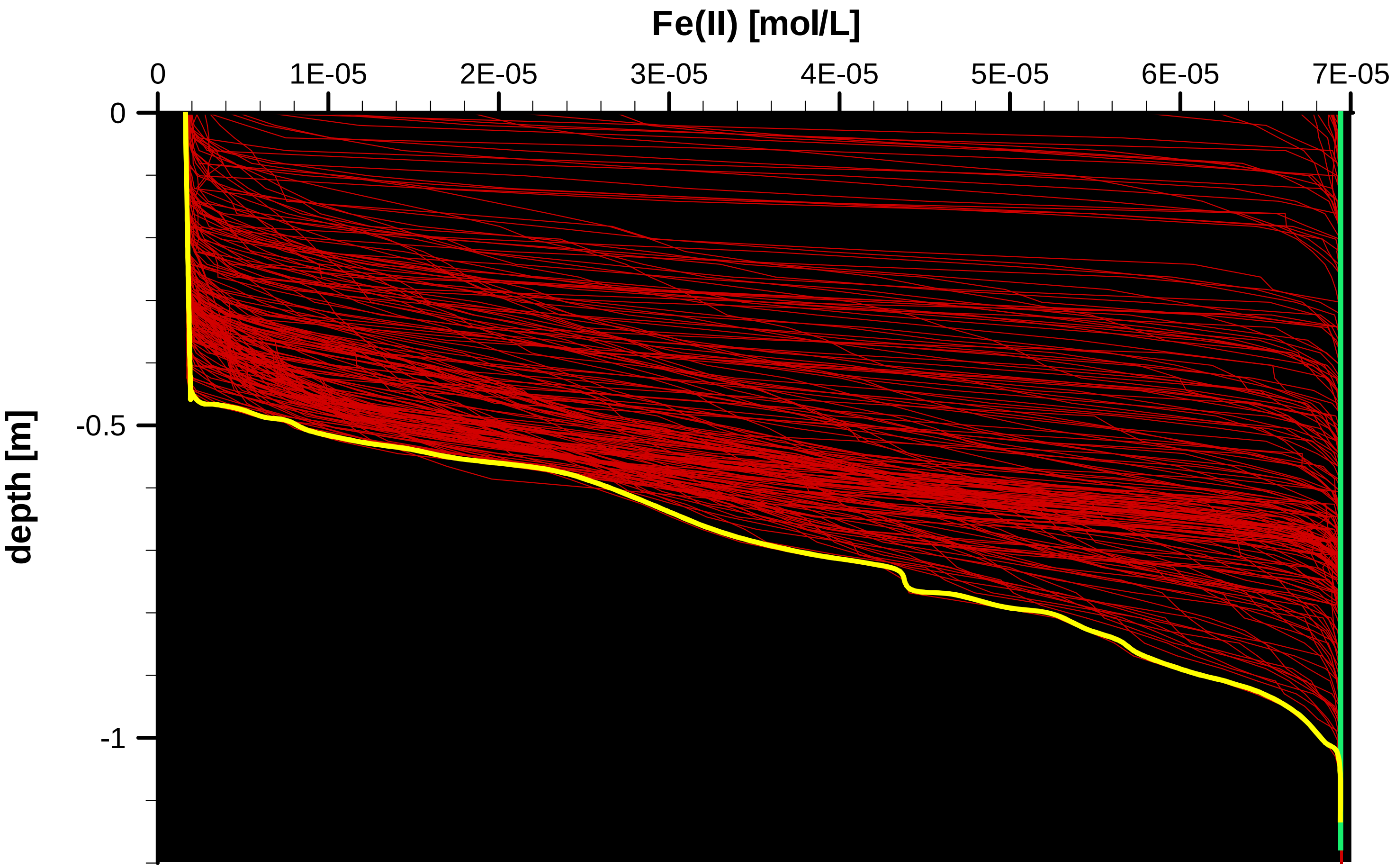

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