# Quantitative $CO_2$ monitoring at the CaMI Field Research Station (CaMI.FRS), Canada, using a hybrid structural-petrophysical joint inversion

Dennis Rippe[1,2], Michael Jordan[2], Marie Macquet[3,4], Don Lawton[3,4], Anouar Romdhane[2] and Peder Eliasson[2]

[1]Helmholtz Centre Potsdam, GFZ German Research Centre for Geosciences, Germany; [2]SINTEF Industry, Norway; [3]University of Calgary, Department of Geosciences, Canada; [4]CMC Research Institutes, Containment and Monitoring Institute, Canada



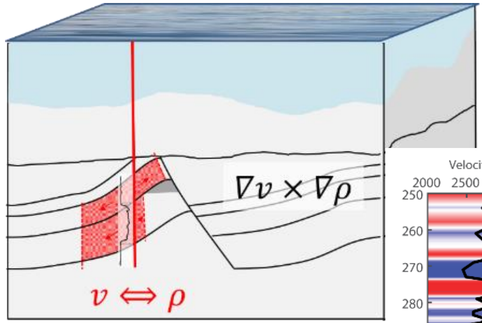

EGU General Assembly: May 4-8 2020
Sharing Geoscience Online (#shareEGU20)

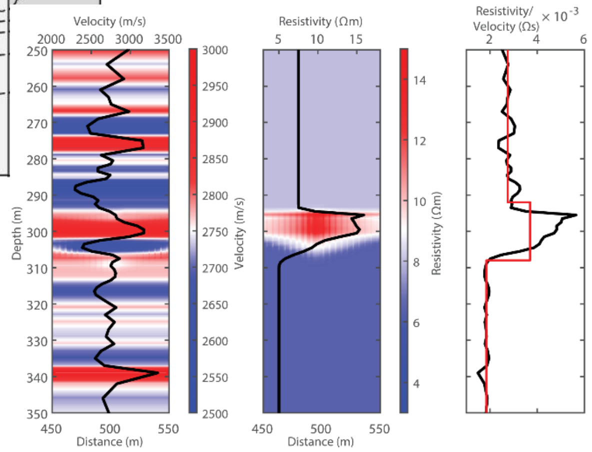
# Summary

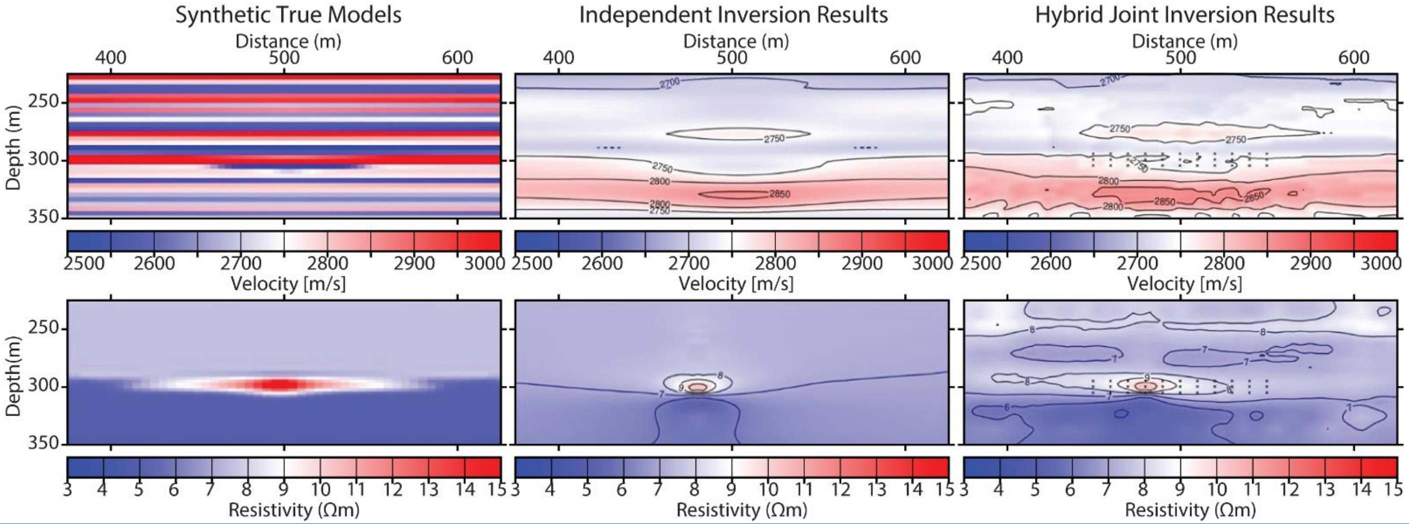
accurate $CO_2$ monitoring using Quantitative joint inversion for large-scale on-shore and off-shore storage applications

