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Application of Reservoir Simulations in Analysis of Existing & Potential Sequestration Structures of Poland

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Existing Sequestration Structure:

- Borzęcin (water beneath gas reservoir)

Future Sequestration Structures (3 and more)

- Budziszewice (deep aquifer)
- Nosówka (oil reservoir)
- N-N (deep aquifer)

Borzęcin structure

Injection target: water bearing zone underlying gas reservoir

Operation: since 1996 (the first inland sequestration structure of Europe)

Injected gas: by-products of amine gas sweeting process (60% CO_2, 15% H_2S) - 3 mln SCm^3

Model construction

Geology

- structural trap - anticline within Fore Sudetic Monocline
- reservoir rock: Zechstein Basal Limestone (30 m thick),
  Rotliegend Sandstone (>300 m thick)
- reservoir boundaries: anhydrite caprock, underlying water

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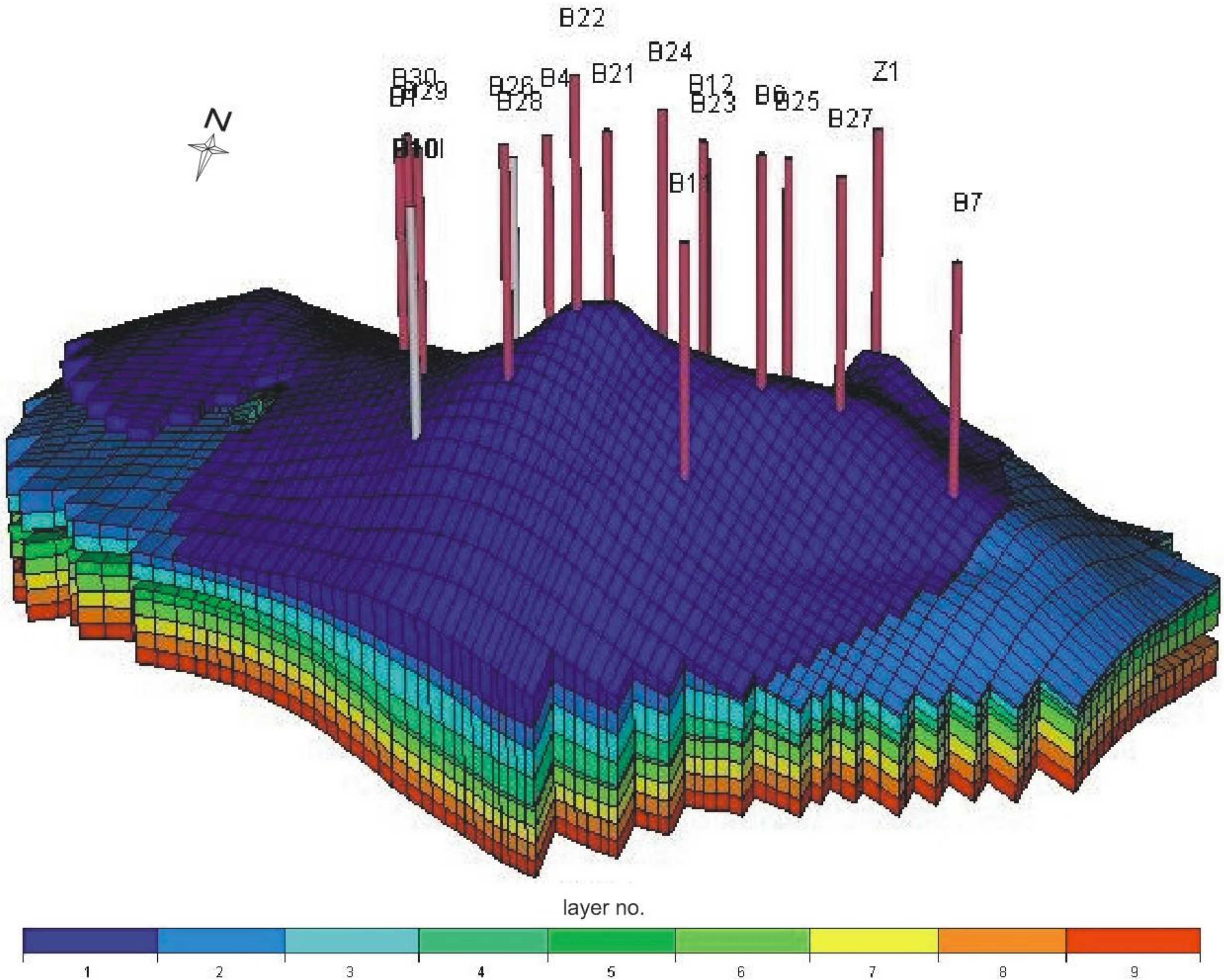
Perspective view of the Borzęcin Structure Model



Model calibration

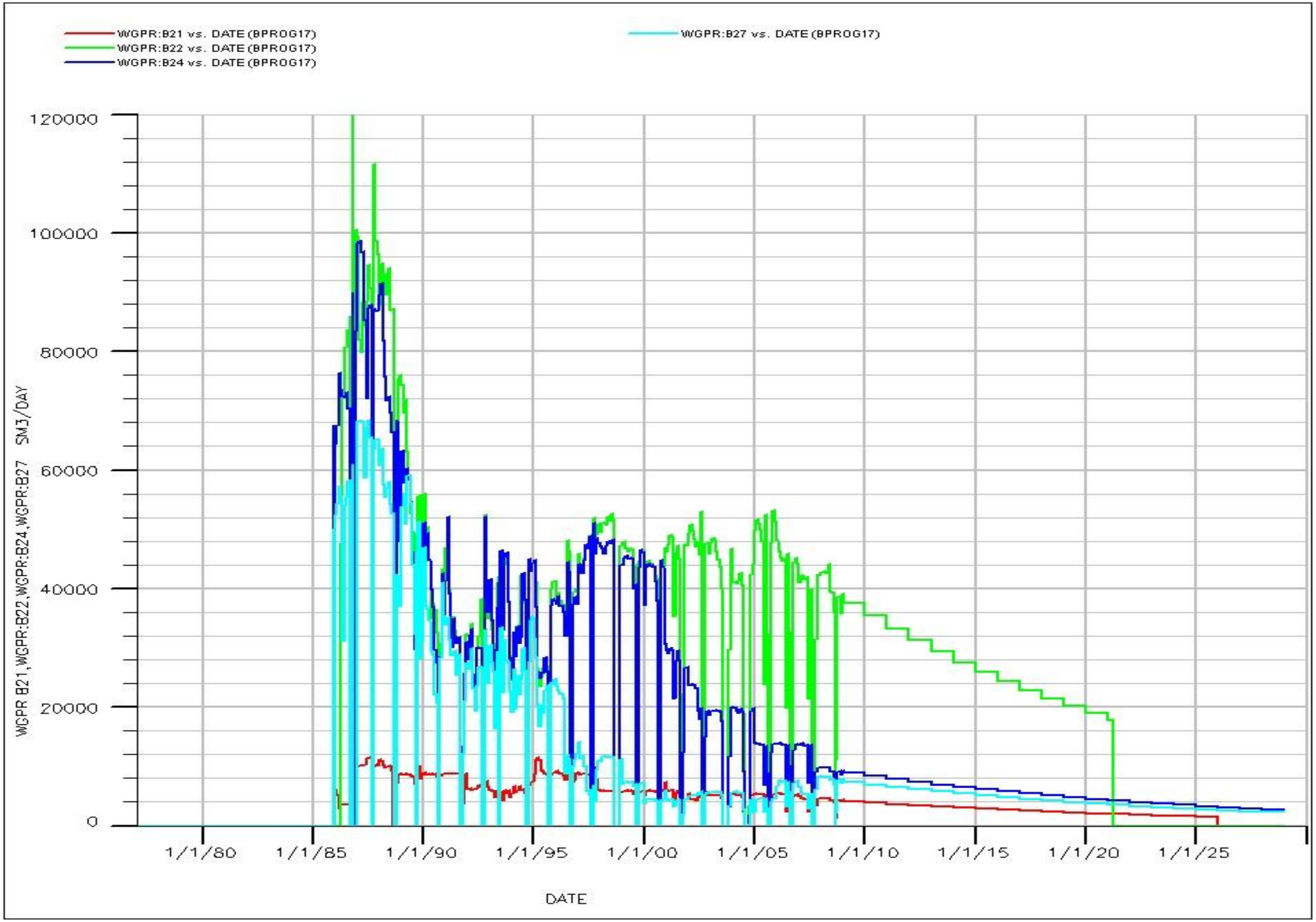
Production data since 1972:

- gas production data (18 wells)
- bottom hole pressures
- water-gas ratios
- water re-injection (well B-10)

Injection data since 1996:

- acid gas injection (well B-28 since 1996, 60% CO_2, 15% H_2S)
- composition of gas produced by individual wells
  (currently 4 producers: B-21, 22, 24, 27)

Borzęcin Gas Reservoir. Production rate q_g of wells: B-21, B-22, B-24, B-27. Historical data and simulation predictions: B-22 stopped in 2022 by water-gas-ratio, B-21 stopped in 2026 due to economic limit