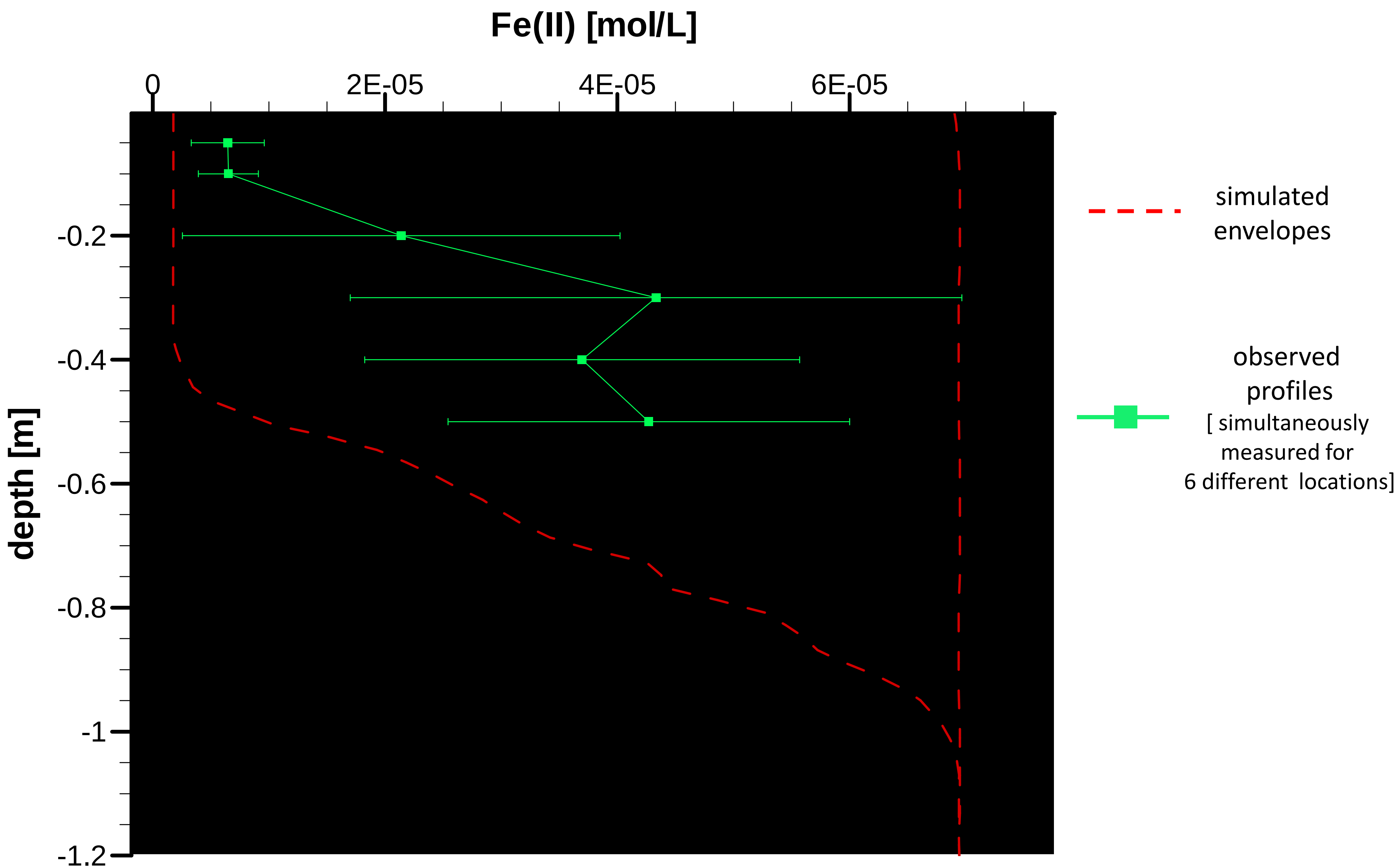
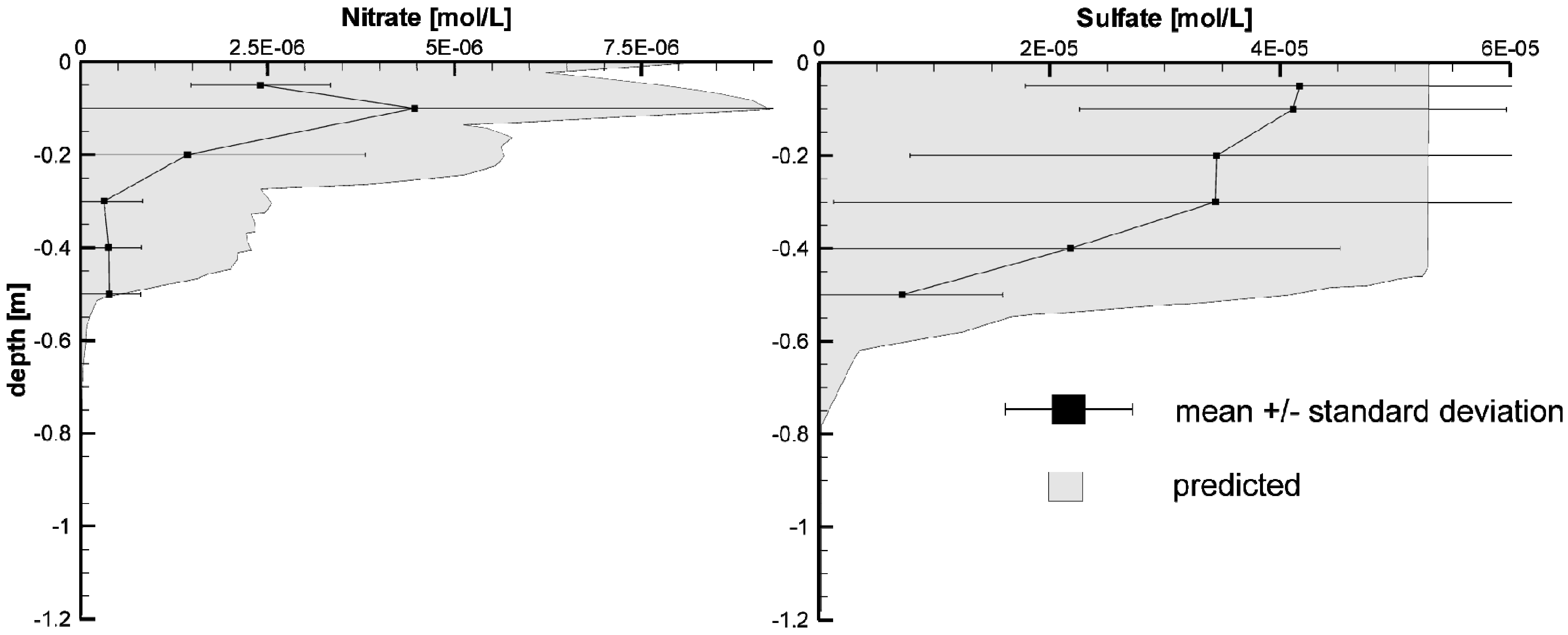
Fe(II)-Profiles:



Nitrate & Sulfate - Profiles:



→ *field variations can be approximated*

SIMPLIFICATIONS

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→ effect of vegetation (root water uptake / ET) not implemented

→ no interactions between subsurface flow path lines → *no dispersion*

→ organic carbon source for microbial catalyzed redox reactions unlimited available within the current modeling approach

→ iron(III) species is treated as a solute affected to transport processes and not as immobile compounds bound to the peat matrix

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MODEL EFFICIENCY

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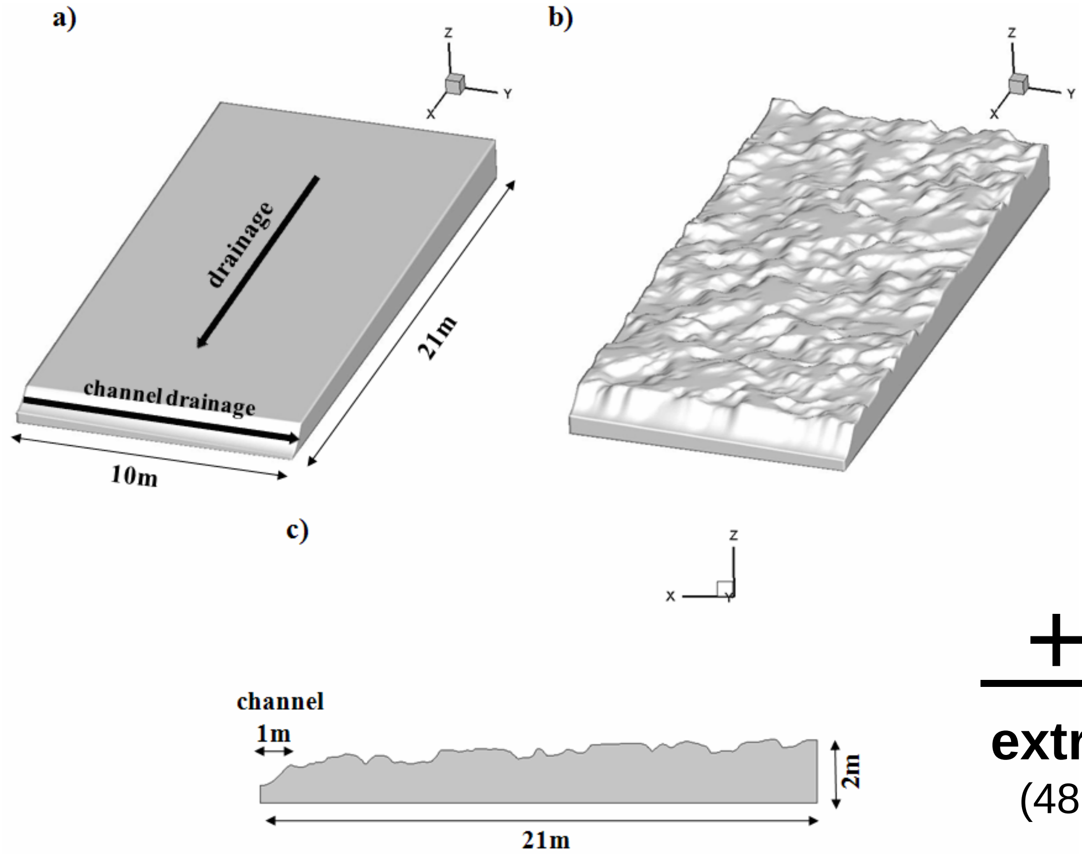

complex subsurface flow

variably saturated flow

integrated surface runoff

complex surface runoff
(surface flow networks)

high grid resolution
(231.000 nodes)

\+ non-parallel version of HGS

extremly long computation times
(48 days for a yearly simulation scenario)

How to speed it up???

reduction of grid resolution without loosing too much process complexity
→ rep. micro-topography by superficial rill storage height variations

RILL / DEPRESSION STORAGE

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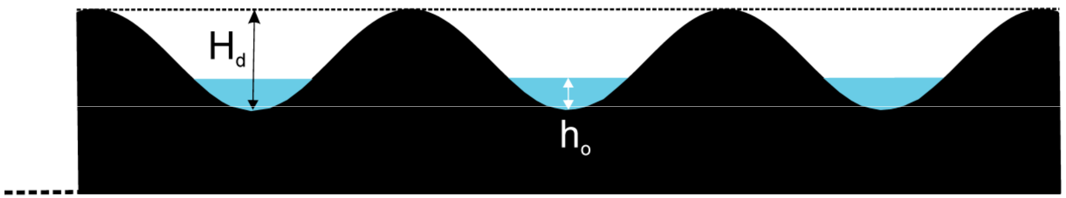
Definition (HGS Manual):

