Spatial-temporal risk mapping at a geologic carbon sequestration site

Brandon Schwartz

PennState

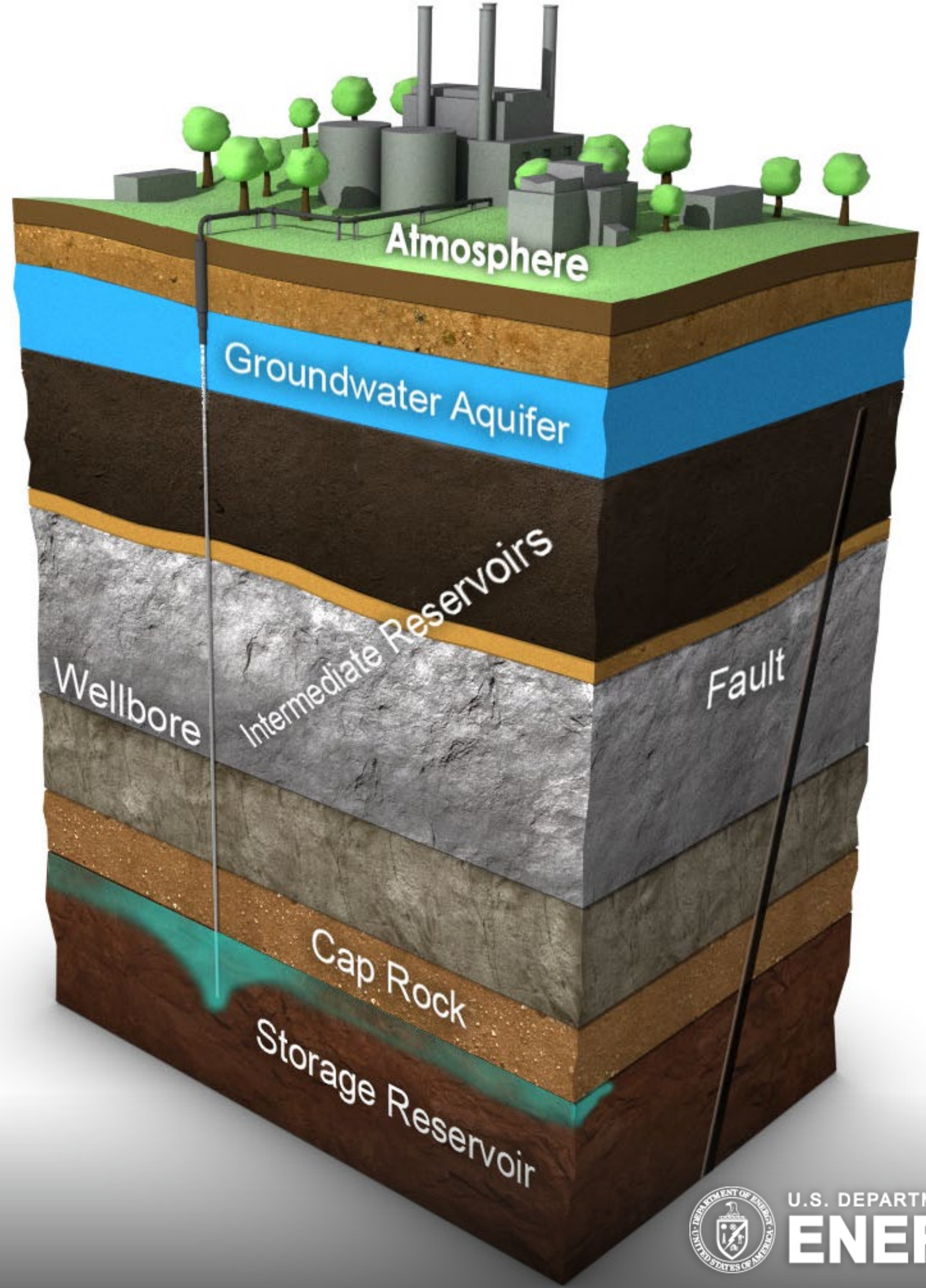
NRAP
National Risk Assessment Partnership

