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LARGE SCALE CO_2 STORAGE IN THE NORTH SEA CAN HANDLE ALL EU COAL POWER CO_2 EMISSIONS

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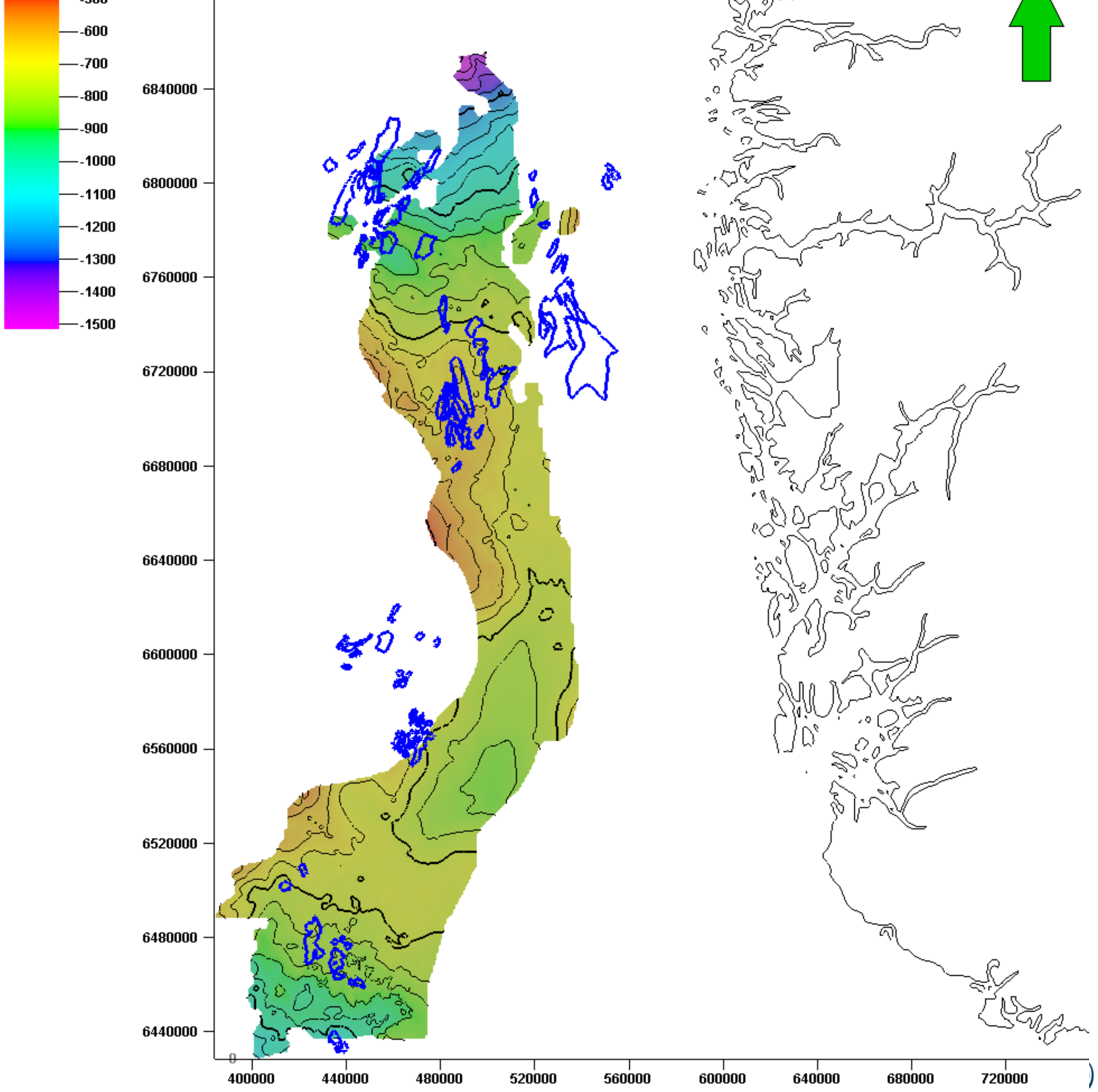
CCUS STUDENT WEEK 2018, Oct. 2018, Golden CO

Utsira and Norwegian gas and oil fields

- Utsira is a 24 000 km^2 sand formation with a typical porosity of 35% and high permeability (1000 to 2000 mD)
- The thickness is 90 m in average varying between 0 and 350 m. The sand is divided by many thin shales reducing the effective vertical permeability to 0.1 of the horizontal permeability
- Typical top depth is 800 m, however, the impression that is also is flat is somewhat delusive…



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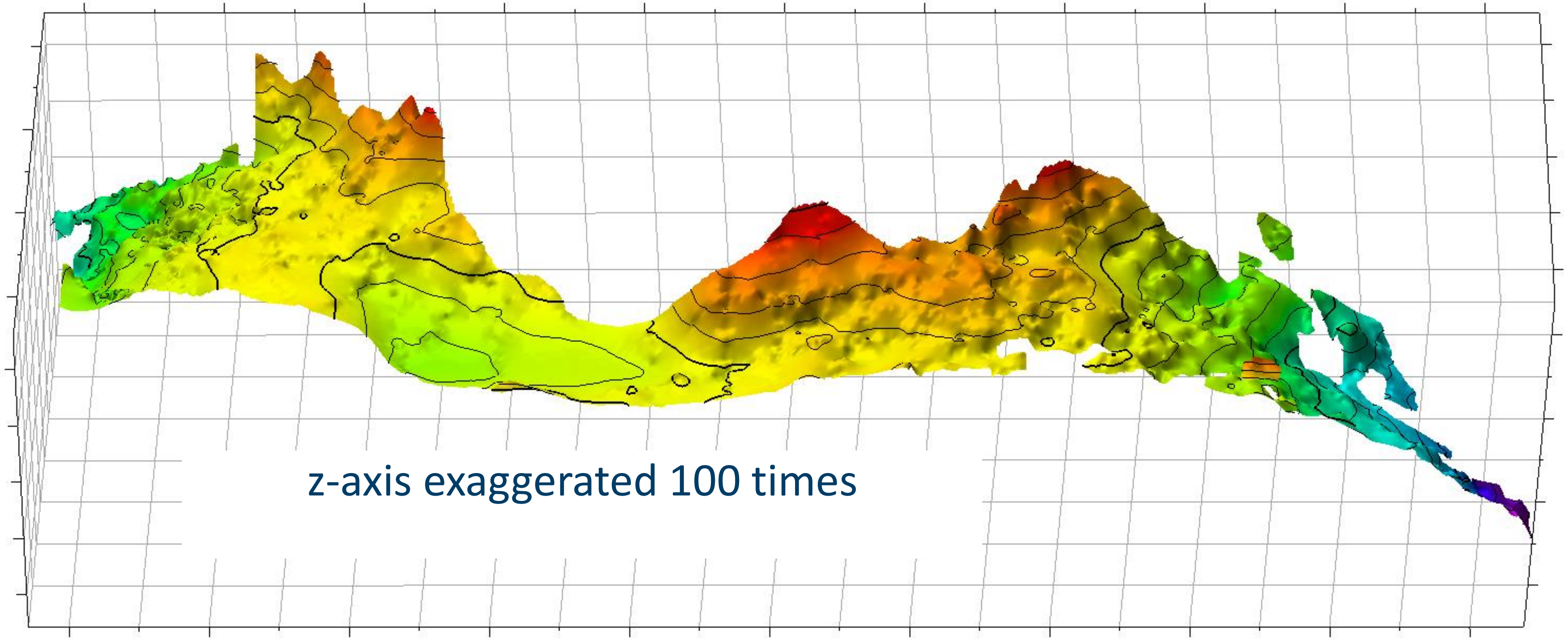
Top of Utsira seen from east

- The top depth varies from the peaks in central western parts of 500 m to the deep northern slope ending at 1500 m depth (125 km apart)
- The dip angle of the steepest parts is still only 0.4°



Reservoir model

- A numerical model of the formation is constructed from by approximately 1 million active grid blocks of 500 m x 500 m lateral size and average of 9 m height.
- The horizontal permeability is set to 1500 mDarcy and the average effective vertical permeability 150 mDarcy
- Porosity is 35%
- The topography of the top and floor is based on an seismic interpretation by Kirby *et al.* (2001)
- The formation is assumed to be a closure, shaling out or thinning out at its borders

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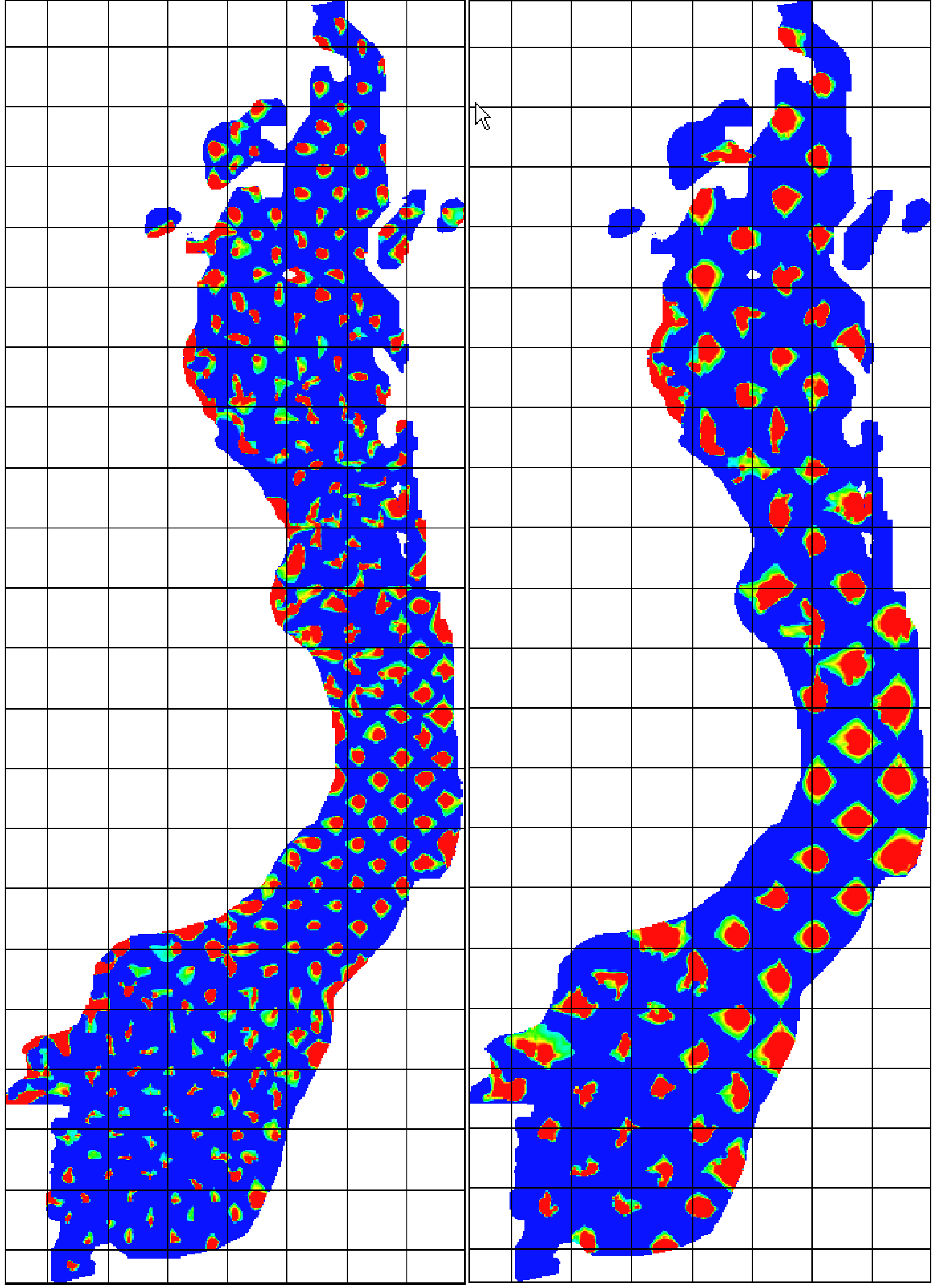
- Conservative presumptions
  - Capillary pressure not included
  - Molecular diffusion not included and accordingly convection due to destabilisation of the water column under-estimated
  - The intra-sand shales are not represented as discrete items, but included in the up-scaled vertical permeability (kv = 0.1 kh)
  - Only four well campaigns during 300 years
- Non-conservative presumption
  - Large gird blocks
  - Solubility included
  - Hysteresis included

Well and injection data

- Injection and water production wells are distributed in a regular 5 spot pattern
- Two different cases tested
  - 7 km well distance (210 injectors and 210 producers)
  - 13 km well distance (70 injectors and 70 producers)
- Injection rate 133 million tonne per year (15% of the yearly power production emissions in EU)
- Injection period 300 years



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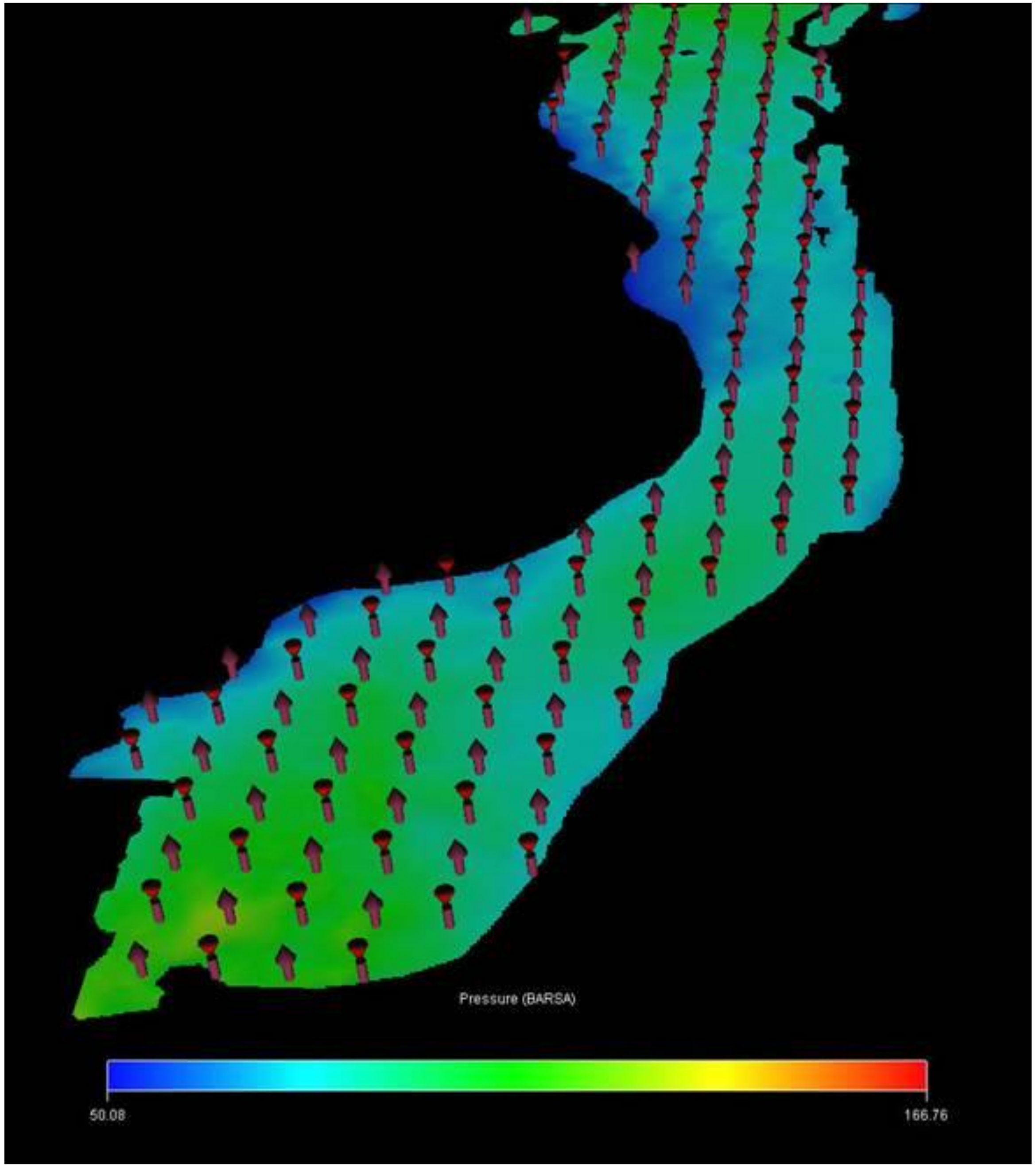
Pressure field, 70 injector scenario



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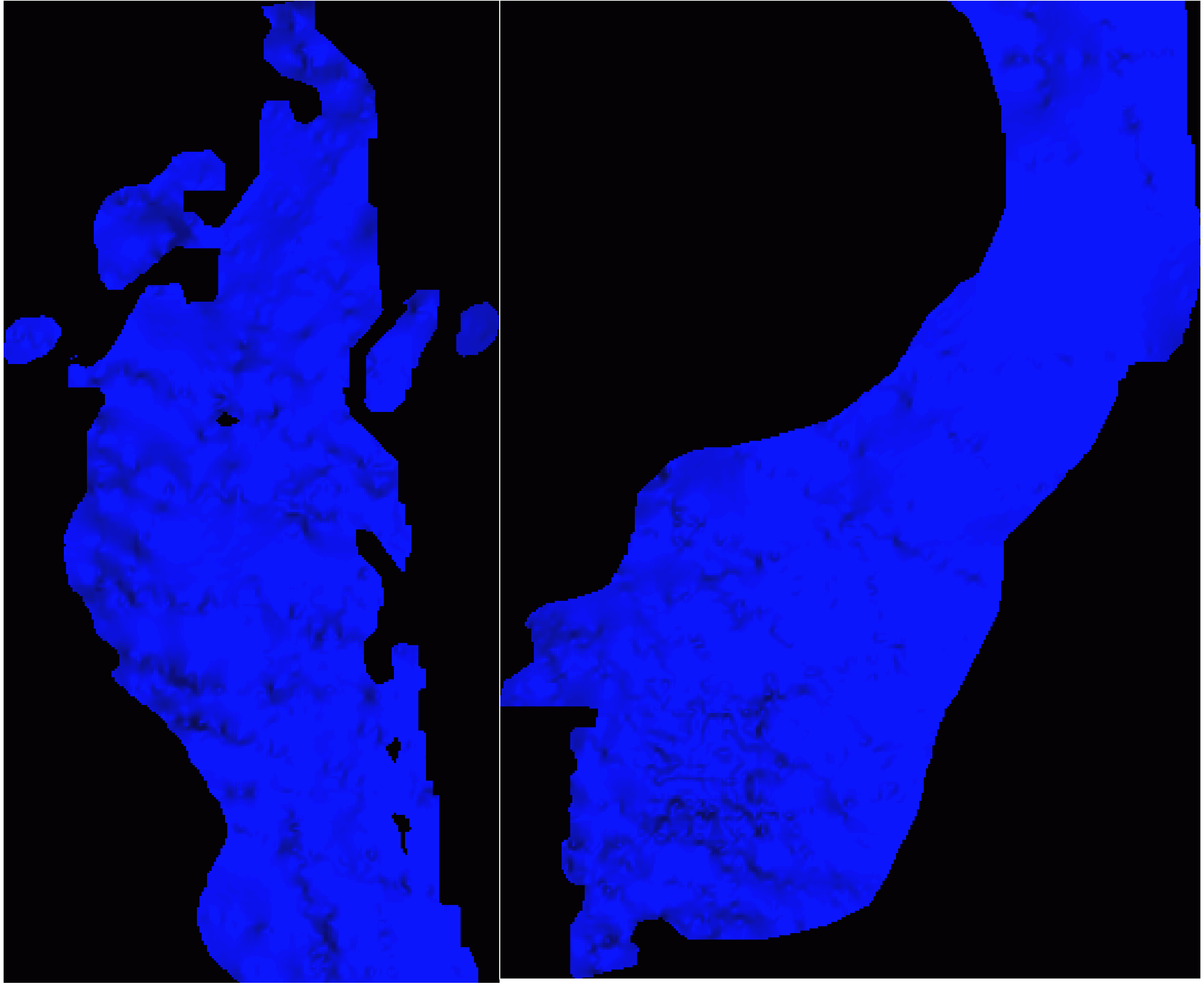

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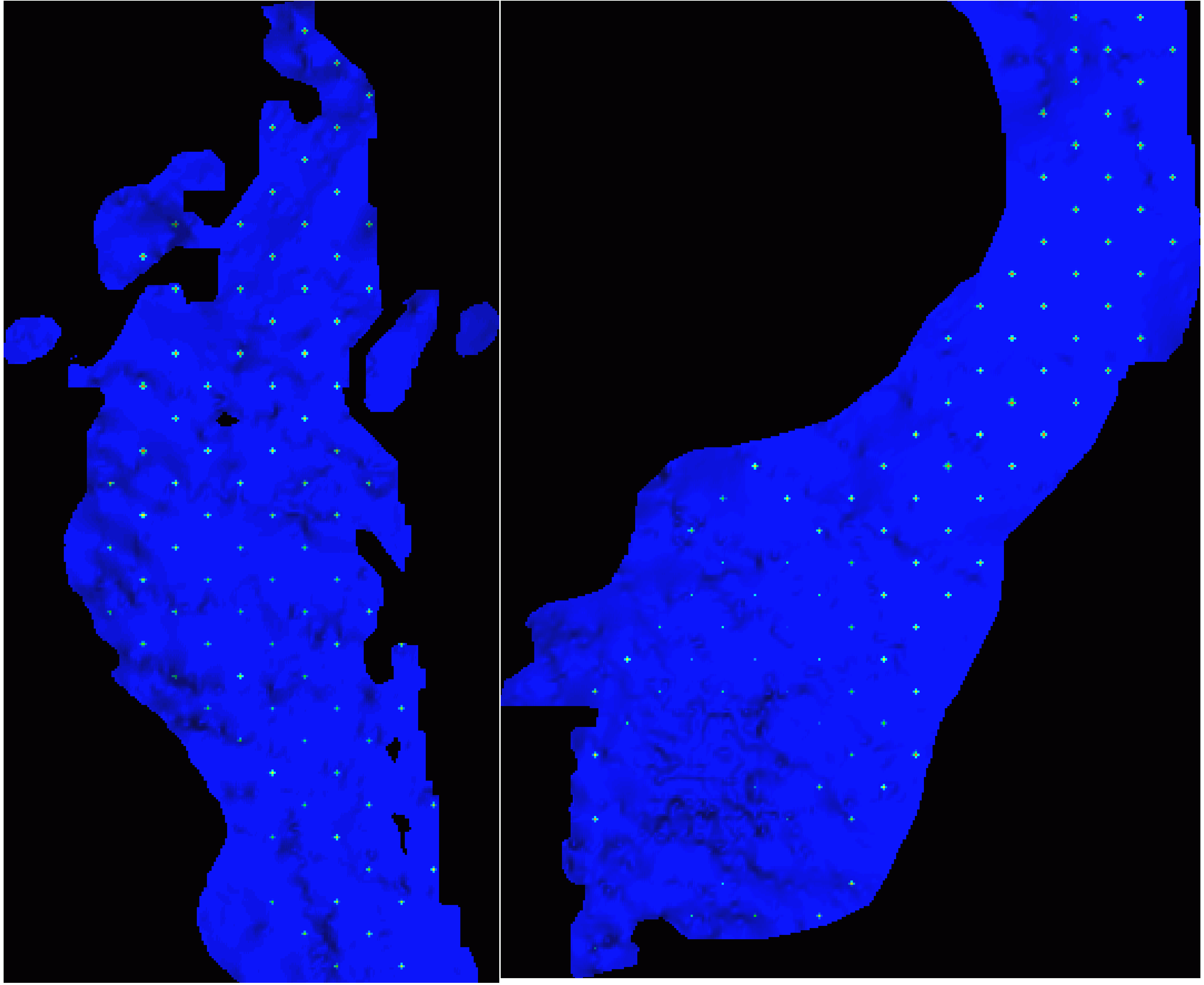

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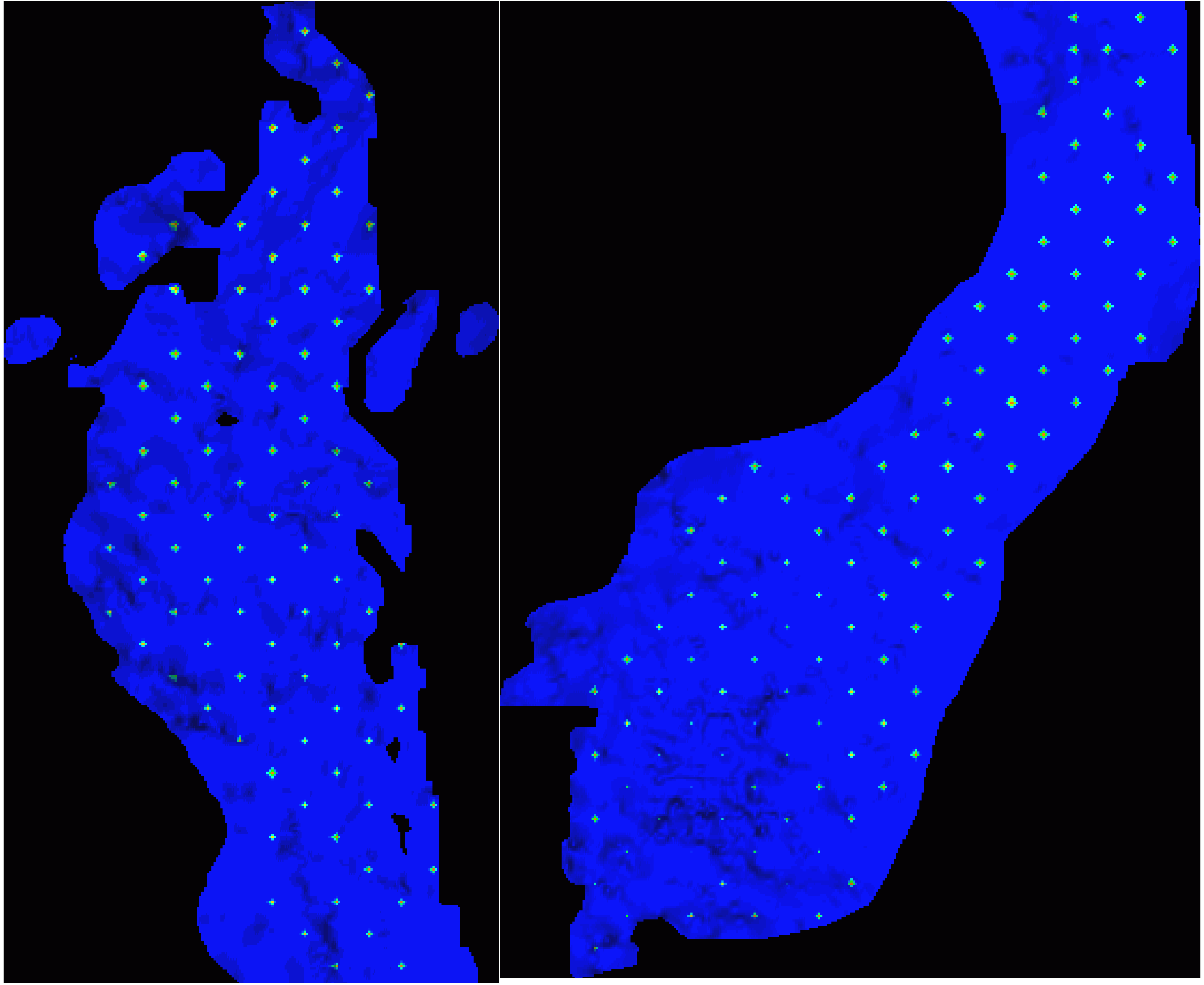

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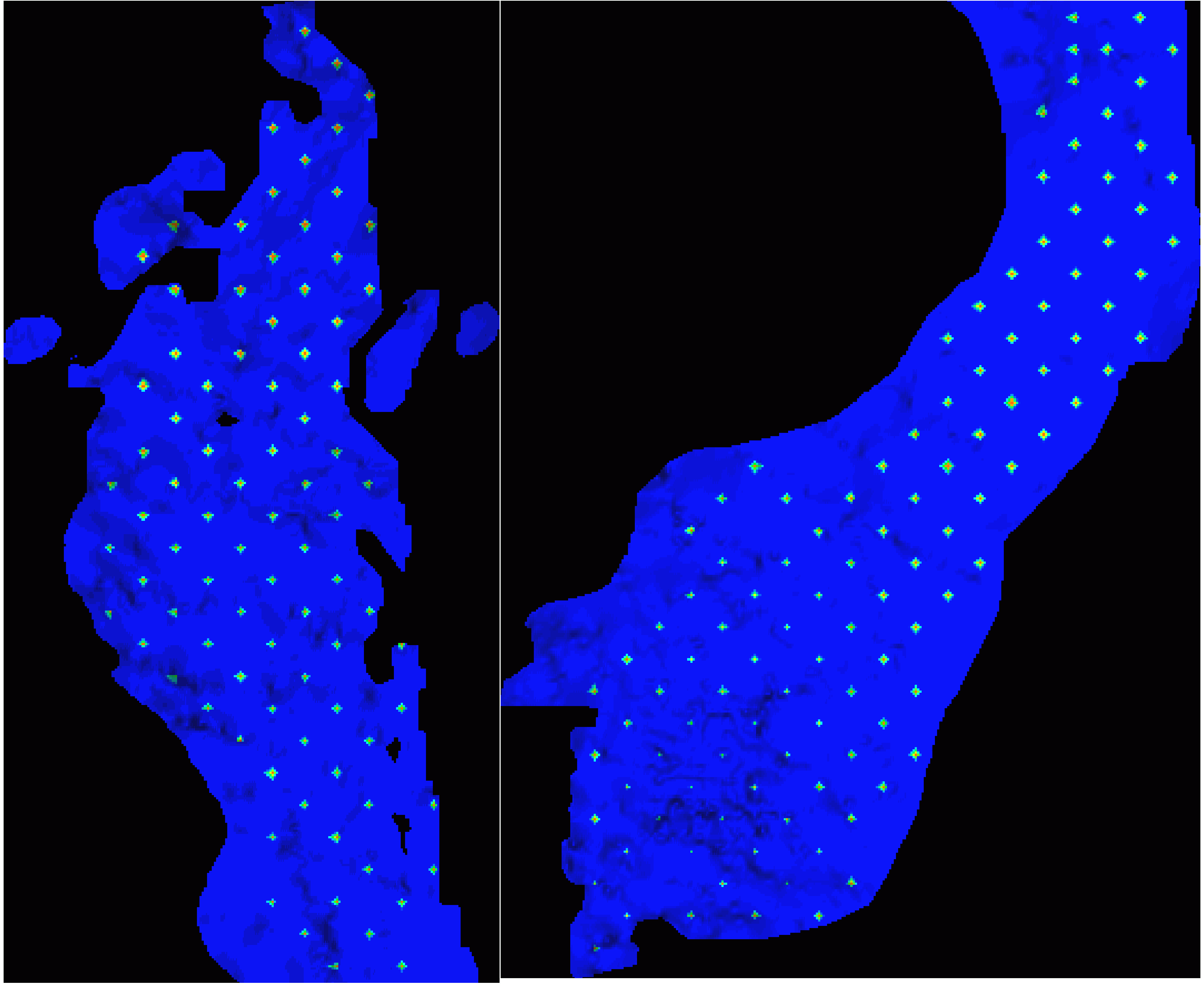

