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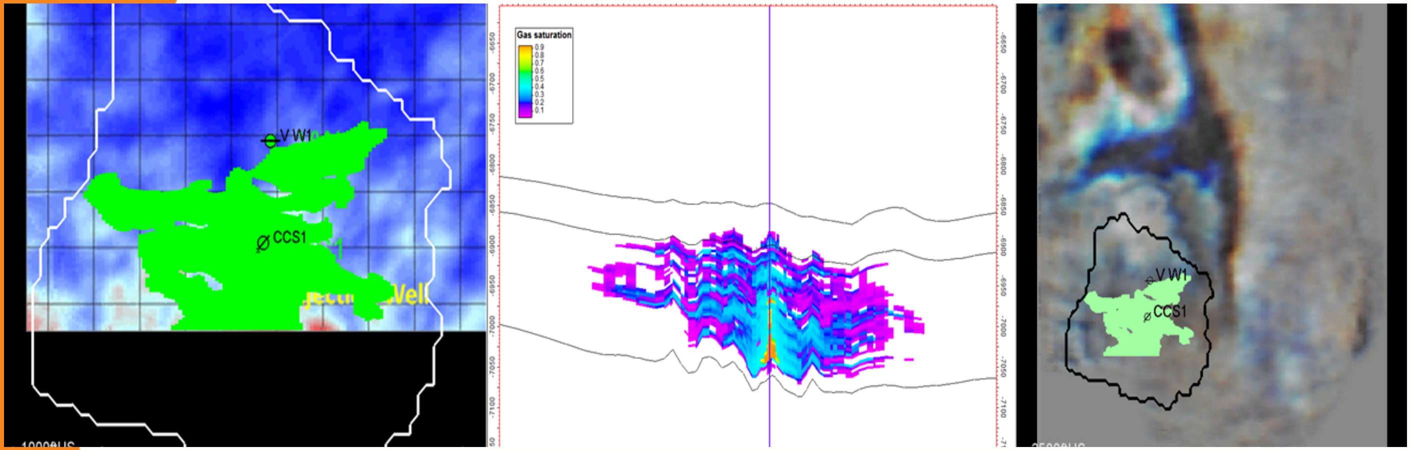

IBDP/ICCS Dynamic Model Update

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Outline

- Modeling Overview
- IBDP Budget Period 5 Reservoir Model Update Plan
- Time-lapse Seismic Integration
- Geomechanics for Microseismic
- ICCS Class VI Permit Area of Review (AoR) Model Update

Modeling Overview

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- **Ongoing IBDP Modeling Efforts:**
  - Geological (static) modeling
  - Reservoir simulation modeling
  - Geomechanical modeling
  - Coupled Hydro-mechanical modeling
- **Common (Modeling) Objective:** Develop and demonstrate reliable methods for assessment of CO_2 storage/containment and plume forecasting.
- **Common Motivation(s):** Regulatory compliance (Class VI), site development planning.
- **Monitoring:** Repeat RST* reservoir saturation tool logs, well pressures, time-lapse seismic, microseismic.

Different Questions

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“Where is the plume now?” (monitoring)

versus

“Where might it be in XX years and what can I do to influence that outcome?” (forecasting)

Modeling Overview

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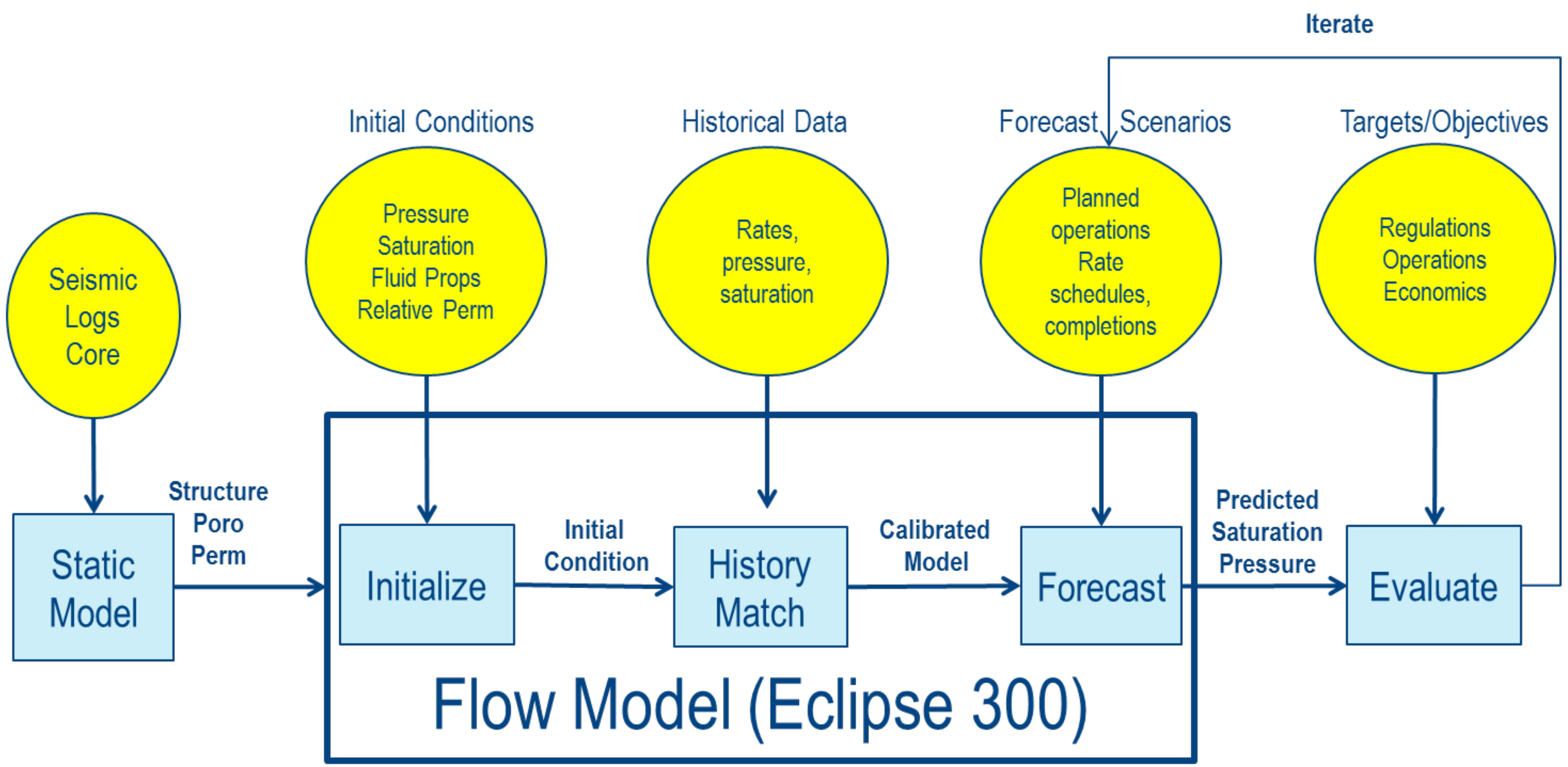
Final Stages of the Project: All modeling efforts come together using cross-disciplinary workflows to "close the loop" between monitoring data and dynamic models to improve storage assessment (static) and plume predictions (dynamic).



