4-D CSEM, A Cost-Effective Tool for Deep-Water Clastic Reservoir Monitoring*

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Search and Discovery Article #42336 (2018)**
Posted December 31, 2018

*Adapted from oral presentation given at 2018 International Conference and Exhibition, Cape Town, South Africa, November 4-7, 2018
 DOI:10.1306/42336Menezes2018

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Abstract

We performed a complete sensitivity study in the Jubarte oilfield RO-300 reservoir (offshore Campos Basin, Brazil) to appraise the applicability, potential, and limitations of the marine CSEM method to monitor deep-water clastic reservoir production. This study is based on present-day CSEM acquisition, operation, and data interpretation technologies. The RO-300 Jubarte reservoir is the first fully optical deep-water Permanent Reservoir Monitoring (PRM) seismic system installed in the Campos Basin. This reservoir was selected to introduce highly realistic models and production effects, usually rare in the literature, in the development, understanding, and assessment of the sensitivity of EM fields to water-flooding in complex and heterogeneous deep-water clastic oil reservoirs. This study, based in fluid substitution, indicates that production effects and associated variations in saturation translate into changes of the reservoir's resistivity structure over time. We demonstrate that coupled 'constrained' inversion can retrieve reservoir production-related resistivity differences. On the other hand, coupled 'localized' inversion focused where the reservoir's volume variations are expected to occur, improves resolution in the identification of parameter changes, even in the presence of repeatability problems. We ultimately provide the step change technology development to transform marine CSEM into a trusted and cost-effective tool to integrate with time-lapse seismic for deep-water clastic reservoirs monitoring.

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Overview

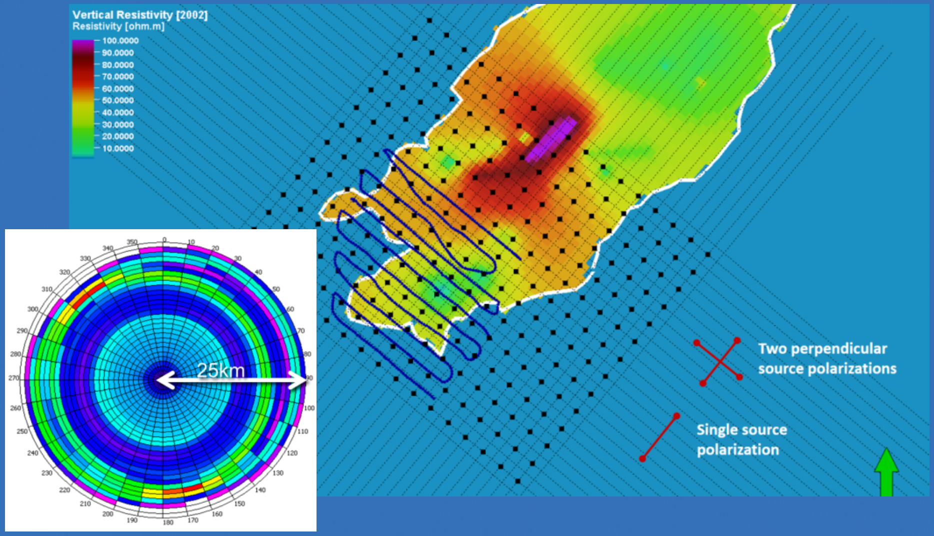
- Motivation
- Technical proposal
- Time lapse EM challenges
- Jubarte feasibility test
  - Synthetic model
  - Inversion results
- Conclusions
- Acknowledgments

Motivation

- 4D seismic is well established for reservoir monitoring.
- The use of 4D mCSEM for reservoir monitoring can be considered incipient.
- A feasibility study for 4D mCSEM was incorporated in a technical cooperation agreement between Petrobras and Schulmberger.

Technical proposal

- **Develop game-changing broadband, full-field, full-azimuth, ultra-long offset integrated seafloor EM technology:**
  - **Deliver higher fidelity reservoir models**
  - **Reduce uncertainties and drilling risks at lower cost thus making the business case**
  - **Build the blocks of next generation EM seafloor-to-borehole and in-reservoir applications**