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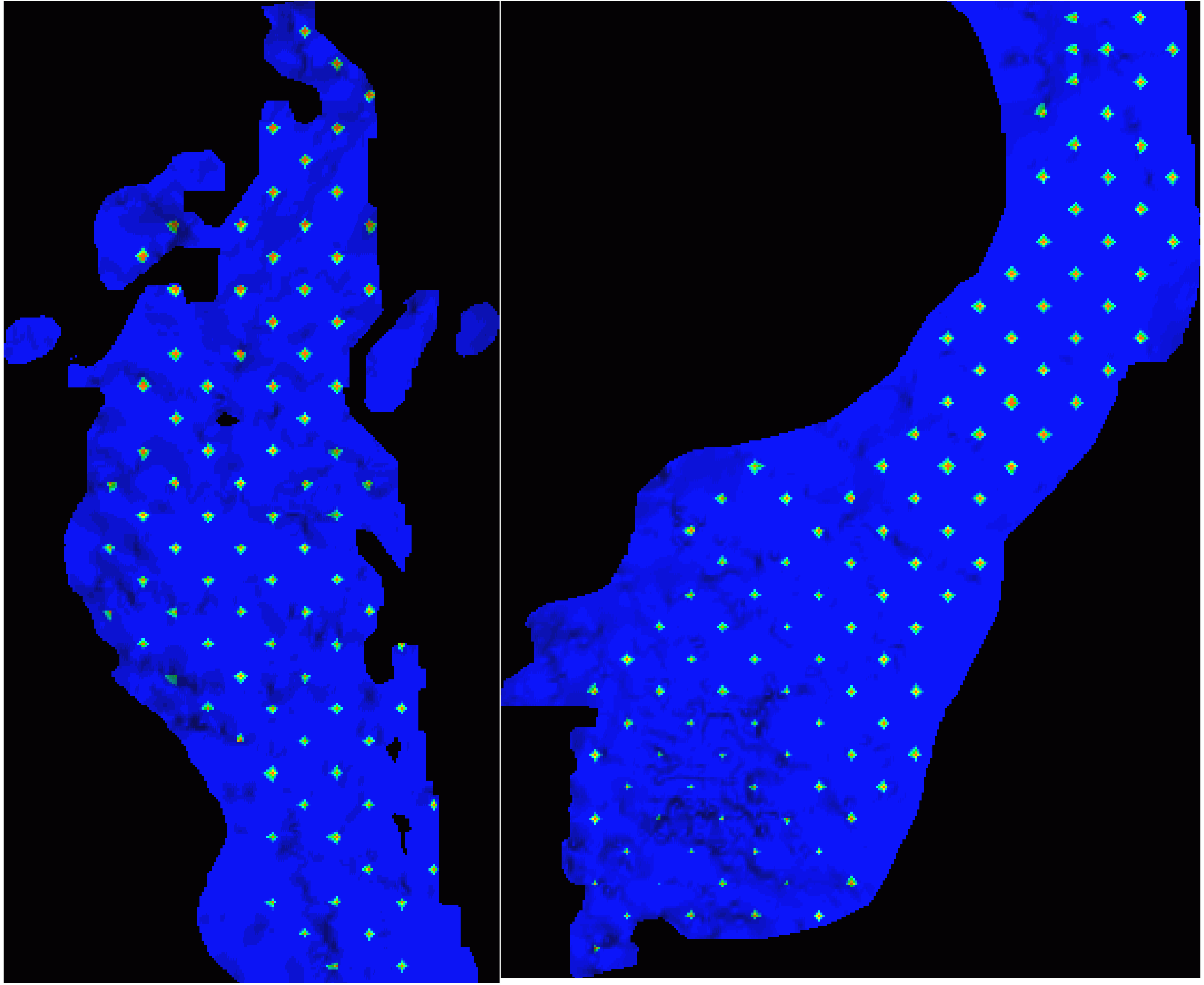

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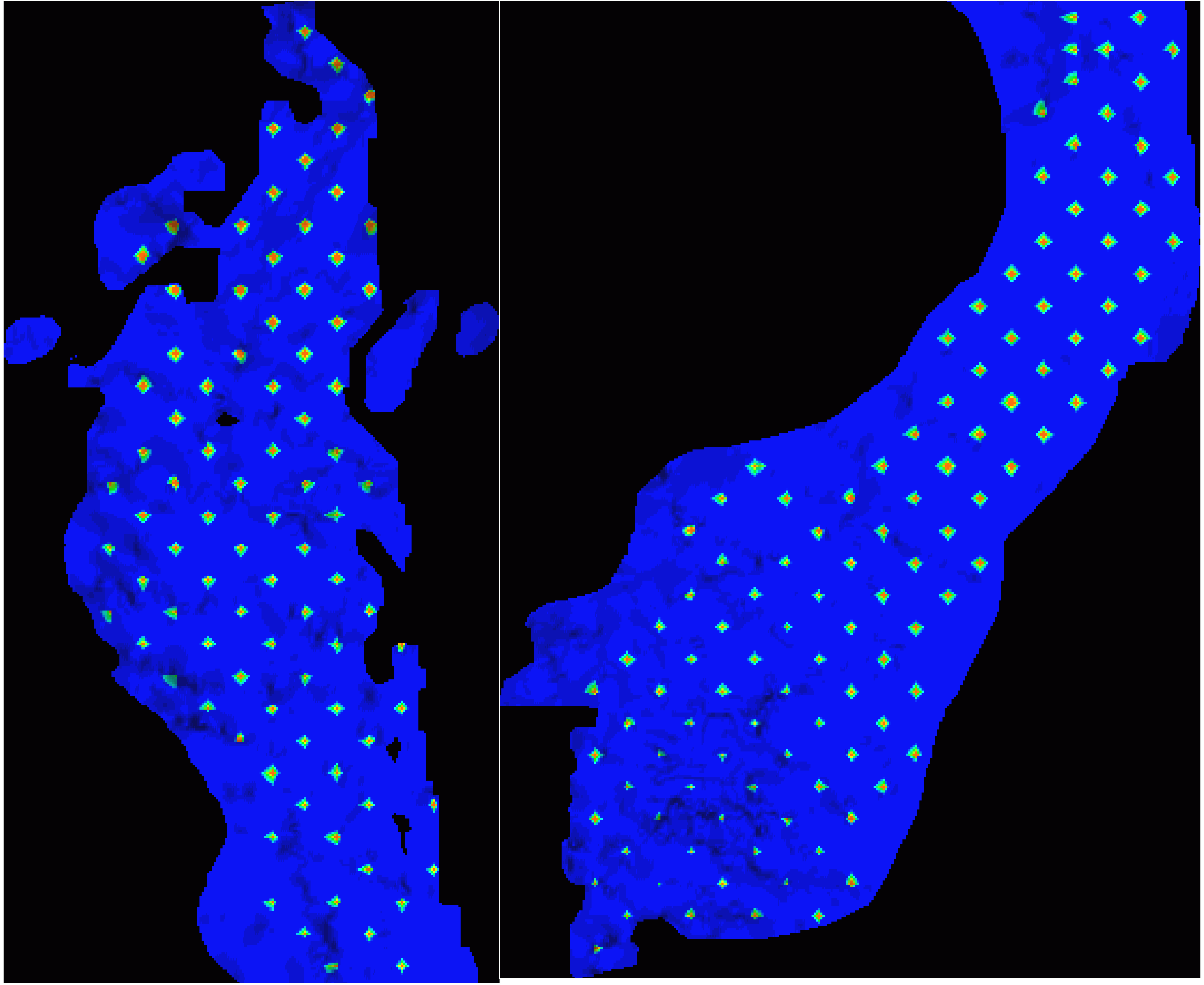

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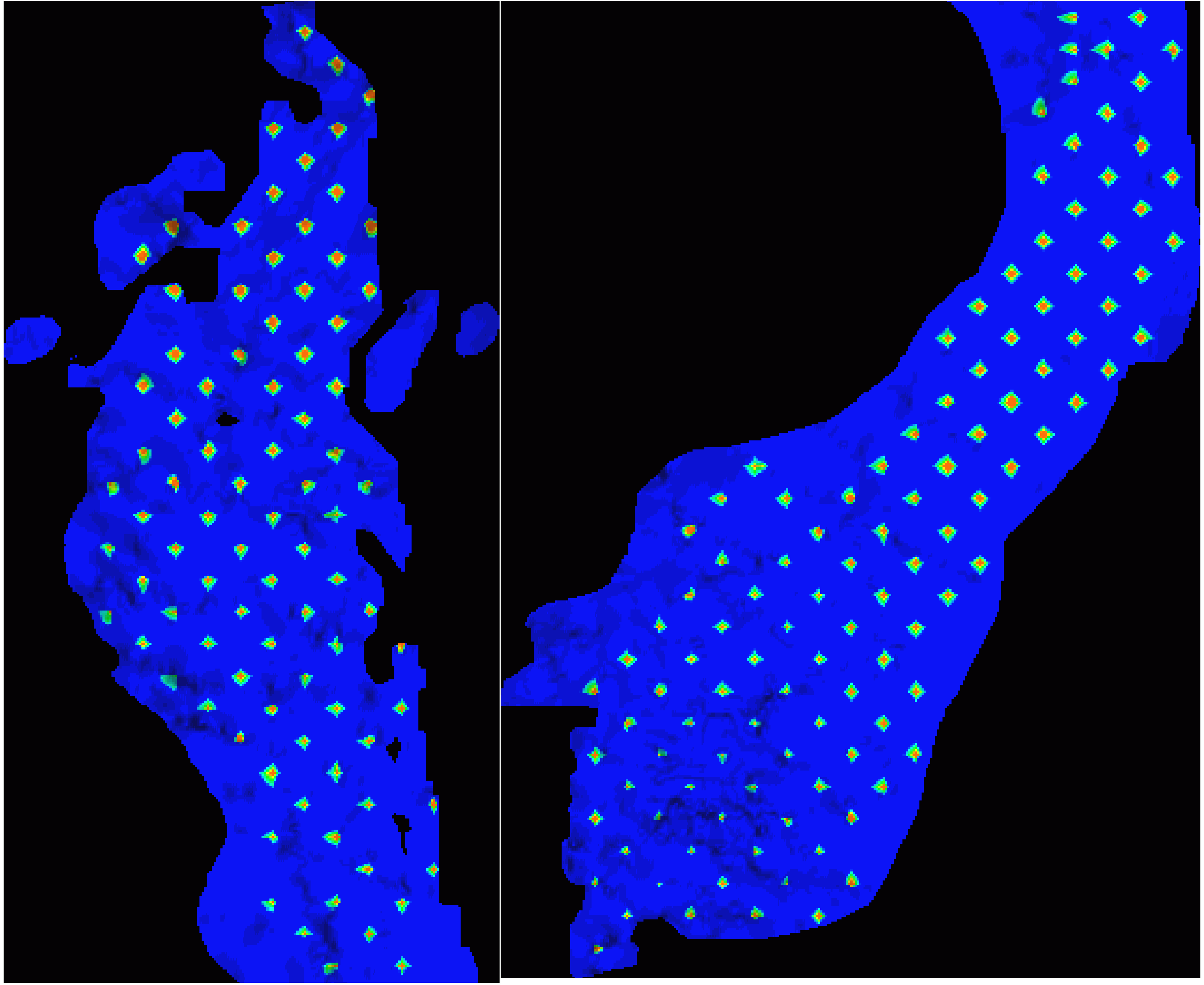

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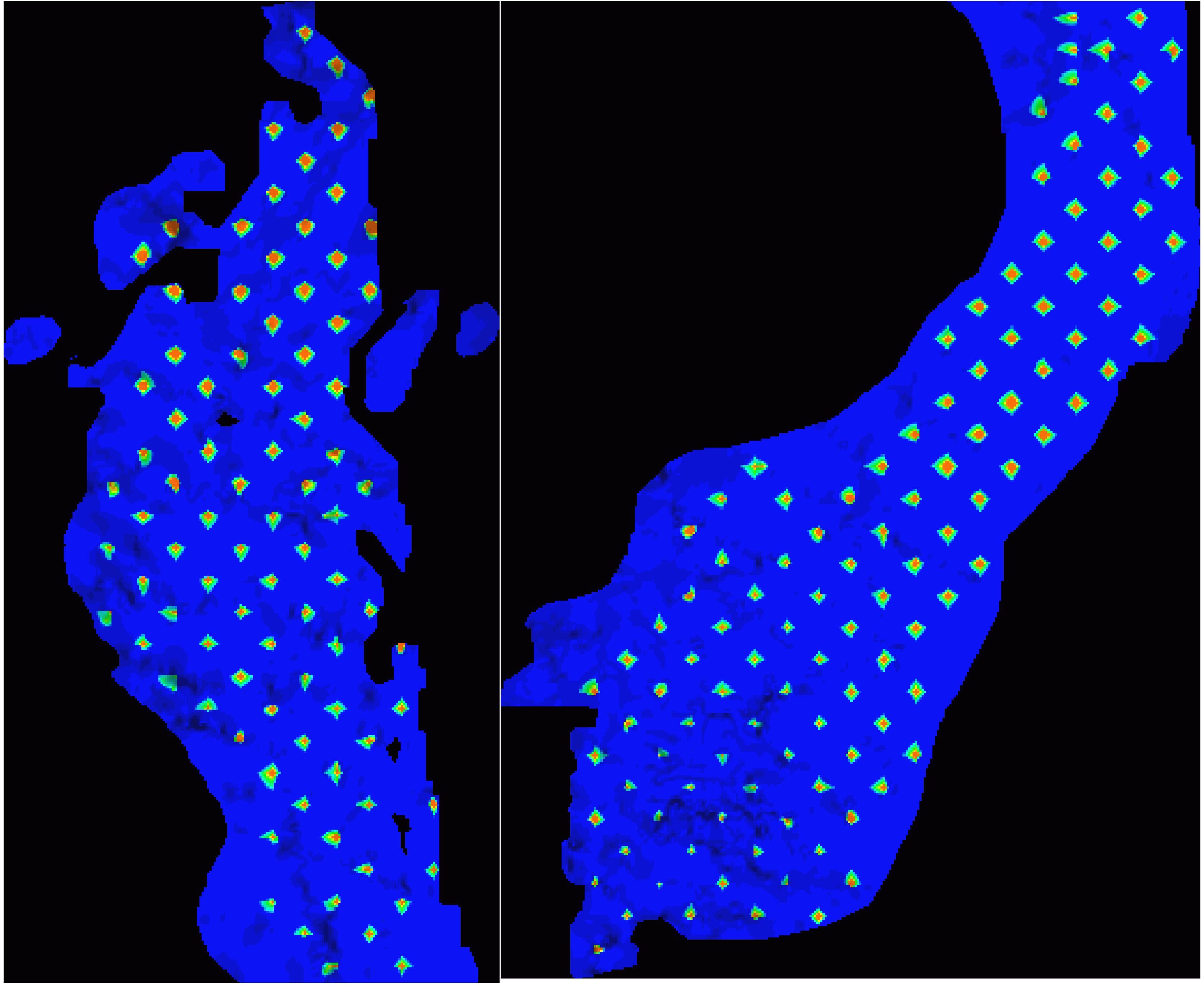

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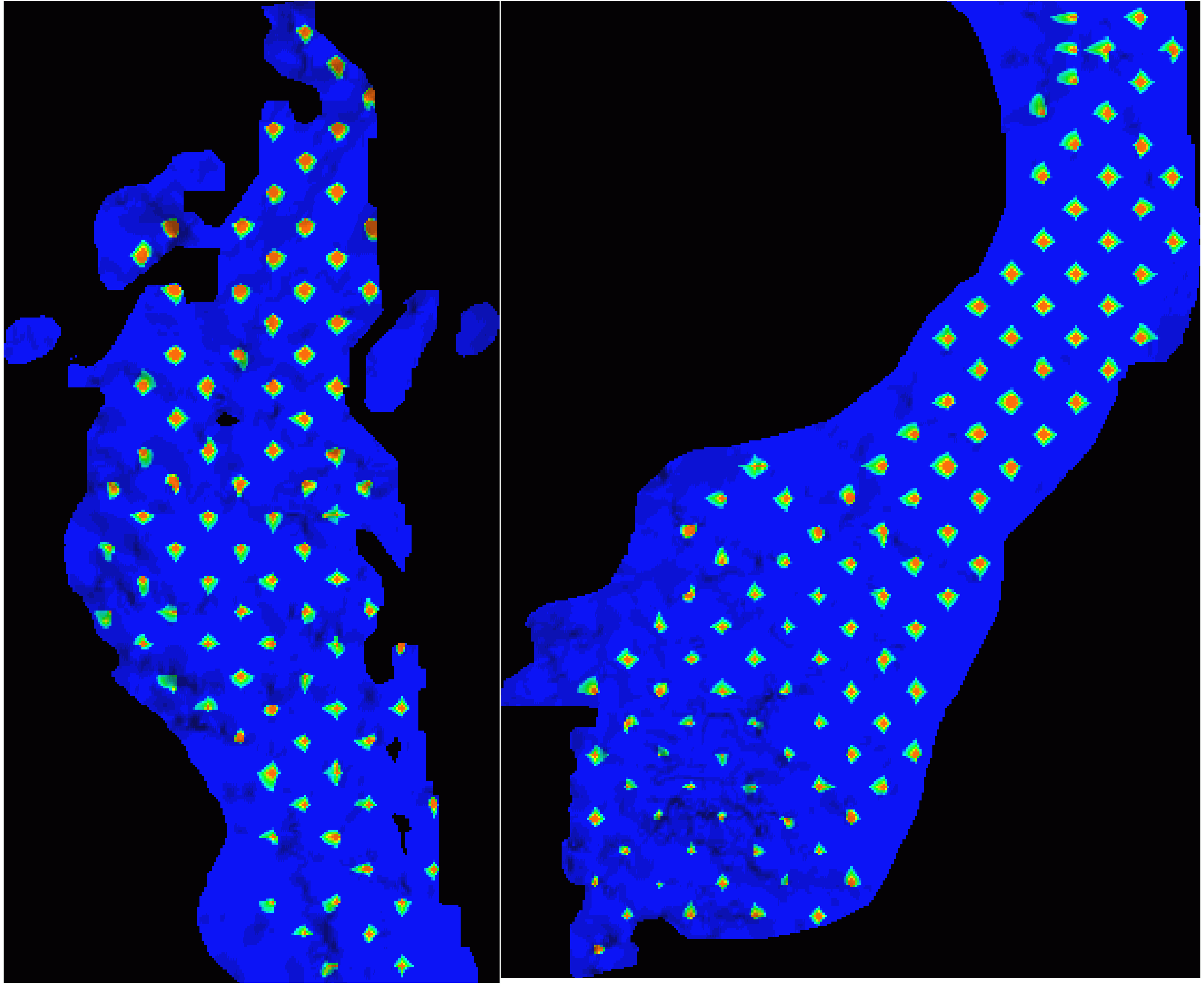

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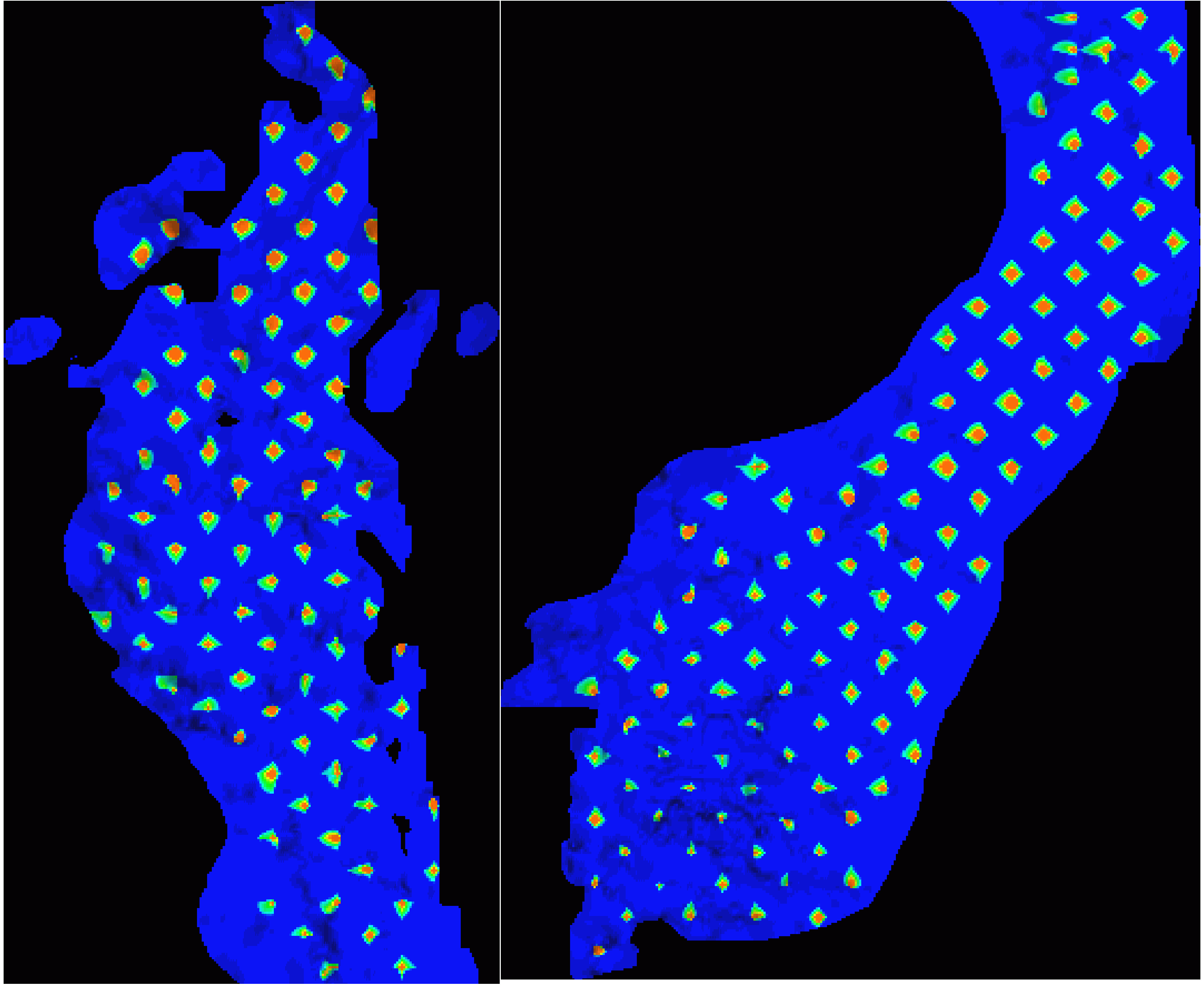

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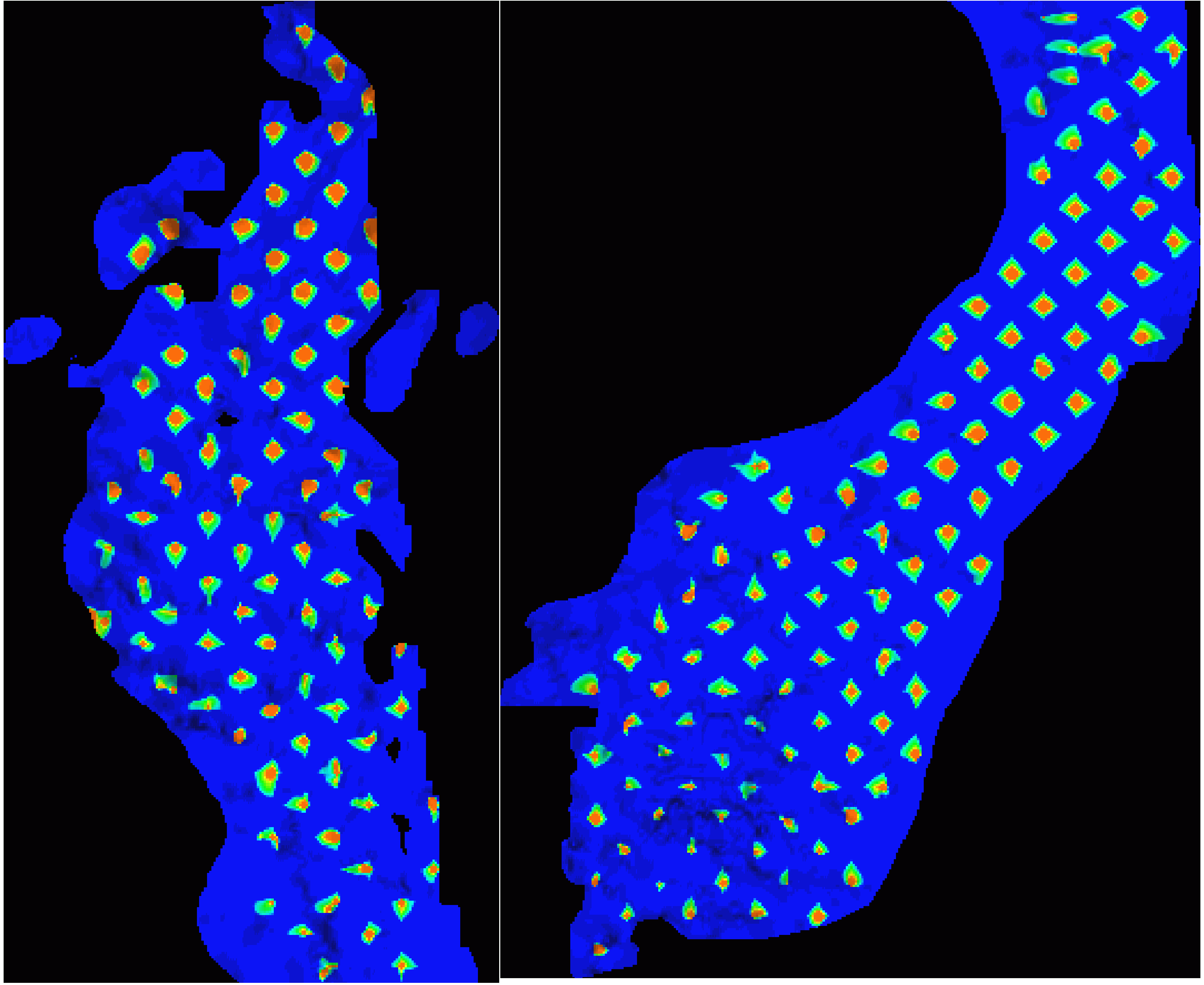

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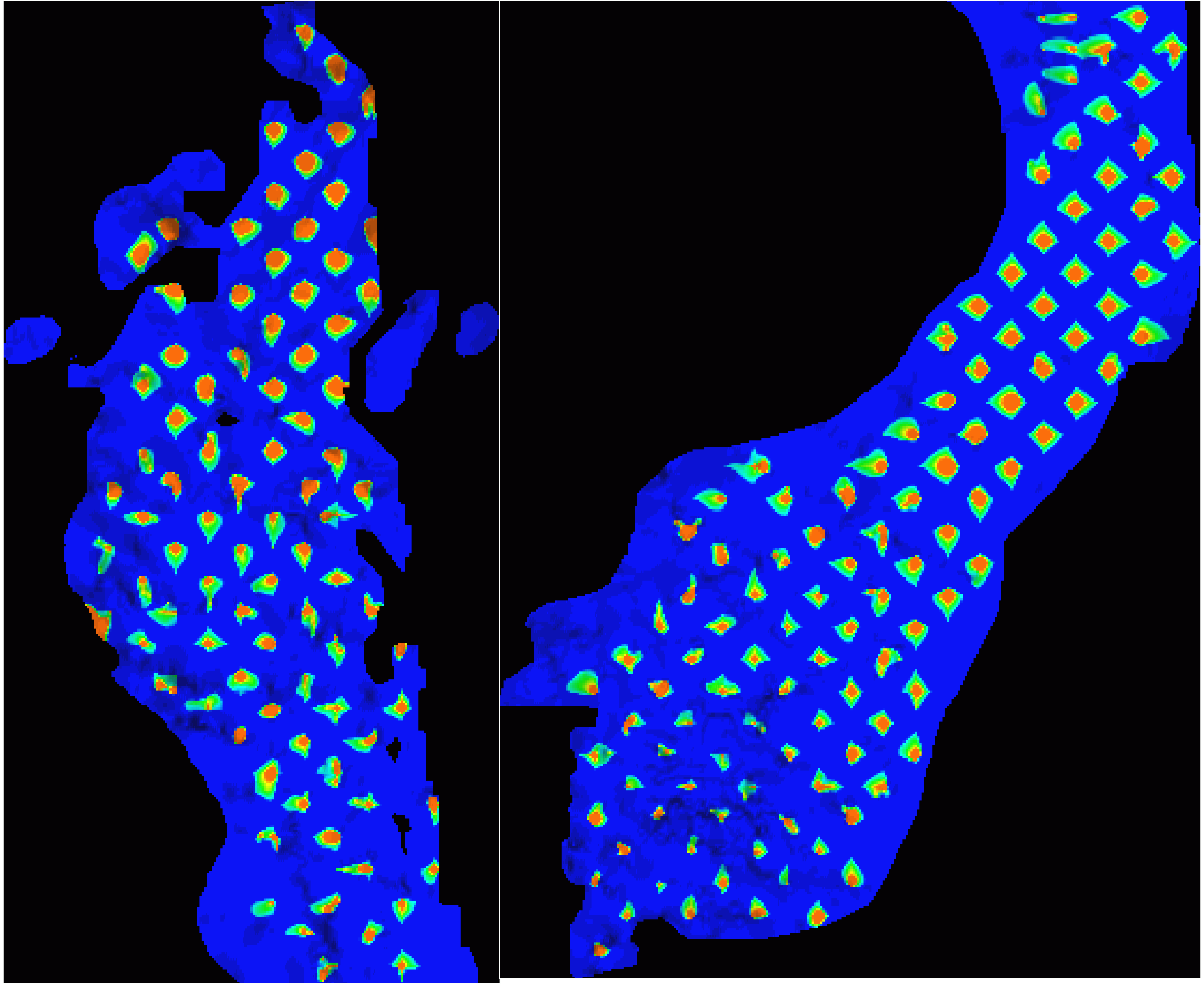