Budget Period 5 Reservoir Modeling Plan Summary

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Key Tasks:

1. **Quantitative integration of time-lapse RST measurements**:
   Prior work on qualitative RST integration will be expanded upon by use of RST measurements in a numerical optimization process.
2. **Time-lapse seismic assisted reservoir model calibration:**
   Application of rock-physics based seismic predictions from a CO_2 simulator model for calibration of the reservoir simulator model.
3. **AoR Forecasting uncertainty:**
   Quantitative analytical support for use of a calibrated model as a proxy for some direct monitoring measurements.
4. **History matching of induced microseismicity using geomechanical modeling:**
   Lessons learned from previous work (presented as a poster at the GHGT-12 conference) will be implemented in continuing work.

Time-Lapse Seismic Surveys

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- Due to complex fluid-rock-reservoir geometry factors seismic does not "see" the entire plume.
- Fluid detection is limited to high saturation x thickness intervals (typically nearest the injection well).
- Only qualitative interpretation possible with stand-alone seismic data.
- Rock physics based integration within a representative geological framework is required to reduce ambiguity of interpretation.

➢ **Time-lapse seismic data can be integrated quantitatively to help calibrate the dynamic model.**

Time-Lapse Seismic Attributes

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- **Amplitude Differences** – 3D volume attribute. Effective for strong Base-Monitor differences and/or very good acquisition conditions.
- **Predictability** – 2d map attribute. Measure of the similarity between base and monitor data within a time window. The ability to predict Monitor survey from the Base survey.
- **Normalized Root Mean Square (NRMS)** – 2D map attribute. Measure of the differences between Base and Monitor survey data within a time interval.
- **Non Rigid Matching (NRM) Displacement** – 3D volume attribute. Time shift required to match Base and Monitor survey data.

✓ NRM displacement can be modeled using rock physics to “close the loop”.

Time-Lapse 3D VSP Surveys

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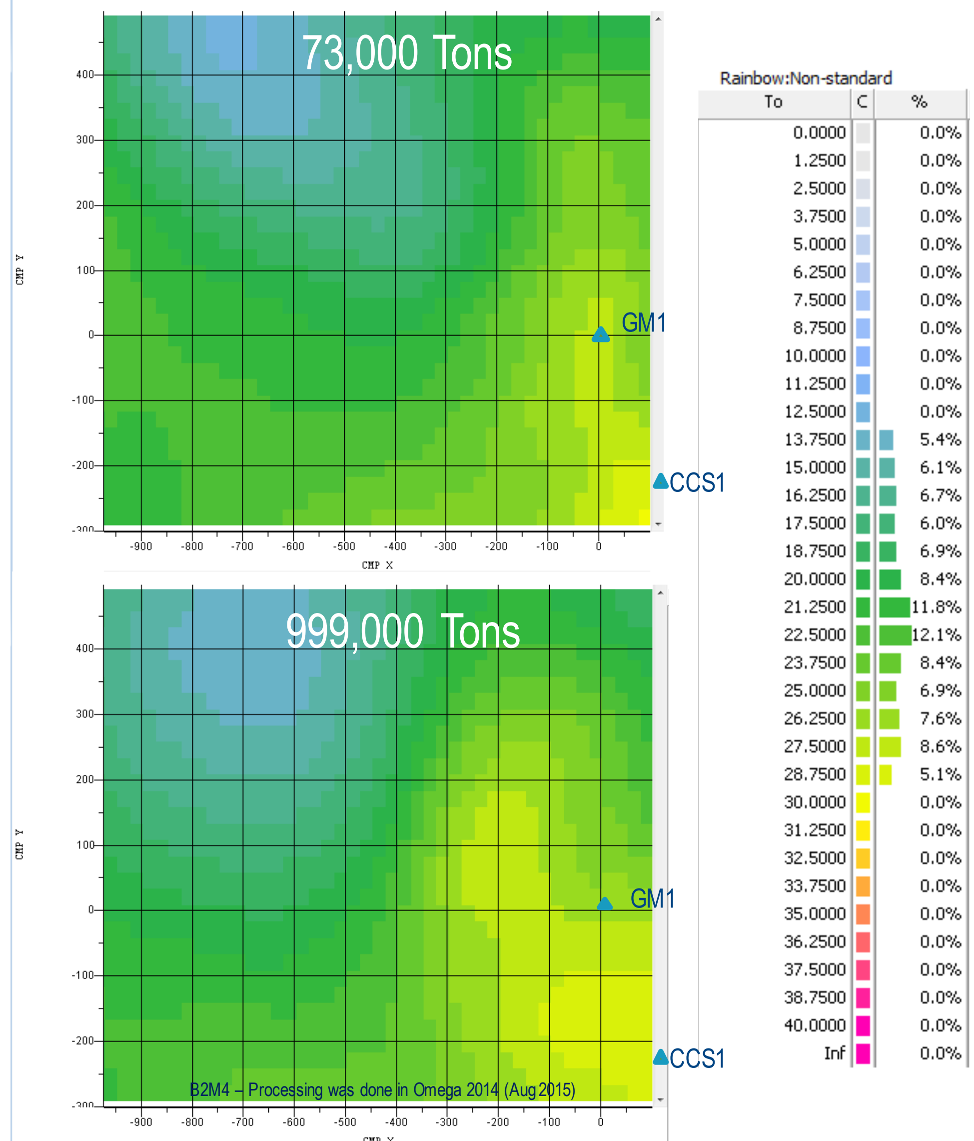
- 2 baseline and 4 monitor surveys were analyzed.
- The most stable time-lapse result was achieved using the final monitor survey with maximum CO_2 injected.
- NRMS generally consistent with modeled CO_2 plume.
- Covers a limited footprint.



