Numerical Simulations of CO_2 Injection in the Altmark Gas Field, Germany

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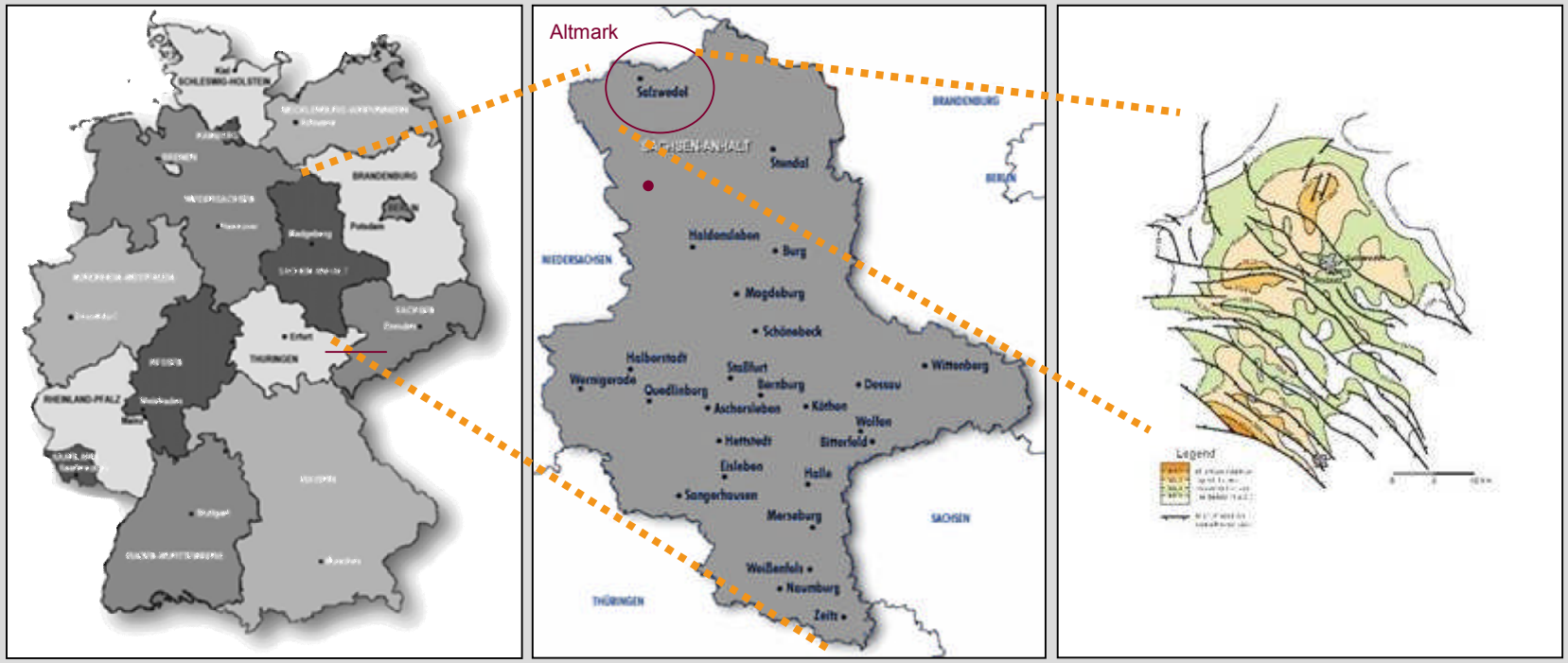
- Salzwedel-Peckensen natural gas reservoir
- Properties of CO_2-CH_4-N_2 gas mixtures
- 3D simulations of CSEGR*
- Injection strategies
- Conclusions

***CSEGR = Carbon Sequestration with Enhanced Gas Recovery**

Location of the Altmark Gas Field

Salzwedel-Peckensen

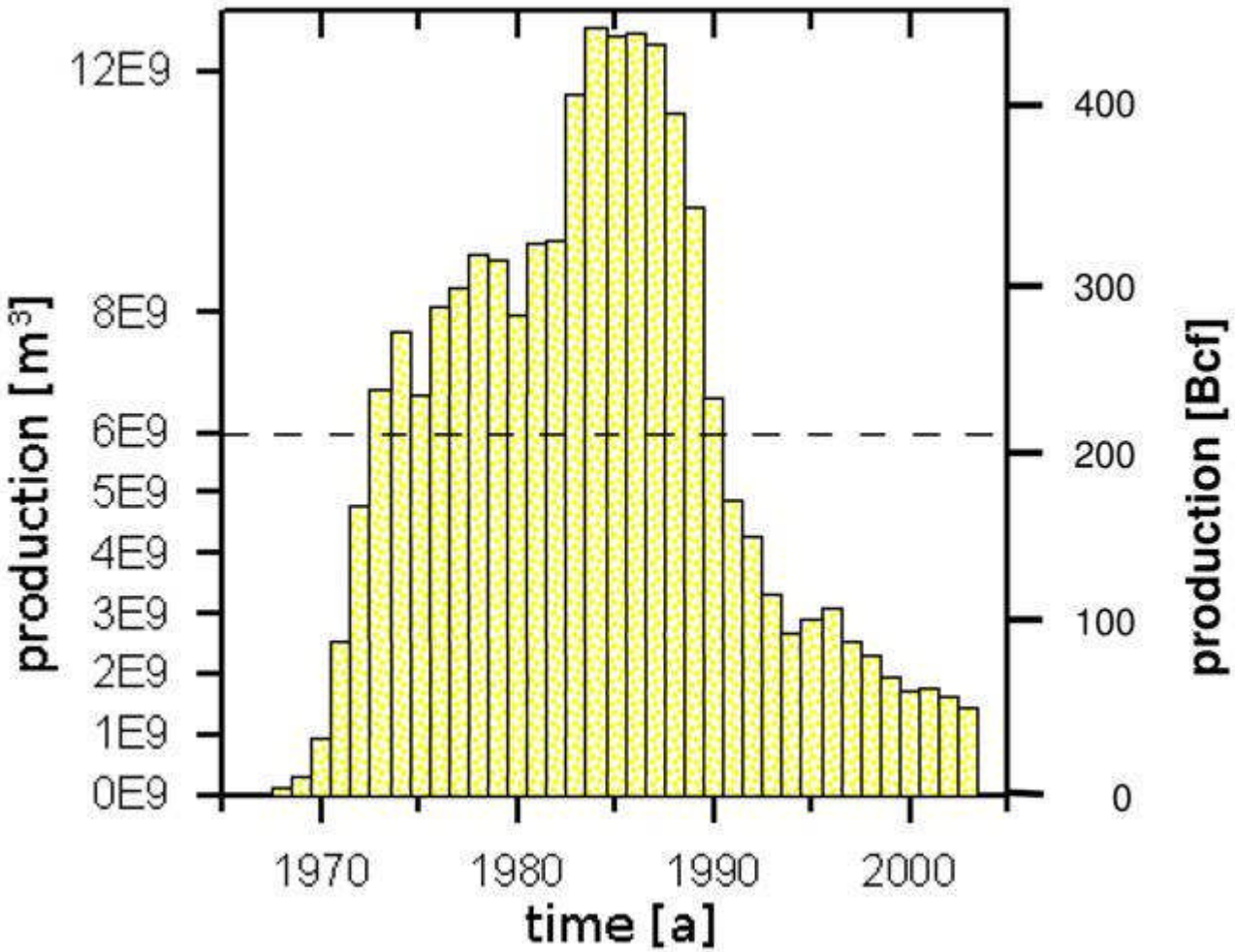


Germany

Sachsen-Anhalt

Altmark

Production History

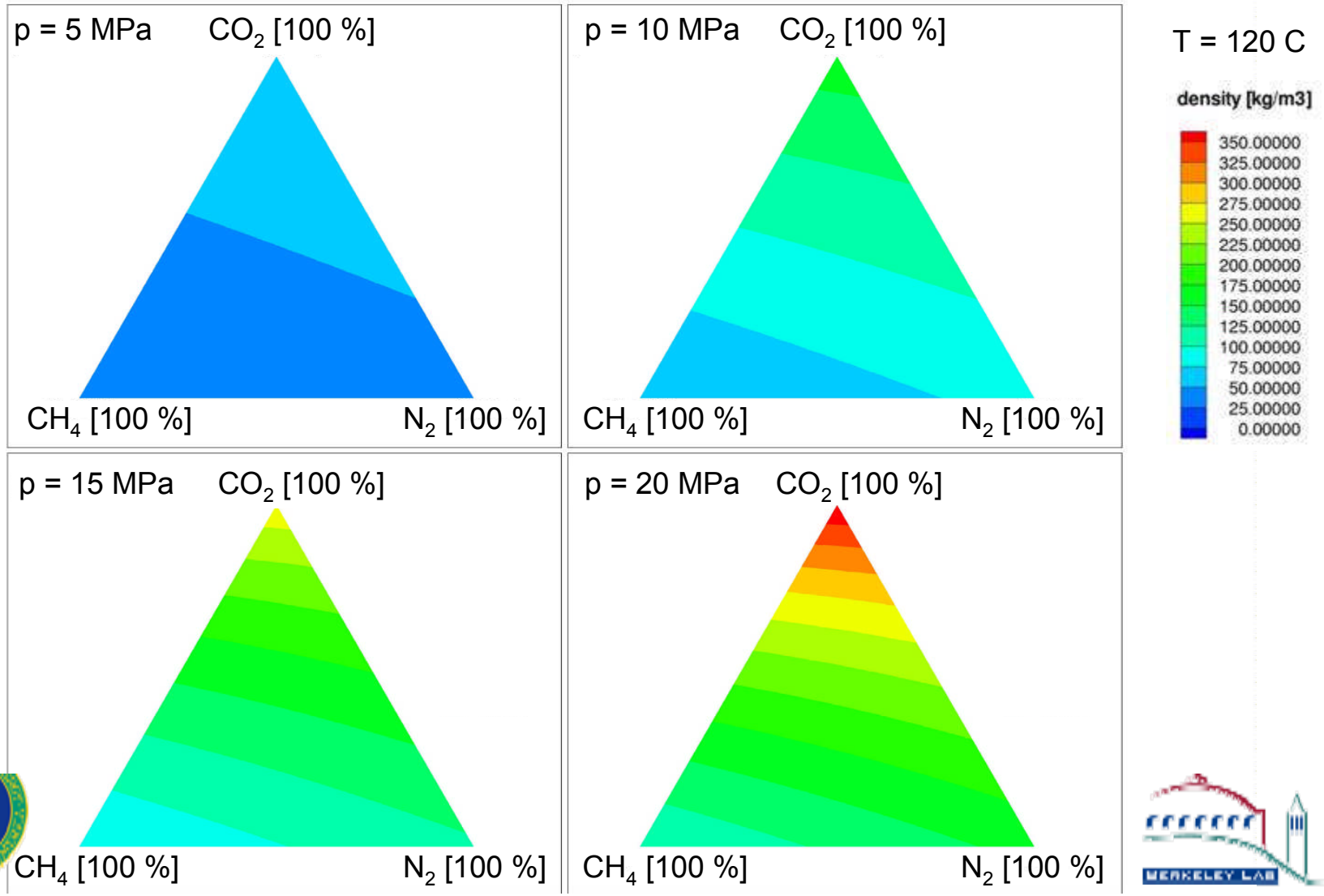


modified after [Pasternak et al., 2001]

Gas Composition

Gas component	vol.%
N_2	40 % - 90 %
CH_4	8 % - 60 %
CH_4 average	32 %
CO_2	< 1 %
C_2H_6	< 1 %