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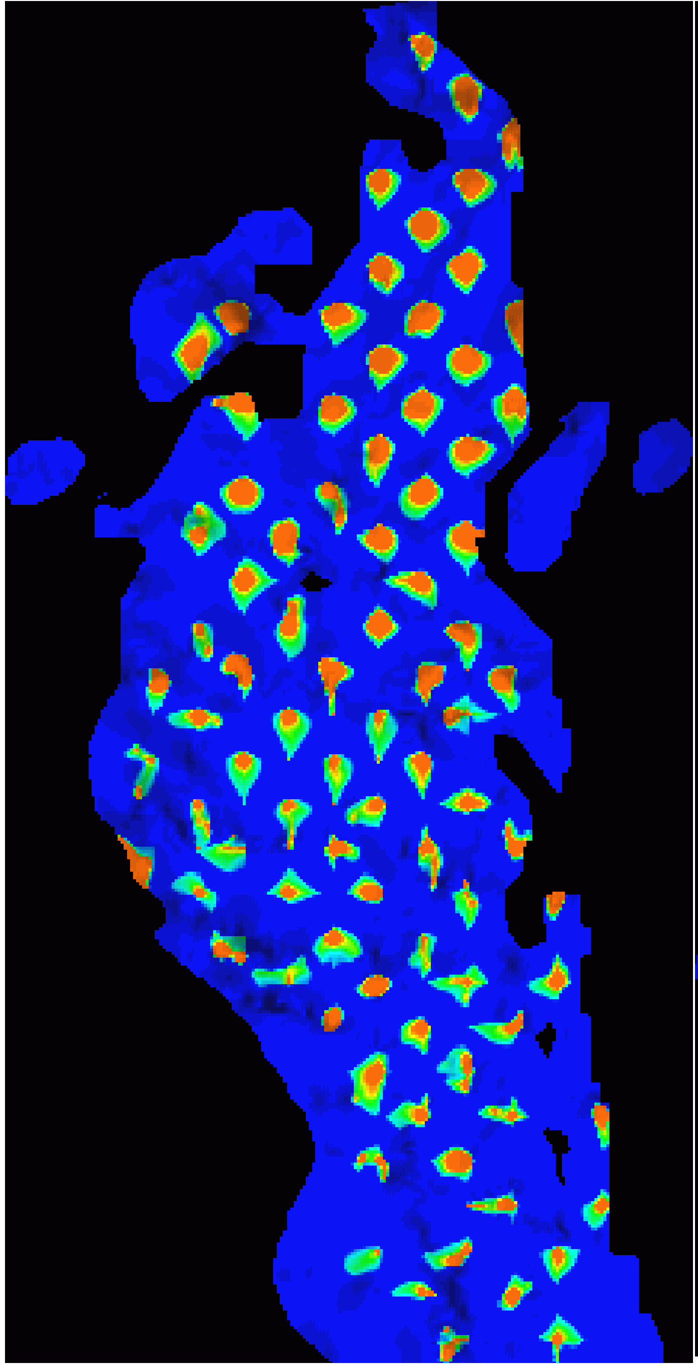

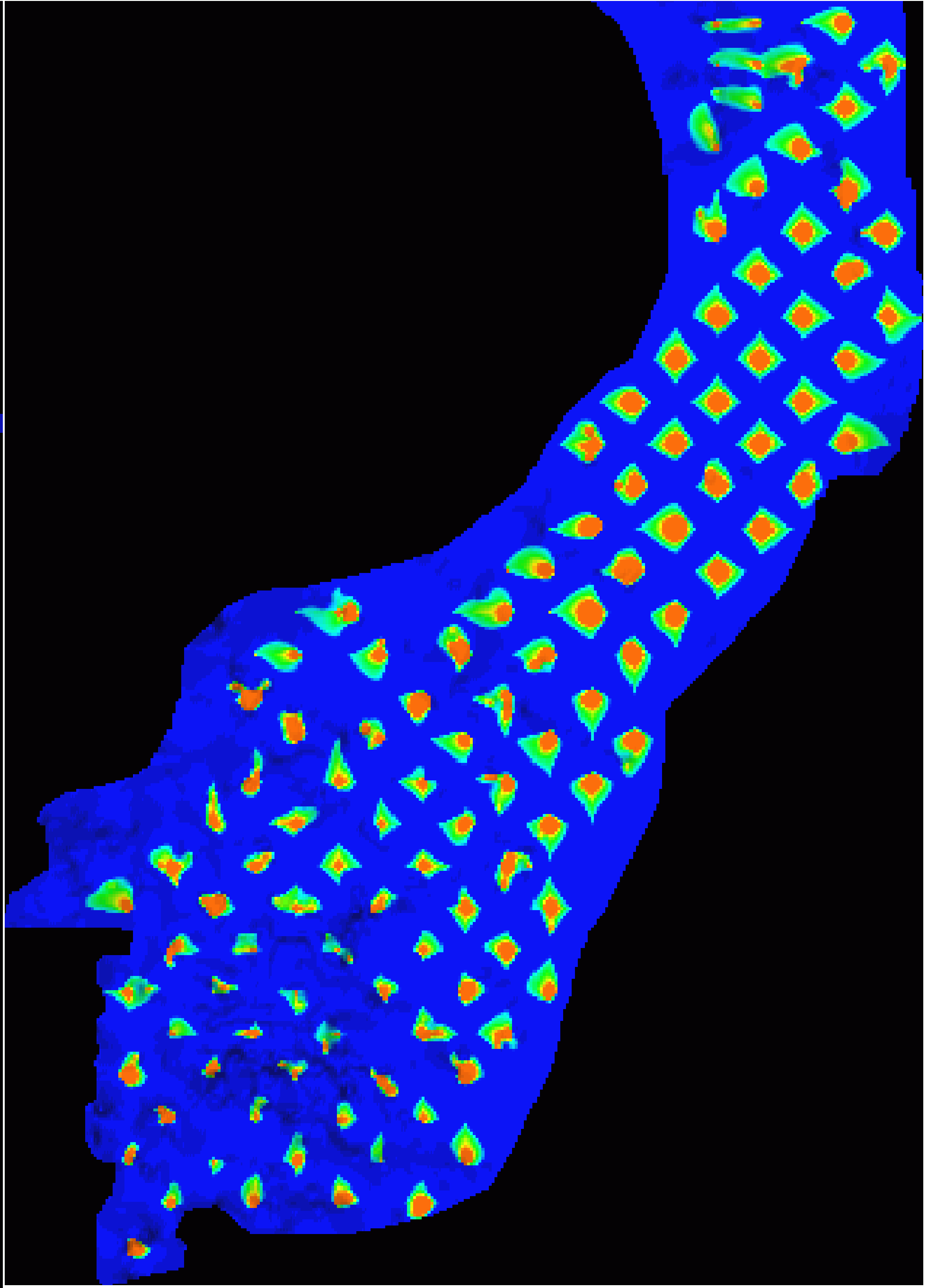

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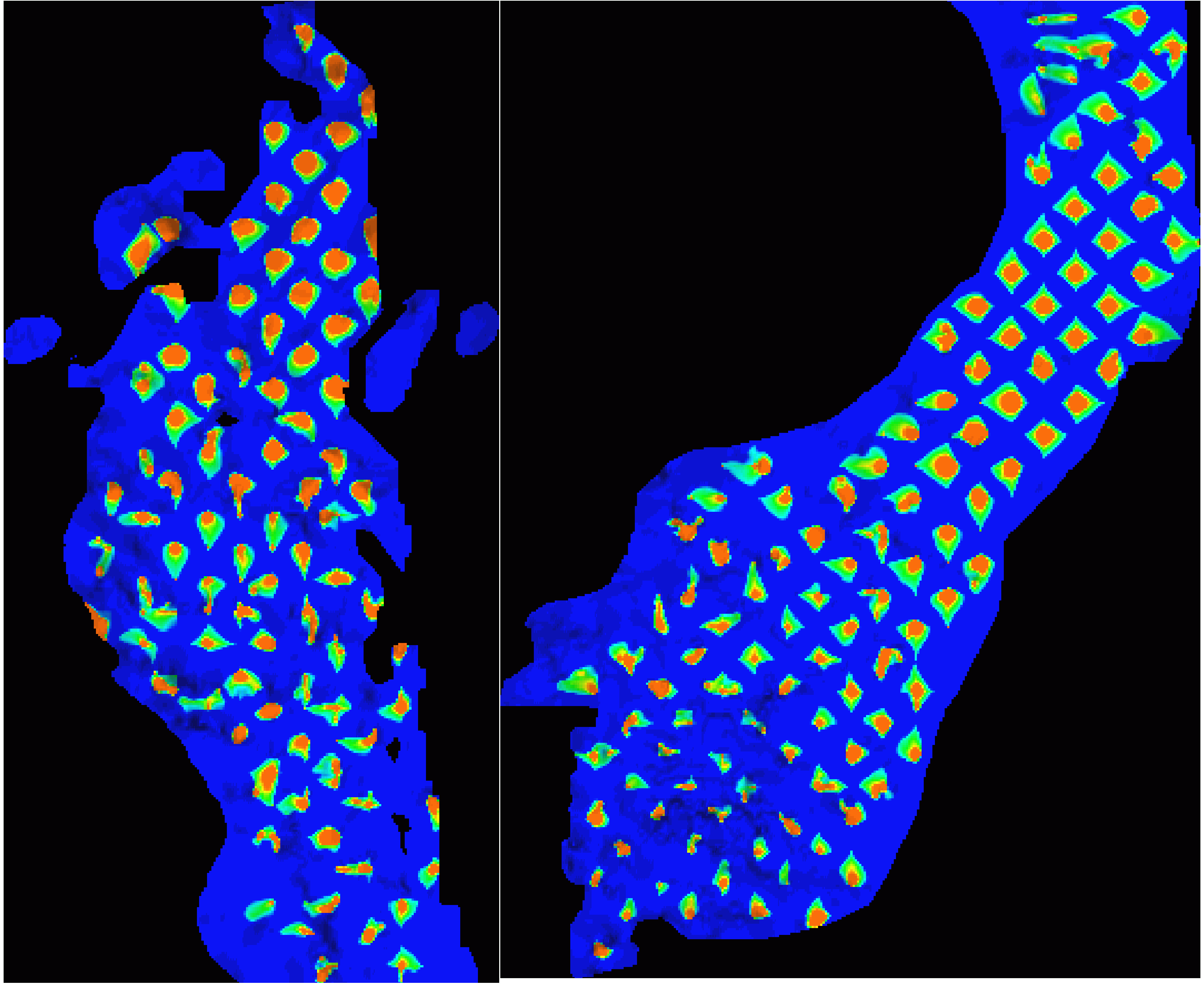

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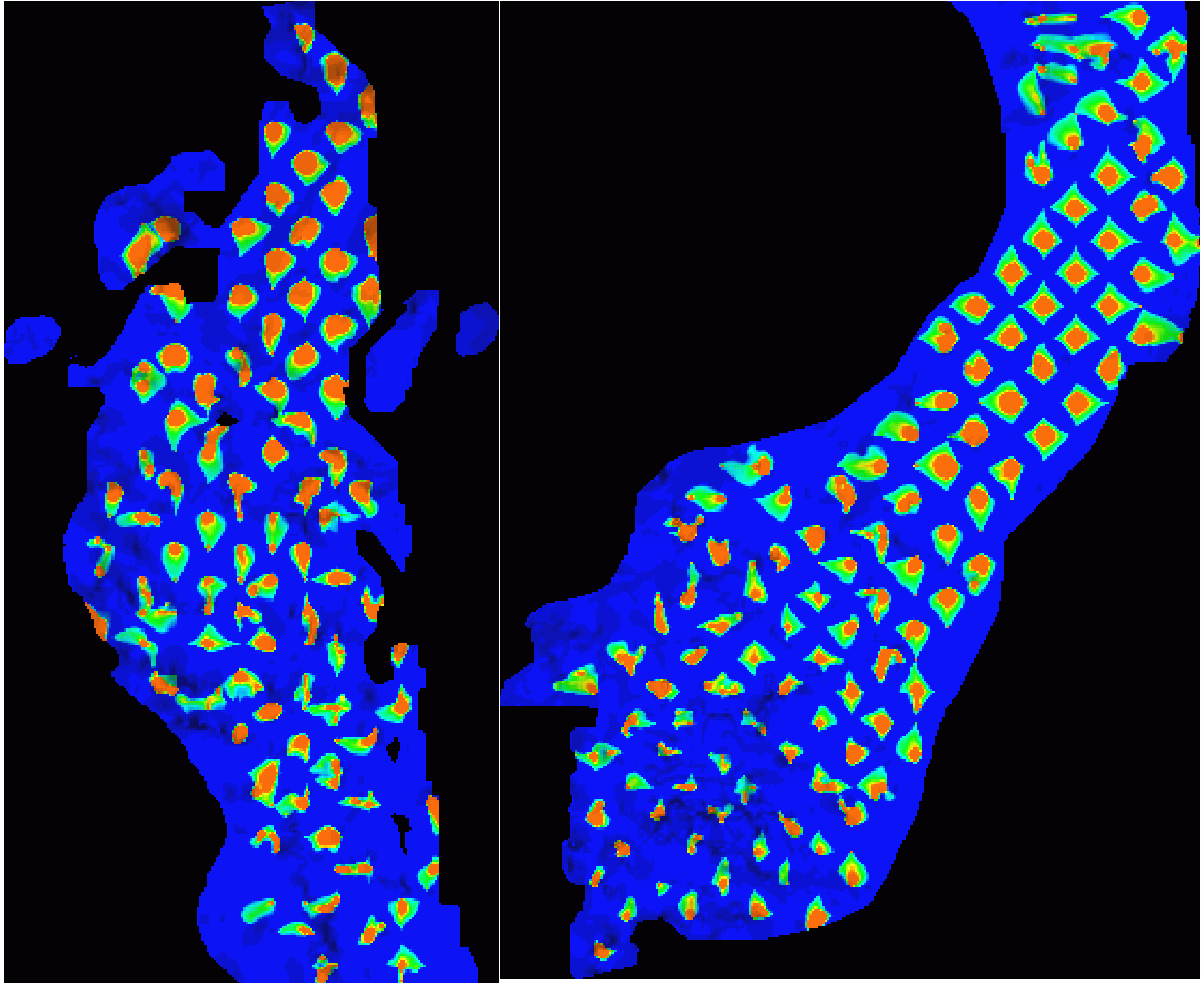

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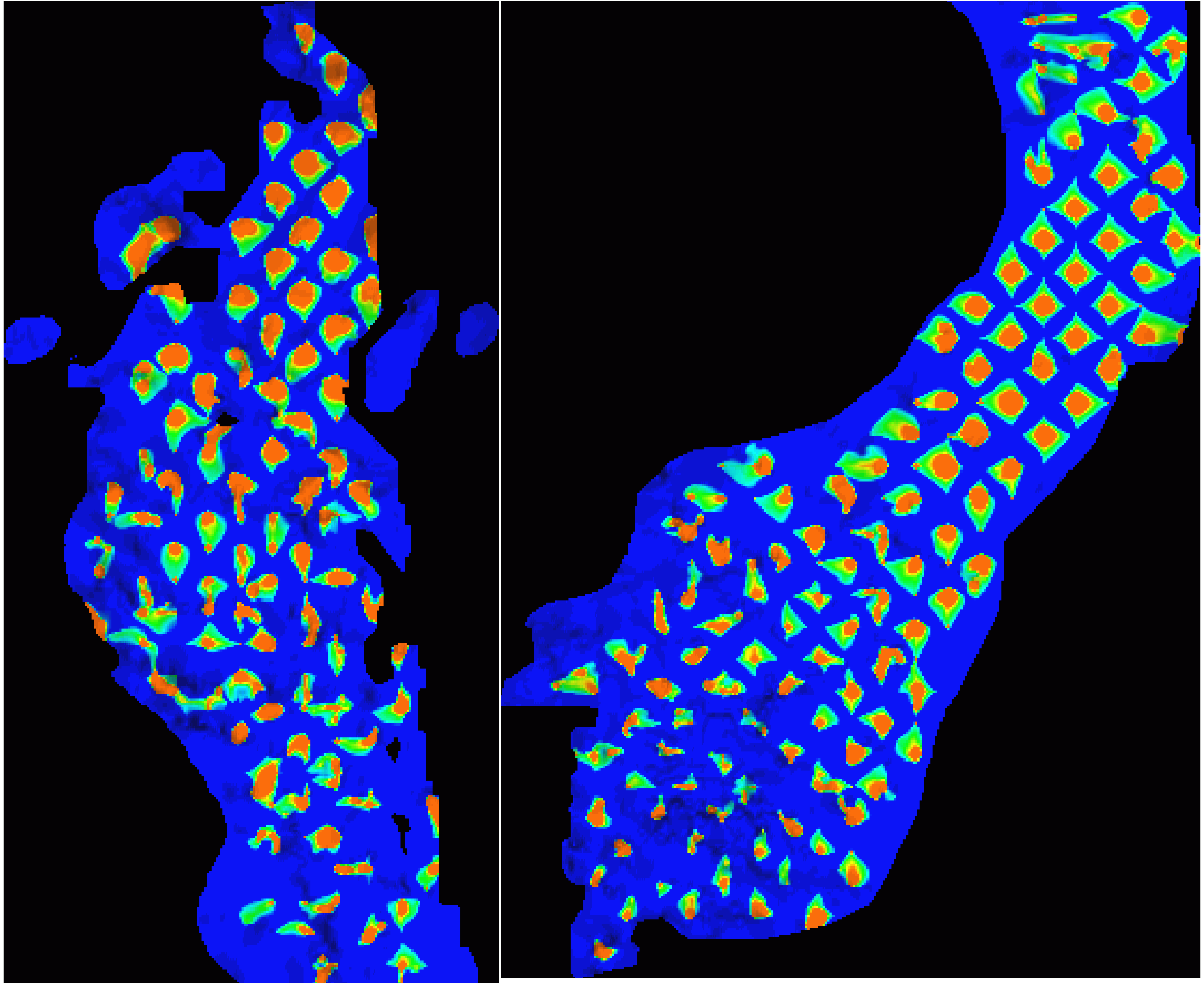

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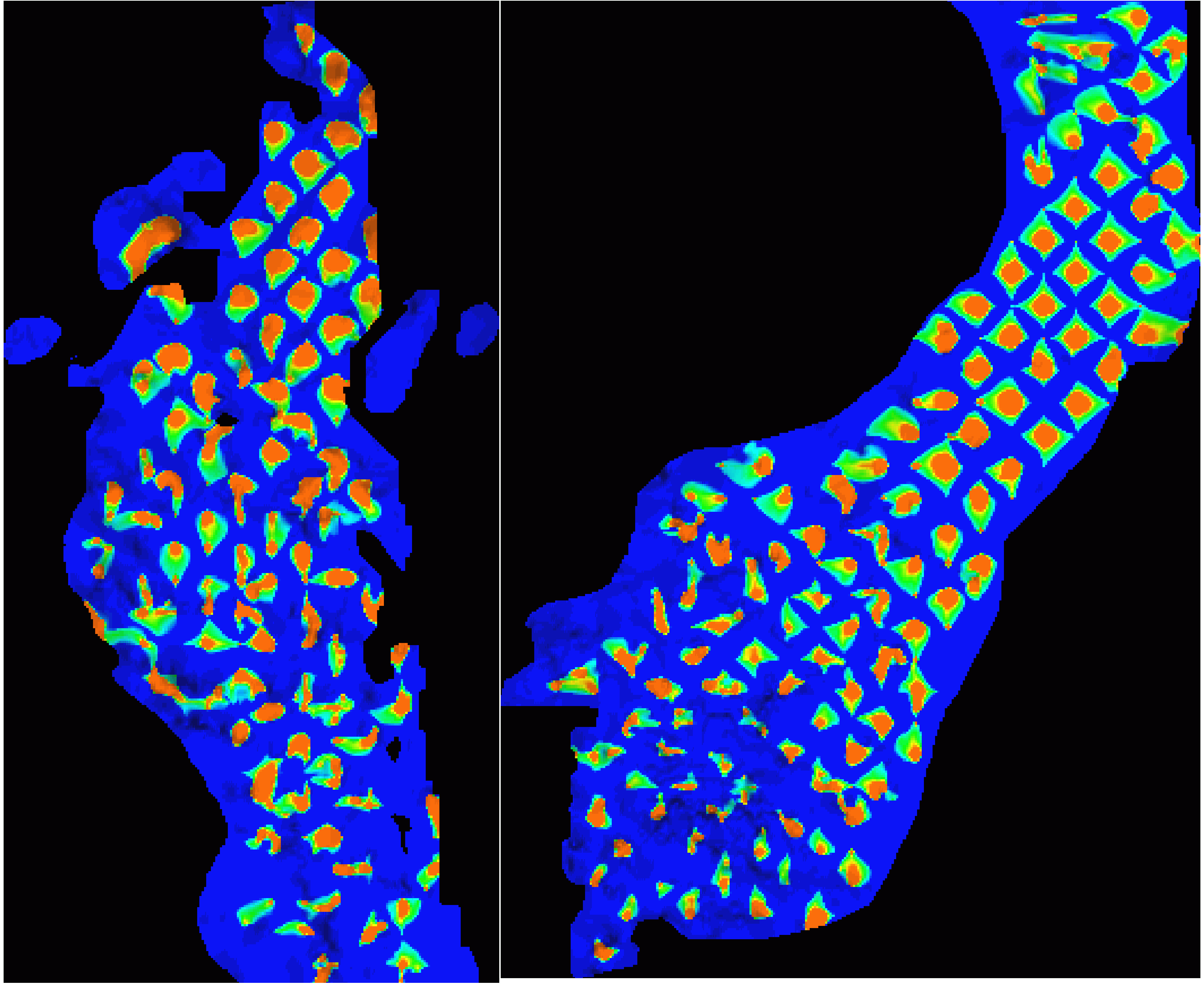

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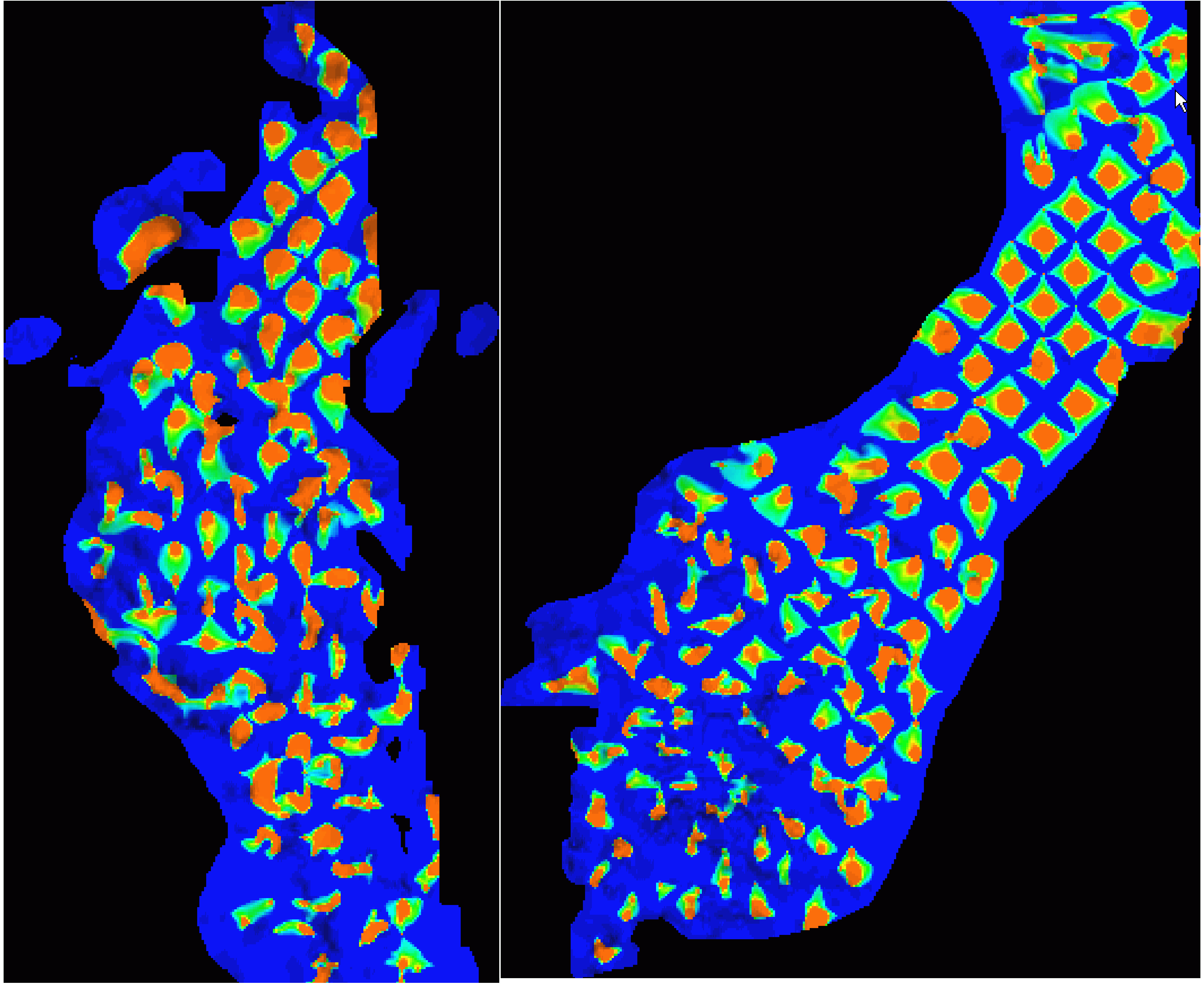

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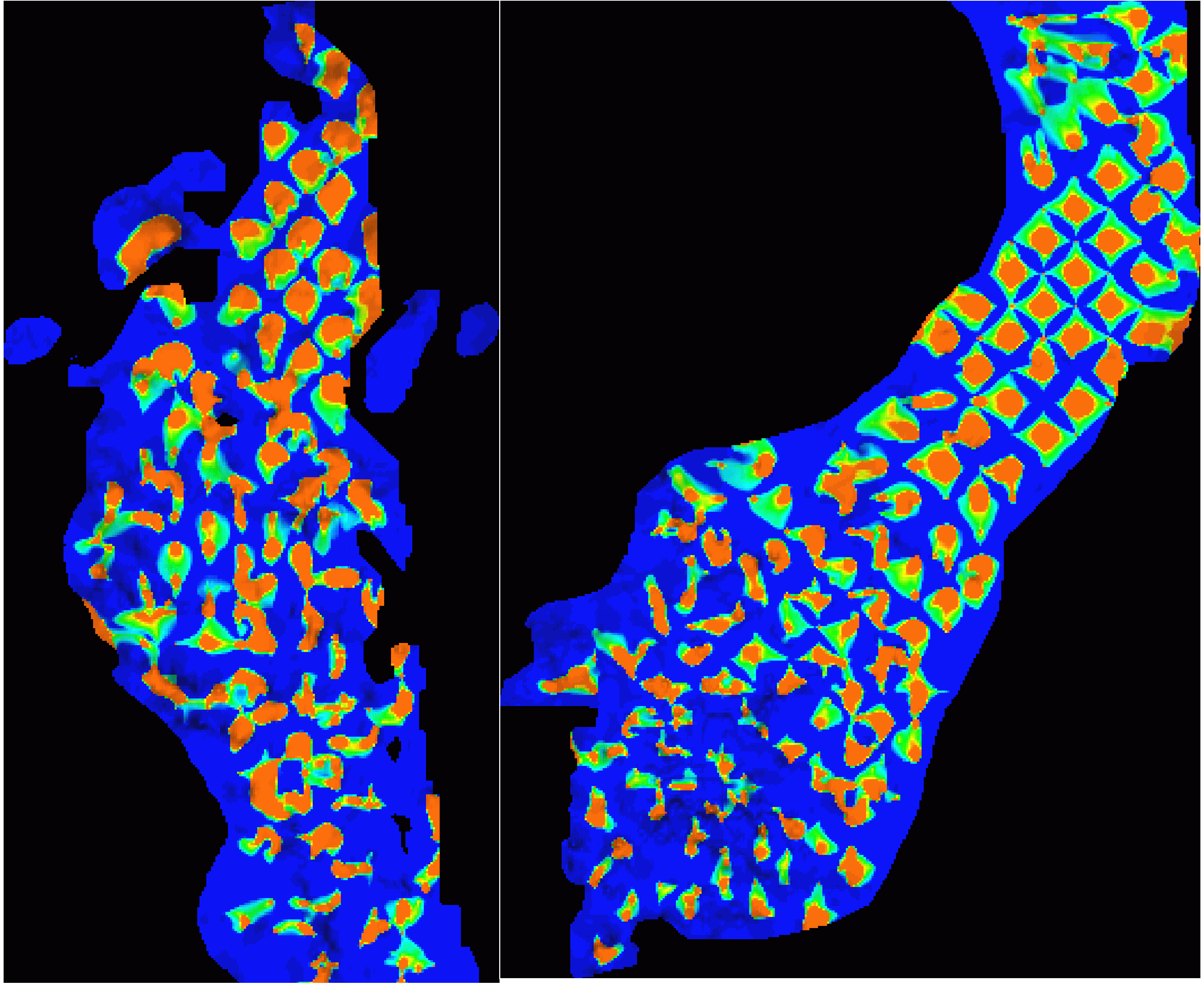