NATIONAL ENERGY TECHNOLOGY LABORATORY

BERKELEY LAB

Los Alamos NATIONAL LABORATORY EST.1943

Pacific Northwest NATIONAL LABORATORY



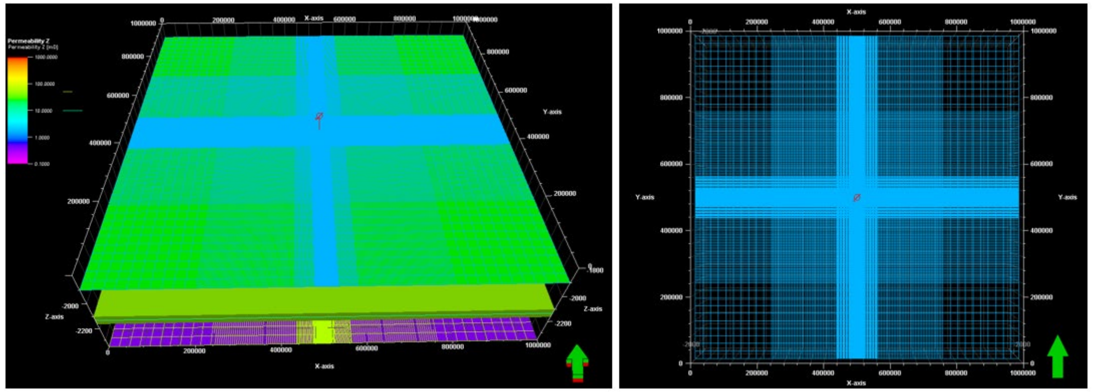
U.S. DEPARTMENT OF ENERGY

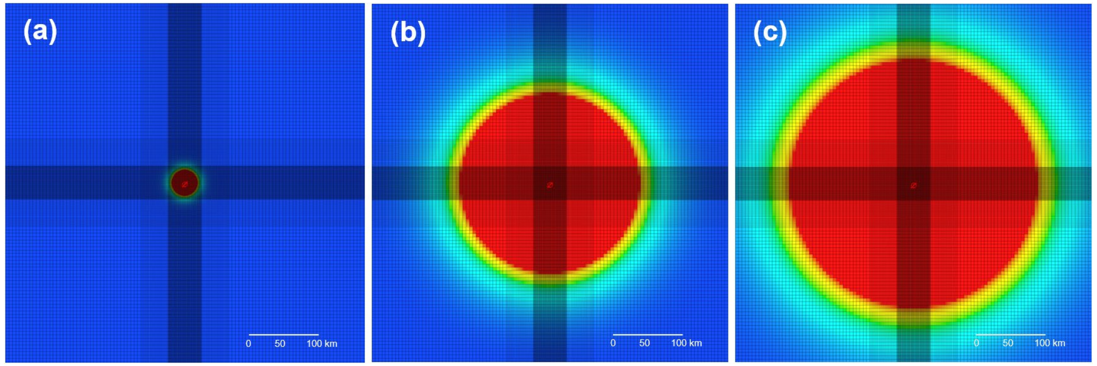
Summary

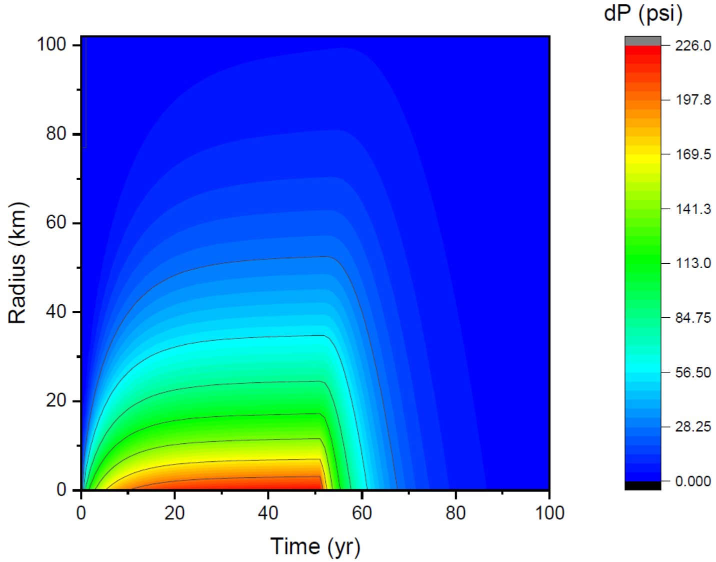
- Topic arose from NRAP Task 6 discussions concerning the subsurface drivers of PISC length
  - What combination of project variables leads to shorter PISC periods?
- This work explores six standard variables: Q, μ, k, h, ϕ, C_t
  - We show that these variables can be grouped: $H = \frac{Q\mu}{kh}$ & $S = C_t \varphi r^2$
- We explore the dependence of pressure evolution on S and H
- We create spatial-temporal maps of leakage risk

Model Development

- Layer cake reservoir model of radial flow with Tartan grid
- Vary properties and measure pressure over 64 combinations of:
  - Q: 0.5 & 3 Mt/a
  - μ: 0.3 & 1.3 cP
  - h: 100 & 500 m
  - k: 50 & 400 mD
  - ϕ: 10% & 40%
  - Ct: 10^{-6} & 10^{-5} psi^{-1}
- 50 years injection, 50 years PISC
- Sample along one radius for lookup tables

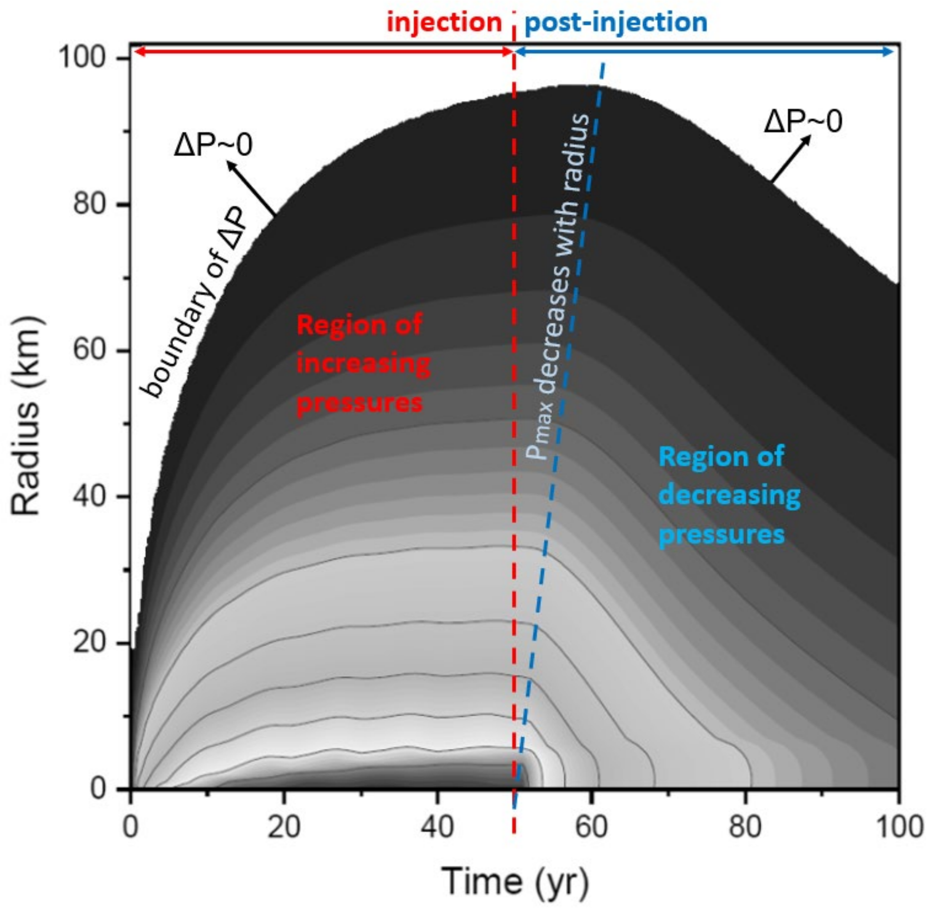






Top: Petrel model. Middle: Pressure evolution at 1 year, 50 years, and 100 years. Bottom: Radius vs time plots showing pressure increase for the entire project.