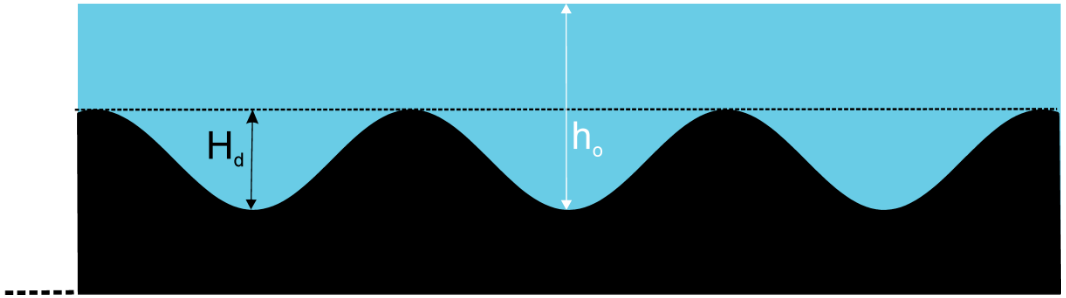
It represents the amount of storage that must be filled before any lateral surface flow can occur. Microtopographic relief, relative to the scale of the finite elements in the grid, is included in rill storage and can have a substantial impact on hydrograph shape [*Woolhiser et al.*, 1997].

h_o <= H_o ⟶ no lateral surface flow



→ implemented within HGS to account for *surface flow retention* due to micro-topography and/or vegetation

h_o > H_o ⟶ lateral surface flow



H_d: rill storage height [L]

h_o: ponded water depth [L]

SUPERFICIAL RILL STORAGE VARIATIONS

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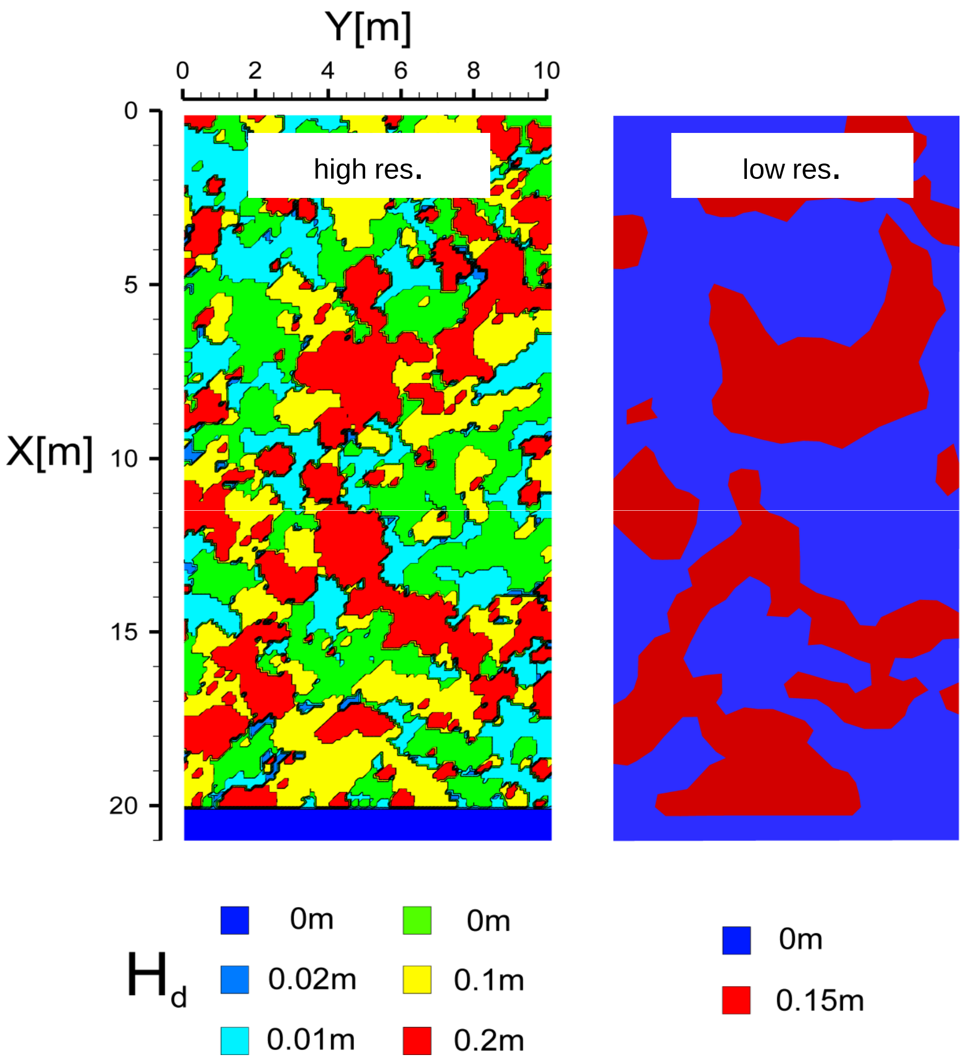

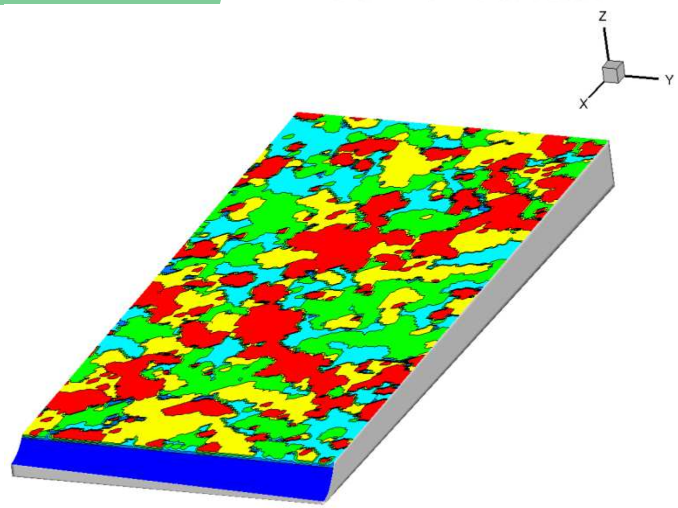

Two different models:

1) *high resolution + rill storage variation*
   (231.000 nodes; planar)
2) *low resolution + rill storage variation*
   (20.900 nodes; planar)

VS.