Time-Lapse VSP NRMS and Modeled CO_2 Saturation Plume

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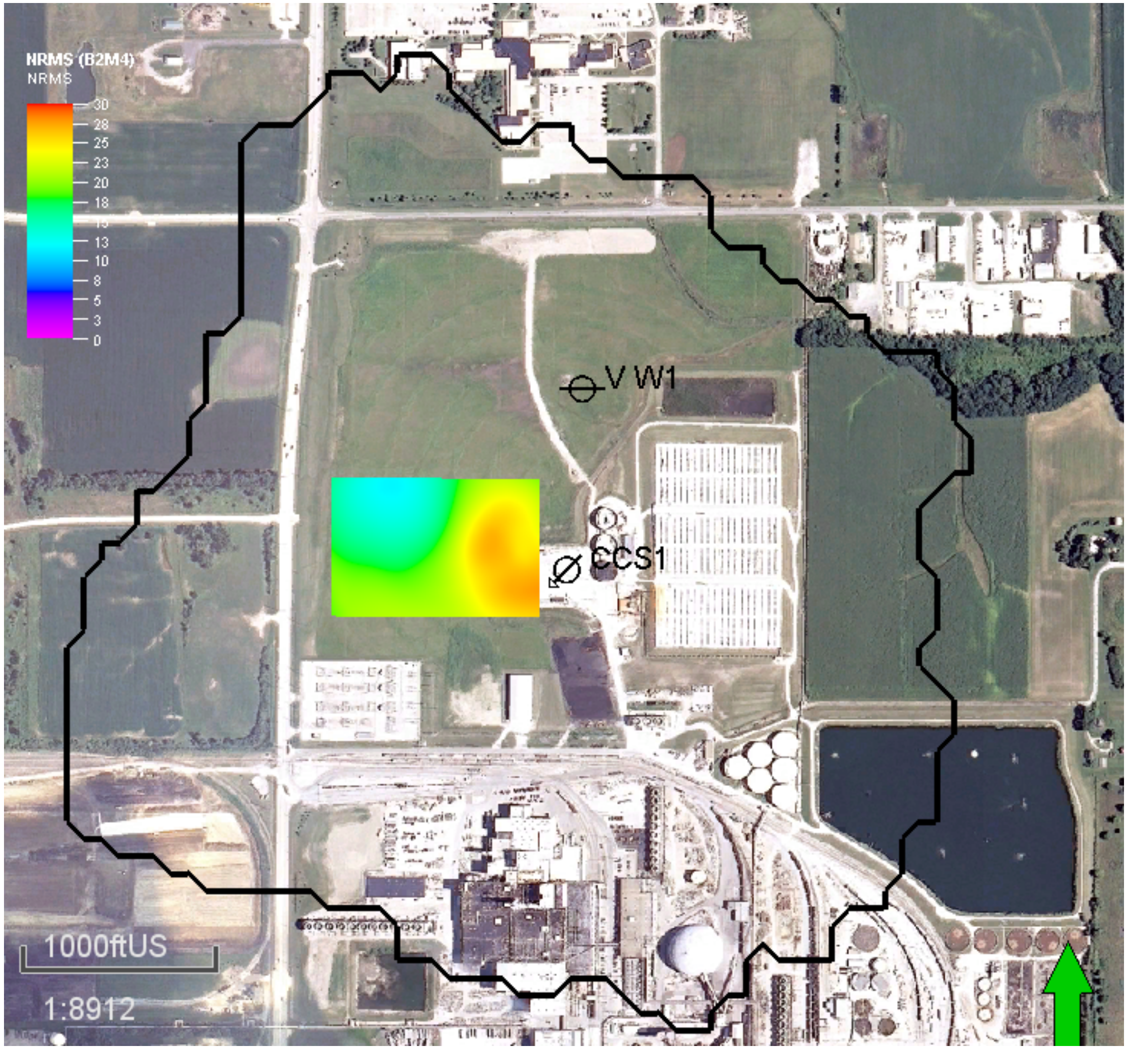
VSP NRMS map and 1% Saturation Boundary of Simulated Plume



3D Surface Seismic Time-Lapse Attributes

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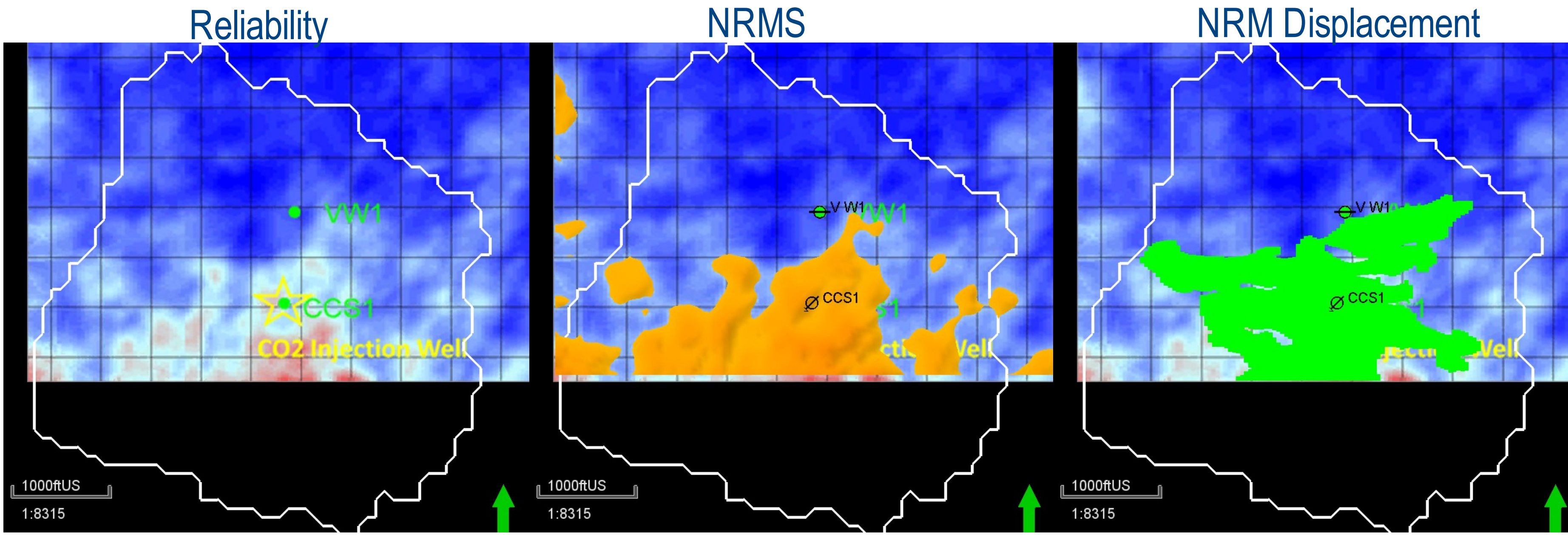