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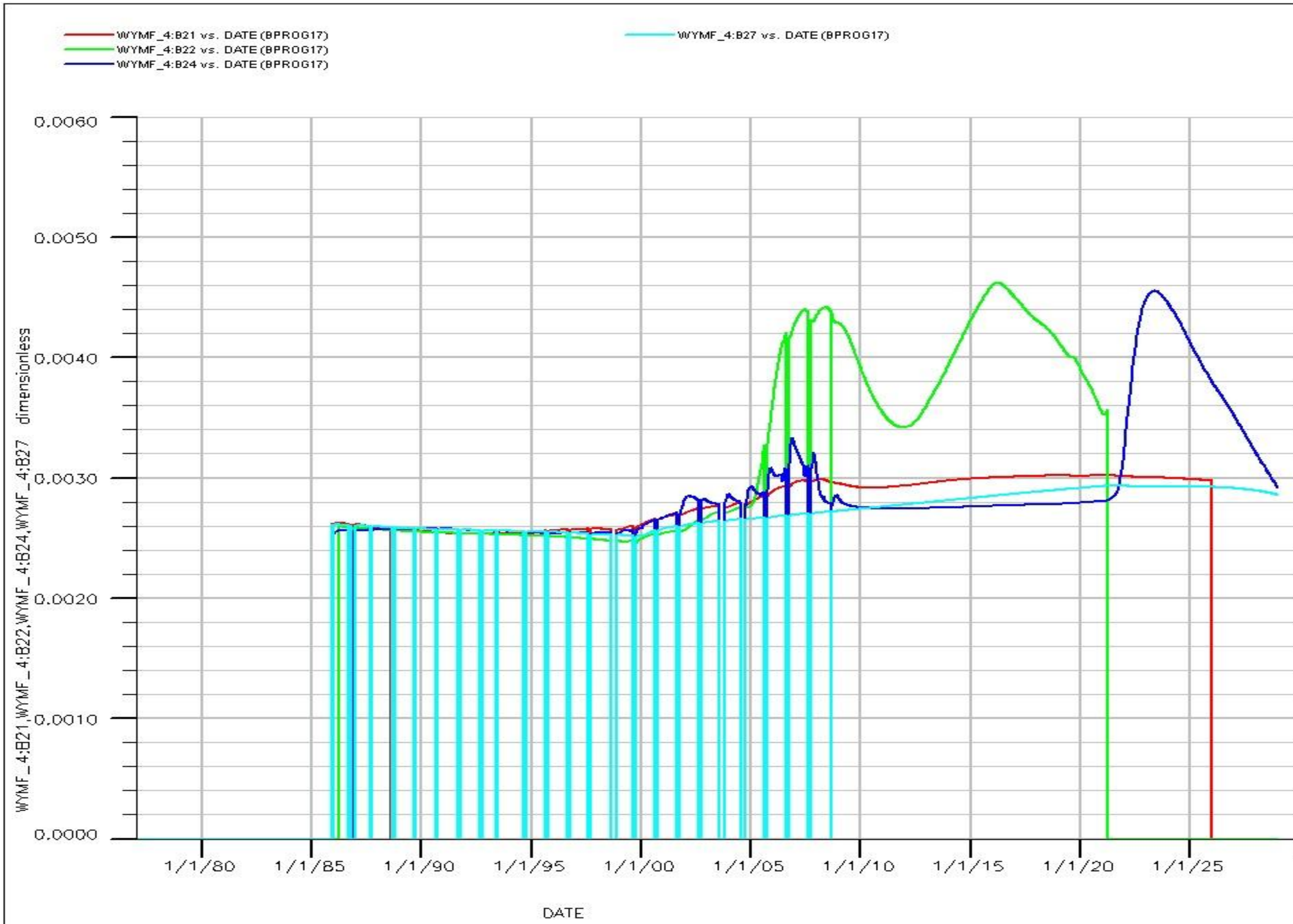
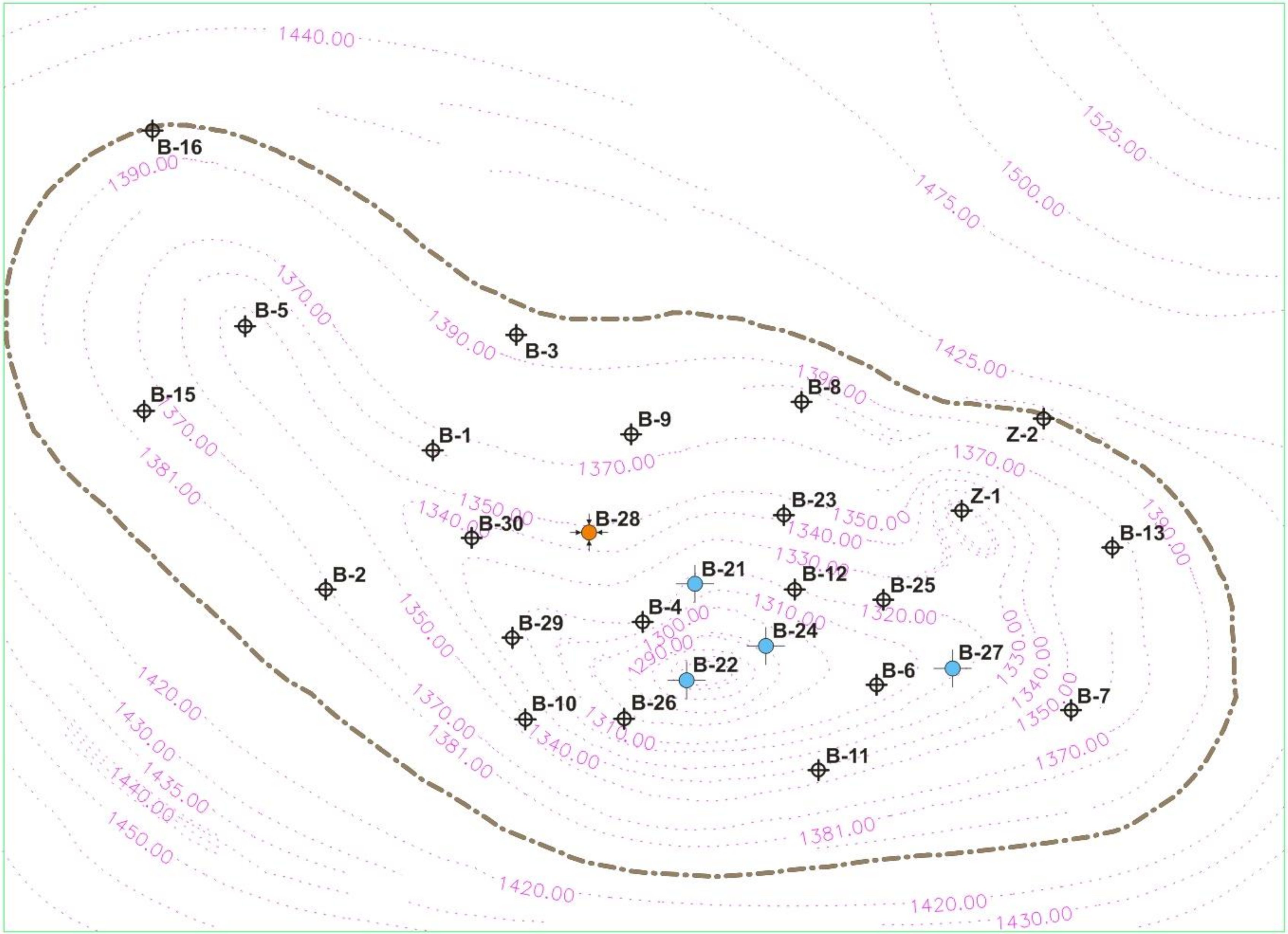
Borzęcin Gas Reservoir. Production Forecast. CO_2 Concentration in produced gas wells: B-21, B-22, B-24, B-27
Time profile of CO_2 concentration complicated due to active water – blocking of gas migration paths - nonuniform CO_2 flow to producers. Maximum CO_2 concentration in produced gas less than 0.5 %



Location of injector , B-28 and 4 producers, B-21, B-22, B-24, B-27 on the structure top map of Borzęcin



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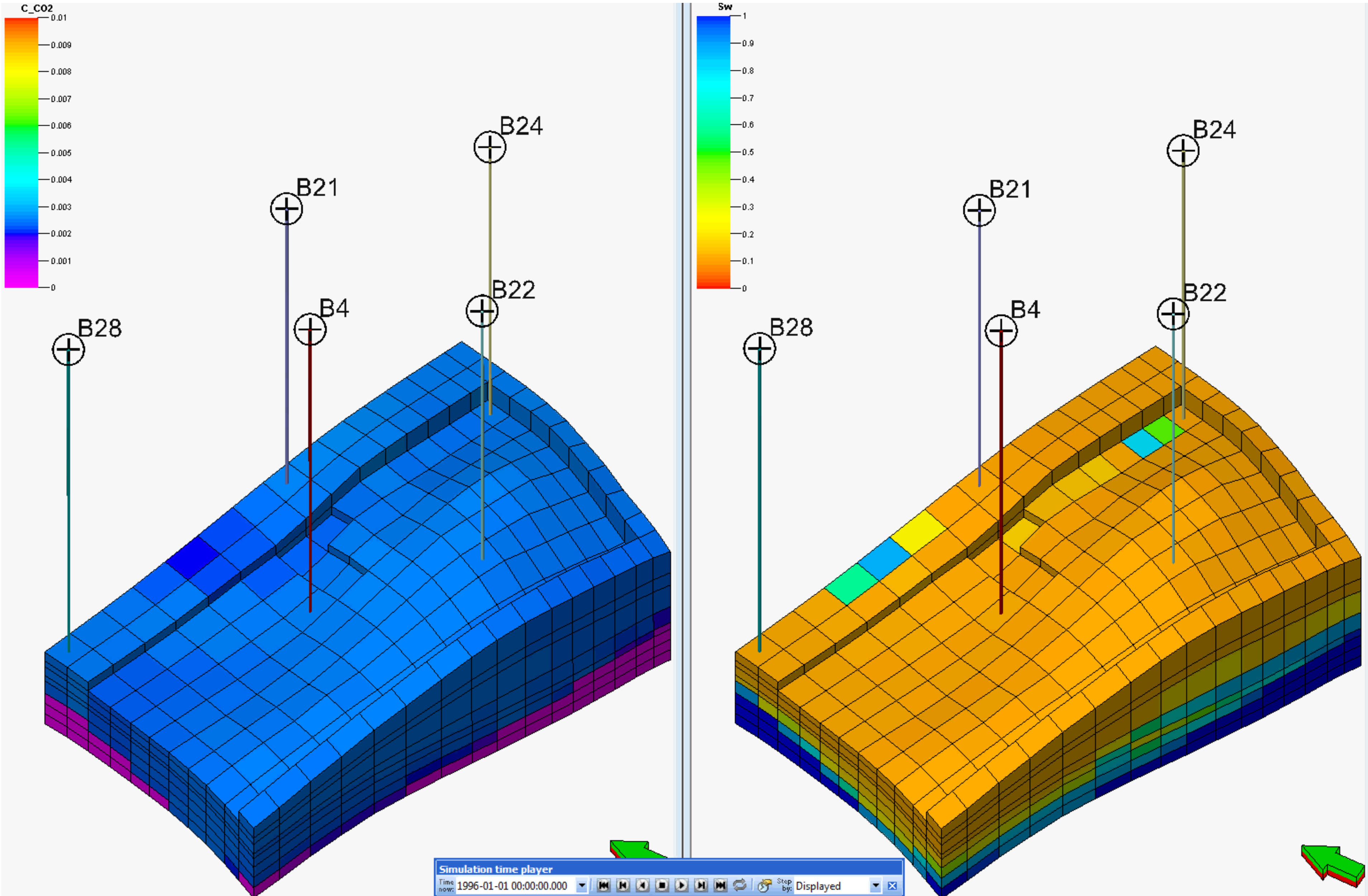
Predicted injected gas migration and water encroachment in Borzęcin structure.