**Integrate multidisciplinary monitoring data** relevant for $CO_2$ storage through an advanced hybrid structural-petrophysical joint inversion method:

- **Structural joint inversion:** Cross-gradient relations encouraging structural similarity
- **Petrophysical joint inversion:** Cross-parameter relations (e.g. from well logs) to constrain model parameters




- Combine robustness of structural joint inversion with quantitative petrophysics-based joint inversion
- Modular integration of multi-disciplinary monitoring methods
- Ability to run on HPC

# Introduction

Regulatory requirements for **$CO_2$ storage operations:**

- **Containment assurance:**
  Demonstration of effective and safe performance
- **Conformance assurance:**
  Consistency between model predictions and monitoring observations

→ Requires **quantitative monitoring** of reservoir parameters
(stress, pressure, saturation, or strain in the overburden)

# Introduction

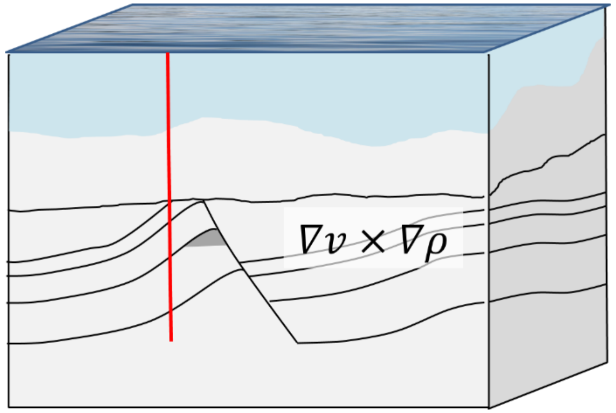
accurate $CO_2$ monitoring using Quantitative joint inversion for large-scale on-shore and off-shore storage applications:

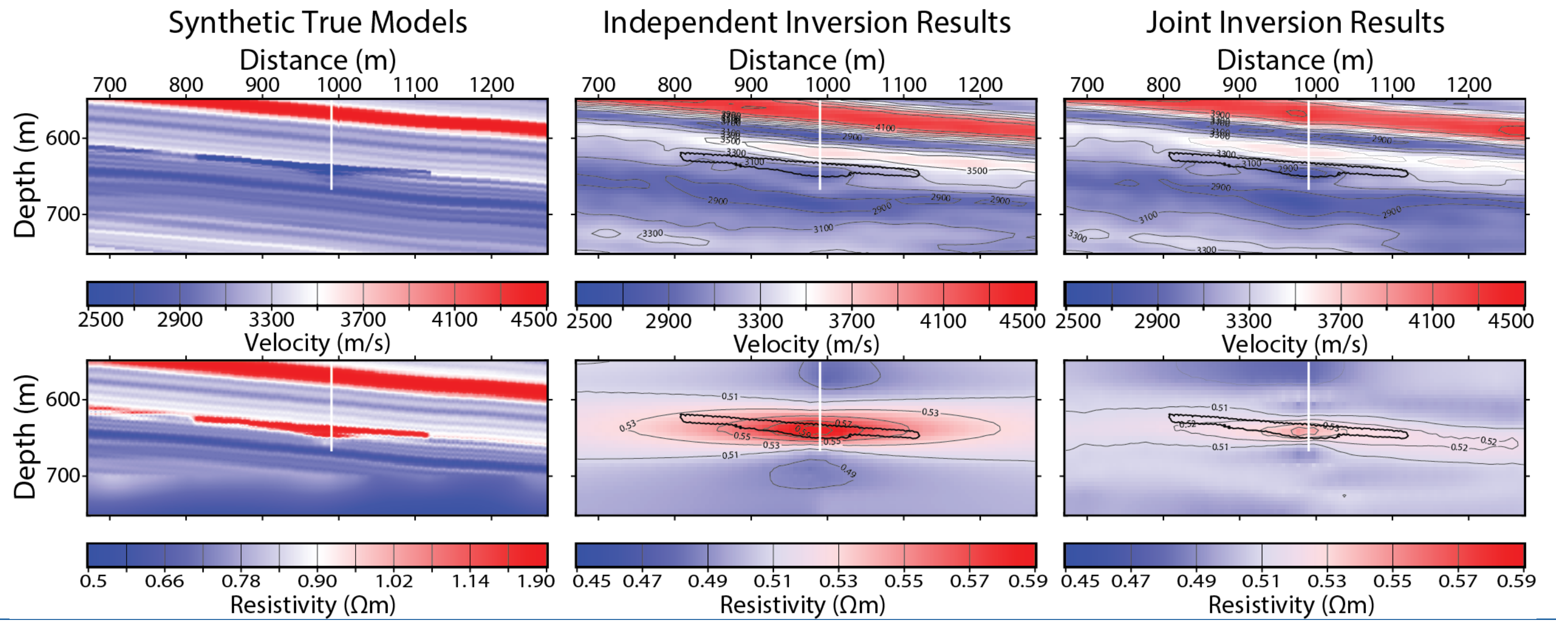
- **Integrate methods** relevant for $CO_2$ storage through an advanced hybrid structural-petrophysical joint inversion method
- **Utilize** Field Research Station (CaMI.FRS) as platform to develop and test the hybrid joint inversion method