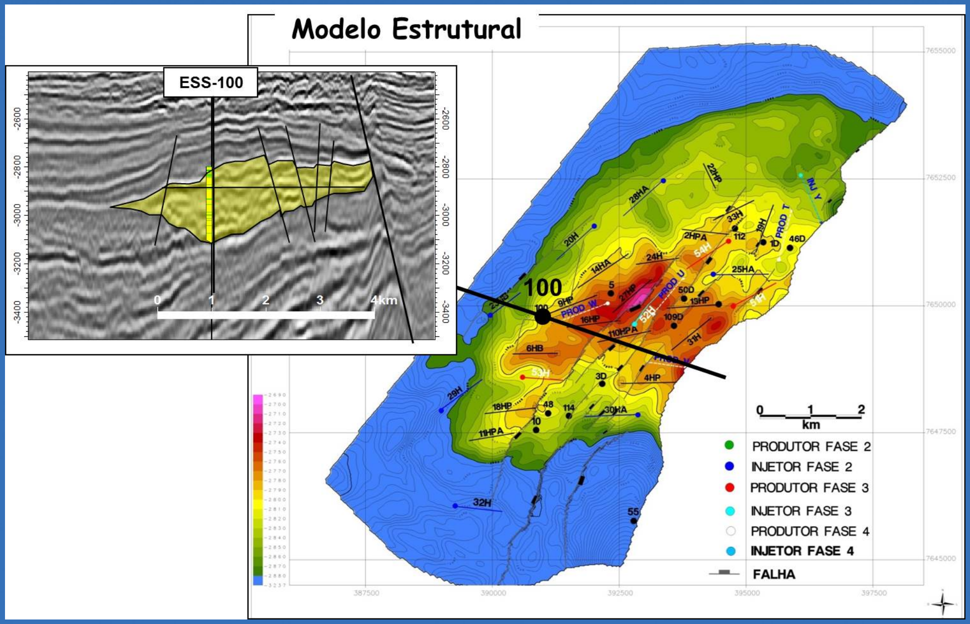


Time-lapse EM challenges

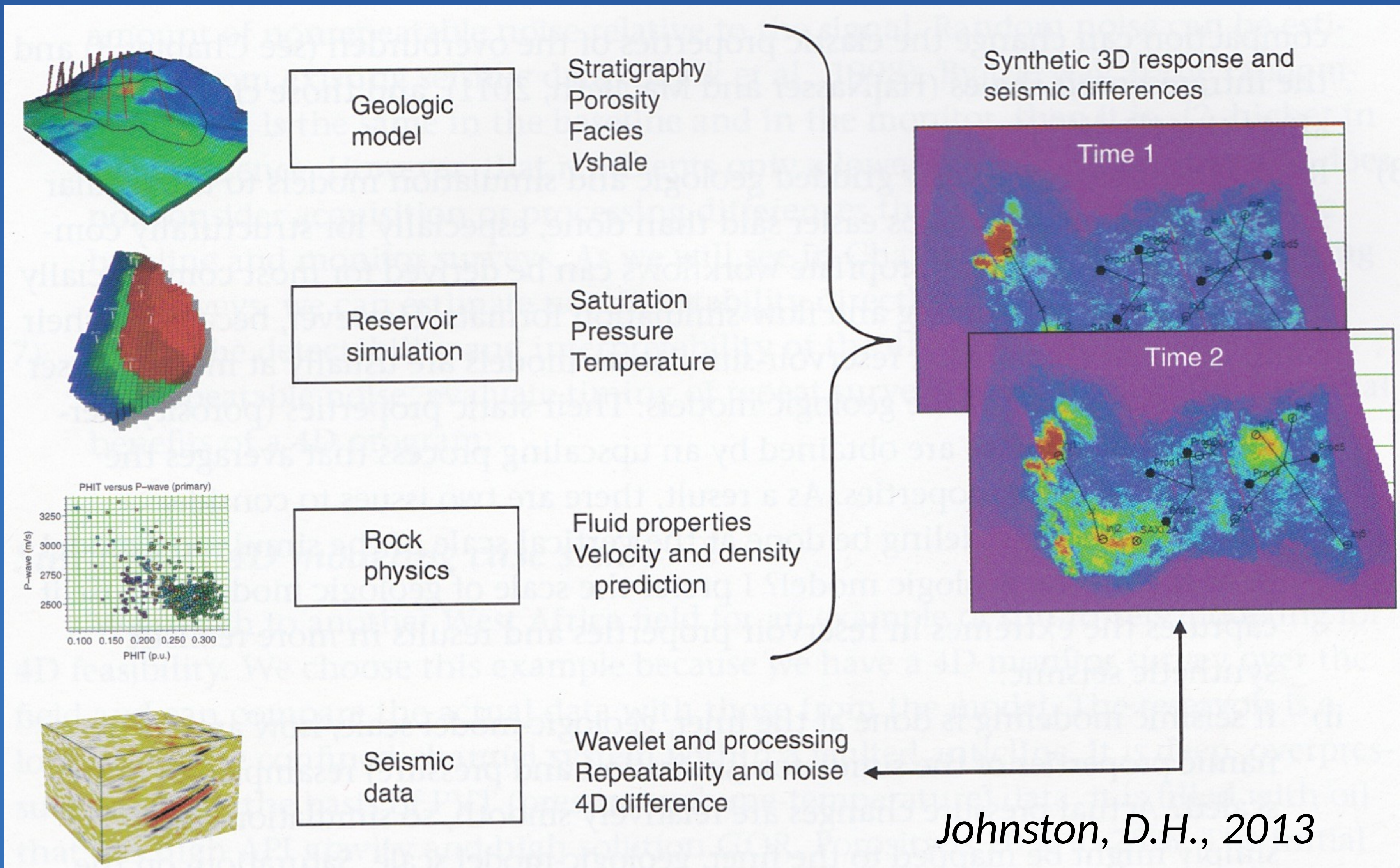
- Technology still in its infancy:
  - Even mCSEM 3D shows few examples for reservoir applications.
- Modeling studies and applications are exceedingly rare.
- Feasibility studies too simplistic leading to poorly understood:
  - Potential
  - Where and when
  - Value and how
  - Key factors in success

The Jubarte case study - offshore Campos Basin, Brazil

- **Maastrichtian deep-water turbidites**
- **Thickness 20 to 140 m**
- **Depth 2700 to 2900 m**
- **First fully optical deep water PRM seismic system**
- **Good characterization**