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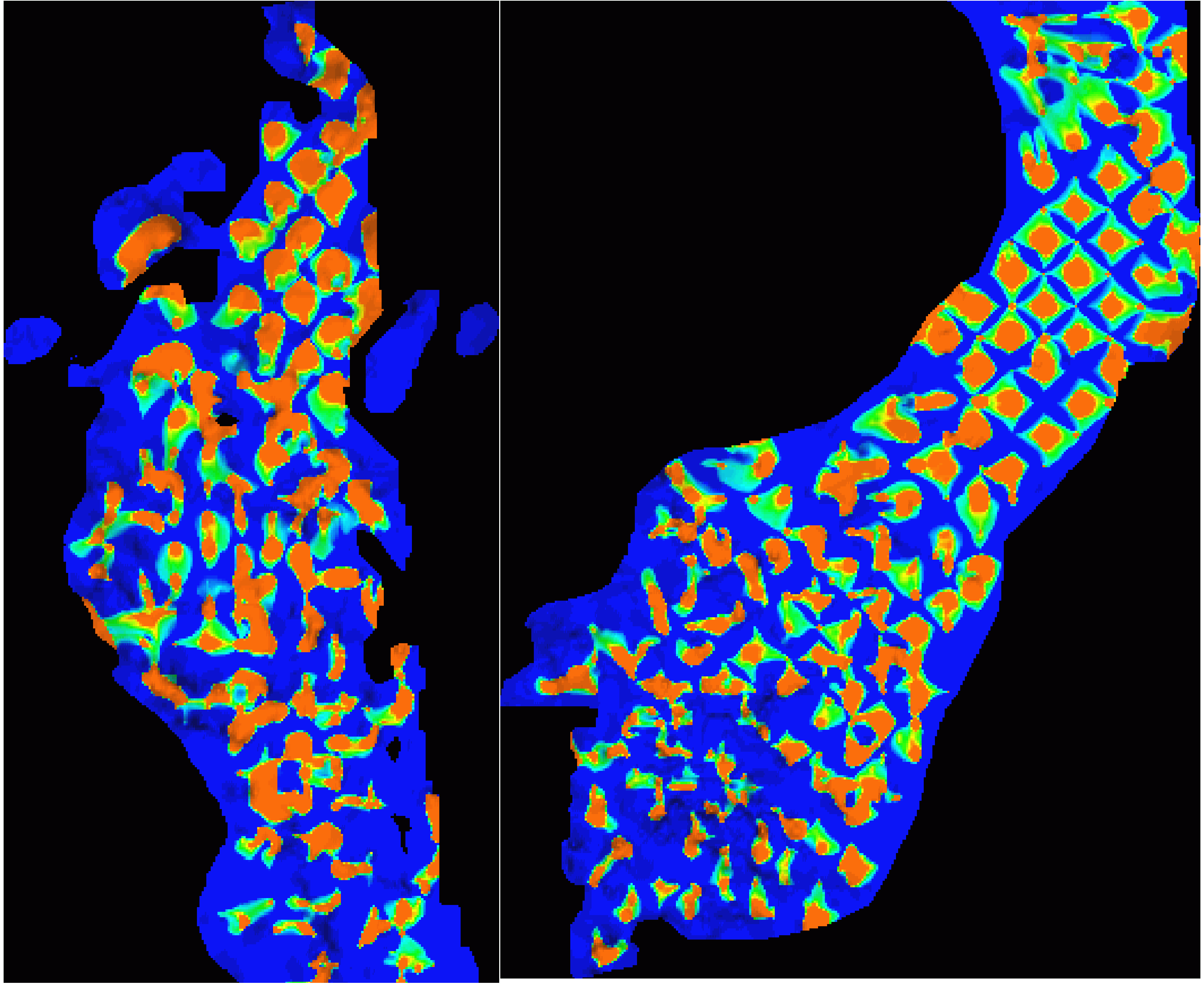

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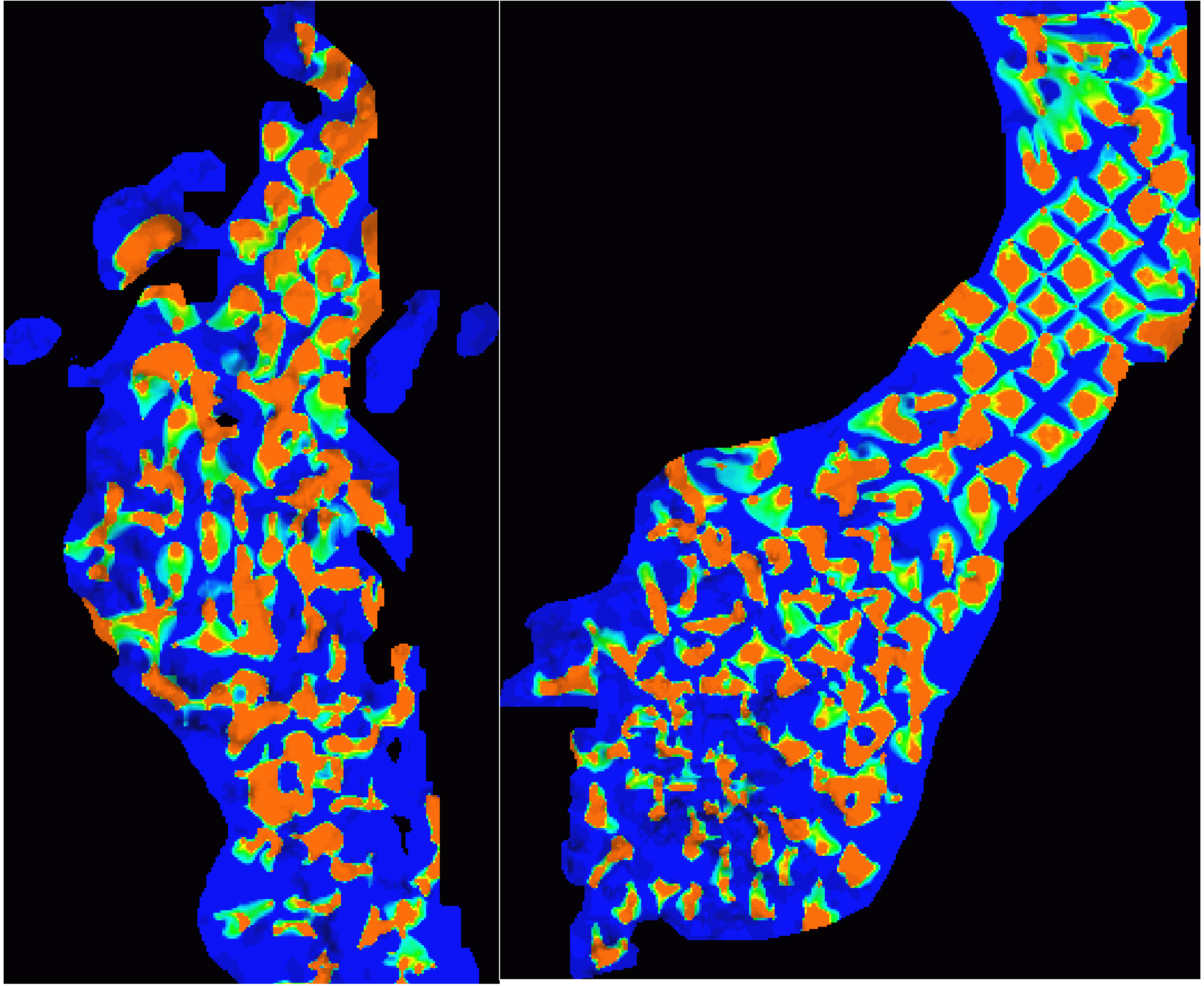

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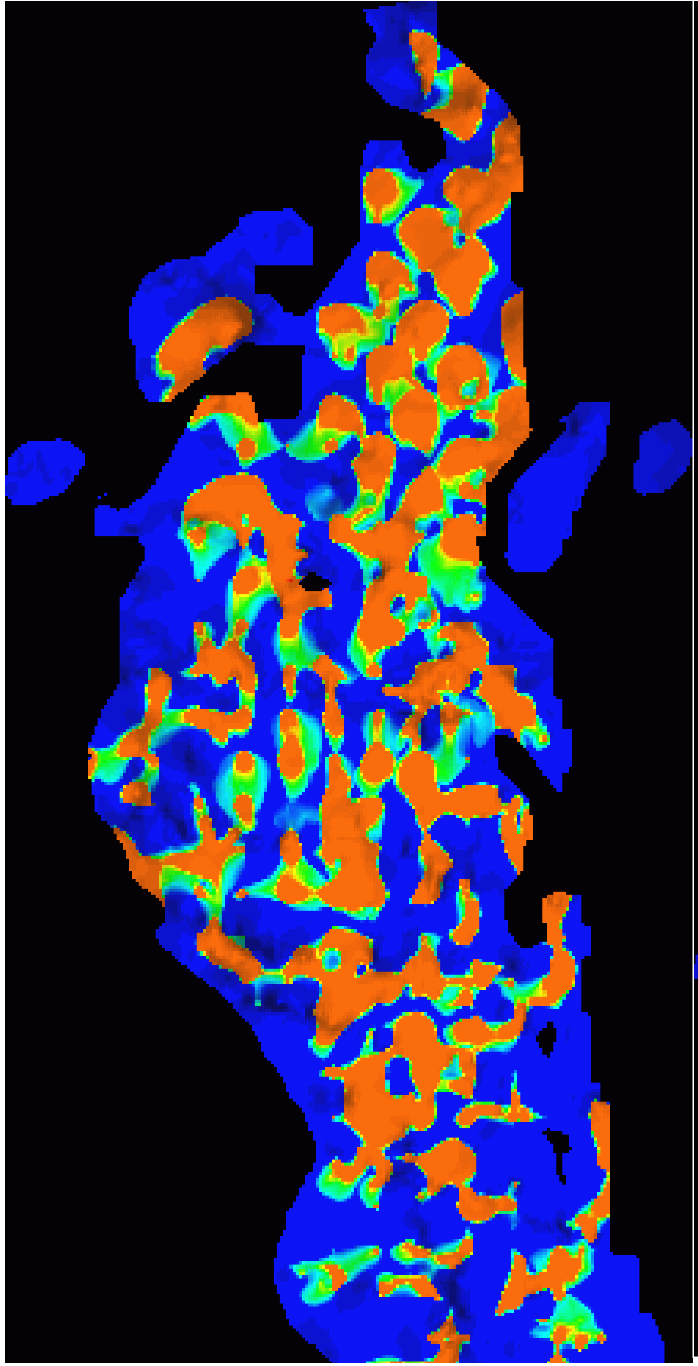

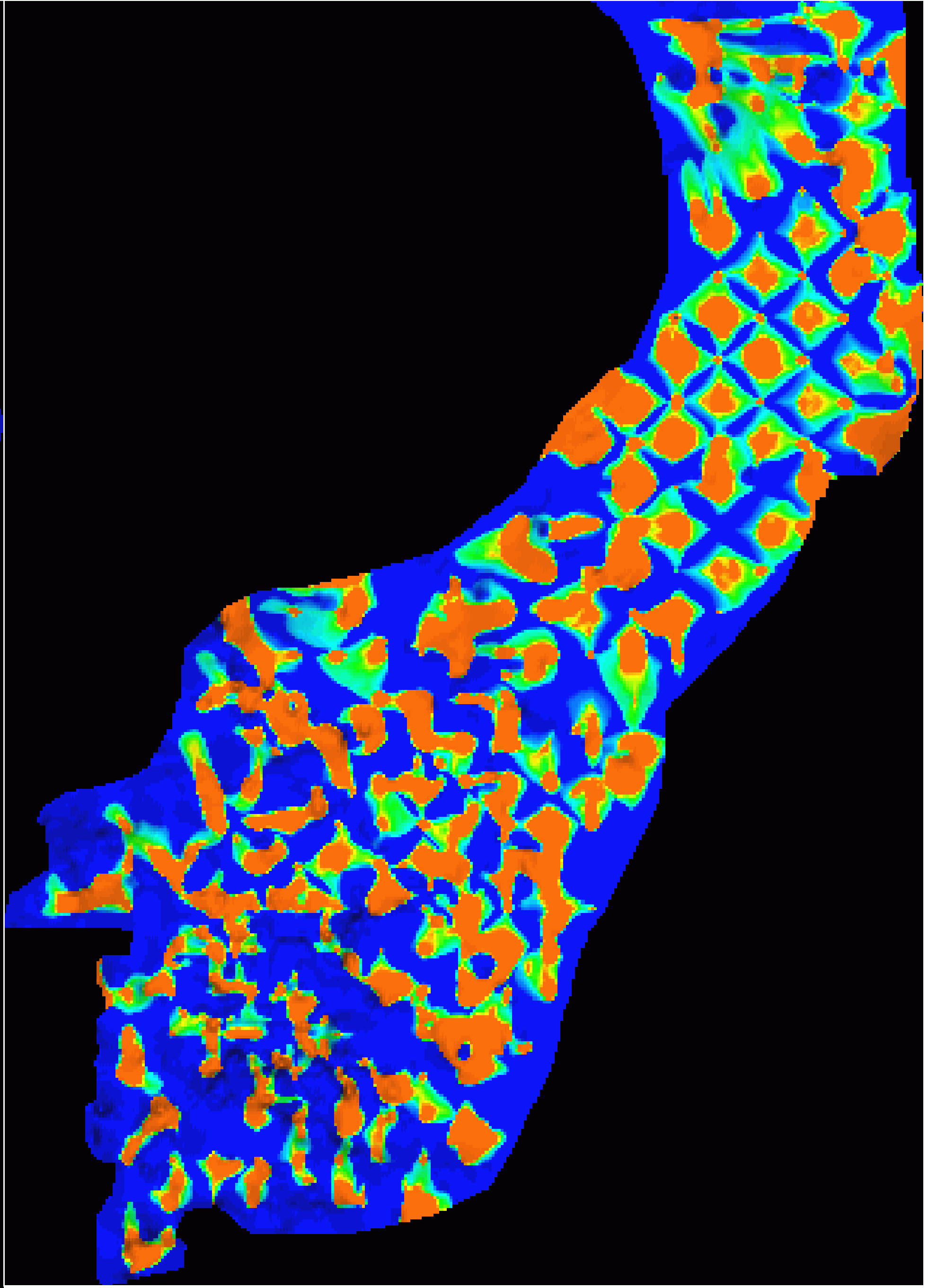

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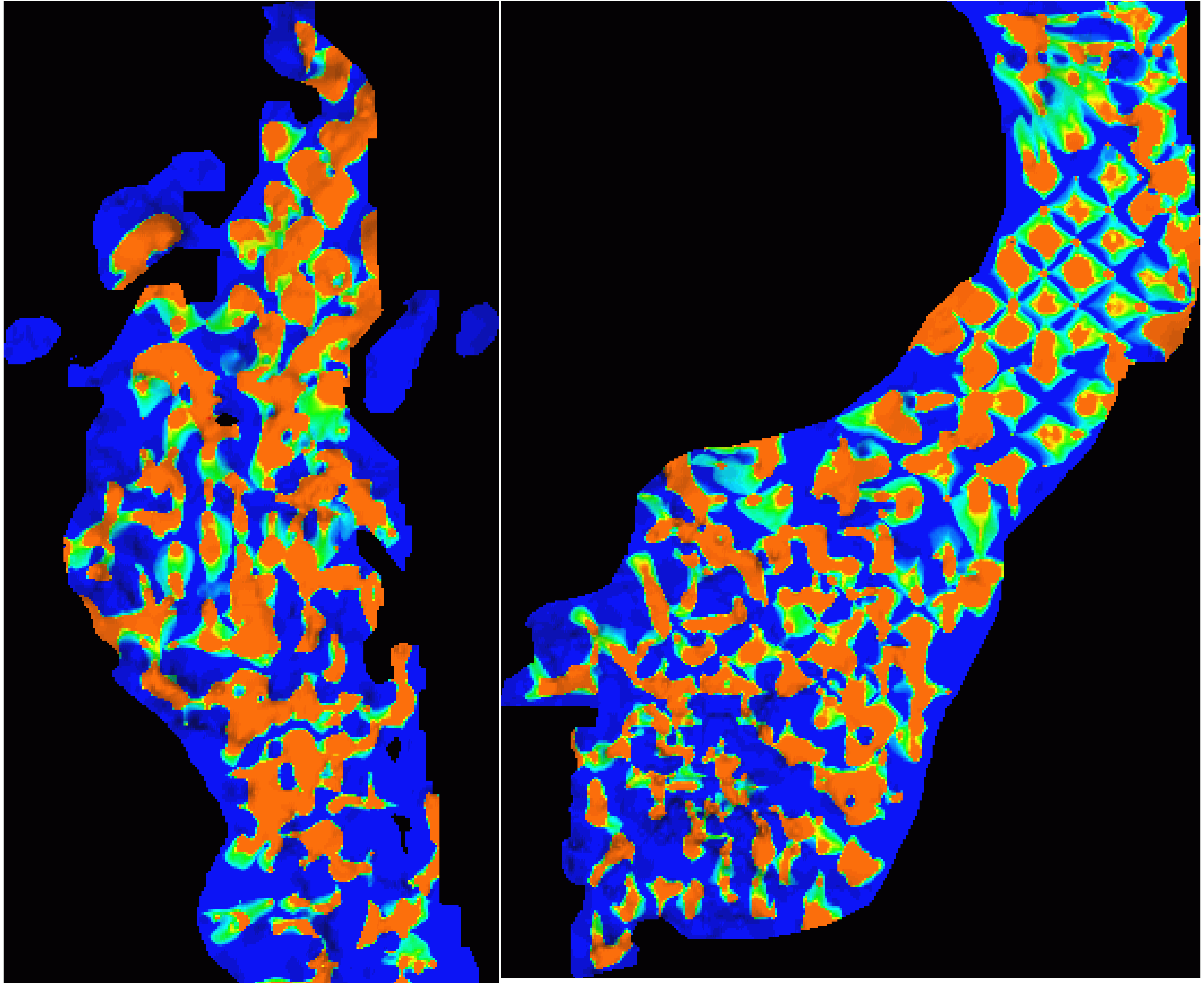

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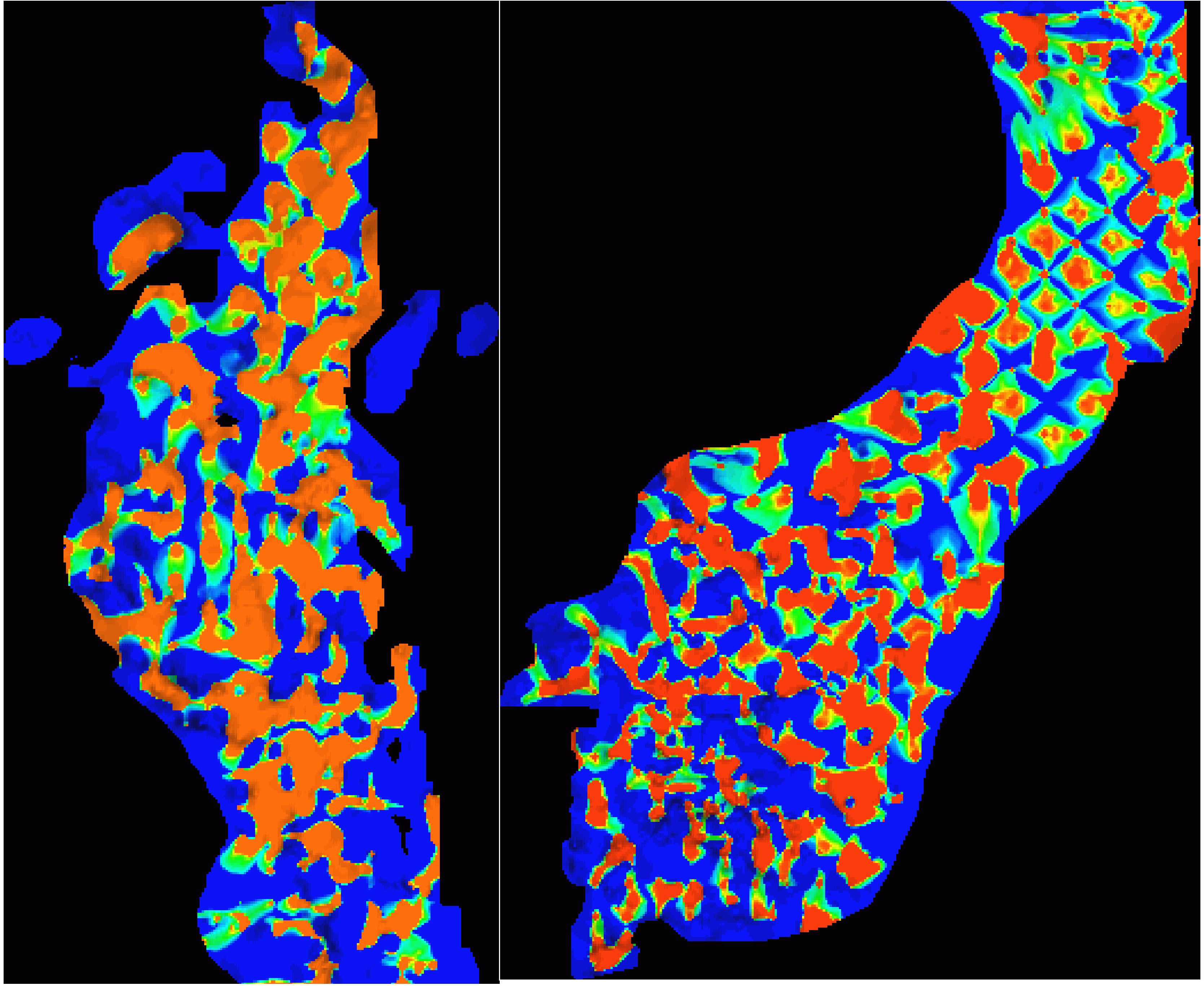

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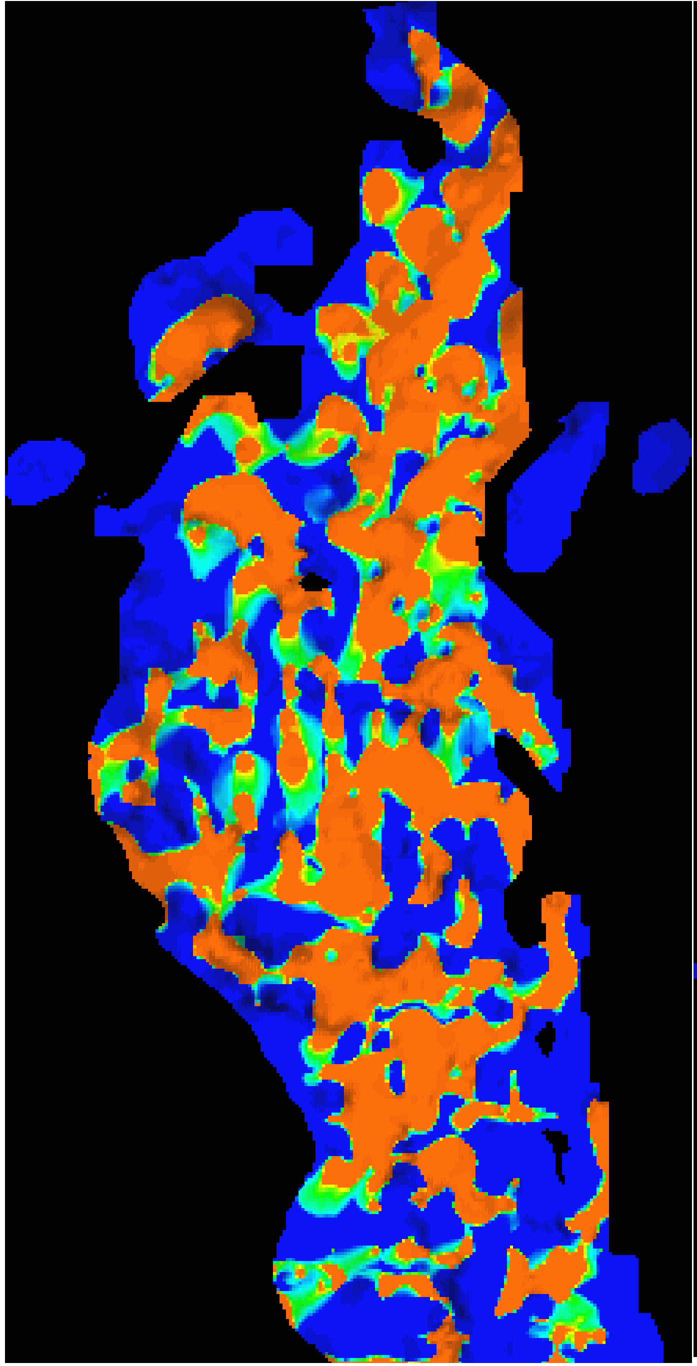

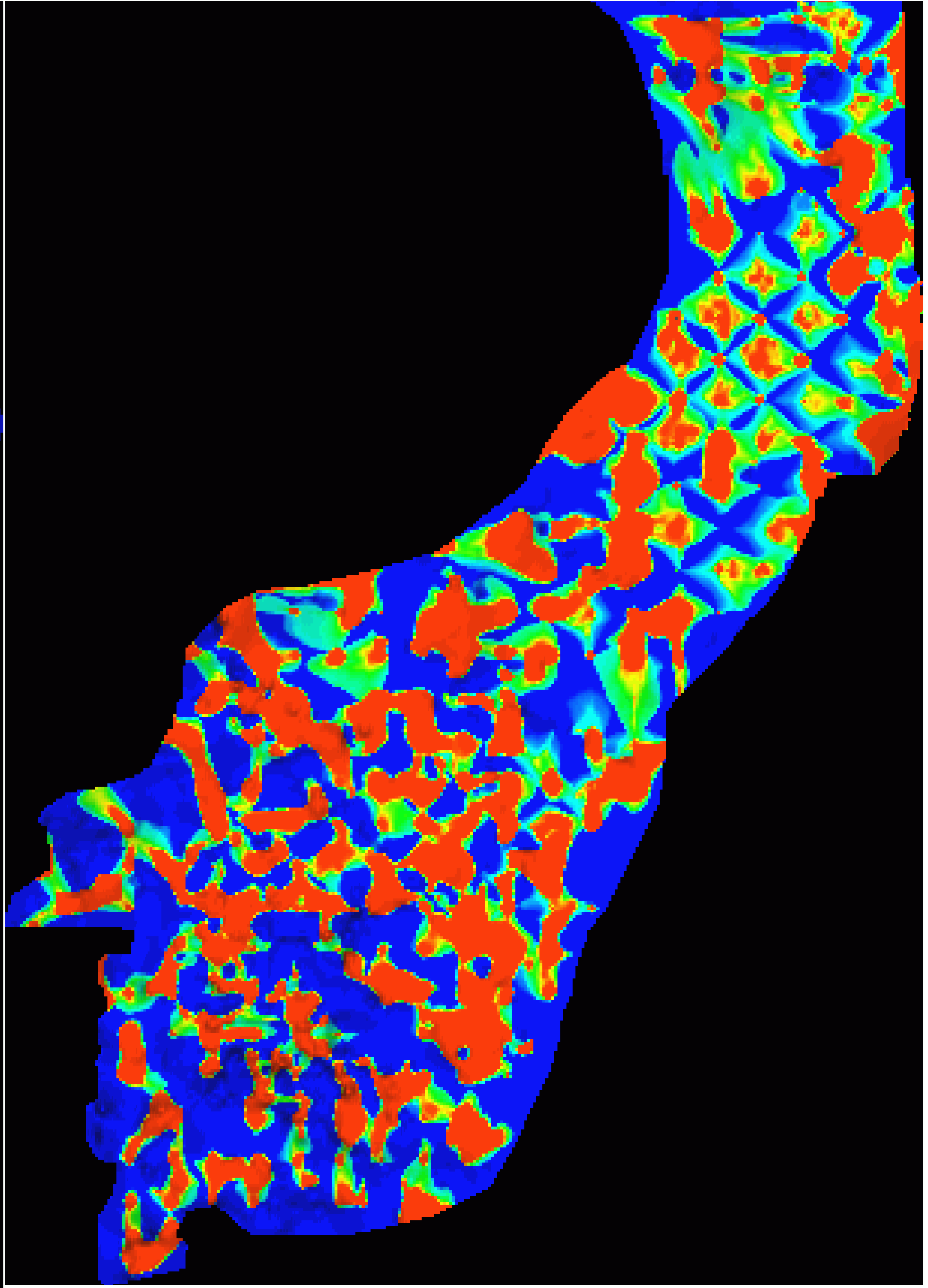

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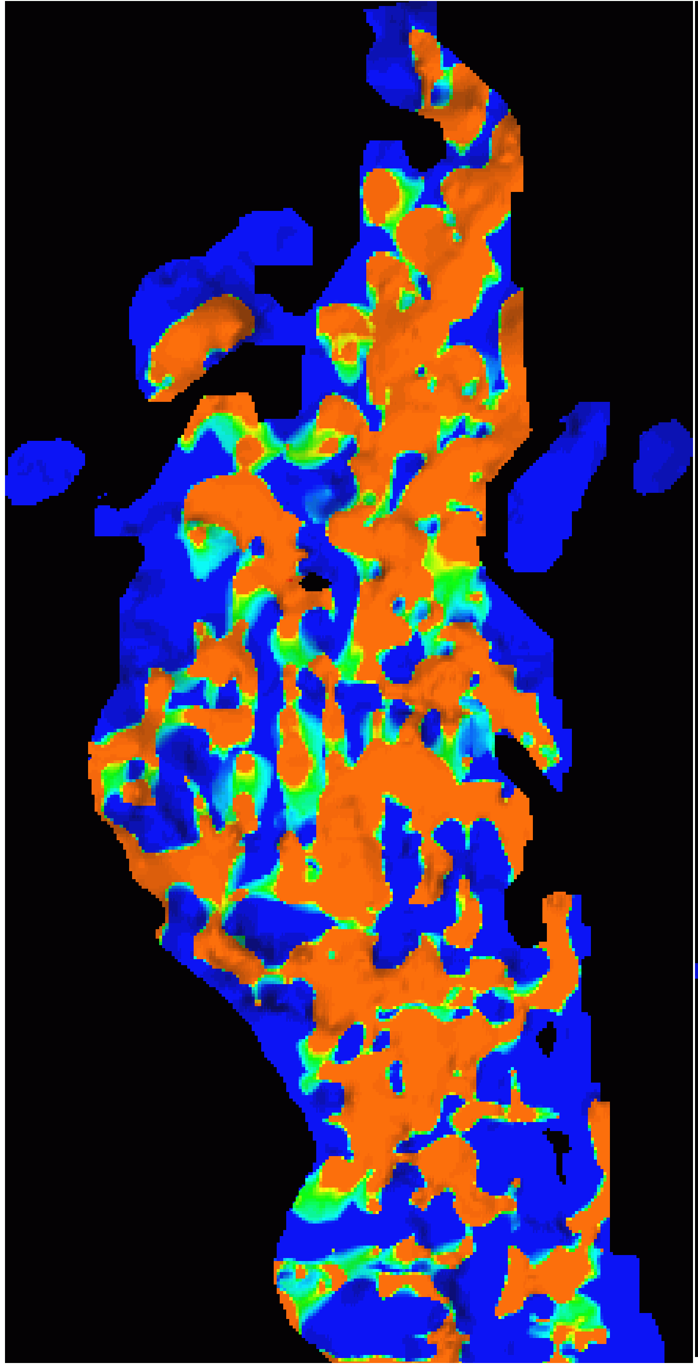