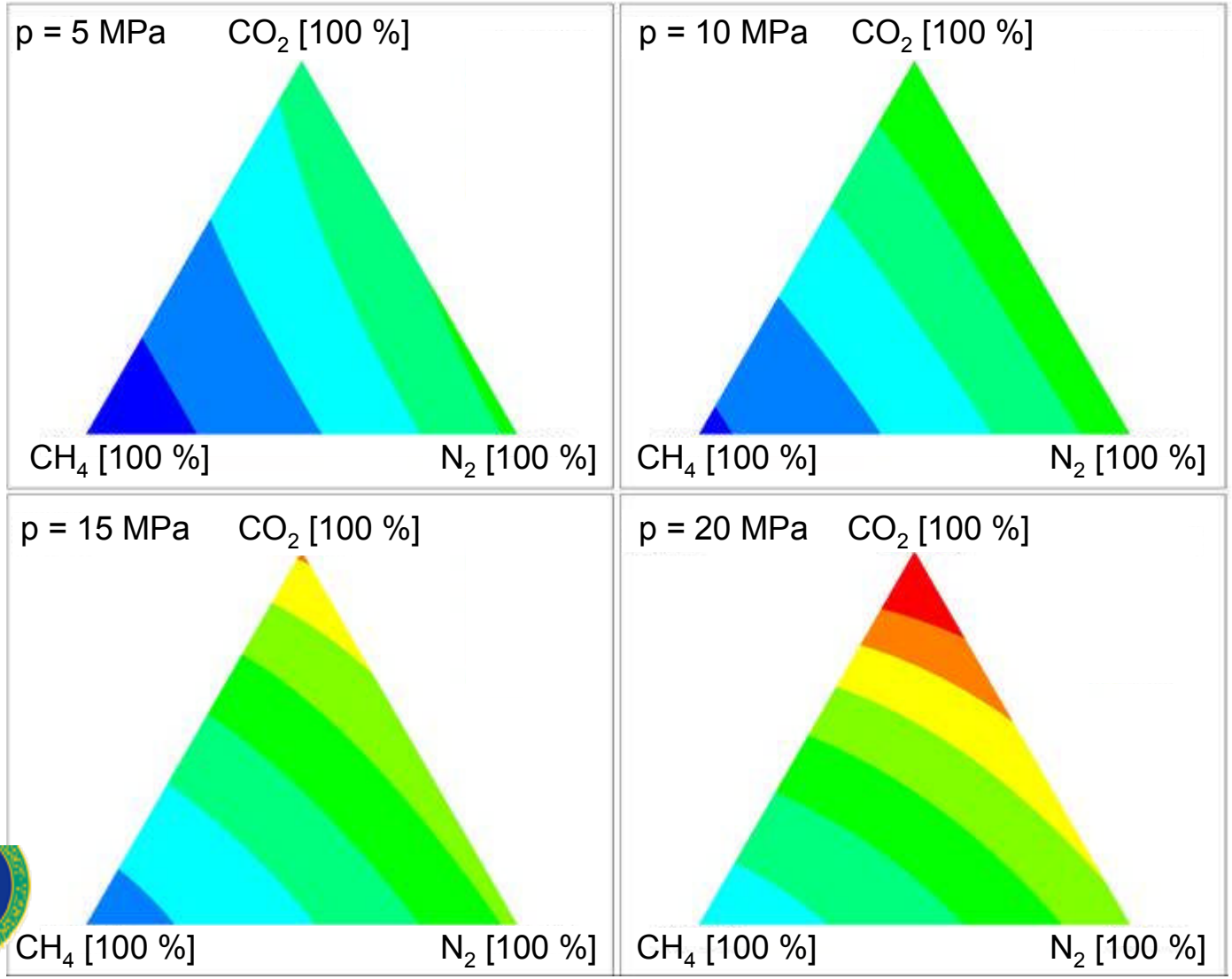
Density of Gas Mixtures



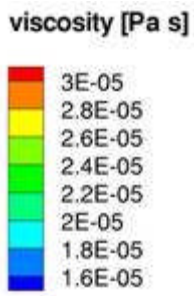
Density

- Natural gas density strongly affected by CO_2 fraction
- Less affected by N_2 fraction
- Small error in using CO_2-CH_4 approx.

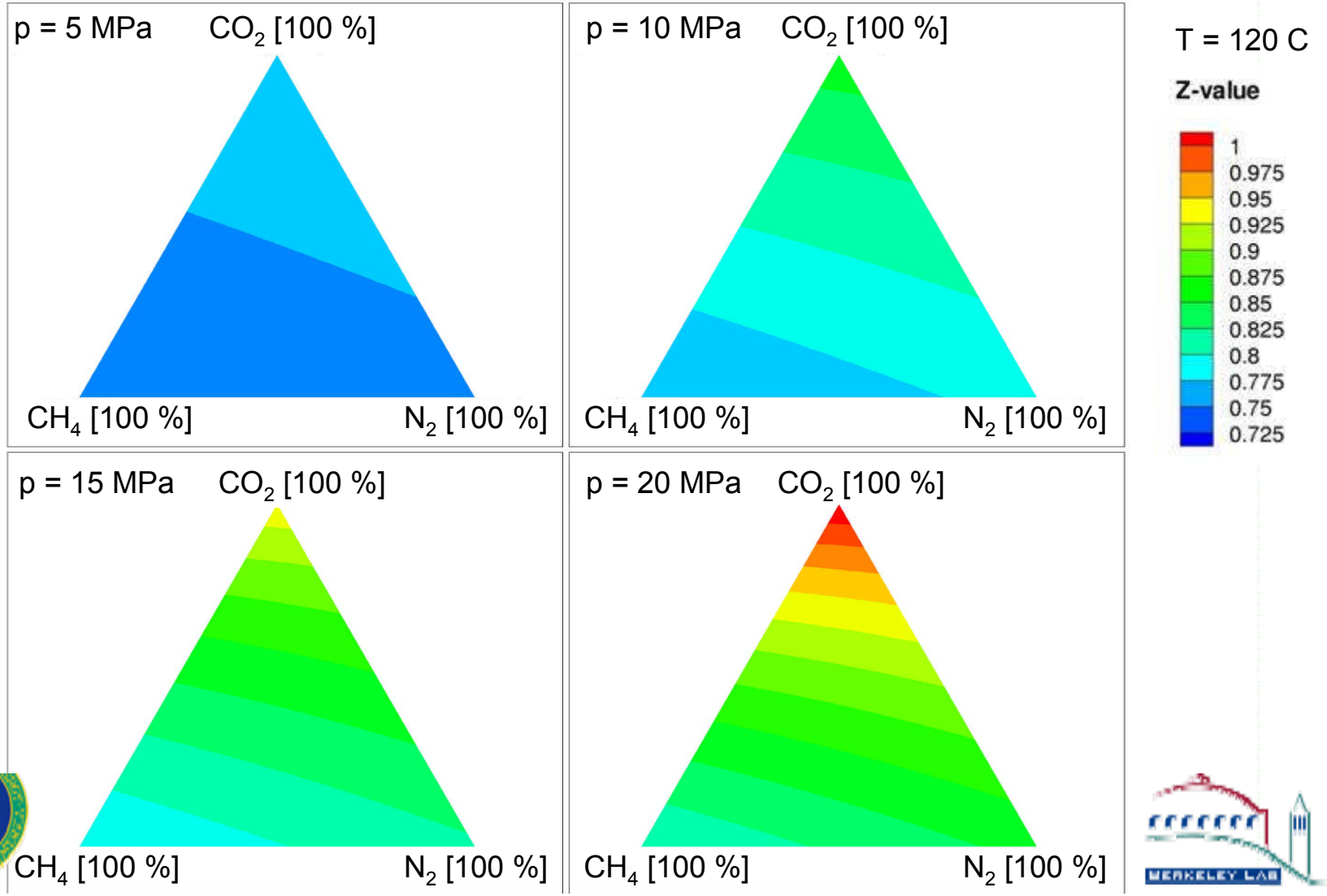
Viscosity of Gas Mixtures



T = 120 C



Density of Gas Mixtures



Viscosity

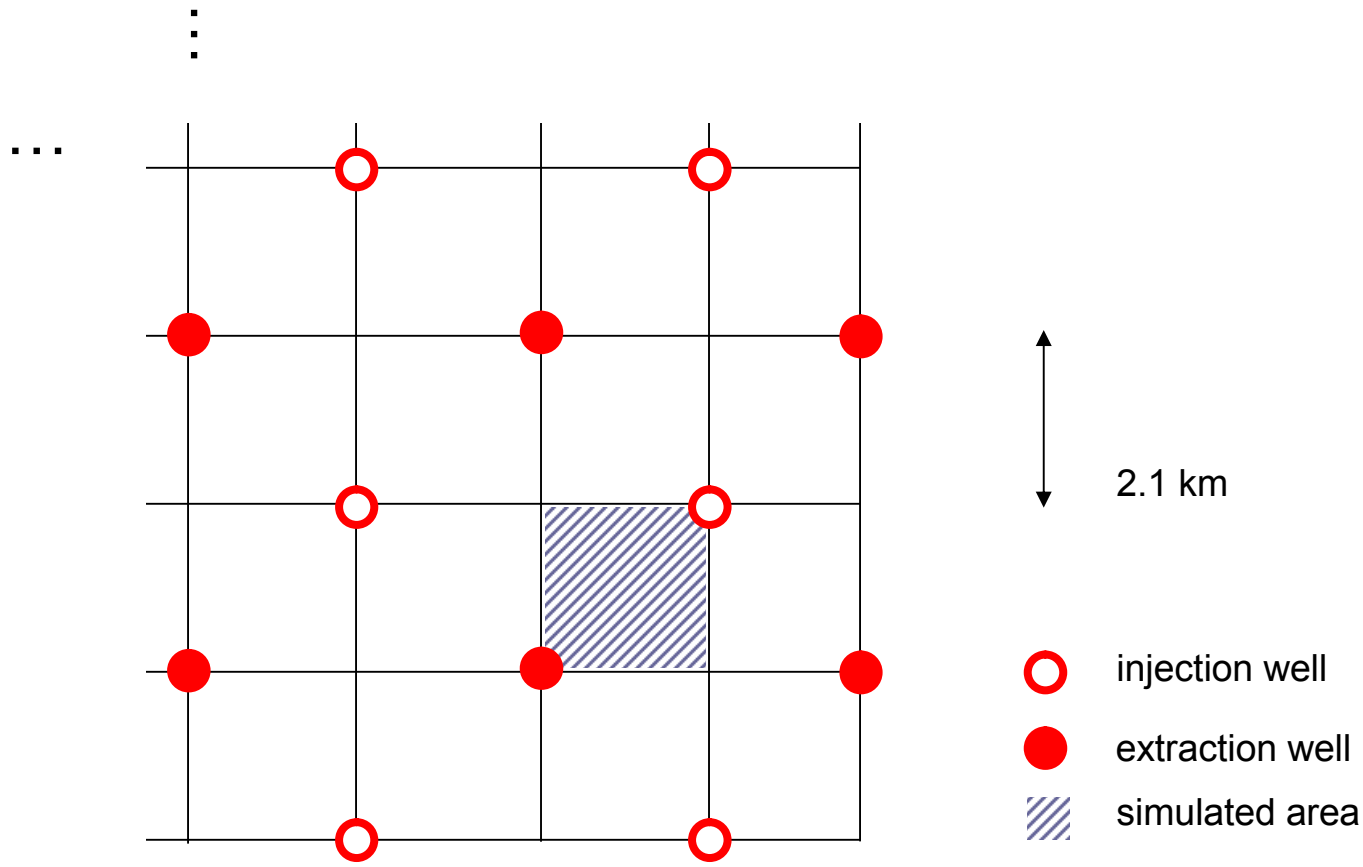
- Natural gas viscosity is strongly affected by CO_2 fraction
- Also strongly affected by N_2 fraction
- Greater error using CO_2-CH_4 approx.

But variation in viscosity is small relative to variations and uncertainty in reservoir permeability (→ gas mobility).

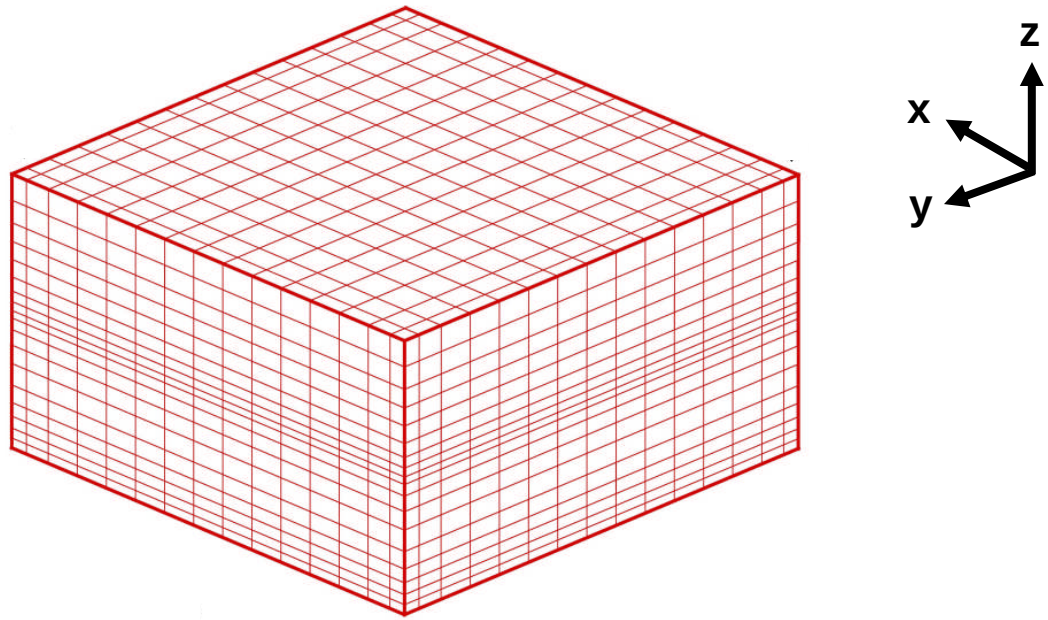
Hydrostratigraphic Units

Sequence	Lithology	Lithostratigraphy	Thickness [m]	Usable Porosity [%]	Abbreviation
Zyklus 17	silt	Mellin(1) Wechselfolge(2)	42	8	Zyk17
Zyklus 16	silt	Mellin Basisfolge(3)	30	5	Zyk16
Zyklus 15	silt	Mellin Wechselfolge	28	5	Zyk15
Zyklus 14	sand	Wechselfolge der oberen(4) Peckensen Schichten(5)	17	14	Zyk14
Zyklus 13	sand	Basissandstein(6) der oberen Peckensen Schichten	12	15	Zyk13
Zyklus 12	clay	Wechselfolge der unteren(7) Peckensen Schichten	25	5	Zyk12
Zyklus 9–11	silt	Mellin Wechselfolge	43.5	8	Z9–11
Zyklus 8	sand	Sandsteinfolge(8) der unteren Peckensen Schichten	22	15	Zyk08
Zyklus 7	sand	Eldena-Wechselfolge(9)	16	5	Zyk07
Zyklus 1–6	sand	Eldena-Basissandstein	90	5	zy1–6