→ *original micro-topography model*
(231.000 nodes; 3D micro-topo)

→ *planar reference*
(231.000 nodes; planar without rill storage variation)

EVENT - RUNOFF GENERATION

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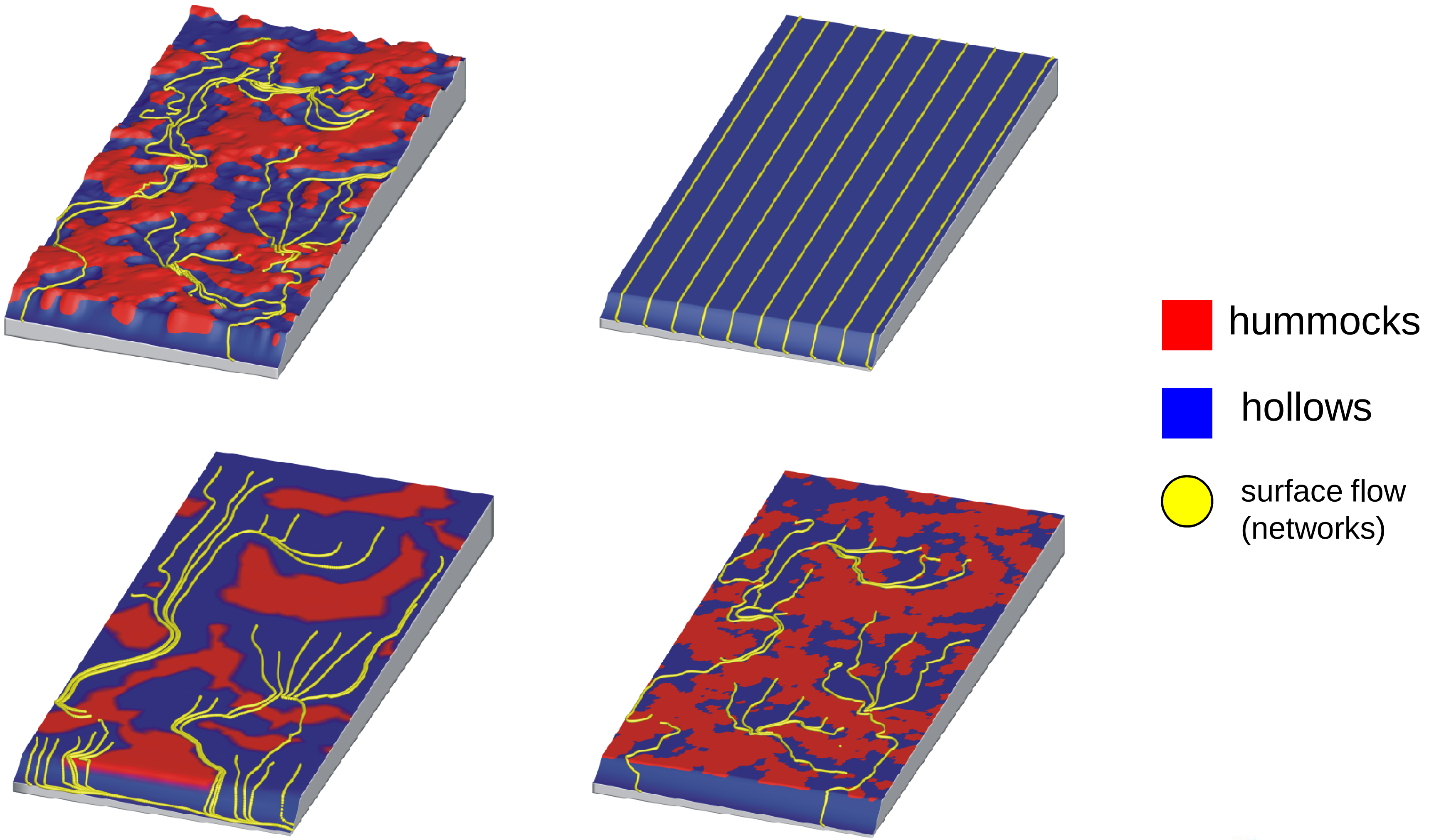
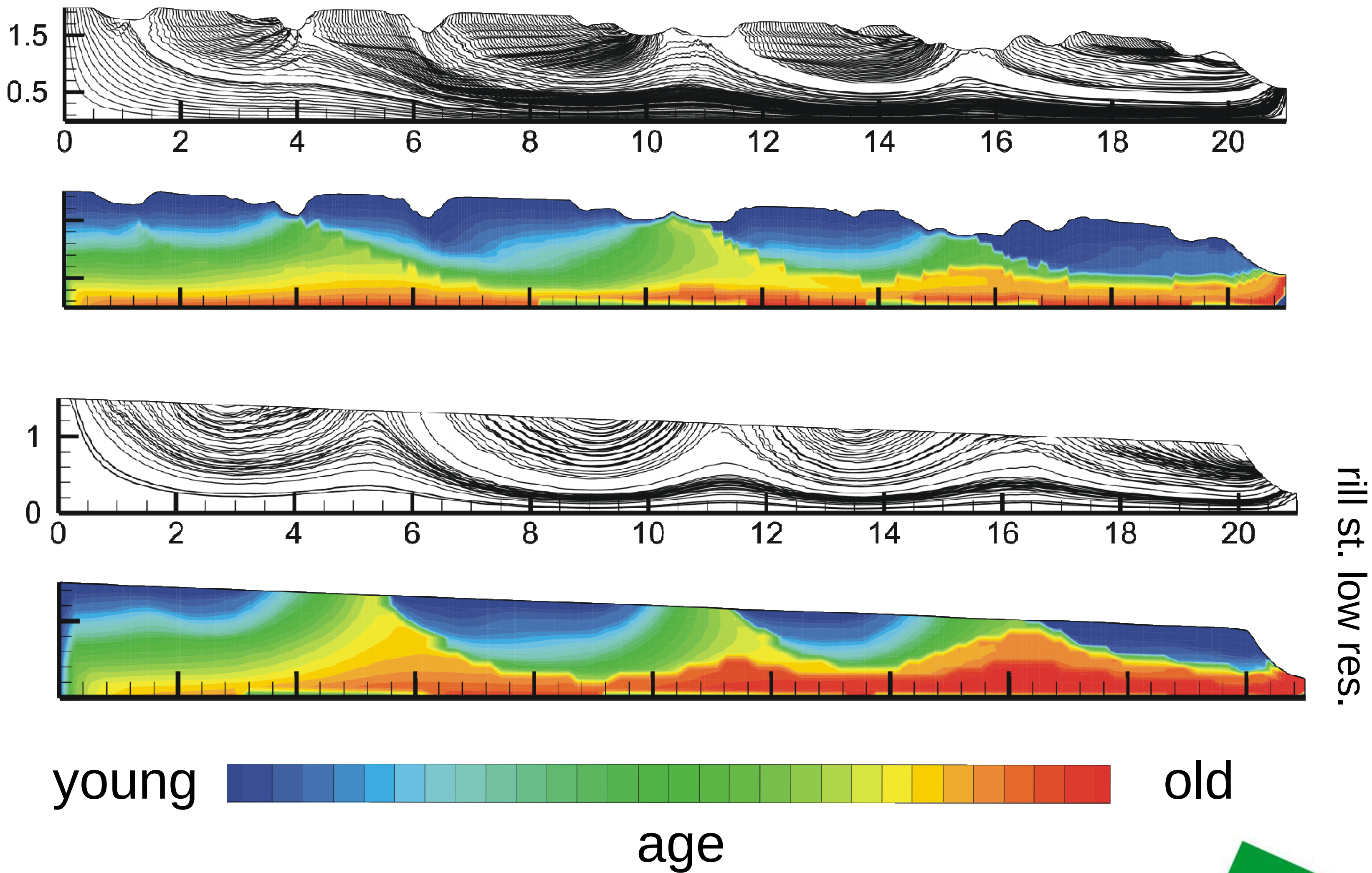
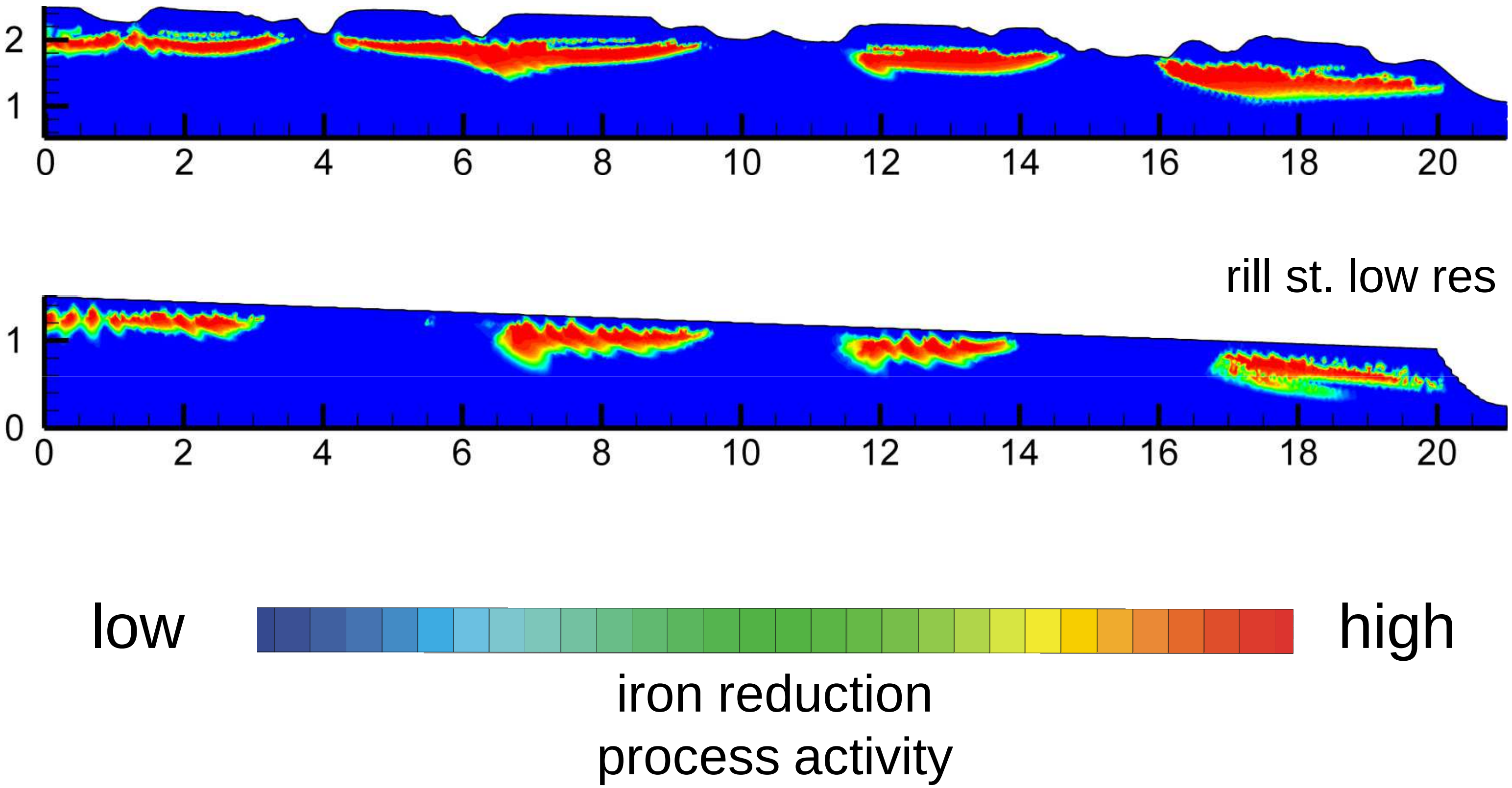


