Big data assimilation and uncertainty quantification in 4D seismic history matching

By Xiaodong Luo, IRIS/NIORC

A research based on the collaborations with the following colleagues at IRIS:

Tuhin Bhakta, **Geir Evensen** (also with NERSC), **Morten Jakobsen** (also with UiB), **Rolf Lorentzen**, **Geir Nævdal**, **Randi Valestrand**

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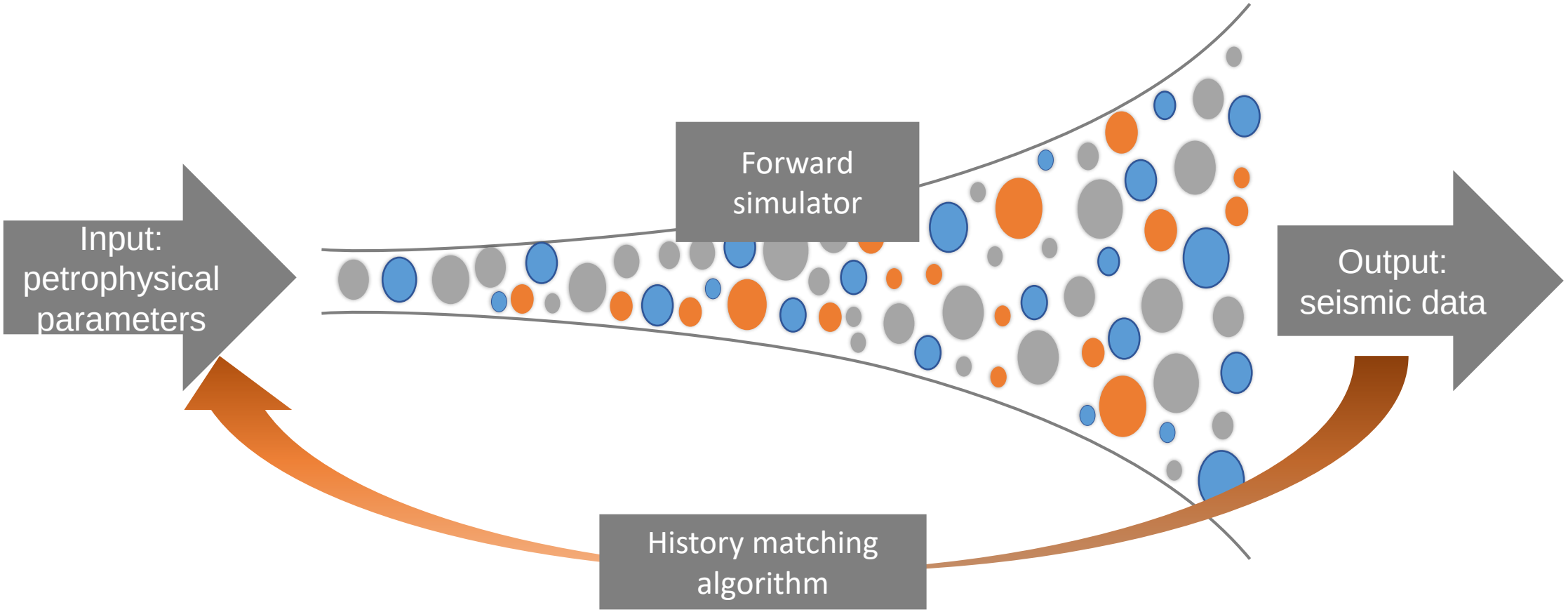
Outline

- Seismic history matching (SHM) for reservoir management and challenges
- Ensemble-based SHM workflow at IRIS
- Application examples of the workflow
- Conclusion and future work

Seismic history matching (SHM)



