

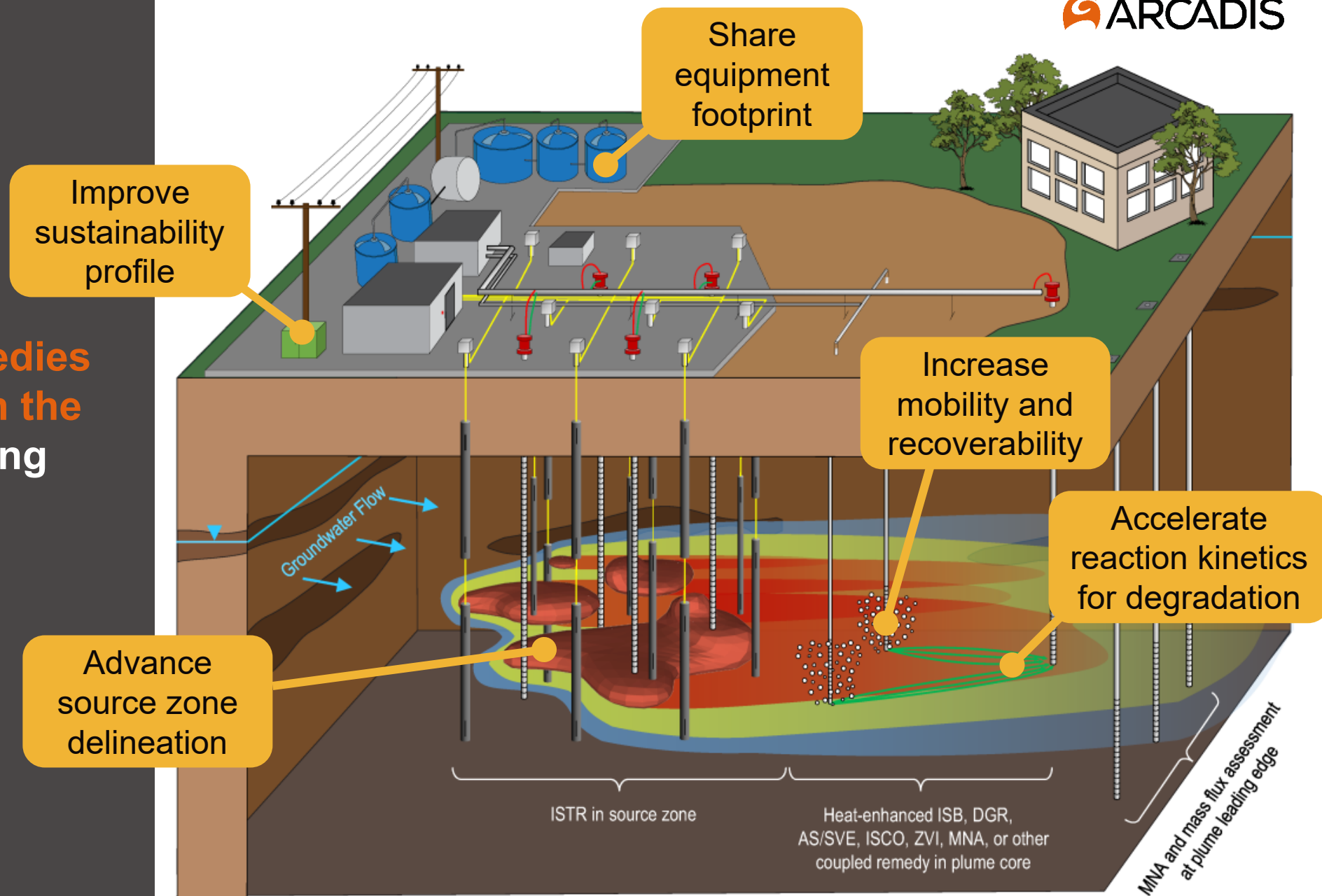
Battelle 2024 Chlorinated Conference

Playing the Long Game: **Predicting Heat Dissipation following In Situ Thermal Remediation to Enhance Degradation**

Paul Hegele, P.Eng.

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Heat-enhanced remedies coupled with ISTR in the source zone have long been proposed



Beneficial effects of heating are well-studied



Enhanced Biodegradation

Stimulate microbial growth and activity
(e.g., 10-35°C for dehalococcoides)



Release of Electron Donor

Mobilize DOC, H₂, and VFAs from soil
organic matter (e.g., > 45-90°C)



Hydrolysis Reactions

Substitution or elimination with H⁺ and OH⁻
(e.g., > 60°C for chlorinated ethanes)



Increased Dissolution

Mobilize VOCs made available for
physical recovery or degradation reactions



Increased Volatility

10- to 30-fold increase in Henry's Law
constant for physical recovery of VOCs



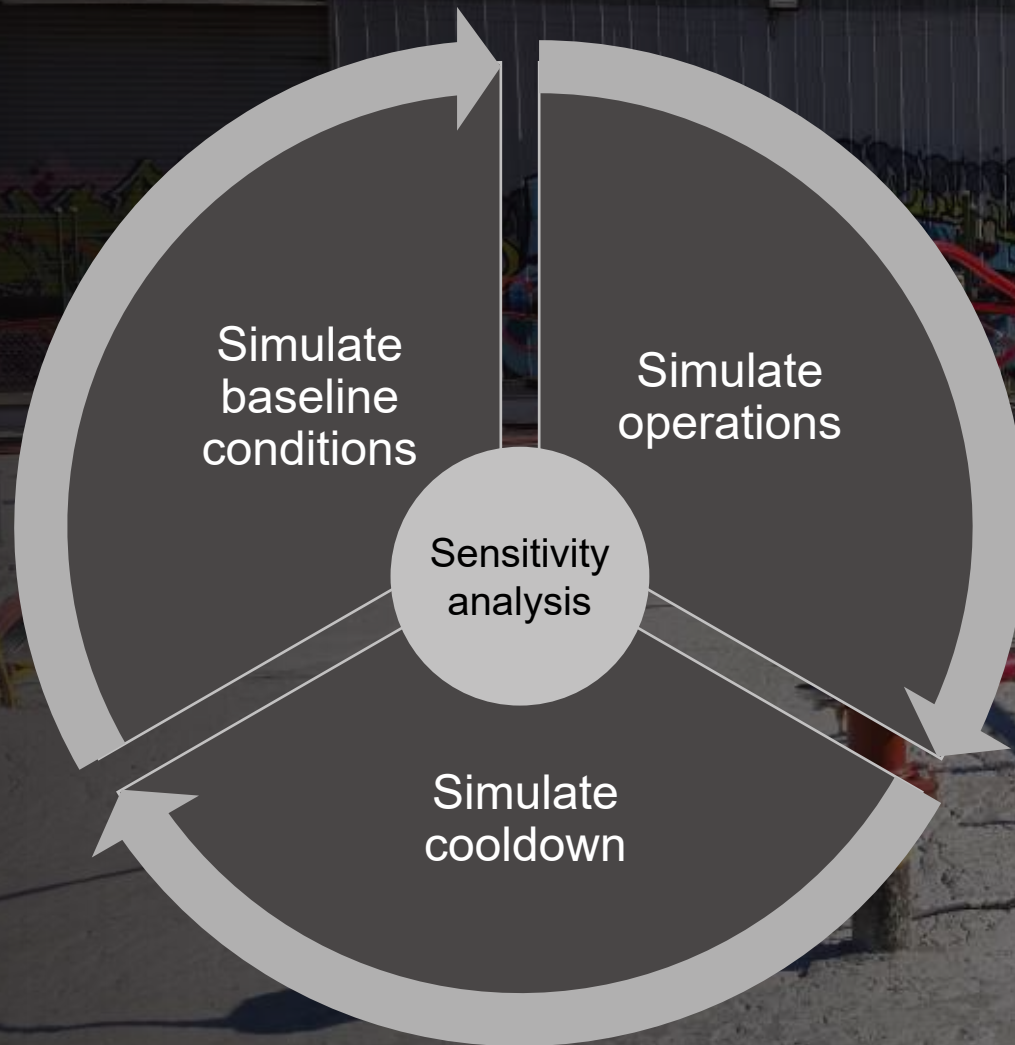
Improved Deliverability

Increased diffusion, dispersivity, and
reaction rates of injected amendments

How do temperatures evolve following ISTR in the source zone?

Relatively few feasibility studies or designs attempt to quantify how temperature can be leveraged for enhanced degradation

Cooldown patterns can be quantified using numerical methods



In this study, we explore the following cases:

1

- Silt unit with fixed properties

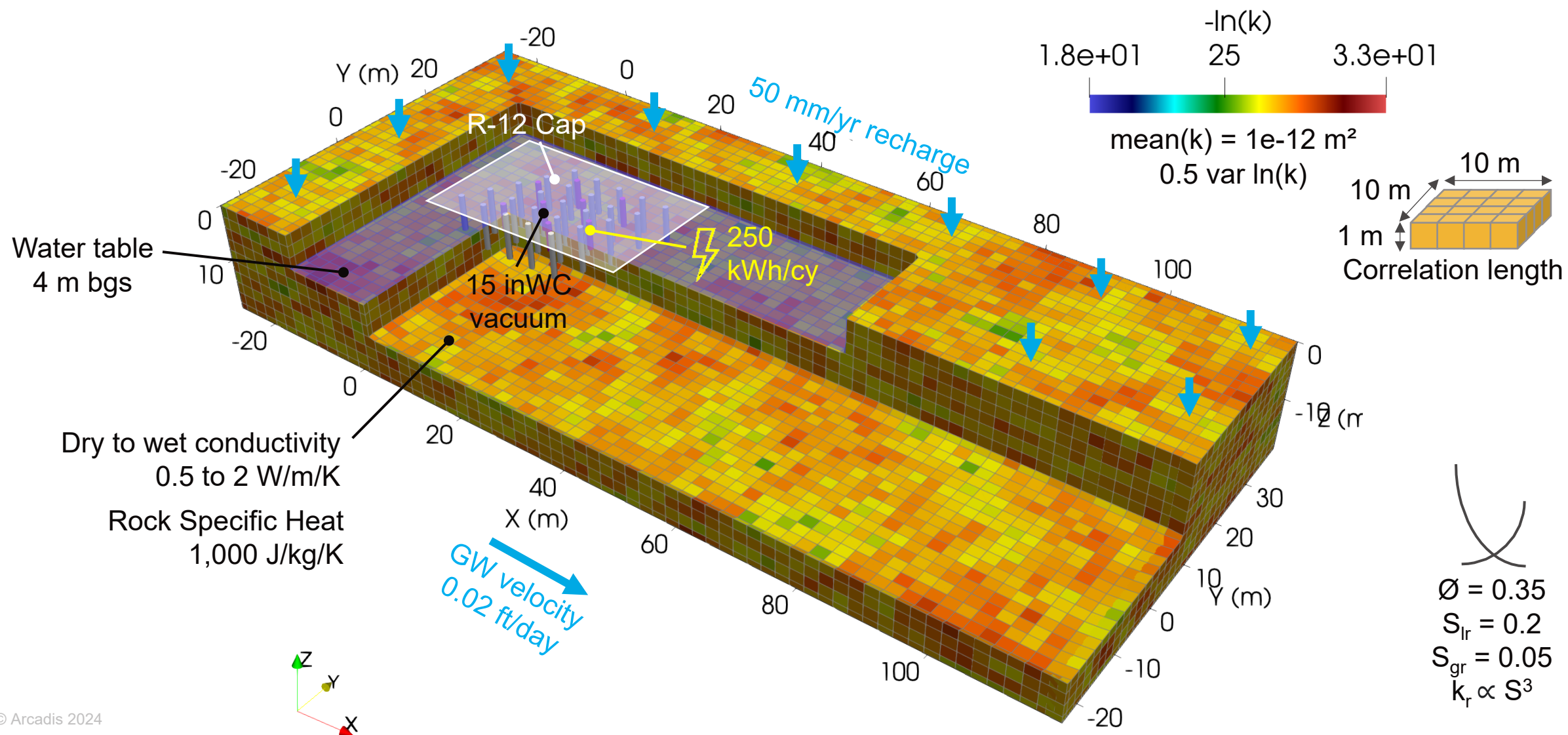
2

- Silt unit with variable properties

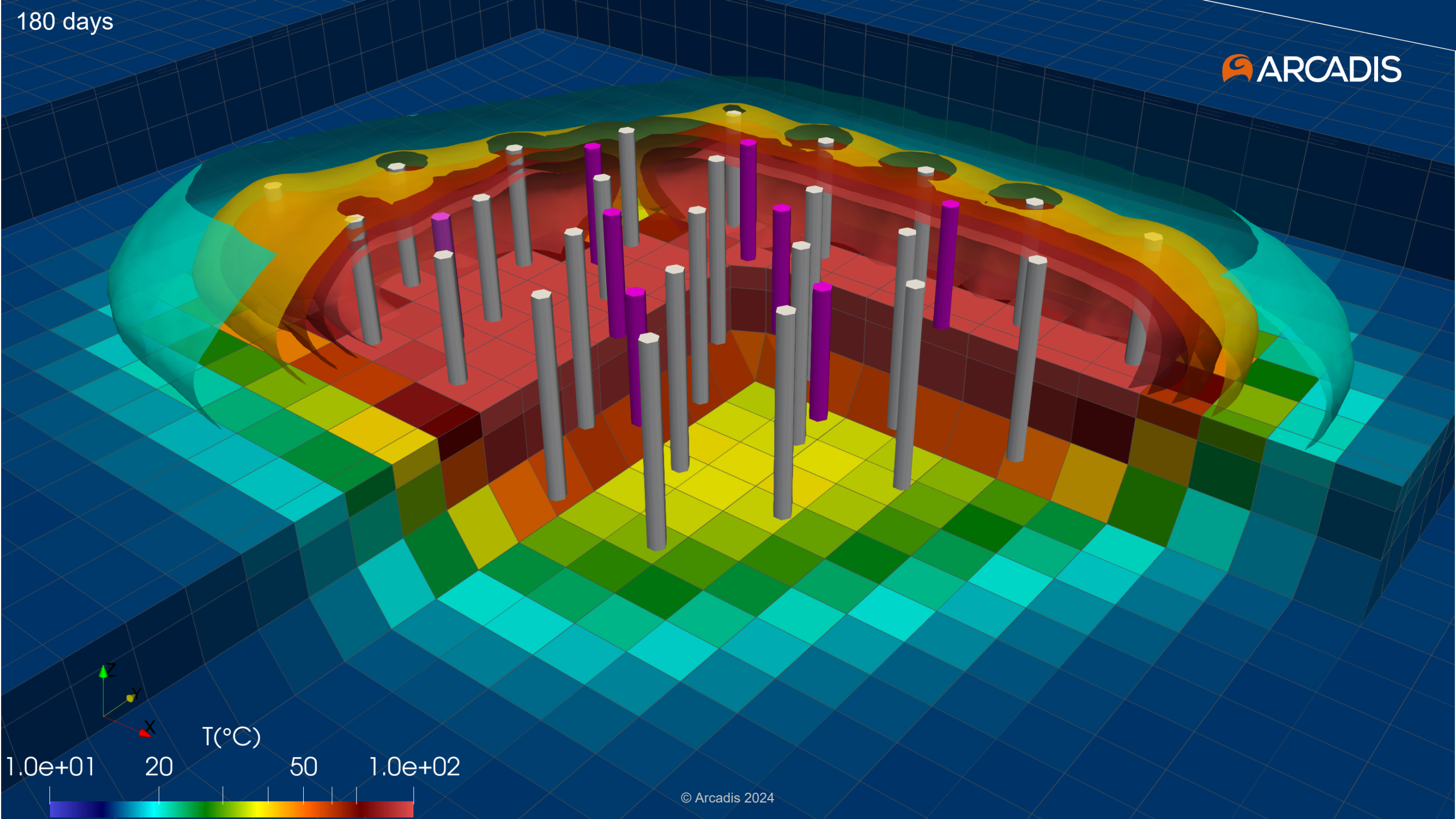
3

- Silt unit with underlying sand aquifer

Numerical Approach for Quantifying Heat Dissipation



180 days

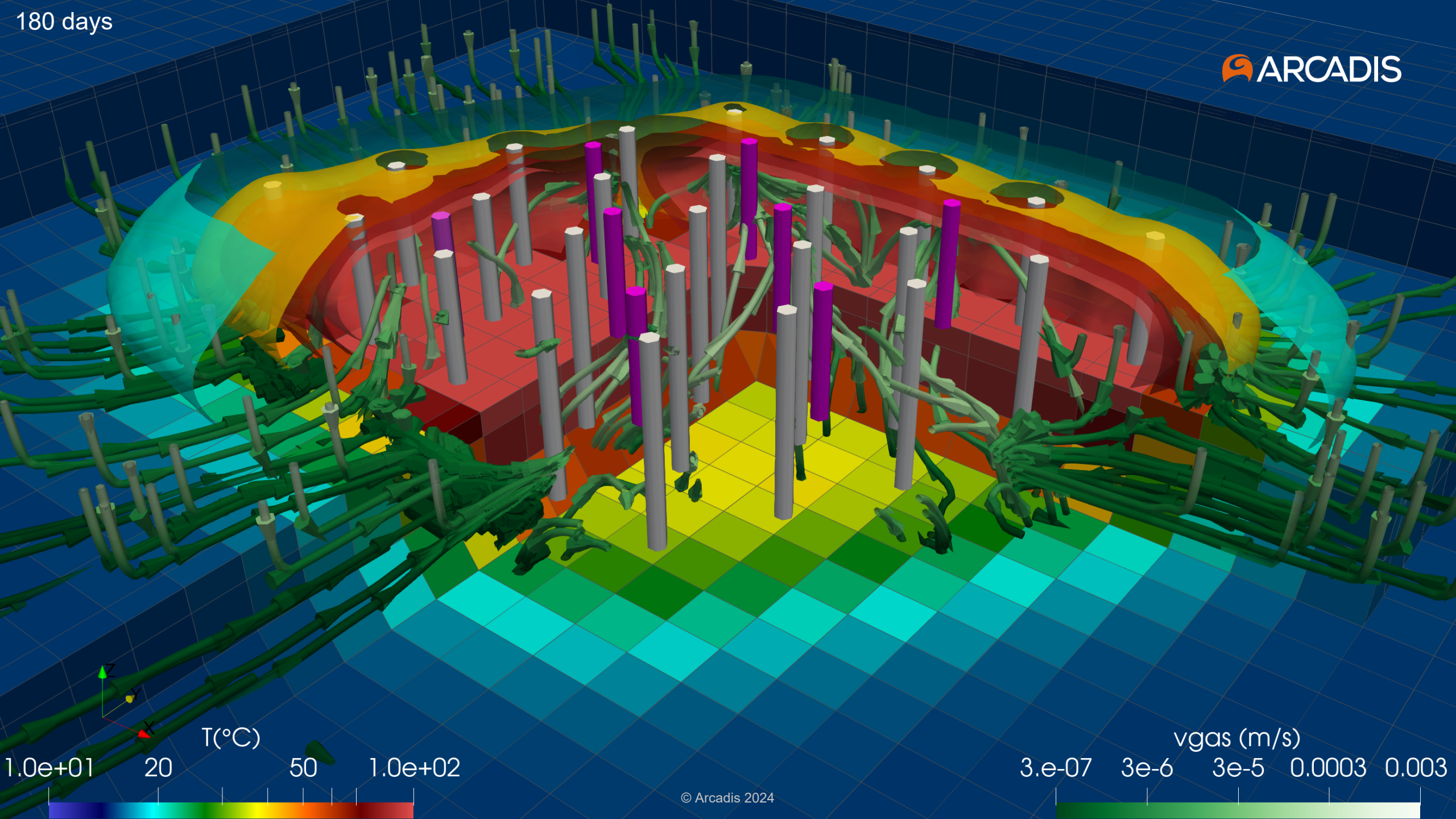


T(°C)