# Joint Inversion

**Integration of multidisciplinary monitoring data:**

- Structural joint inversion
- Based on cross-gradient relations encouraging structural similarity (Gallardo and Meju, 2004)
- Developed in Ketzin COMPLETE project (Jordan et al., 2017)

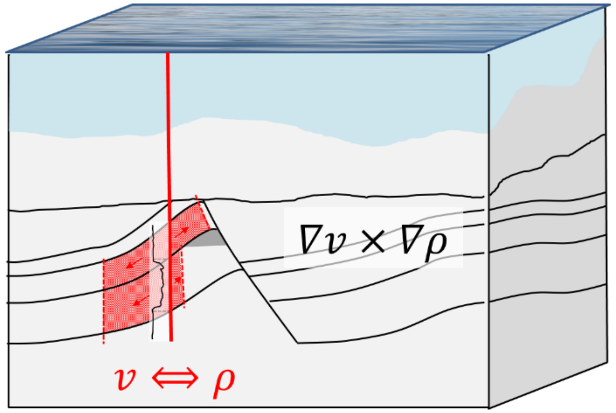


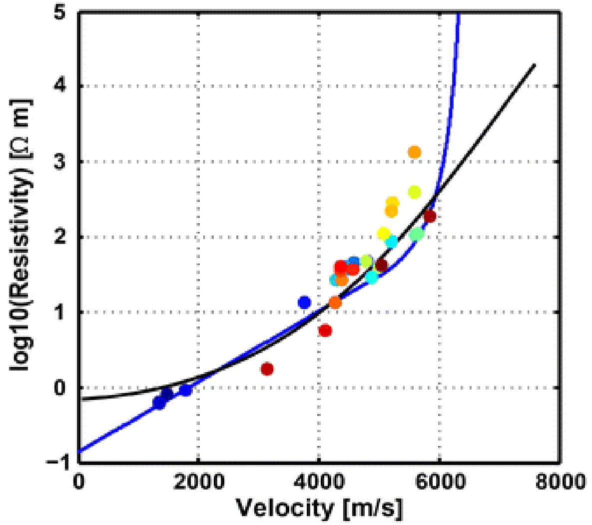



# Joint Inversion

**Hybrid structural-petrophysical inversion:**

- Extension of the previously developed structural joint inversion
- Combines robustness of structural joint inversion with quantitative petrophysics-based joint inversion
- Petrophysical cross-parameter relations (e.g. from well logs) to constrain model parameters
- 3D and 4D petrophysical joint inversion:
    - 3D inversion uses static piecewise linear relationships, the correlation coefficients are treated as additional parameters and inverted for (Zeyen and Achauer, 1997)
    - 4D joint inversion takes into account pressure and saturation changes; currently in development



