

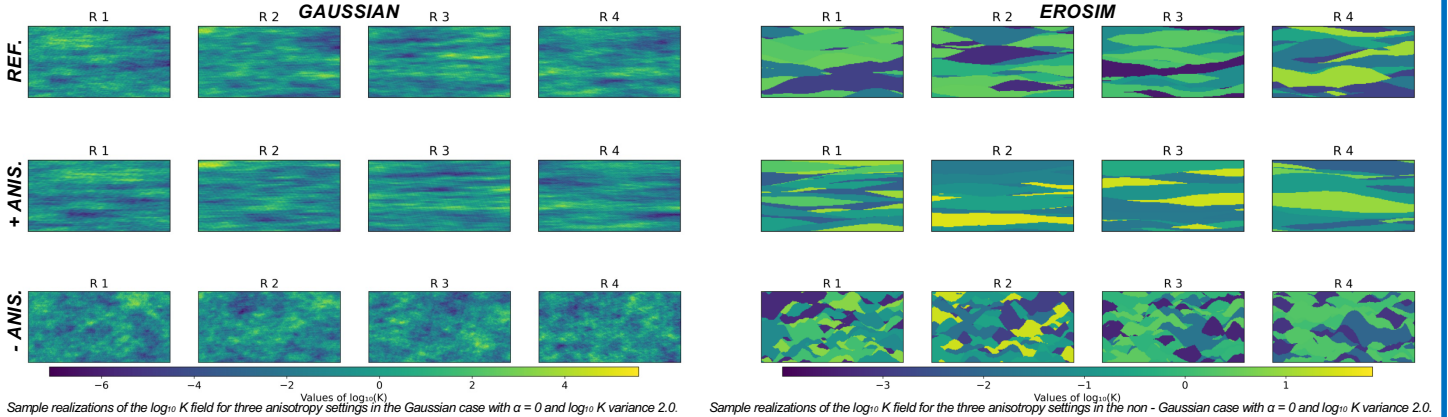
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1. Introduction

Gravity currents (GCs) are density-driven horizontal flows in porous media, relevant for seawater intrusion, CO₂ sequestration, geothermal energy and contaminant transport. Classical GC theory assumes homogeneous porous media, whereas real formations are highly heterogeneous and anisotropic, with hydraulic conductivity spanning several orders of magnitude at the sub-meter scale. Here we investigate how the anisotropy ratio of Gaussian and non-Gaussian heterogeneous log₁₀K fields affects GC propagation, using a MODFLOW-NWT model validated against similarity solutions.