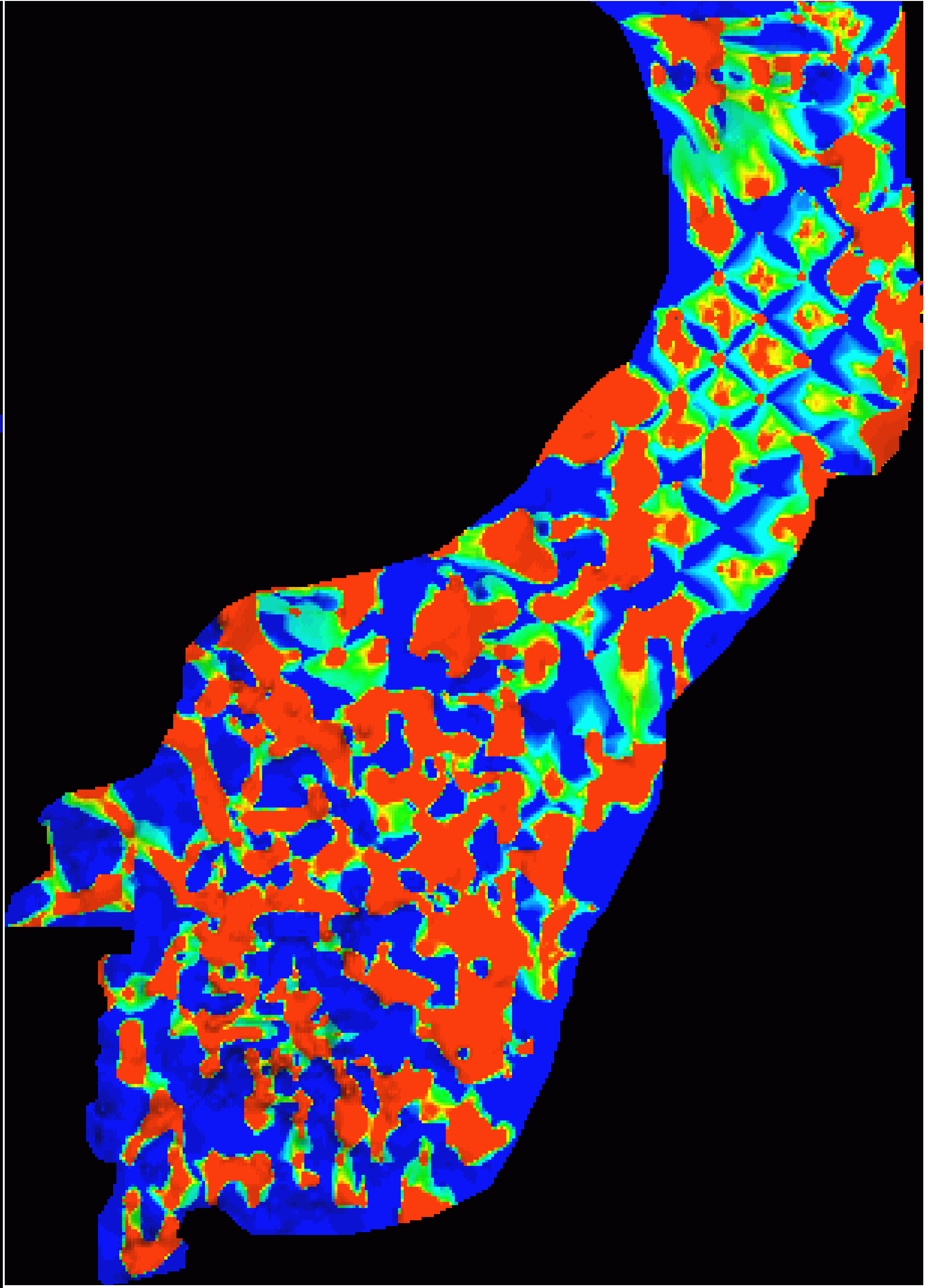

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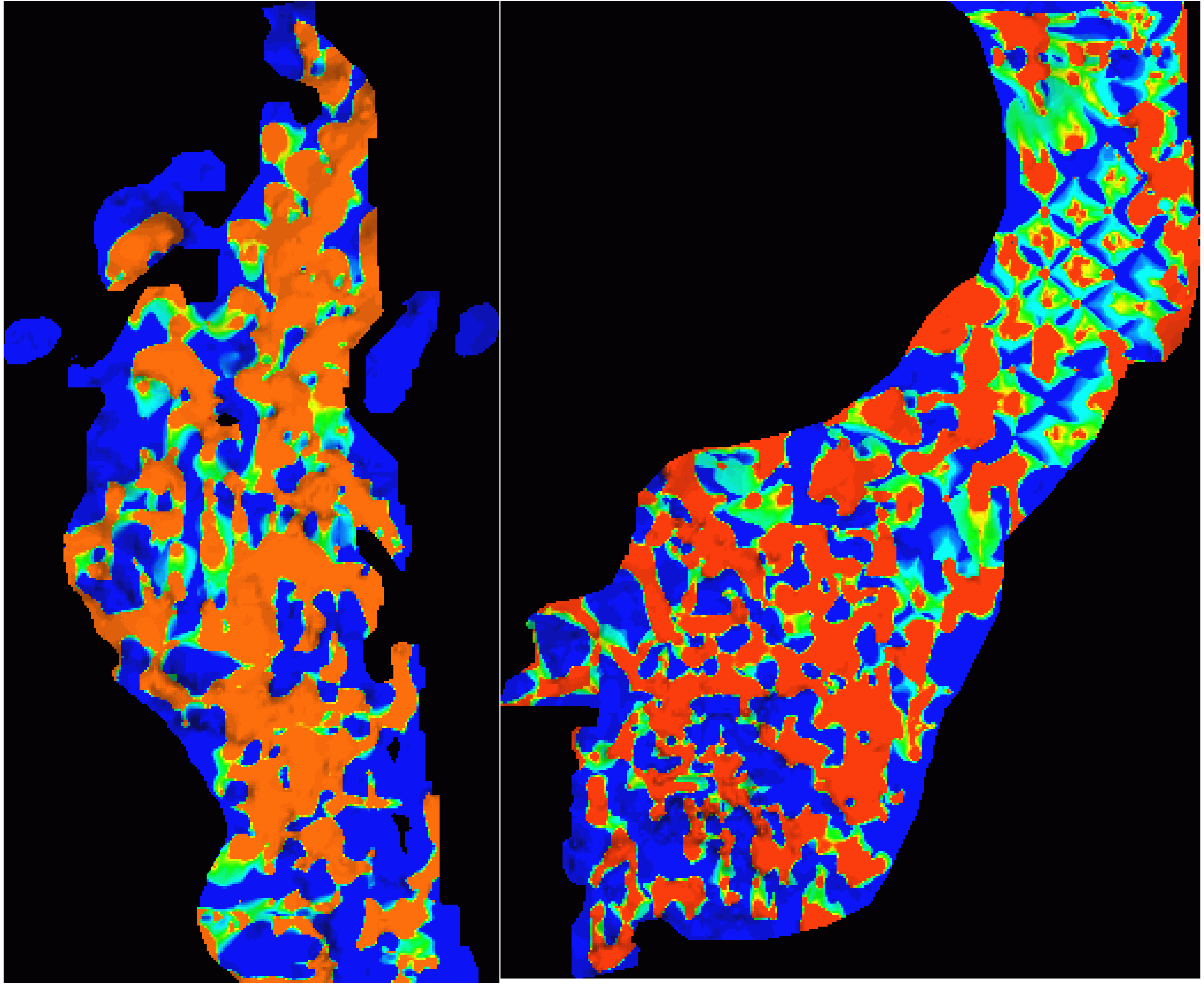

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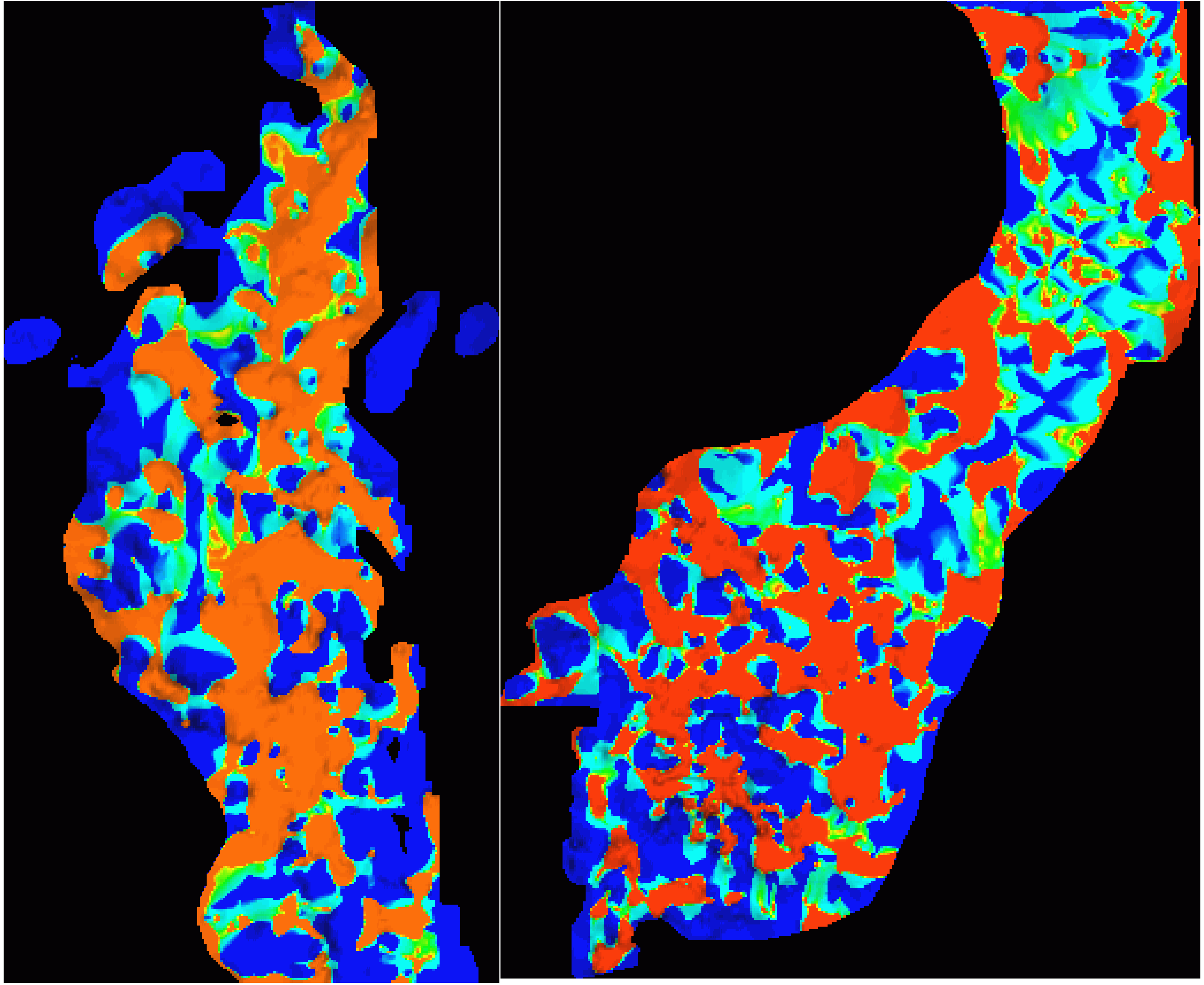

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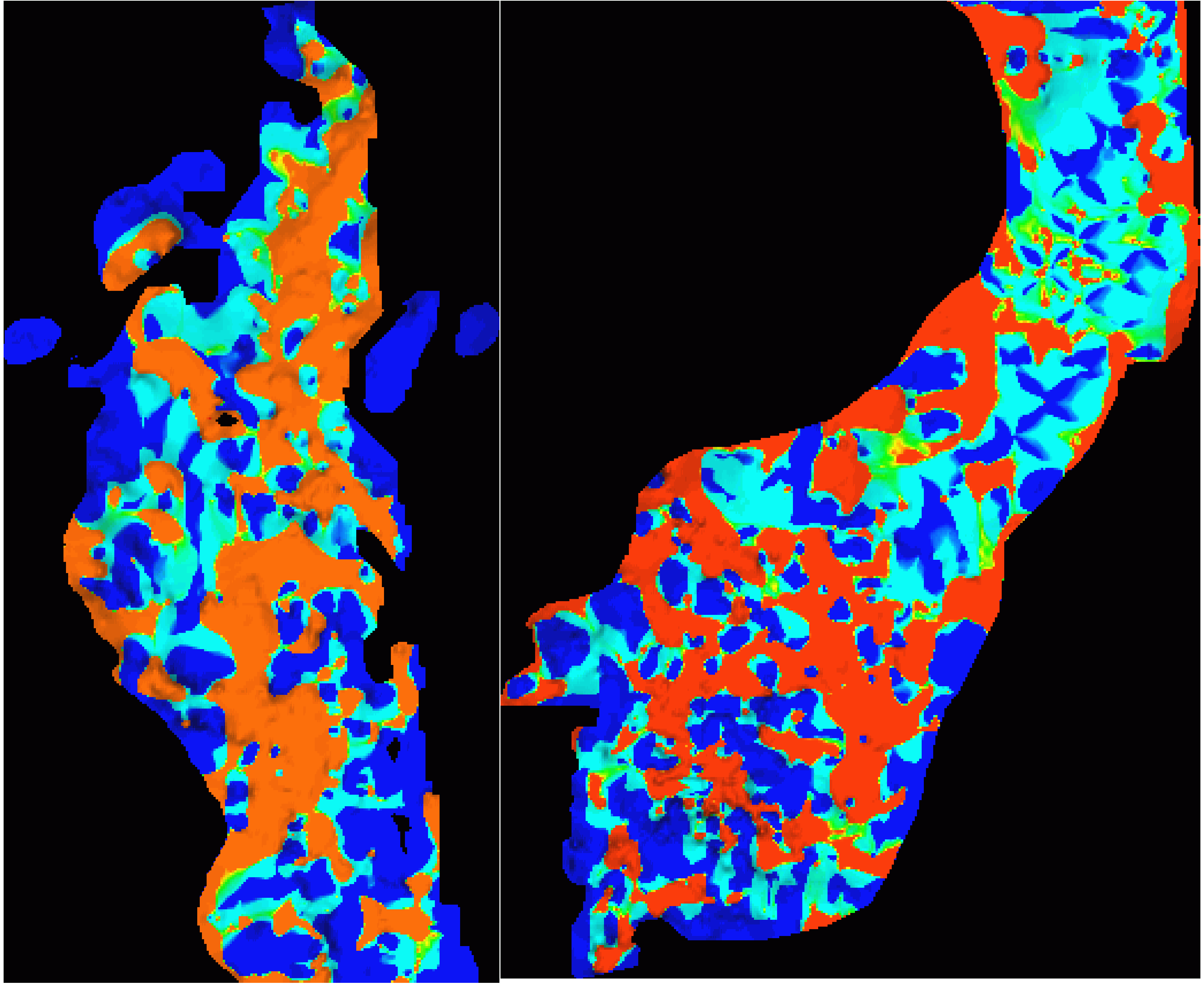

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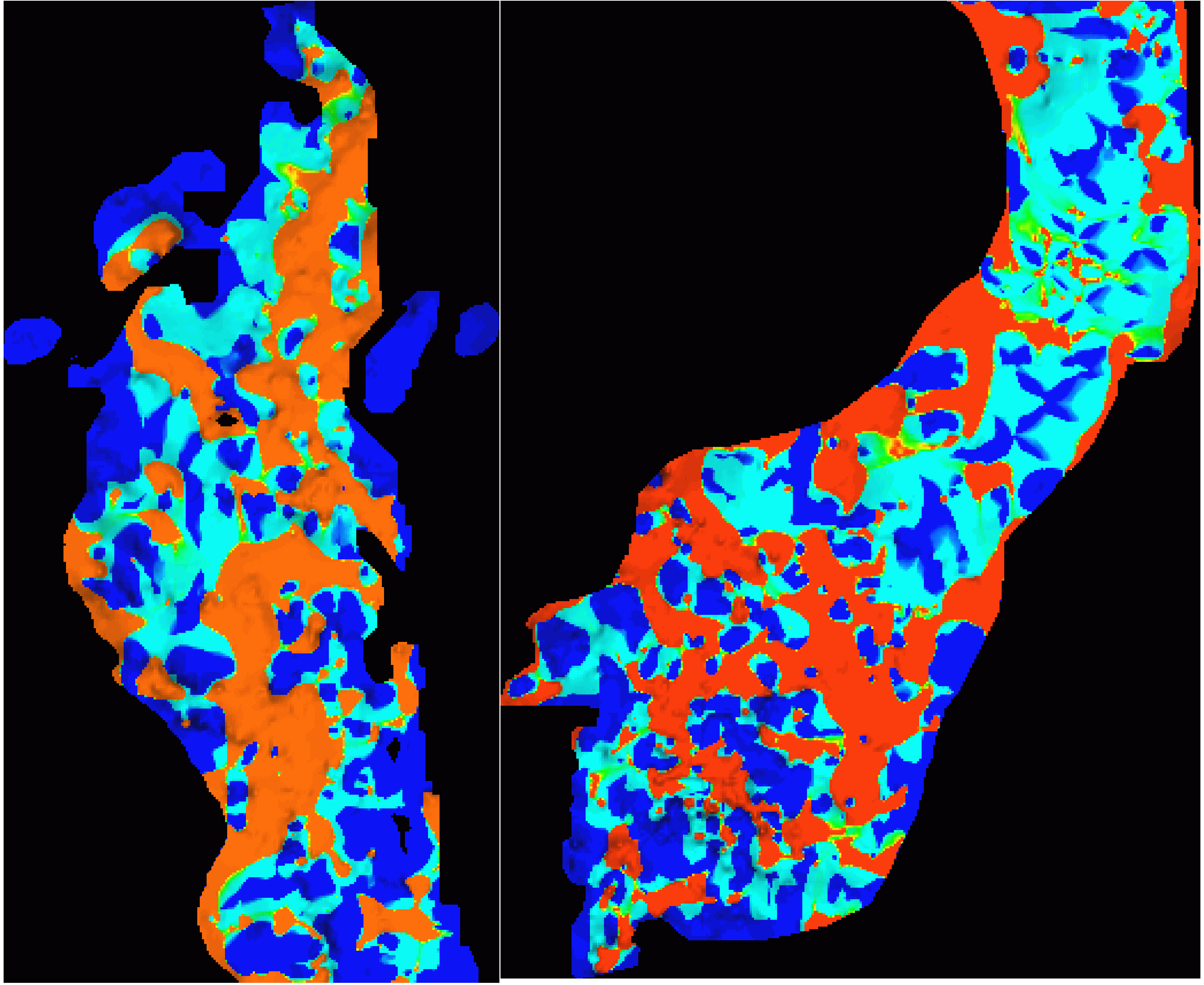

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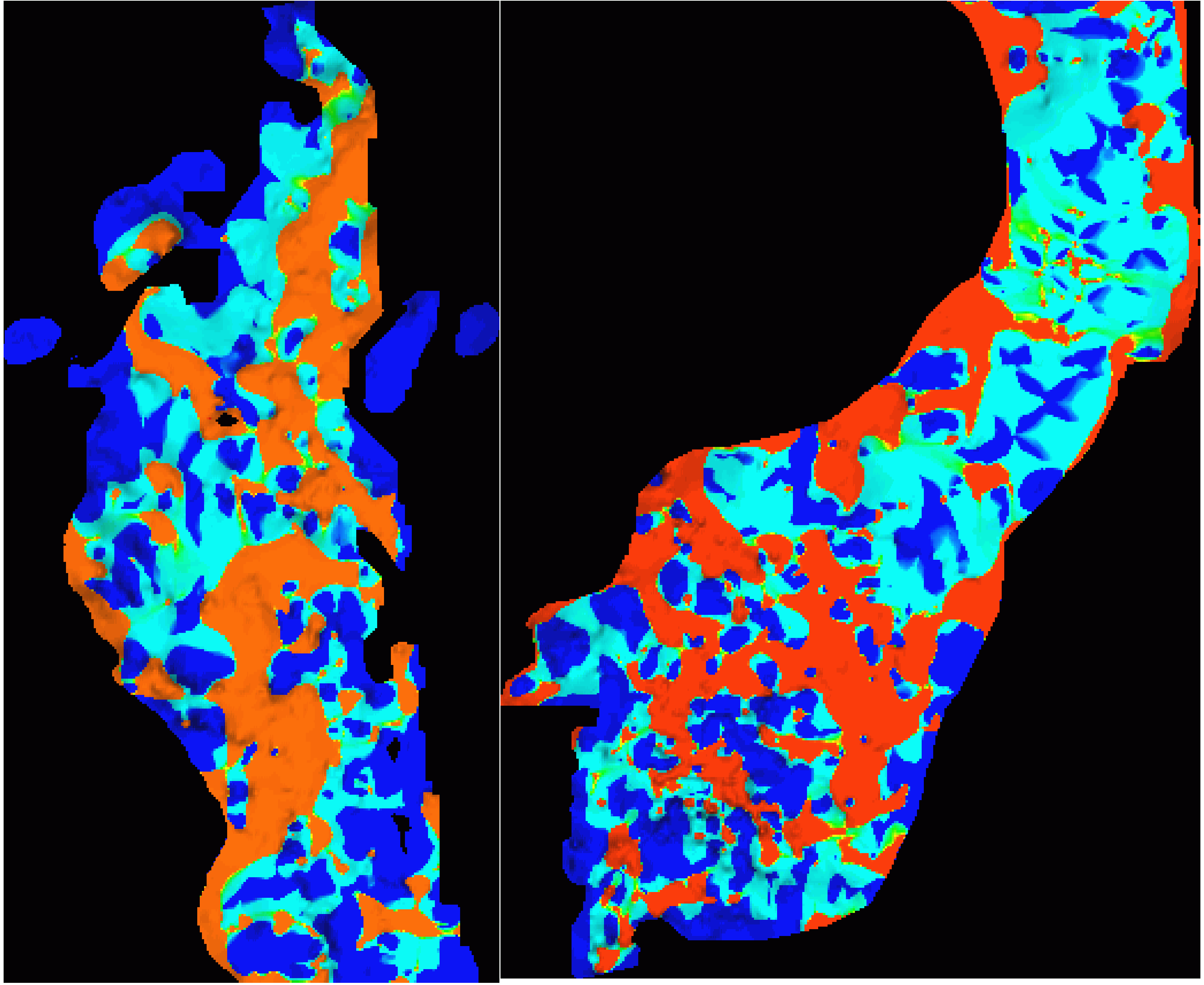

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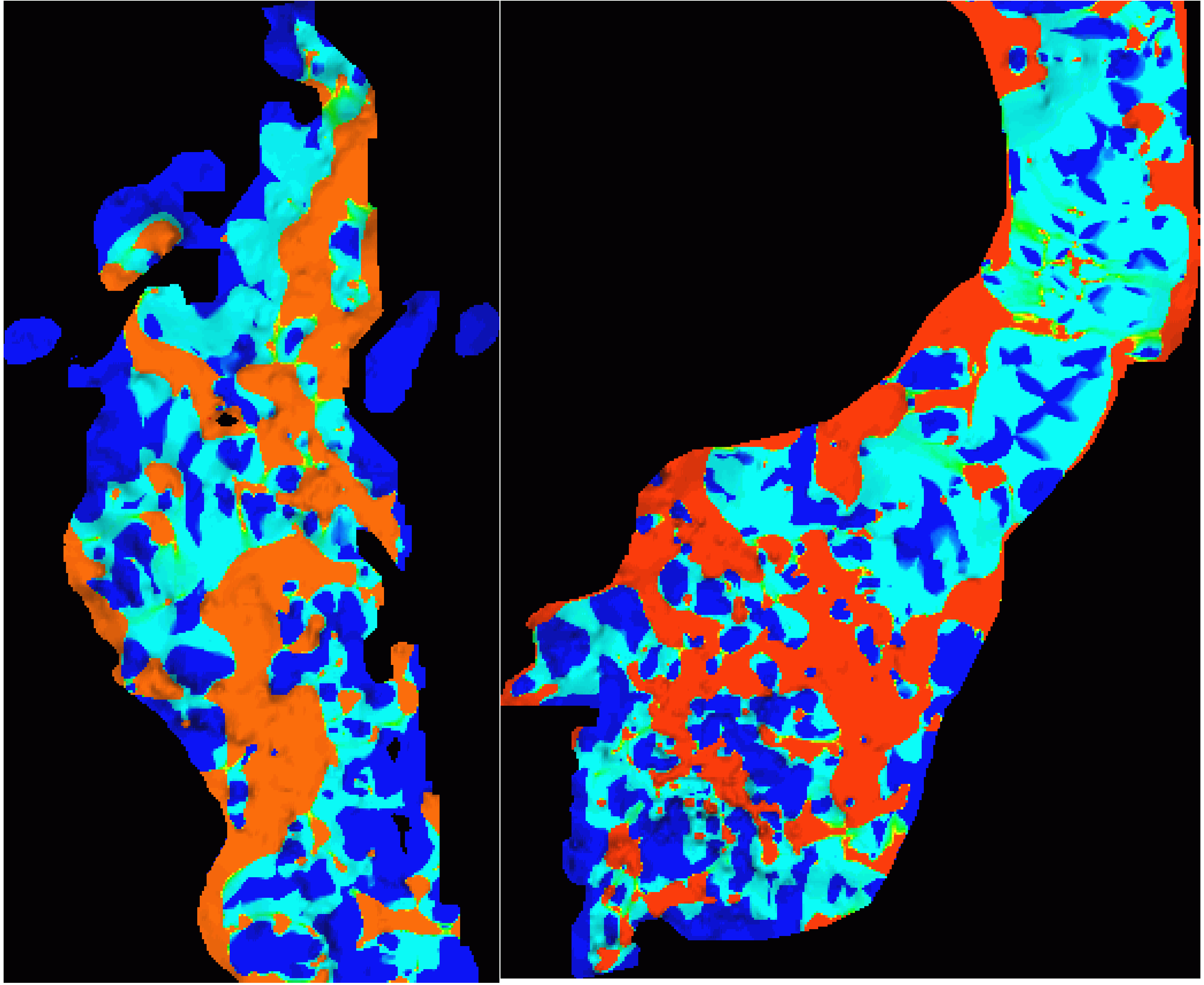

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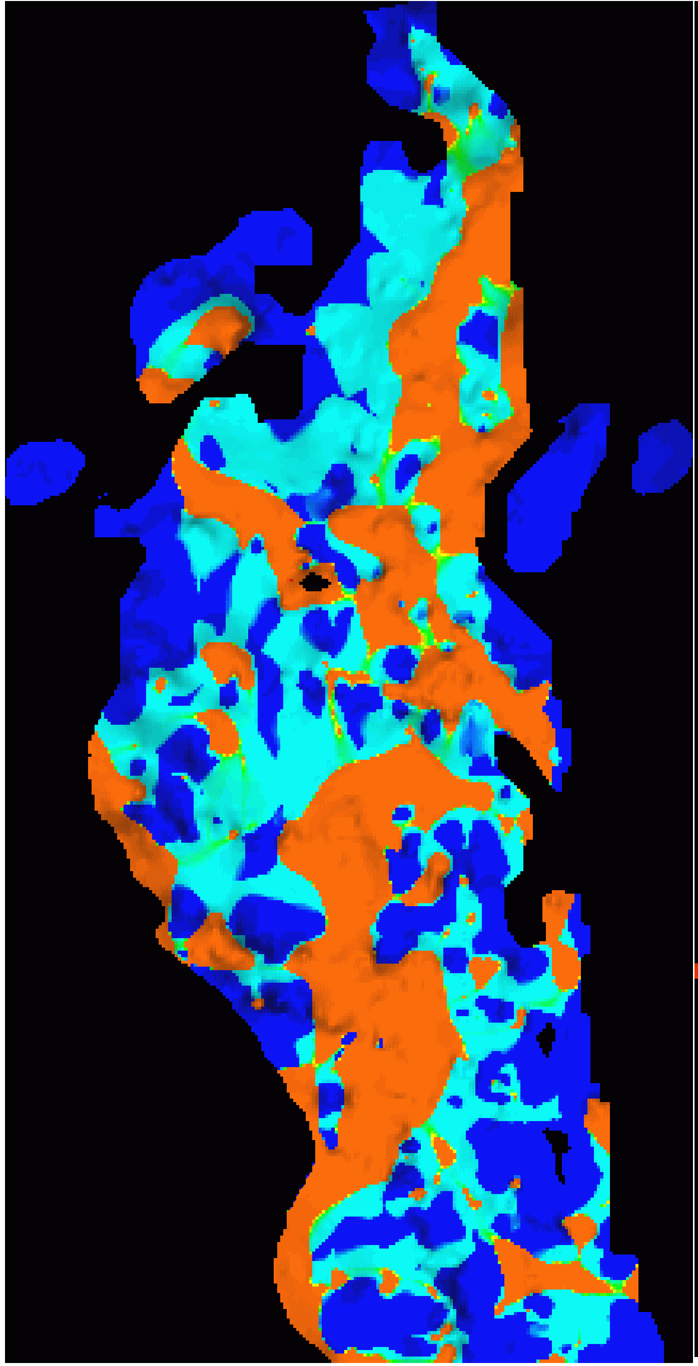