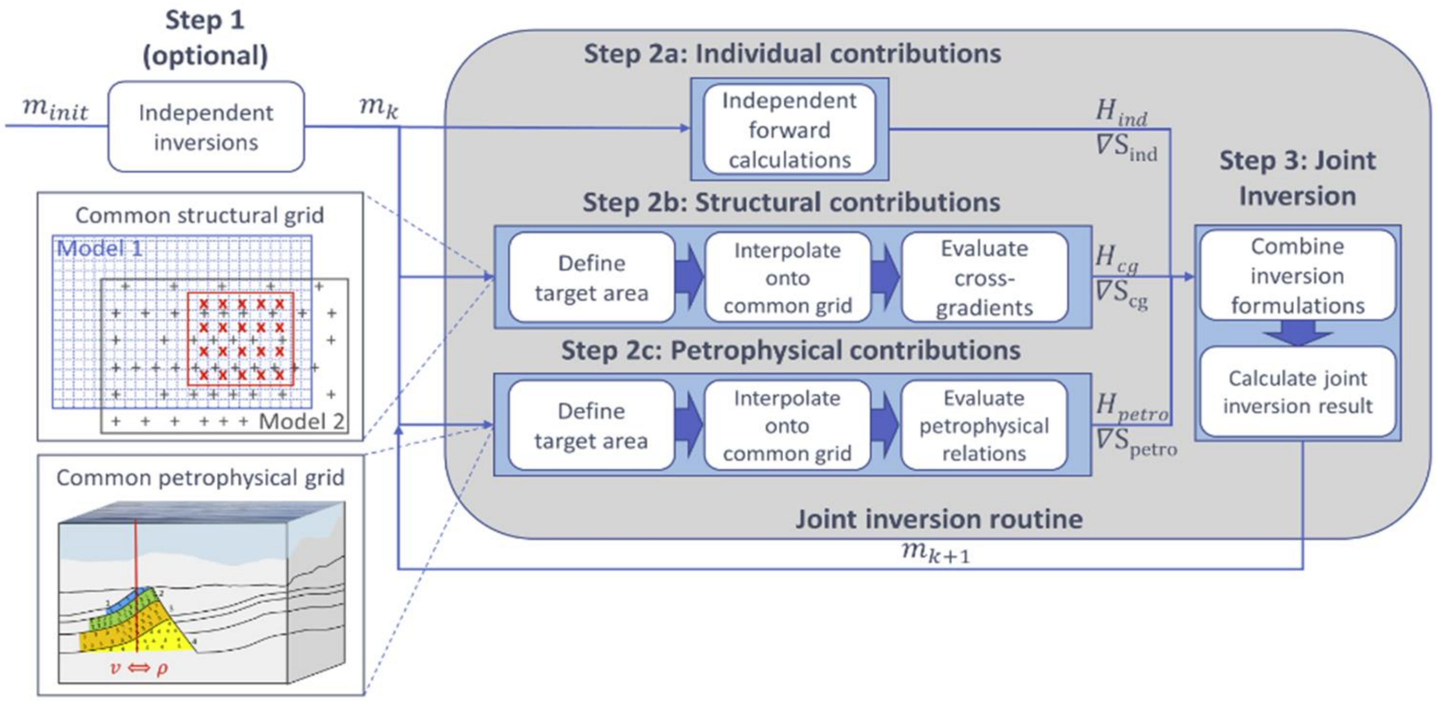




Example of velocity-resistivity cross-plot, averaged at 100 m depth intervals. (Moorkamp, 2017)

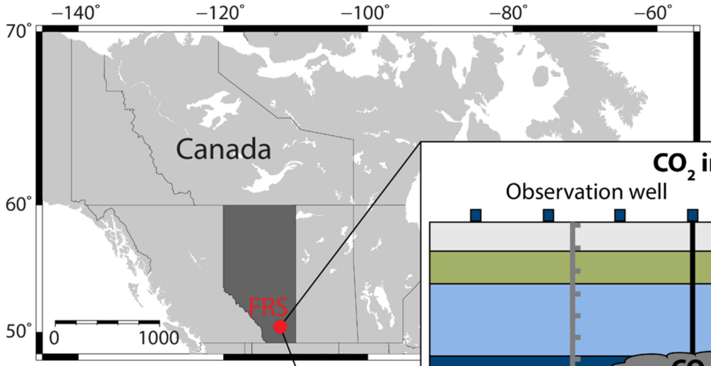
# Joint Inversion

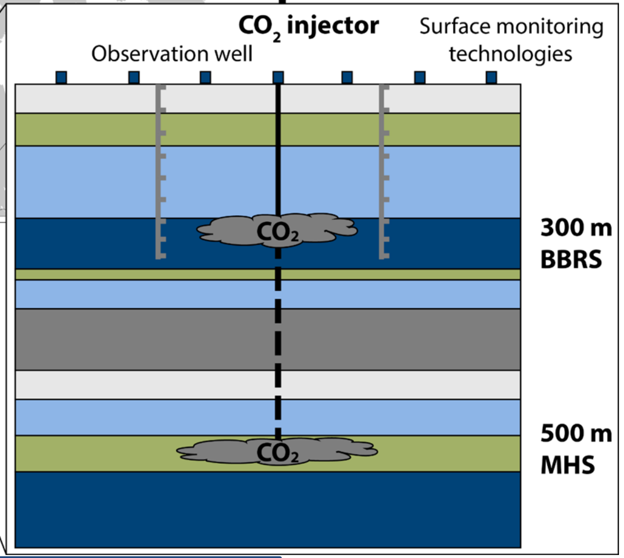
## Joint Inversion Implementation:

- Full Bayesian formulation
- Modular design:
  - FWI, ERT, CSEM, MMR, gravity integrated
  - Additional methods possible
- Independent of individual model geometries:
  - Constraints evaluated on common grid
- Parallel code on HPC:
  - Large-scale and high-resolution application



# CaMI Field Research Station (CaMI.FRS)



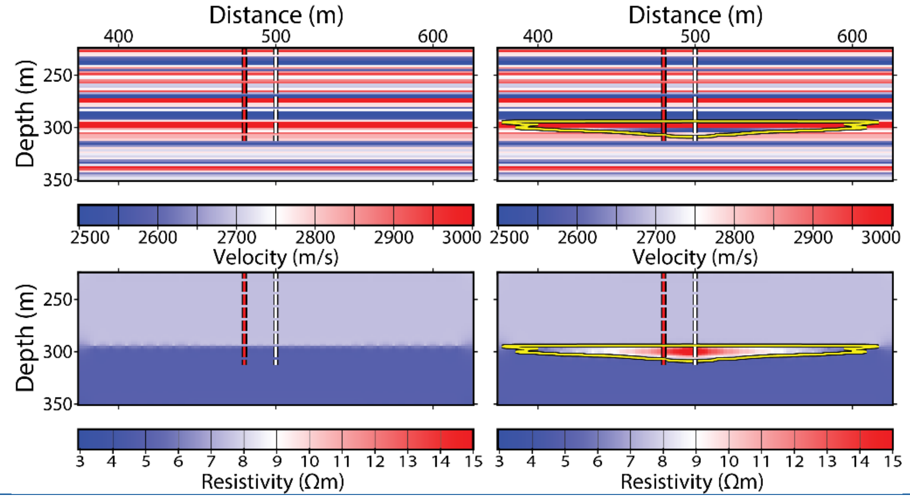

**Platform for the development and deployment of advanced $CO_2$ monitoring technologies:**

- Located 20 km SW of Brooks, AB
- Operated by the Containment and Monitoring Institute (CaMI) of Carbon Management Canada
- $CO_2$ injection at 300 m depth into the Basal Belly River Sandstone (BBRS)
- Geophysical and geochemical monitoring:
  - Permanent downhole instrumentation (geophones, electrodes, optical fiber, fluid recovery U-tube)
  - Periodic surface monitoring technologies (seismic, ERT, CSEM, MMR)

# CaMI Field Research Station (CaMI.FRS)

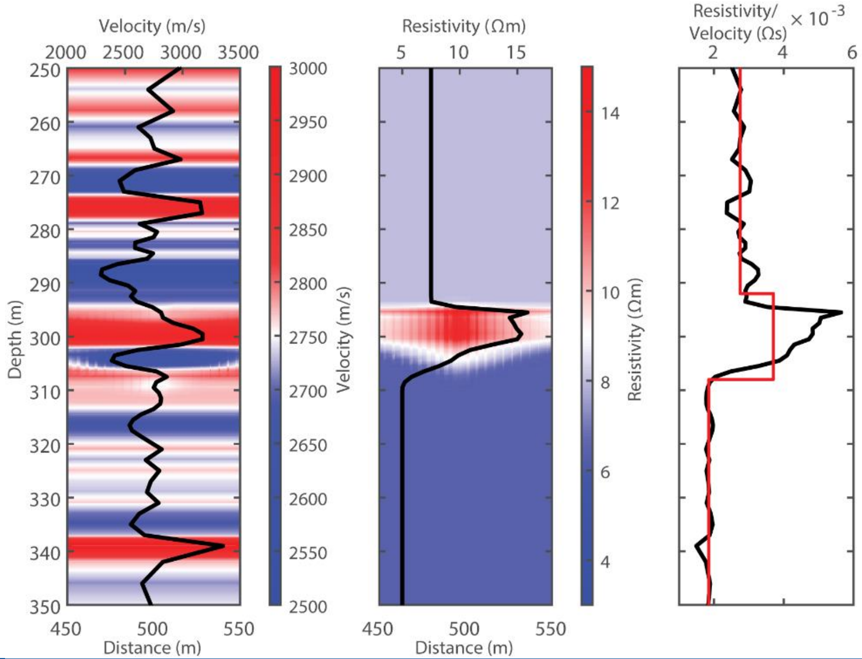
## Synthetic seismic velocity and electrical resistivity models:

- Geostatic model of the CaMI.FRS site
- Dynamic fluid flow simulations with 3150 t of $CO_2$ over 5 years (Macquet et al., 1998)
- Velocity and resistivity changes due to fluid substitution inferred from Gassmann's Equation and Archie's Law