5-Spot Model

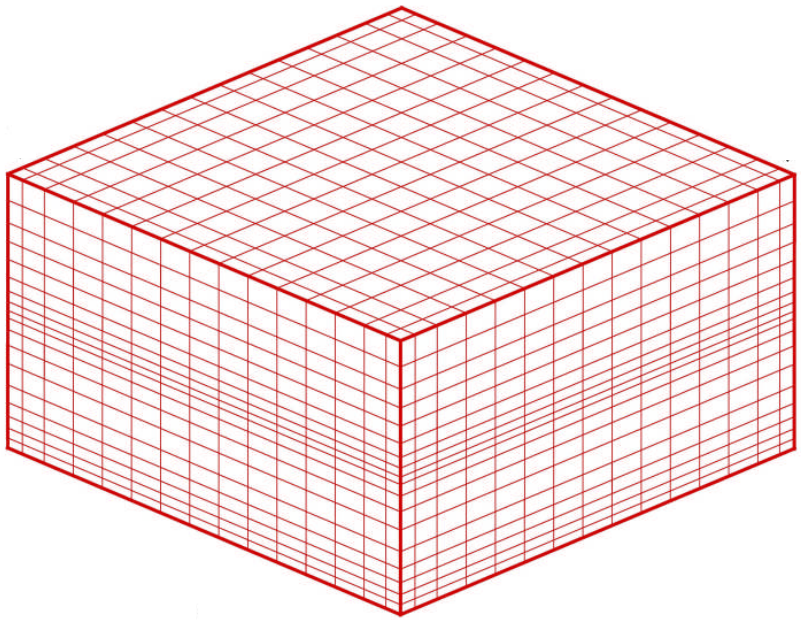


3D Grid



15 x 15 x 18 elements
2.1 km x 2.1 km x 226.5 m

3D Grid

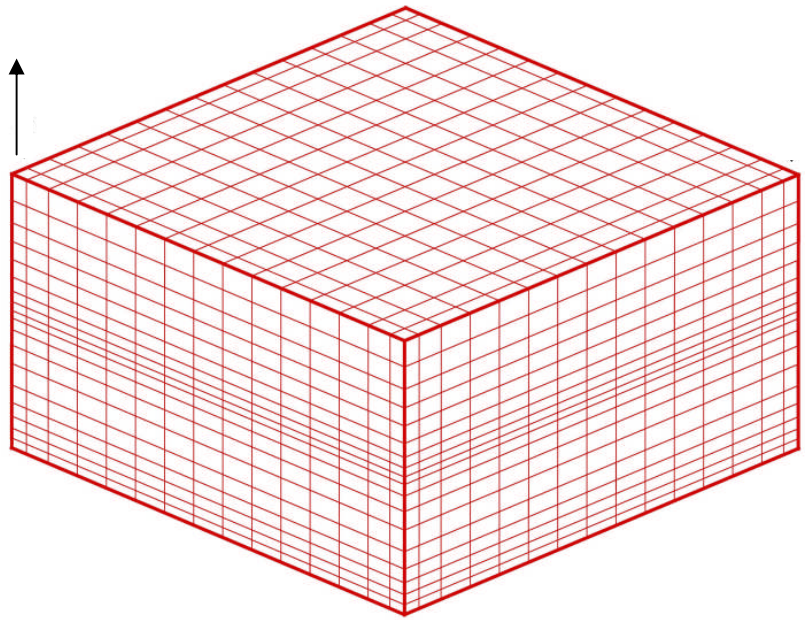


2 high permeability layers

3D Grid

extraction of CH_4 in 18 elements in a vertical column

CH_4 extraction

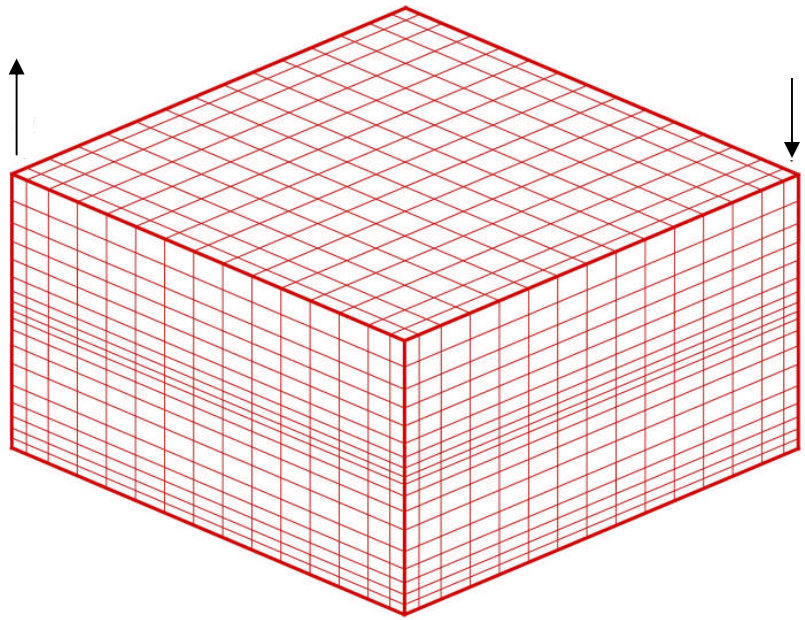


3D Grid

extraction of CH_4 in 18 elements in a vertical column

injection of CO_2 in 18 elements in a vertical column

CH_4 extraction



CO_2 injection

Properties of 3D Model

Model parameter	Value
number of injection wells in total	10
number of extraction wells in total	10
model type	five-spot configuration
model area	2.1 km × 2.1 km
reservoir height	226 m
dip of layers	0°
temperature	120 °C, constant
pressure	hydrostatic distribution
pressure at the bottom	20 MPa
duration of CO_2 injection phase	40 a
total CO_2 injection rate	4.2×10^{11} kg CO_2
CO_2 injection rate at one sink site[1]	8 kg/s
geometry of source	vertical column
duration of CH_4 extraction	40 a, simultaneous to CO_2 injection
geometry of sink	vertical column

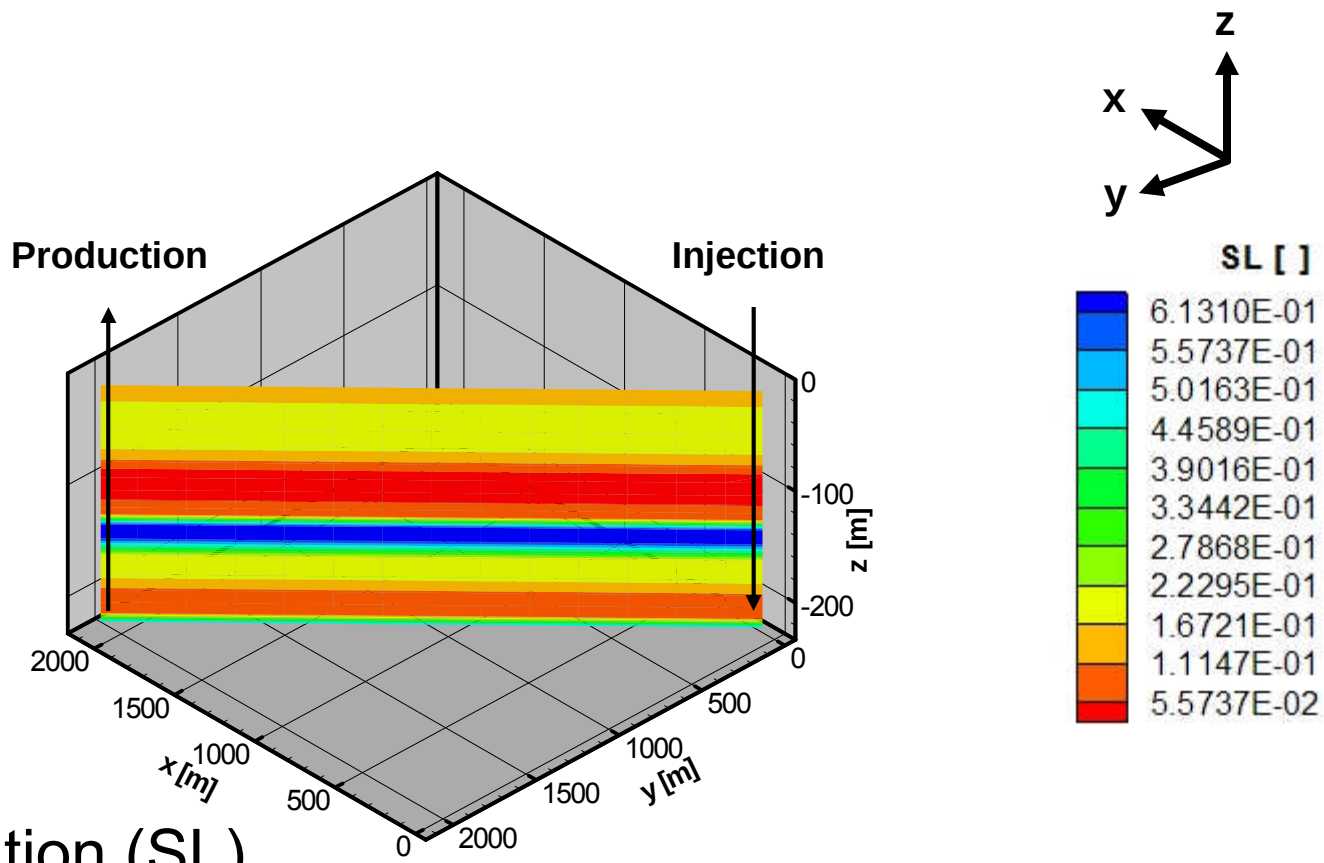
Injection Strategies

- CO_2 injection rate 1.6 kg/s to 16 kg/s
- Permeability of rock layers

  low: 5×10^{-17} m^2 -- 2.5×10^{-15} m^2

  high: 10^{-13} m^2 -- 10^{-11} m^2
- Water injection for mobility reduction

Initial Conditions



Liquid Saturation (SL)

