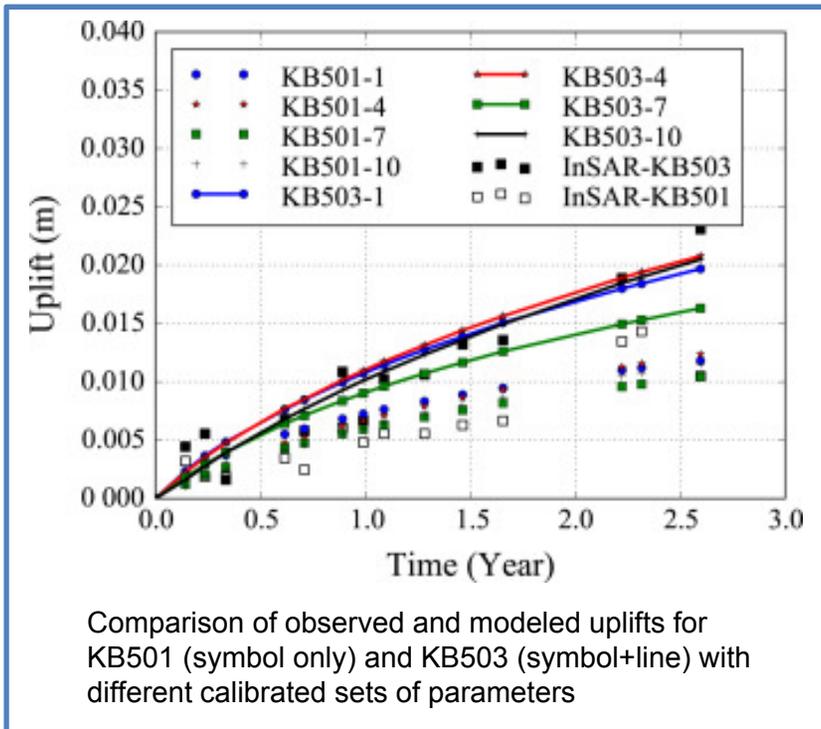


Investigation of the Influence of Geomechanical and Hydrogeological Properties on Surface Uplift at In Salah



Newell, P. Yoon, H. Martinez, M.J., Bishop, J.E. Bryant, S.L (2016, in press), Investigation of the influence of geomechanical and hydrogeological properties on surface uplift at In Salah, Journal of Petroleum Science and Engineering, <http://dx.doi.org/10.1016/j.petrol.2016.11.012>

Scientific Achievement: Mechanical properties of reservoir and caprock materials can significantly influence the surface uplift

Significance and Impact: Coupled fluid flow and geomechanical modeling of CO₂ storage can significantly enhance parameter estimation of the geomechanical response during GCS

Research Details

- Forward modeling results highlight the importance of Biot's coefficient in coupled reservoir and geomechanical models of subsurface system
- Multiple sets of parameters including both geomechanical and permeability values can match the observed data equally well
- Inverse modeling results show the inclusion of the pore pressure constraint is essential to estimate the coupled flow and geomechanical properties associated with different surface uplift data

Work was performed in the computational engineering and geoscience divisions at Sandia National Laboratories in collaboration with the University of Texas at Austin (S. Bryant) as part of the Center for Frontiers of Subsurface Energy Security (CFSES) (100% CFSES funded)



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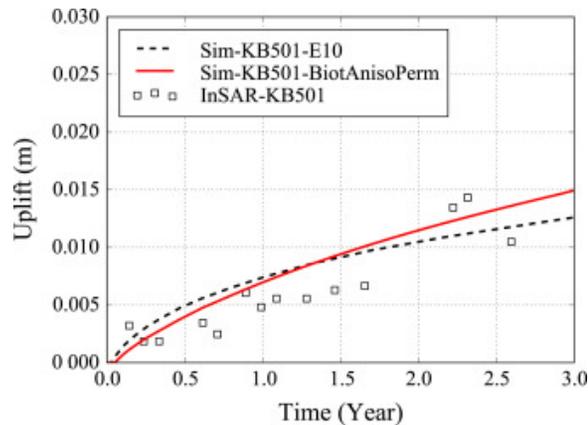
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The University of Texas at Austin



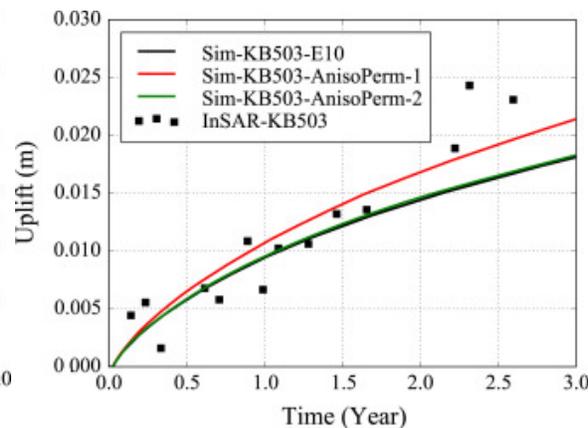
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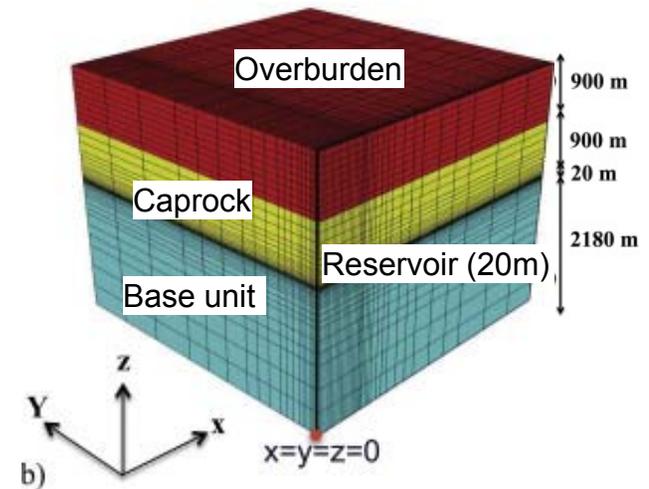
- ▶ In Salah Gas project in Algeria: CO₂ recovered in natural gas production was re-injected into a sandstone reservoir formation, resulting in the deformation of reservoir and other geological units
- ▶ Surface uplift data based on the satellite based interferometry (InSAR) was used to investigate reservoir properties and coupled flow and mechanical processes
- ▶ Two simulation domains represent two characteristics of surface uplift data (low uplift at KB501 and high uplift at KB503)
- ▶ The Sierra simulation software developed at Sandia Lab was used for the numerical analysis. Sierra is an engineering mechanics simulation code that includes a suite of highly parallelized finite element analysis modules for different physics