Left panel: CO_2 concentration distribution   Right panel: water saturation distribution



Summary and Conclusions for the Borzęcin Structure Operation and Simulations

1. 15-years experience of acid gas injection - confirmed practical feasibility of acid gas storage in continuously producing gas reservoir
2. constant monitoring of the acid gas storage - safety of the process with respect to chosen materials and technology
3. despite relatively fast migration of the injected gas to the original gas bearing zone – very low contamination of original gas production
4. dominating process of gas storage in water bearing zone - upward migration driven by buoyancy effect

Budziszewice structure

deep aquifer in lower Triassic formations

Geological model: anticline of the middle and lower Bunter sandstones, various realisations of basic geological parameters

Measured flow properties: relative permeabilities, capillary pressure

Reservoir fluid descriptions: Peng-Robinson EoS; measured brine properties, incl'd CO_2 solubility in reservoir brine

Boundary conditions: open boundaries with external aquifers of different size

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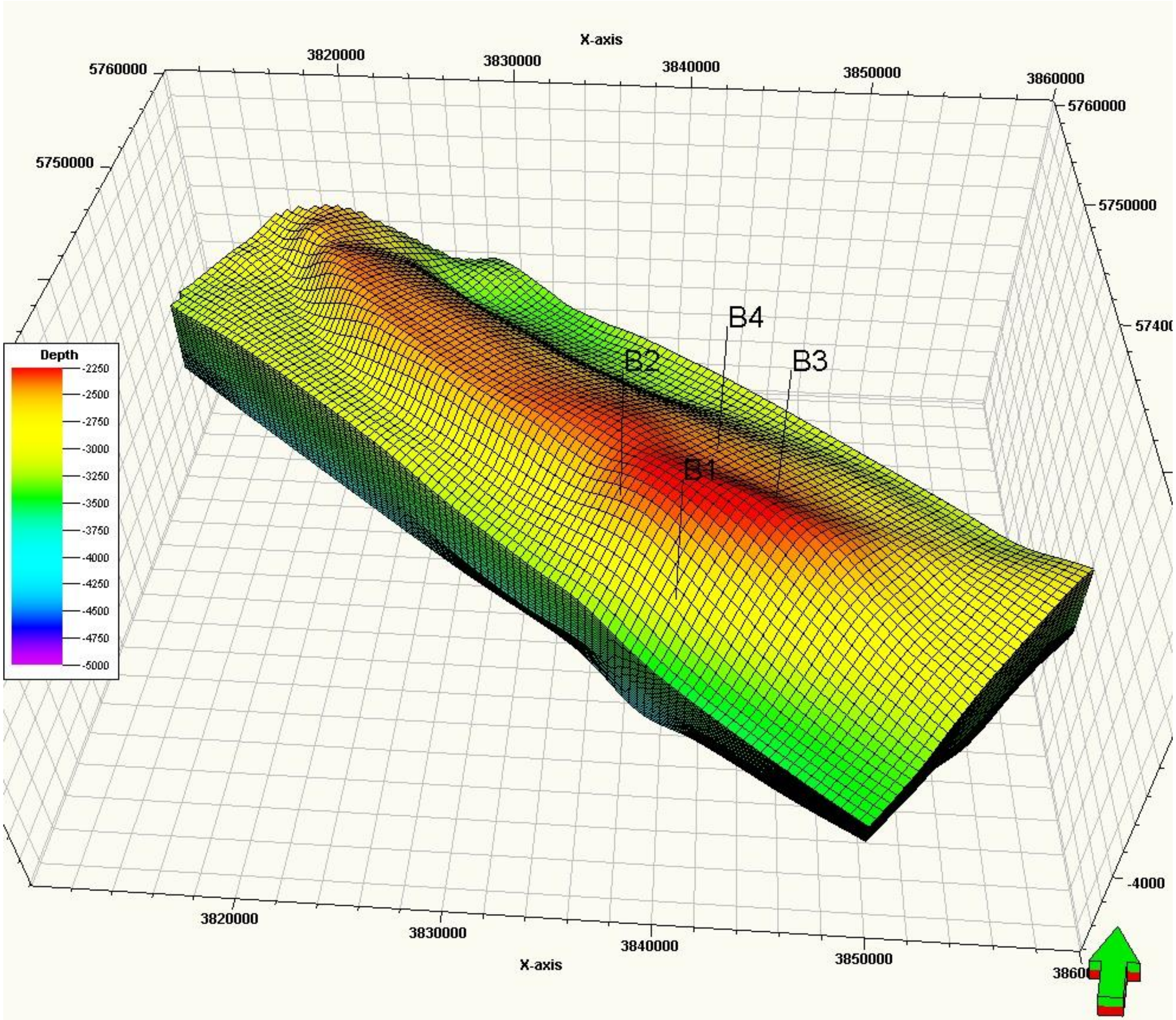
3D view of the Budziszewice model



Simulation of CO_2 sequestration process:

- 4 injectors
- q_{inj} = 624 Nm^3/d/well (0.45 Mt/year/well)
- t_{inj} = 25 years
- G_{inj} = 5.67 x 10^9 Nm^3/well (11.25 Mt/well)

Processes during and after injection

- upward migration of CO_2 towards structure top (buoyancy effect)
- solubility of CO_2 in brine
- brine convection (density changes due to CO_2 solubility in brine)

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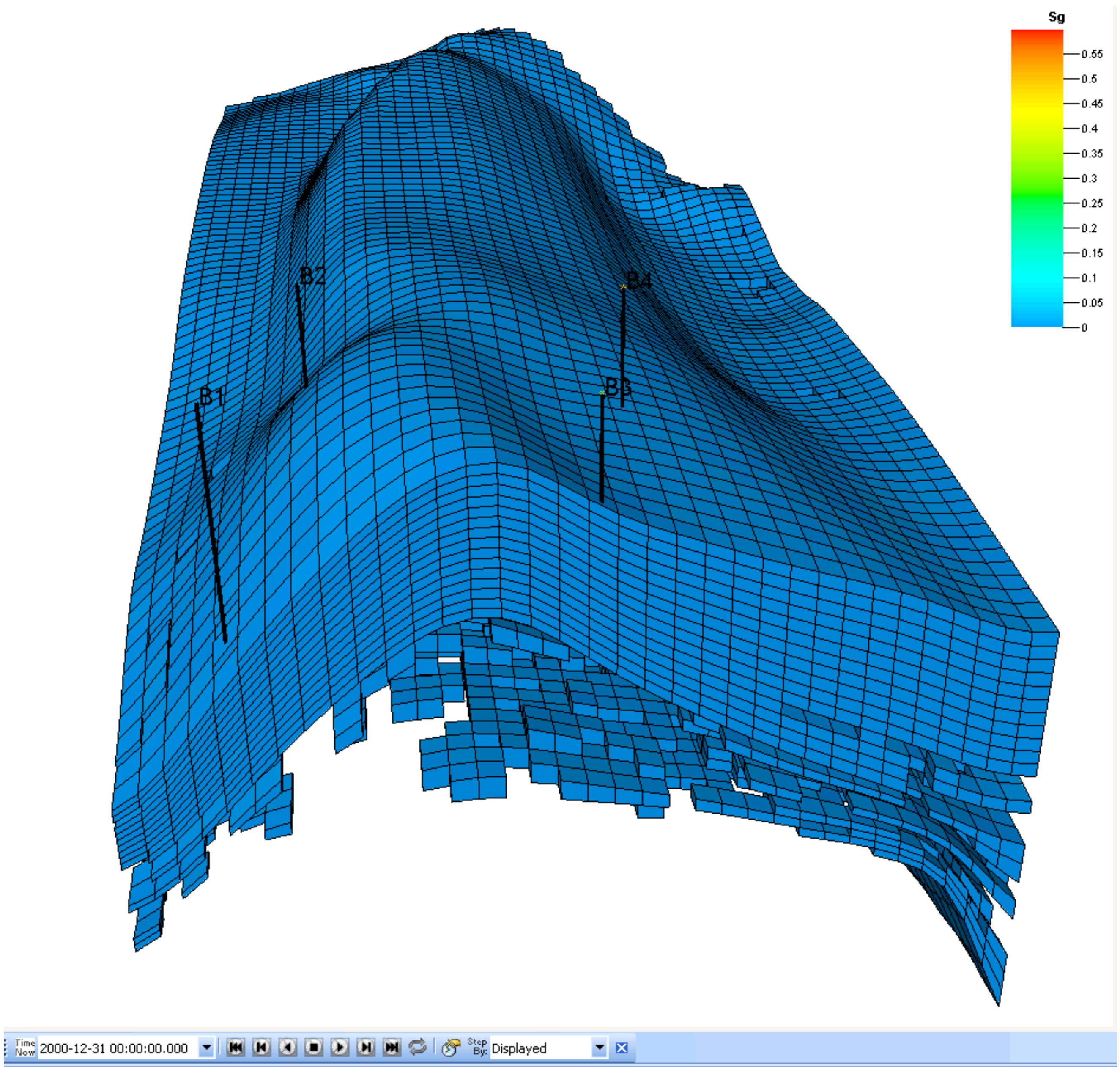
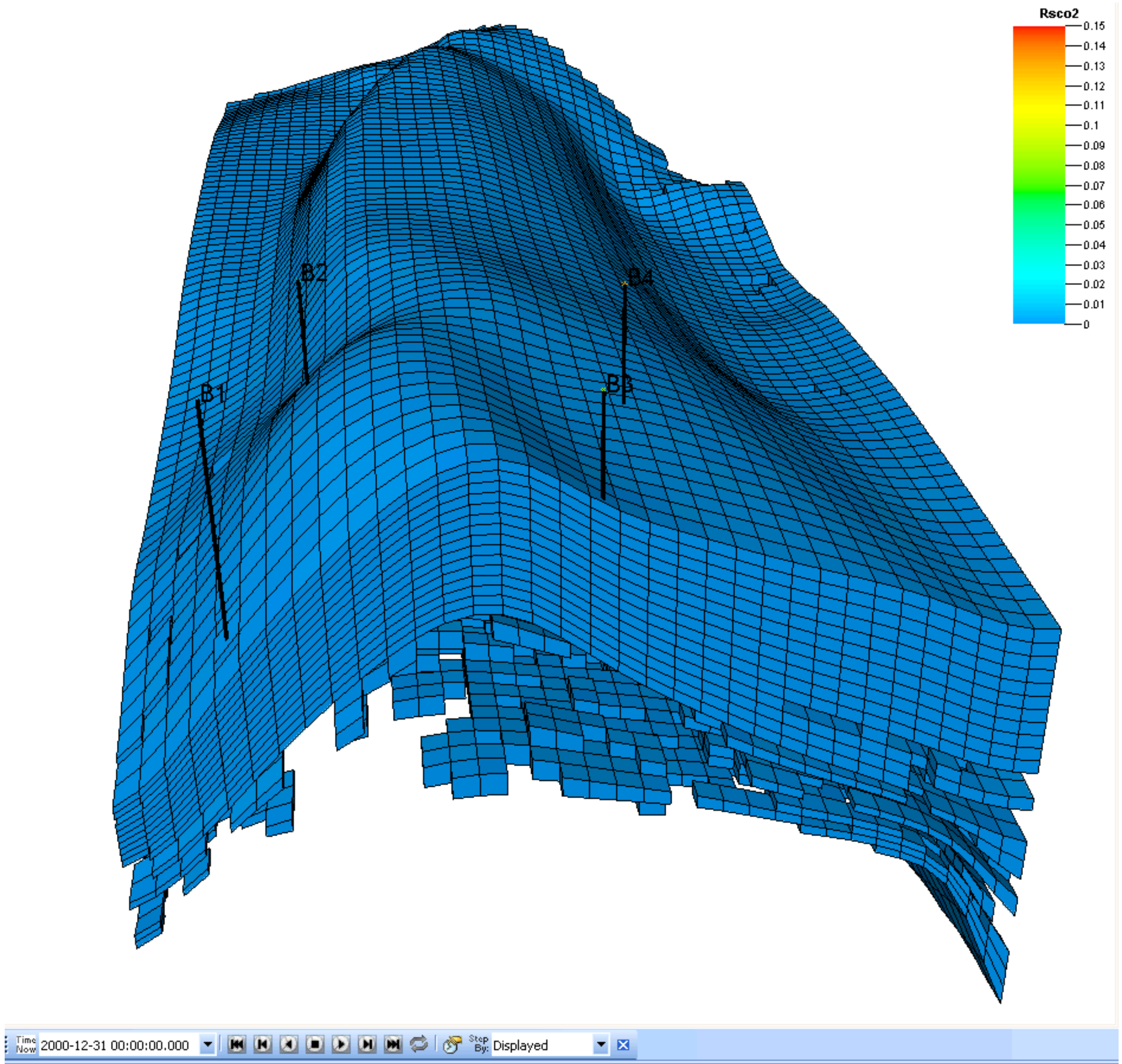
Distribution of free CO_2 in the Budziszewice structure – general view