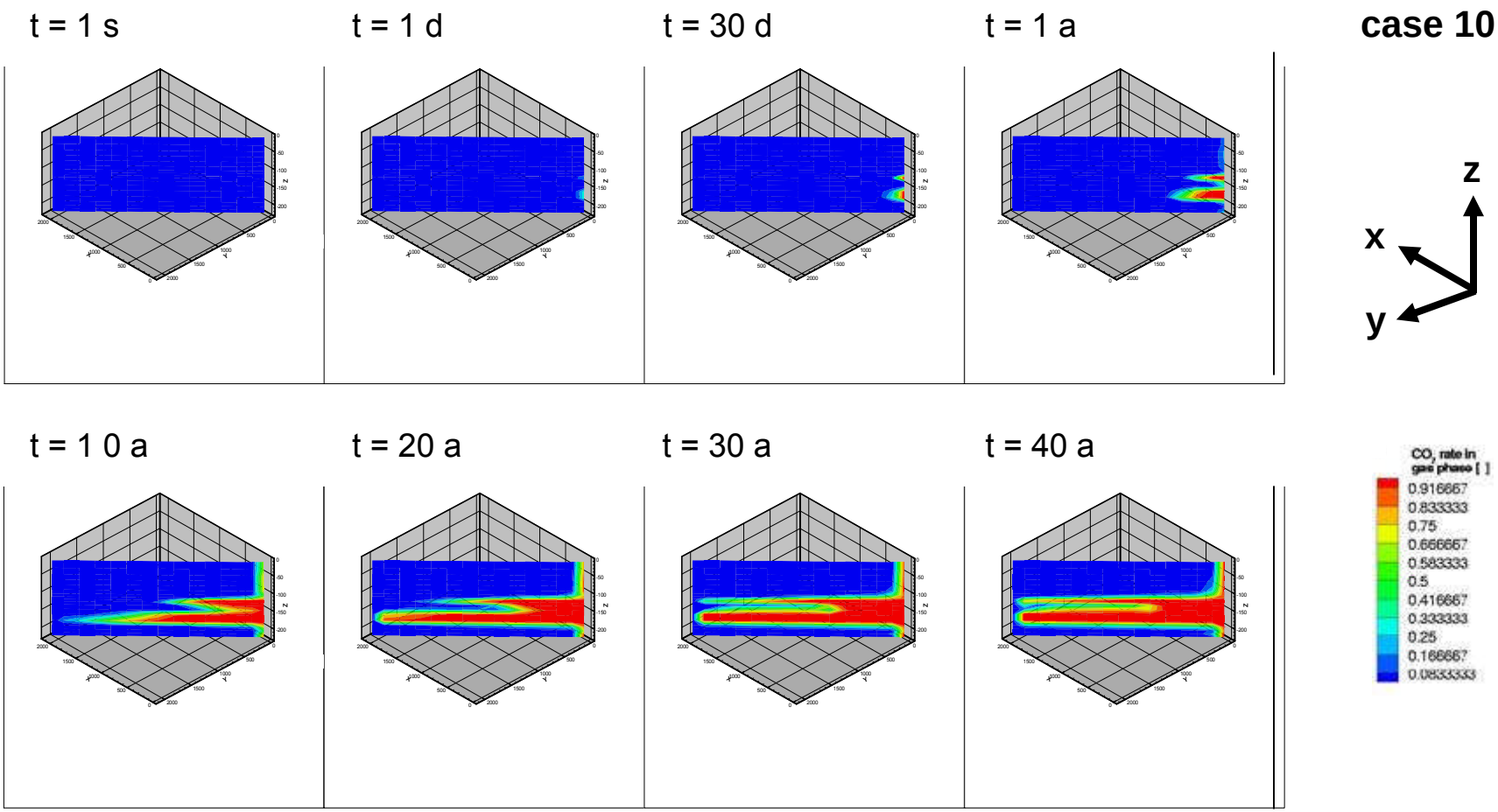
120 ºC
200 bars (bottom)

CSEGR Simulations

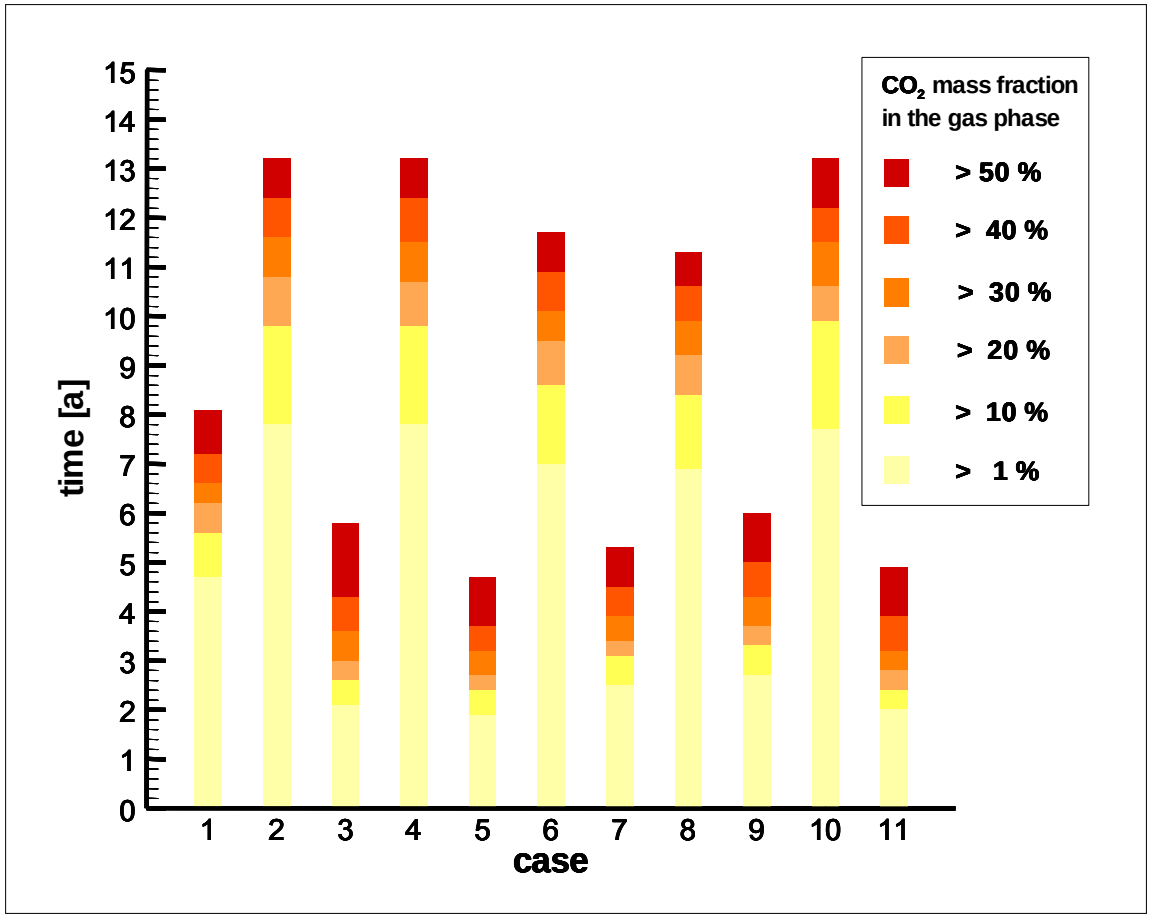
CO_2 injection rate	8 kg/s
low permeability layers	10^{-16} m^2
high permeability layers	10^{-13} m^2
CO_2 in gas phase > 10 %	9.7 a

Simulations are carried out using TOUGH2/EOS7C (Oldenburg et al., 2005)

