Groundwater life expectancy simulations in strongly coupled density-dependent flow above a salt dome

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Abstract

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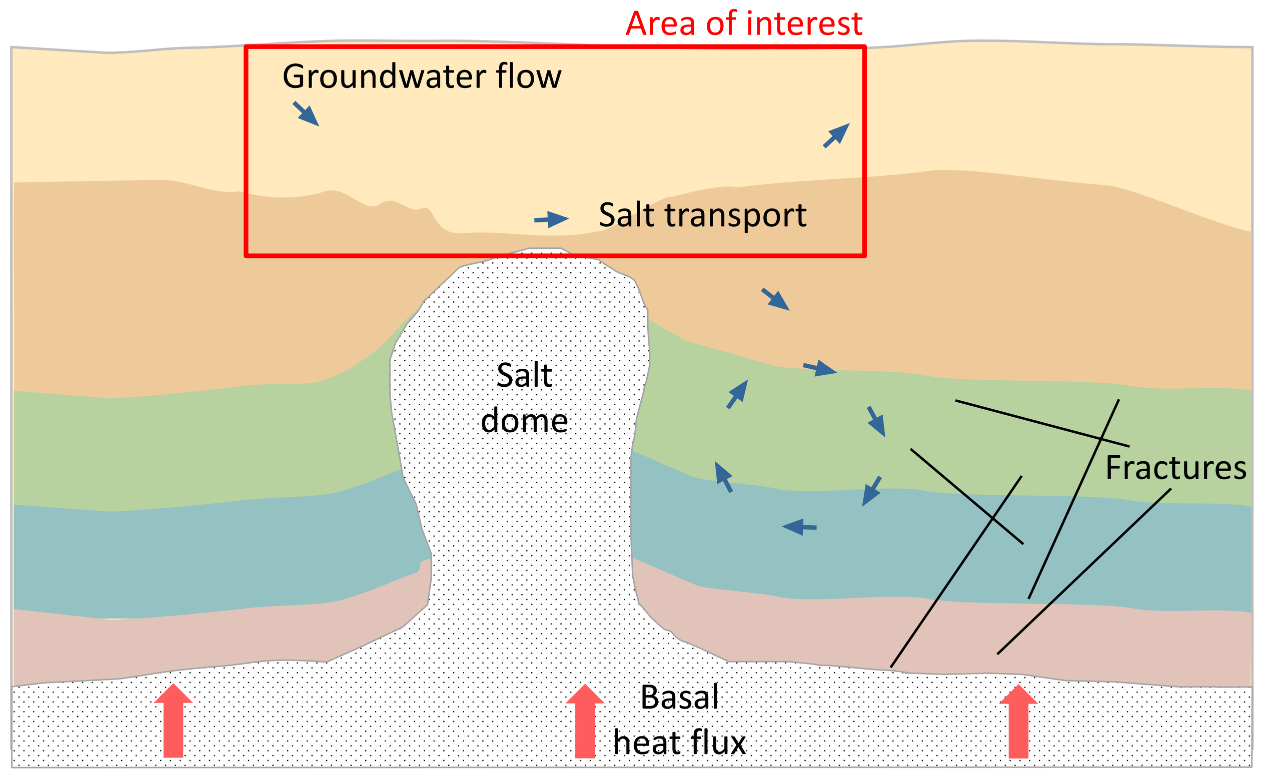
Motivation

- Salt domes considered as sites for **deep geological repository** of high-level nuclear waste
- Potential transport of accidentally leaking radionuclides via groundwater in overburden
- **Groundwater life expectancy** is estimate of radionuclide travel times in safety assessment (Cornaton et al. 2008)
- Variable groundwater density
- Dispersivity aquifer specific and highly uncertain



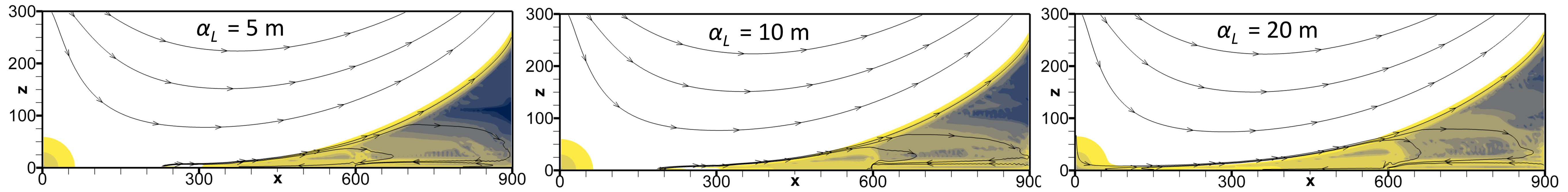
Research Objective

Numerically investigate and understand:

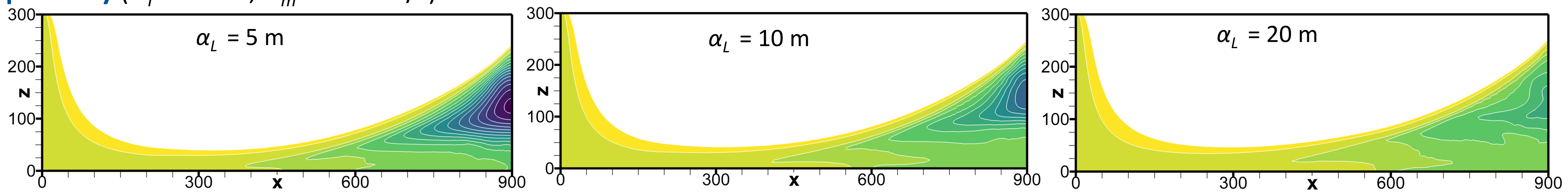
- effects of **uncertain transport parameters** on **density-dependent flow (DDF)** above a salt dome
- effects of DDF along with uncertain transport parameters on the **groundwater life expectancy** as used for the **safety assessment of nuclear waste repositories**

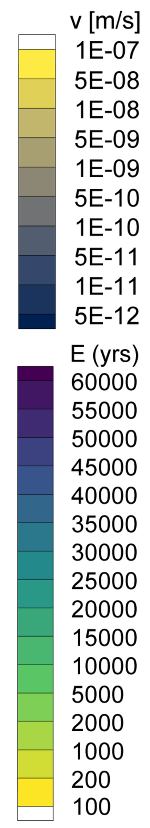
Results

Flow (α_T = 0.4 m, D_m = 10^{-9} m²/s)



Life expectancy (α_T = 0.4 m, D_m = 10^{-9} m²/s)