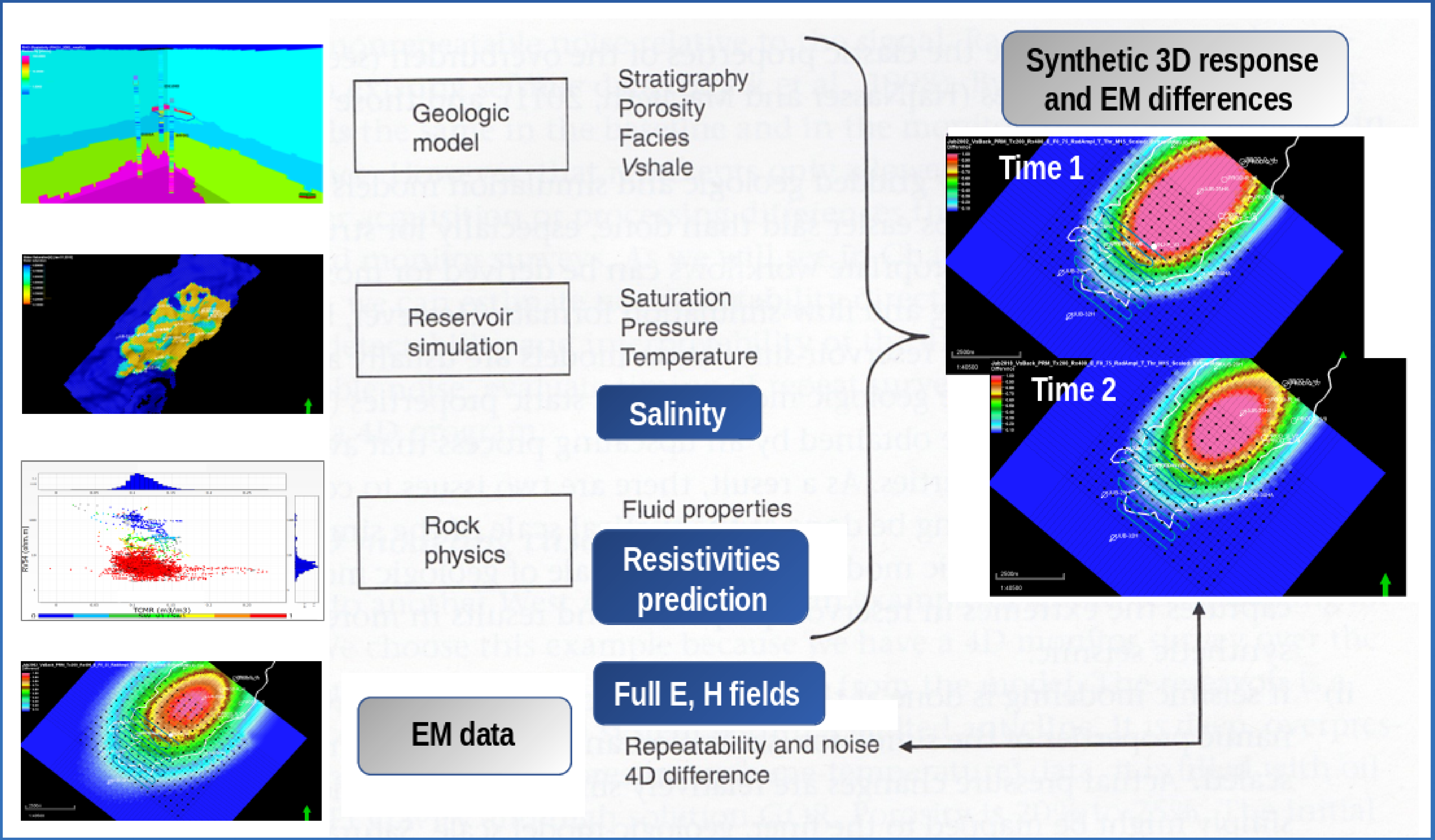


Simulation-to-seismic modeling workflow

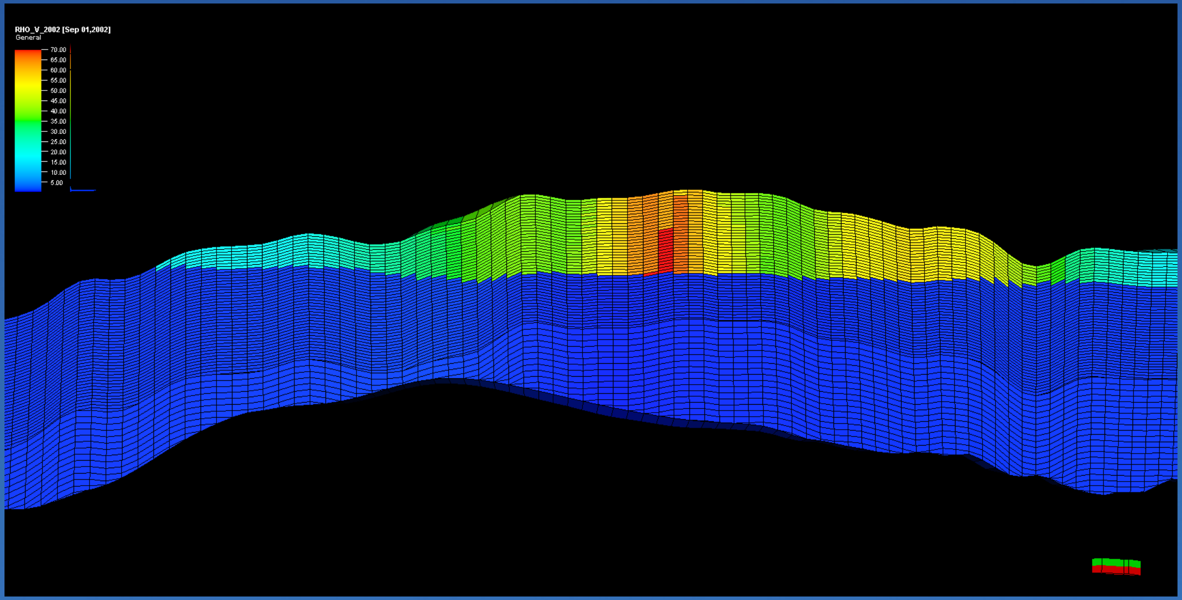


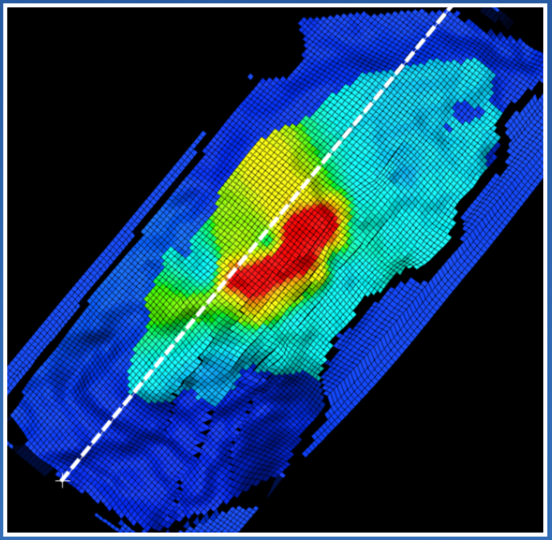
Johnston, D.H., 2013

Simulation-to-EM modeling workflow



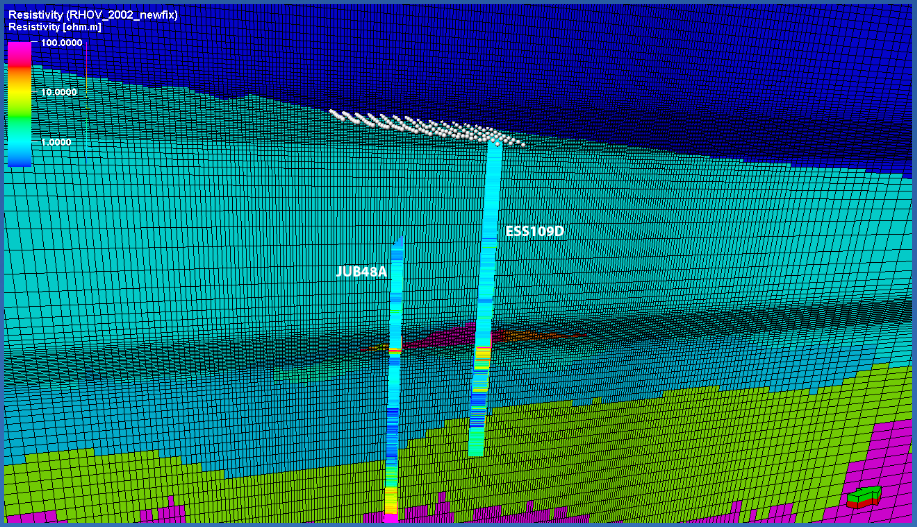
Simulation-to-EM

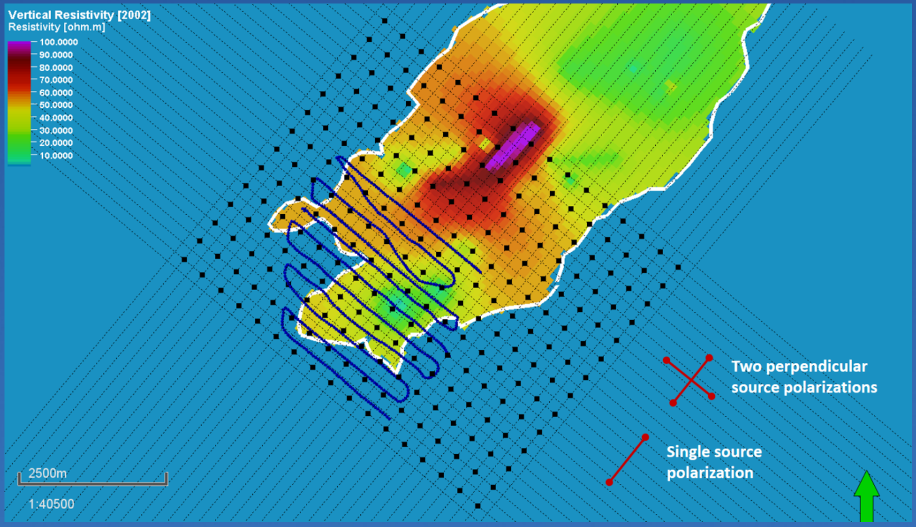




- **Up to 20 Million cells**
- **Maximum resolution 5 m within reservoir**
- **Base 2013, production times in 2015, 2018, 2030**