1.0e+01 20 50 1.0e+02



180 days



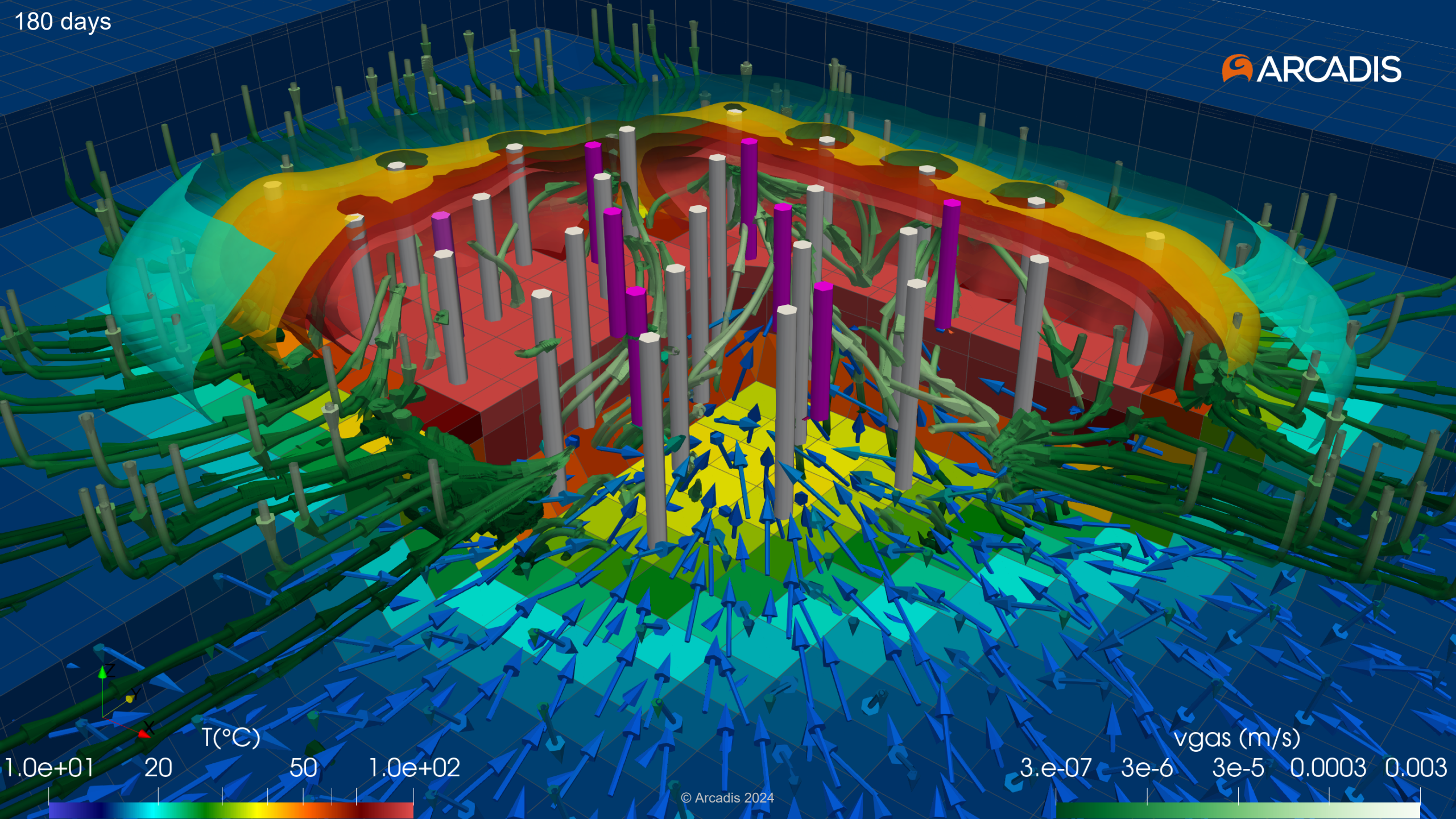
$T(^{\circ}C)$

1.0e+01 20 50 1.0e+02

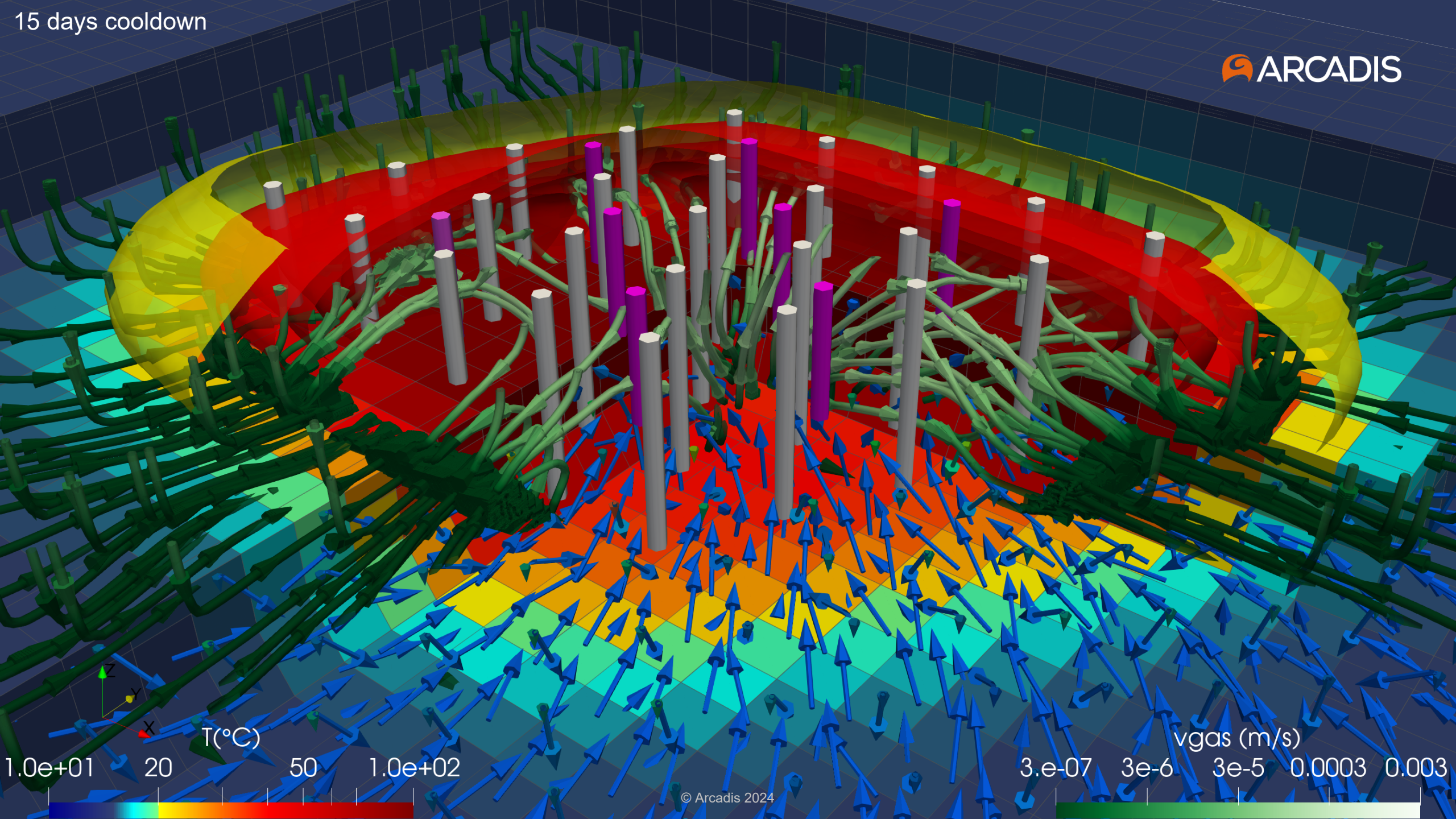
$v_{gas} (m/s)$

3.e-07 3e-6 3e-5 0.0003 0.003

180 days



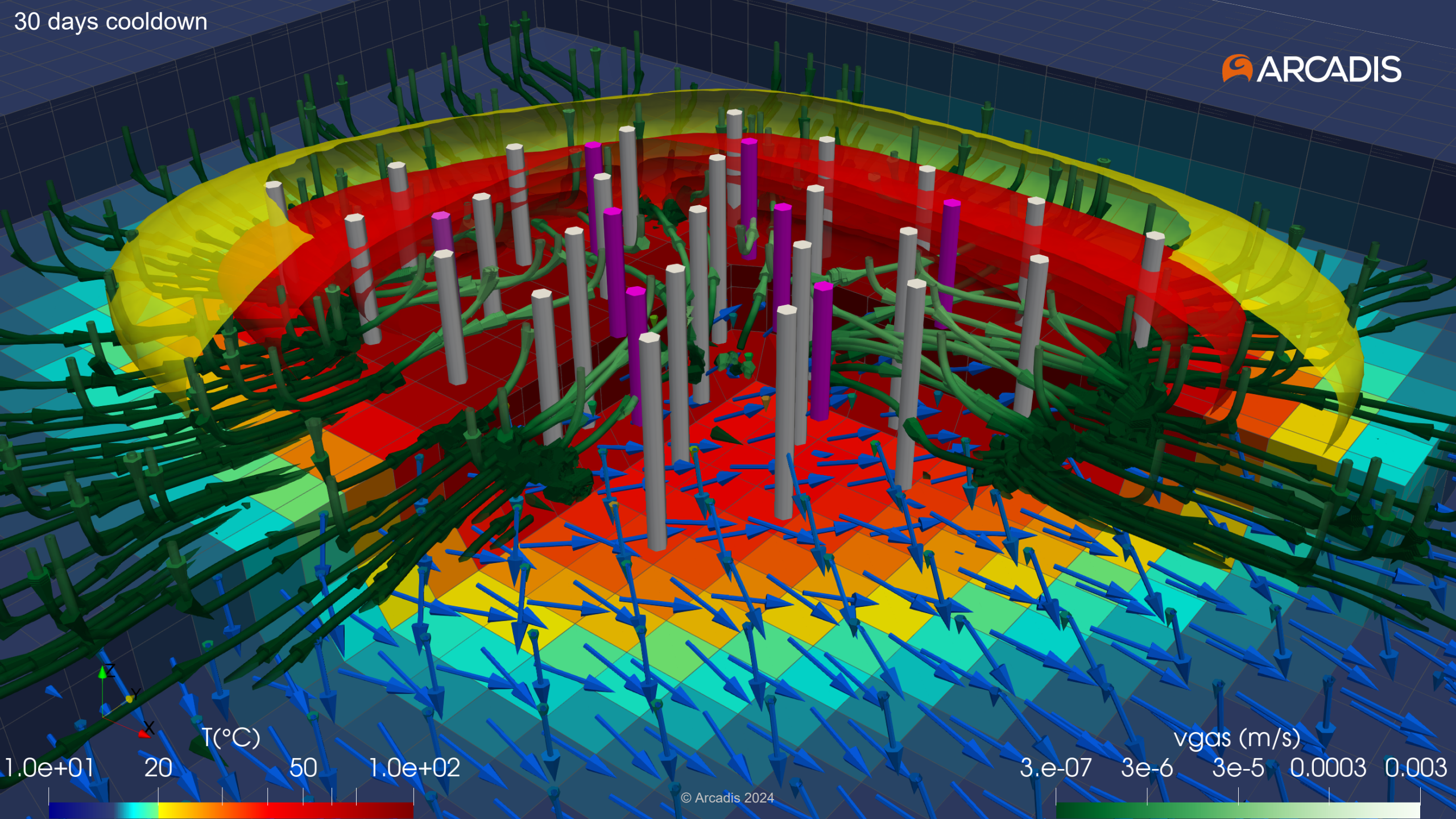
15 days cooldown



$T(^{\circ}C)$
1.0e+01 20 50 1.0e+02

$v_{gas} (m/s)$
3.e-07 3e-6 3e-5 0.0003 0.003