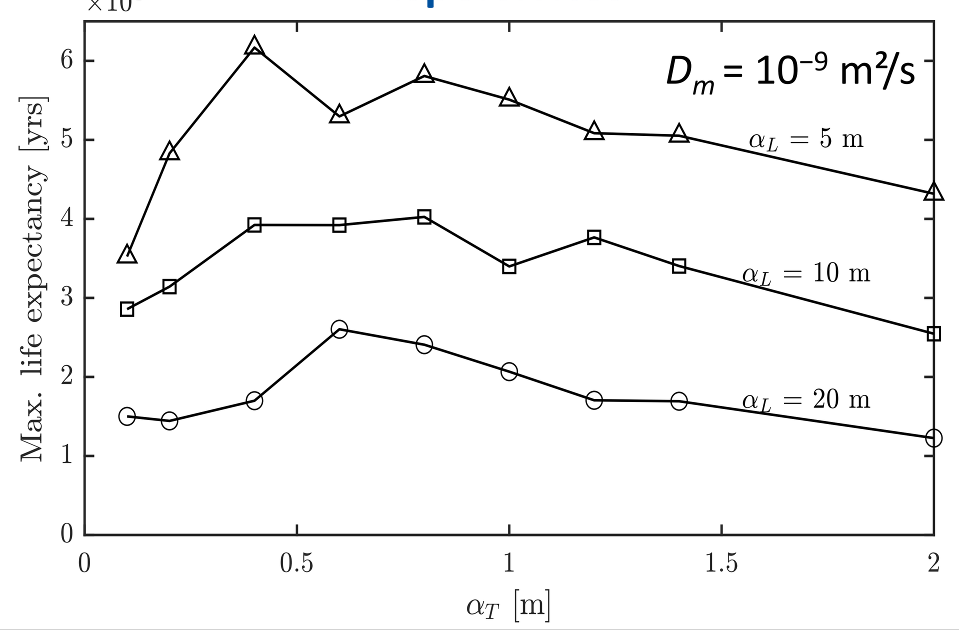




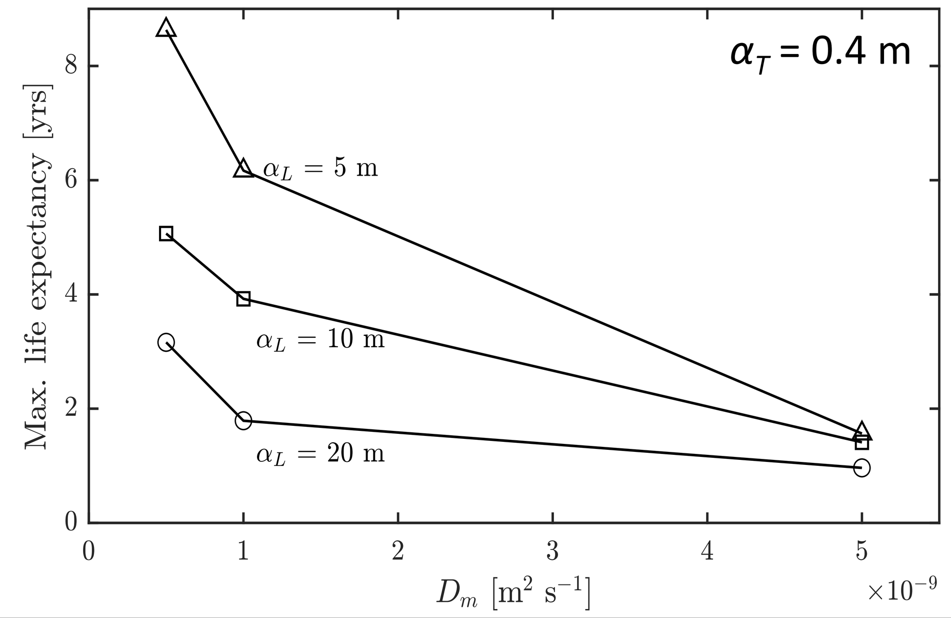
Maximum life expectancy:

- Life expectancy mainly influenced by DDF velocity magnitude and distribution
- **α_L, α_T and D_m have considerable impact** on life expectancy
- Overestimation of life expectancy for smaller α_L and D_m
- Non-linear effect with α_T

Dispersivites

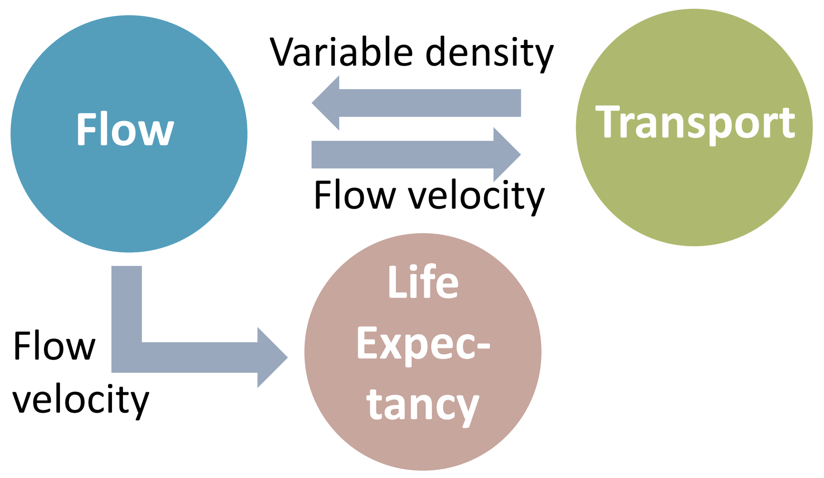


Diffusion coefficient



Methodology

Numerical model

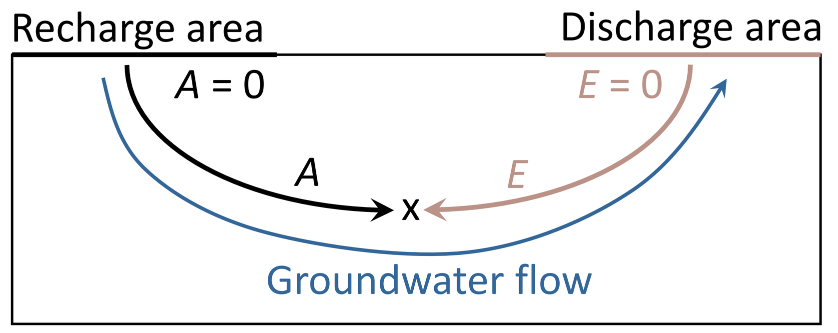


- Strongly coupled transient DDF model
- Resulting steady-state flow velocities as input for steady-state life expectancy simulation
- Advection-Dispersion equation for life expectancy (Molson and Frind 2012)
- FE code Saltflow (Molson and Frind 2023)