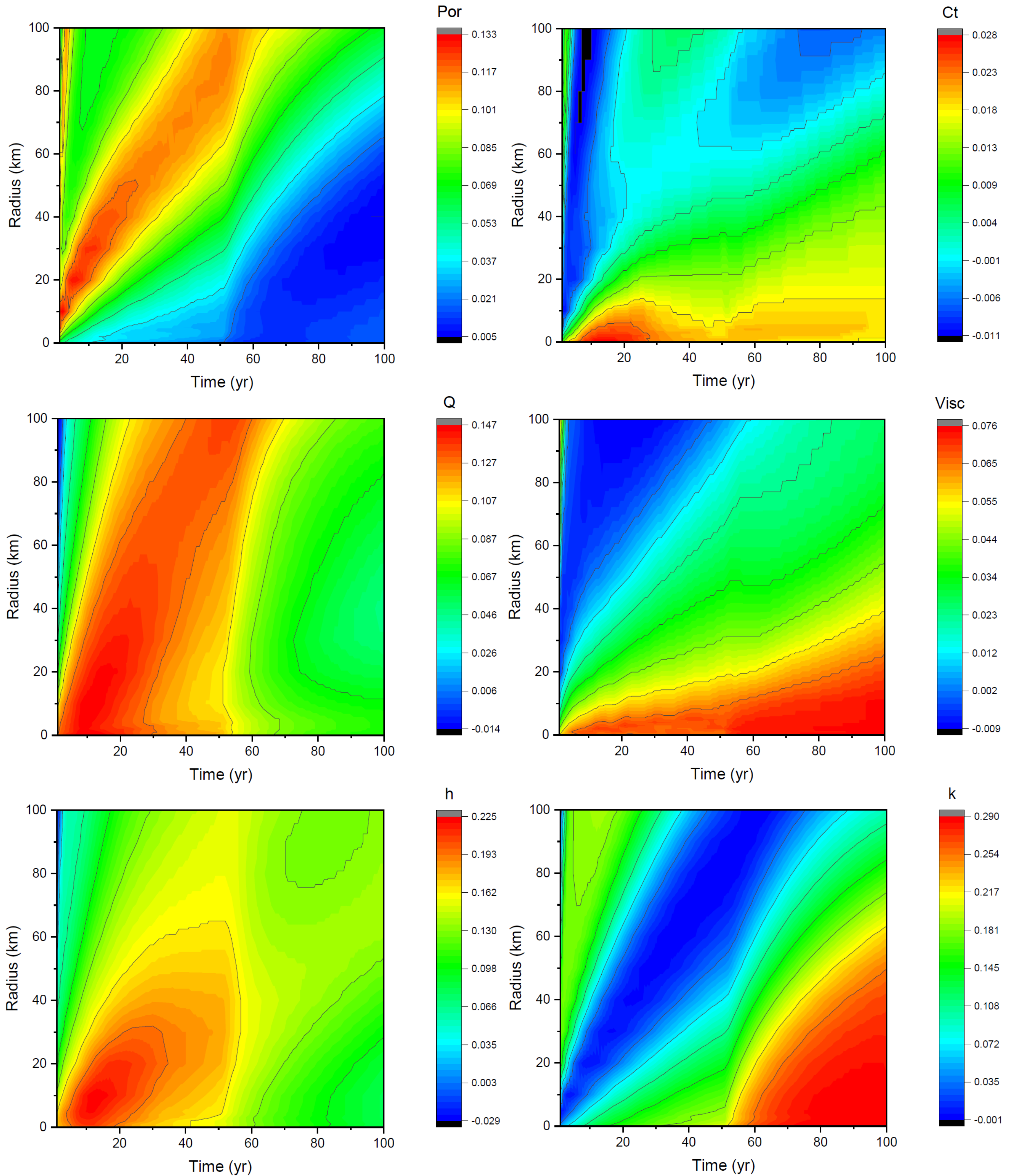
Spatial-temporal Mapping

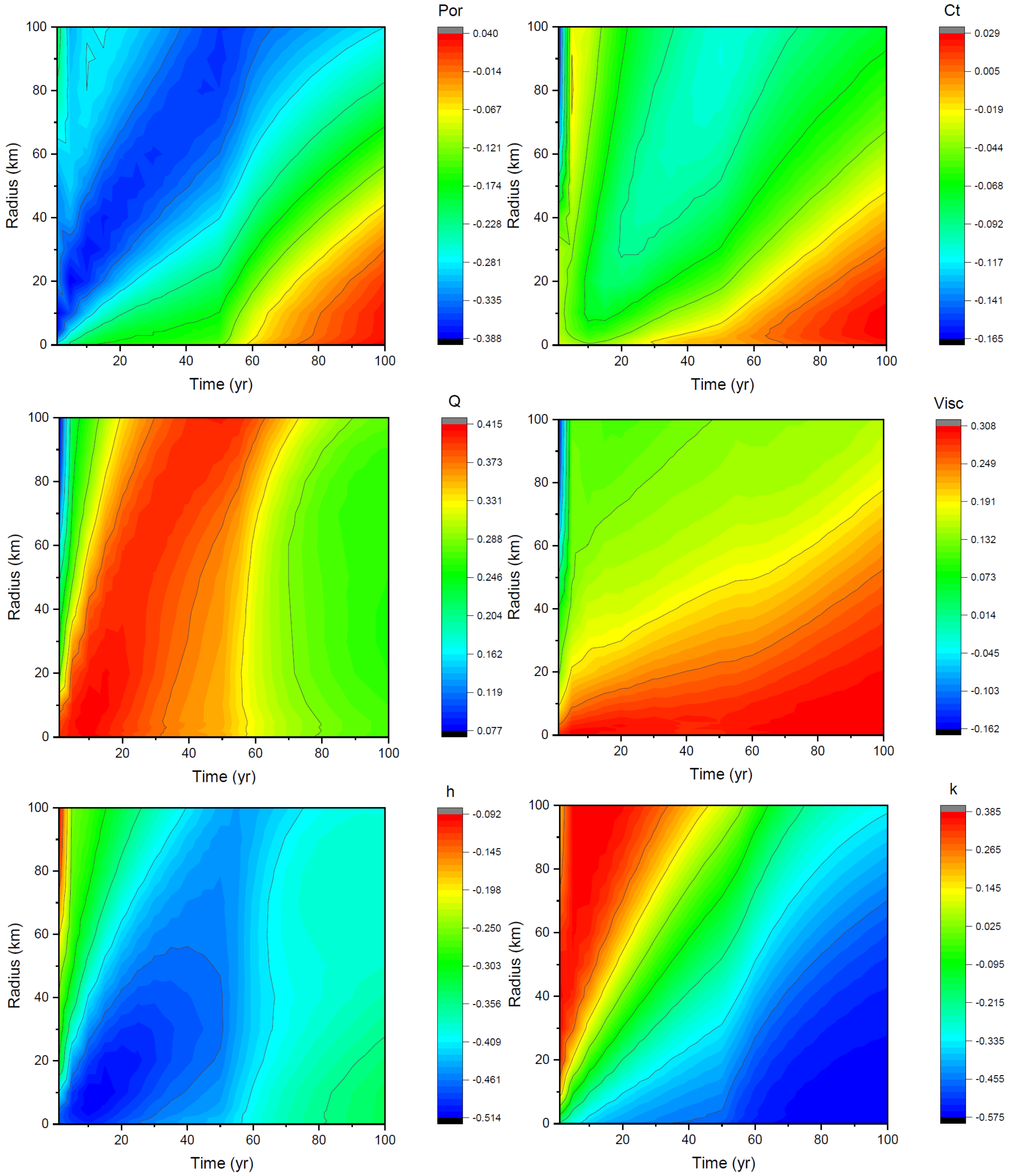


- Radius vs time
- Boundary of pressure front
- Region of increasing pressure during injection; decreasing pressures post-injection
- Post-injection buildup strongly influenced by H
  - $H = \frac{Q\mu}{kh}$

1st Order Sensitivity of Individual Variables

- Porosity and rock compressibility have low sensitivity
- Injection rate and reservoir thickness has a stronger influence during the injection period
- Brine viscosity has a low sensitivity that follows the pressure plume
- Permeability has a stronger influence on nearfield pressure





Correlation Coefficients of Individual Variables

- Porosity and rock compressibility have a negative correlation with pressure buildup
- Injection rate and brine viscosity have a positive correlation with pressure buildup
- Reservoir thickness and permeability have a negative correlation with pressure buildup

2 Grouped Variables

H is a measure of flow resistance:

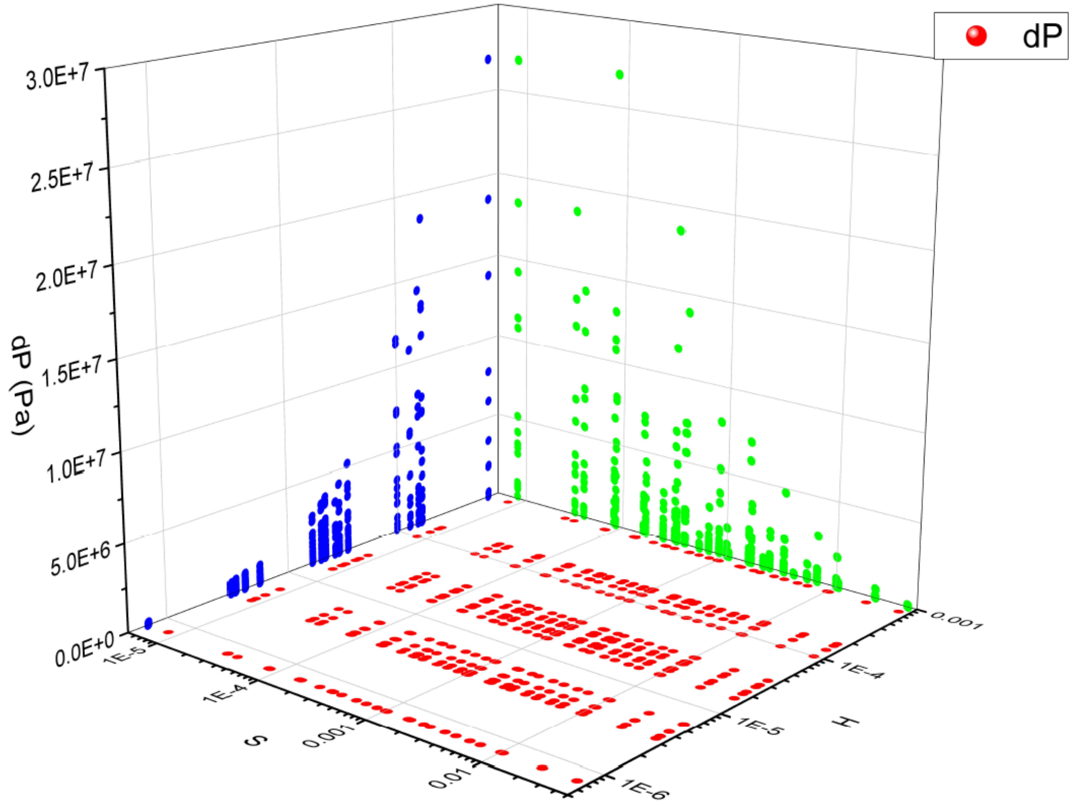
- $H = \frac{Q\mu}{kh}$
- Units: Pa

S is a measure of storage capacity:

- $S = C_t \varphi r^2$
- Units: m^2/Pa

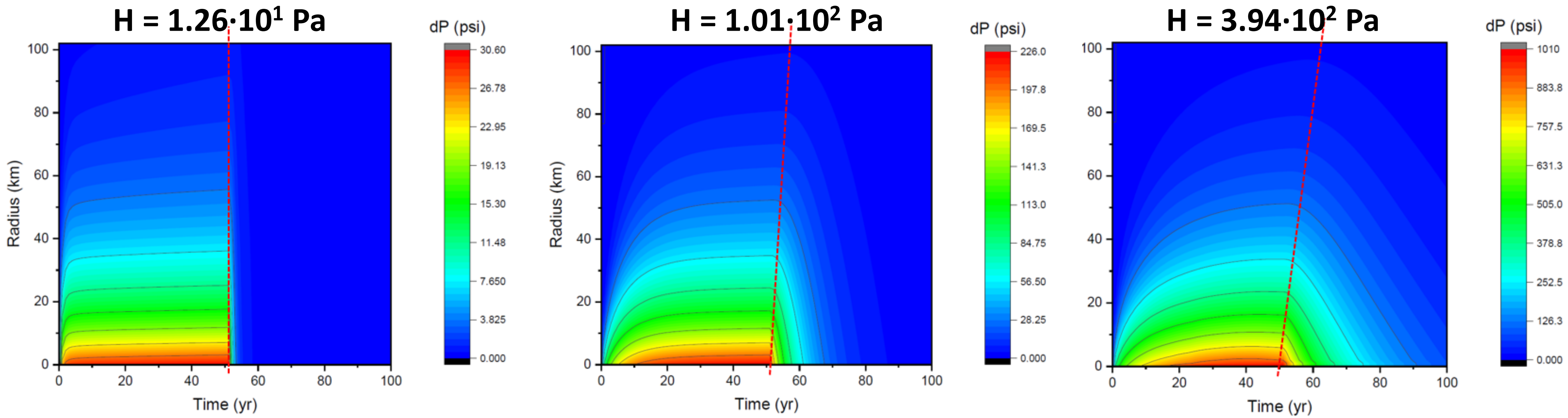
Both variables can predict pressure evolution during injection and PISC periods. H is a much stronger predictor, especially a) during injection and b) close to the wellbore