- **Different receiver grids and source shootings**
- **Broadband, full-field, full-azimuth data**
- **Repeatability tests**

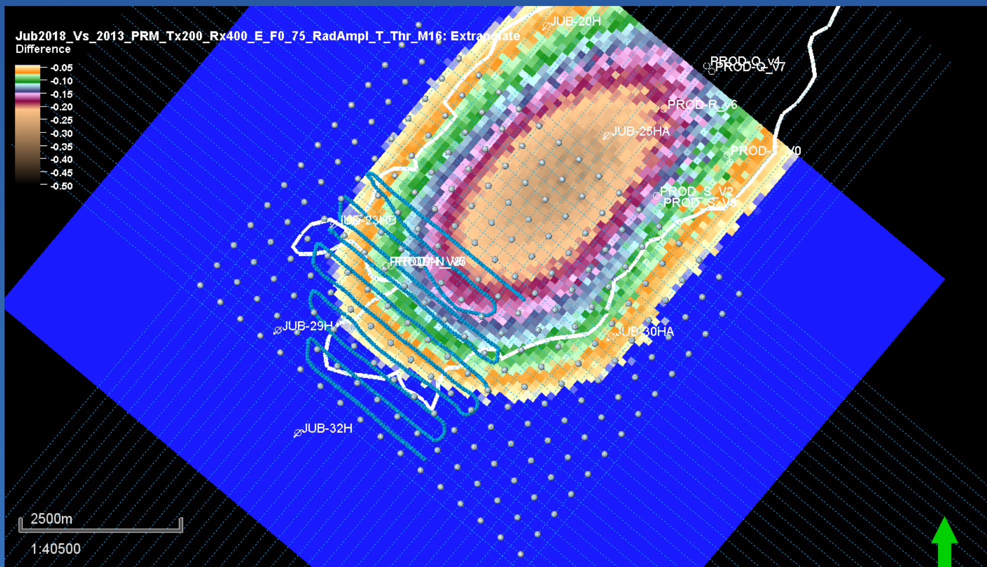
Simulation-to-EM





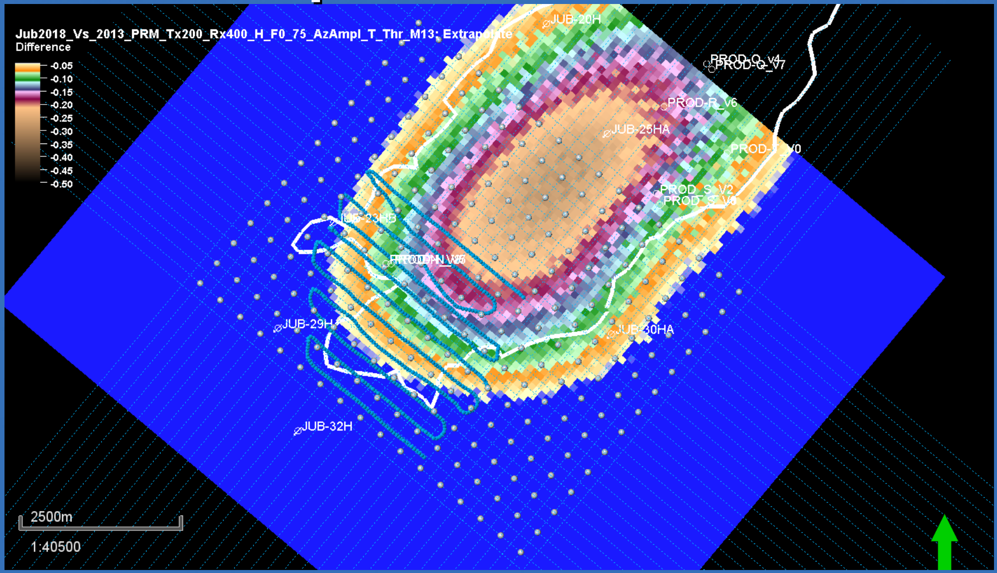
- Calibrate wells and EM data
- Derive petro-electric model
- Convert reservoir and simulation models to EM
- Append the overburden and underburden
- Calculate the EM responses
- Add realistic noise
- Assess detectability and interpretability of 4D signal