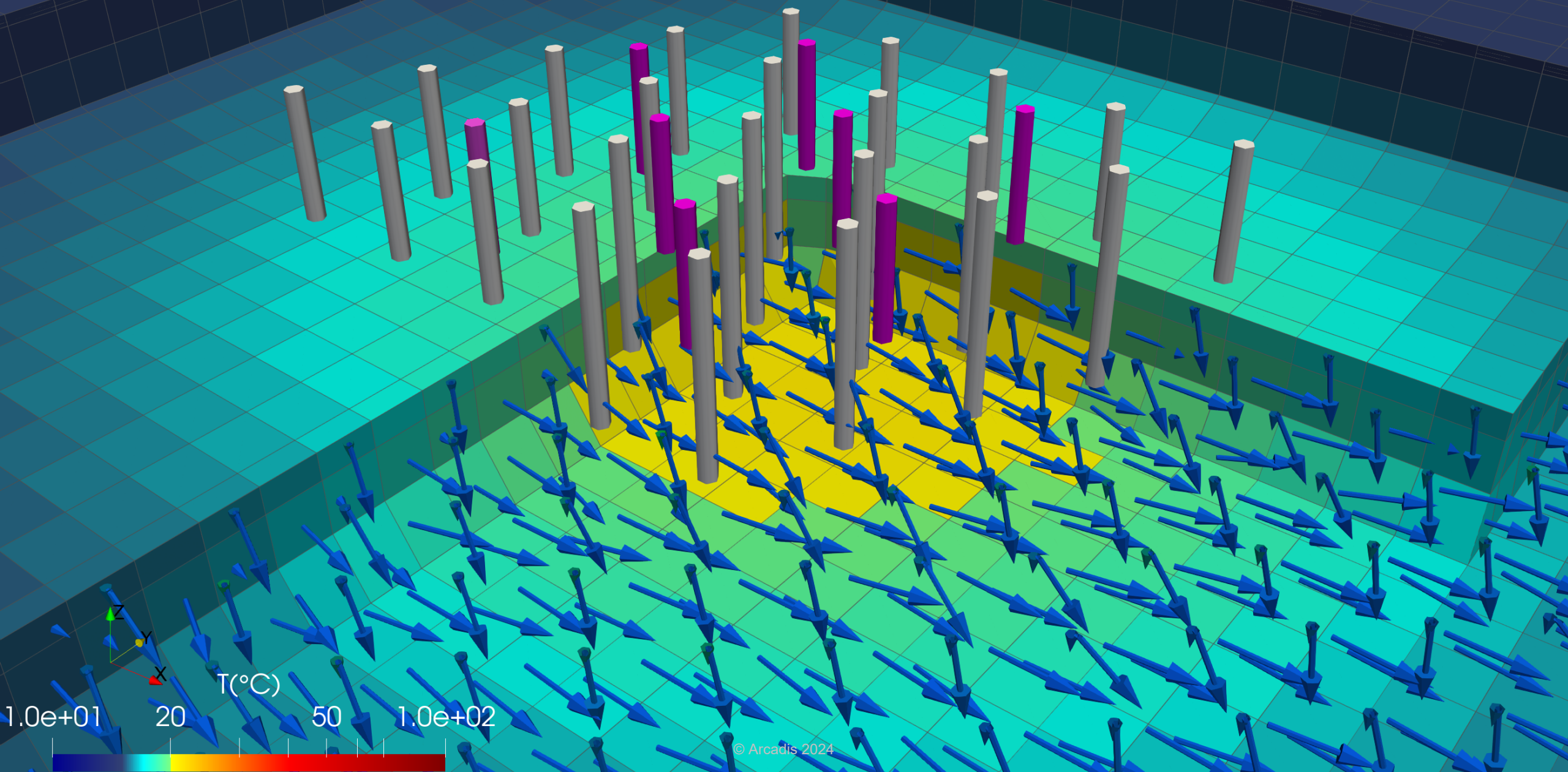
30 days cooldown



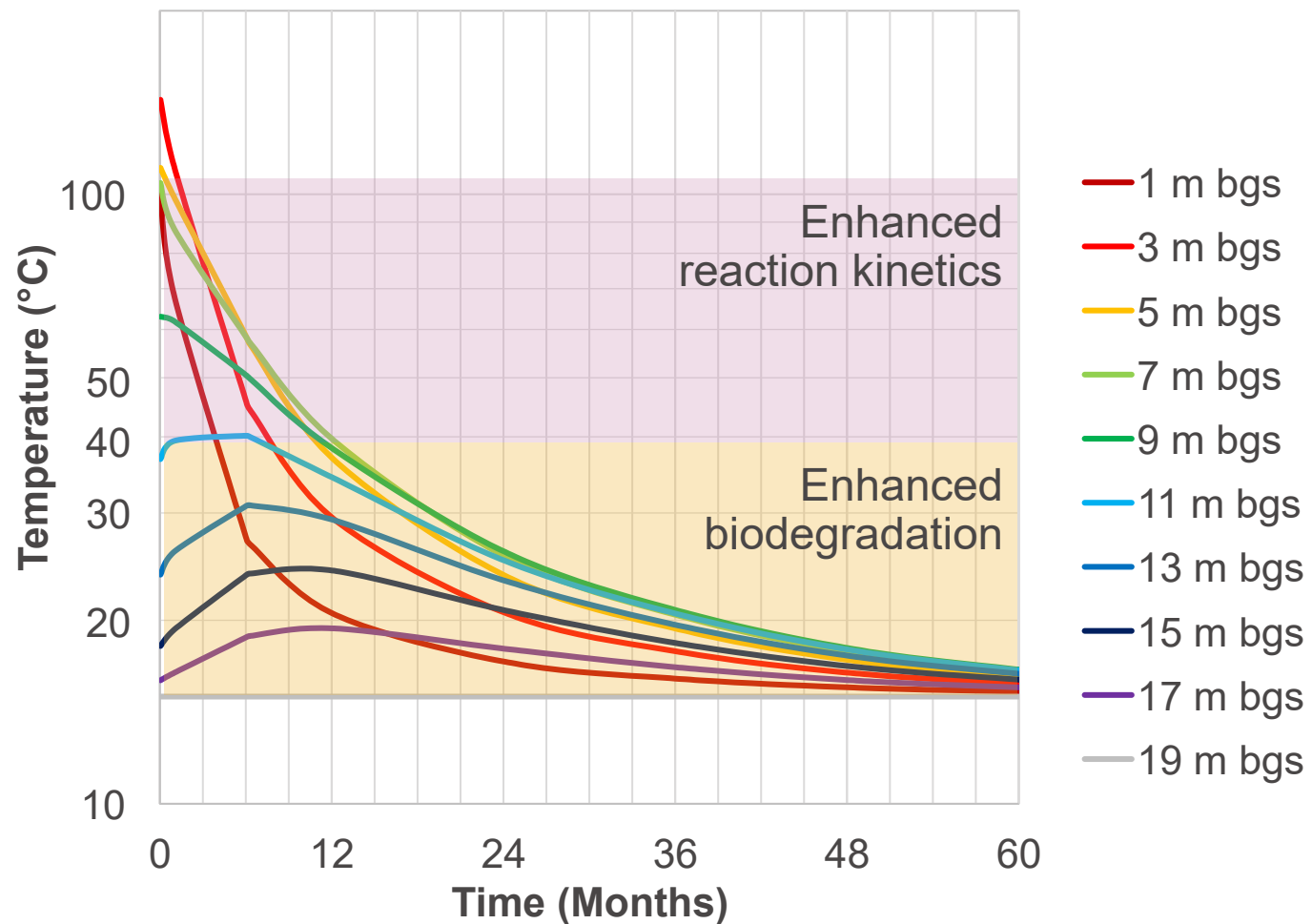
$T(^{\circ}\text{C})$
1.0e+01 20 50 1.0e+02

$v_{\text{gas}} \text{ (m/s)}$
3.e-07 3e-6 3e-5 0.0003 0.003

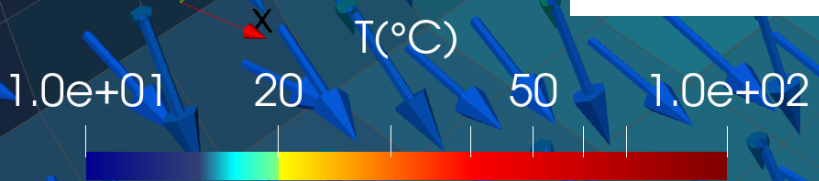
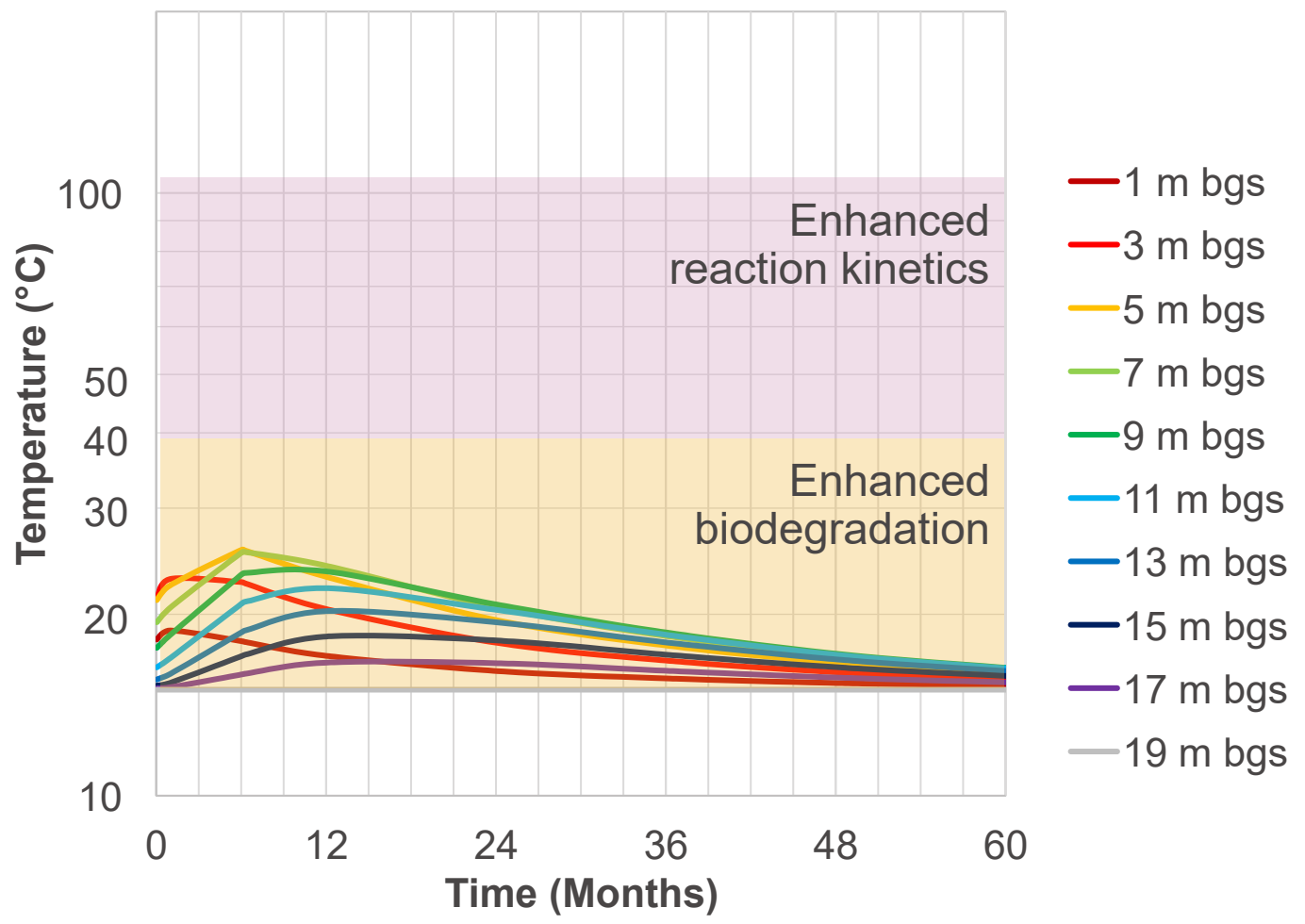
3 years cooldown

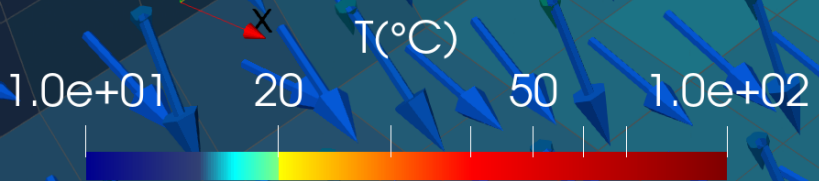
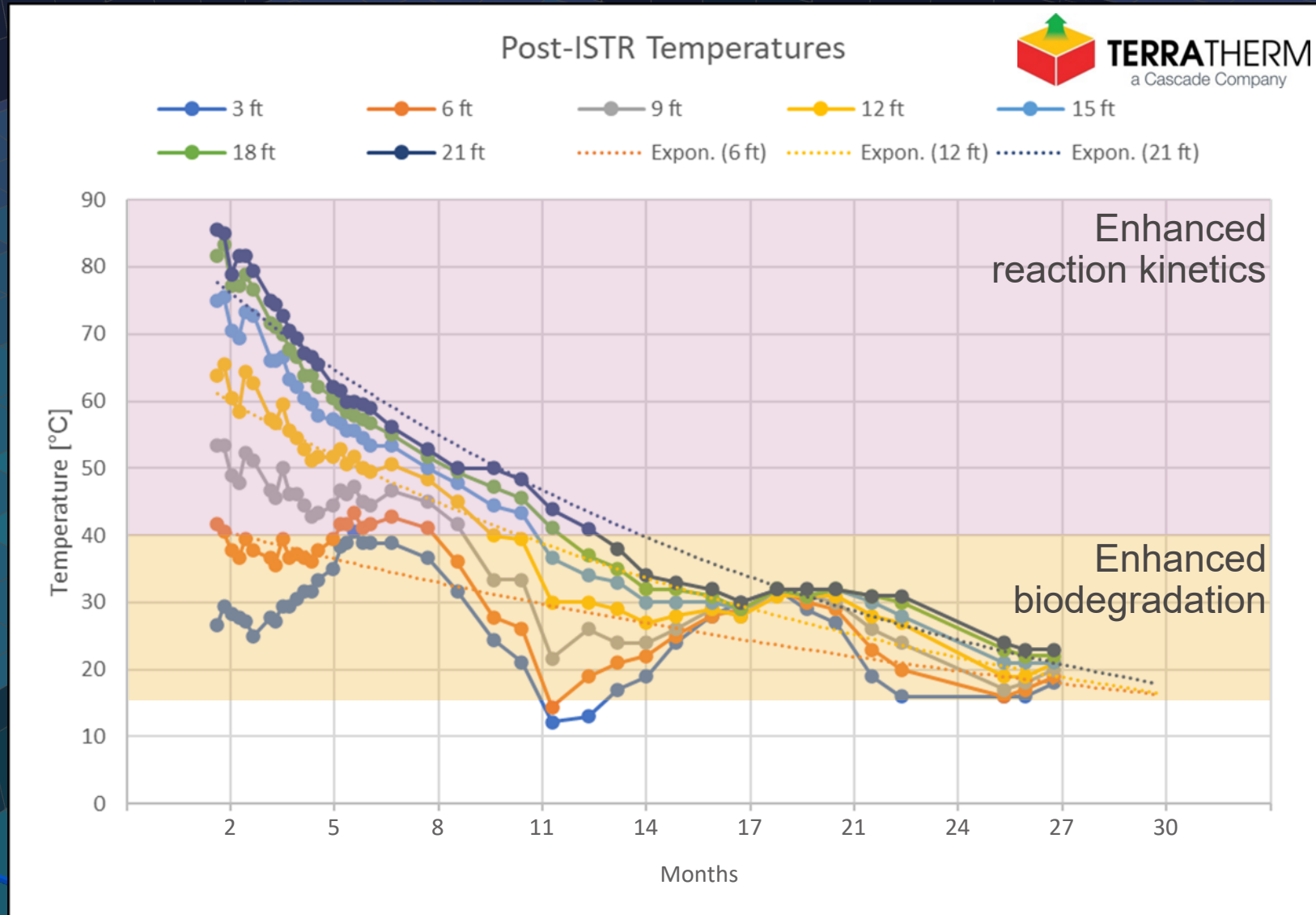