Governing equations

- Darcy eq. $$\mathbf{q}_i = -\mathbf{K}_{ij}\left[\frac{\partial h_0}{\partial x_j} + \gamma c \mathbf{n}_j\right]$$
- Flow eq. $$\frac{\partial}{\partial x_i}\left[\mathbf{K}_{ij}\left(\frac{\partial h_0}{\partial x_j} + \gamma c \mathbf{n}_j\right)\right] = S_s \frac{\partial h_0}{\partial t}$$
- Mass transport eq. $$\frac{\partial}{\partial x_i}\left(\mathbf{D}_{ij}\frac{\partial c}{\partial x_j}\right) - \mathbf{v}_i \frac{\partial c}{\partial x_i} = \frac{\partial c}{\partial t}$$
- Life expectancy eq. $$\frac{\partial}{\partial x_i}\left(\mathbf{D}_{ij}\frac{\partial E}{\partial x_j}\right) + \mathbf{v}_i \frac{\partial E}{\partial x_i} + 1 = 0$$

Concept of Groundwater Life Expectancy (*E*)



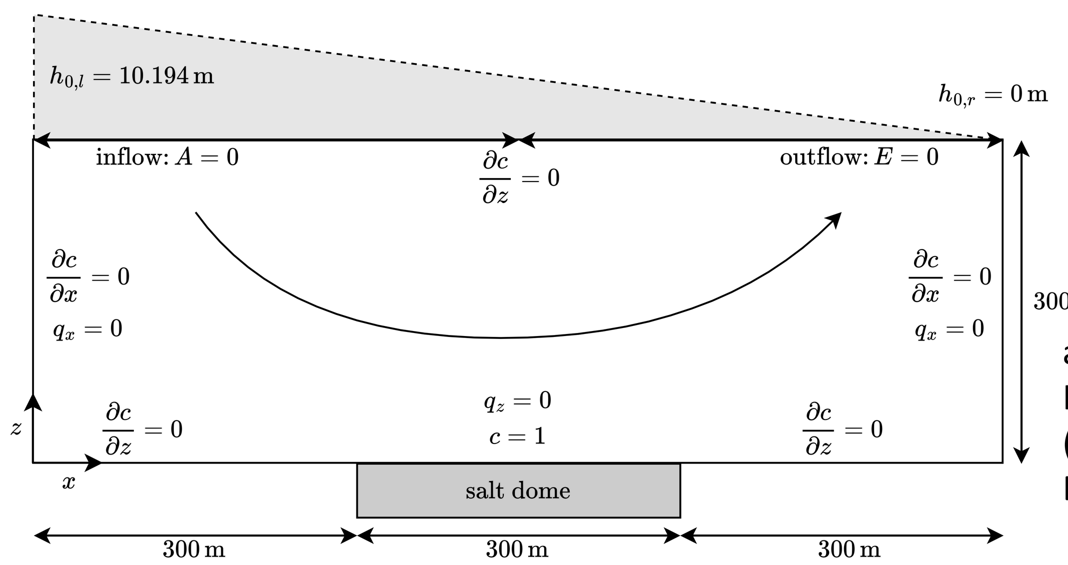
adapted from Molson and Frind (2012)

T = *A* + *E*

T – residence time; *A* – groundwater age

Test case: Salt dome problem (e.g. Herbert et al. 1988)

- Simplified 2D hydrogeological situation of real saltdome
- Coupled flow and transport with strong density variation (20 %)



adapted from Herbert et al. (1988) and Diersch (2013)

Uncertain transport parameter $\mathbf{D}_{ij} = D_m\mathbf{I} + (\alpha_L - \alpha_T)\mathbf{v}_i\mathbf{v}_i^T/|\mathbf{v}| + \alpha_T|\mathbf{v}|\mathbf{I}$

- Dispersivity: longitudinal α_L = [5, 10, 20] m; transverse α_T = [0.1 - 2] m
- Diffusion coefficient D_m = [$5{\cdot}10^{-9}$, 10^{-9}, $5{\cdot}10^{-10}$] m²/s

Summary & Conclusion

- DDF velocities are majorly impacting life expectancy
- Uncertain transport parameters have **strong effect** on life expectancy in the context of nuclear waste disposal
- **Maximum life expectancy may be overestimated** for smaller longitudinal dispersivity and diffusion coefficients

Results highlight the **importance of transport parameter choice and considering parameter uncertainty** when numerically calculating groundwater life expectancy in density-dependent flow in the safety assessment of nuclear waste disposal.

Outlook: Full **global sensitivity analysis** of direction-dependent dispersivities on DDF flow and resulting life expectancy

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For more information, scan:

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