Key Observations

2 Footprint

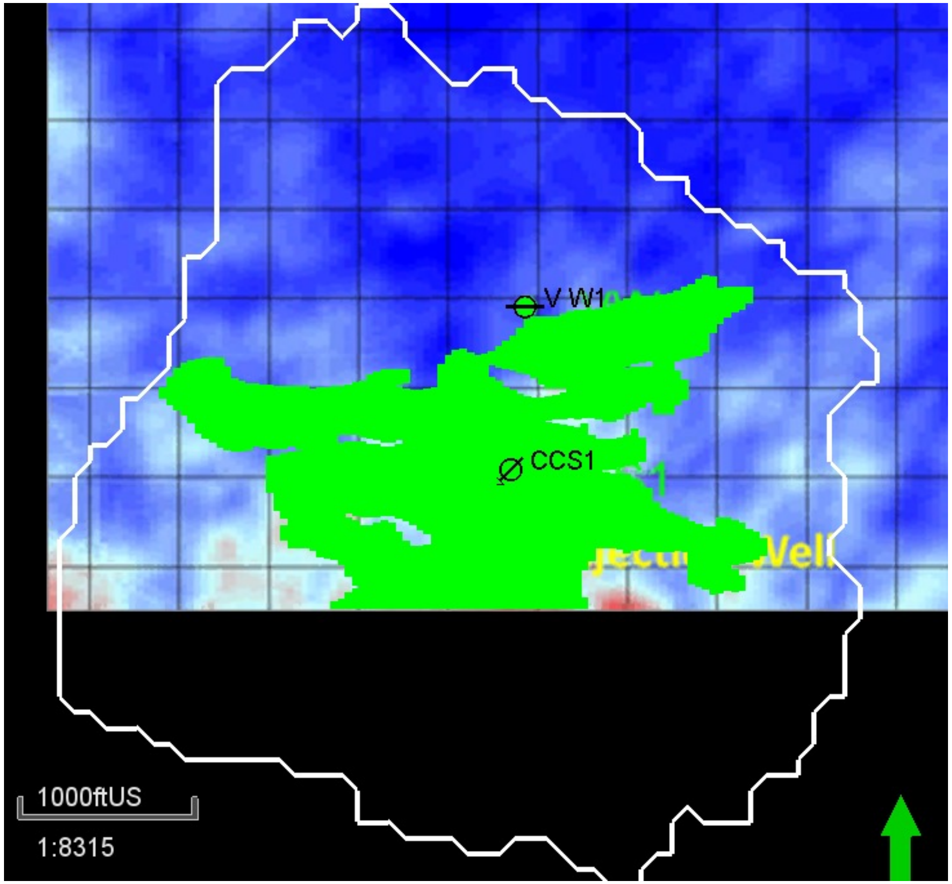
1 Consistency between attributes

3 Difference in symmetry/shape … anisotropy (structural or property control)

Integrating Time-Lapse Attributes

- Why are modeled and measured results different?
  - Detection limit.
  - Model deficiencies.
- Dynamic model calibration is poorly constrained in the inter-well space.
- How do we use time-lapse seismic data to improve the reservoir model?

NRM Displacement



Quantitative Integration of Time-lapse Data

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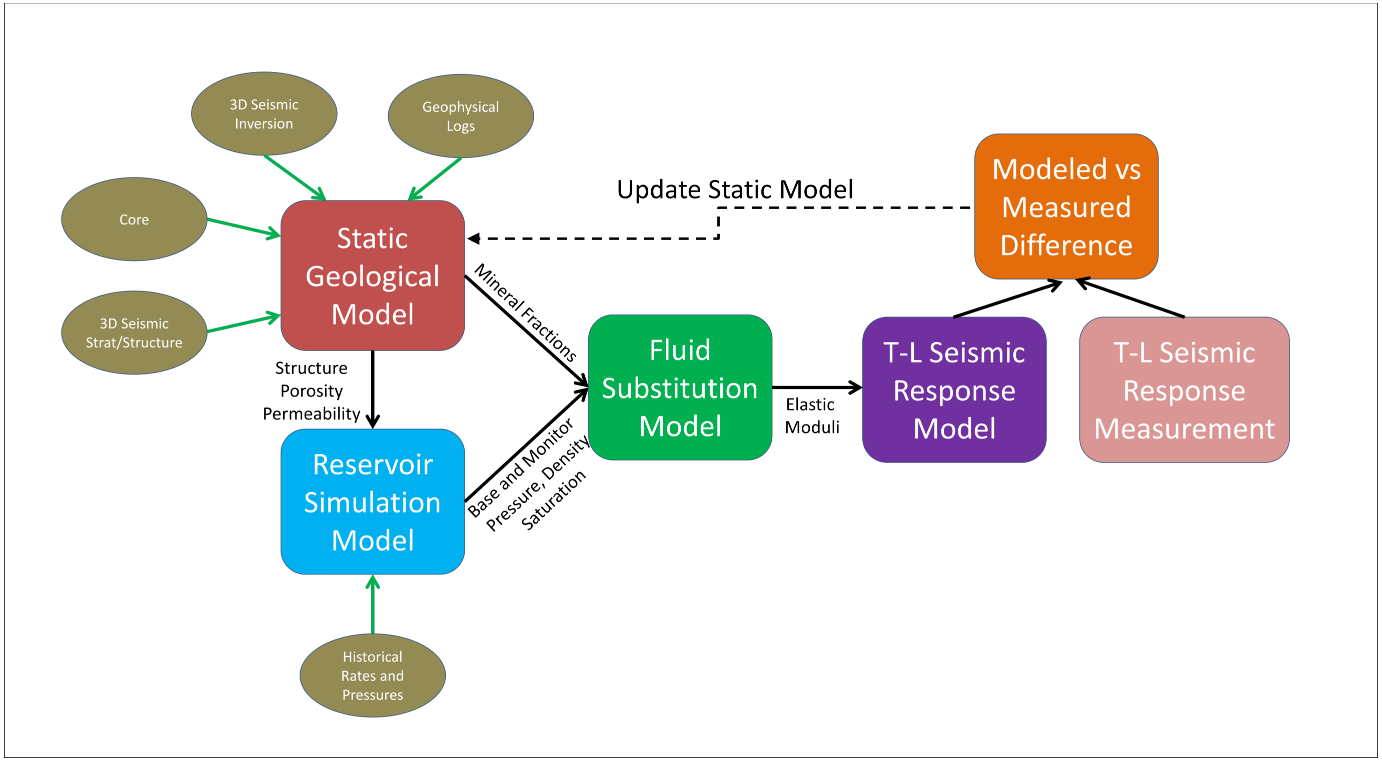
1. **Forward model time-lapse seismic response from reservoir simulation results.**
2. **Compute modeled versus observed time-lapse differences.**
3. **Update static and/or dynamic model parameters.**
4. **Check differences.**
5. **Iterate.**