Distribution of CO_2 in brine concentration in the Budziszewice structure – general view



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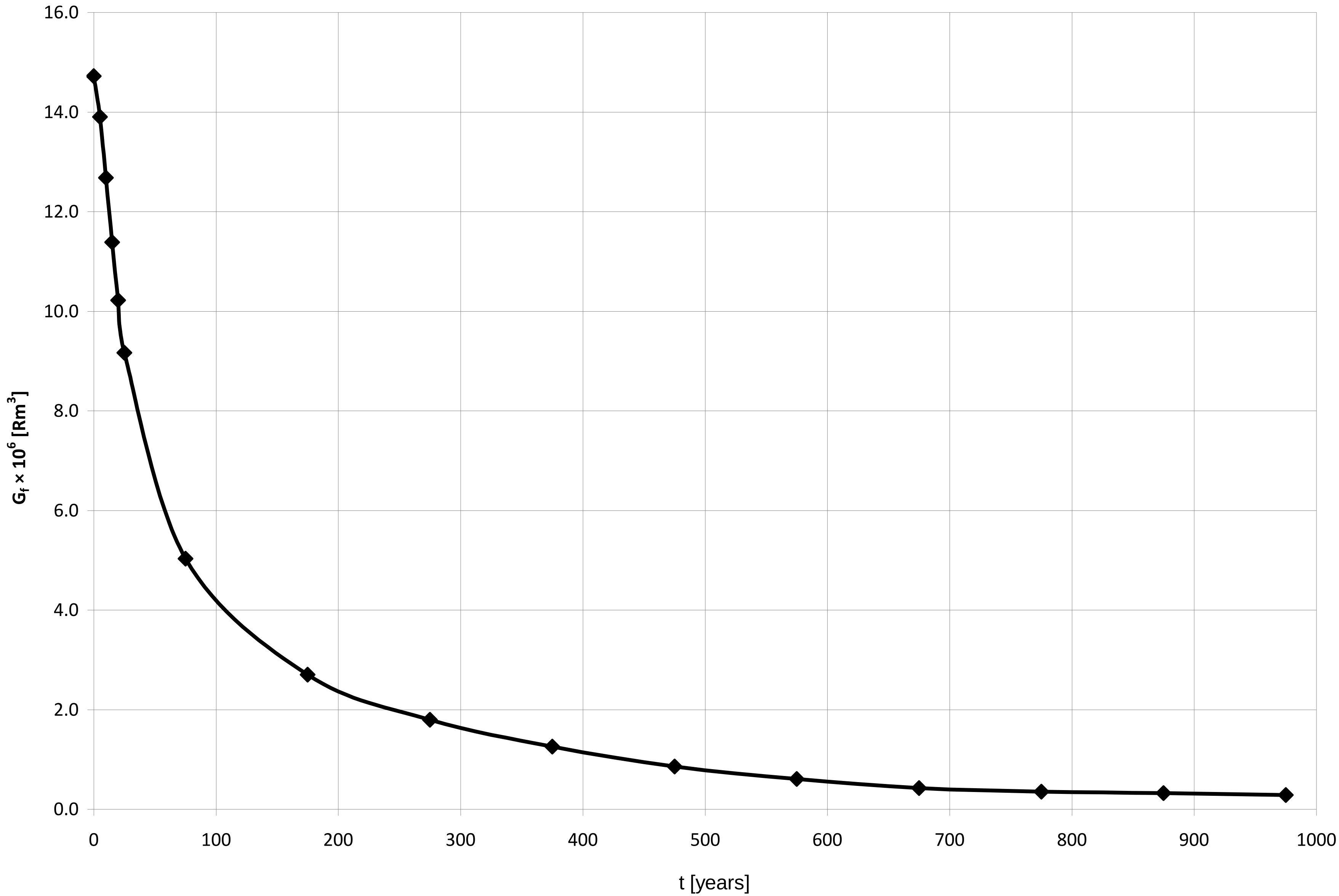
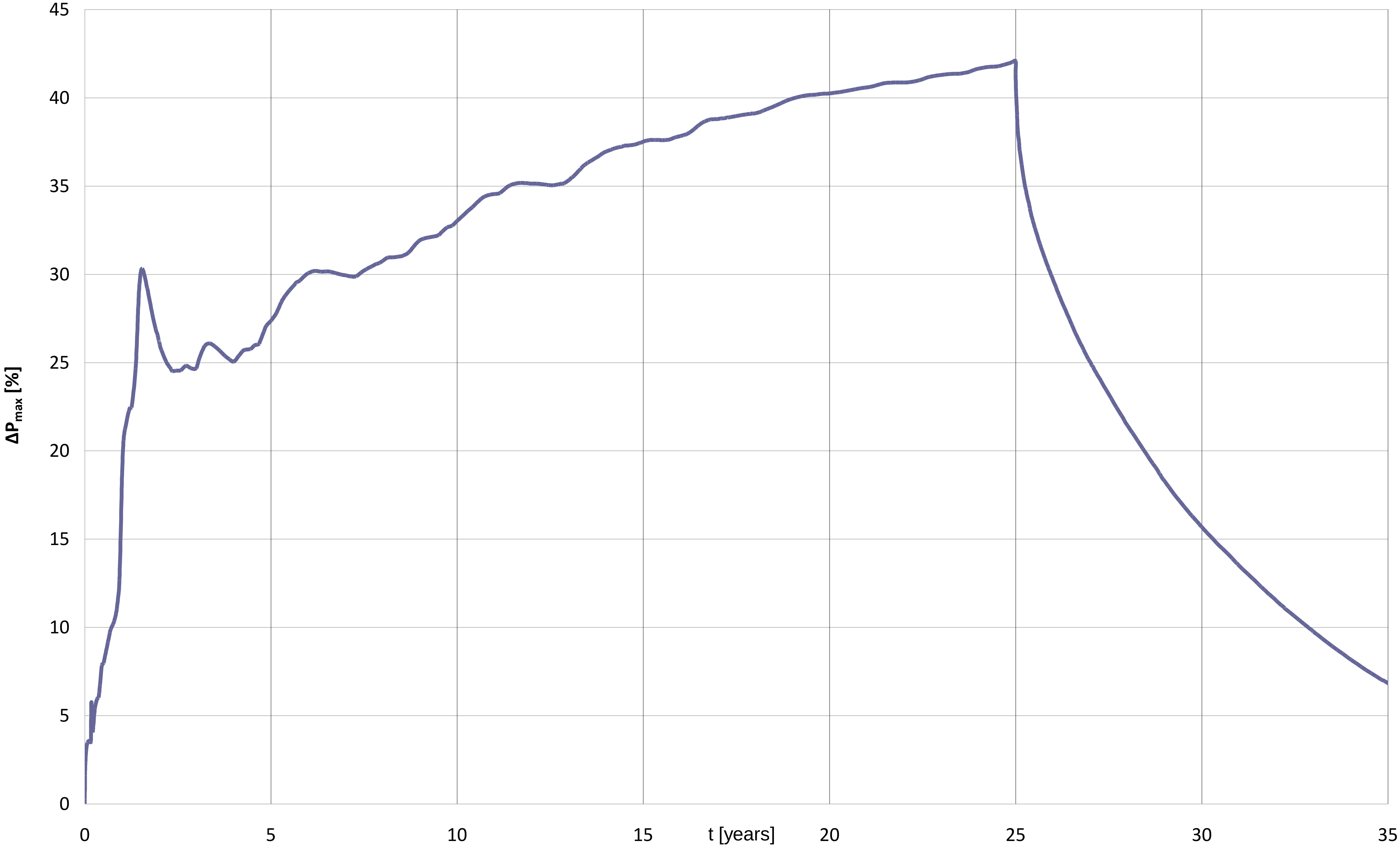
Budziszewice structure – volume changes of free CO_2, G_f, with time, t