High values of H and low values of S correspond to higher pressure buildup



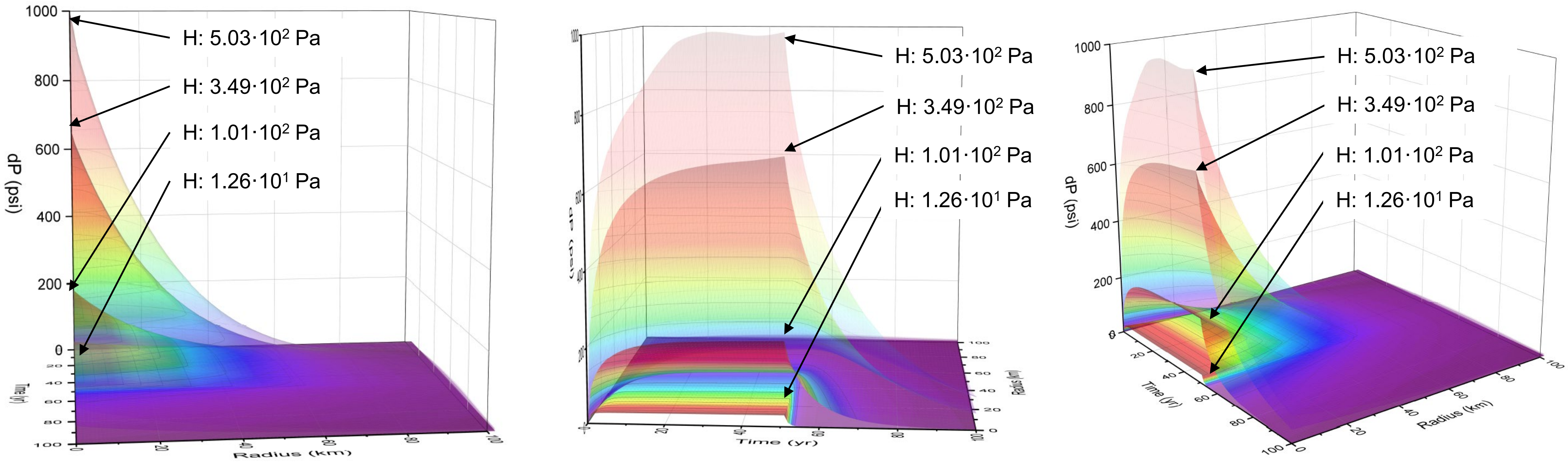
Petrel → OriginPro

Results: Pressure Evolution



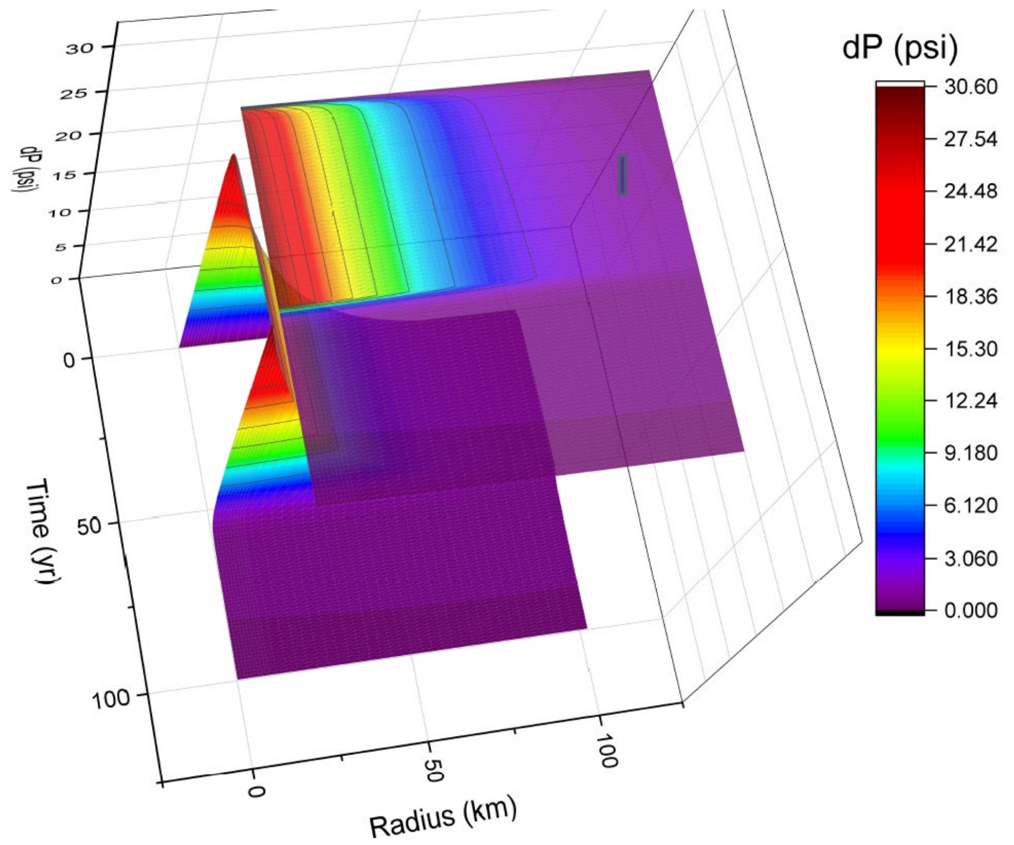
- For all cases, pressure buildup is characterized as
  - Close to the injector
  - Largest during the injection period
  - Rapidly falls off during PISC
- Pressure buildup is largest for
  - High H, Low S
  - High Q, μ
  - Low k, h, ϕ, C_t, r
- PISC pressure “move out” controlled by H