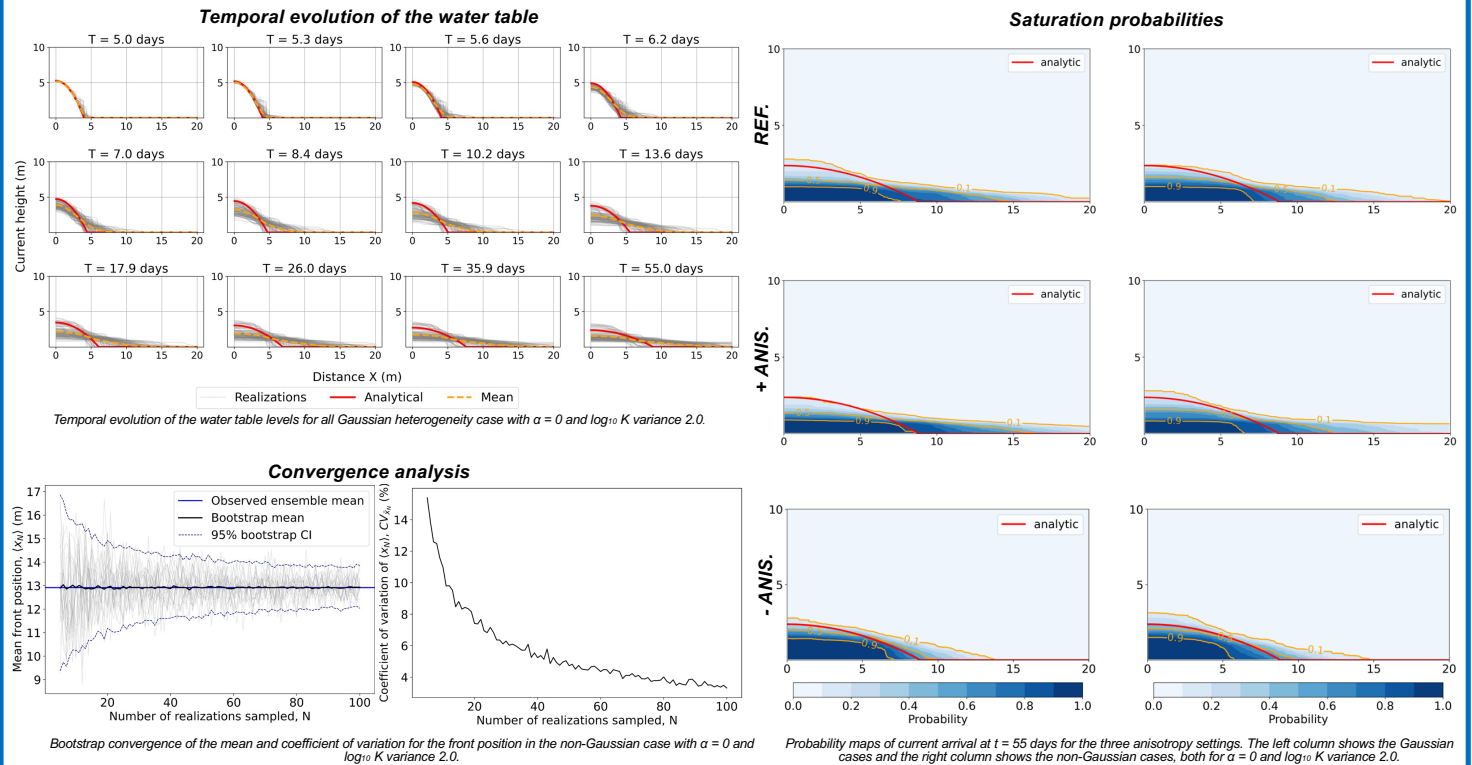


2. Methodology

- **Numerical Model:** MODFLOW-NWT, validated against classical similarity solutions (Huppert & Woods, 1995) for instantaneous ($\alpha=0$) and constant injection ($\alpha=1$).
- **Heterogeneity Fields:** Gaussian (log-normal) and non-Gaussian (EROSIM) log₁₀K fields, 100 realizations per case and variance $\sigma^2 = 0.5, 1.0, 2.0$ (log₁₀ m/day)².
- **Anisotropy Ratios:** Exponential variogram with $\lambda_v = 0.67$; $\lambda_h = 1.33, 4.5$ and 8.0 m; yielding $\lambda_h/\lambda_v = 2.0, 6.7$ and 11.2 (nearly isotropic, reference, high anisotropy).

3. Results

- **Model validation:** Numerical water-table profiles closely match analytical similarity solutions in a homogeneous medium.
- **Heterogeneity effects:** Individual realizations diverge from the homogeneous solution, fronts may advance faster or slower depending on the realization.
- **Number of realizations:** About 100 realizations provide stable statistics (mean and coefficient of variation).
- **Probability maps:** Higher variance and higher anisotropy lead to more elongated and flattened probability maps. In the nearly isotropic case, the 0.1 region shrinks and the 0.5 contour approaches the homogeneous analytical solution.
- **Gaussian vs non-Gaussian:** Non-Gaussian fields produce less stretched maps than Gaussian fields at the same variance and anisotropy.
- **Anisotropy influence:** Increased horizontal correlation length (λ_h) stretches probability maps and increases forecast dispersion.



4. Conclusions

- ✓ Heterogeneity accelerates GC propagation on average; homogeneous solutions systematically underestimate front advance.
- ✓ Higher anisotropy (larger λ_h) produces more elongated probability maps and greater prediction uncertainty.
- ✓ Non-Gaussian fields (EROSIM) better represent geological facies and yield less elongated probability maps than Gaussian fields at the same variance.
- ✓ About 100 realizations suffice for stable statistics, supporting a practical uncertainty-quantification workflow for gravity currents.