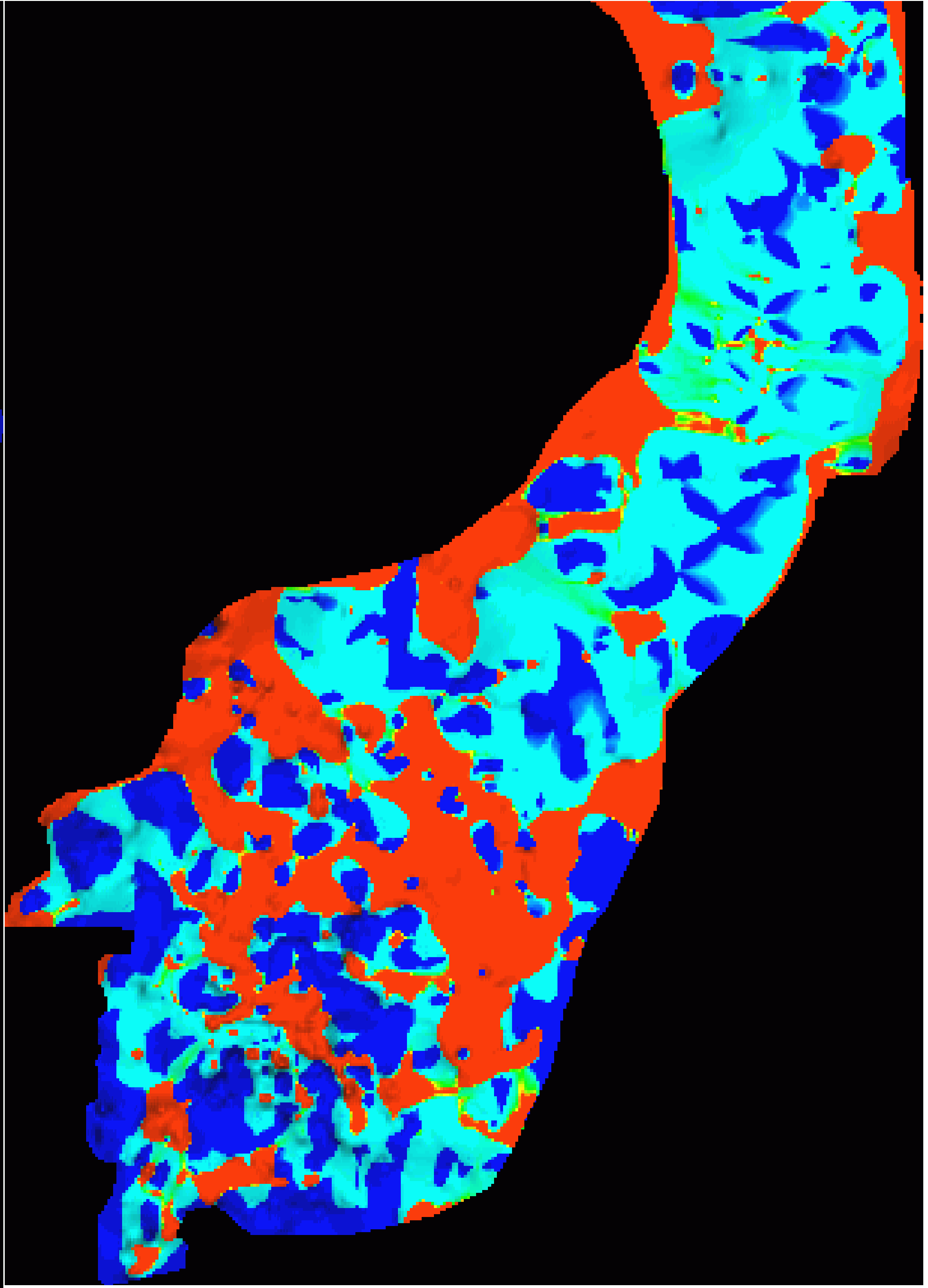

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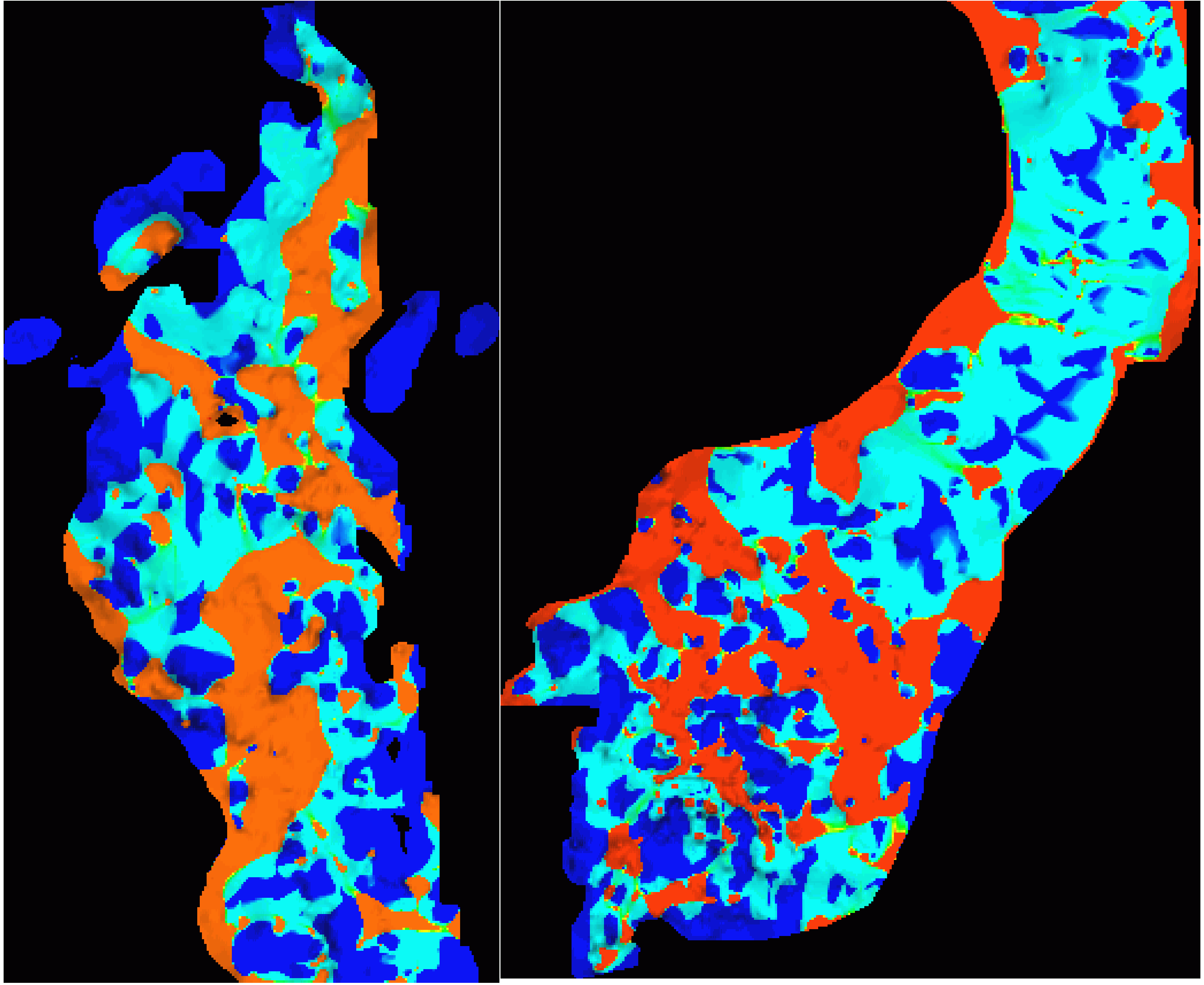

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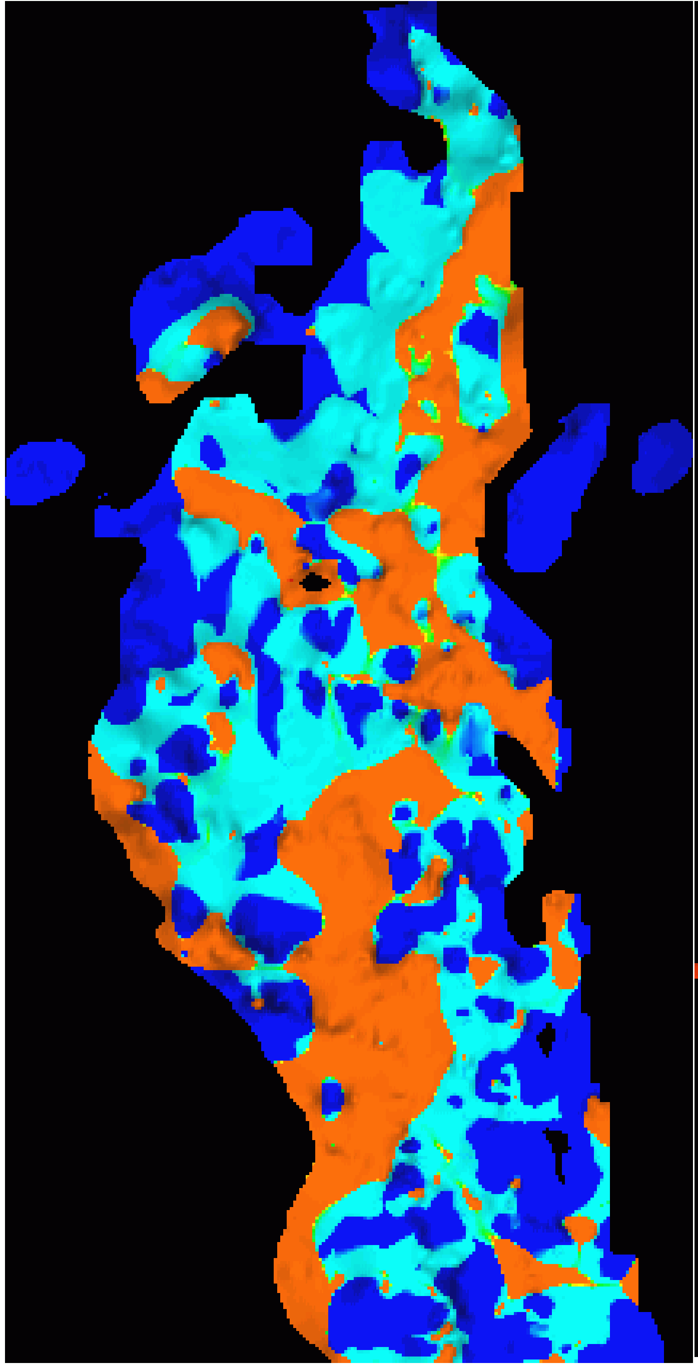

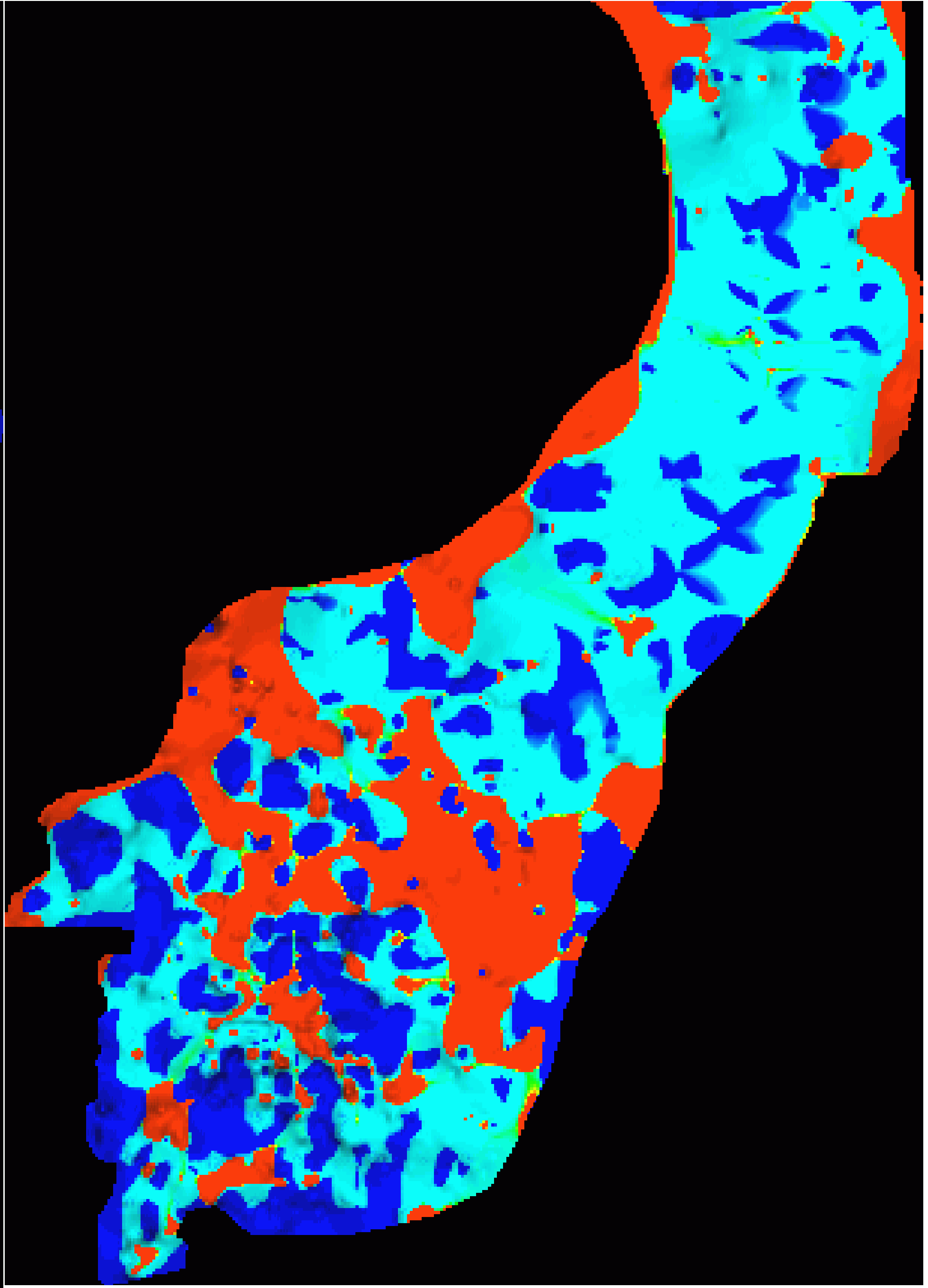

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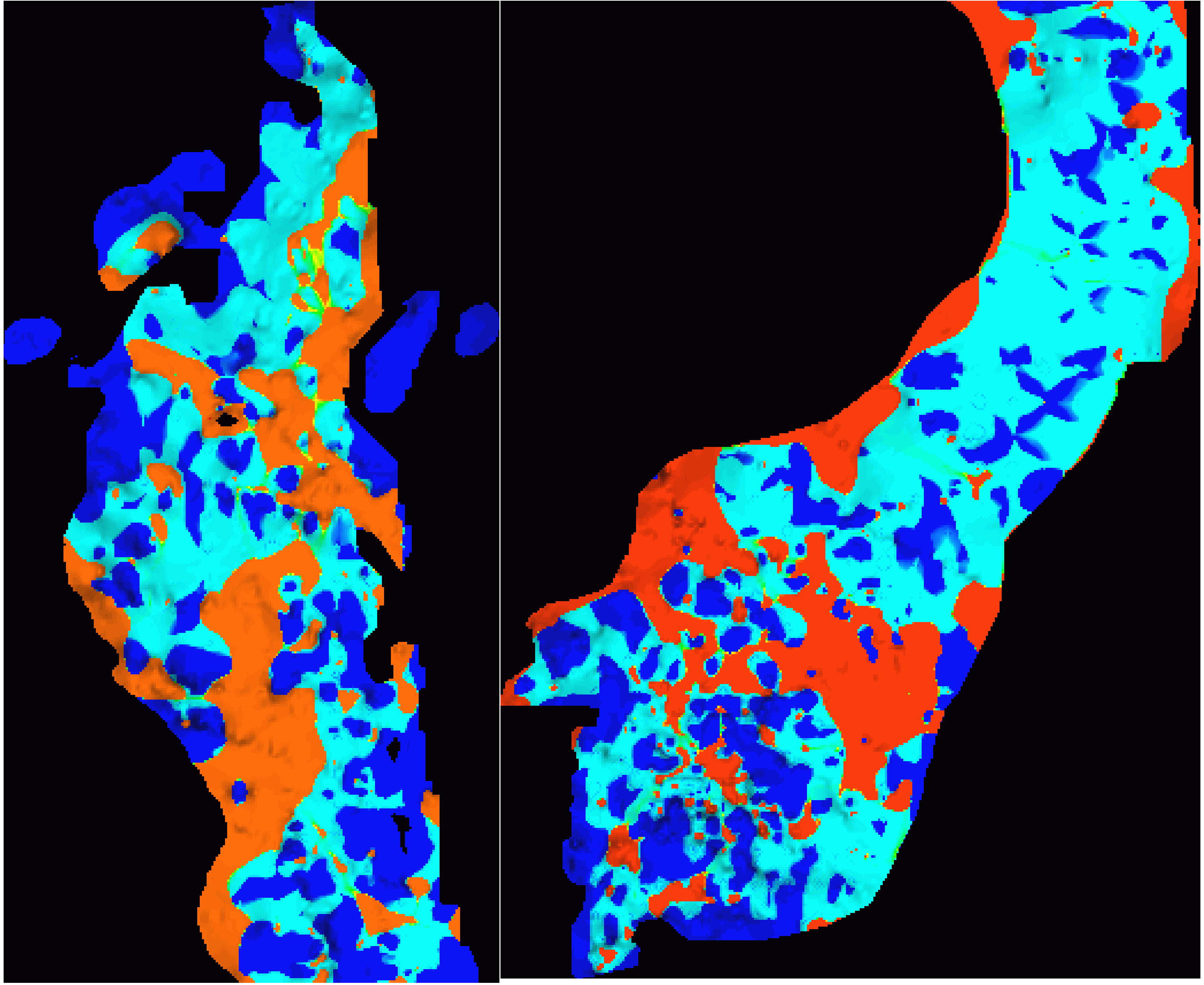

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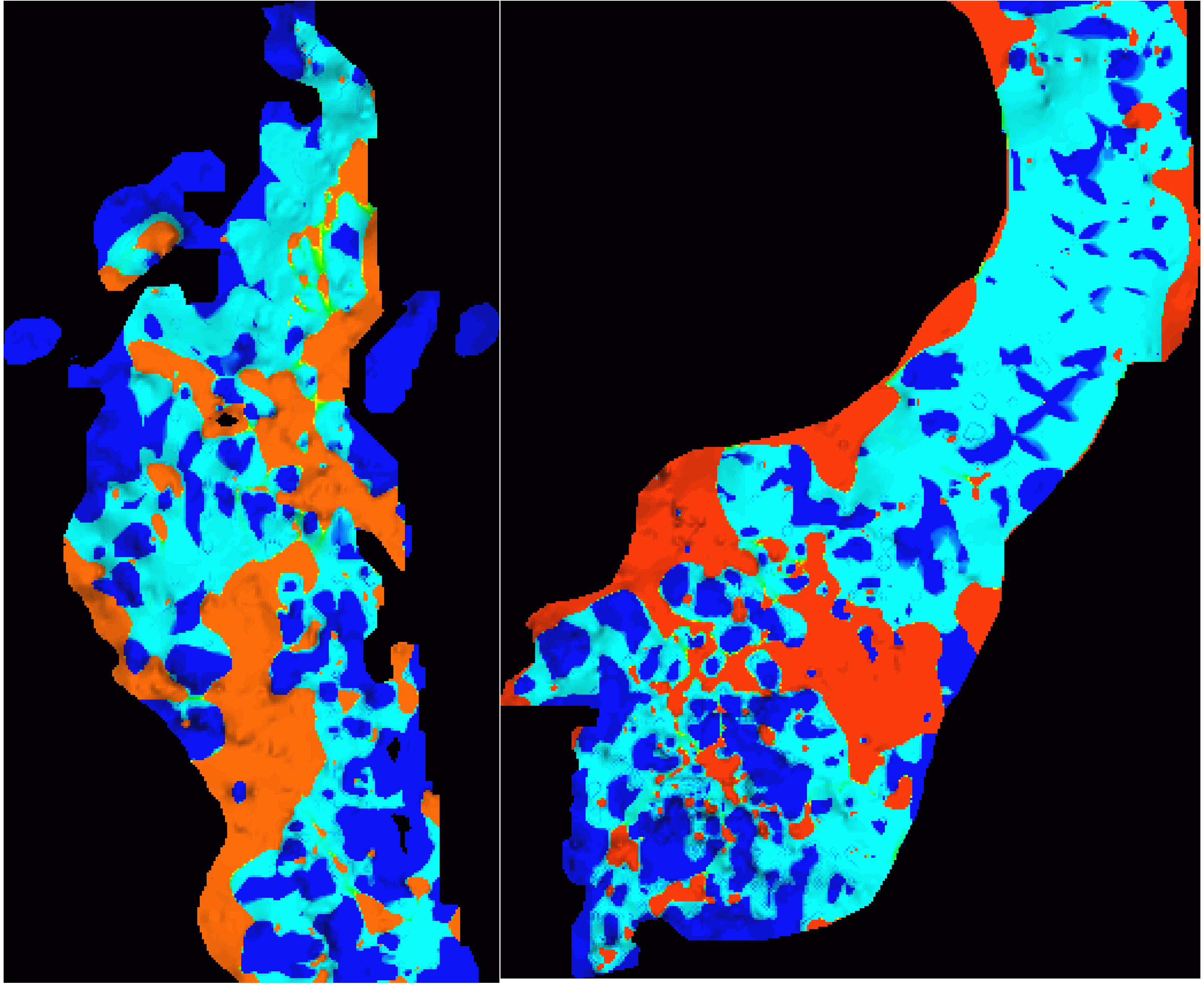

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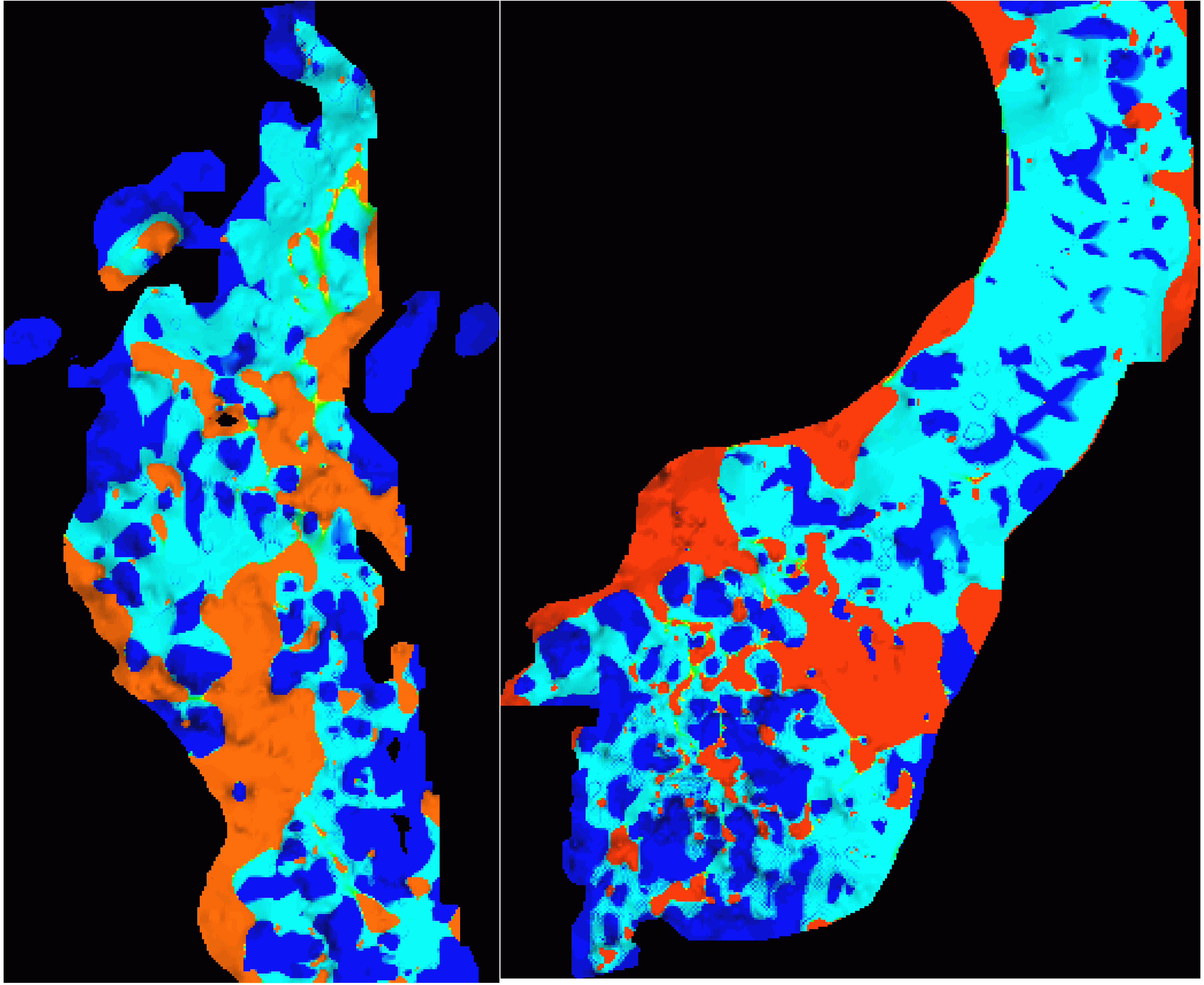

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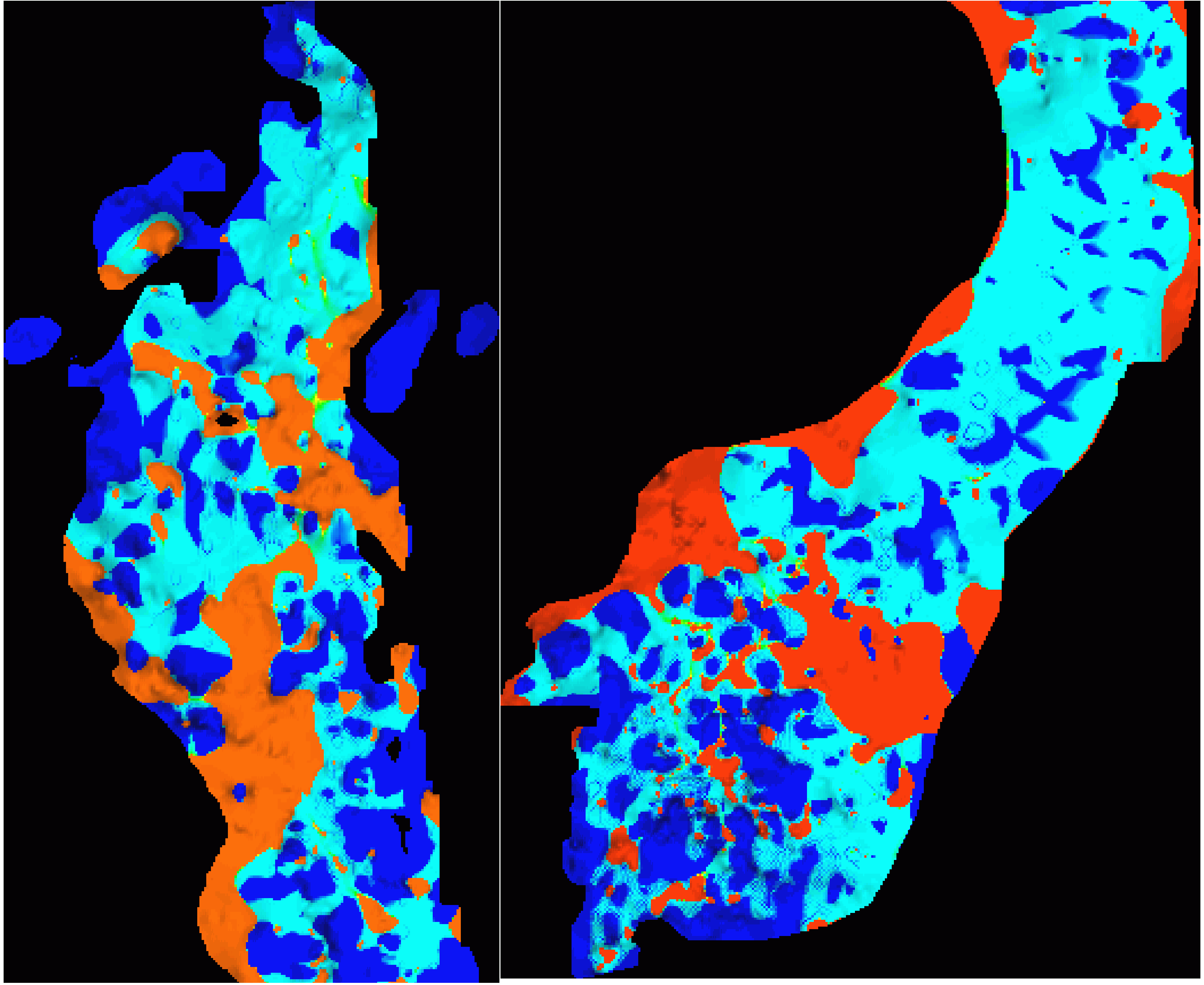