Pressure Buildup Dependence on H

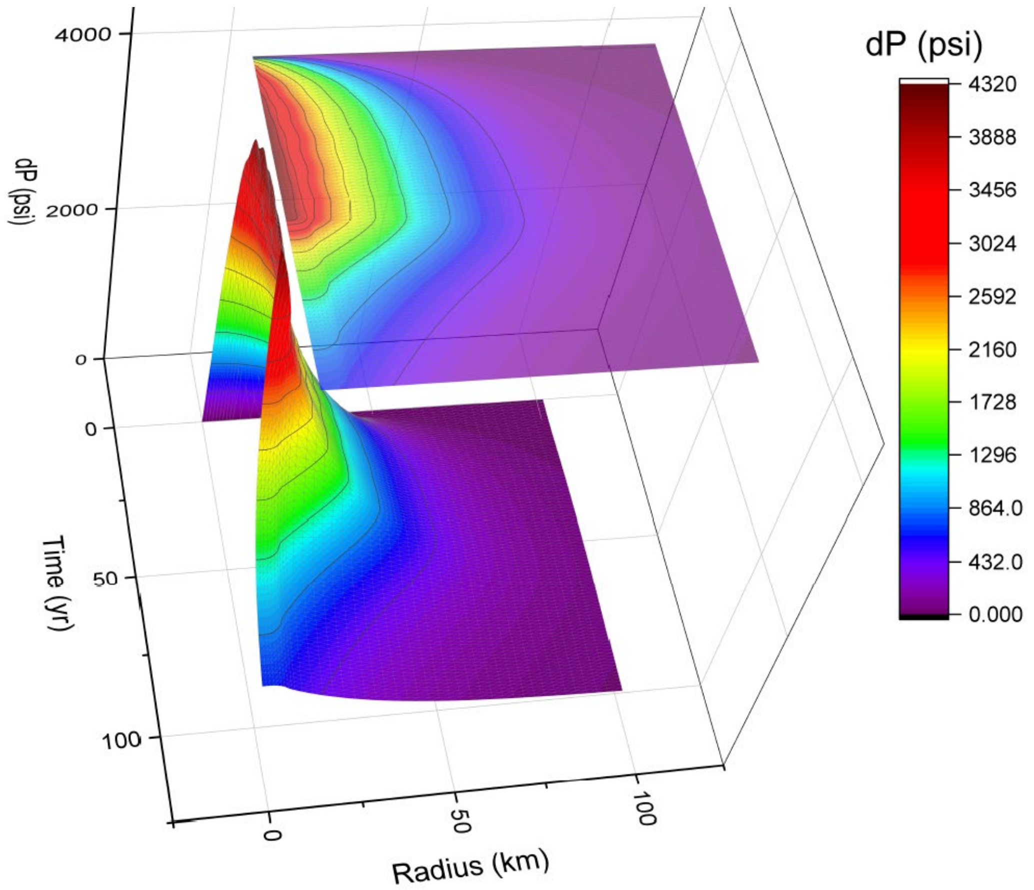


Low values of H have quick pressure drops after injection ceases

Low H

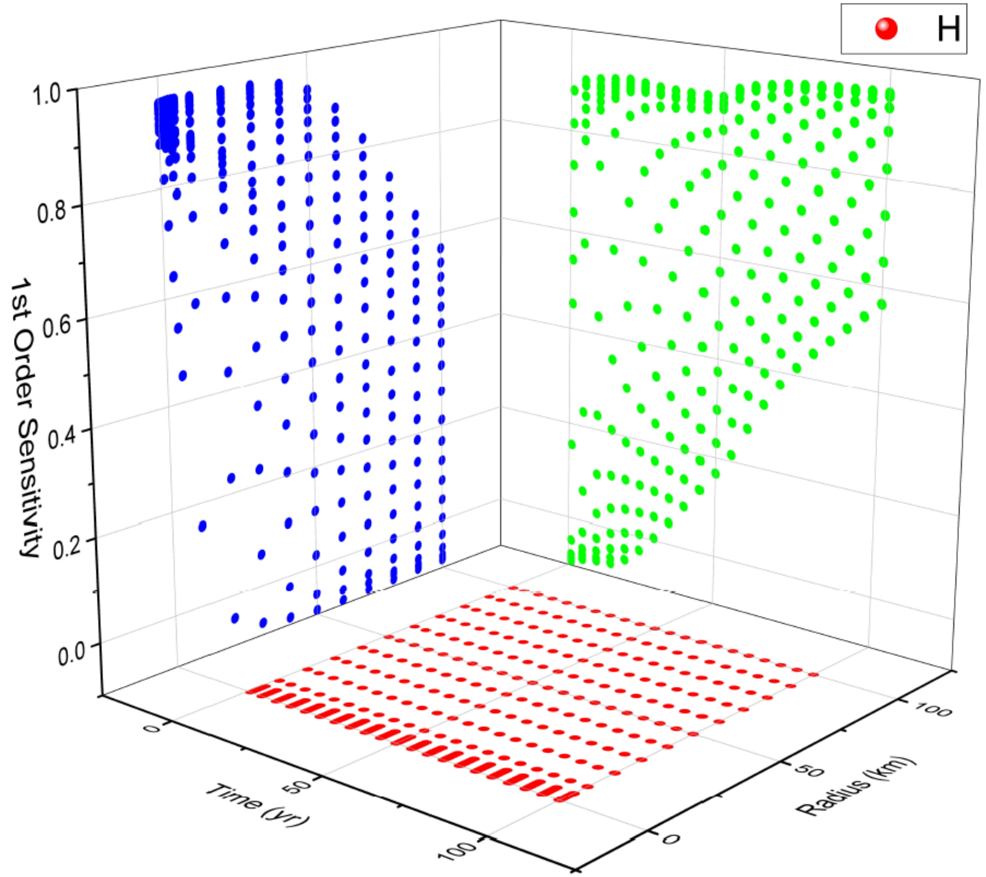


High H



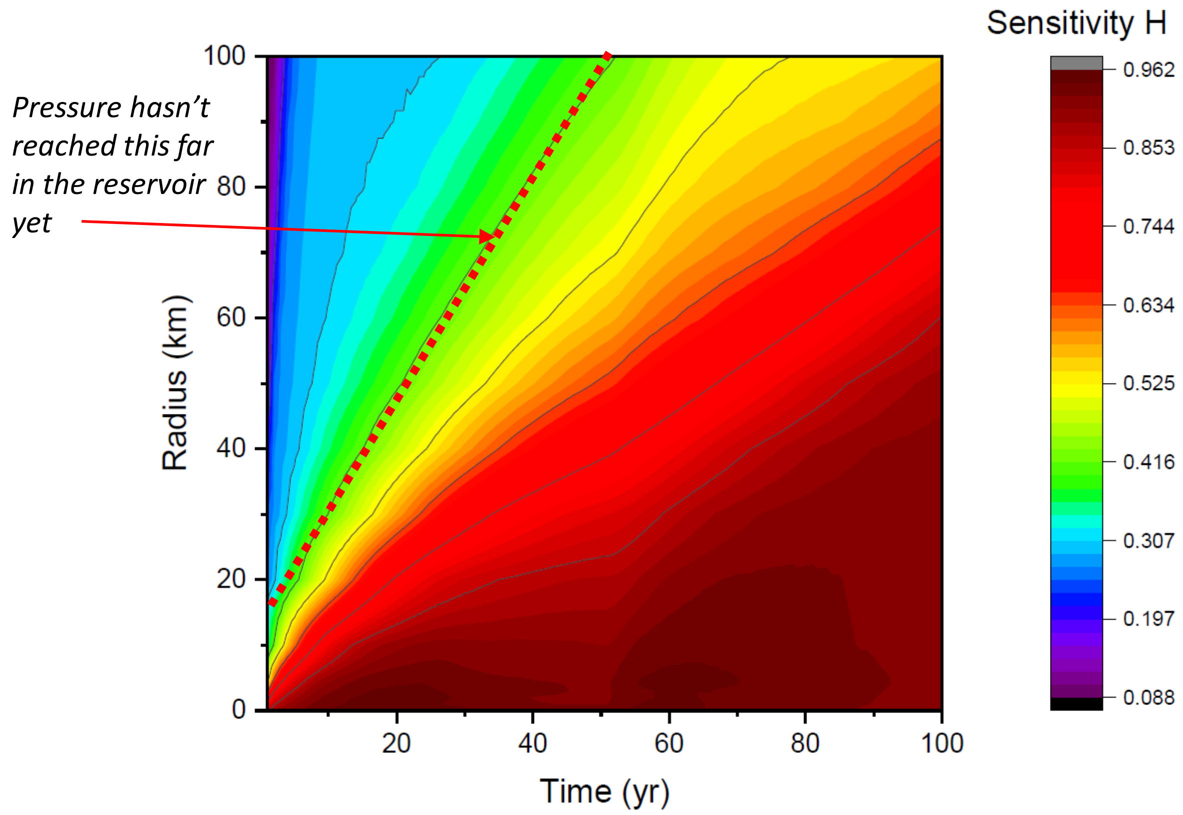
1st Order Sensitivity

- Used Open-IAM to calculate time series sensitivity at certain radii
- H has a high 1st order sensitivity, especially from 0-50 years and close to the wellbore
- S is analyzed with radius removed in order to use Open IAM
  - $S = C_t \varphi r^2$
  - $S' = C_t \varphi$