EM differences



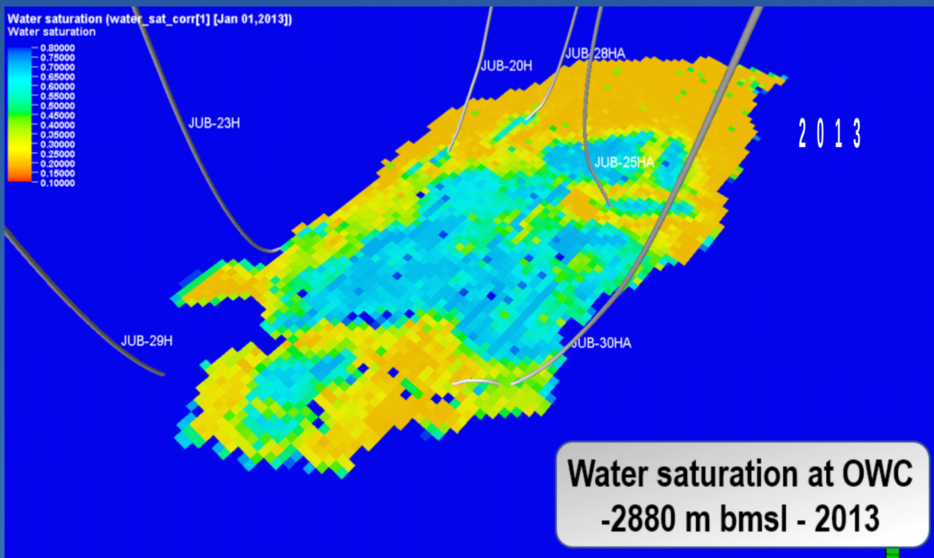
4D radial electric field magnitude differences after 5 years of water injection (2013-2018).

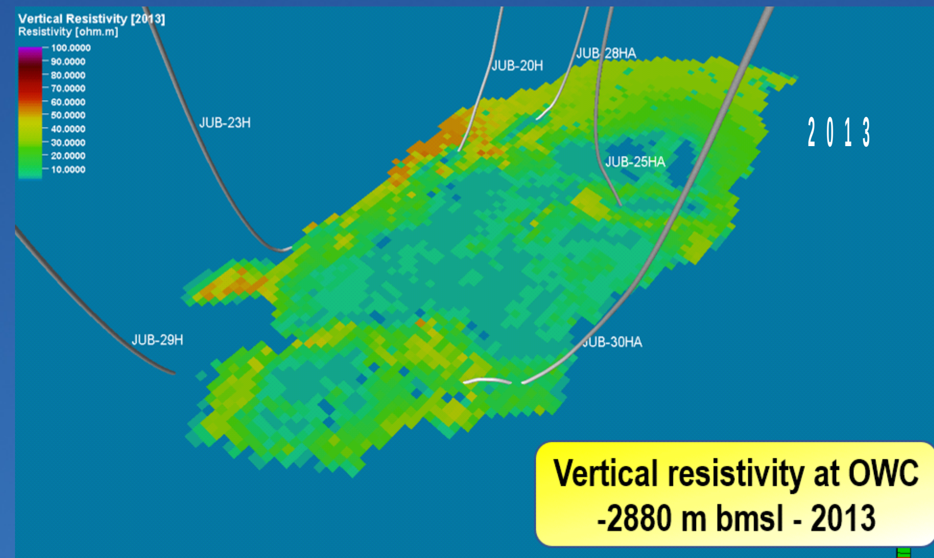
Differences up to 30% in amplitude.