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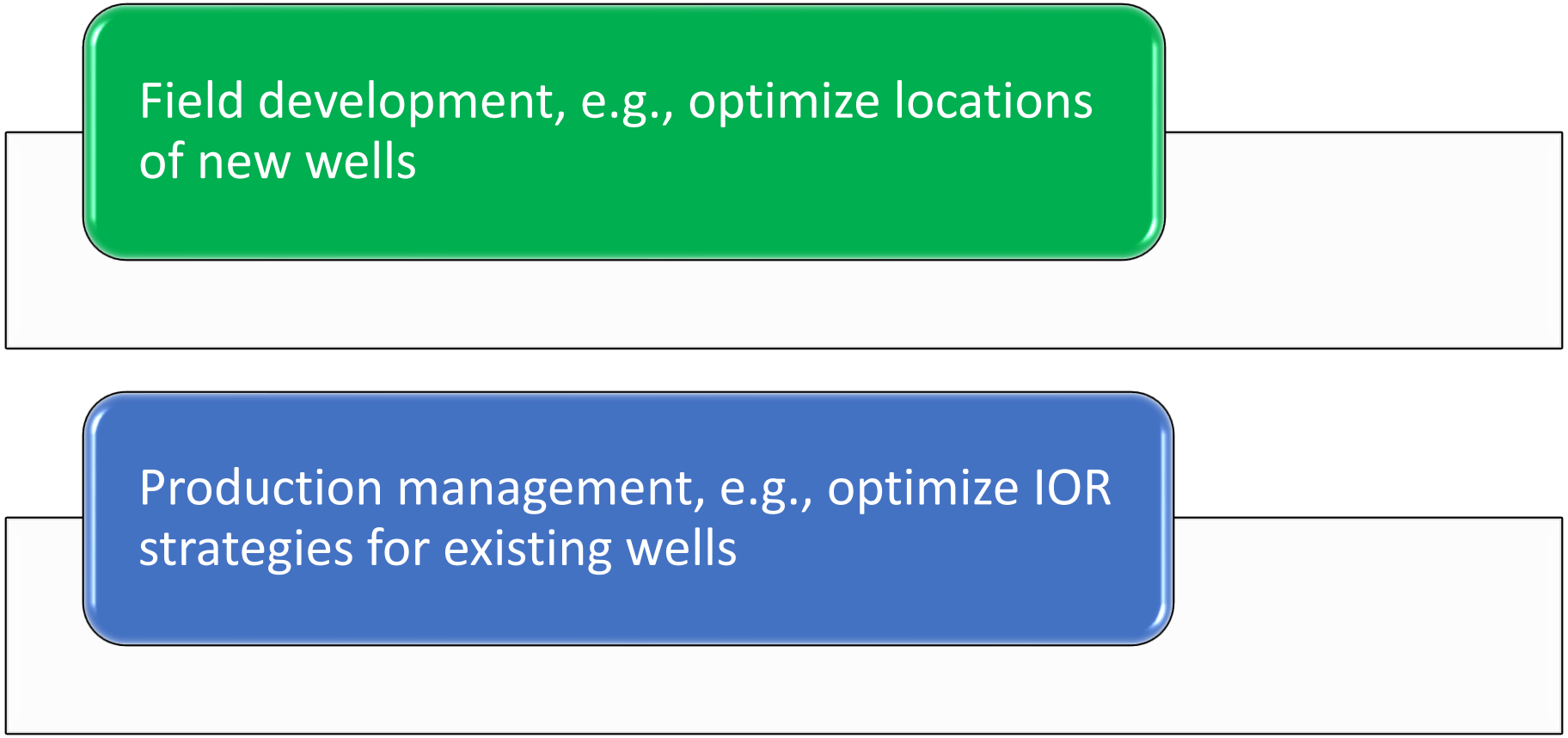
Integrating the results of seismic history matching for reservoir management