Modeled CO_2 Plume at Monitor Survey Time

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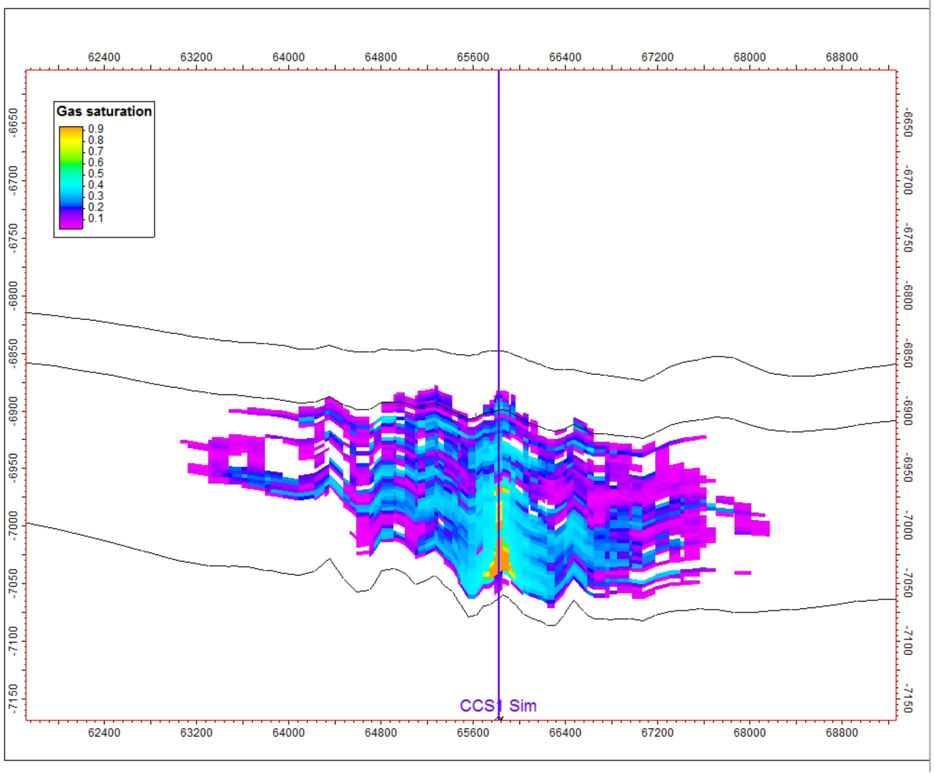
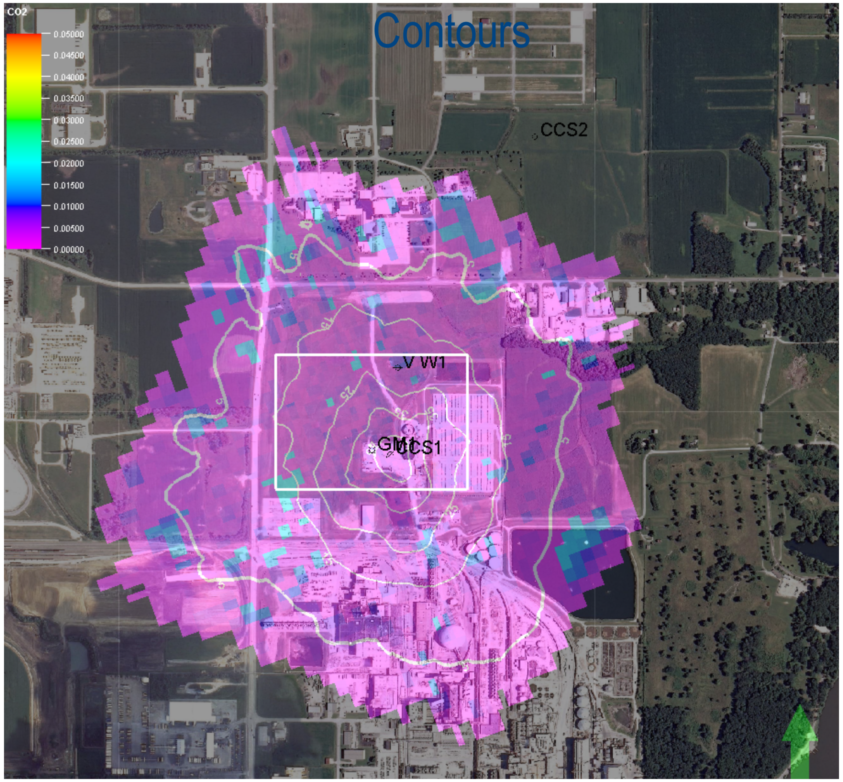
Dynamic model is currently calibrated to CCS1 and VW1 pressures.

East-West Cross Section (CO_2 Saturation)



Map of modeled CO_2 Saturation and Saturation x Thickness Contours



Rock Physics Forward Modeling

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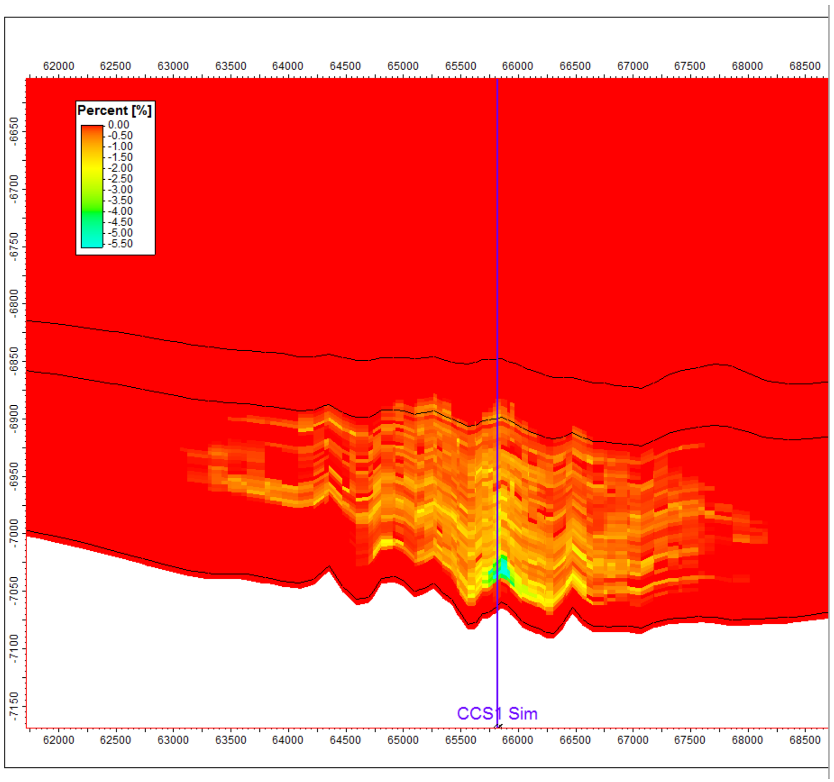
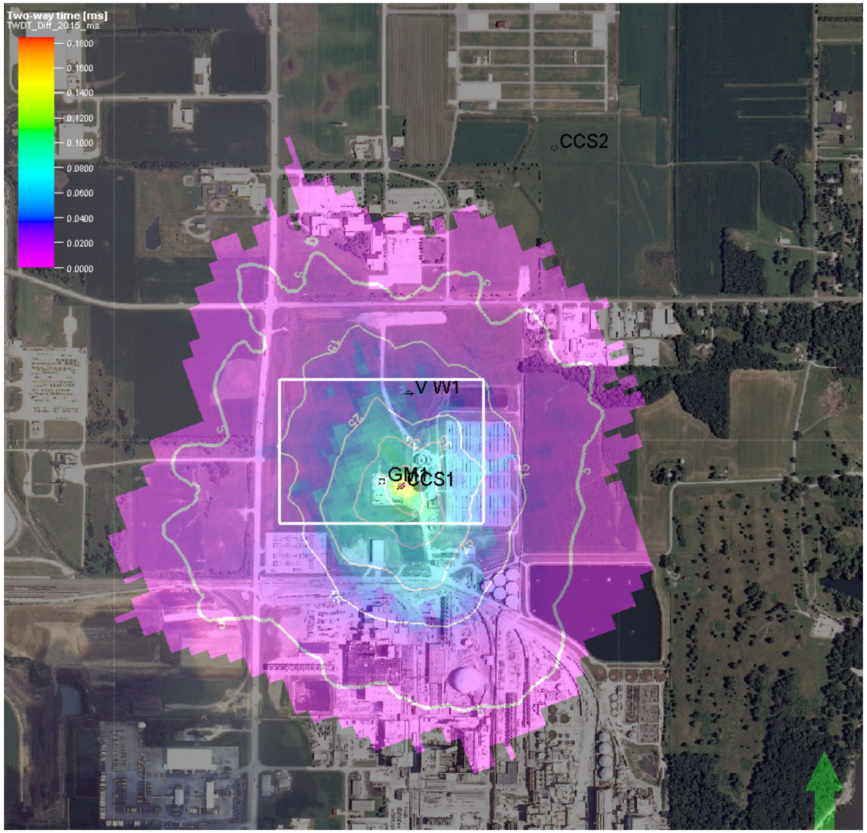
Percent Change in V_p (E-W Cross Section)