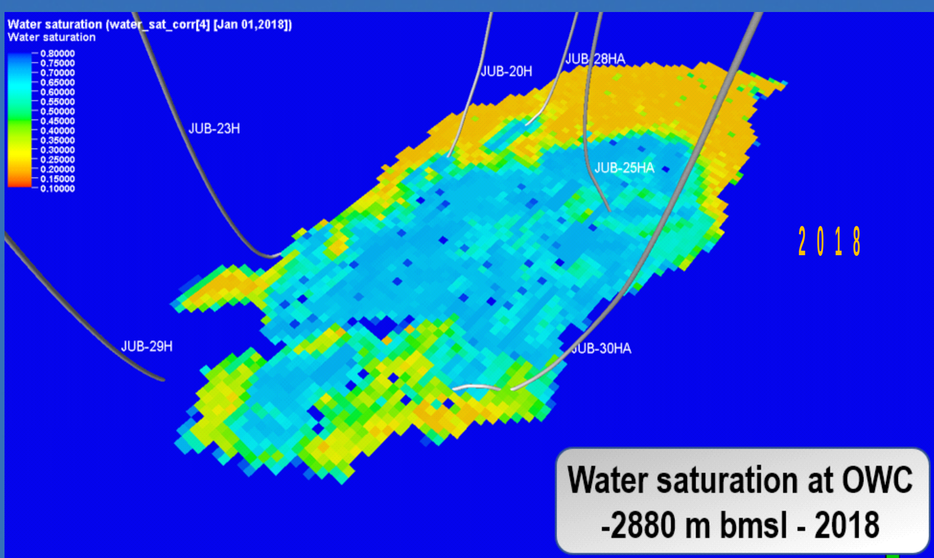


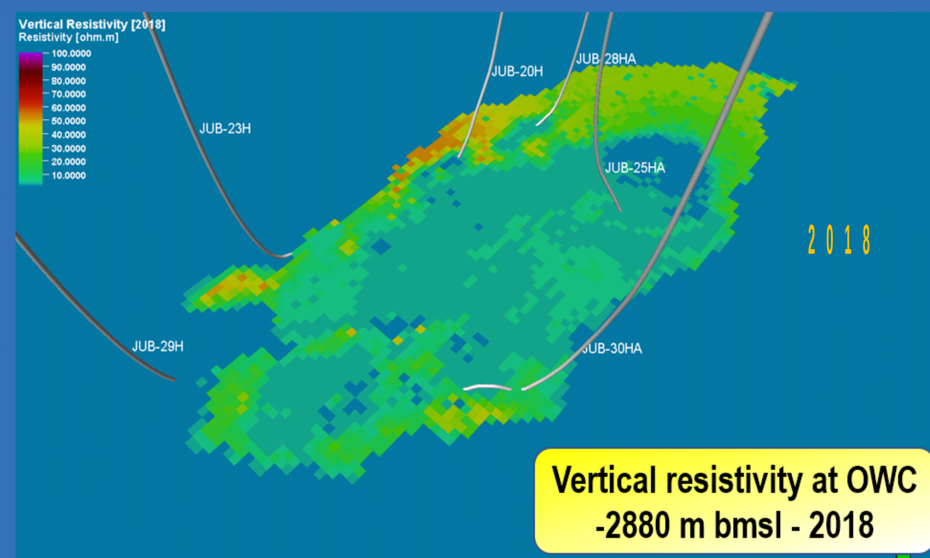
4D azimuthal magnetic field magnitude differences after 5 years of water injection (2013-2018).