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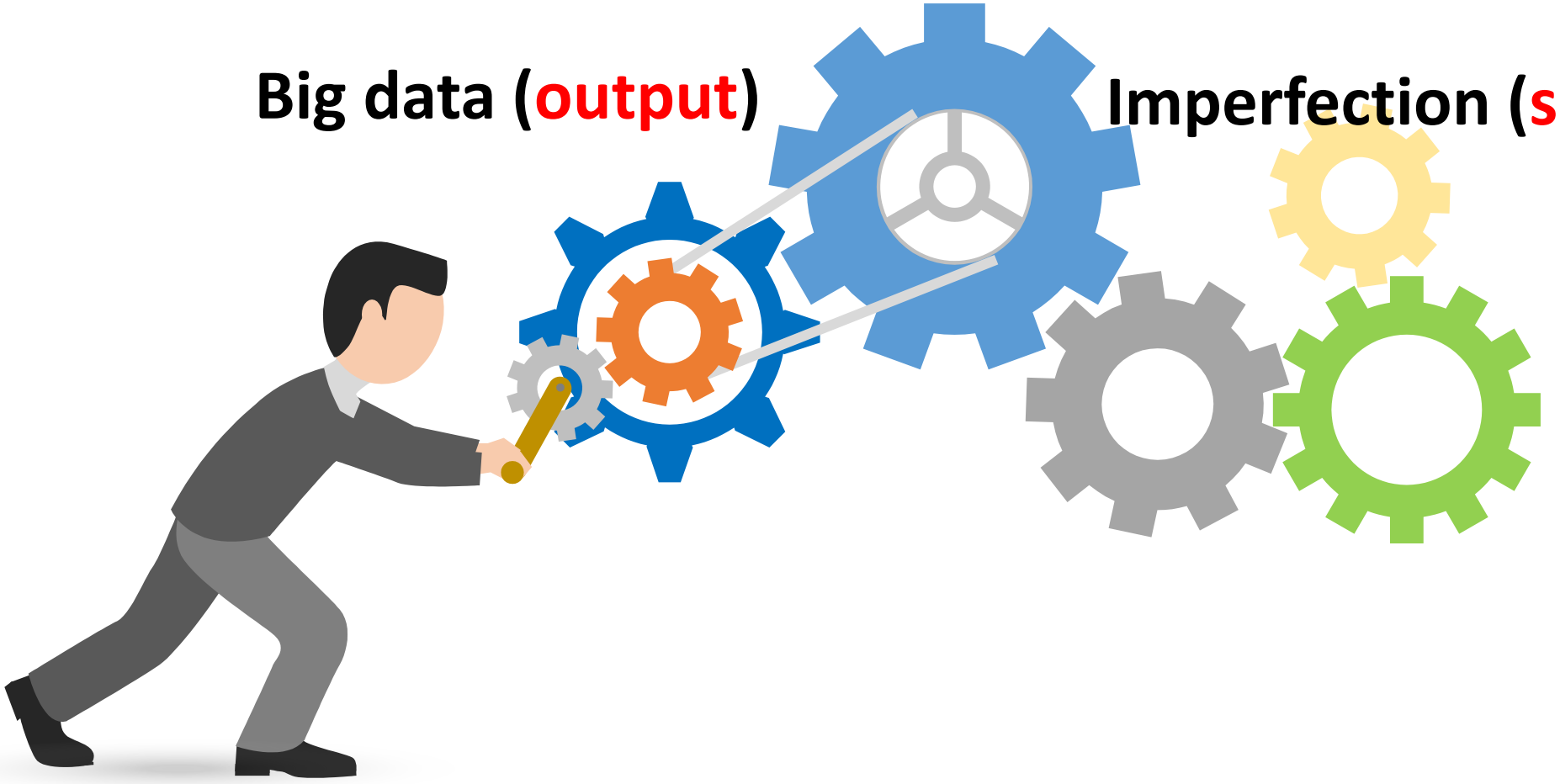
Challenges in seismic history matching (SHM)

Uncertainties (input/output)

Big data (output)

Imperfection (simulator)