Modeled time shift and Saturation × Thickness Contours



Informing The Model Update

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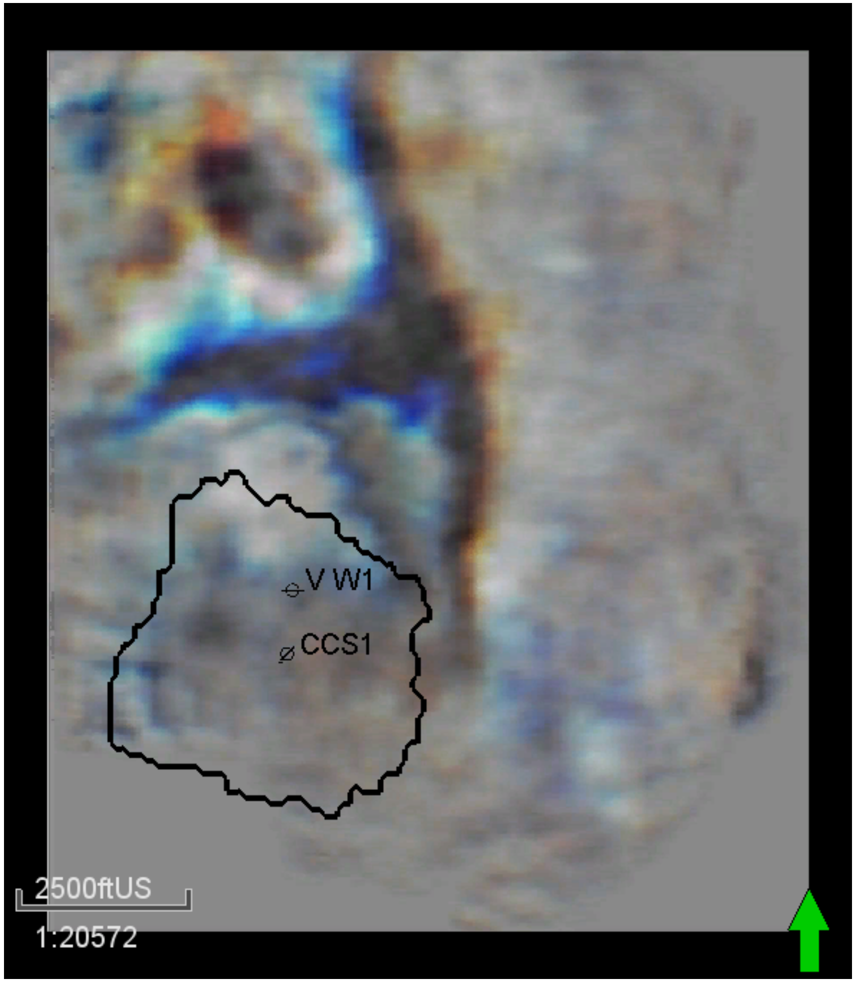
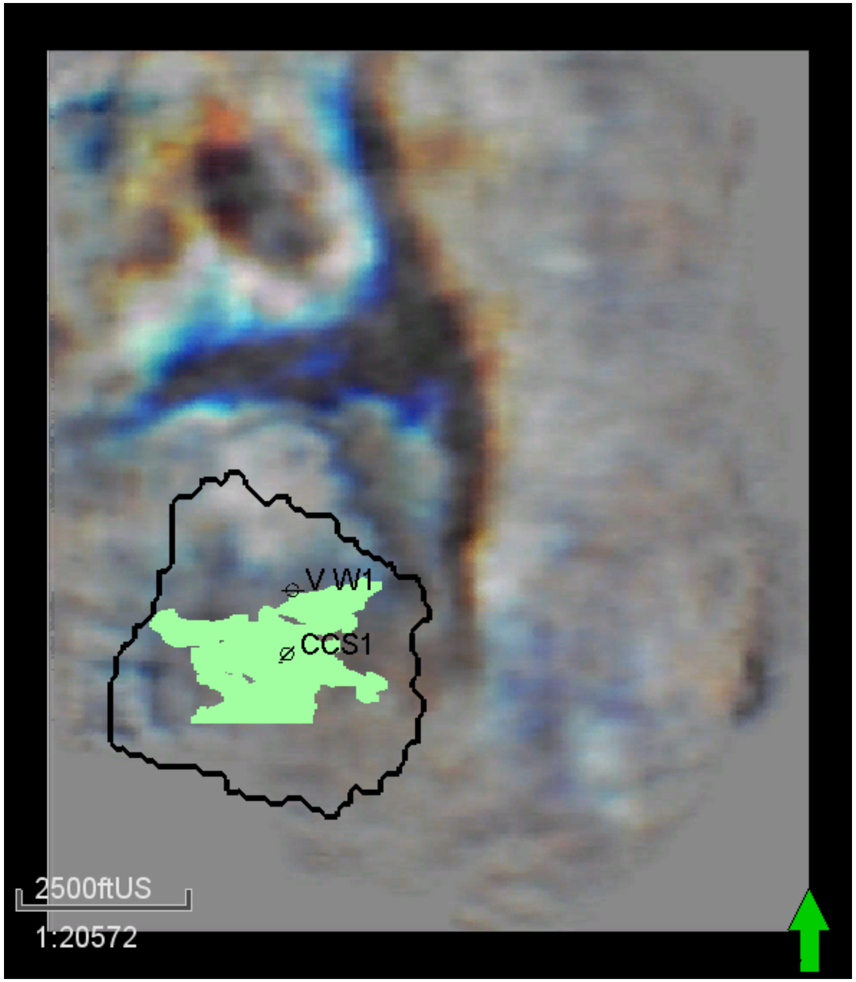
Subtle feature in eXchromaSG seismic attribute at reservoir depth in Base survey suggests possible geologic control on plume shape not captured in current static model.