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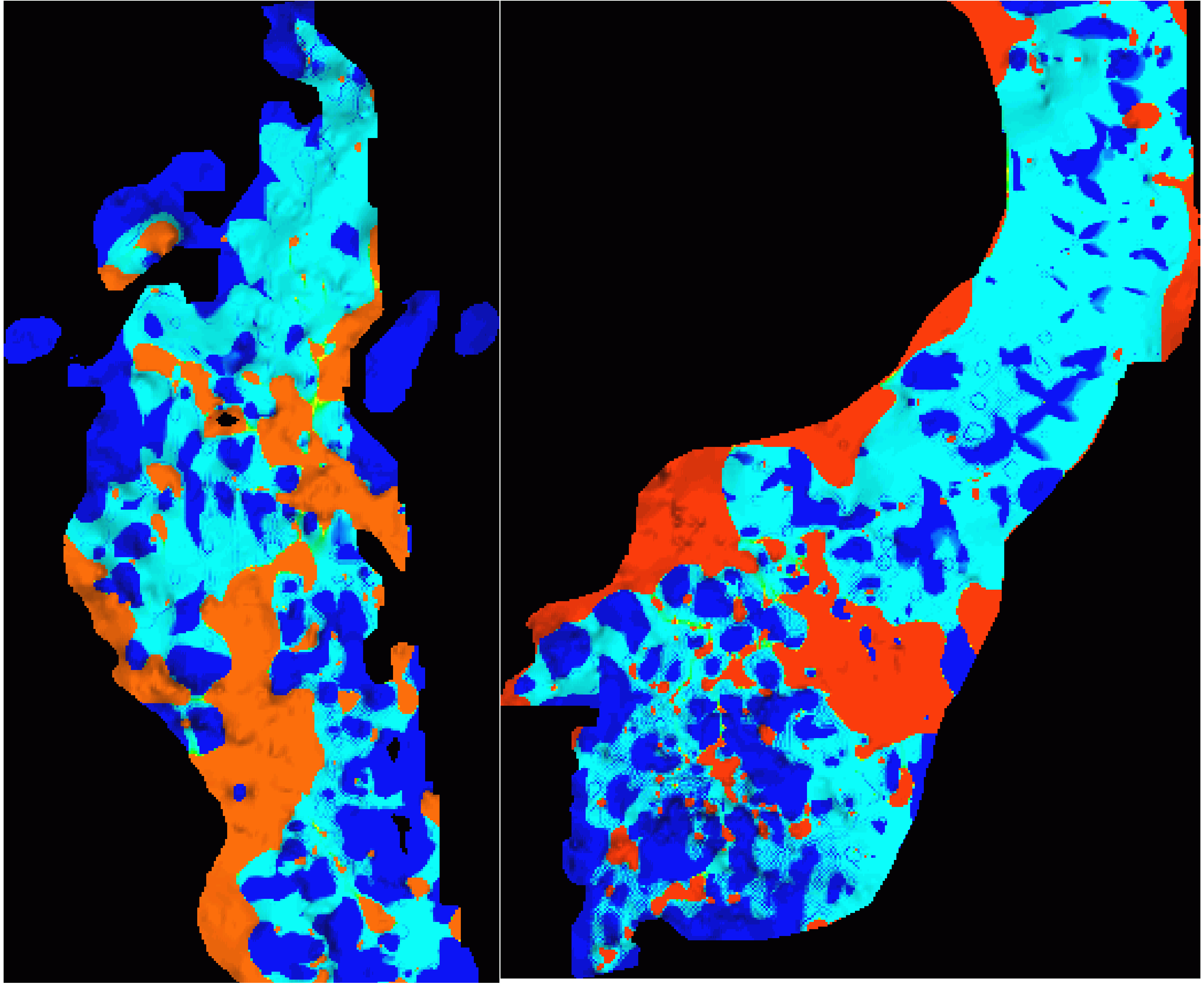

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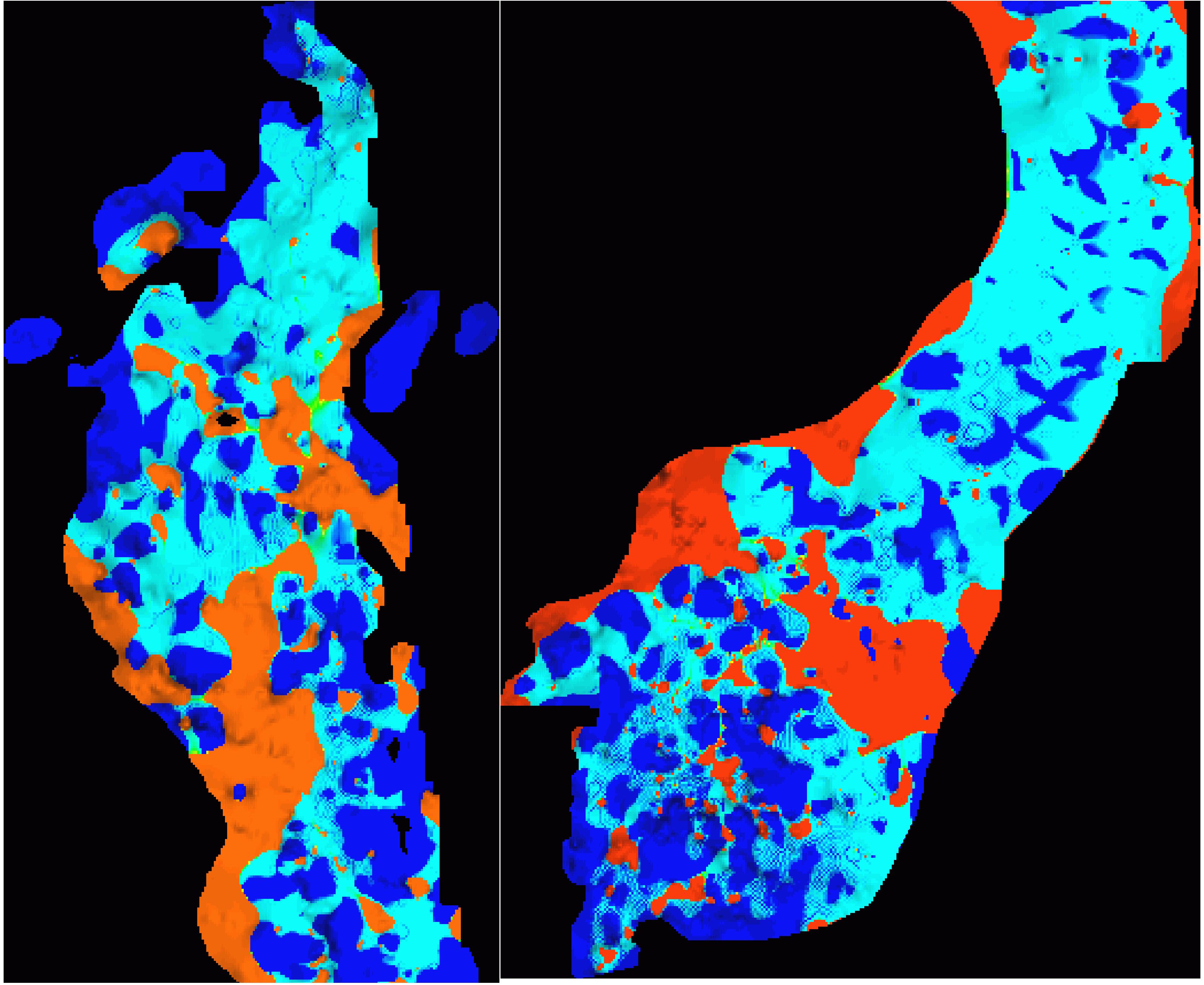

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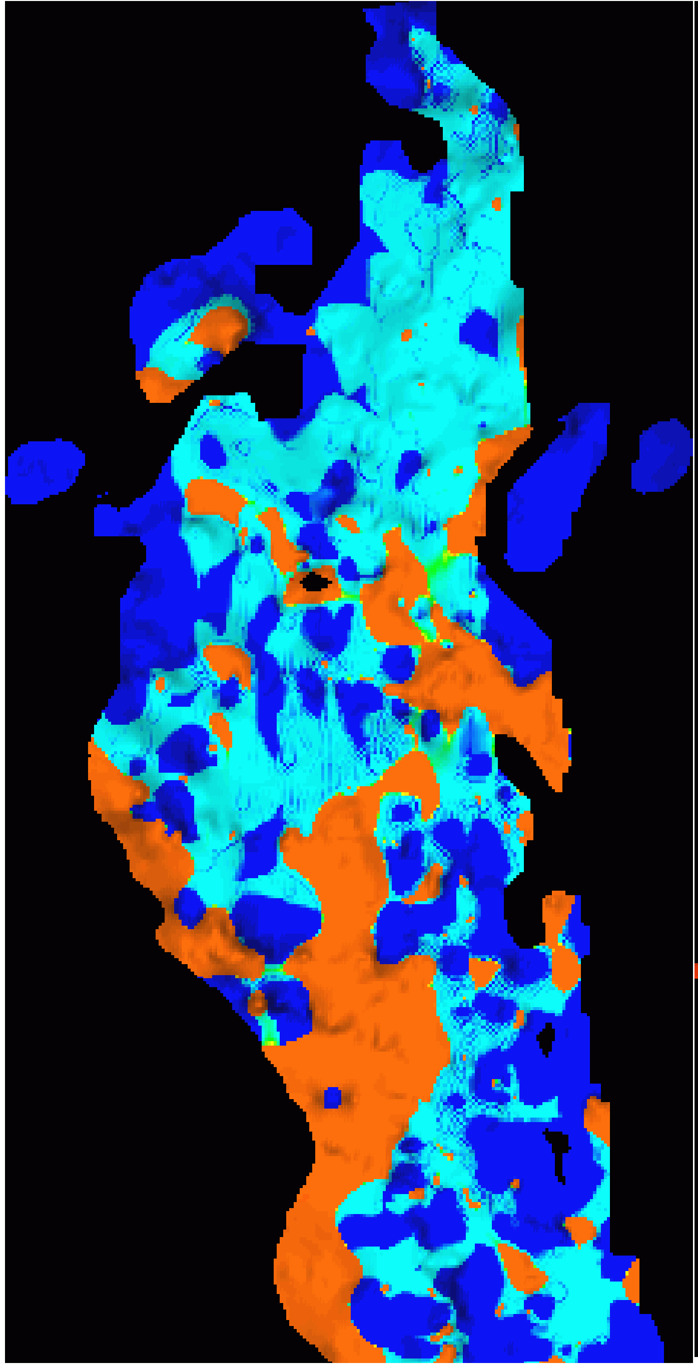

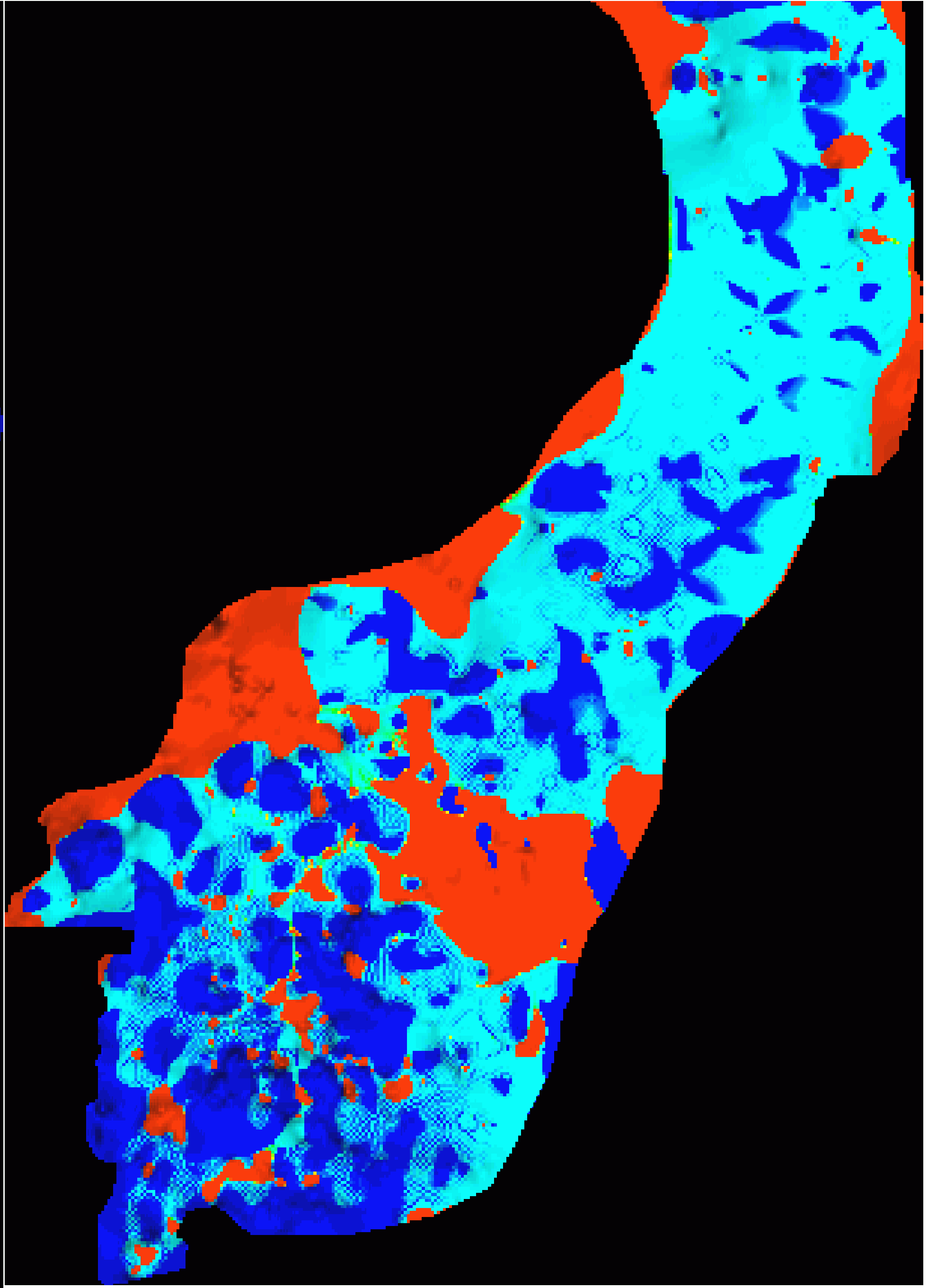

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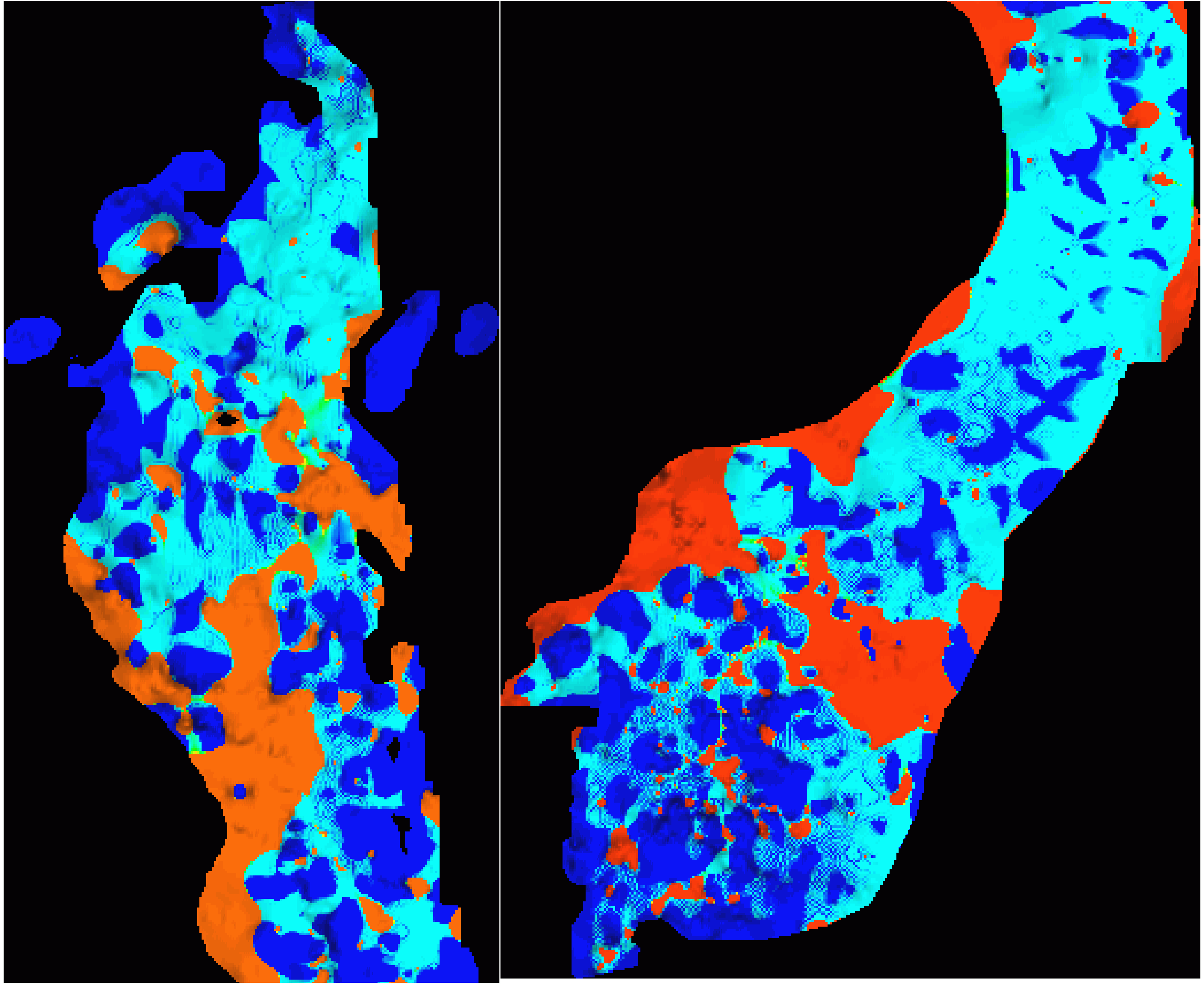

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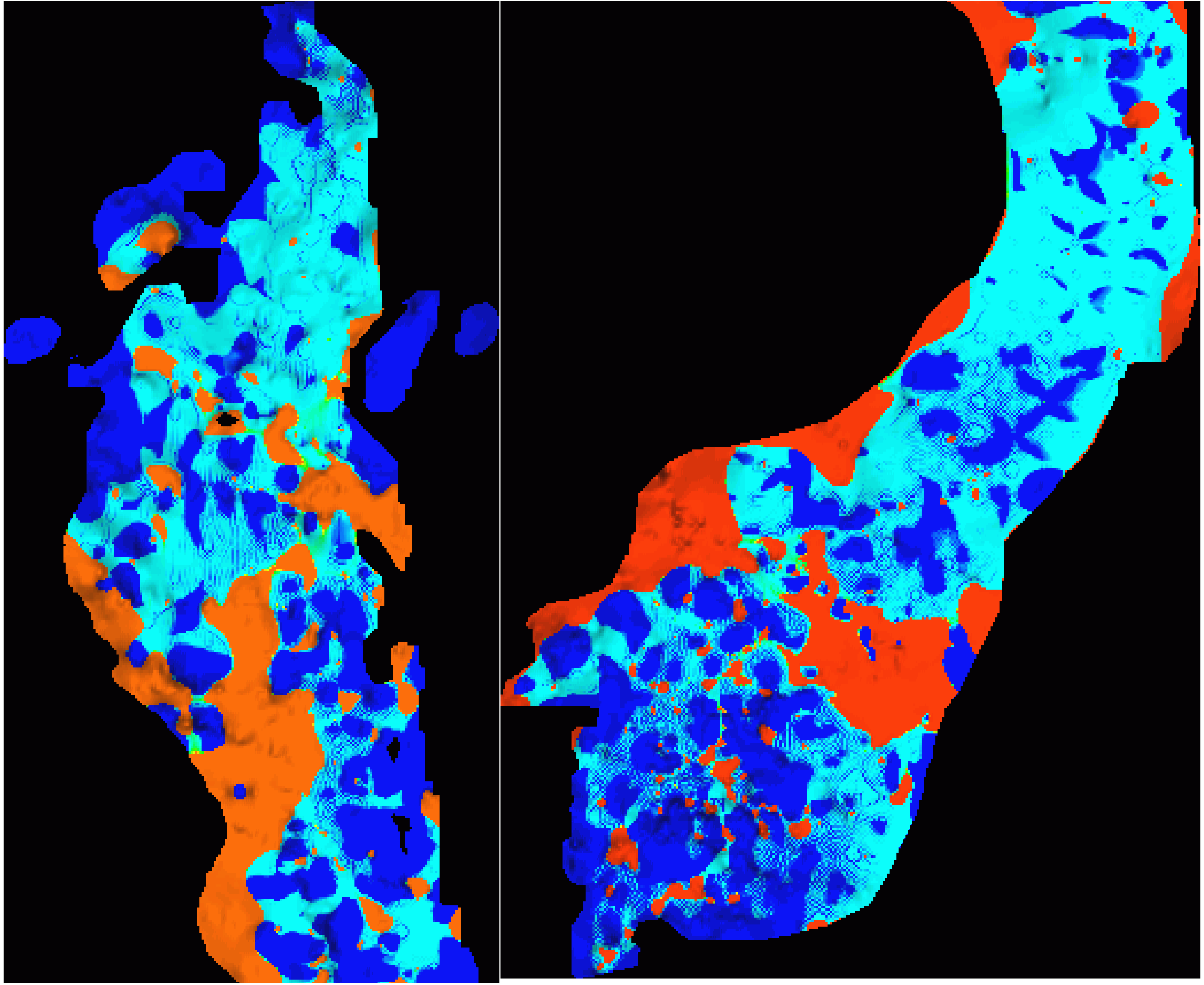

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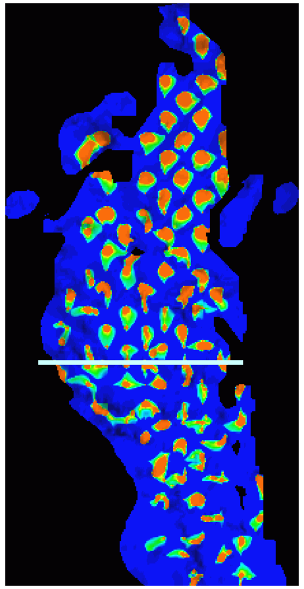
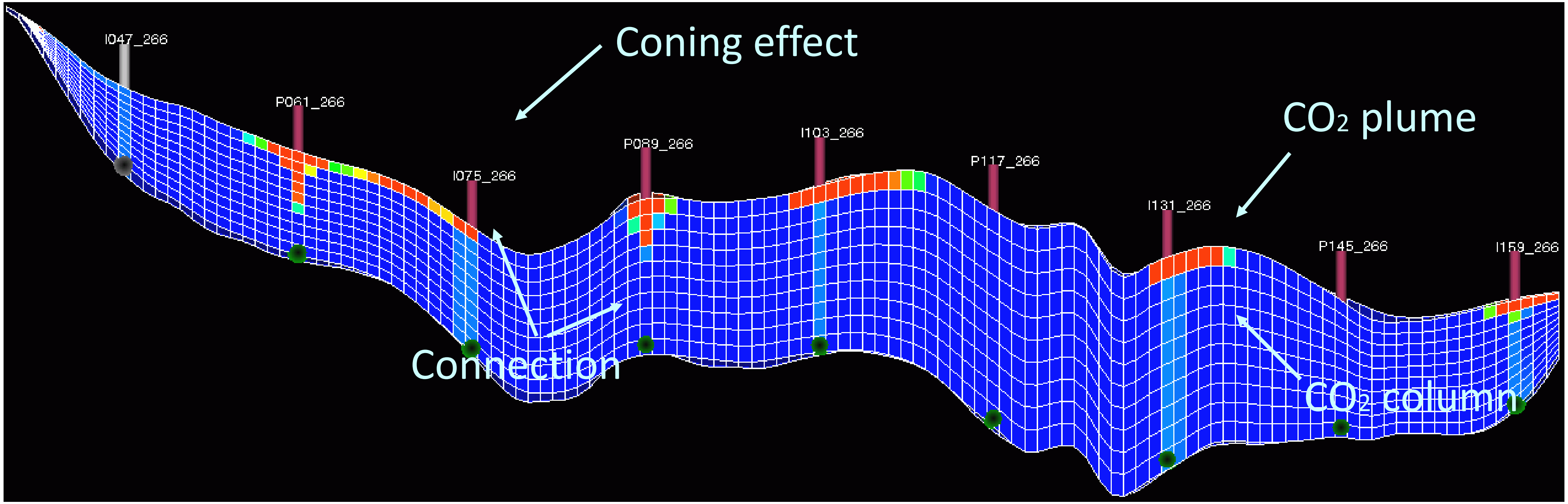
East-west profile illustrating the major challenge: gas coning into water production wells





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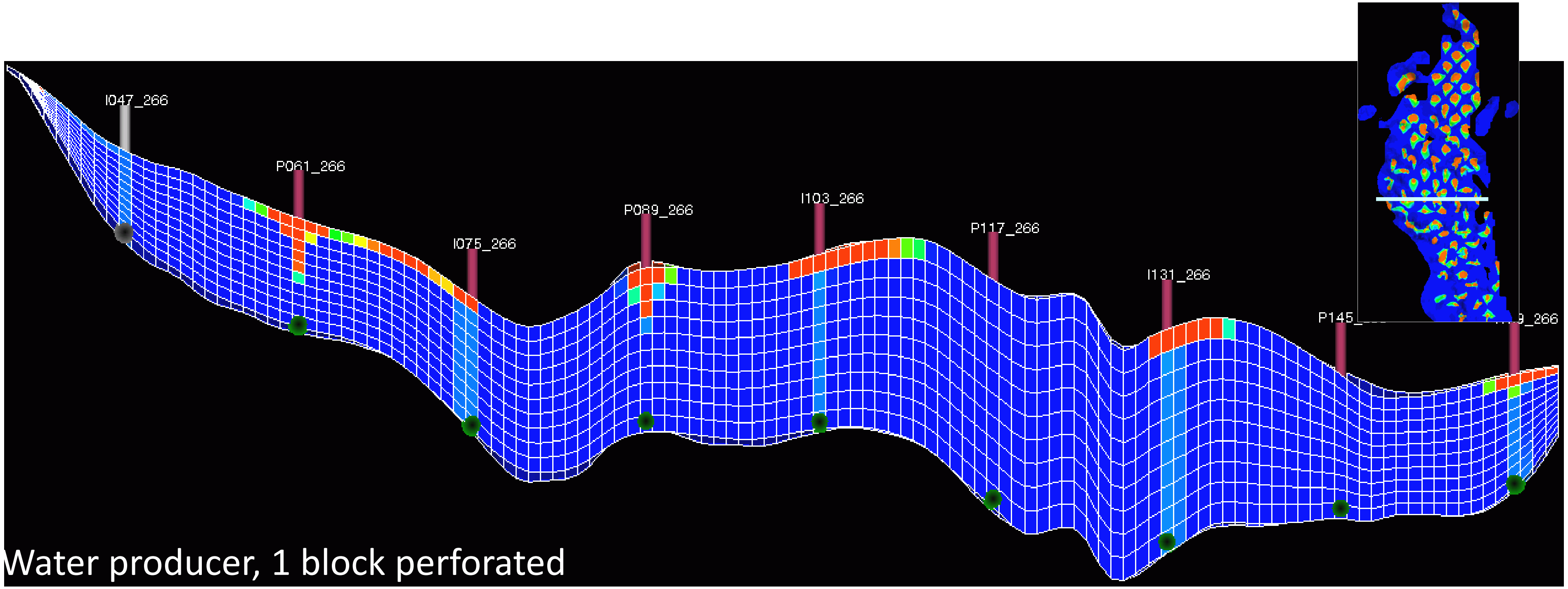
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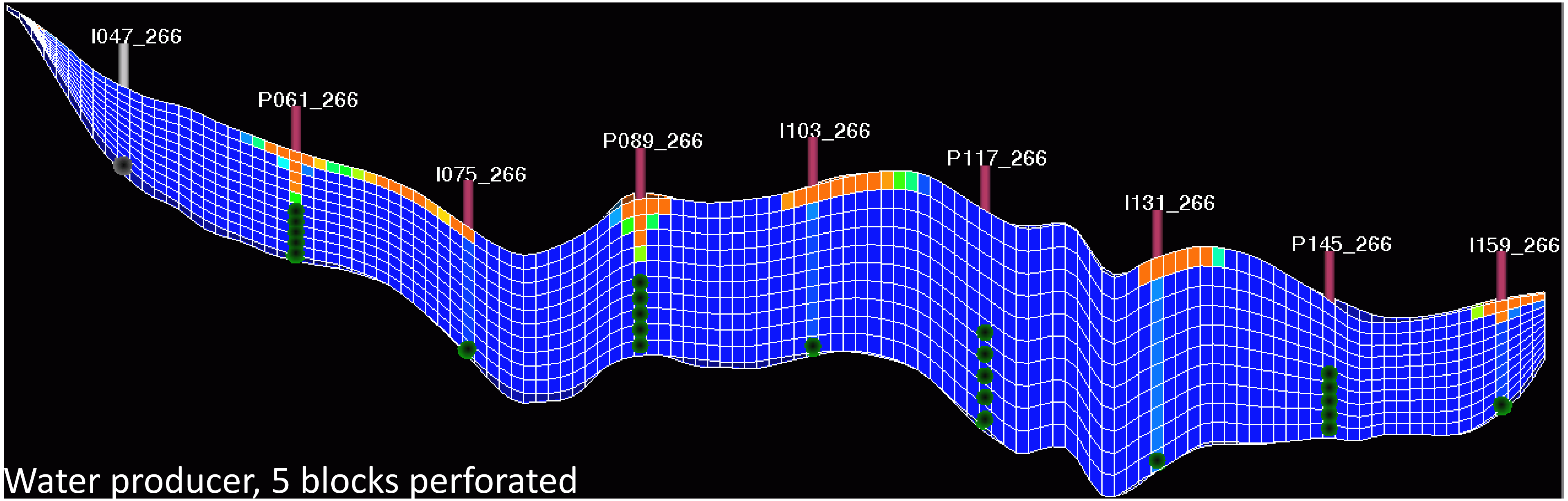
_266
Water producer, 1 block perforated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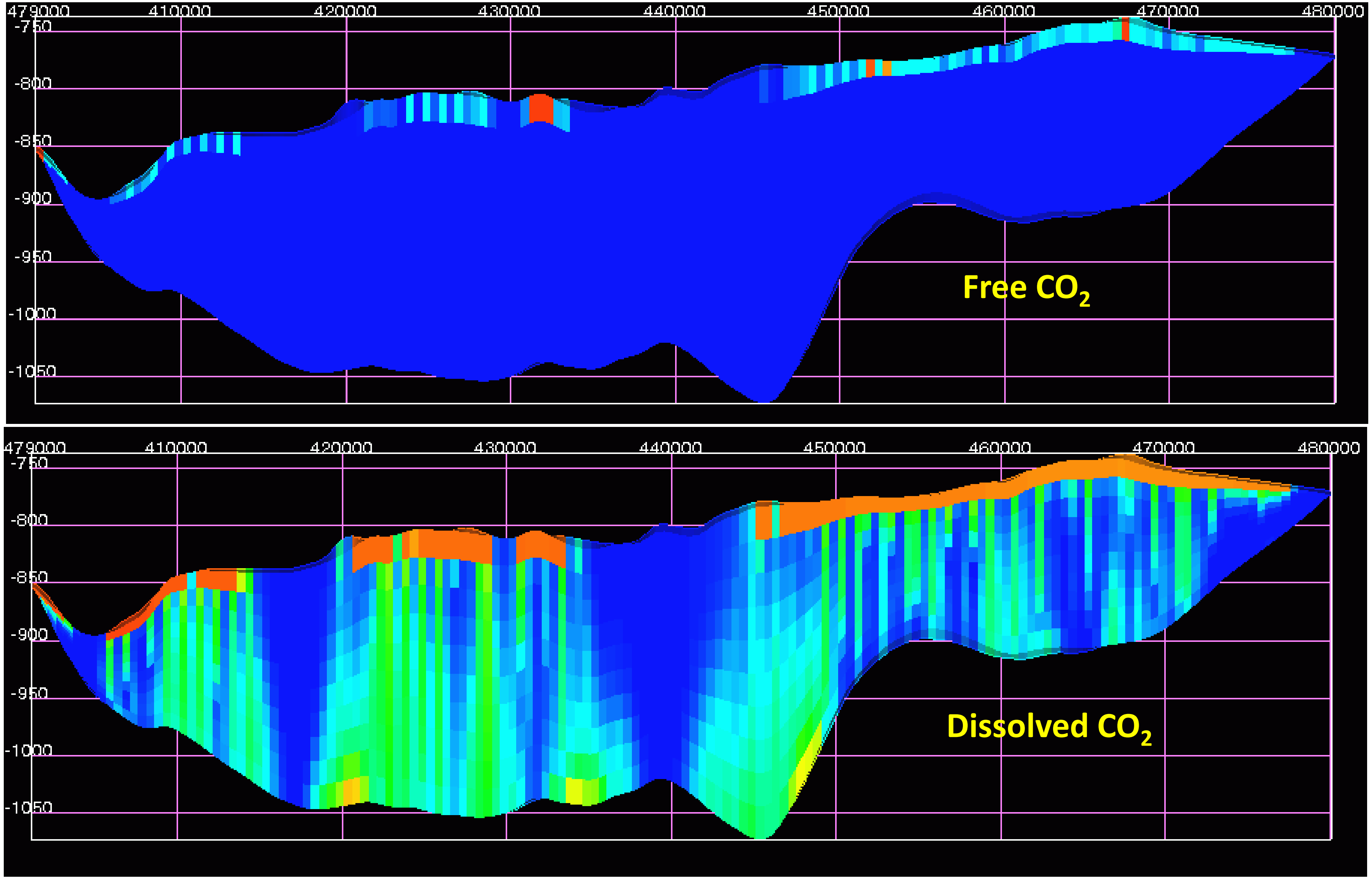
Water producer, 5 blocks perforated