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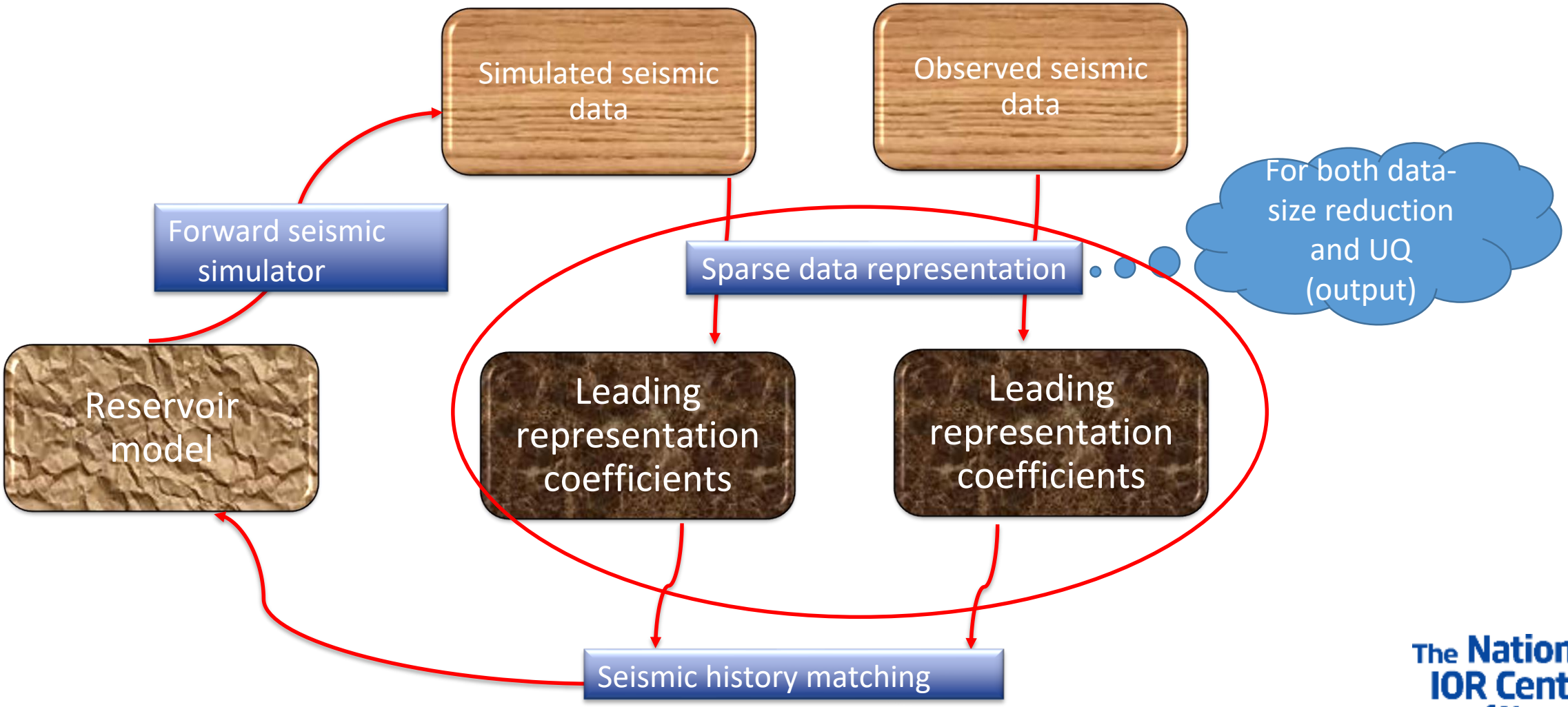
Ensemble-based SHM workflow at IRIS