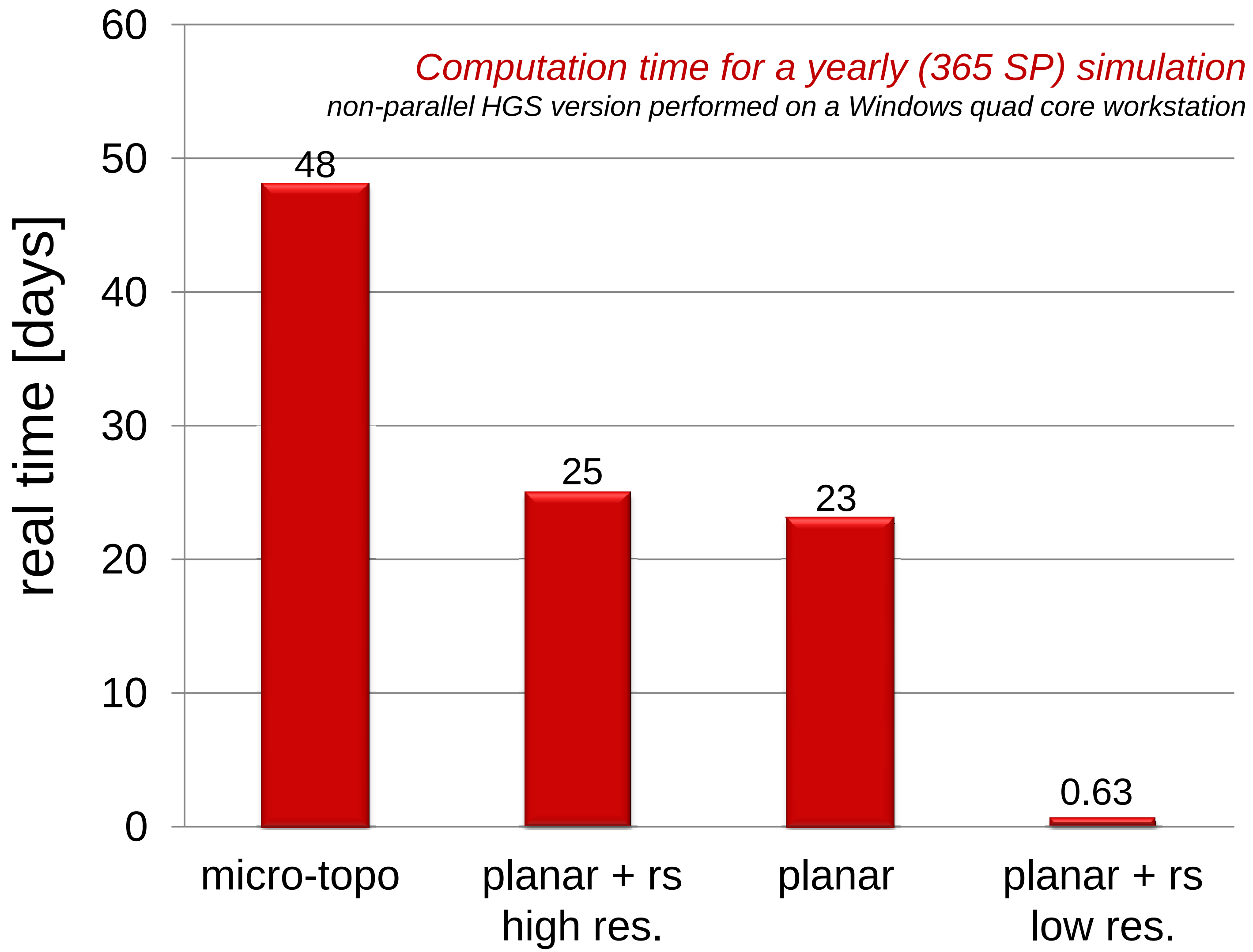
SUBSURFACE FLOW



HOT SPOT FORMATION



RUN TIMES


Computation time for a yearly (365 SP) simulation
non-parallel HGS version performed on a Windows quad core workstation
real time [days]
60
50
40
30
20
10
0
48
25
23
0.63
micro-topo
planar + rs high res.
planar
planar + rs low res.

SUMMARY & CONCULSIONS

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→ formation of HOT SPOTS without material heterogeneity

→ formation of HOT SPOTS due to complex spatial re-distribution of redox- sensitive solutes + biogeochemical reactions

→ field variations can be approximated