Comparing a profile of free and dissolved after 5000 years: density driven convection



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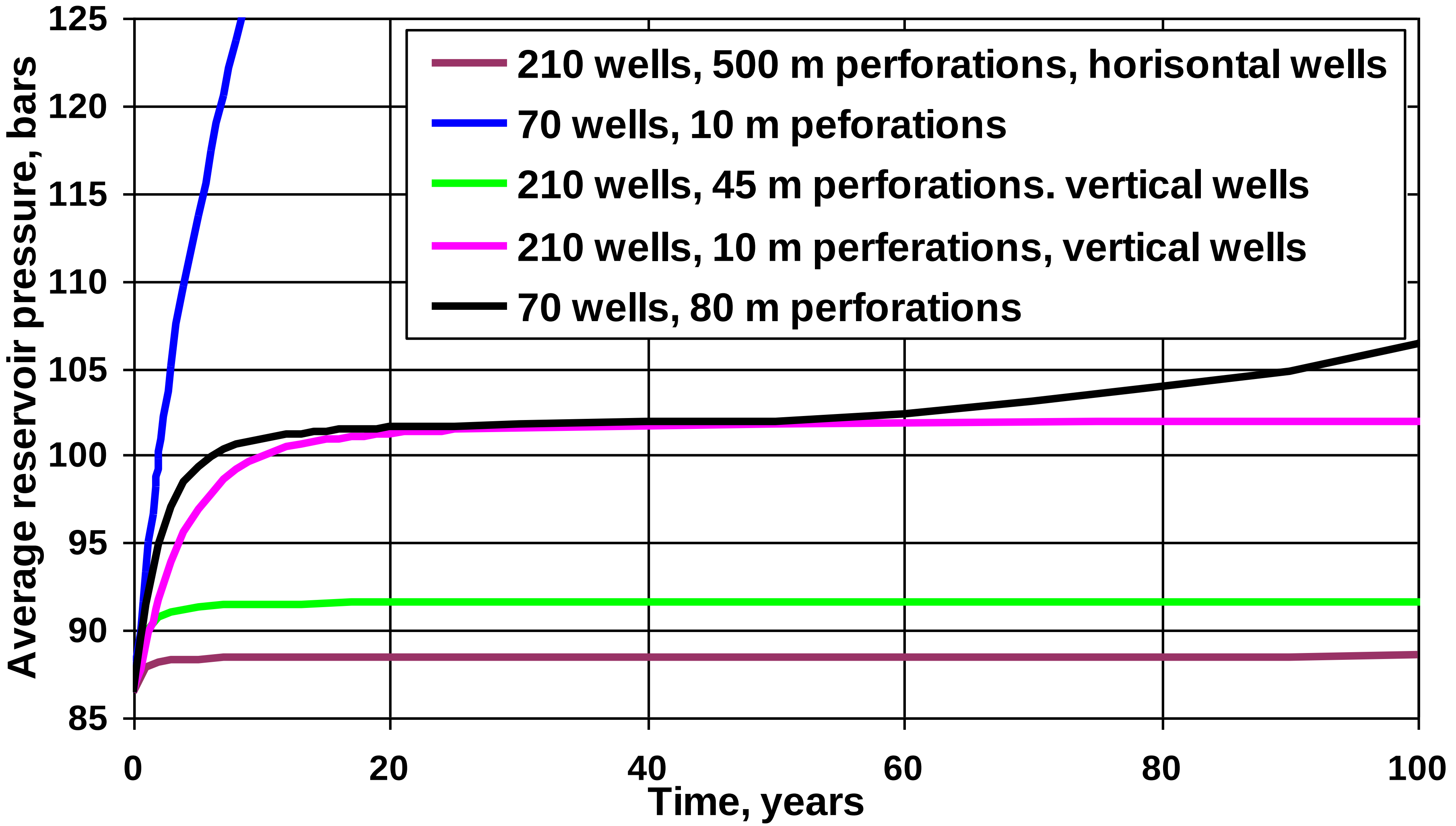
Number of water production wells and their performance



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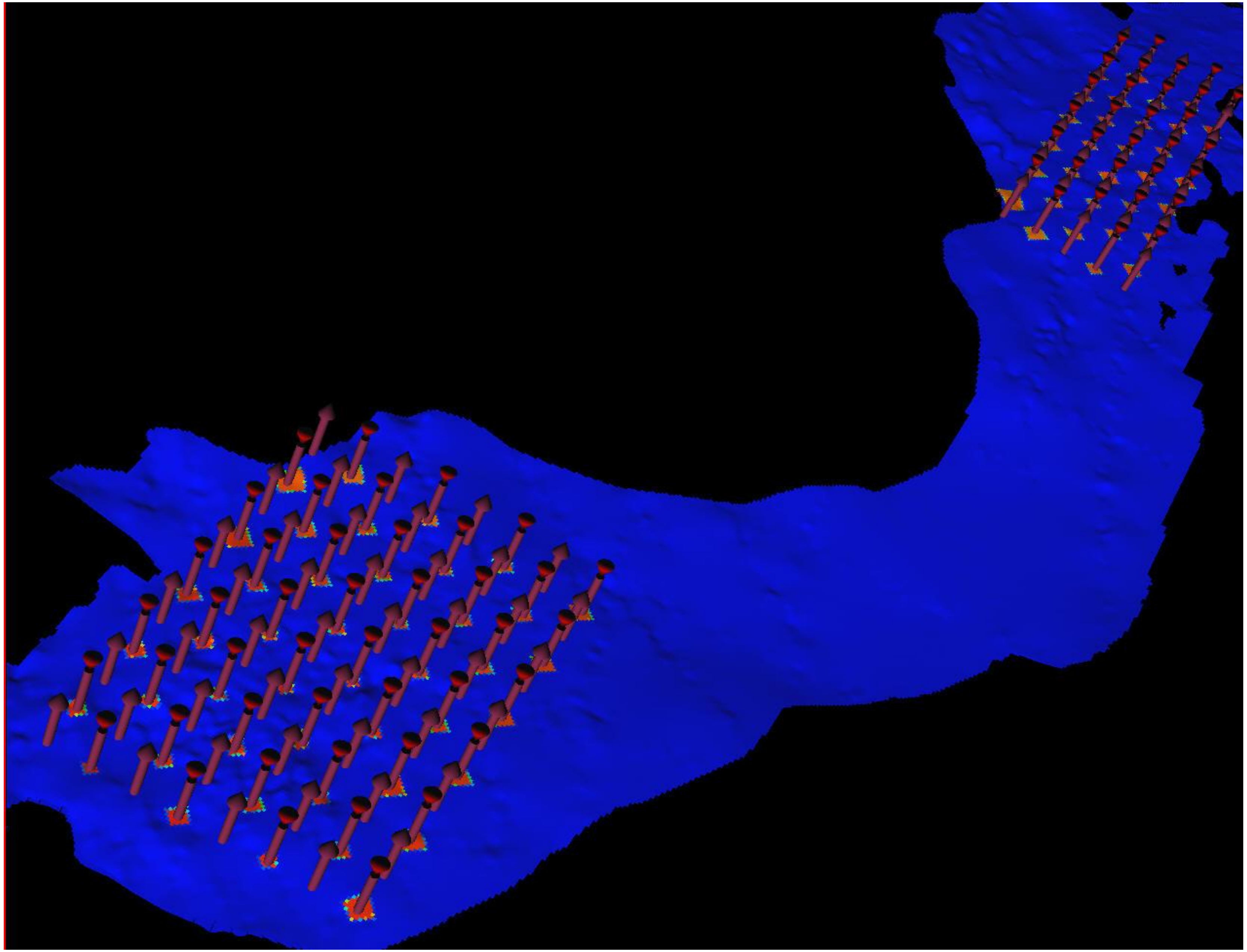
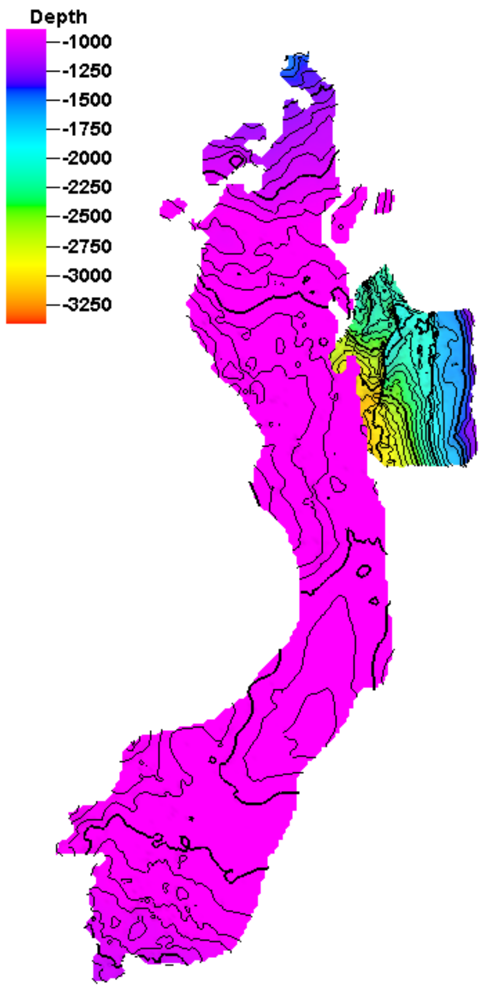
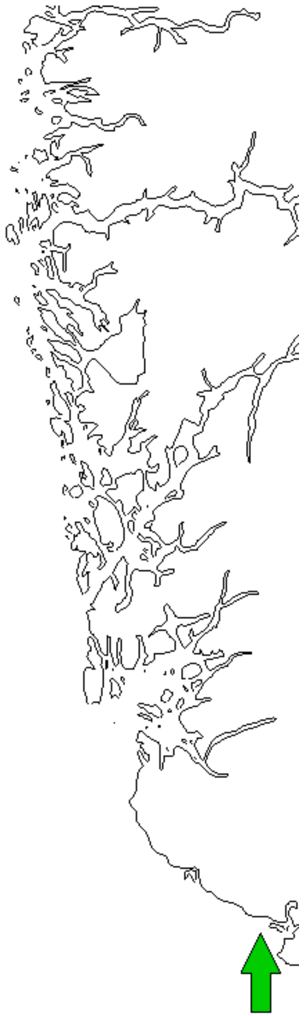
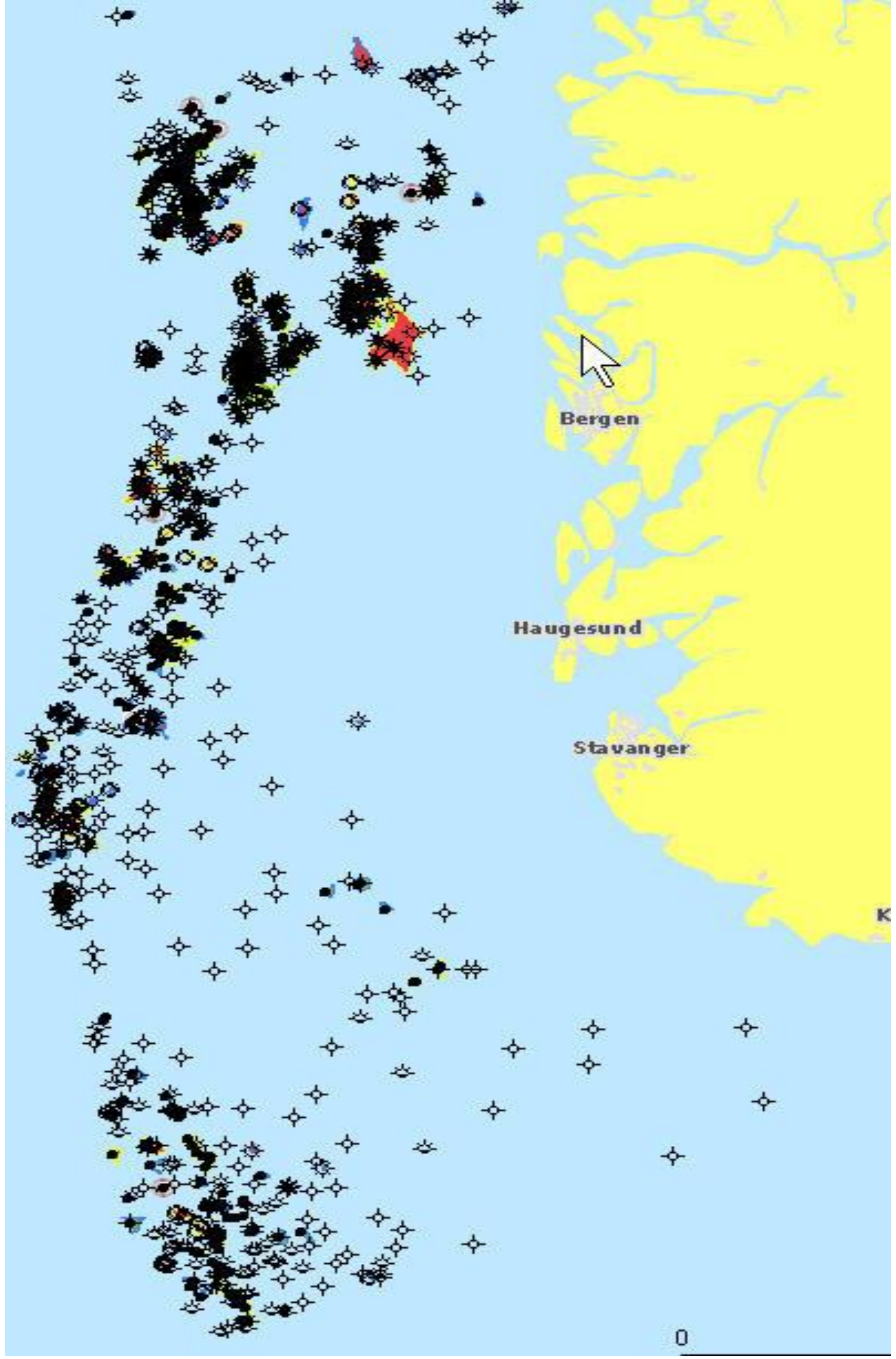
No real optimisation, *e.g.* only utilising the thickest era could reduce the number of wells









Formations without wells?

Monitoring and remediation

- 40 Gtonne CO_2 stored during 300 years corresponds to approximately 15% of all CO_2 from power production in EU for the same period of time
- 40 Gtonne CO_2 stored represents a value of 823 billon USD with the present EU CO_2 quota price (20.6 USD/tonne CO_2) in the emission trading system.
- The CO_2 emission penalty has to be at least 50 USD/tonne and in this case the stored CO_2 would represent a value of 2000 billion USD
- The project could therefore afford monitoring and well remediating program at leat during the injection period.

Consequences

- Is this exercise not only a worst case scenario because the Utsira formation is probably in pressure communication with other pressure units, and therefore not so many water production wells would be needed?
- No, each project must manage the pressure so that neighbouring storage resources (other pressure units, ref. to EC directive on storage) are not impaired
- In closed systems this means that for each project approximately the same volume of water in the formation must be produced as CO_2 volume being injected
- Offshore storage may have an advantage compared to onshore in getting emission permits for saline water. An emission permit for approximately 50 km^3 3 % brine into the North Sea will be needed

Compressibility storage

- Assuming the formation is a closure

$$\beta = -\frac{1}{V}\left(\frac{\partial V}{\partial p}\right)_T$$

$$\beta_{total} = \beta_{brine} + \beta_{pore\ volume}$$

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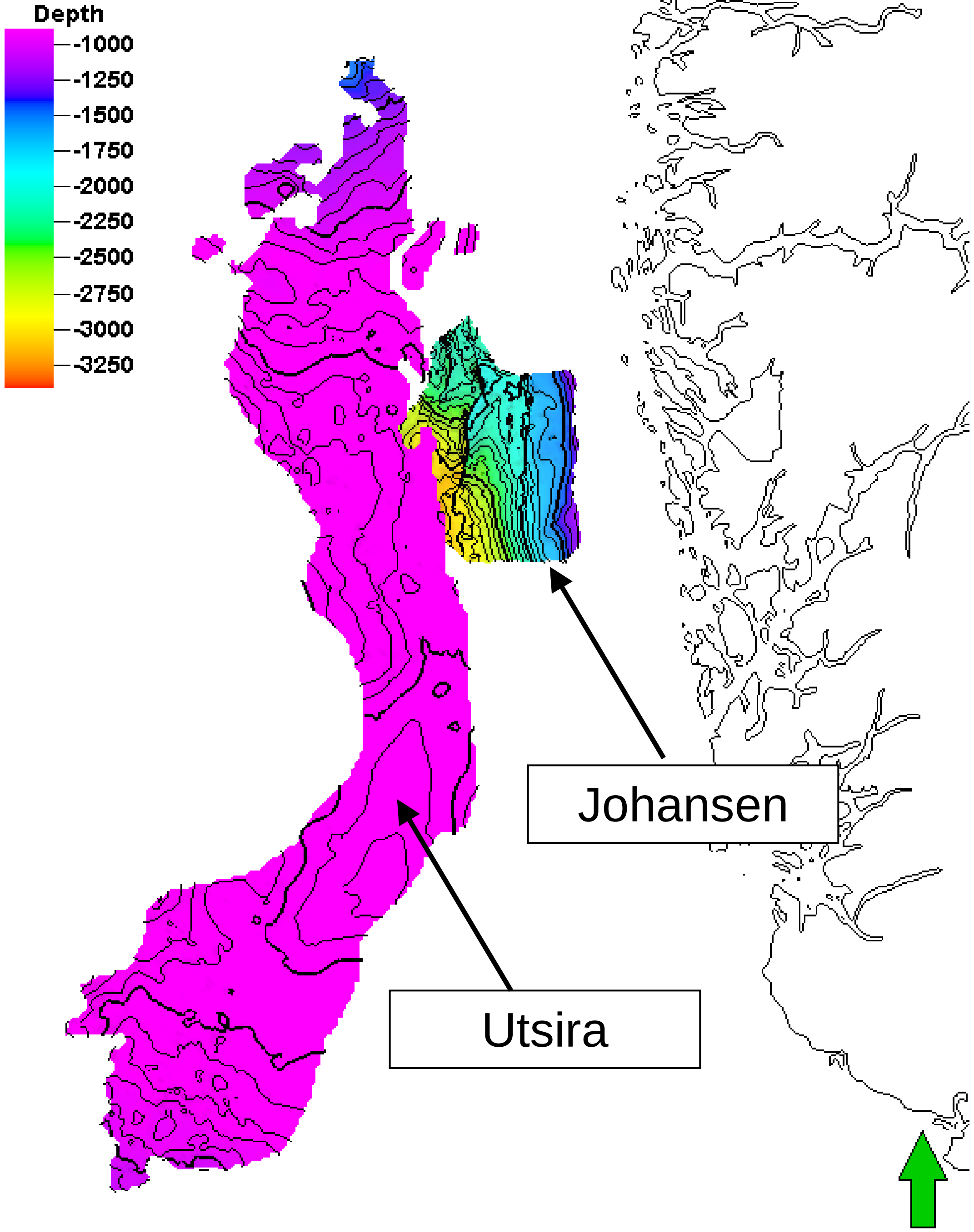
Compressibility storage



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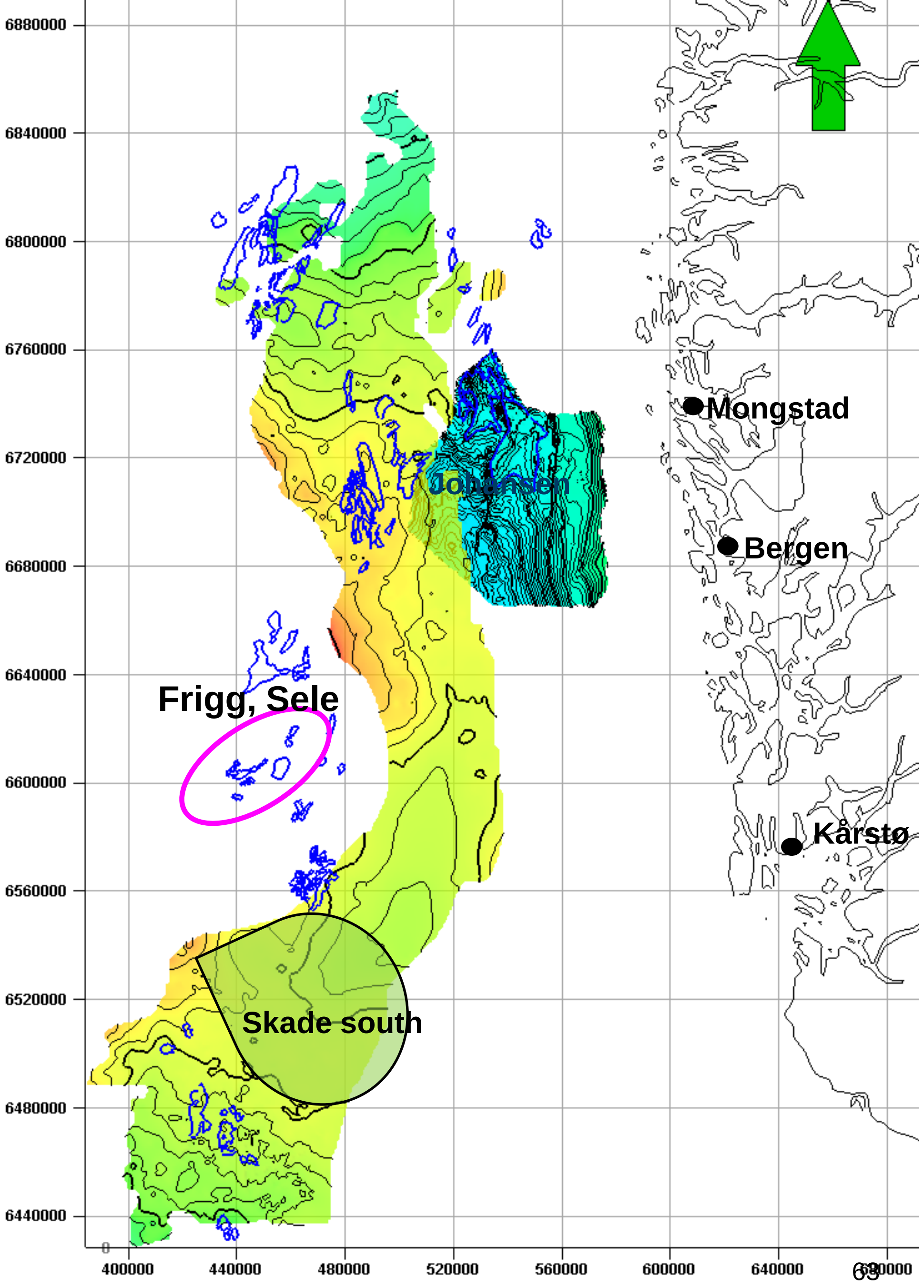
"Compressibility storage"

	Utsira	Johansen
Initial pressure under cap rock, bar	80	225
Rock compressibility, bar^{-1}	$4.50 \cdot 10^{-4}$	$1.00 \cdot 10^{-5}$
Brine compressibility, bar^{-1}	$4.36 \cdot 10^{-5}$	$4.74 \cdot 10^{-5}$
Total compressibility, bar^{-1}	$4.94 \cdot 10^{-4}$	$5.74 \cdot 10^{-5}$
Lithostatic pressure, bar	140	450
Storage - pressurize to Lithostatic pressure, %	2.96	1.29
Storage - pressurize to 0.8 · (Lithostatic pressure)	1.58	0.78

Selection mature of sites

- Skade formation below Utsira
- Sele formation below Frigg



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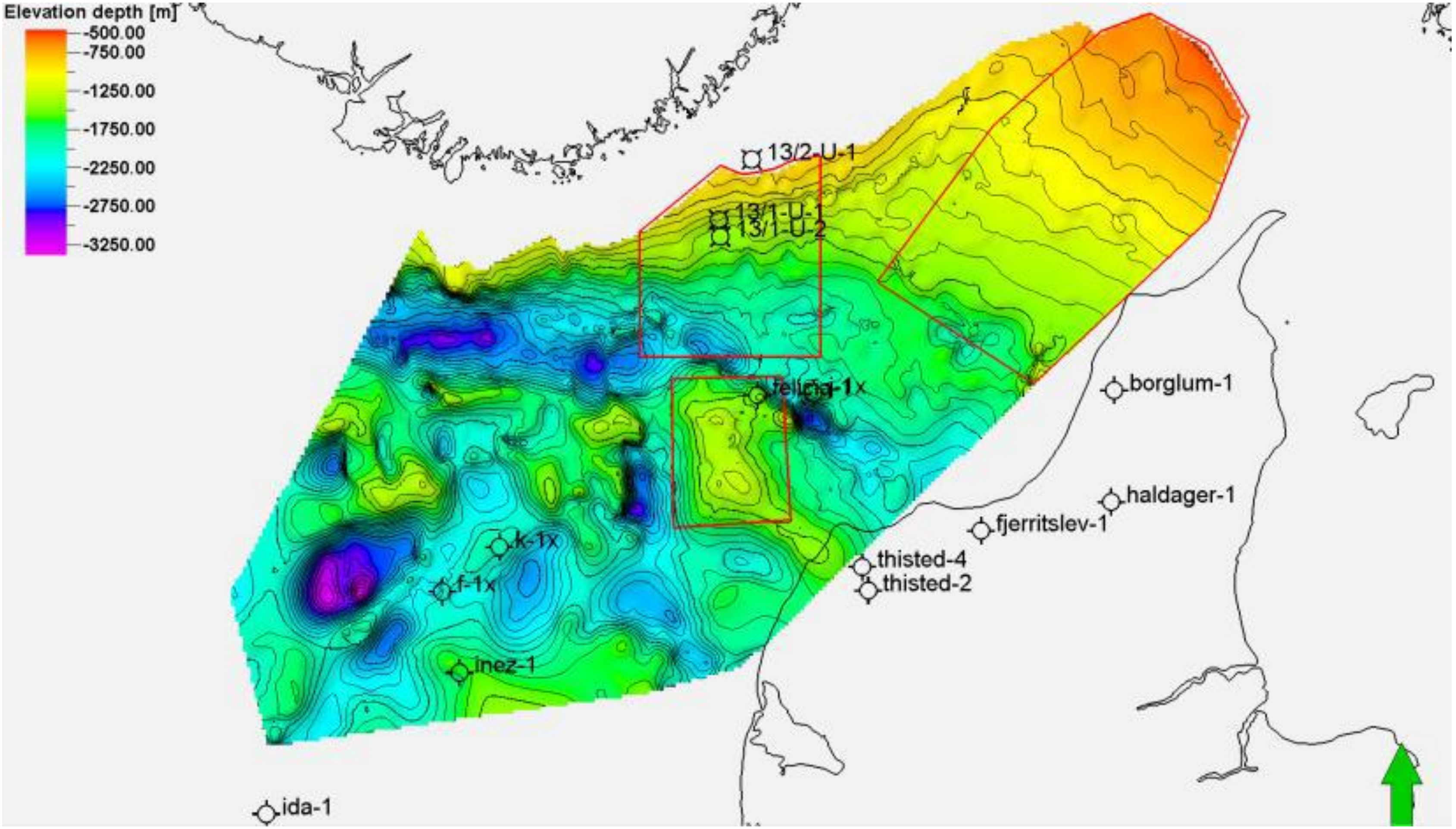
Gassum formation in the Skagerrak



What do we NOT need to study?

- Chemical reaction – will occur but due to the buffering in the residual water they will quickly stop
- Well cement – they are fine
- Core flooding of cores with brine with dissolved CO_2 – it is not a analogue to what will happen during storage
- Pipeline transportation – long record of successful transport
- Equation of state for CO_2 or CO_2-rich mixtures – GREG 2008 etc are sufficiently accurate
- Improved reservoir simulators. We have both commercial and academic simulators that can take care of the most of the physics inolved

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