Cooldown within ISTR Volume



Cooldown 30 ft downgradient

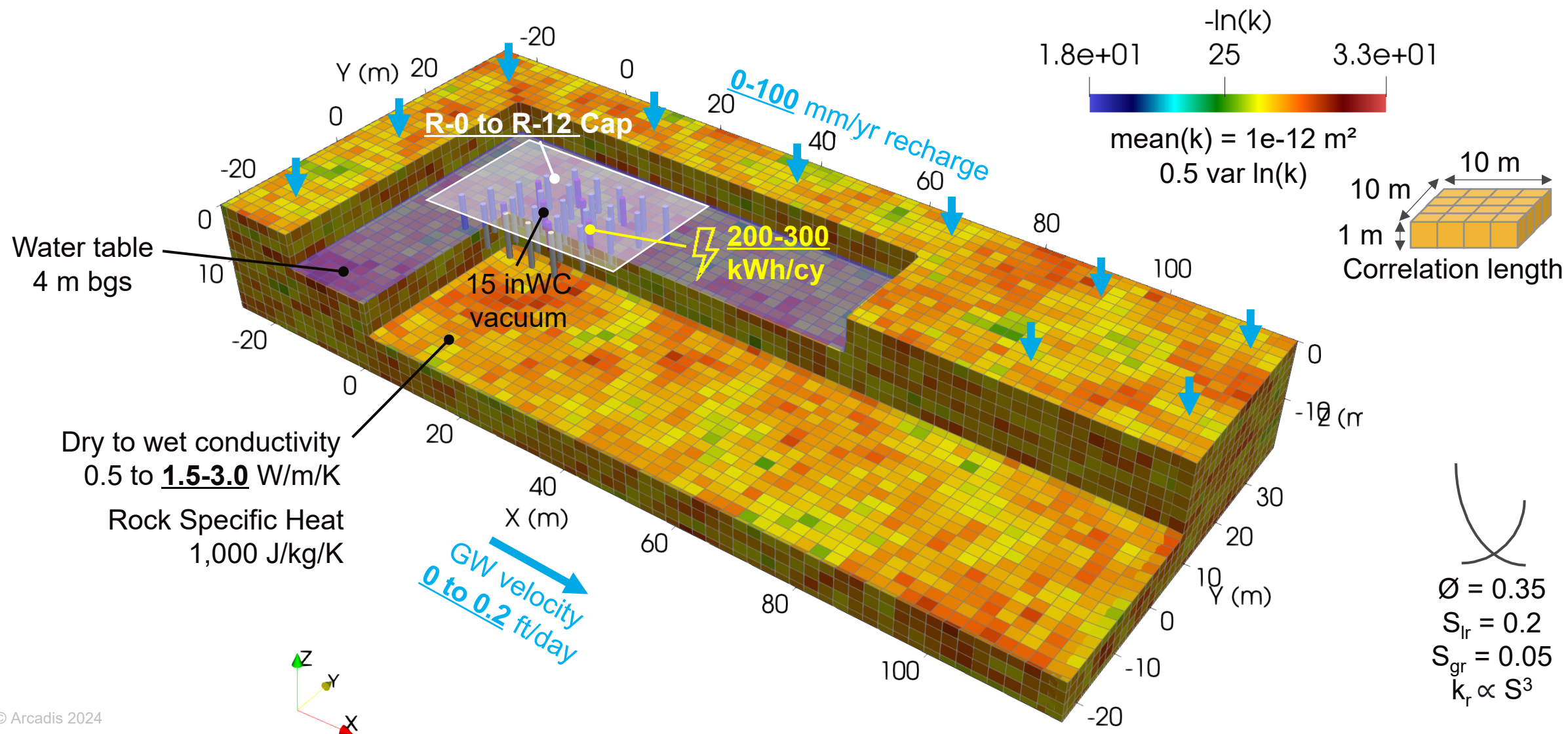




ISTR operations can have long-lasting beneficial effects in the subsurface

Elevated temperatures can persist for 1-3 years
Gentle heating can occur ~ 30-50 ft around the ISTR volume
Gas phase collapse and inward hydraulic gradients can develop
Buoyancy effects can create rising groundwater flow patterns

Parameters Modified for Sensitivity Analysis



Cooldown patterns influenced by:



Groundwater Flow
Washes heat downgradient



Thermal Conductivity
Diffuses heat laterally



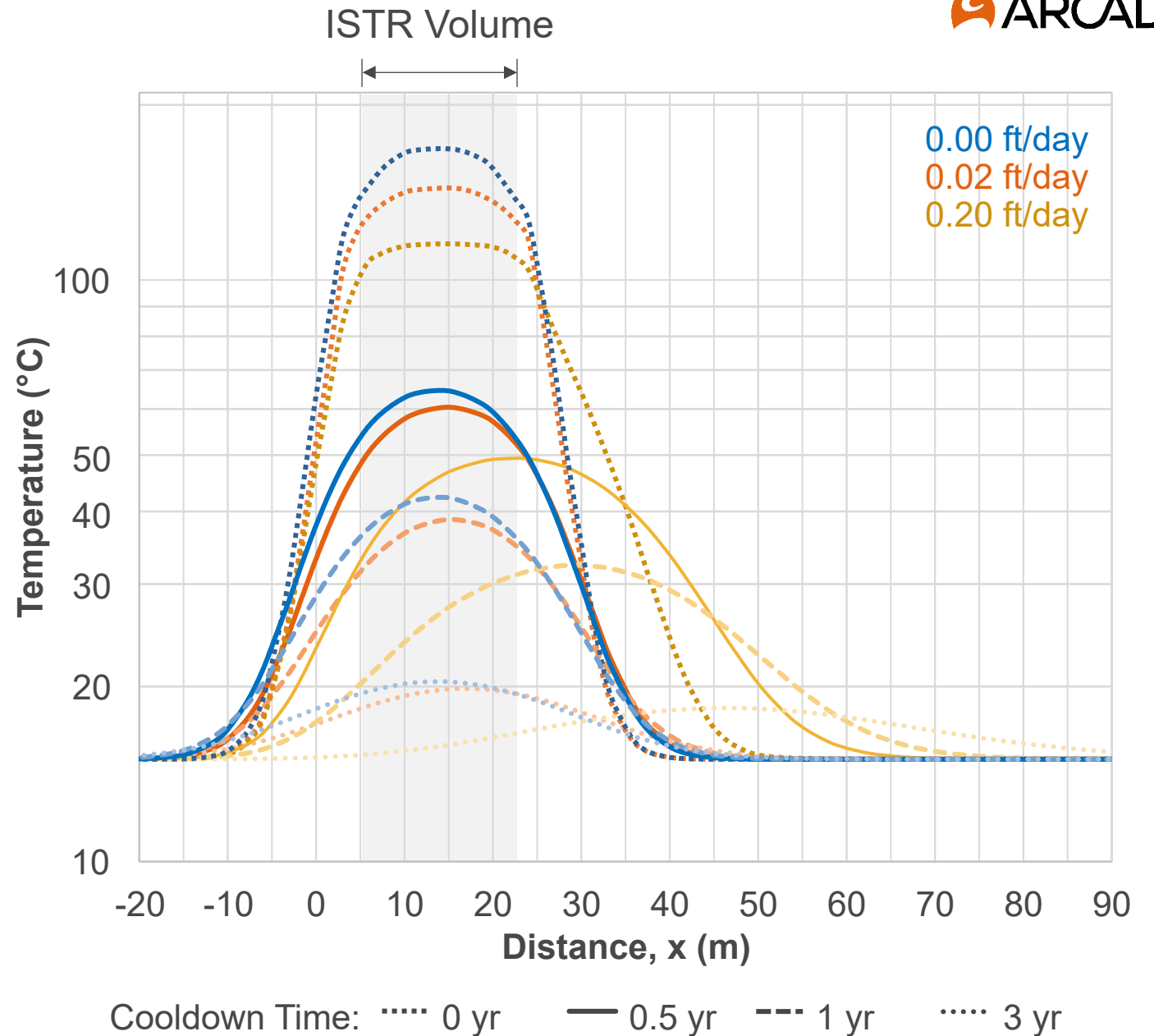
Power Density
Influences operating temperature



Recharge
Brings cool water into subsurface



Vapor Cap
Insulates subsurface



Cooldown patterns influenced by:



Groundwater Flow
Washes heat downgradient



Thermal Conductivity
Diffuses heat laterally



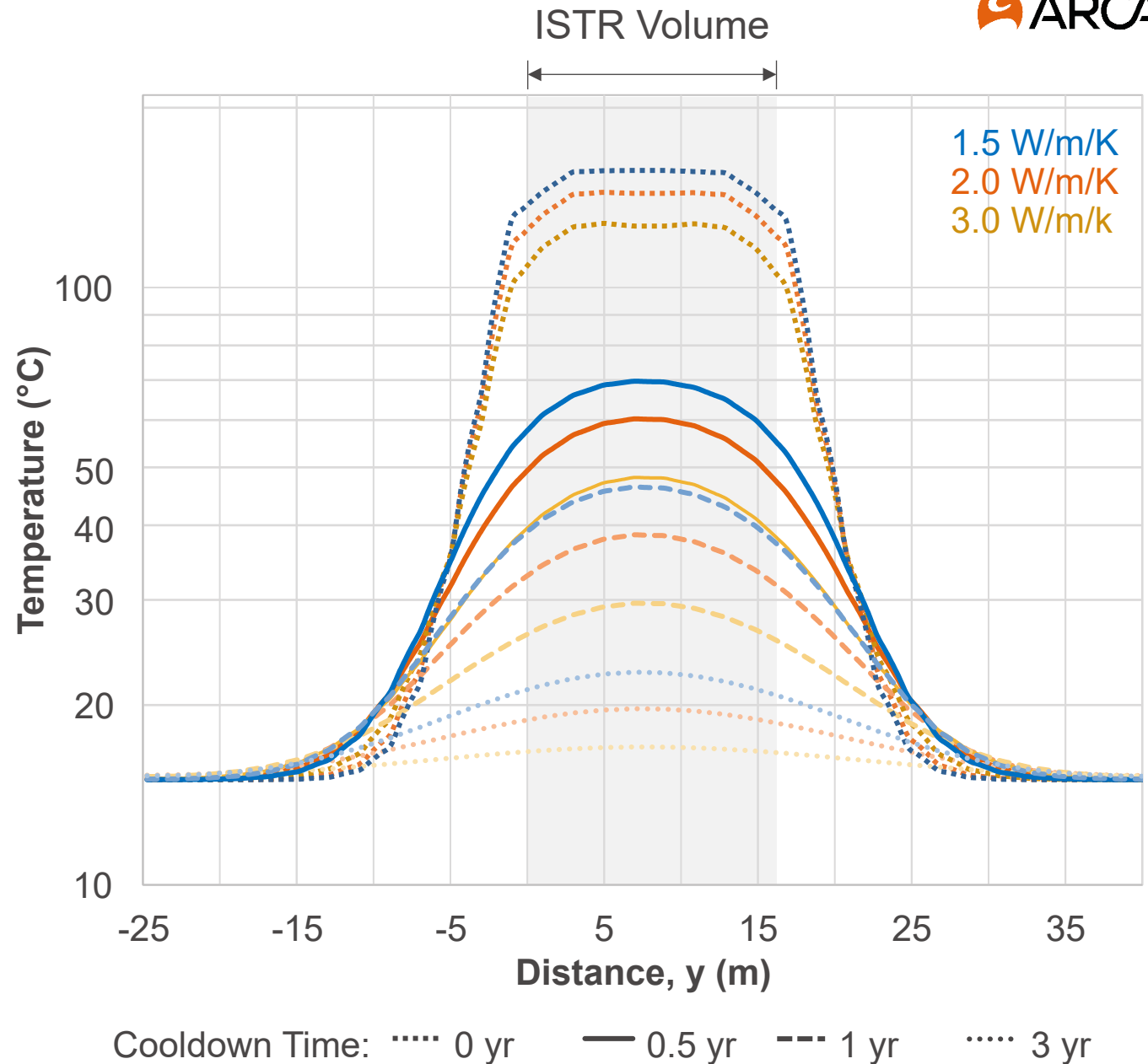
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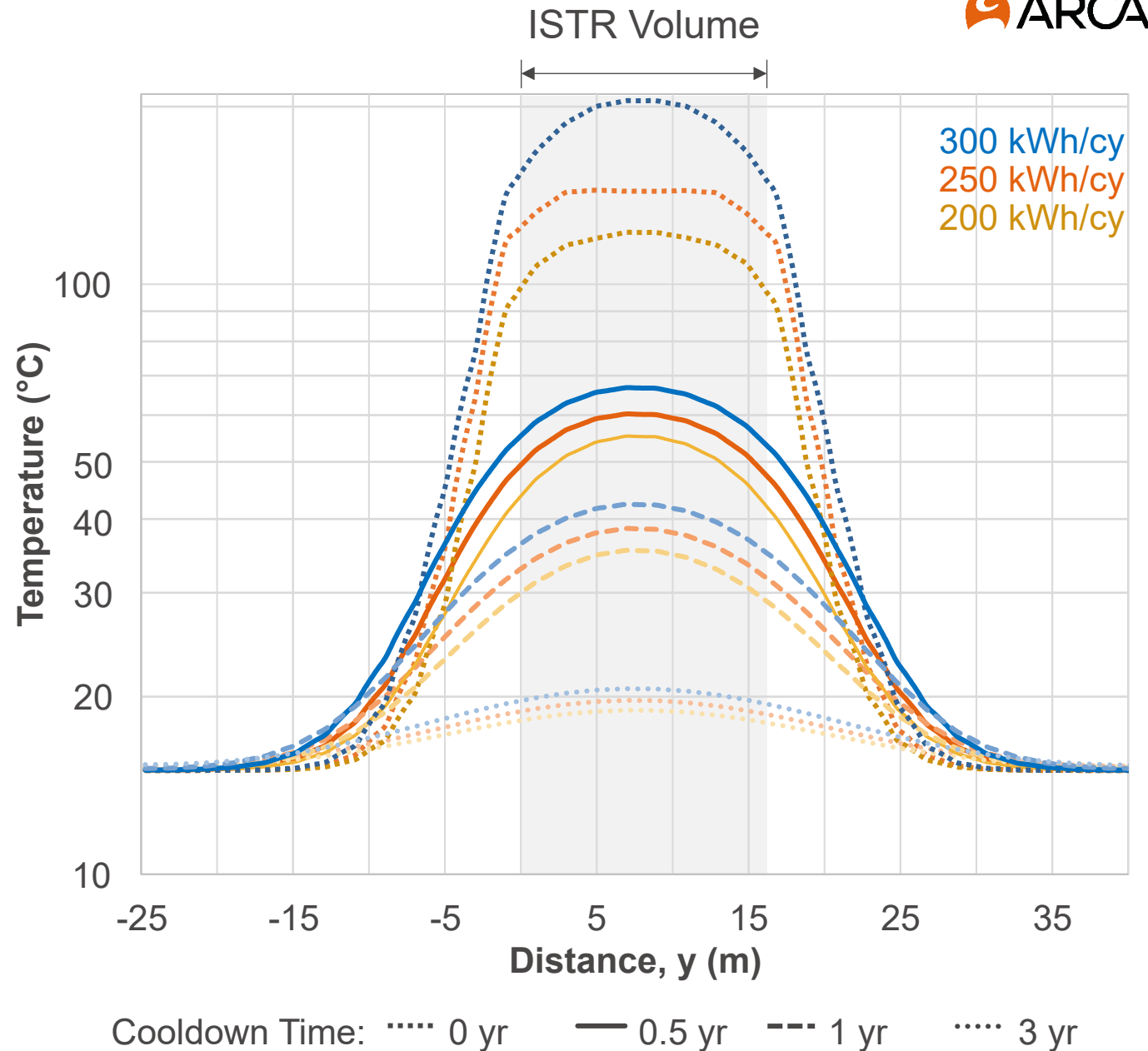
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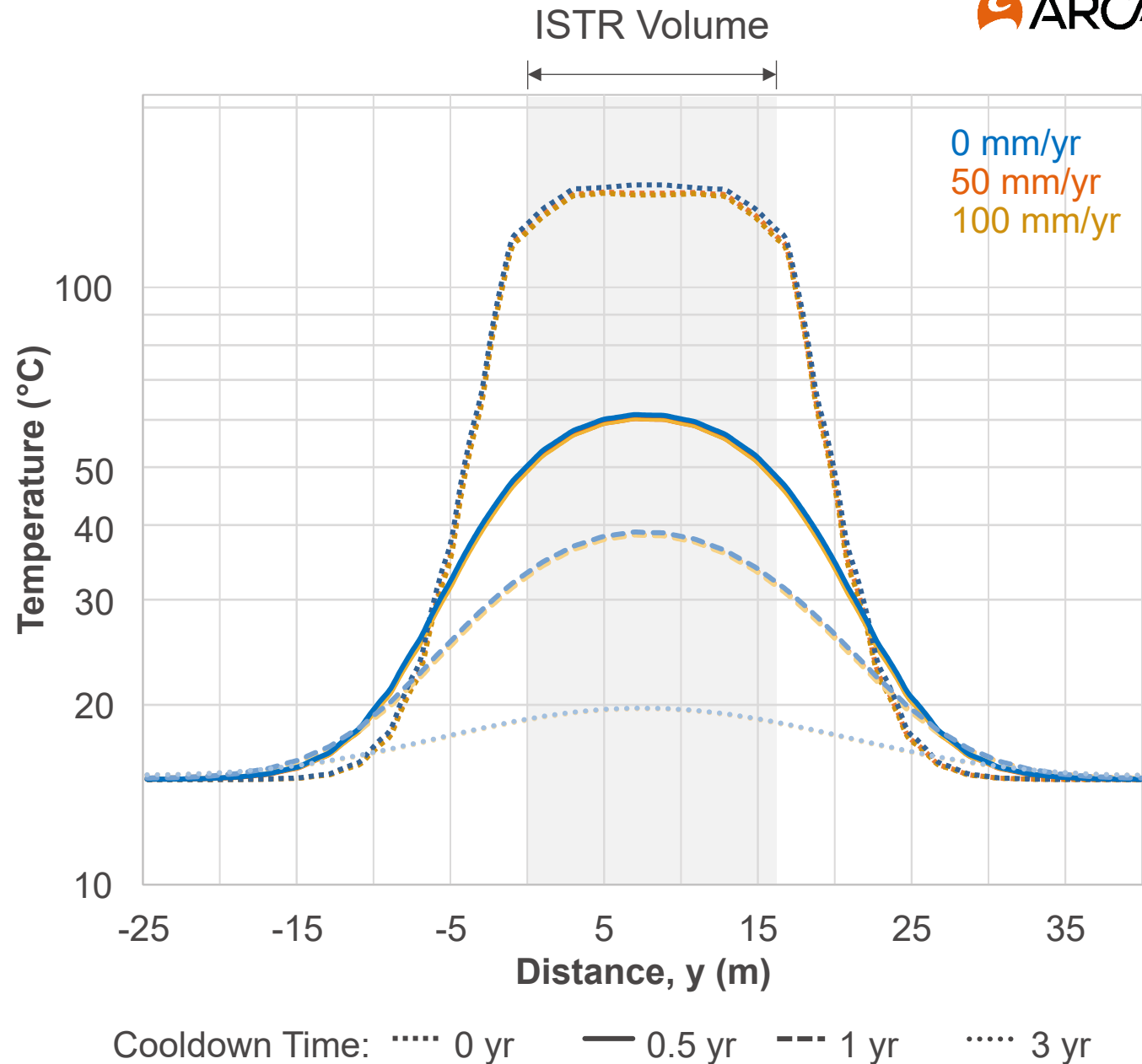
Power Density
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Recharge
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Vapor Cap
Insulates subsurface

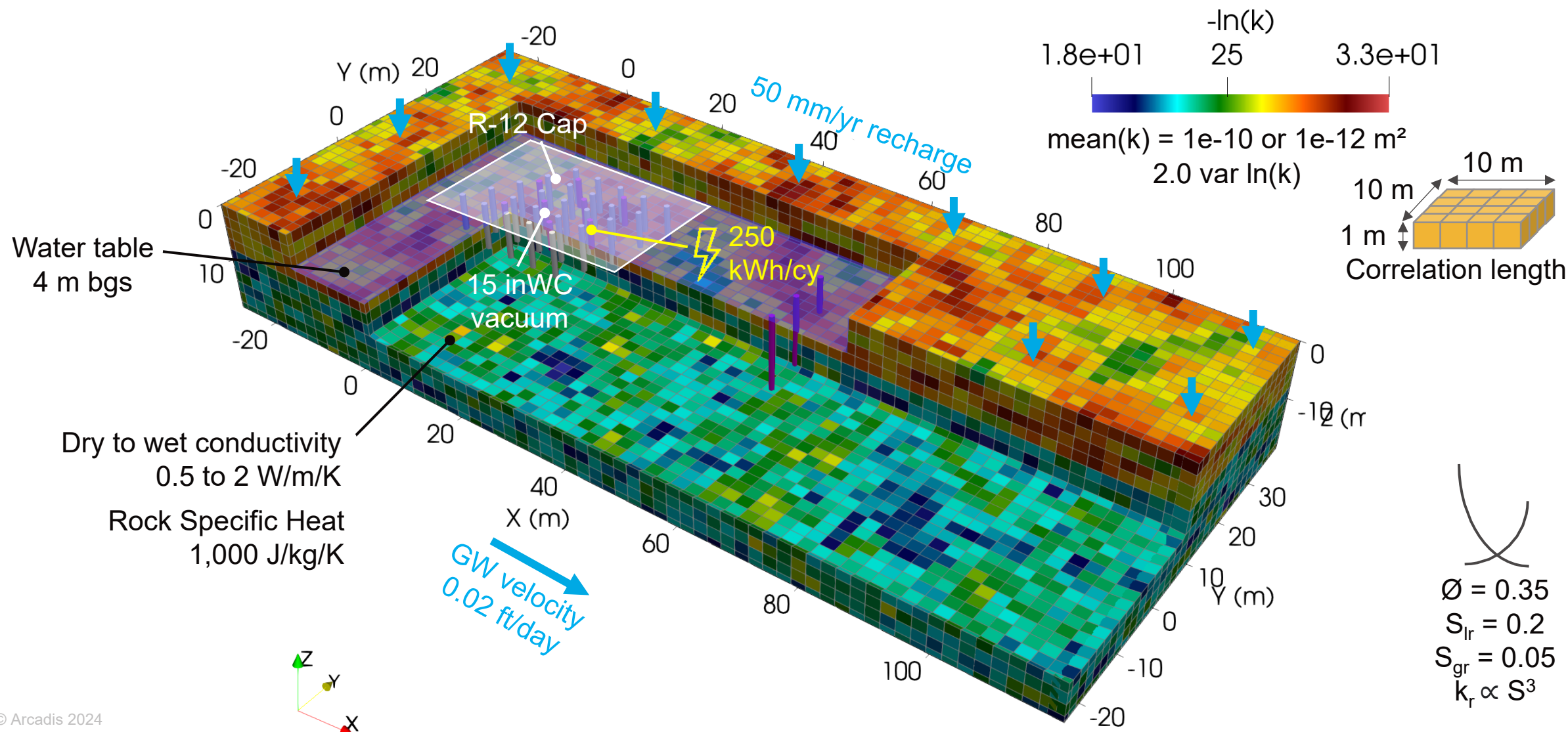


- **Groundwater Flow**
Washes heat downgradient
- **Thermal Conductivity**
Diffuses heat laterally
- **Power Density**
Influences operating temperature
- **Recharge**
Brings cool water into subsurface
- **Vapor Cap**
Insulates subsurface