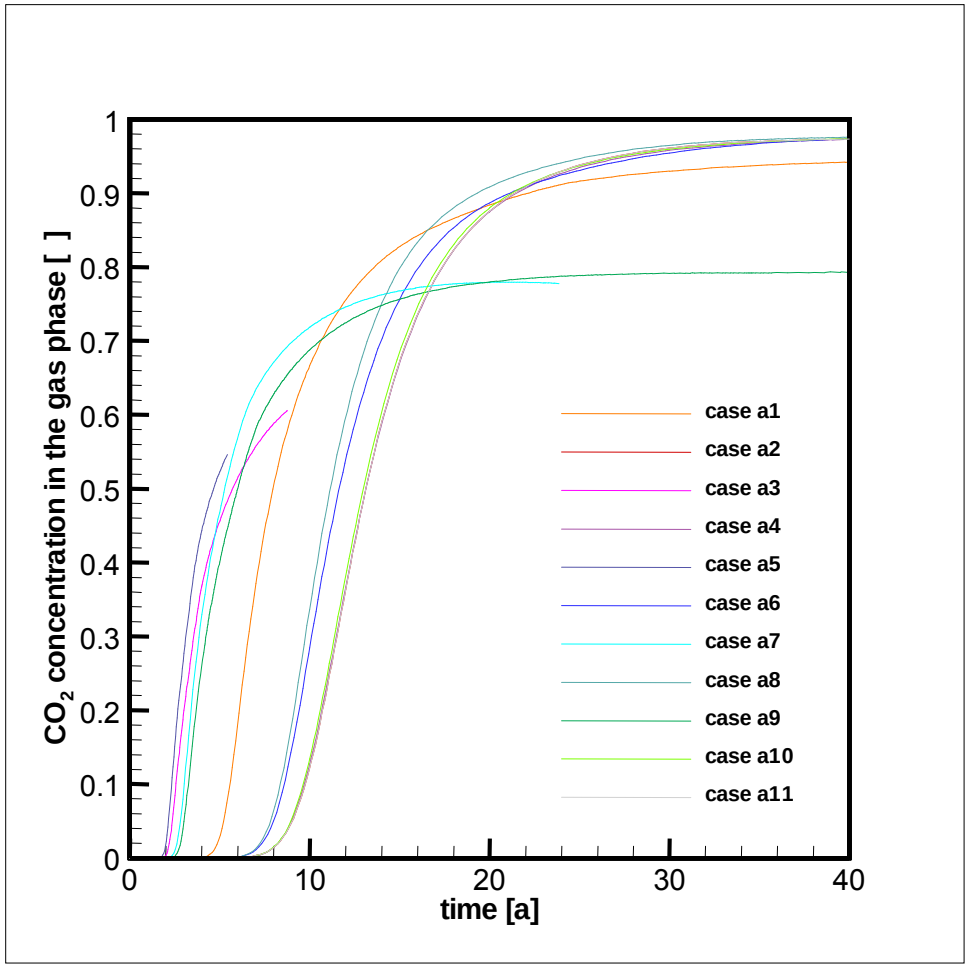
CO_2 in the Gas Phase



Breakthrough Times



CO_2 at the Production Well

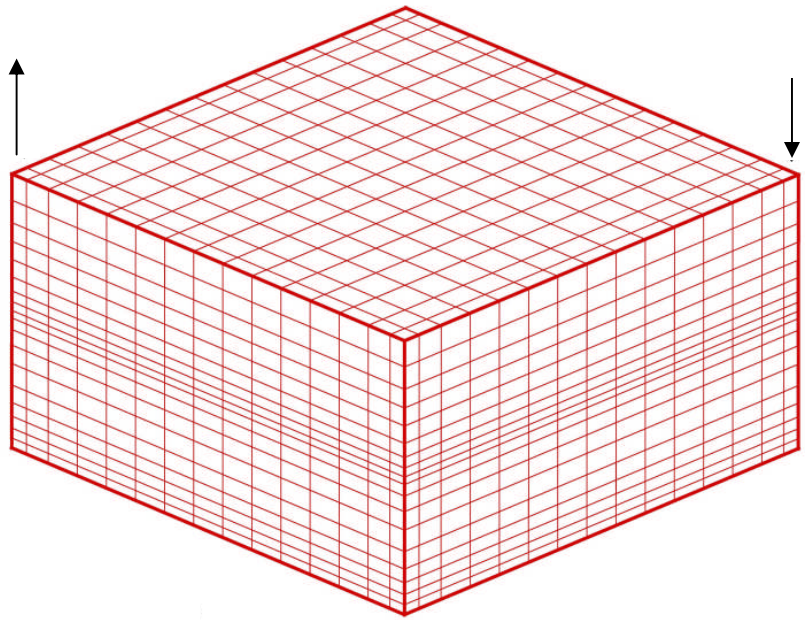


Mobility Control

extraction of CH_4 in 18 elements in a vertical column

injection of H_2O in 18 elements in a vertical column

CH_4 extraction

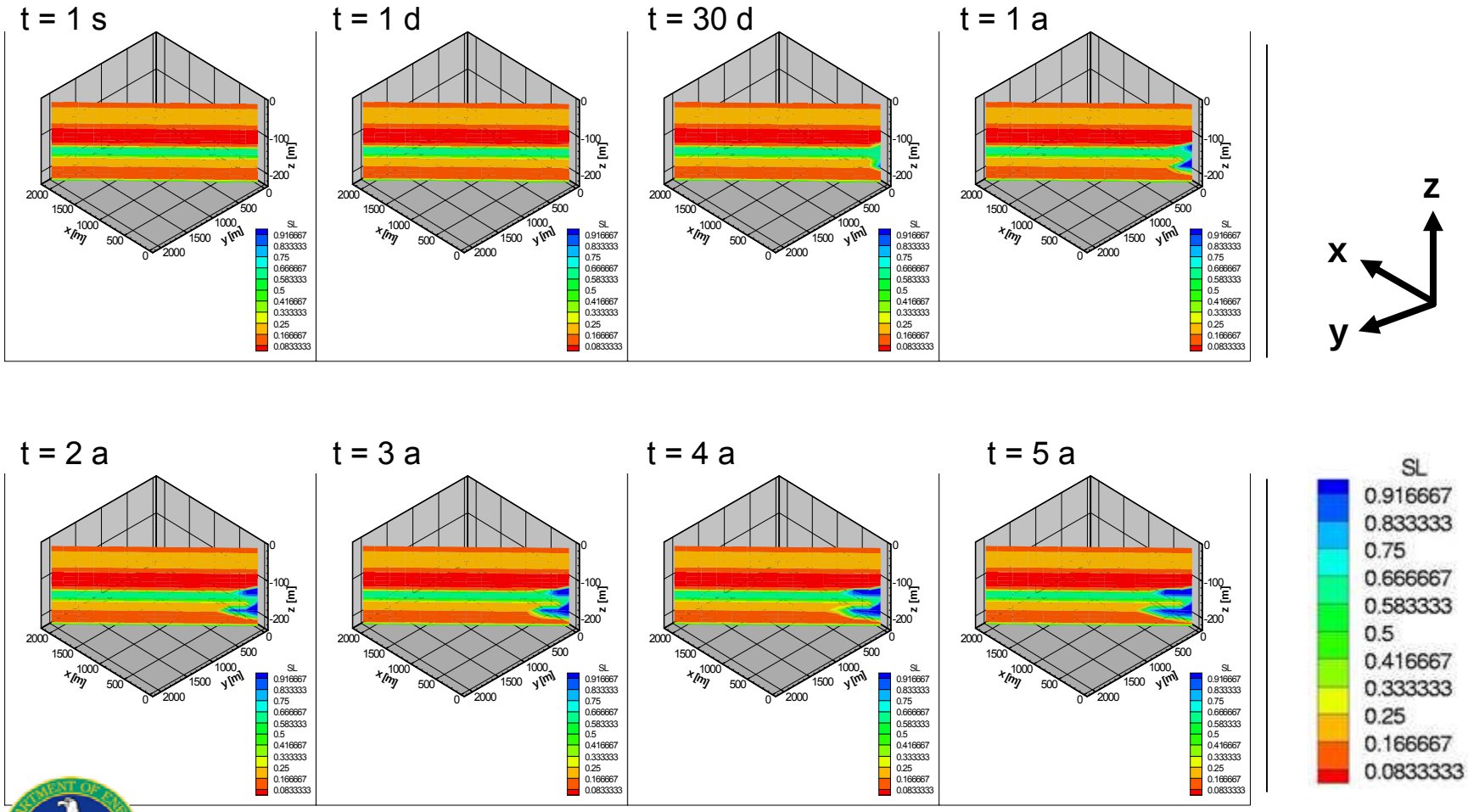


H_2O injection

15 x 15 x 18 elements

2.1 km x 2.1 km x 226.5 m

Liquid Saturation



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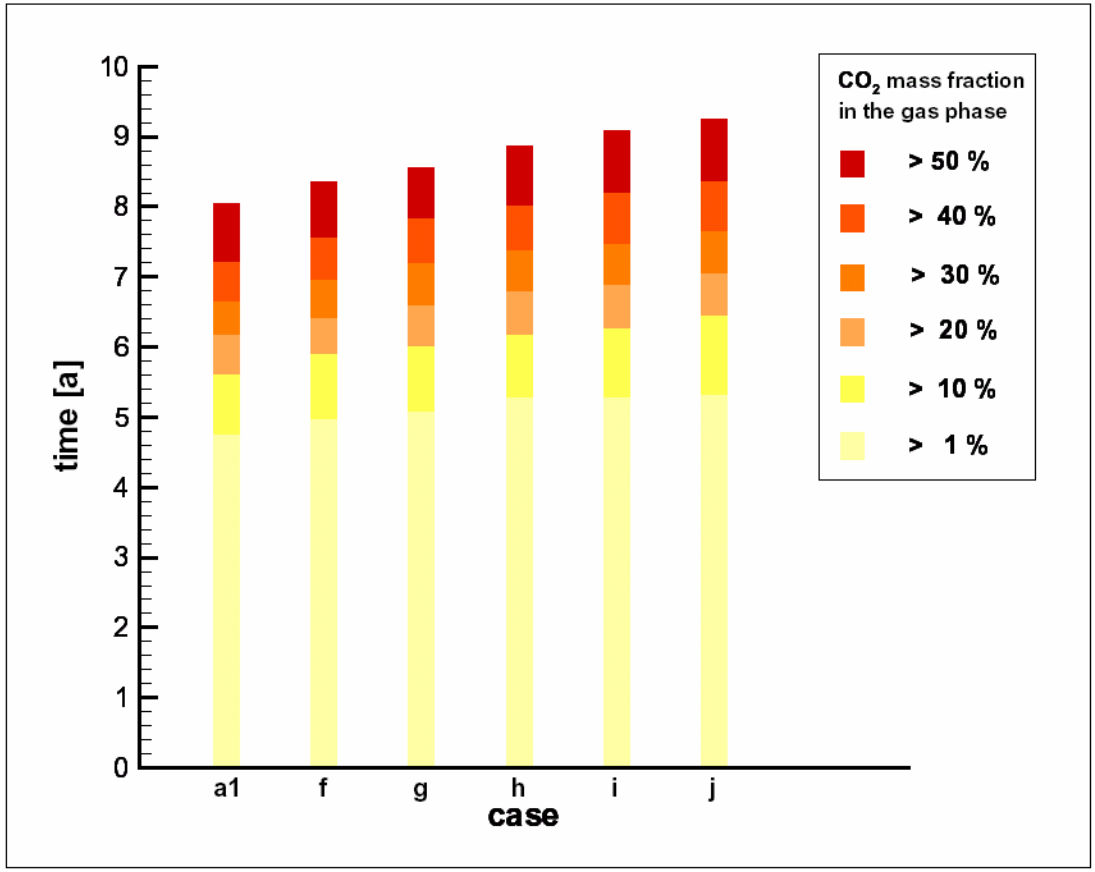

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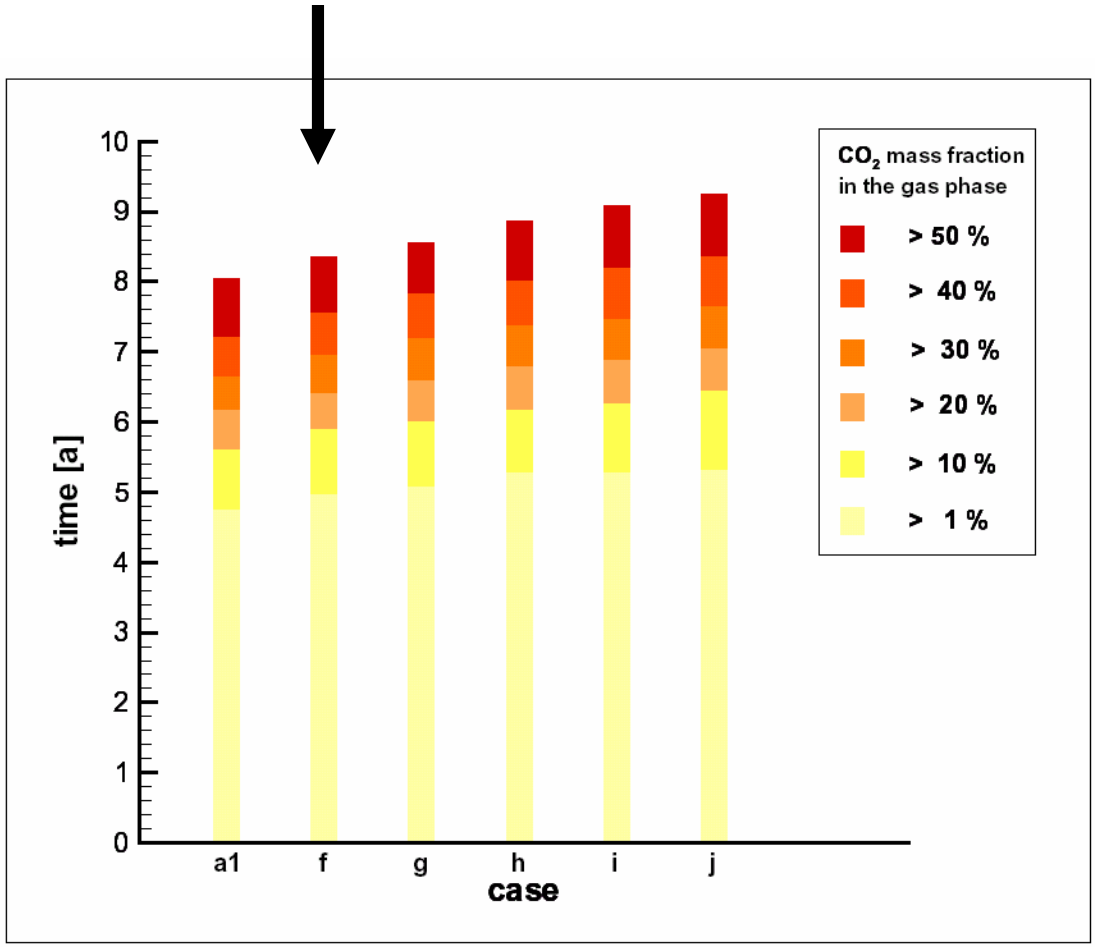
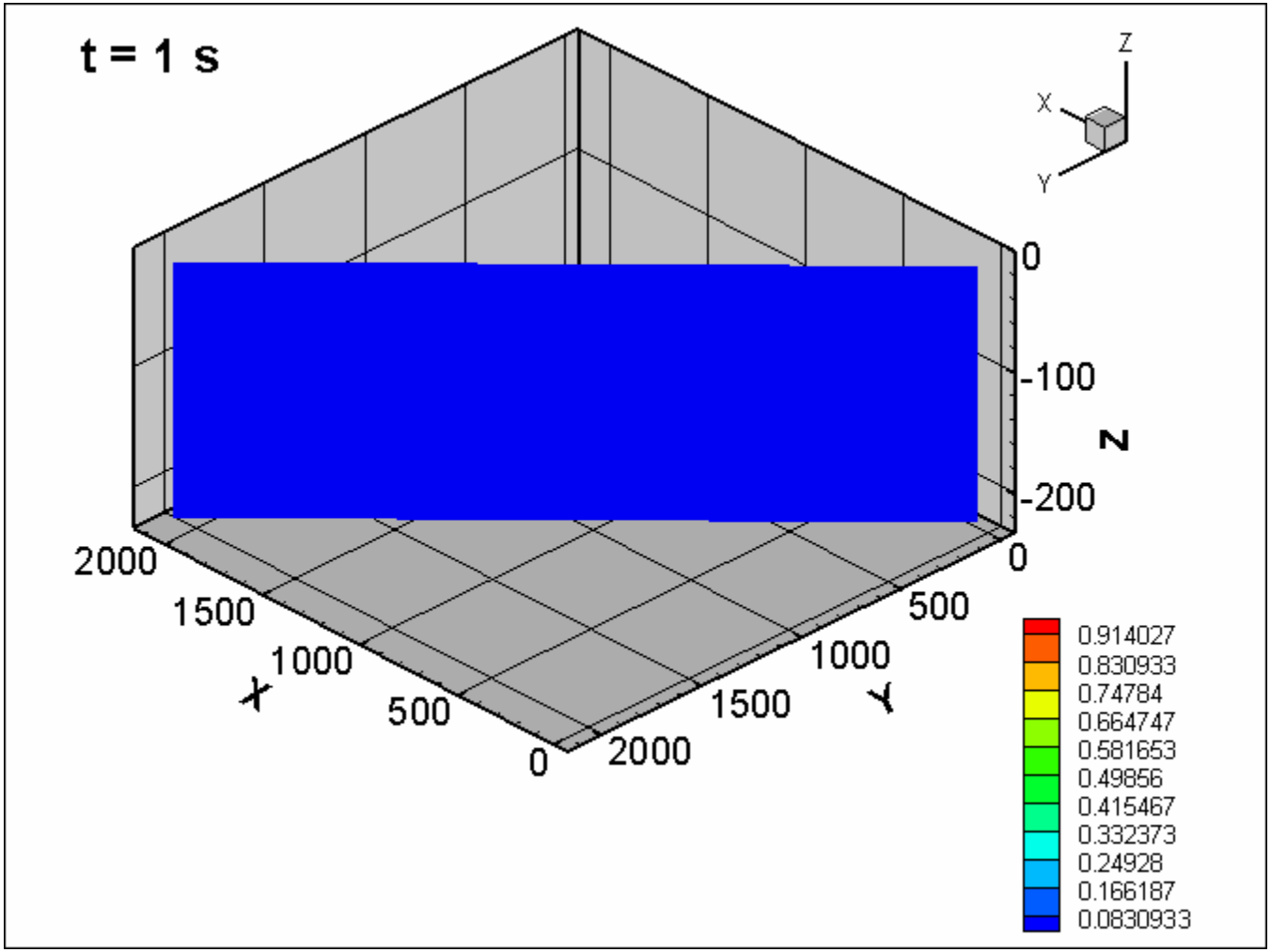