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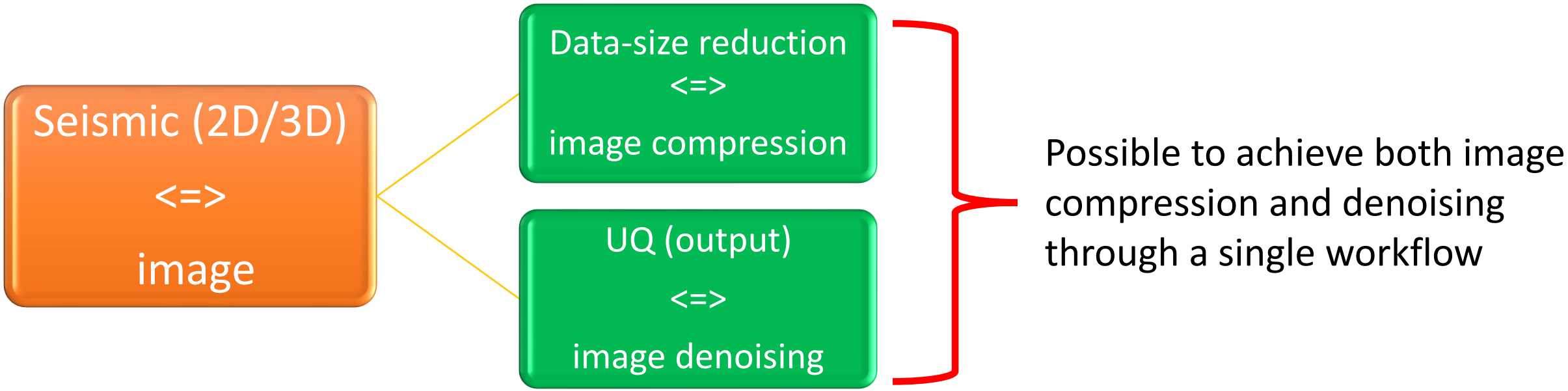
Sparse representation to handle big seismic data and UQ (output)



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Example: workflow of wavelet-based sparse representation*

- Discrete wavelet transform (DWT)

- Estimate noise in wavelet coefficients*
- Apply thresholding to remove small wavelet coefficients

- Efficient reduction of data size
- UQ (output) in the wavelet domain as a by-product
- Applicable to various types of image-like seismic data (AVA, impedance, time shift etc.)

* Luo, X., Bhakta, T., Jakobsen, M., & Nævdal, G. (2016). An ensemble 4D seismic history matching framework with sparse representation based on wavelet multiresolution analysis. *SPE Journal, 22,* 985 - 1,010

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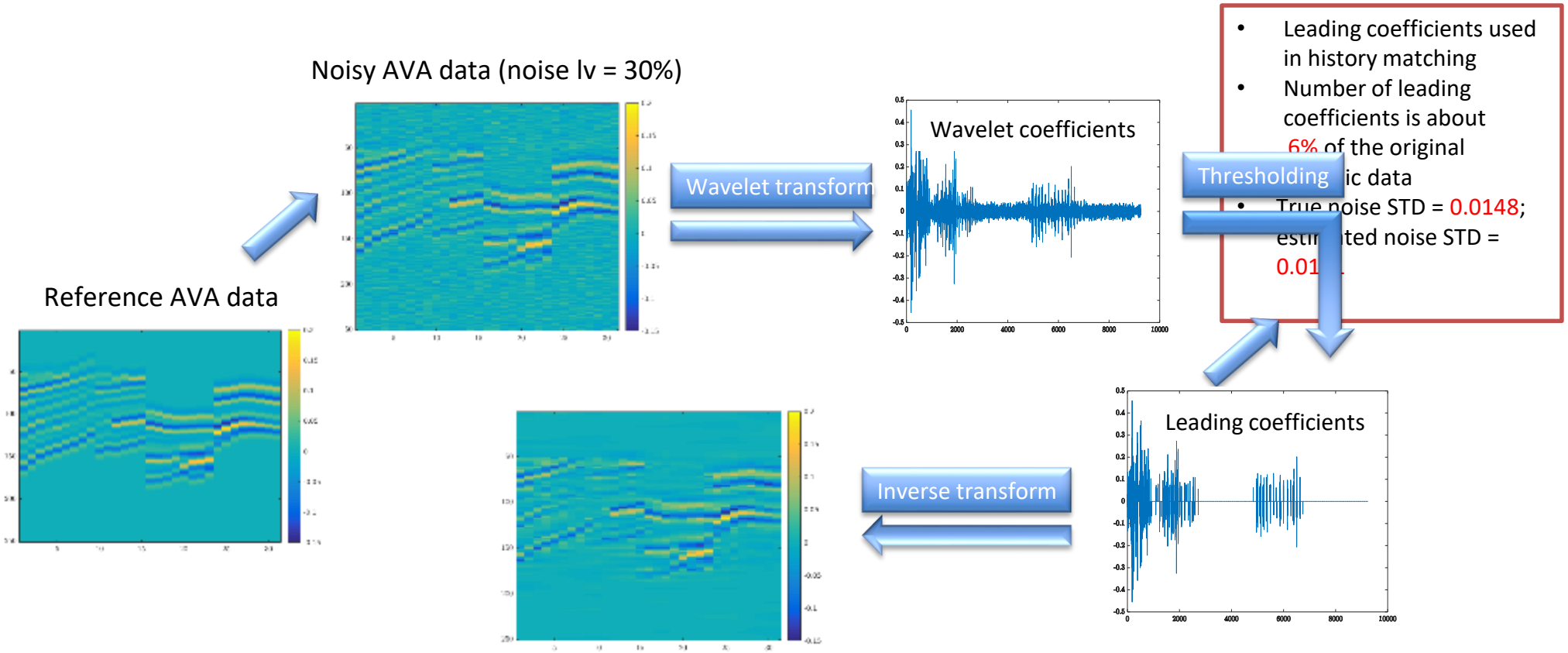
Wavelet-based sparse representation to handle big seismic data and UQ (output)