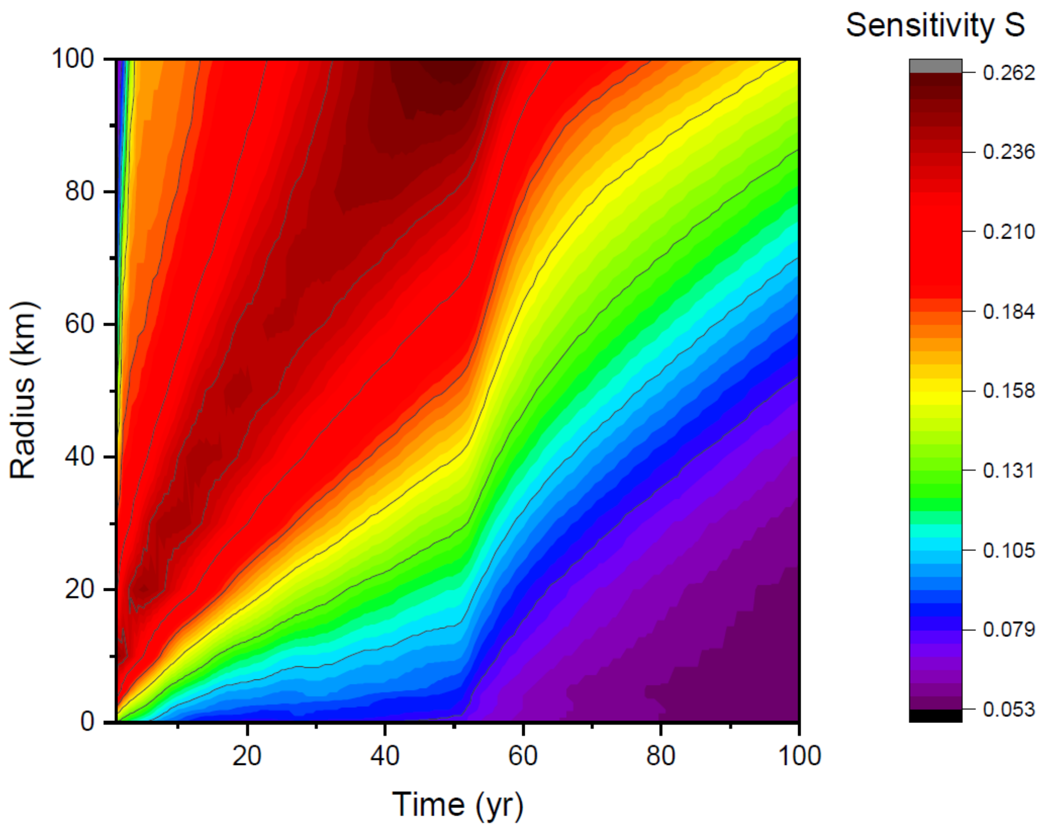


1st Order Sensitivity of Grouped Variables

H strongly predicts pressure buildup

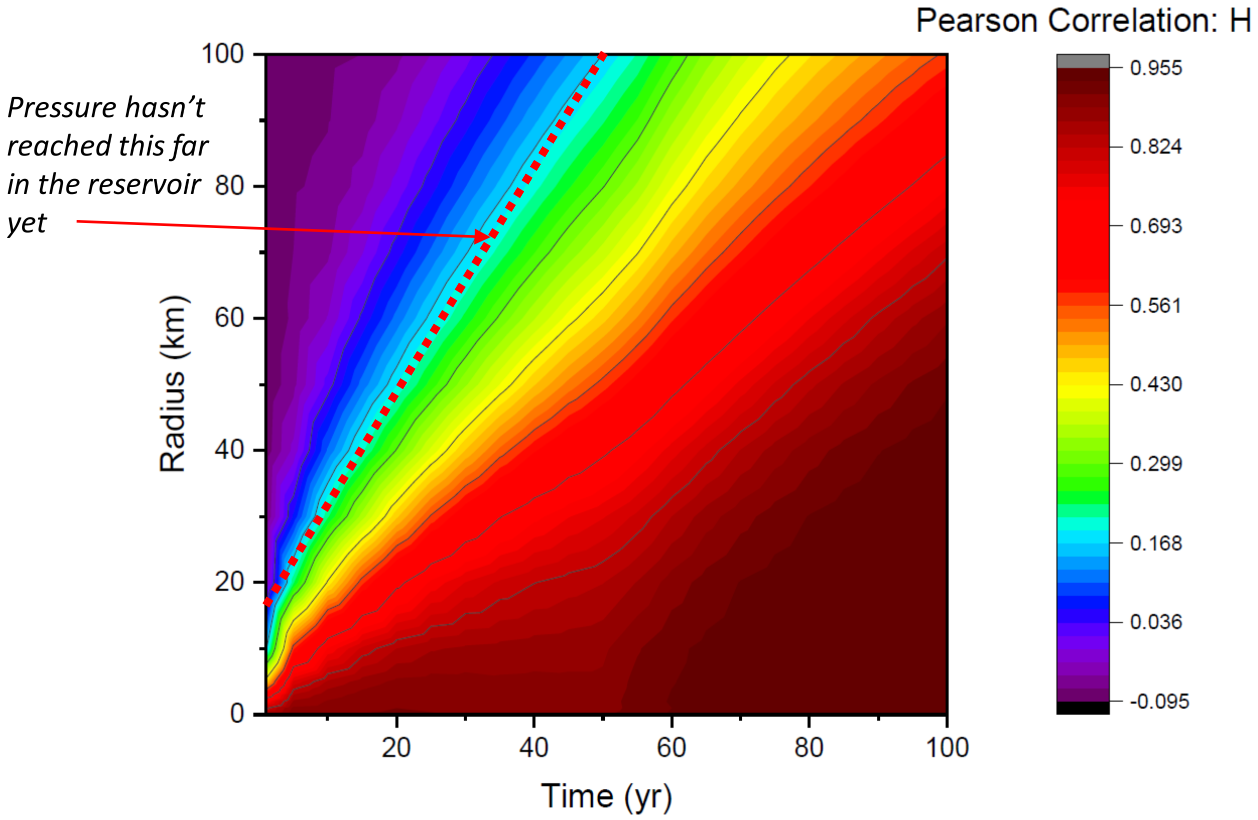


S predicts pressure buildup during PISC far away from well

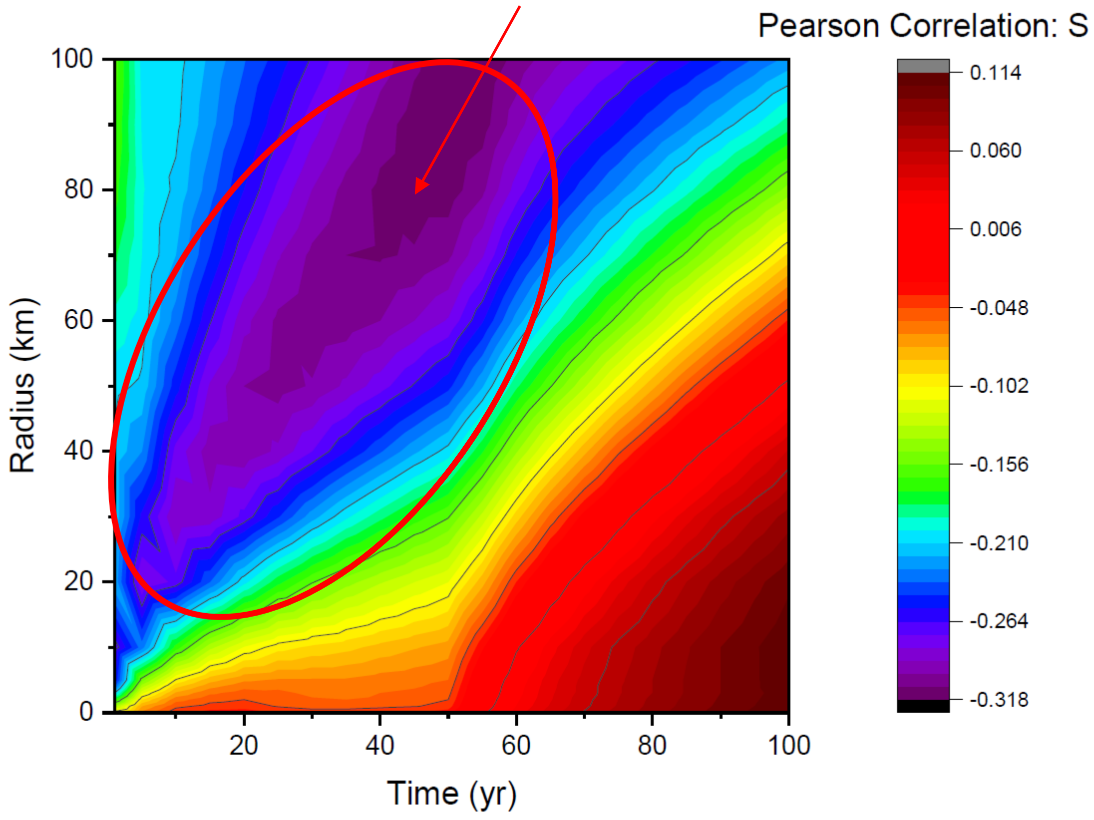


Correlation Coefficients

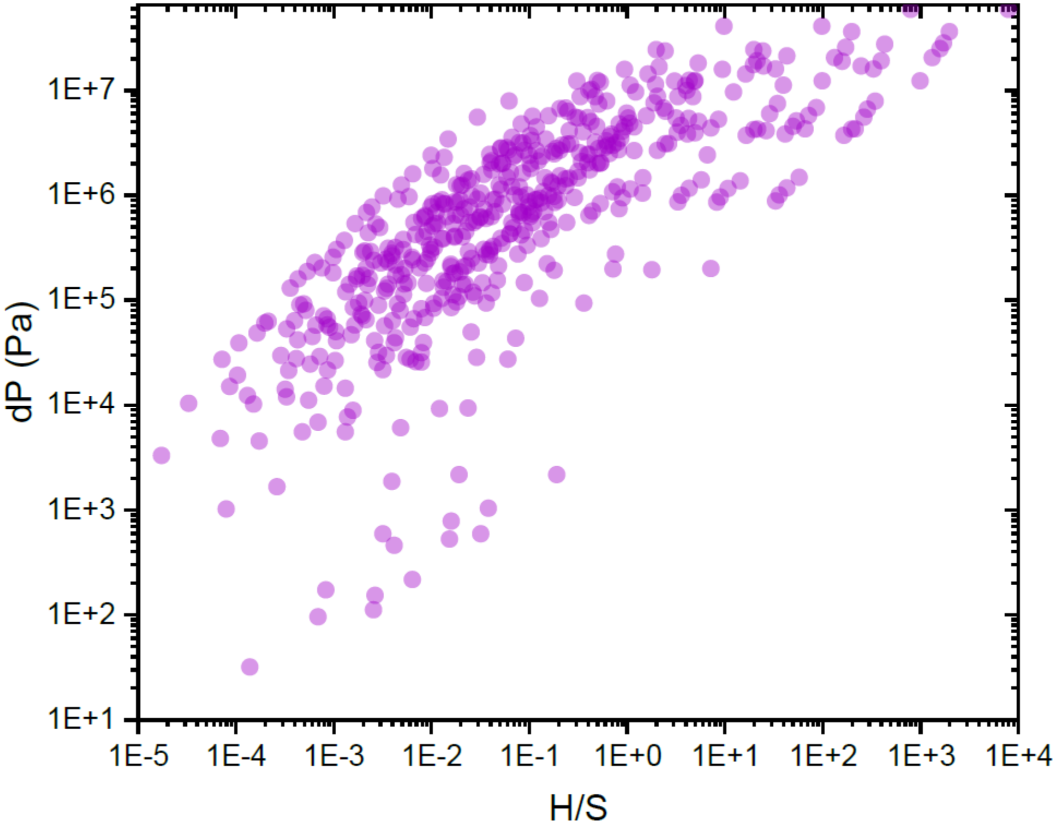
H strongly predicts pressure buildup

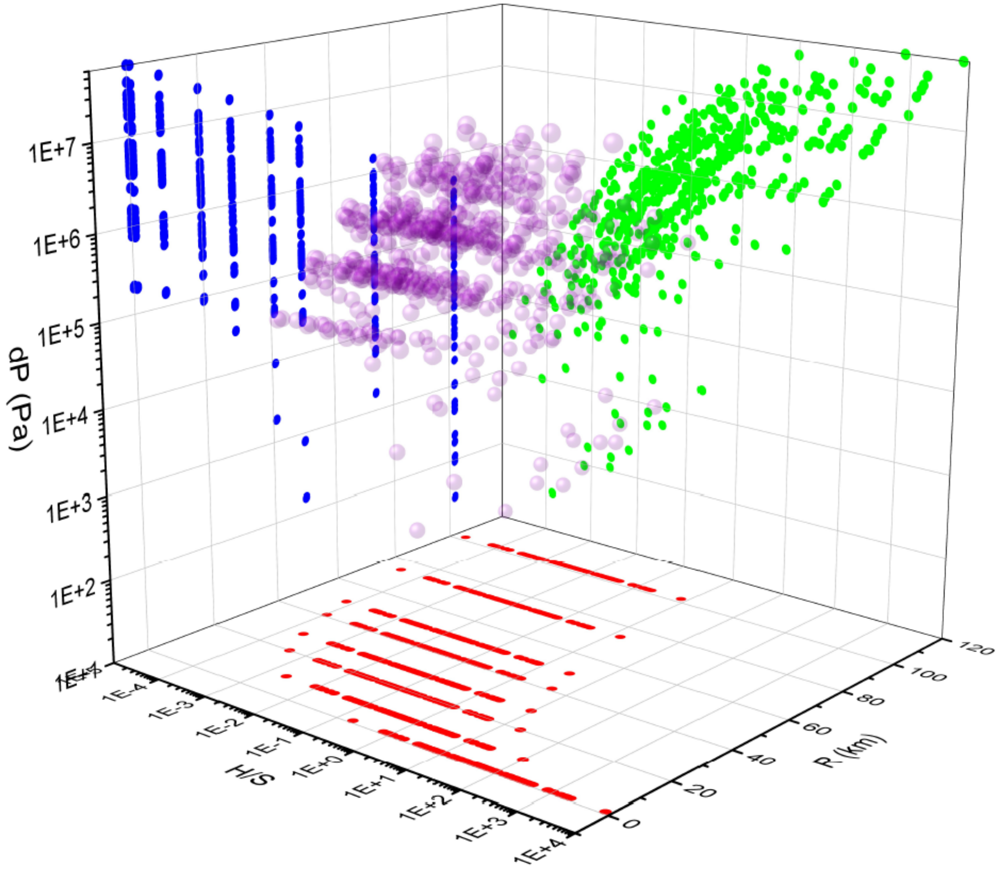


S predicts pressure buildup during PISC far away from well



Data for H and S suggest that H/S should better predict pressure evolution

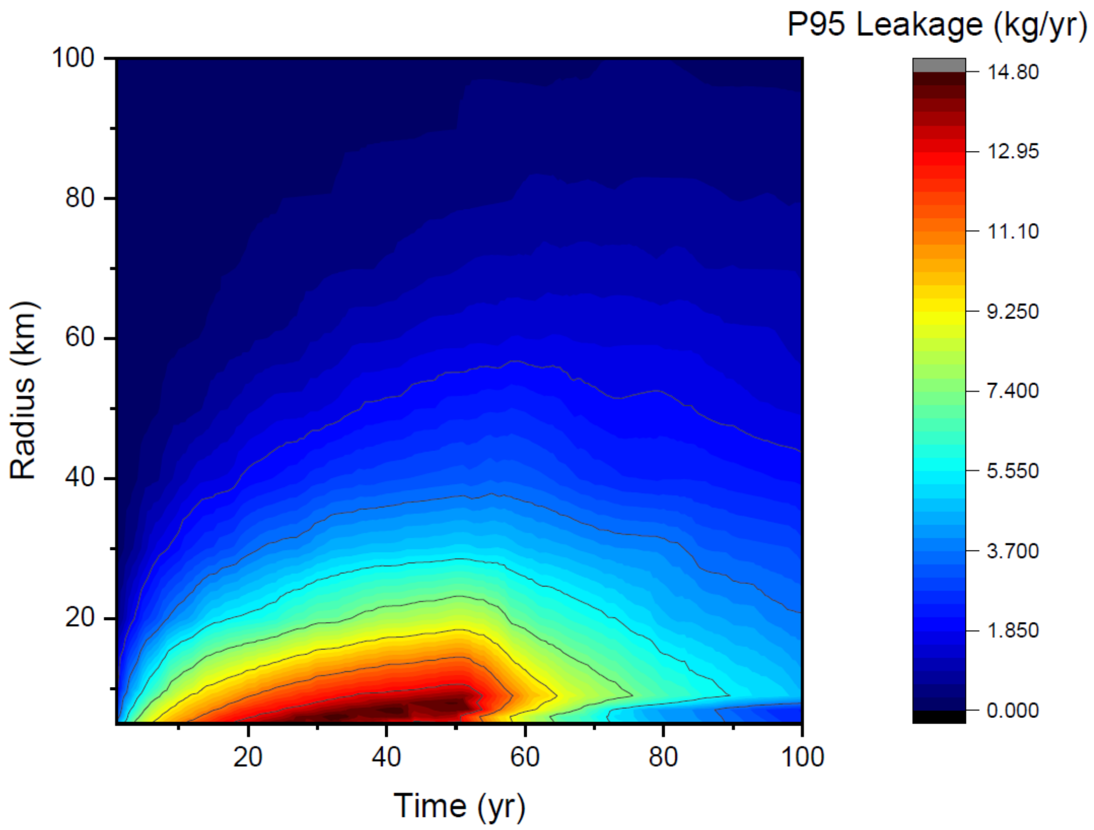




Mapping risk of leakage vs radius and time

- Using NRAP Open-IAM, wellbores were placed at increasing radial distance from the injector
- Well permeability (log) was varied between -17 and -13
- Lookup tables for all combinations of subsurface variables were used to generate 10,000 realizations with varying well permeability
- P95 leakage rate was selected and mapped vs. radius and time
  - *Open-IAM utilizes a conservative approach which may be considered specific to over-pressured reservoirs*

Result: Spatial-temporal Leakage Risk Map



- Left: P95 of leakage rate into aquifer
  - *95% of 10,000 realizations had leakage equal or less than shown*
- The P95 leakage occurs when $\log(k_{well})$ is -13.2
  - Solution is dependent on range of permeabilities selected
- Leakage risk is concentrated a) during the injection period and b) closer to the injector

Thank you!

Questions?

schwartz@psu.edu