Modelling Focused Fluid Flow in the Subsurface for Methane Emission Assessment in the North Sea

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Methane emissions from the North Sea are strongly influence by subsurface fluid migration processes, particularly around complex geological structures and legacy wells. As part of the WELLFATE project, we integrate high-resolution seismic interpretation with advanced numerical simulations to investigate fluid flow in the Tampen area.

Our modelling framework couples seismic-derived stratigraphy and property cubes with a fully coupled poroviscoelastic approach. The governing equations account for mass and force balance, Darcy flow, and permeability evolution, and are solved using a physics-inspired pseudo-transient method on staggered grids. This approach enables the simulation of both vertical and horizontal migration pathways, capturing the effects of geological heterogeneities such as clinoforms and block structures. The model incorporates mechanisms such as porosity waves, where asymmetric compaction and decompaction rheology lead to the formation of focused fluid channels. We systematically explore the impact of material property contrasts, layer width, and multi-layered systems on channel development and deformation. GPU-accelerated computations allow for large-scale 2D and 3D simulations, with model sizes up to 10,000 × 10,000 nodes in 2D and 500 × 500 × 500 in 3D. Preliminary results show that narrow geological blocks tend to deflect fluid laterally with minimal deformation, while wider blocks allow for slower, more vertically focused channel development and significant deformation. Intra-reservoir channels create high-permeability pathways, facilitating methane migration towards the seabed. The permeability of overlying layers is a key control on shallow migration and potential methane leakage. This integrated framework provides new insights into the controls on methane seepage in the North Sea, supporting improved risk assessment and mitigation strategies for offshore methane emissions.