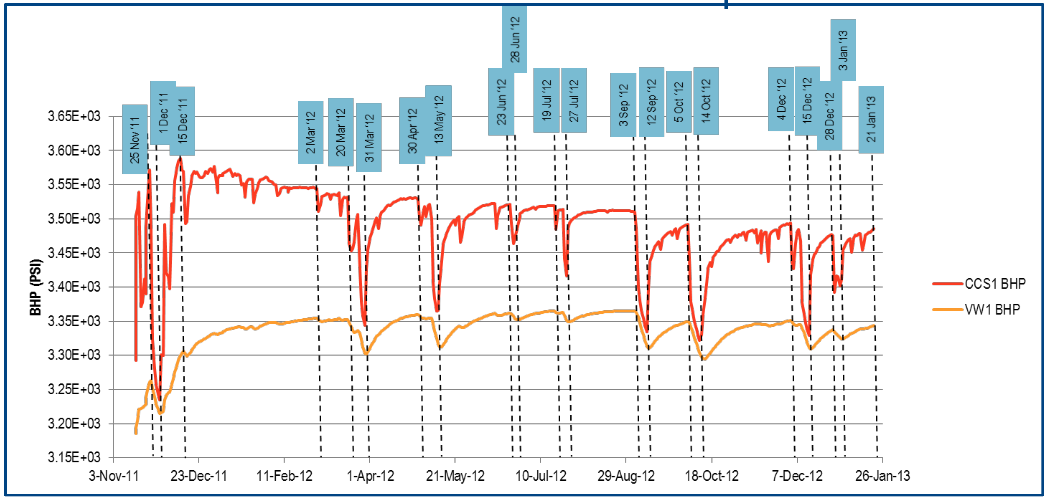




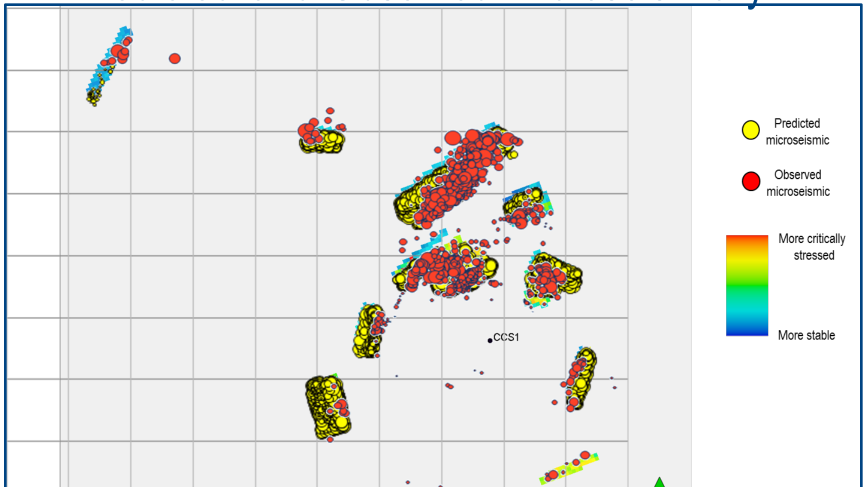
Geomechanics for Microseismicity

- Another example of “Closing the Loop”.
- Reservoir simulation pressure estimates were used for input to coupled hydro-mechanical modeling.
- Planes of weakness inverted from microseismic clusters were included in the mechanical model.
- Induced seismic emission moment tensors were forecasted.
- Uncertain parameters of the failure planes were calibrated.
- Lessons learned from previous work (presented as a poster at the GHGT-12 conference) will be implemented in continuing work.

Reservoir Simulator Pressure Step Selection



Predicted and Observed Microseismicity



ICCS EPA Class VI Permit AoR Model Update

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- EPA required update or Area of Review (AoR) simulation model using recently acquired data prior to grant of injection permit.
- New data included logs, well tests, and core analysis from wells VW2 and CCS2.
- Porosity and permeability distributions updated with logs.
- Much emphasis placed on constitutive relationships (relative permeabilities) for different rock types.
- Simulations included CCS1 and proposed CCS2 injection schedules.
- Simulations run to 2072 to include a 50 year Post Injection Site Closure period after cessation of CCS2 injection in 2022.

Extent of Plume & Saturation Cross Section
April 1, 2021 [DPif > 62.2 psi, SCO2 > 1.0%]

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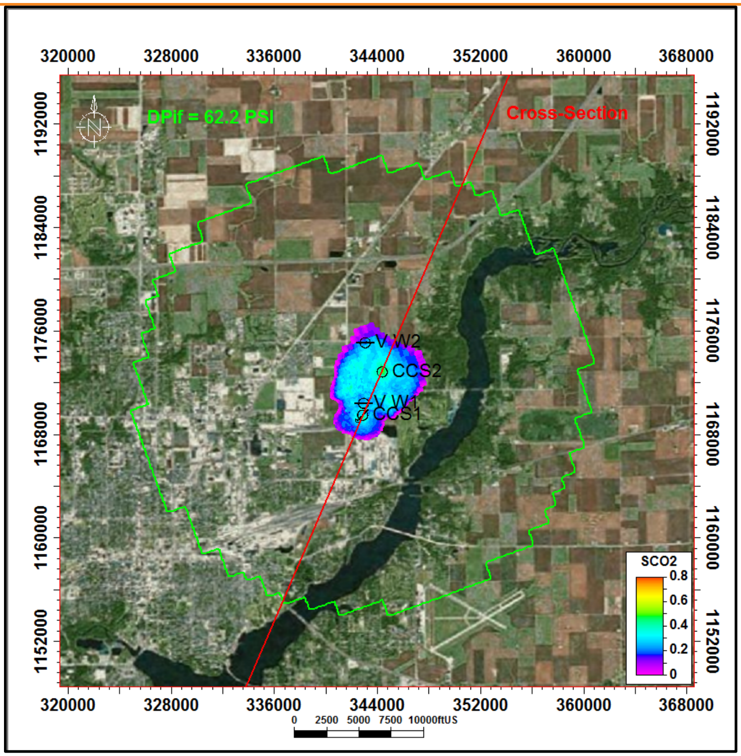

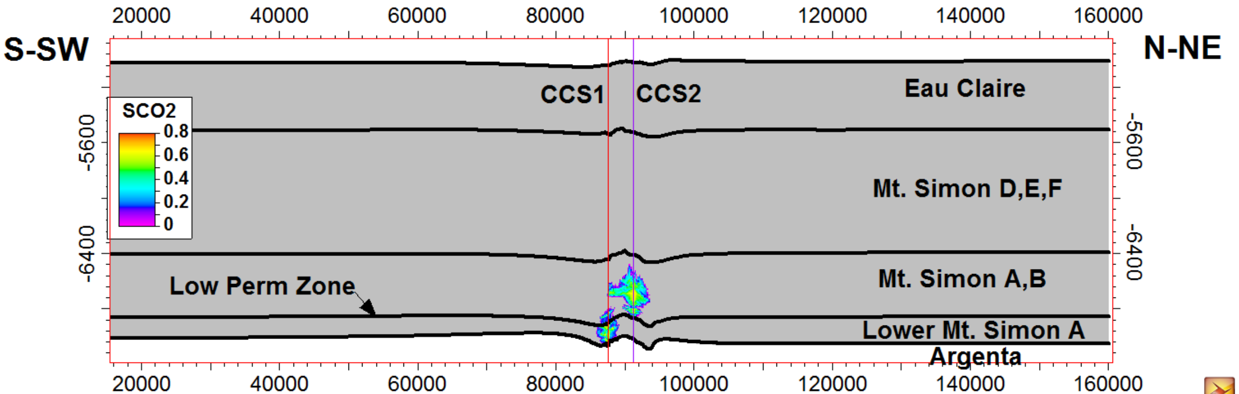

PETREL

Extent of Plume & Saturation Cross Section April 1, 2071 [DPif > 62.2 psi, SCO2 > 1.0%]