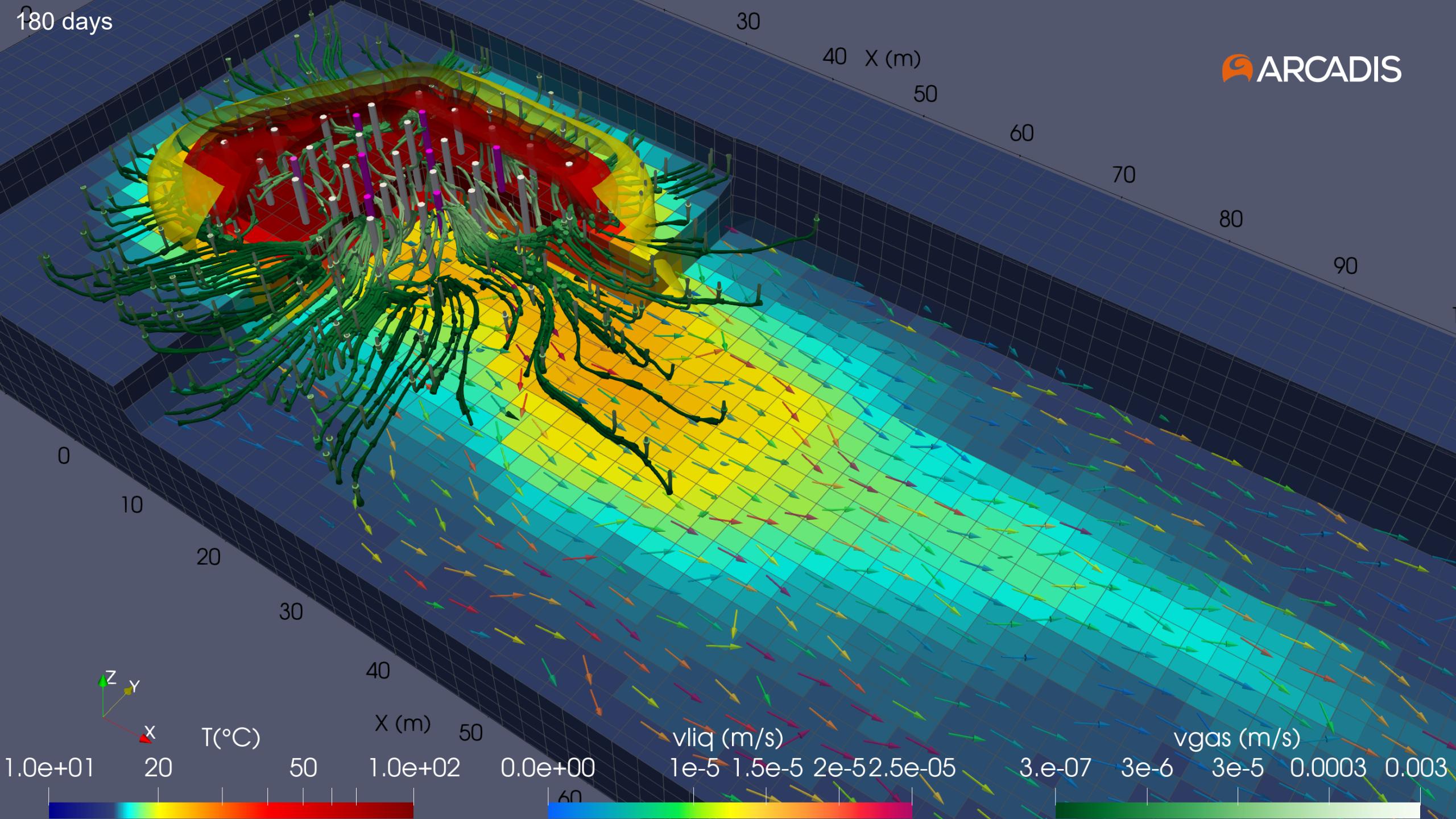
Heat dissipation is most influenced by groundwater flow velocities

Soil thermal conductivities also influence how quickly heat diffuses
ISTR operating strategy affects initial temperature distributions
Heterogeneity affects groundwater flow and heat dissipation

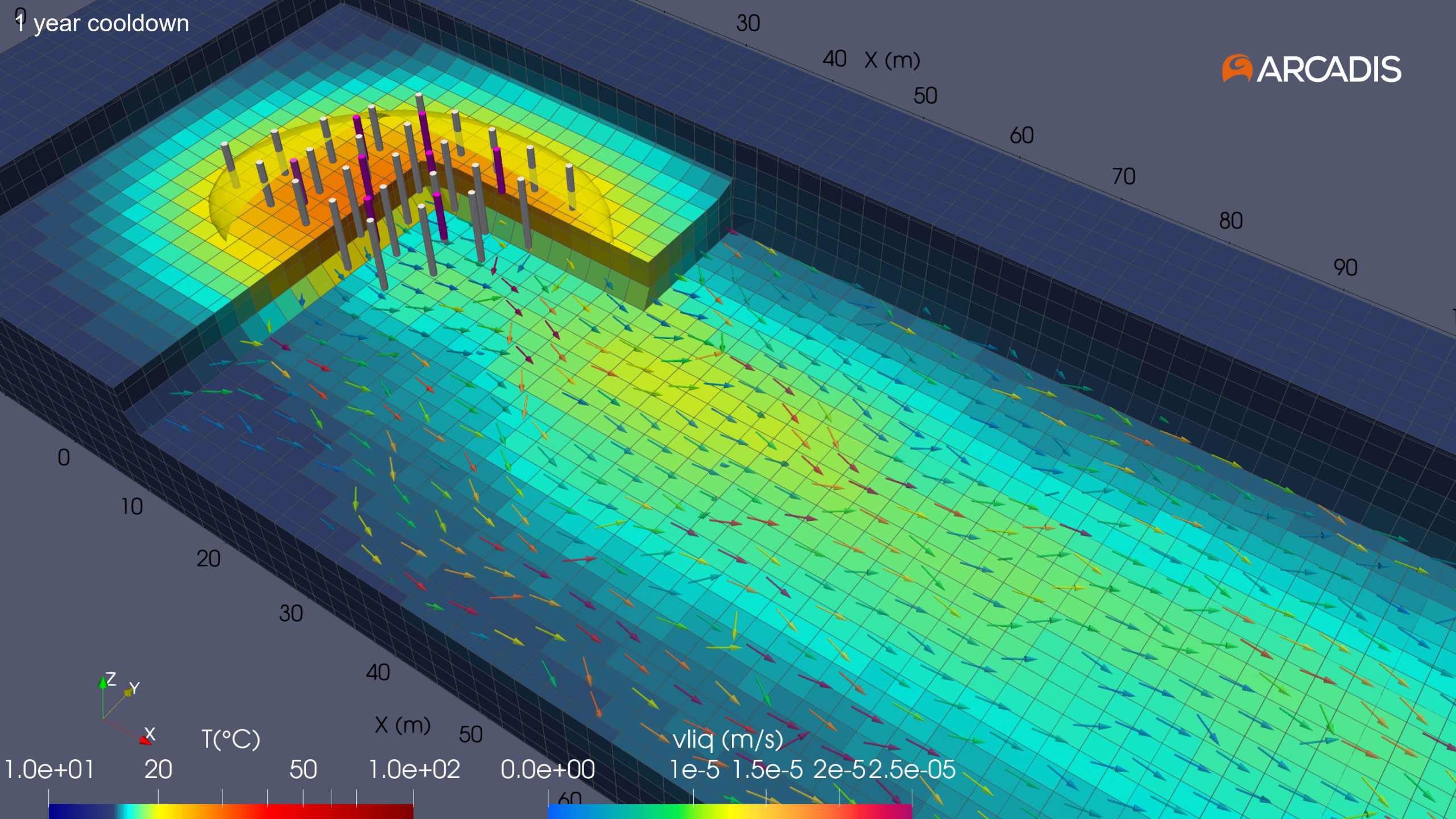
Heating a lower permeability unit with an underlying aquifer

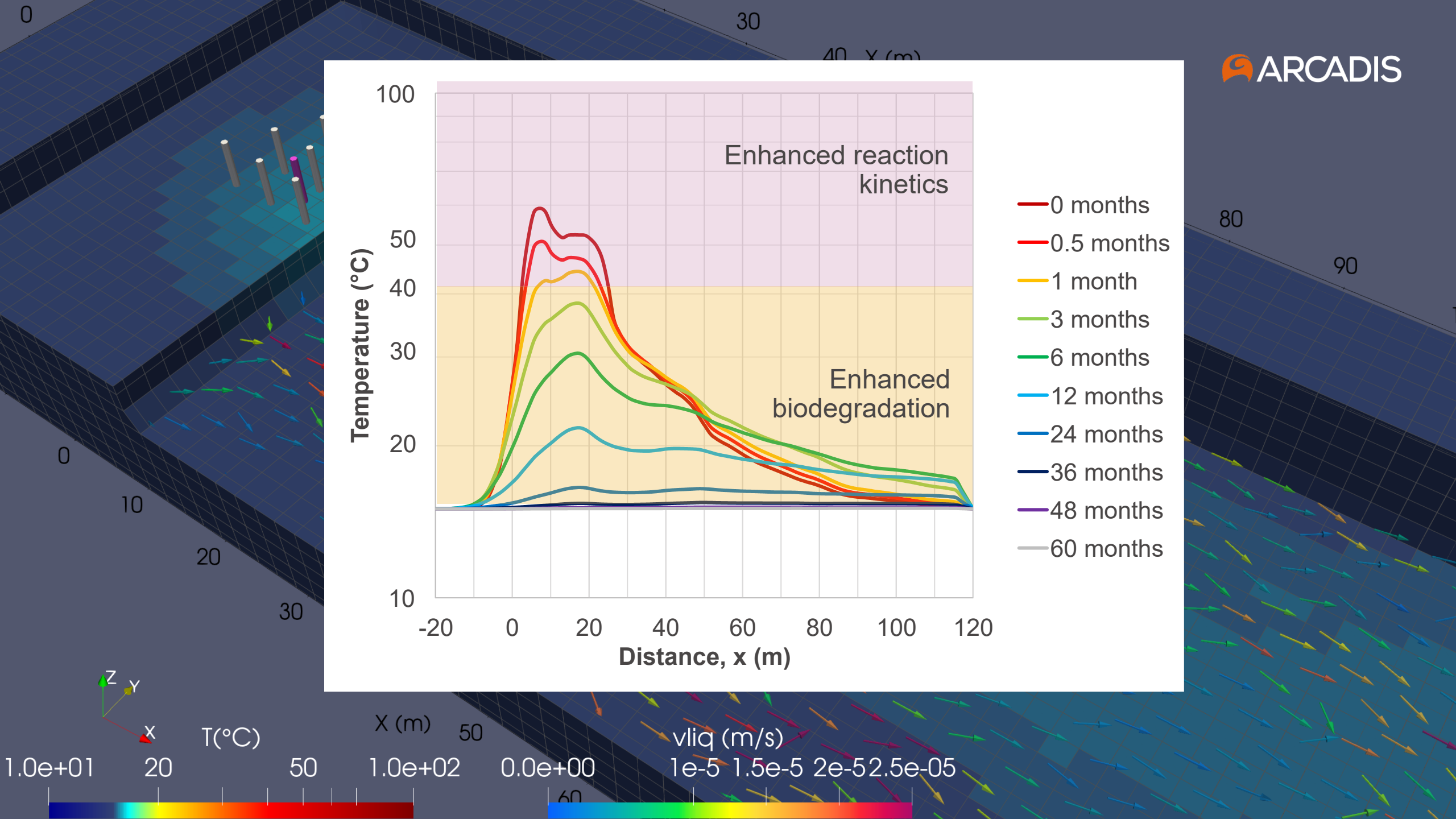
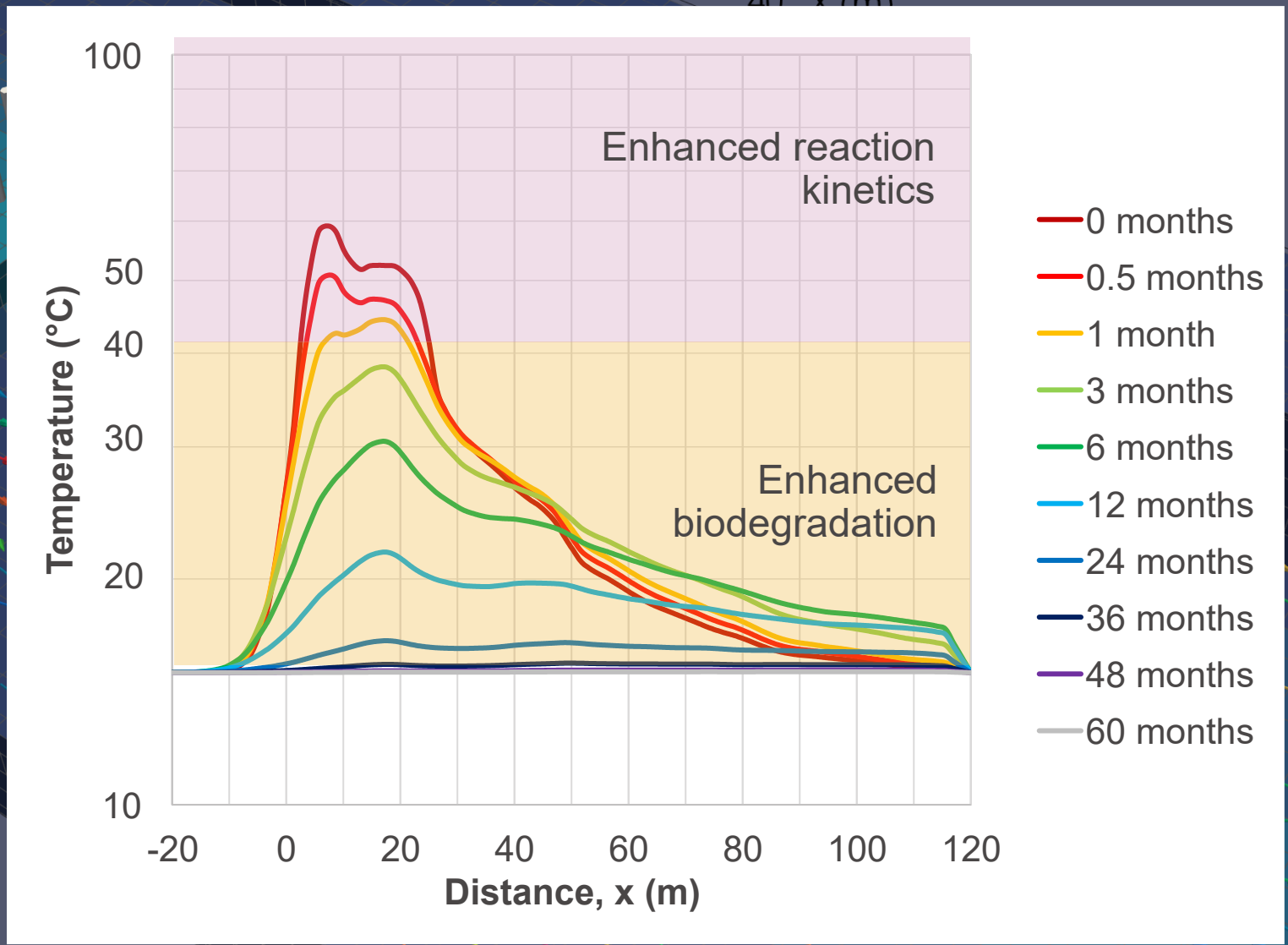