Pressure issues

- maximum increase at the structure top (cap rock tightness)
- maximum pressure in the structure bulk and maximum gradient with depth (rock fracturing)
- maximum bottom hole pressure and well head pressure (injection technical parameters)

Maximum pressure increase at the structure top (cap rock tightness)



Sensitivity studies

- external aquifer size
- uncertainity of basic geological parameters (porosity, permeability)

Summary and Conclusions for the Sequestration Simulations of Budziszewice Structure

1. Estimation of the CO_2 plume extention and its evolution with time
2. Possible risk analysis of the structure tightness due to pressure increase in the structure
3. Variation of basic injection results with the uncerntainty of geological modeling
4. Estimation of CO_2 in brine solubility effects

Nosówka structure

partially depleted oil reservoir – CO_2 sequestration and EOR production

Geological model – Carpathian Flysch region, Carbonate formations: limestone & dolomitic limestone, structure confind by system of faults, no active aquifers

3-phase fluid interactions (oil, gas, CO_2) by Soave-Redich-Kwong EOS

Simulation Model calibrated w/r 20 years' production (production rates, bhp's, gas oil ratios)

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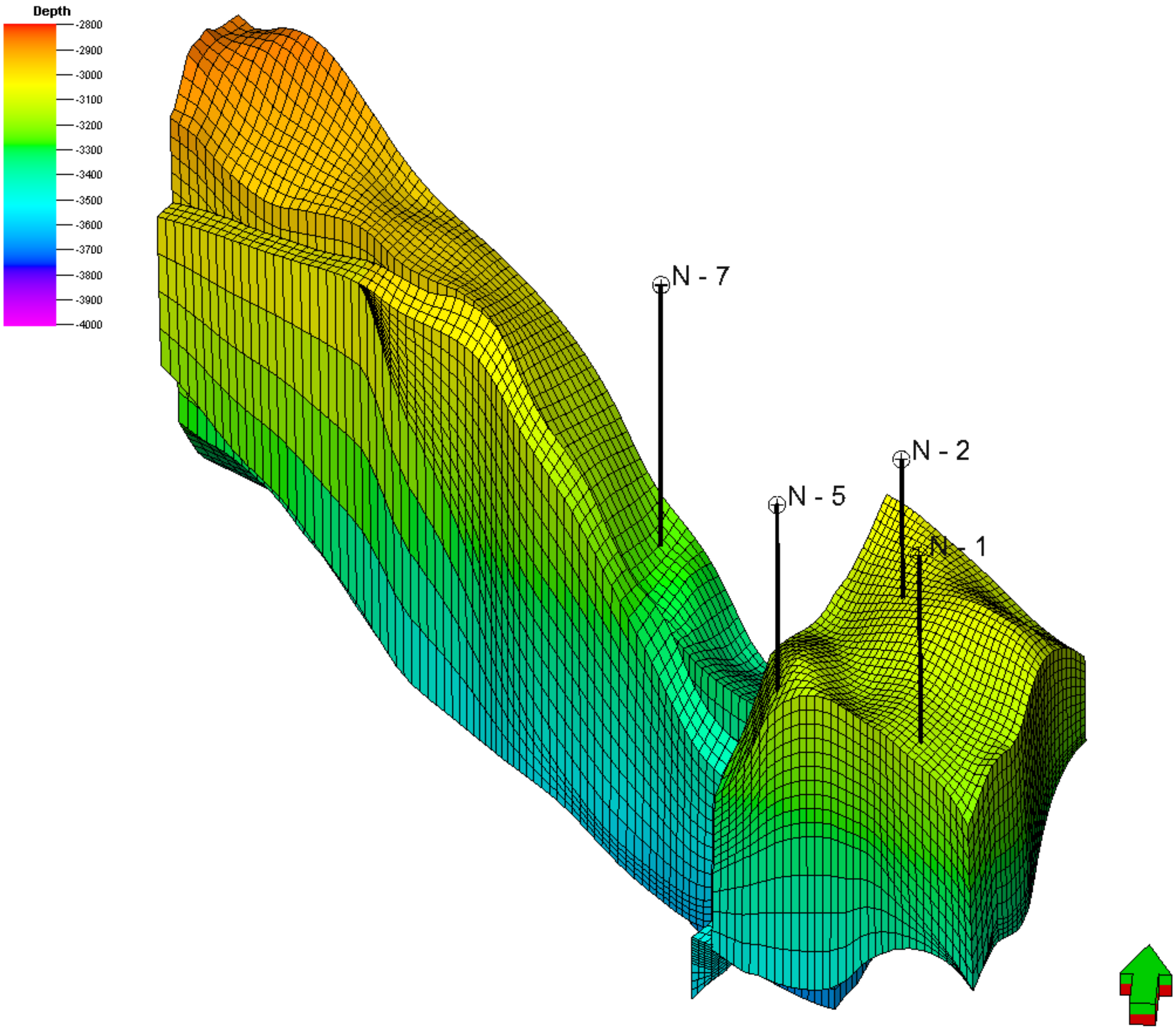
Perspective view of the Nosówka Structure Model



Model calibration

Production data since 1989:

- oil production data (4 wells)
- botom hole pressures
- water-gas ratios

CO_2 sequestration and EOR simulations

Various scenarios of injection–production process:

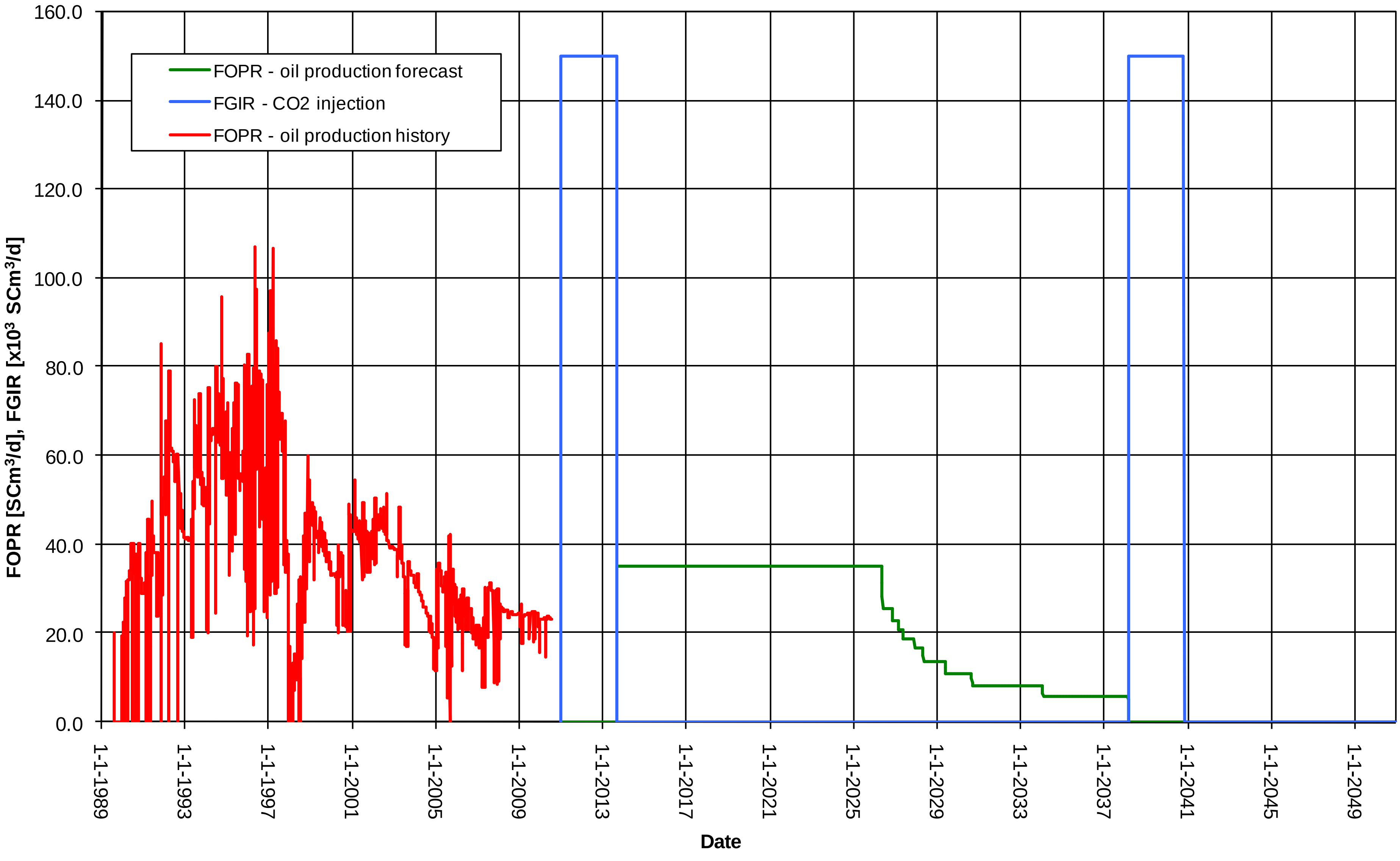
1. sequential conversion of producers into injectors
2. injection before production + final injection (most effective)
3. cyclic injection–production scheme (with reservoir pressure kept above saturation pressure)