CO_2 in the Gas Phase



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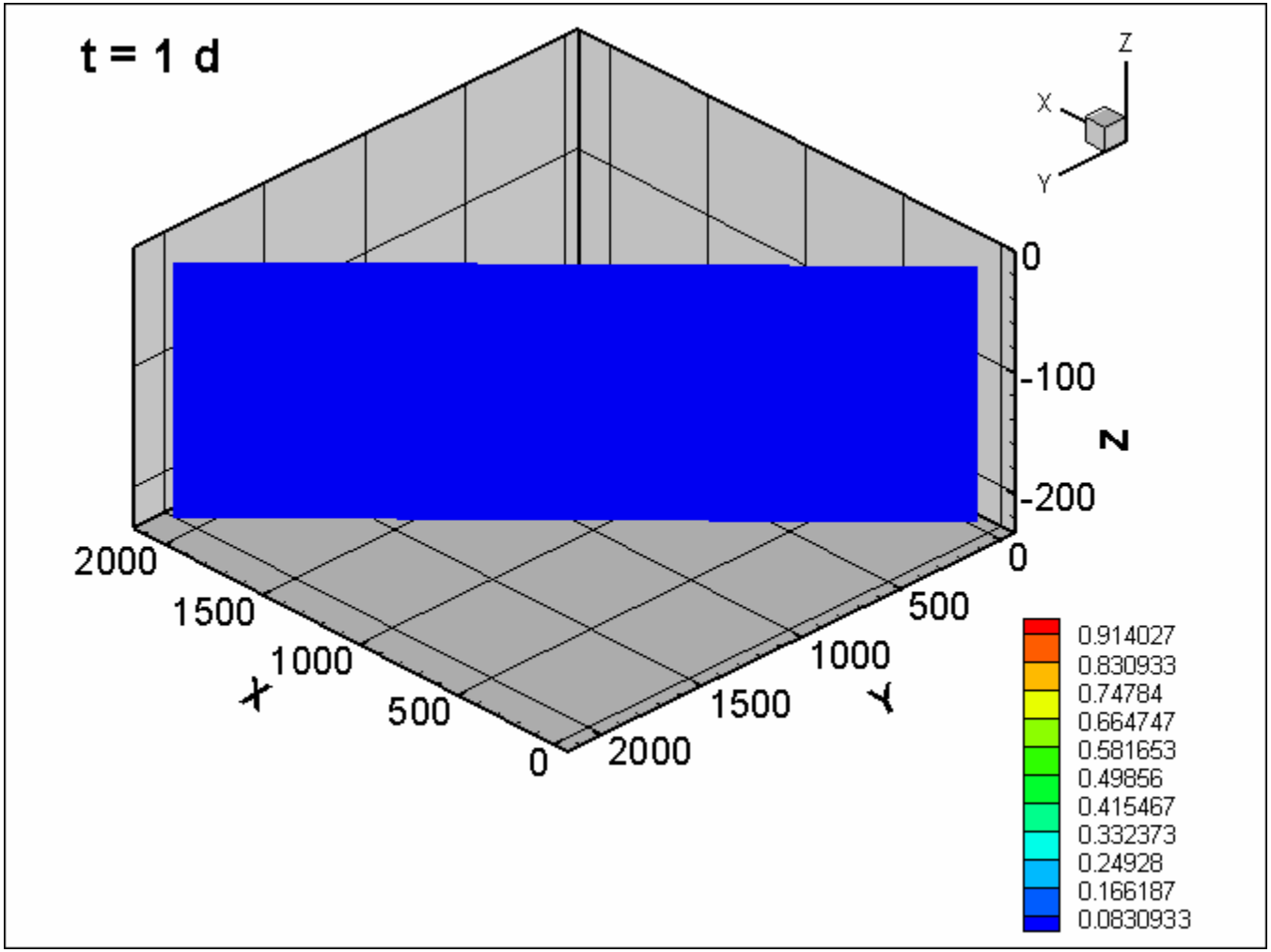

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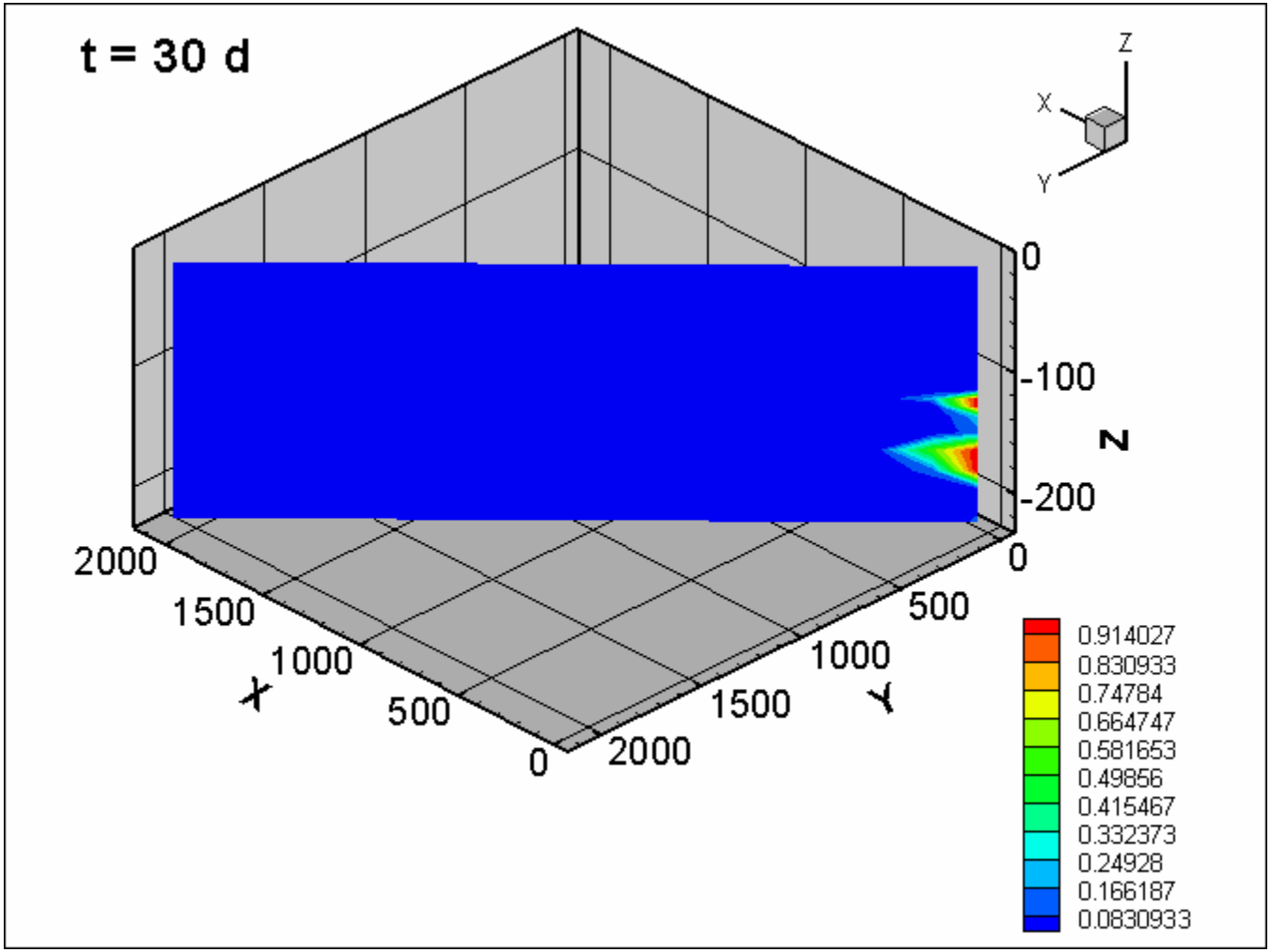

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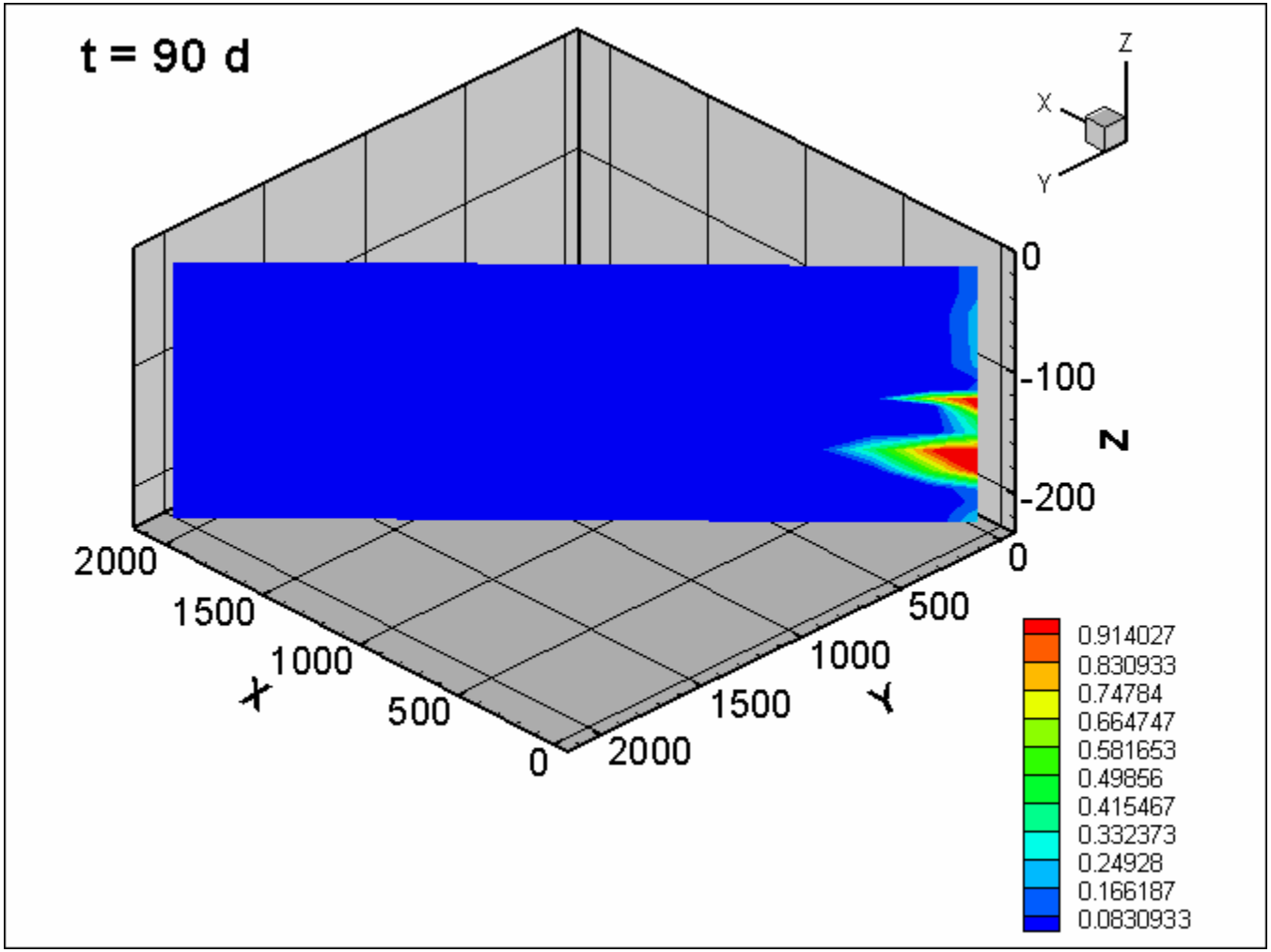