Reservoir model parameters

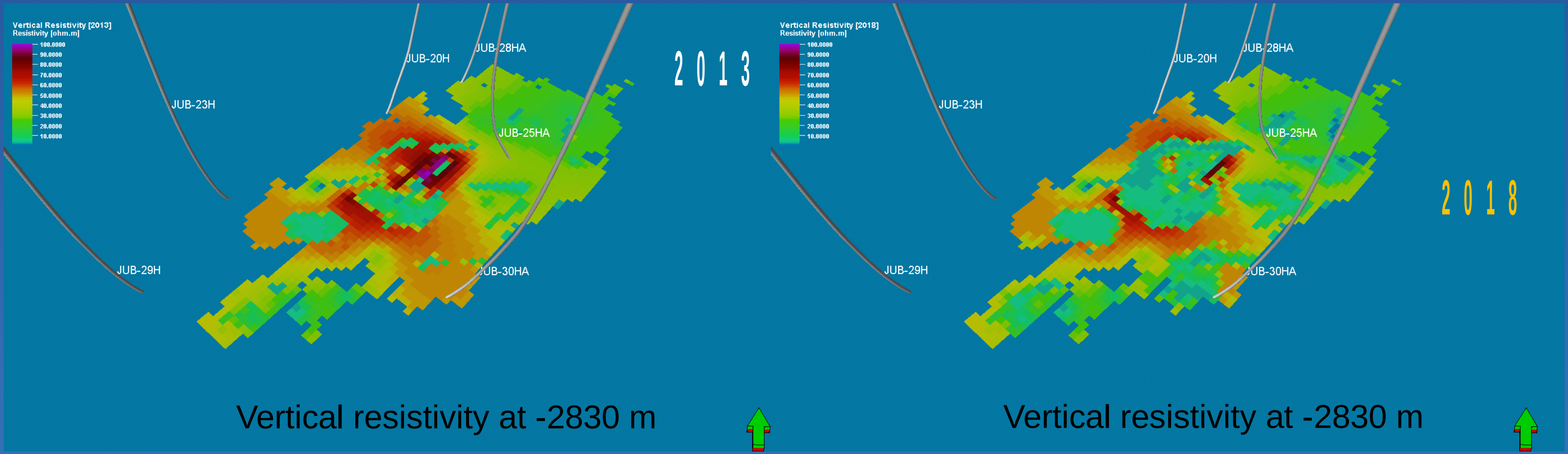






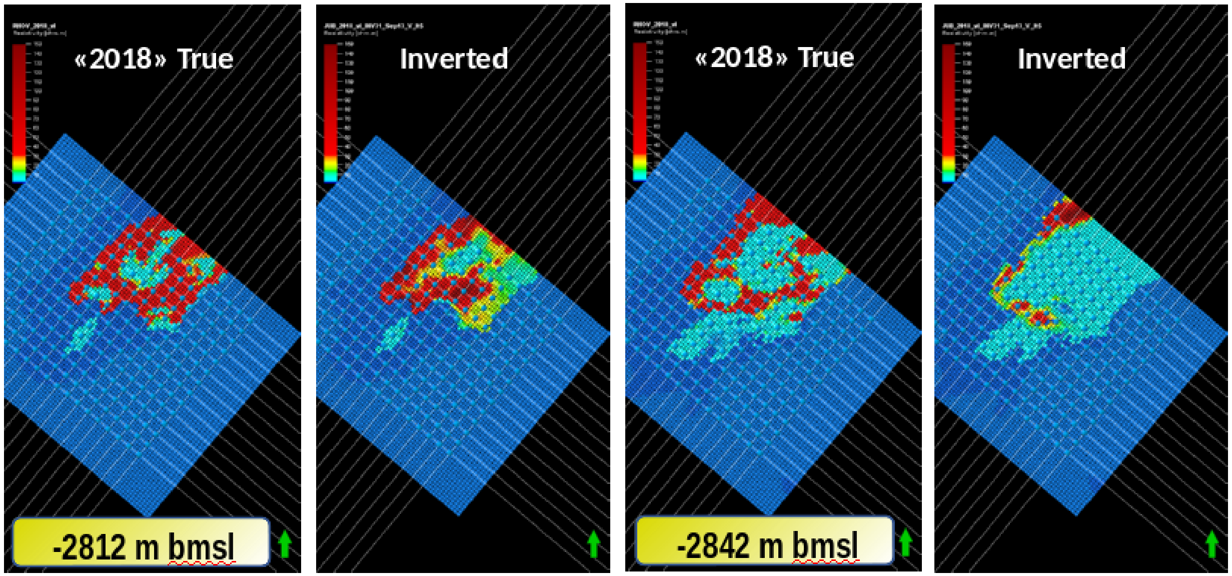


Realistic model

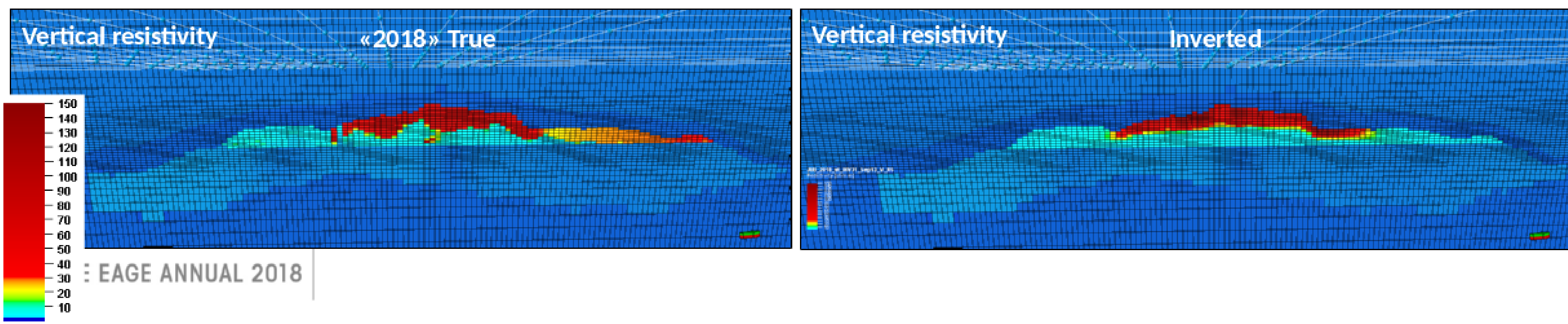


- **Making a realistic case isn't that simple.**
- **Critical factors:**
  - **Effect of overburden changes**
  - **Production-induced effects**
  - **Errors in survey geometry**
  - **Effect of ocean conductivity**
  - **Effect of cased wells/seabed pipelines/oilfield infrastructures**

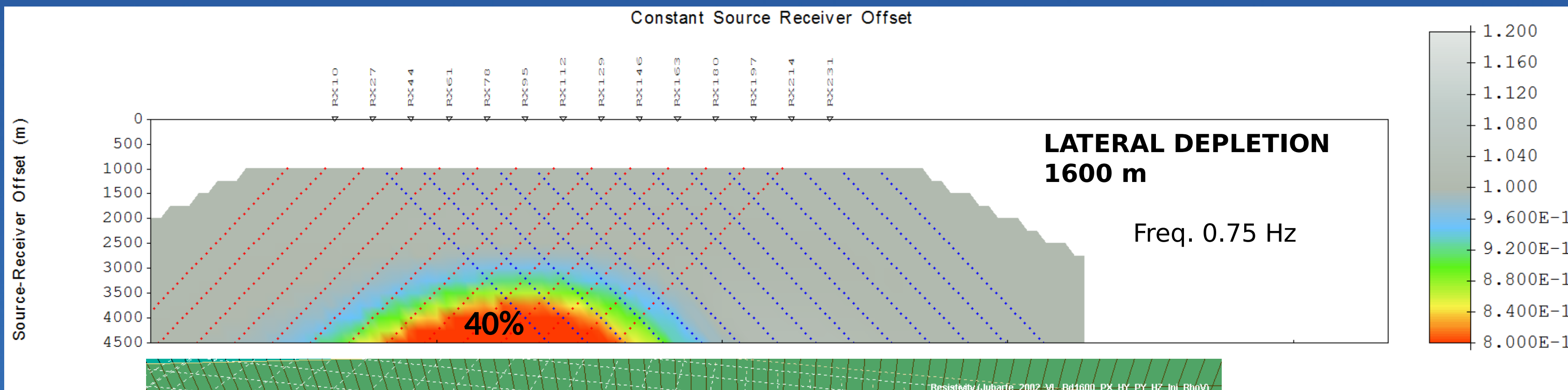
Inversion results

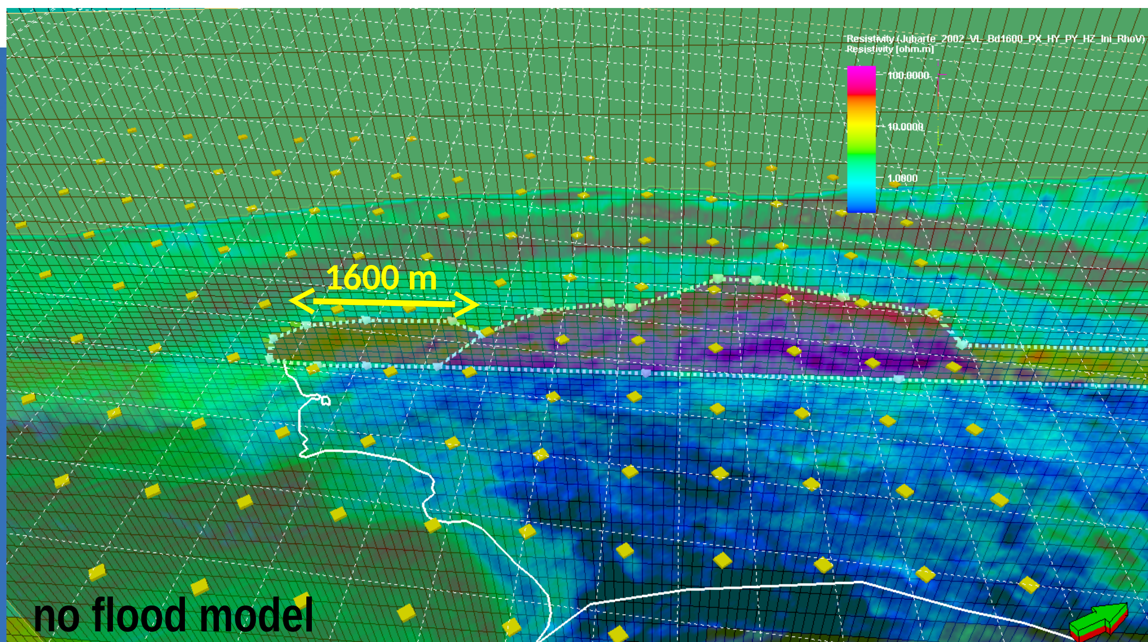


- Broadband, full-field, full-azimuth data
- Variable regularization parameters
- Repeatability accounted for
- Recovery of changes in small volumes
- Poorer recovery of bottom flooding