Best results of scenario no. 2:

oil production total, OPT = 206 x 10^3 Nm^3 (17% gain of recovery)

total CO_2 injection, GIT = 285 x 10^6 Nm^3

CO_2 injection into Nosówka oil reservoir. Oil production rate, FOPR, CO_2 injection rate, FGIR



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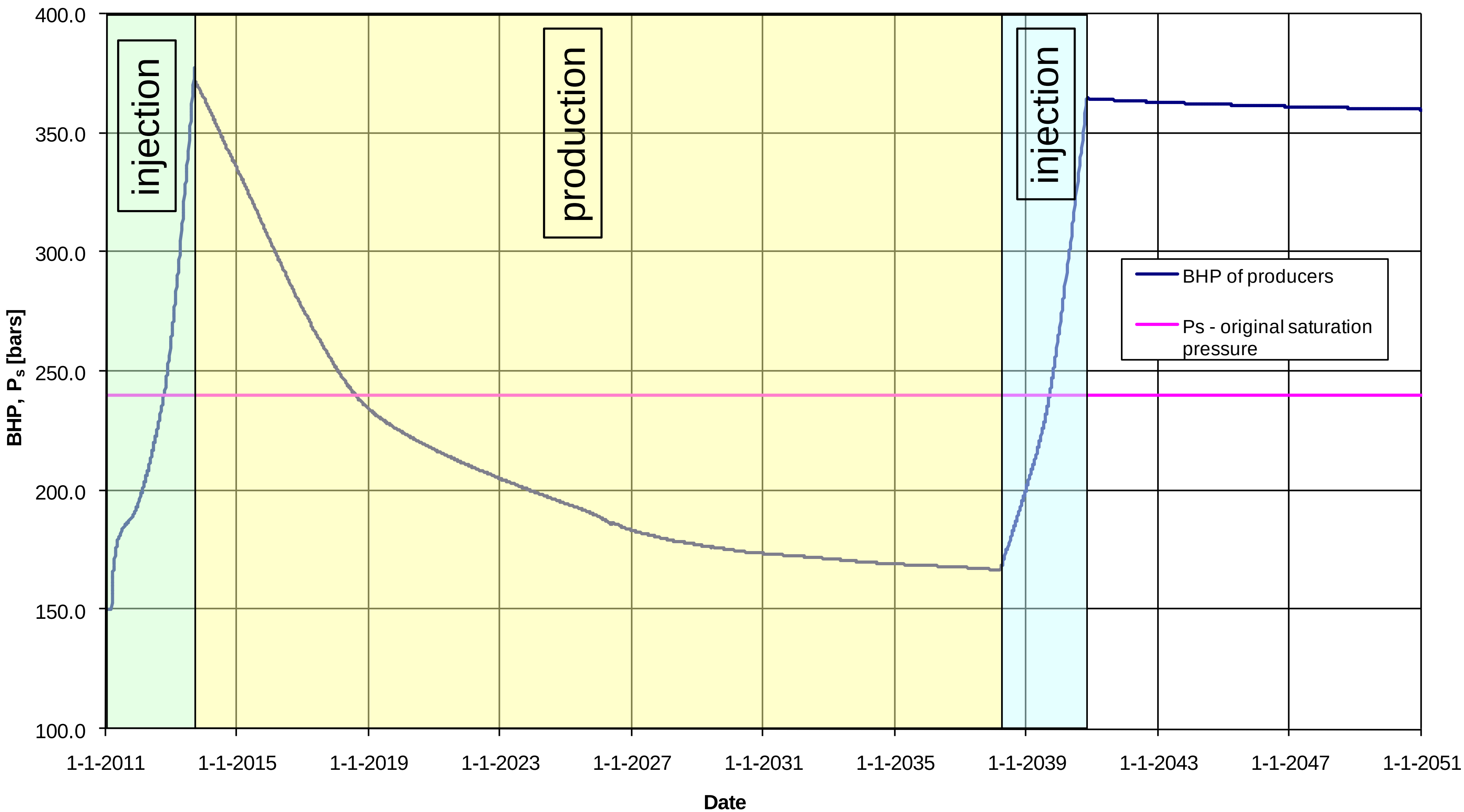
CO_2 injection into Nosówka oil reservoir.
Bottom hole pressure of producers, BHP vs original saturation pressure, Ps



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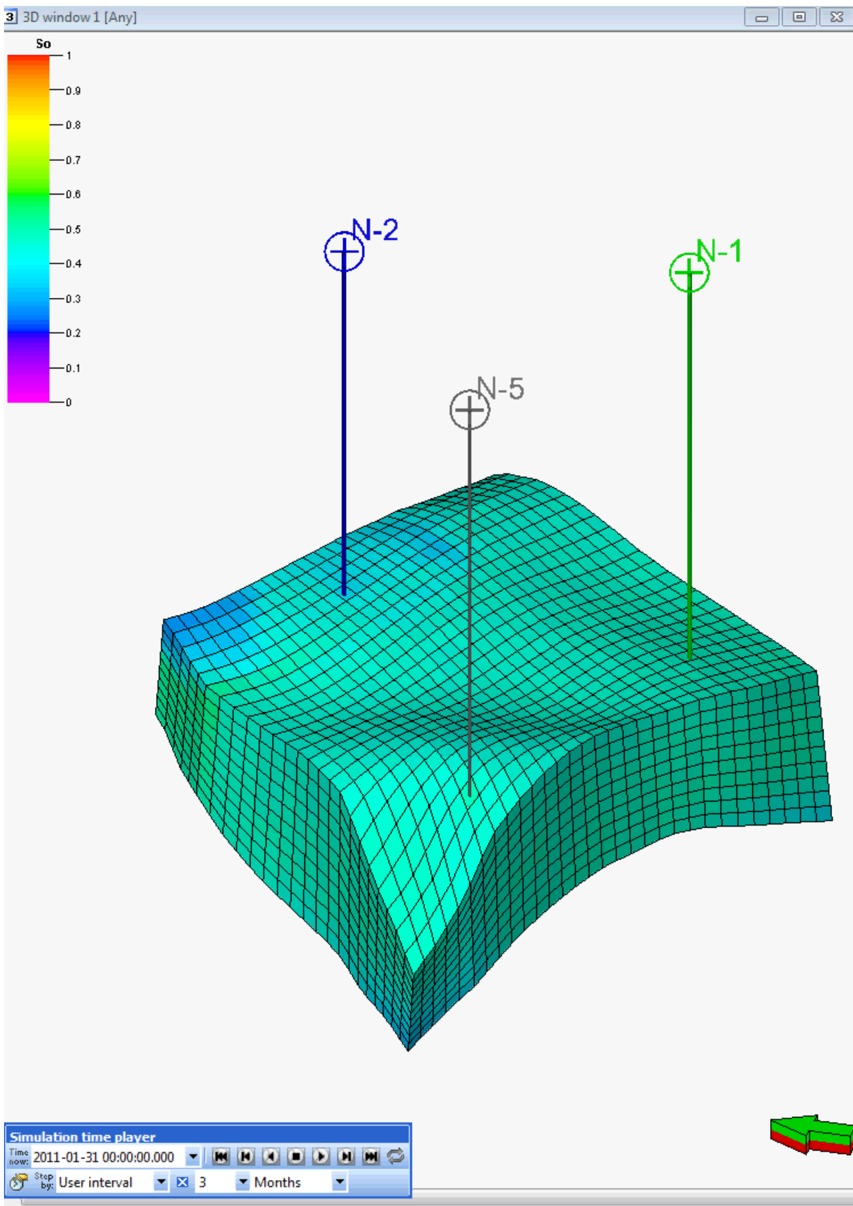
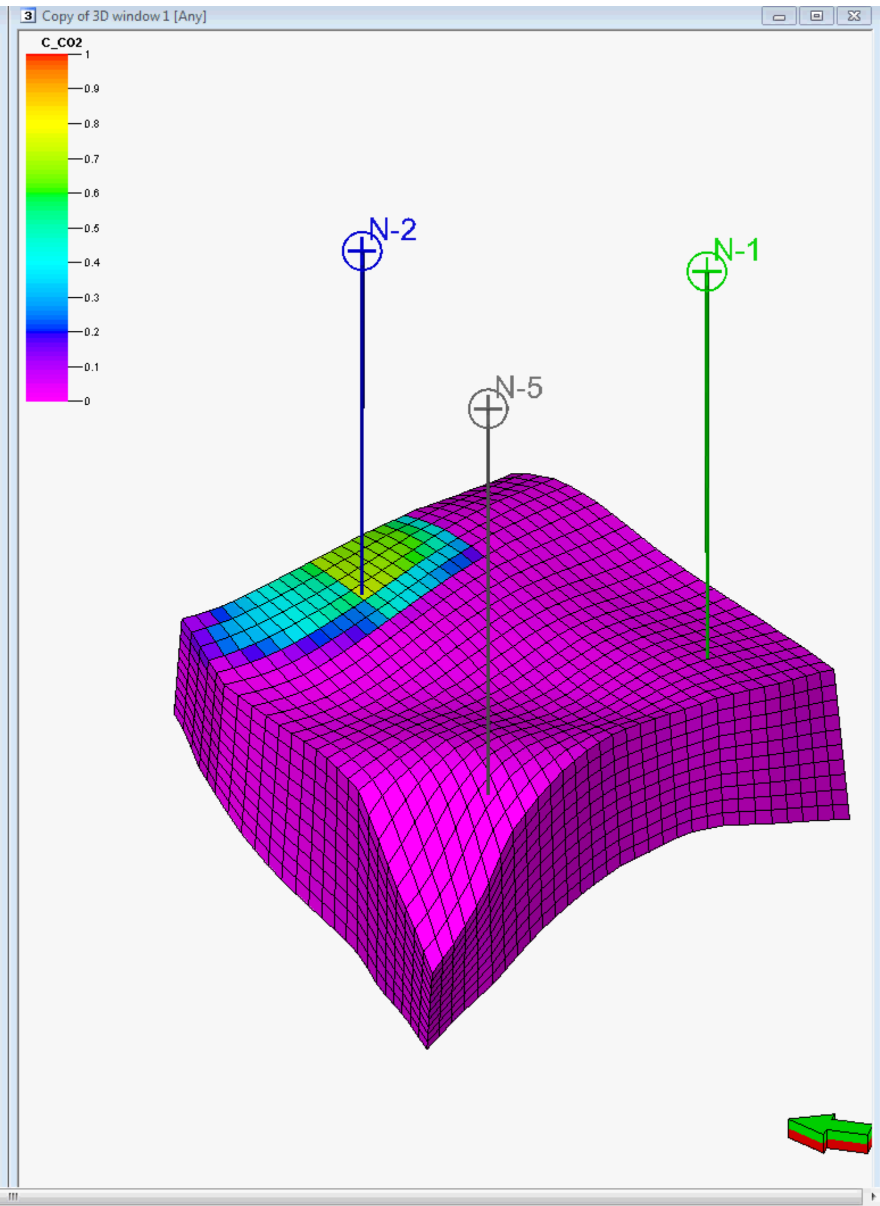
CO_2 injection into Nosówka oil reservoir. Distribution of:

oil saturation, S_o, and



CO_2 concentration in liquid phase, C_{CO2}



Summary and Conclusions for the EOR and Sequestration Simulations of Nosówka Oil Field