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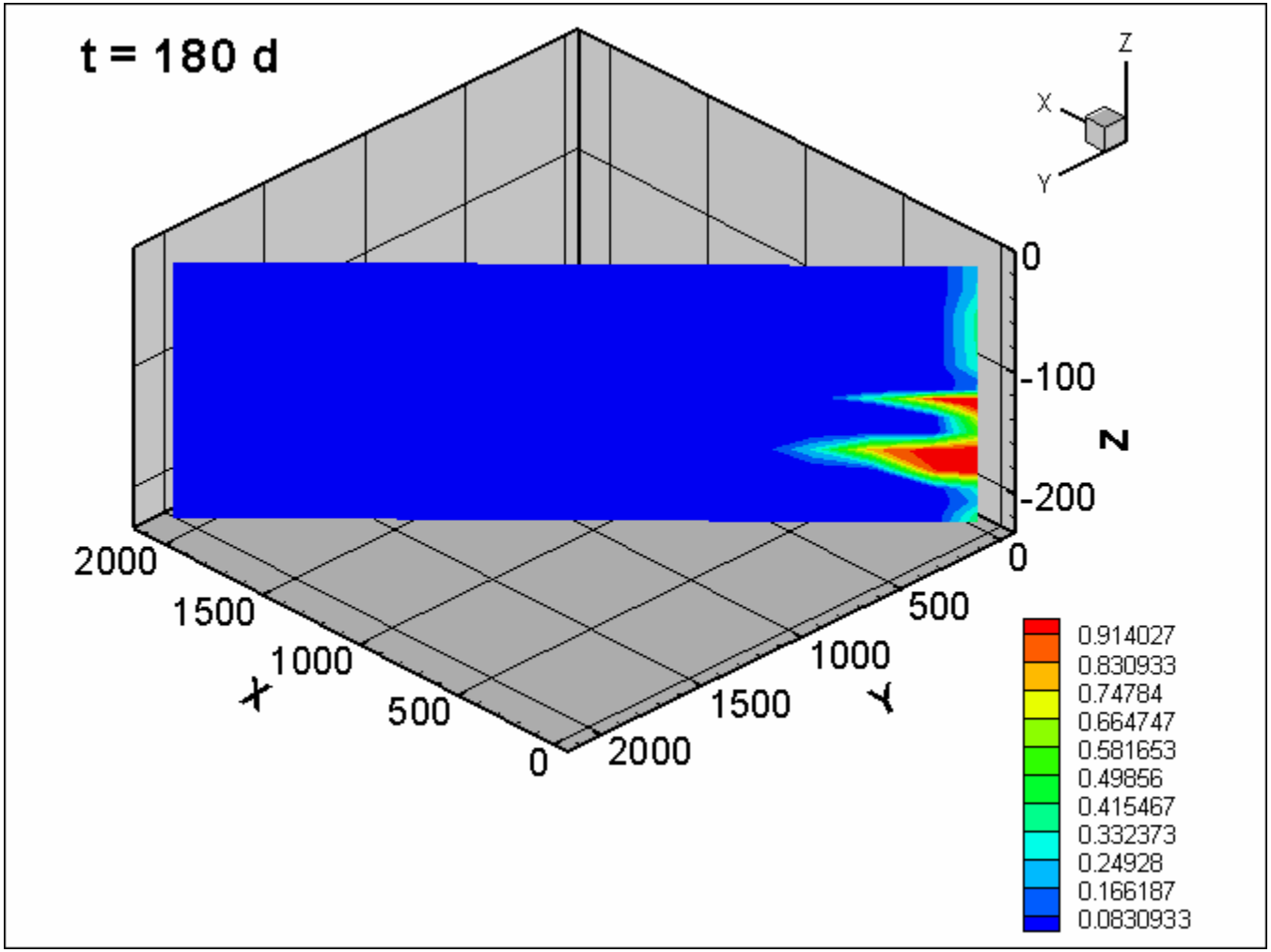

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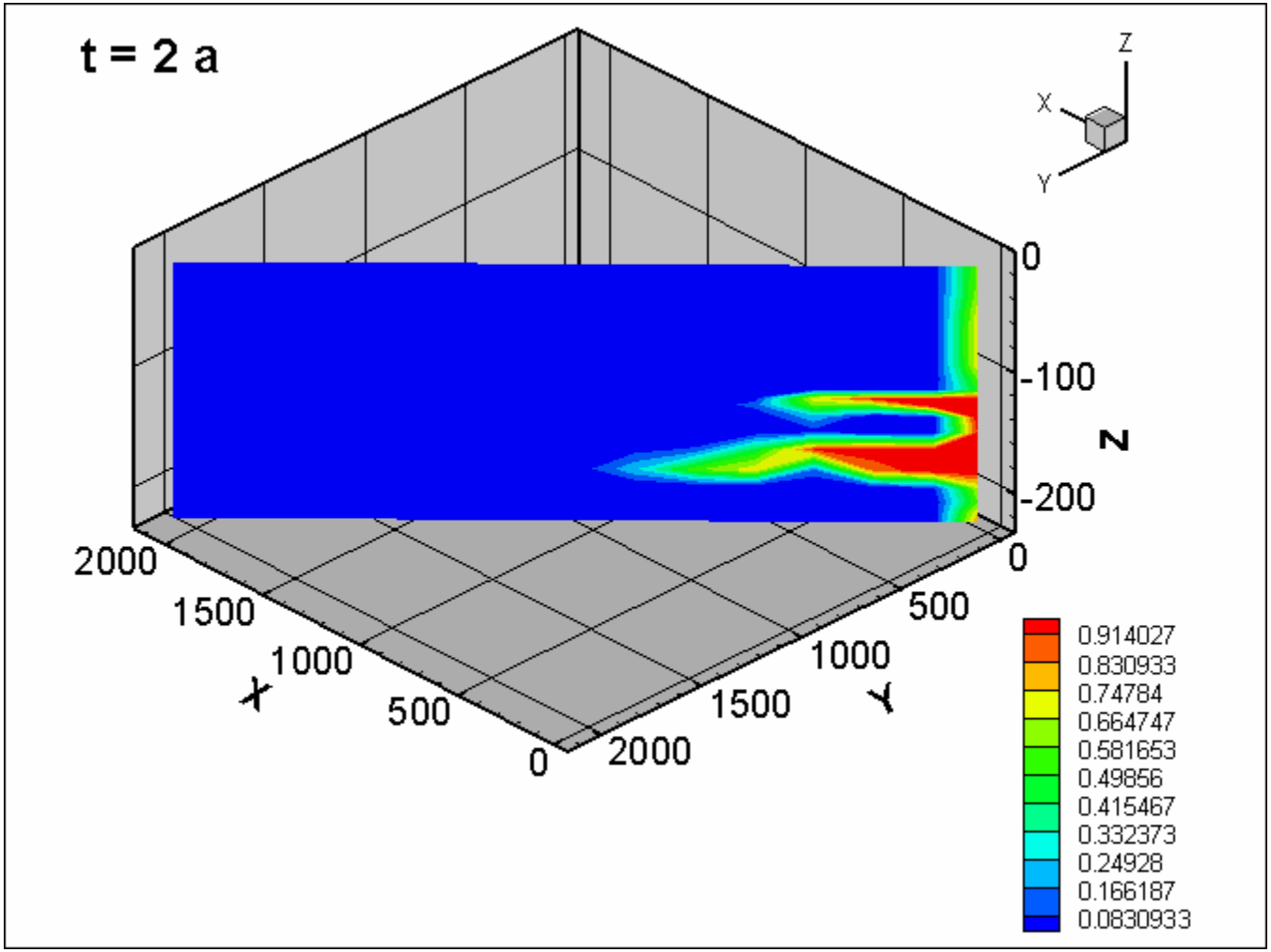

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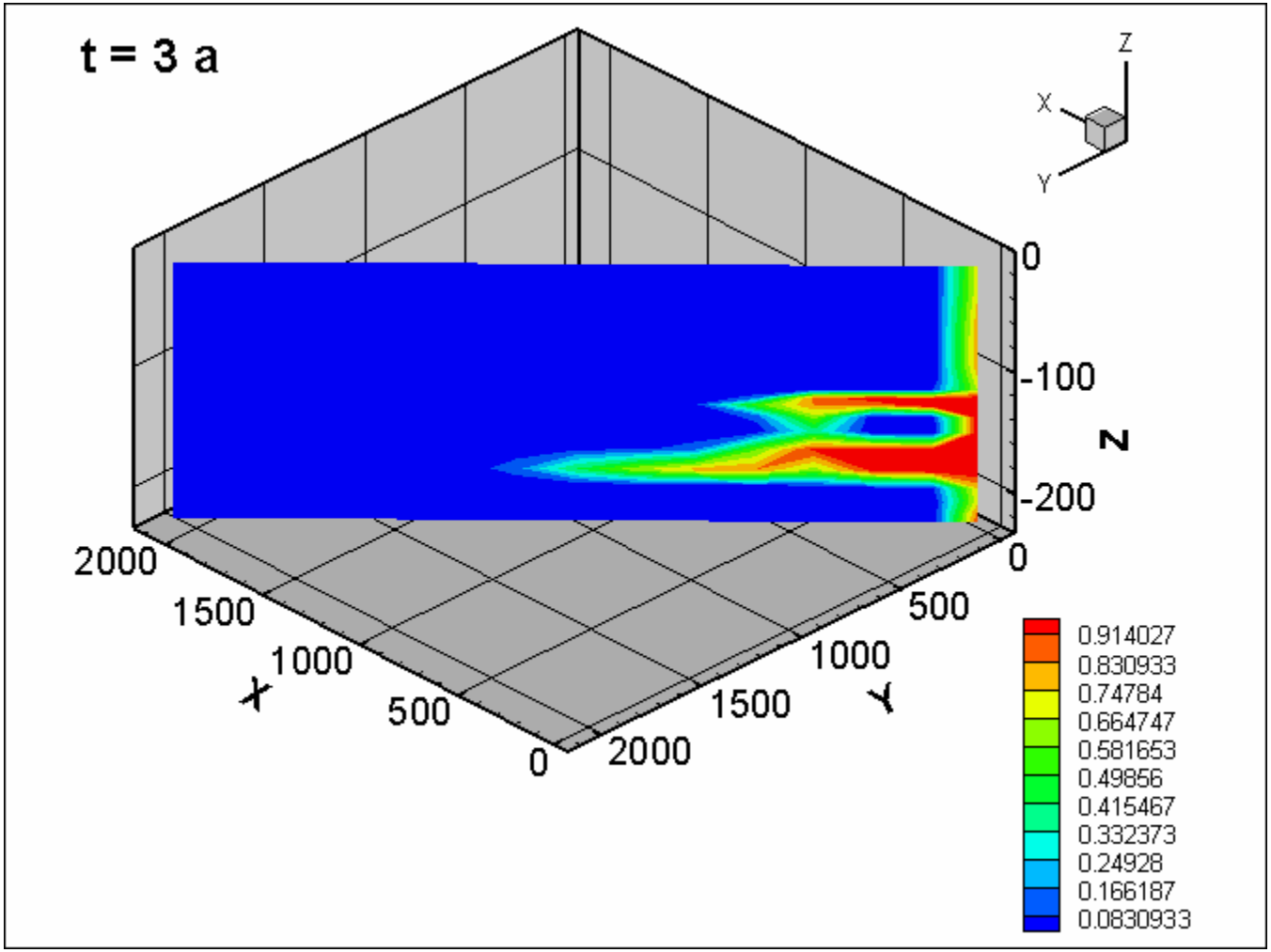

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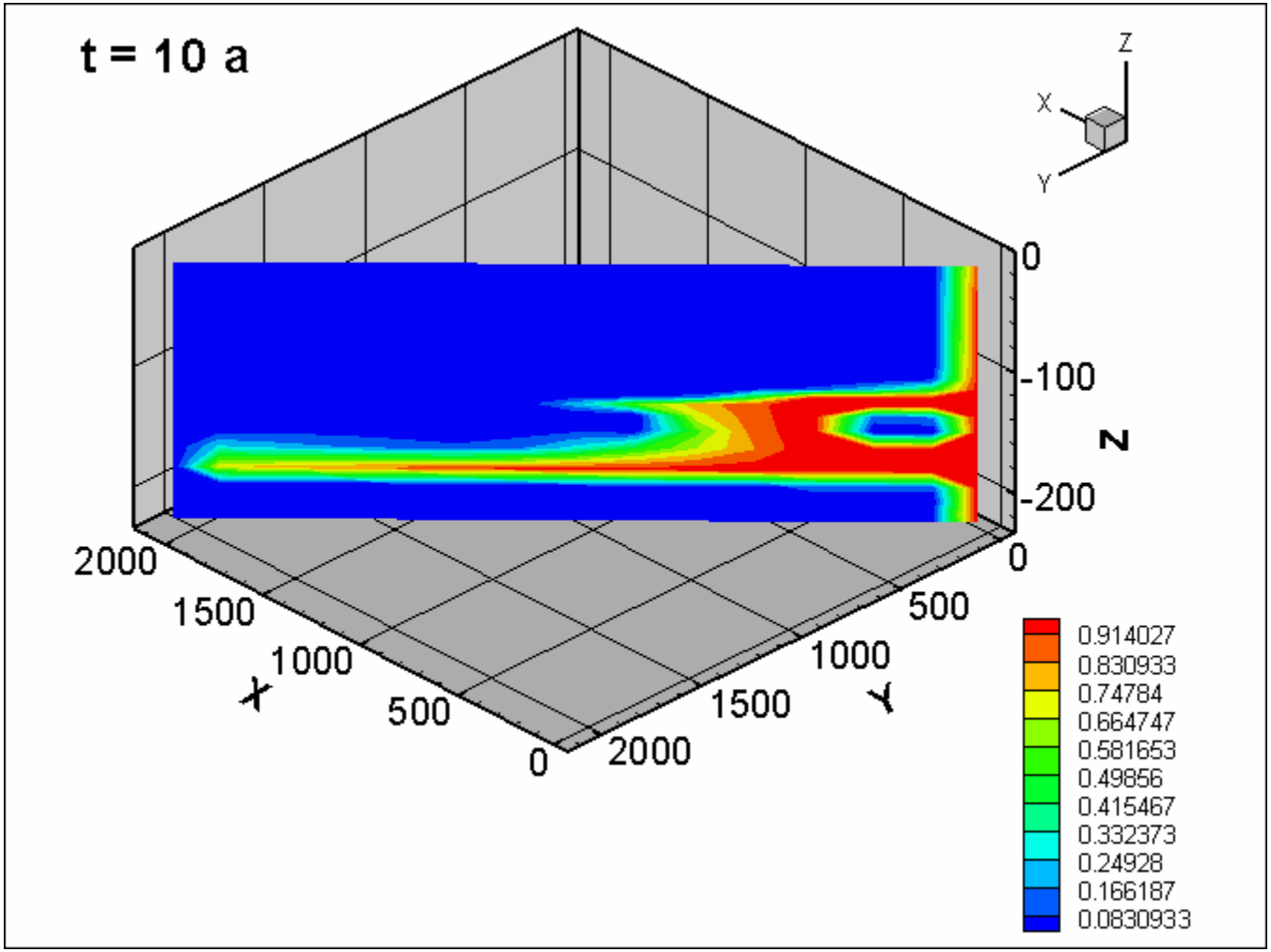