180 days

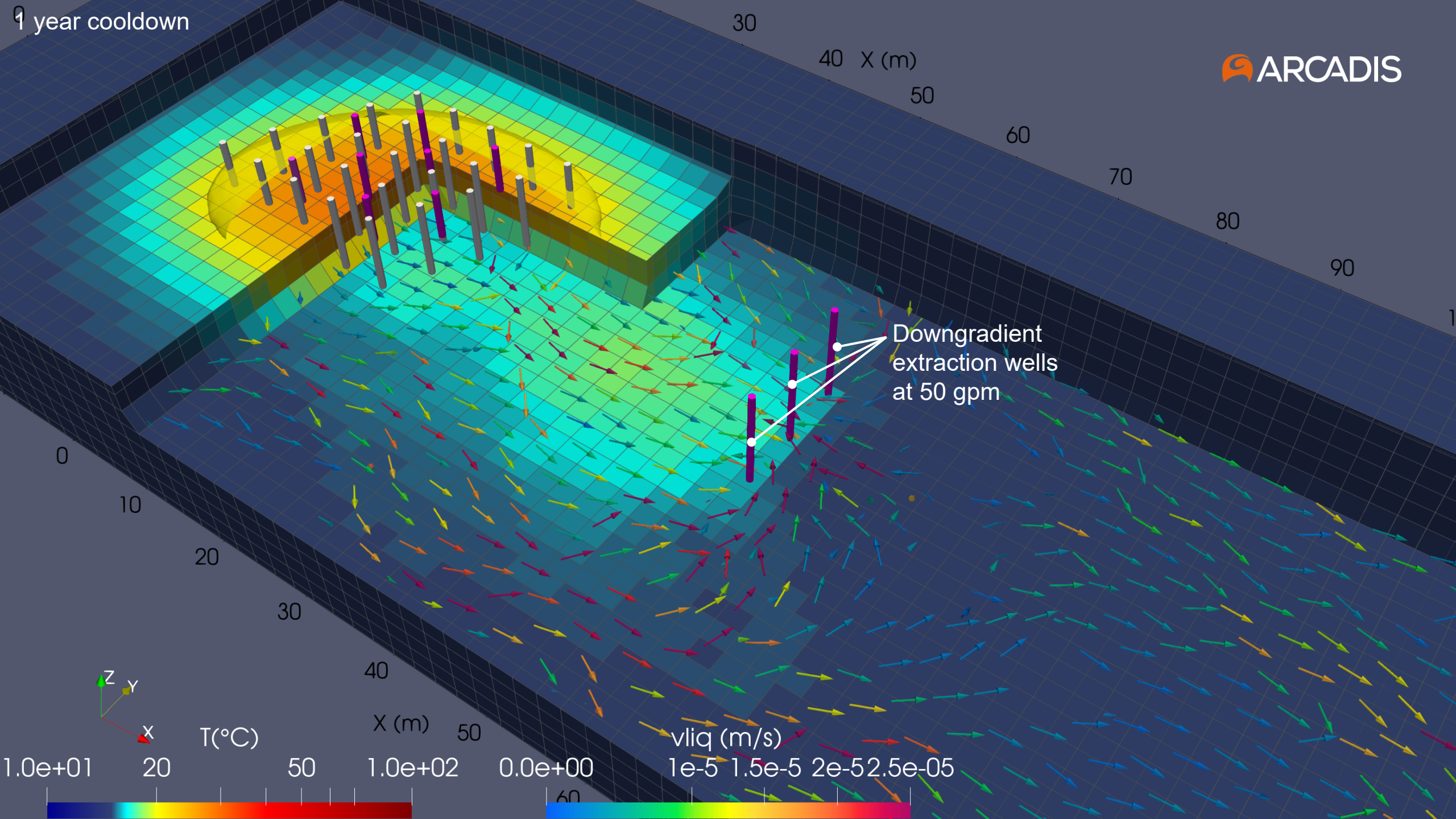


1 year cooldown





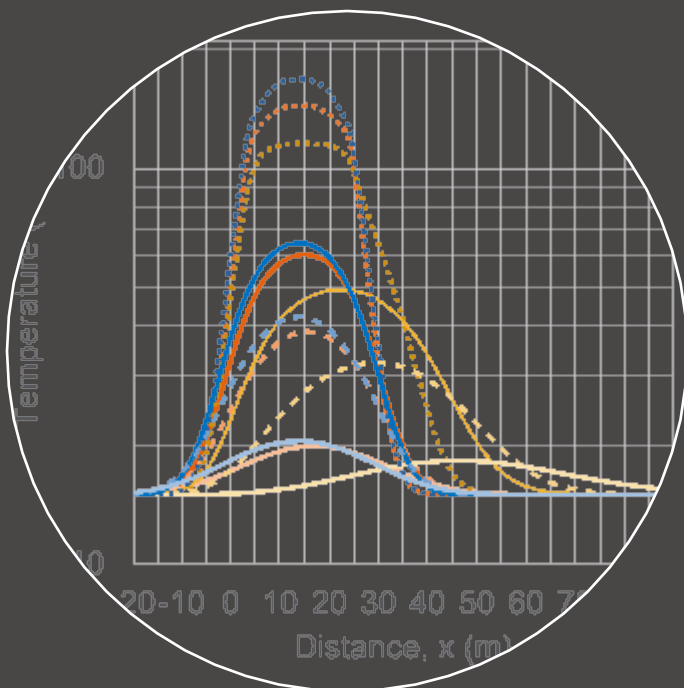
1 year cooldown



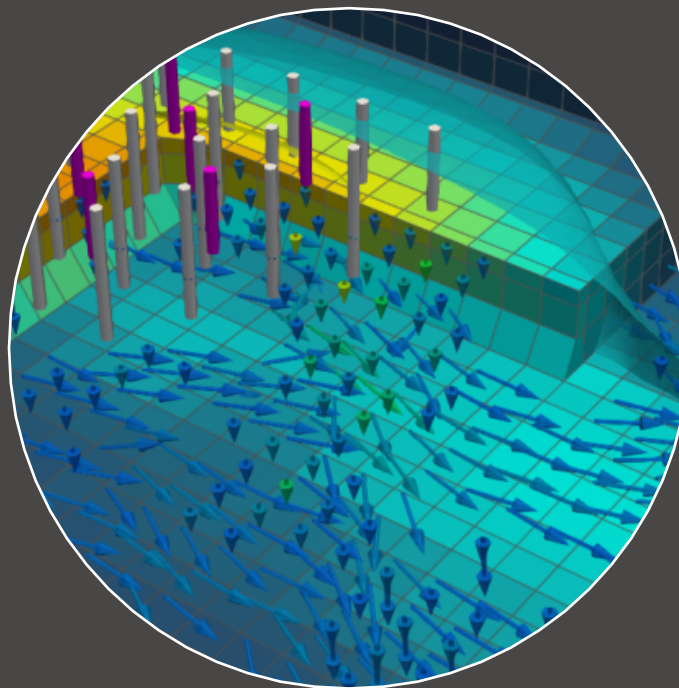
How could predicting heat dissipation be utilized by the practitioner?

Evaluate site conditions and ISTR approach
Quantify heat dissipation in and around the ISTR volume
Combine with site-specific data to identify potential synergies for holistic plume management or polishing steps

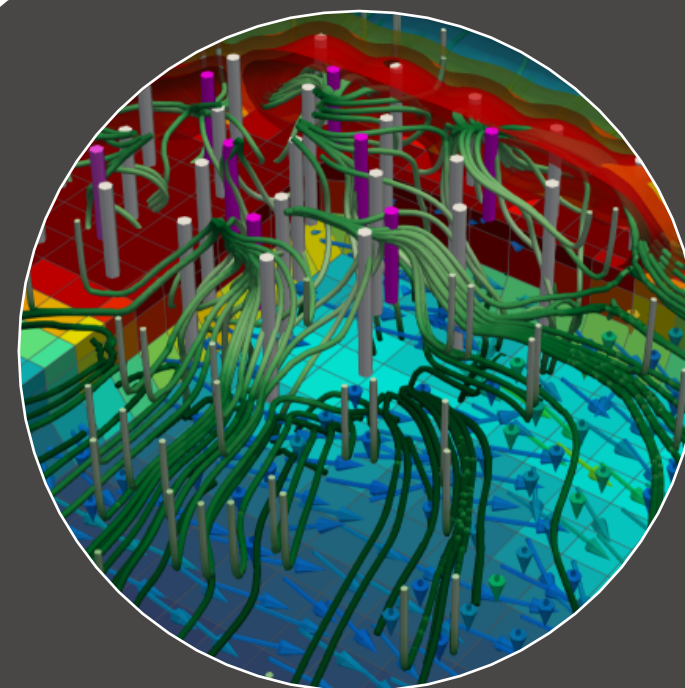
How do temperatures evolve following ISTR in the source zone?



Elevated subsurface temperatures can persist 1-3 years after ISTR is completed in the source zone



Cooldown patterns can be sensitive to thermal properties, groundwater flow, heterogeneity



Gas phase collapse, buoyancy effects, and downgradient pumping wells can influence flow paths

Thank you for joining us!

Questions? please reach out to:

Session presenters



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