→ due to limitations/simplifications stream tube approach so far only applicable to test case scenarios (further improvement necessary)

→ alternative representation of micro-topography using rill storage height variations increases modeling efficiency without loosing too much process complexity

→ role of HOT SPOT patterns for solute export (DOC or nitrate) out of riparian wetlands must be addressed in future research

OUTLOOK

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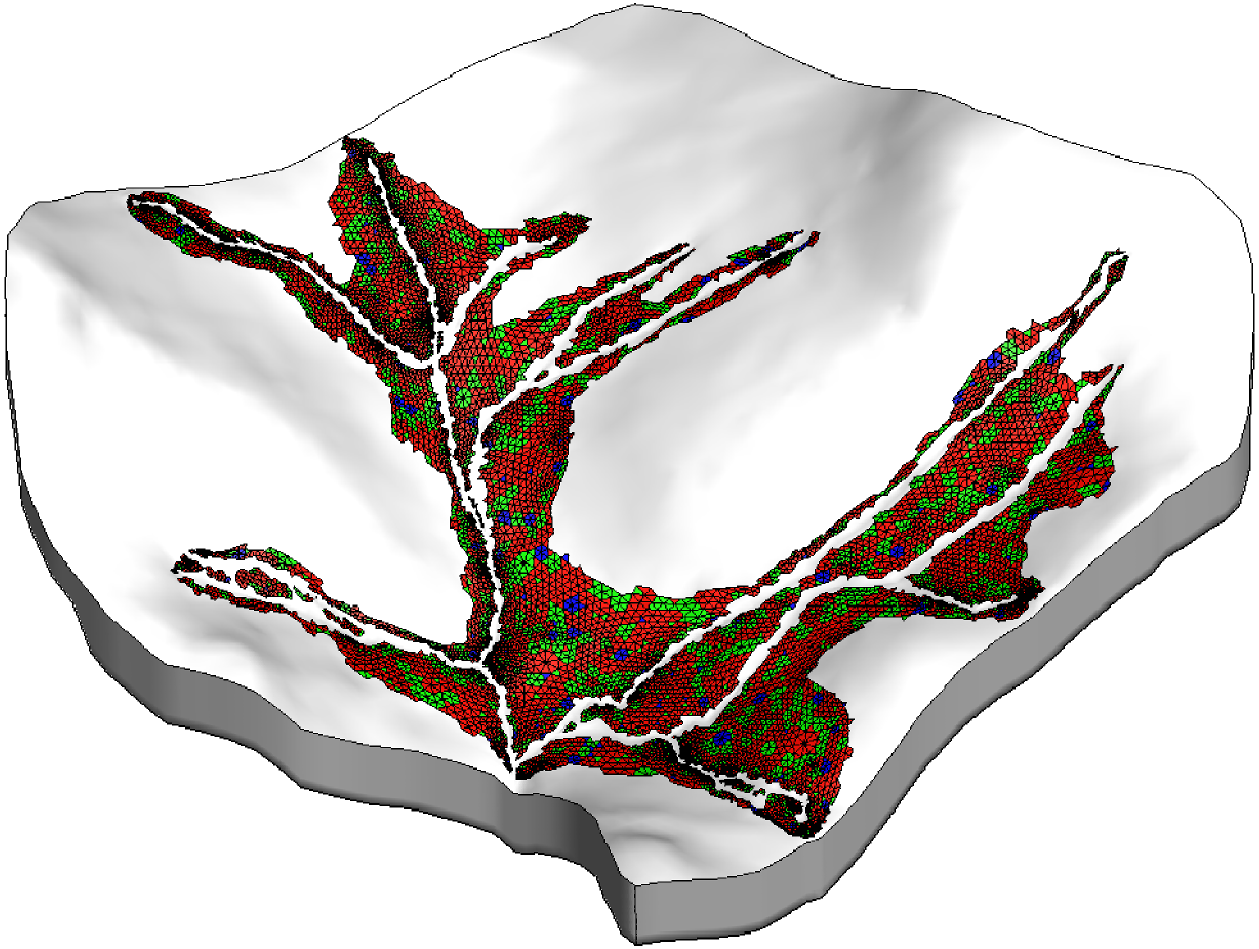

→ reproduce ***micro-topographical effects*** on a larger scale using rill storage height variations

Thank you for your attention