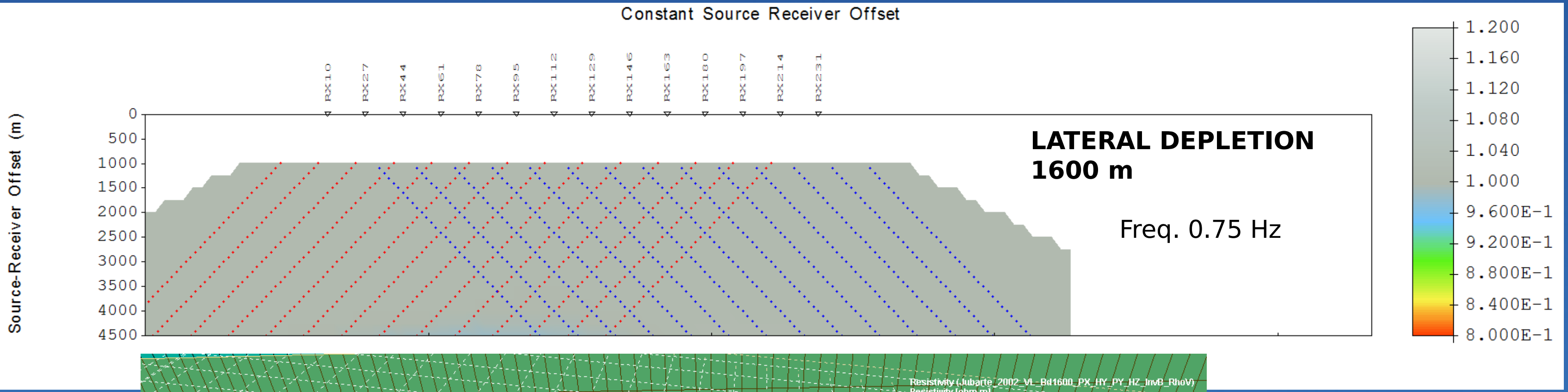
Localized inversion

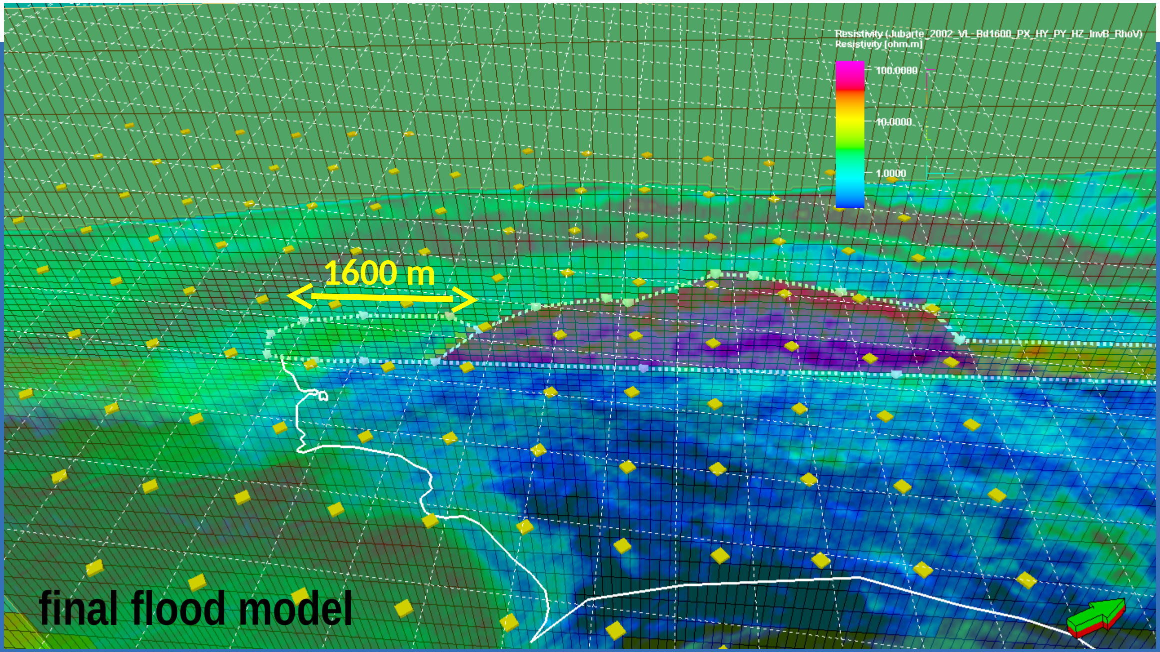




- **More accurate flood estimates**
- **Minimal repeatability issues**
- **Cost and turnaround time reductions**

Localized inversion





- **More accurate flood estimates**
- **Minimal repeatability issues**
- **Cost and turnaround time reductions**

Conclusions

- Time-lapse EM can make a difference:
  - Production effects and variations in saturation translate into reservoir resistivity changes over time.
- Realistic models allow:
  - Learn the value of acquisition geometry, sensitivity of fluid changes and timing for repeatability.
- Inversion is the key interpretation product:
  - Value and advantages of inversion methodologies can be assessed.
  - Take advantage of localized inversions to increase resolution and save computer time.
- Major technological enhancements required:
  - Tensorial source for complete amplitude reconstruction.
  - Multiphysics receptors for cost-effective seafloor acquisition.

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ACKNOWLEDGMENTS

- Thanks to Petrobras and Schlumberger for support and permission to share these results.

- Thanks to Fabio Miotti of Schlumberger.