1. Comparisons of various injection-production scenarios
2. Best results for separate production and injection periods
3. Analysis of complex phase behaviour – original hydrocarbon gas solution/desolution; miscible/immiscible oil displacement by CO_2

N-N structure

deep aquifer in lower Cretaceous series

Geological model – structural trap of anticline type of double dome; containing of Barremian sanstones, Aptian claystones and mudstones and Albian sandstones; various ralisations of basic geological parameters

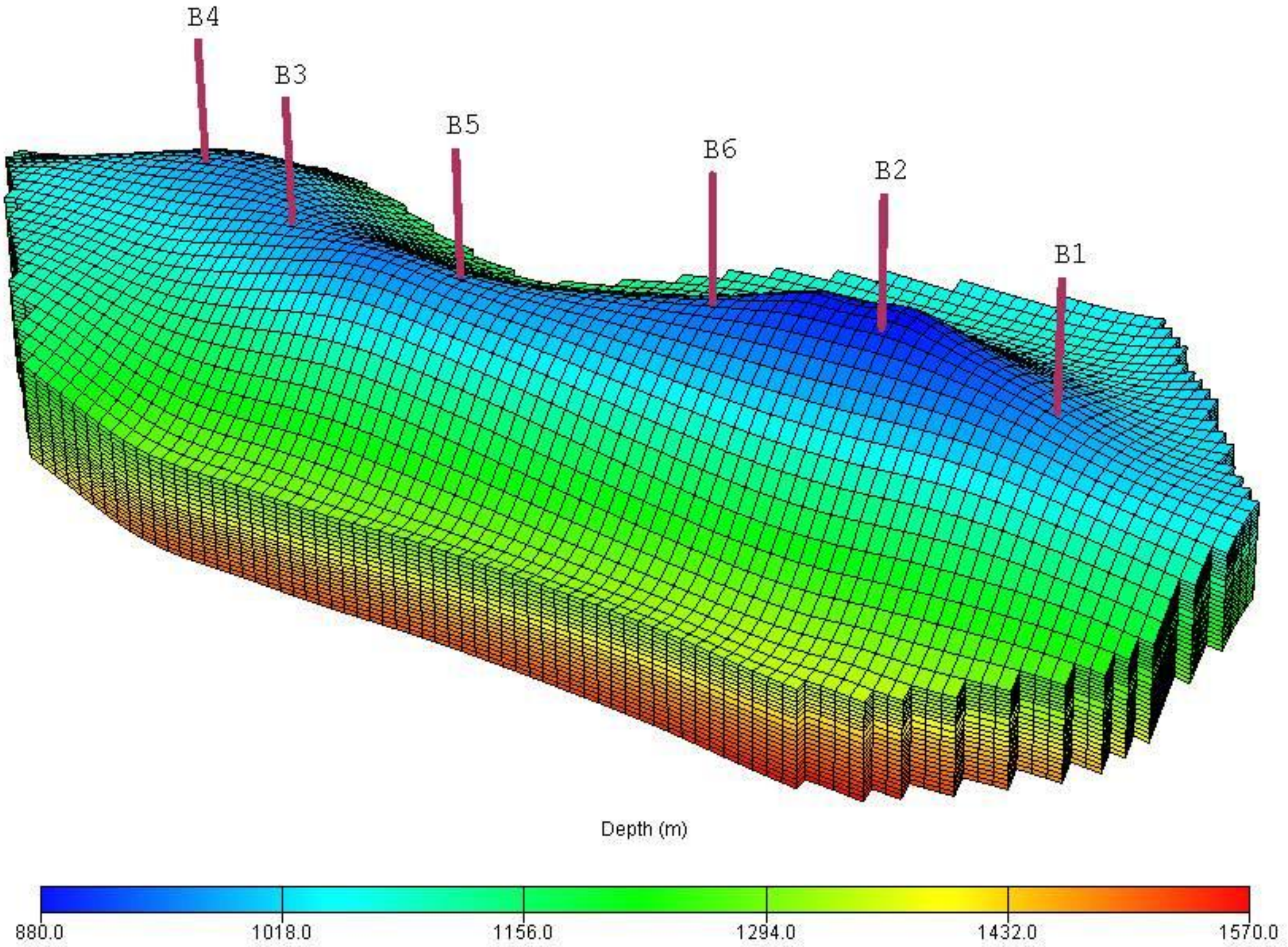
Standard flow properties: relative permeabilities, capillary pressure

Reservoir fluid descriptions: Peng-Robinson EoS; CO_2 solubility in reservoir brine

Boundary conditions: open boundaries with external aquifers of different size

Application of Reservoir Simulations in Analysis of Existing & Potential Sequestration Structures of Poland

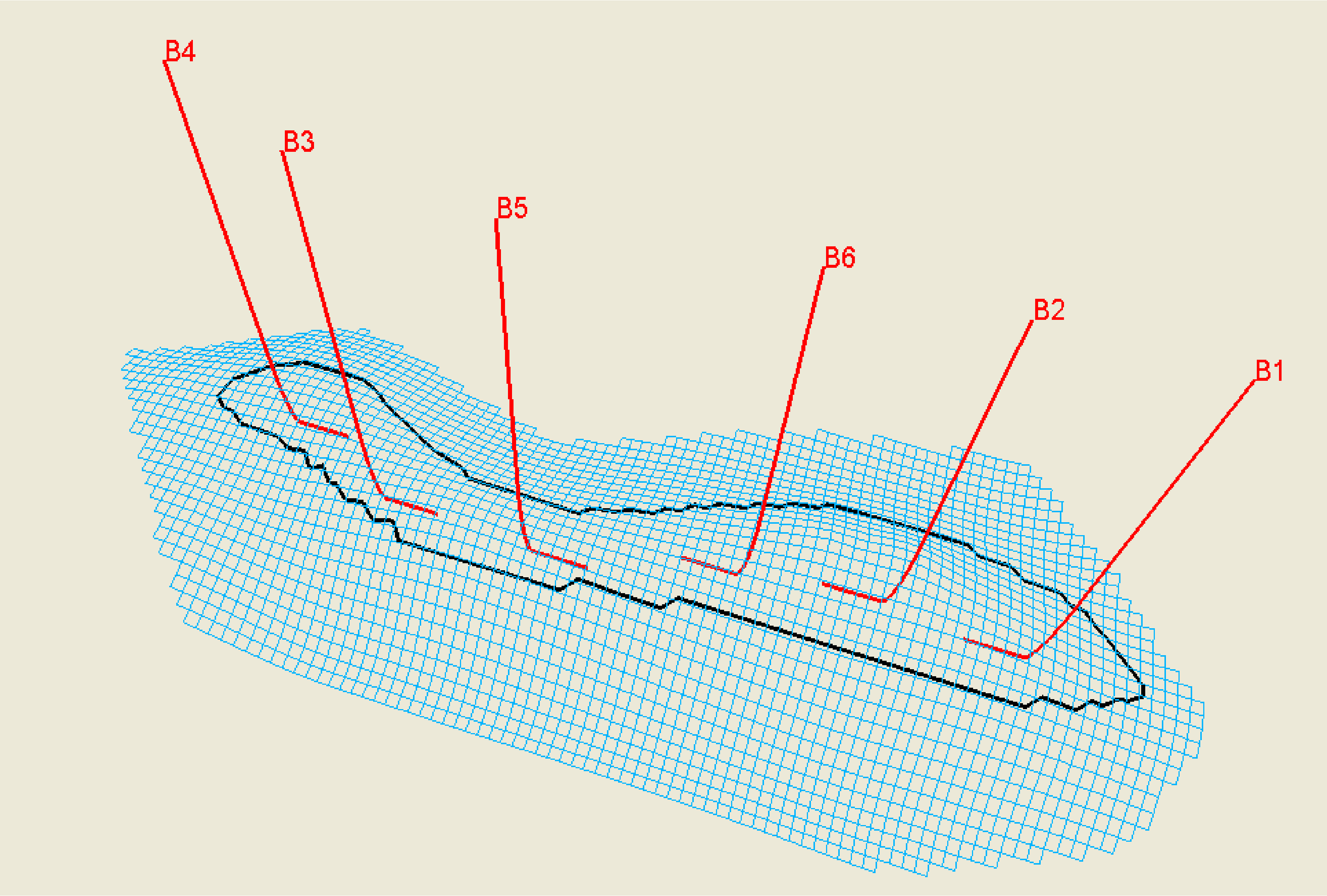
Perspective view of the simulation model



Simulations of CO_2 sequestration

- optimized number and location of injectors (2 scenarios – various completion depths)
- injection rate: monotonically increasig: 5 mln tons/year of CO_2 in 2020 through 10 mln tons/year of CO_2 in 2050
- injection time profil: 15% of annual totals injected in January, 85% of annual totals injected in remaining months
- total injection time: up to full structure capacity
- total injection = structure capacity
- optimized well contributions to total injection