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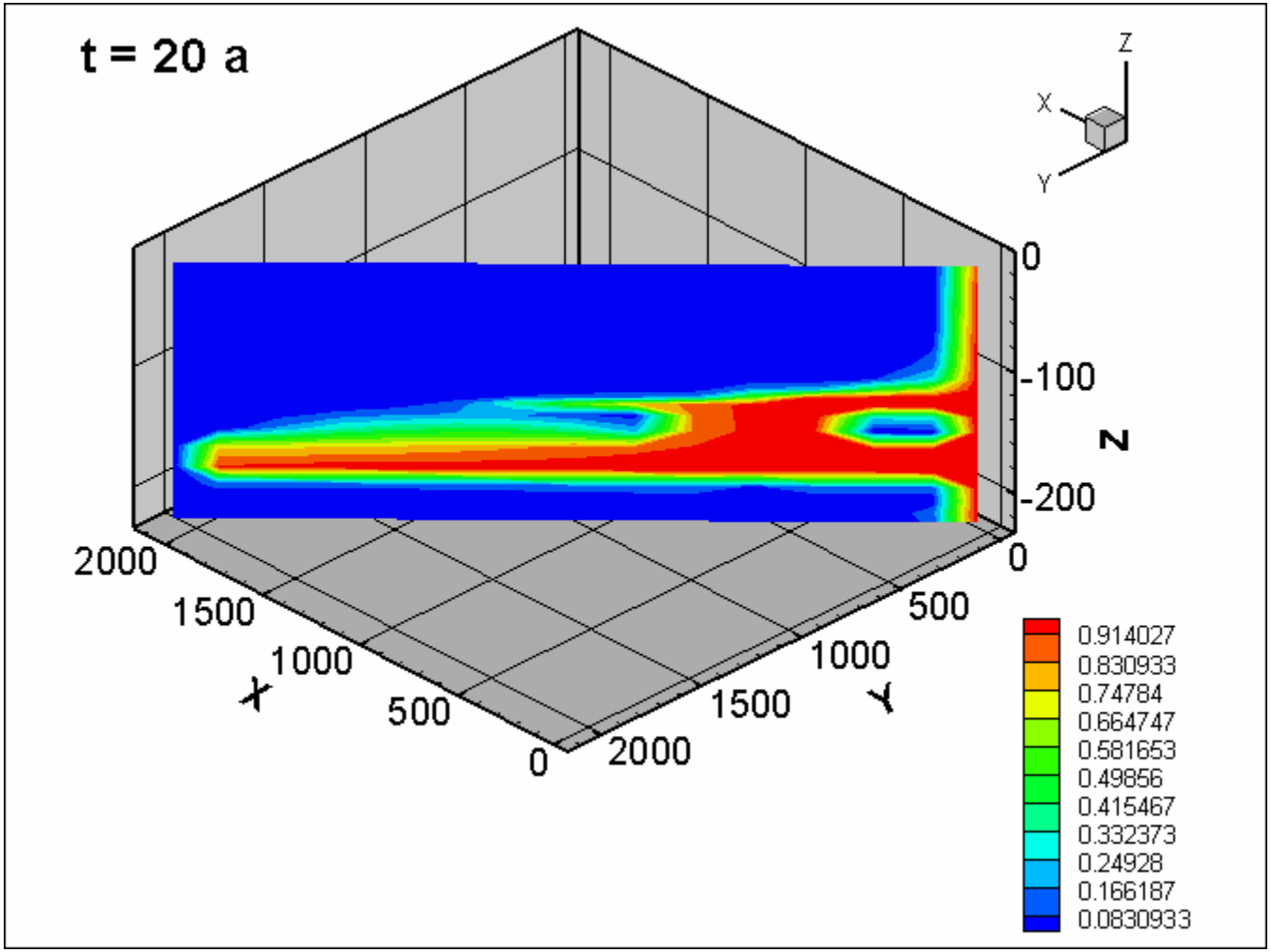

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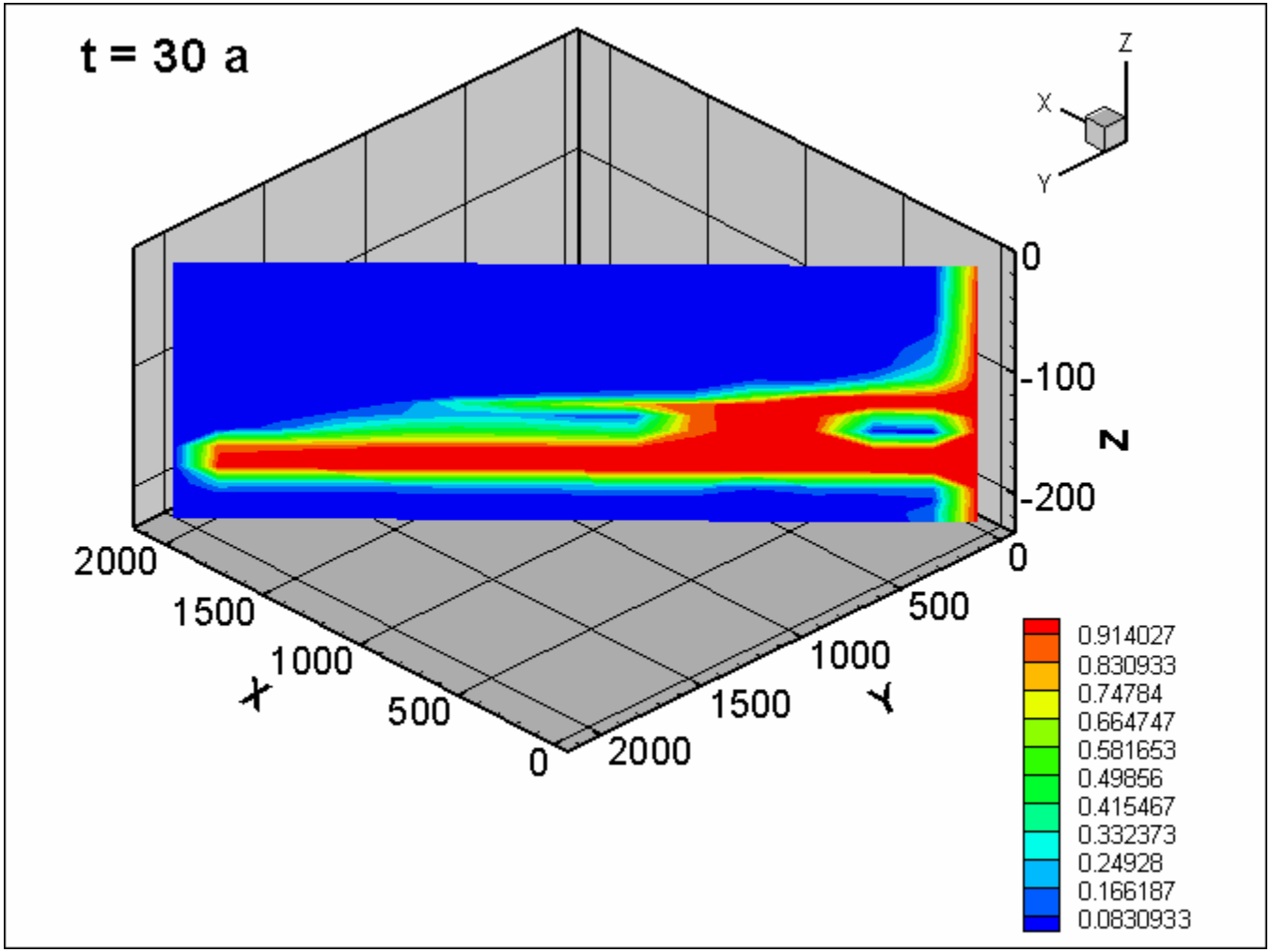

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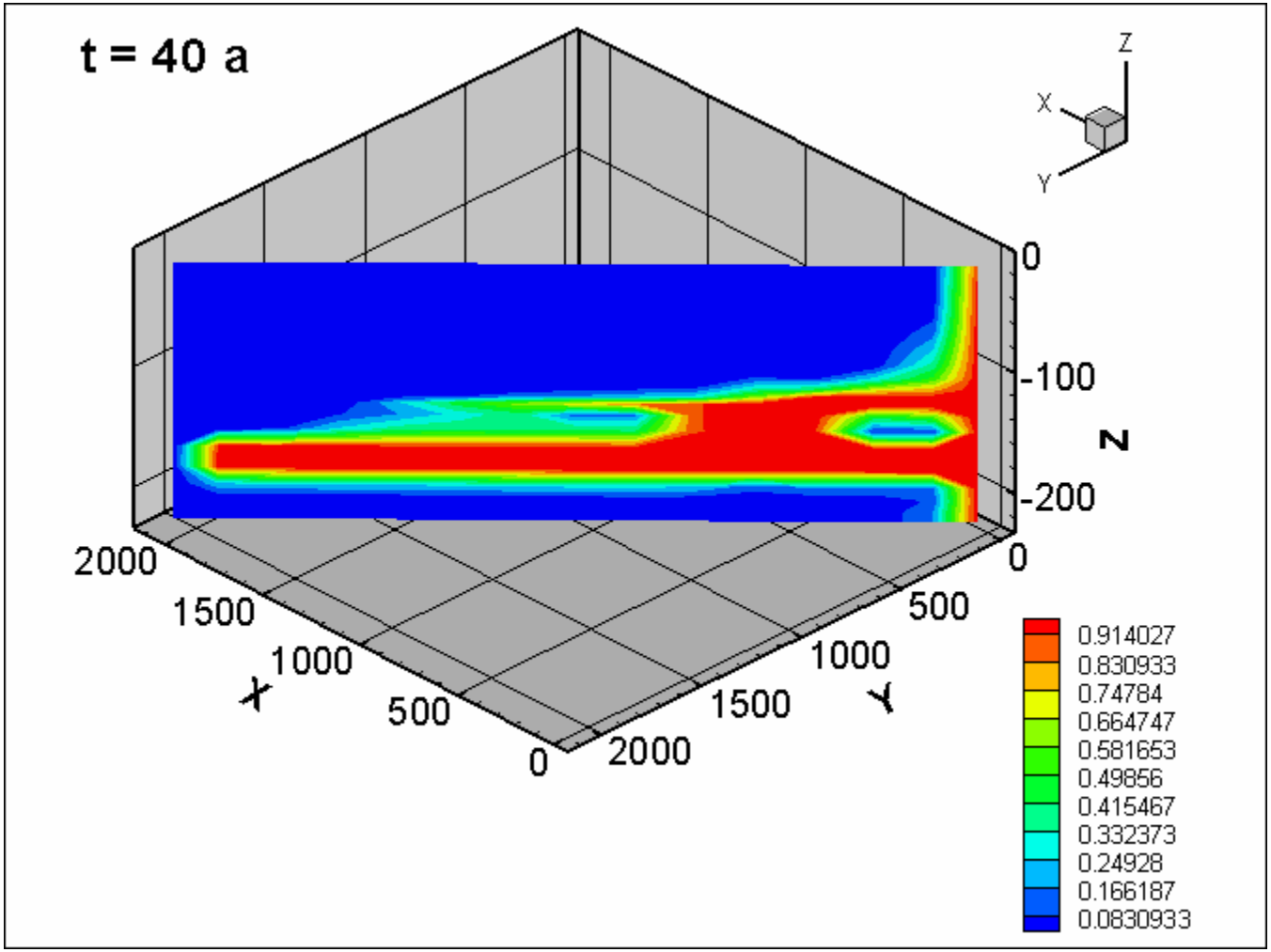

Conclusions

- Altmark area suitable for CSEGR
- Breakthrough occurs through high permeability layers within 3 a to 10 a
- Possible breakthrough delay of ~1 a
- More specific results based on site-specific data

Acknowledgments

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