Effect of combination of the geomechanical (Biot's coefficient) and hydrogeological (anisotropic permeability) properties of reservoir on the surface uplift in KB501 (low surface uplift case)
(Sim-KB503-E10 is the base case)



Effect of anisotropic permeability of the reservoir on the surface uplift in KB503. This case has all the properties of the base case (Sim-KB503-E10), except the permeability field for the reservoir



Schematic of the 3-D simulation domain and finite element mesh. (Newell et al., 2016)

$$\sigma^{\text{eff}} = \sigma - bIp$$

Poroelasticity approach to account for the pore pressure effect on the stress tensor:
 σ^{eff} is the effective stress tensor
 b is Biot's coefficient
 p is the pore fluid pressure
 I is the identity tensor

Newell et al. (2016, In press, JPSE)

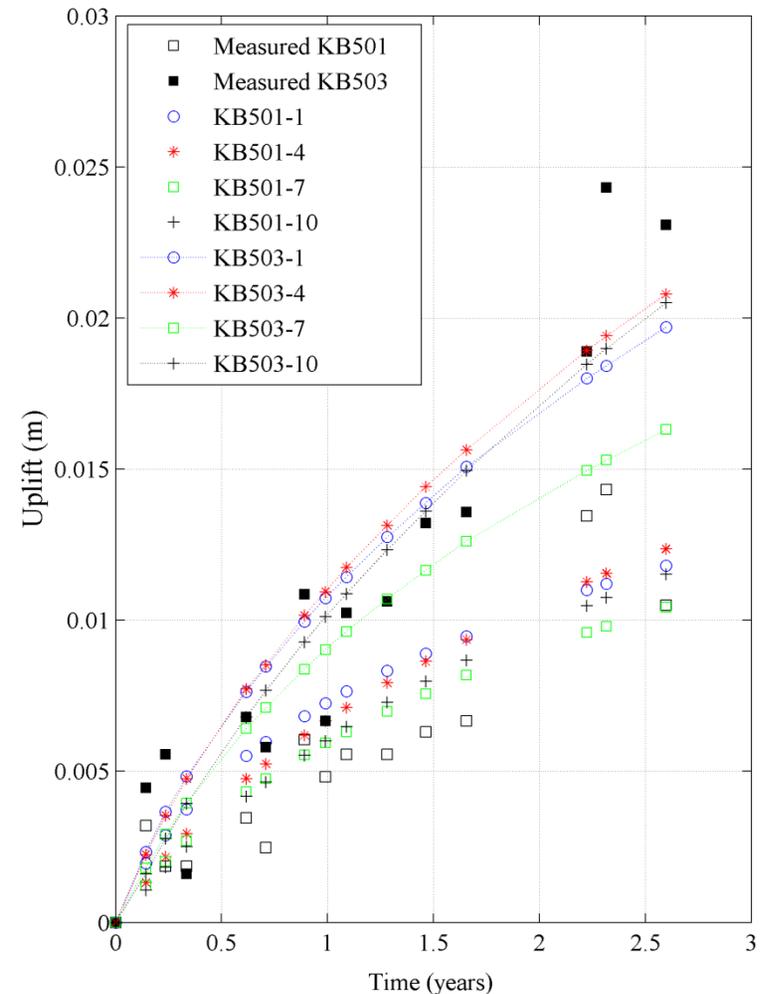
Inverse Modeling of Coupled Geomechanical and Hydrogeological Processes

Model Calibration (Inverse Modeling)

- ▶ Forward modeling results illustrated that the InSAR data can be fit equally well by variation of different sets (hydrogeological or geomechanical properties or both), demonstrating more rigorous parameter estimation is required to evaluate the impact of different properties on the surface uplift
- ▶ Key parameters investigated:
 - Caprock permeability (k_z)
 - Young's modulus of reservoir and caprock (E_{res} and E_{cap})
 - Biot's coefficient of reservoir and caprock (b_{res} and b_{cap})
 - Anisotropy ratio of the reservoir permeability (α_{res})
- ▶ Parameter estimation package PEST for model calibration
- ▶ Measured data:
 - Surface uplift and maximum pore pressure increase (10 MPa)

Key Implications

- ▶ Multiple sets of parameters can match the observed data equally well and the inclusion of the pore pressure data is critically important to constrain the parameter solution during inverse modeling
- ▶ Parameter estimation with surface uplift and pore pressure data can be utilized to determine optimal operation conditions during GCS (e.g, CO2 injection rates, failure criteria)



Comparison of observed and modeled uplifts for KB501 (symbol only) and KB503 (symbol+line) with different calibrated sets of parameters