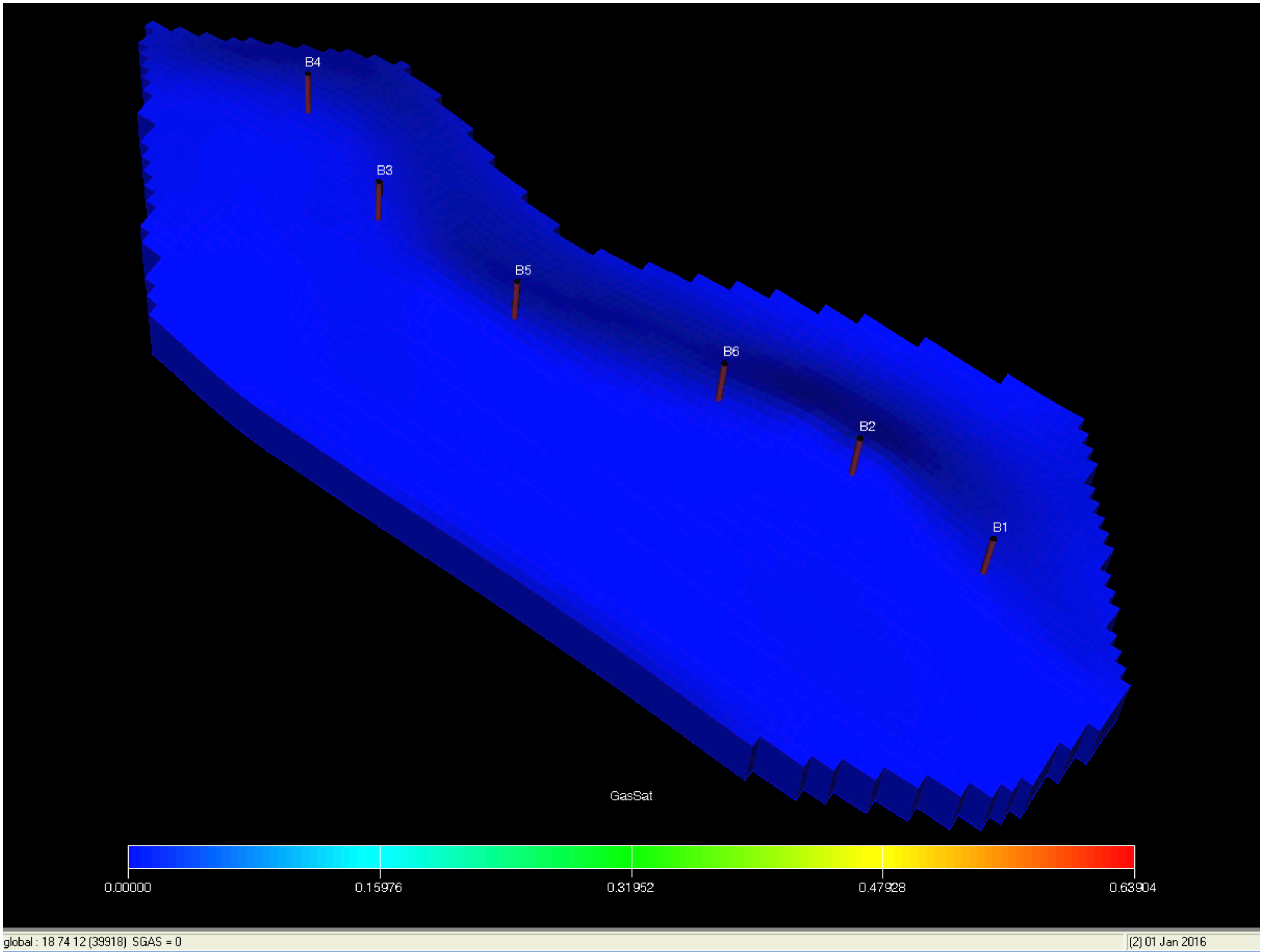
Injector localization on the structure. Scenario with deep completions



Processes during and after injection

- CO_2 plume evolution within the structural trap – no lateral leakage from the trap
- CO_2solubility in brine
- brine convection (density changes due to CO_2 solubility in brine)
- no mineral trapping (neglected as less significant)

Distribution of CO_2 in the simulated structure – general view



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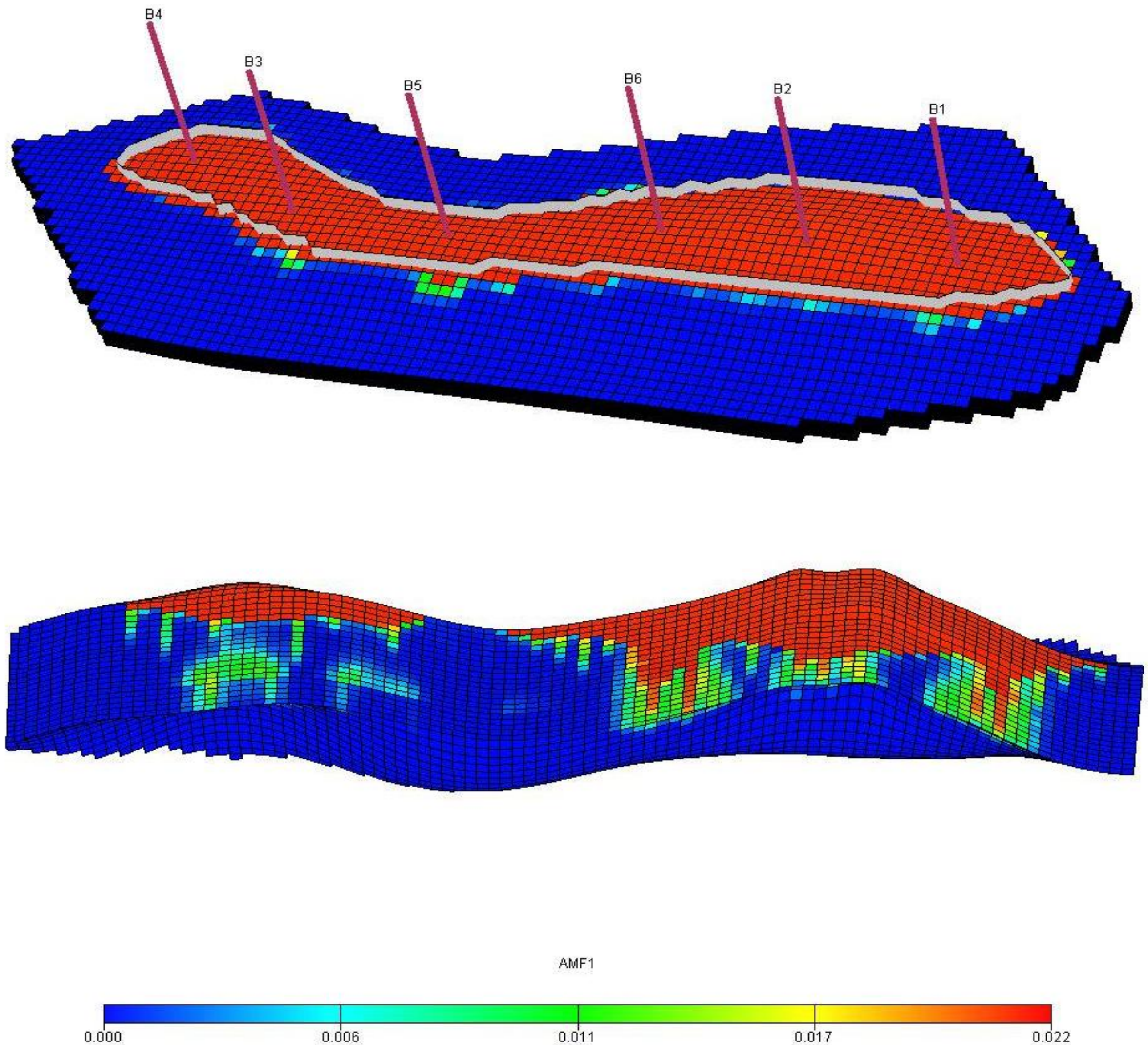
CO_2 dissolved in water (mole fraction) concentration map in top layer and along vertical cross section in 2600. Scenario with deep completions



Sequestration capacity of the structure. Scenario I (shalow completions) and II (deep completions)

Scenario no.	Total capacity	Free CO_2 capacity		CO_2 capillary trapping capacity		CO_2-in-water dissolution capacity	
	[Mt]	[Mt]	[%]	[Mt]	[%]	[Mt]	[%]
I	168.24	126.56	75.23	5.61	3.33	36.07	21.44
II	209.50	152.56	72.82	9.32	4.45	47.62	22.73

CO_2-in-water dissolution capacity vs time

Scenario no.	CO_2-in-water dissolution capacity [Mt]	
	2040/2045	2600
I	27.2	36.1
II	37	47.6

Pressure issues

- maximum increase at the structure top (cap rock tightness)
- maximum pressure in the structure bulk and maximum gradient with depth (rock fracturing)
- maximum bottom hole pressure and well head pressure (injection technical parameters)

Sensitivity studies

- external aquifer size: pressure effects
- uncertainity of basic geological parameters (porosity, permeability): pressure effects and storage capacity uncertainty - within the range: 177-229 Mt (most pbrobable 210 Mt)

Sequestration capacity of the structure

Scenario no.	Total capacity	Free CO_2 capacity		CO_2 capillary trapping capacity		CO_2-in-water dissolution capacity	
	[Mt]	[Mt]	[%]	[Mt]	[%]	[Mt]	[%]
optimistic	228.51	168.81	73.87	8.44	3.69	51.26	22.43
pessimistic	177.12	120.93	68.27	12.70	7.17	43.49	24.55
average	209.50	152.56	72.82	9.32	4.45	47.62	22.73

Summary and Conclusions for the Sequestration Simulations of N-N Structure

1. Practical feasibility of the structure as the sequestration site: total sequestration capacity = 210 Mt of CO_2
2. Identified three basic trapping mechanisms with their contributions to the total capacity
3. Significant part of the convection process in the total capacity potential of the structure: very long time scale – hundreds of years
4. Critical role of pressure quantities: maximum pressure increase at the structure top – strongly dependent on the effective size of the hydrodynamic system to which the structure belongs
5. Capacity uncertainty determined by details of the geological model

Conclusion

Numerical simulations provides an efficient tool for the modeling and analysis of CO_2 injection into geological formations: both into waterbearning zones and into hydrocarbon reservoirs.

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Thank you for your attention