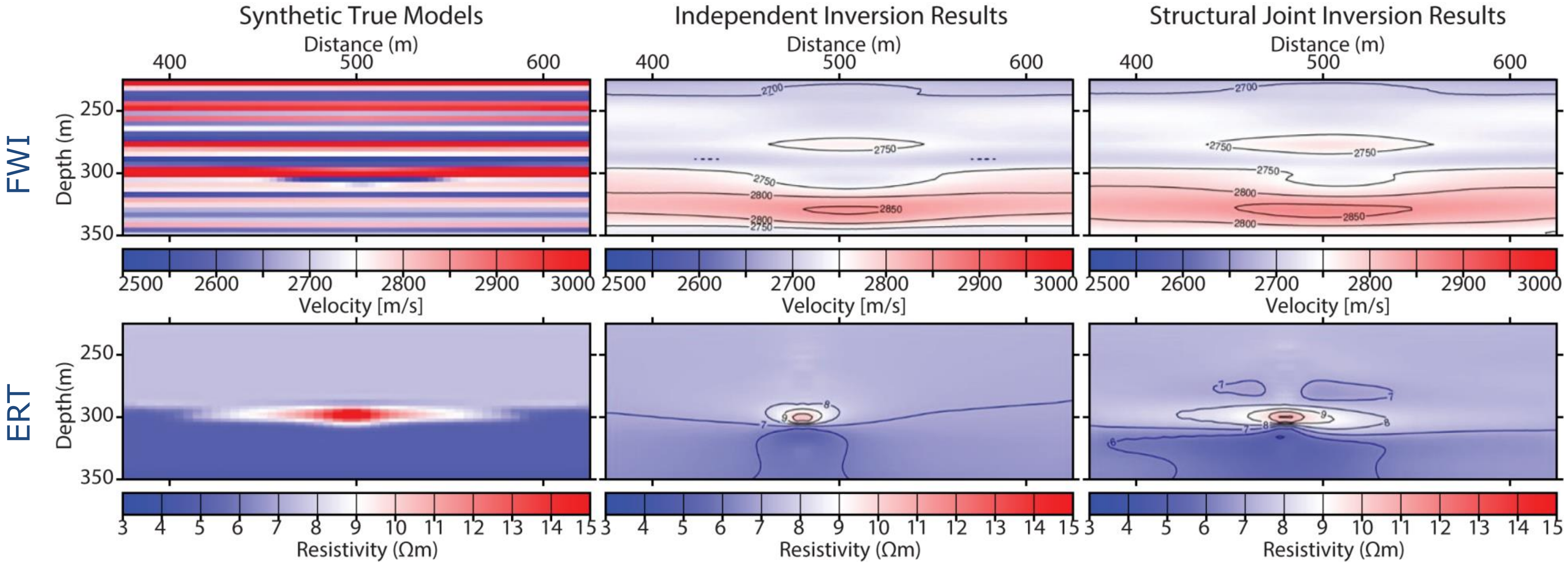

## Synthetic petrophysical model:

- Vertical log at injection well
- Three petrophysical units
- Averaged correlation coefficients with variable validity away from the well