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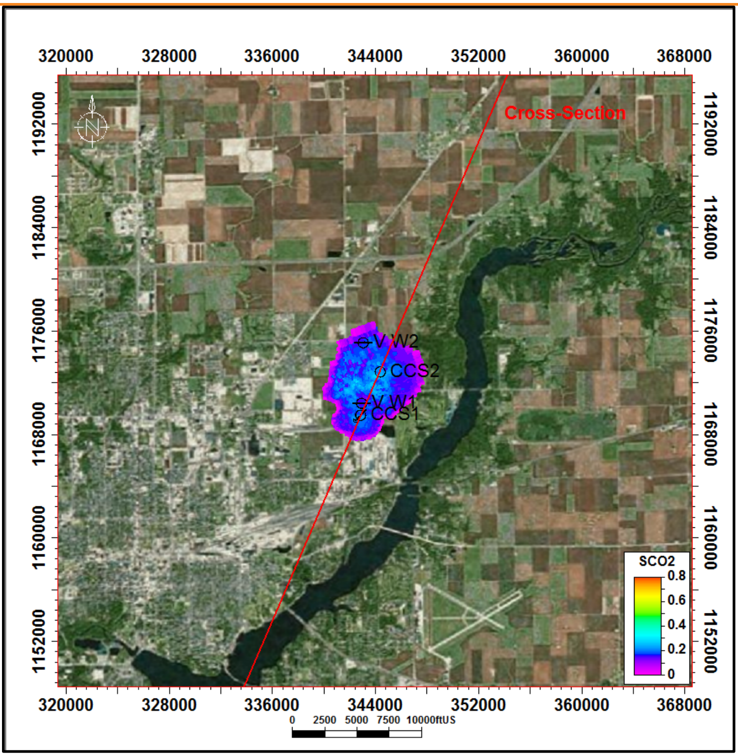
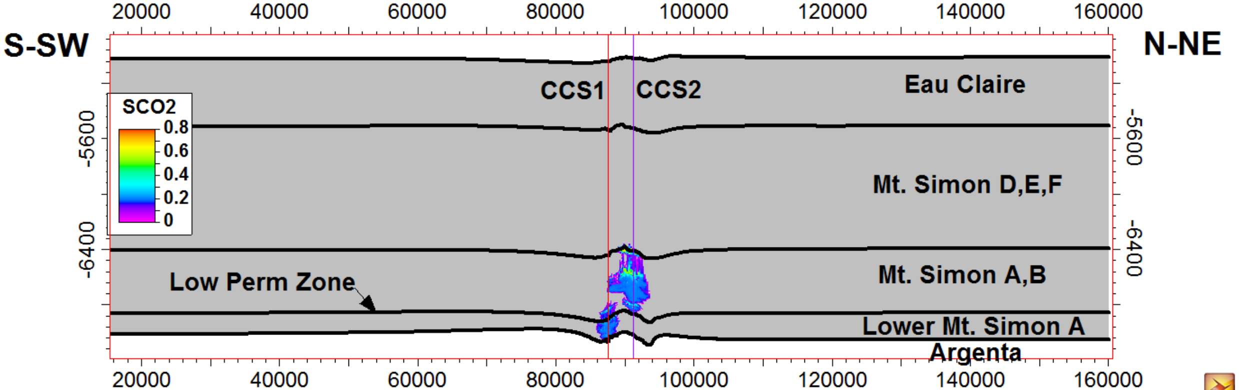
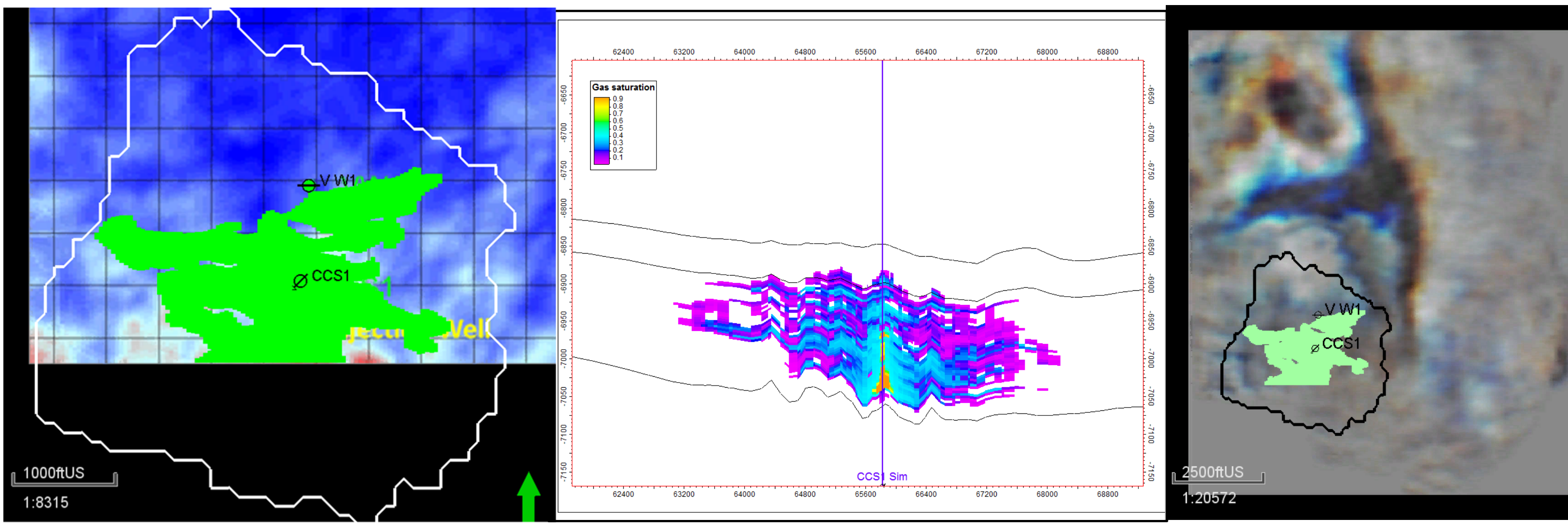




PETREL

Thank You!

Questions?


V W1
CCS1
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CCS1 Sim
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