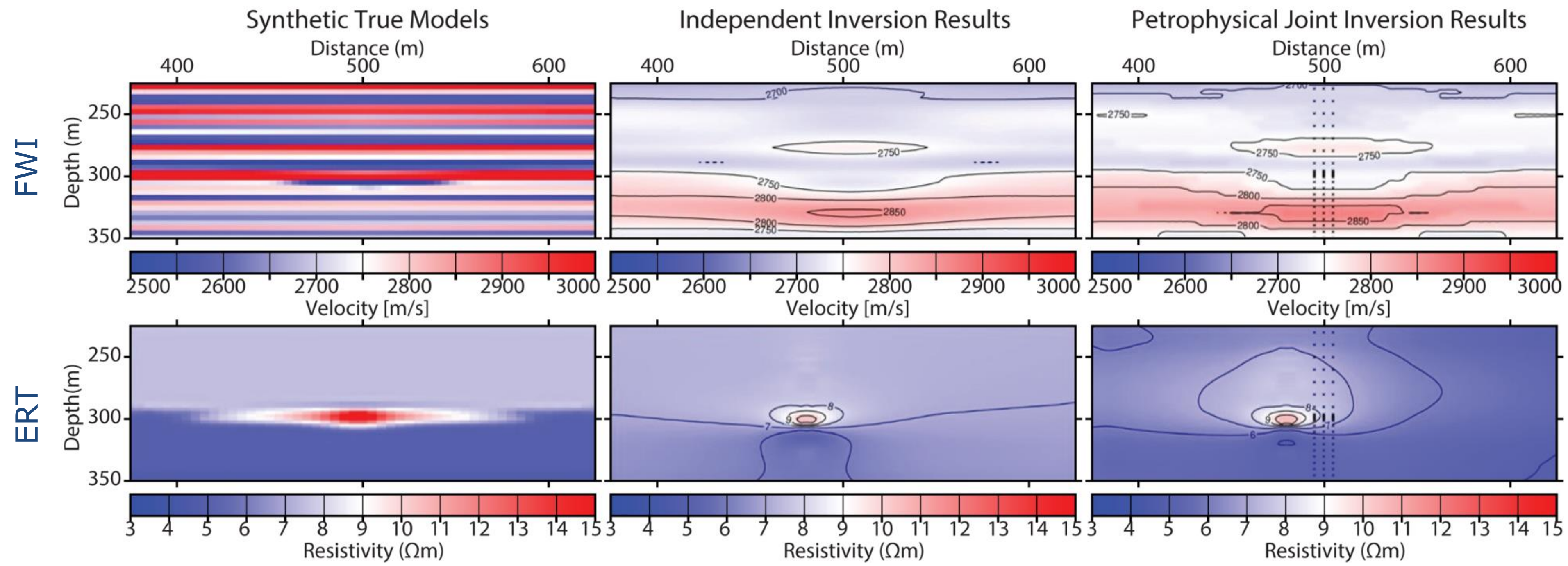
# Structural Joint Inversion Application

Initial inversion results after one iteration:
Comparison between independent inversion and structural joint inversion



# Petrophysical Joint Inversion Application

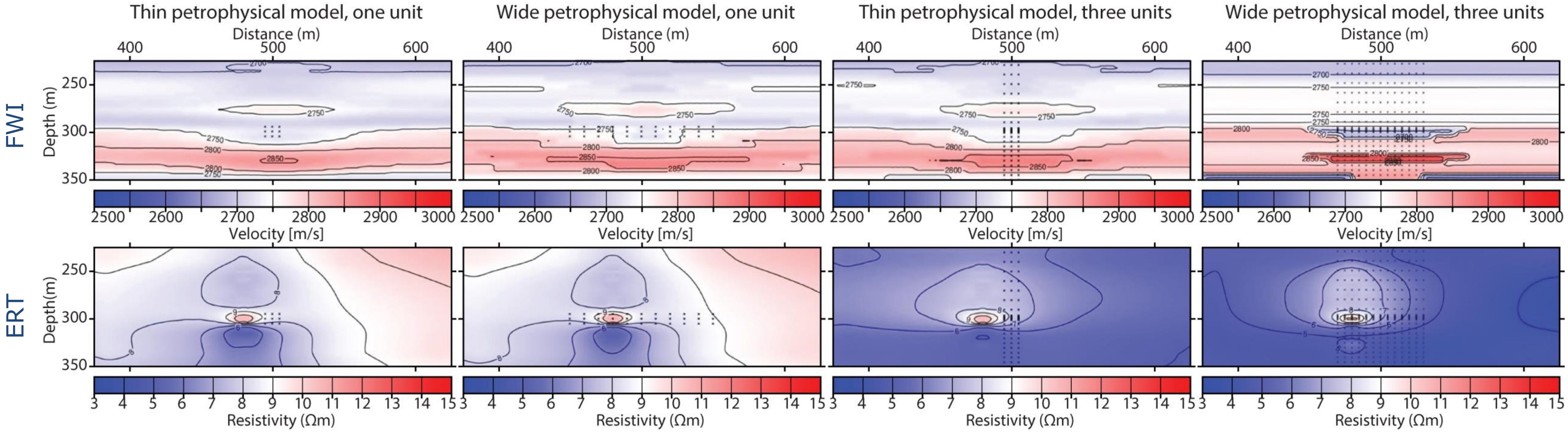
Initial inversion results after one iteration:
Comparison between independent inversion and petrophysical joint inversion



# Petrophysical Joint Inversion Application

Comparison between different petrophysical models, defined at locations indicated by black dots:

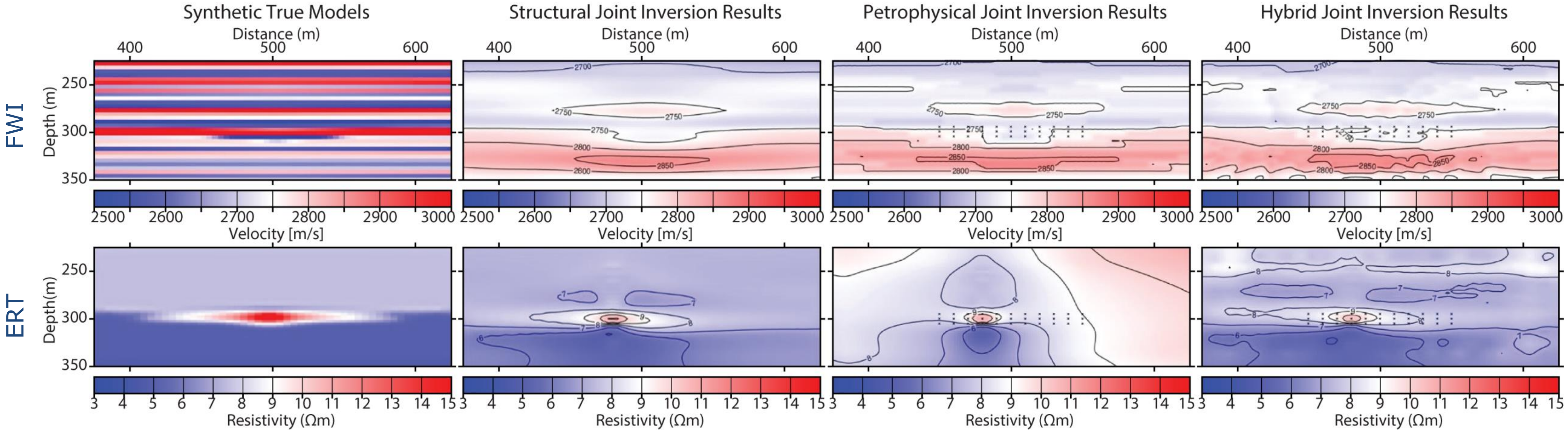
- one unit (reservoir) vs. three units (overburden, reservoir, substratum)
- thin model (limited to well vicinity) vs. wide model (extending further away from the well)



# Hybrid Joint Inversion Application

Initial inversion results after one iteration:
Comparison between structural, petrophysical and hybrid joint inversion

Hybrid joint inversion shows clear improvement of the resolution of the $CO_2$ plume and better separation between layers



# Conclusions

- Development of a **hybrid structural-petrophysical joint inversion** to improve quantitative monitoring of reservoir parameters (e.g. pressure and saturation).
- Use of a **synthetic realistic models and data** from the Field Research Station (CaMI.FRS) to develop and test the hybrid joint inversion method.
- Initial joint inversion using synthetic FWI and ERT data shows a **clear improvement of the resolution of the $CO_2$ plume** and surrounding structure, compared to independent inversion results.
- The **petrophysics-based extension** appears to provide valuable constraints, such as improved definition of the $CO_2$ plume and better separation between layers.
- Our goal is to **mature the joint inversion technology** further towards large-scale $CO_2$ storage applications, e.g. on the Norwegian Continental Shelf.

# Acknowledgements

Financial support by

GASSNOVA CLIMIT equinor

and our consortium partners is gratefully acknowledged.

SINTEF CMC RESEARCH INSTITUTES UNIVERSITY OF CALGARY BERKELEY LAB INRS UNIVERSITÉ DE RECHERCHE QUAD GEOMETRICS SCRIPPS INSTITUTION OF OCEANOGRAPHY

# References


Gallardo, L.A. and Meju, M.A. (2004): Joint two-dimensional DC resistivity and seismic travel time inversion with cross-gradients constraints. *Journal of Geophysical Research: Solid Earth*, **109**, B03311.

Jordan, M., Rippe, D., Schmidt-Hattenberger, C. and Romdhane, A. (2017): Joint Inversion for Improved $CO_2$ Monitoring at the Ketzin Pilot Site, Germany. *EAGE/SEG Research Workshop 2017, Trondheim, Norway*.

Macquet, M., Lawton, D. and Saeedfar, A. (2018): Reservoir simulation and feasibility study for seismic monitoring at CaMI.FRS, Newell County, Alberta. *Geoconvention 2018, Calgary, Canada*.

Moorkamp, M. (2017): Integrating Electromagnetic Data with Other Geophysical Observations for Enhanced Imaging of the Earth: A Tutorial and Review. *Surveys in Geophysics*, **38**, 935–962.

Zeyen, H. and Achauer, U. (1997): Joint inversion of teleseismic delay times and gravity anomaly data for regional structures. In: Fuchs, K.(Ed.), *Upper mantle heterogeneities from active and passive seismology, pp.* 155-168. Springer, Dordrecht.