Illustration: 2D amplitude versus angle (AVA) data*



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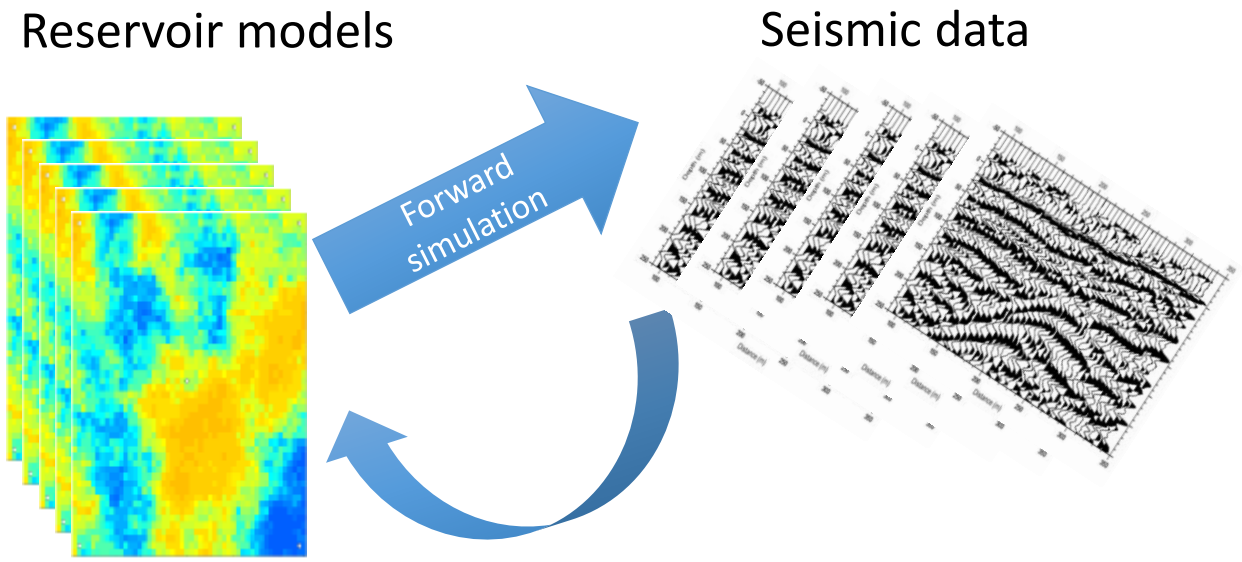
UQ (input) through ensemble-based history matching algorithms



- ✓Ensemble-based history matching methods provide a means of ***uncertainty quantification (UQ)*** for the estimated petrophysical parameters (inputs)

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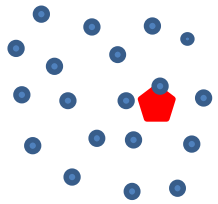
Poor UQ (input) performance due to ensemble collapse

Desired scenario



Reality: ensemble collapse

- Estimates
- Truth

❑ **Ensemble collapse**: a phenomenon in which estimated reservoir models become almost identical with very few varieties

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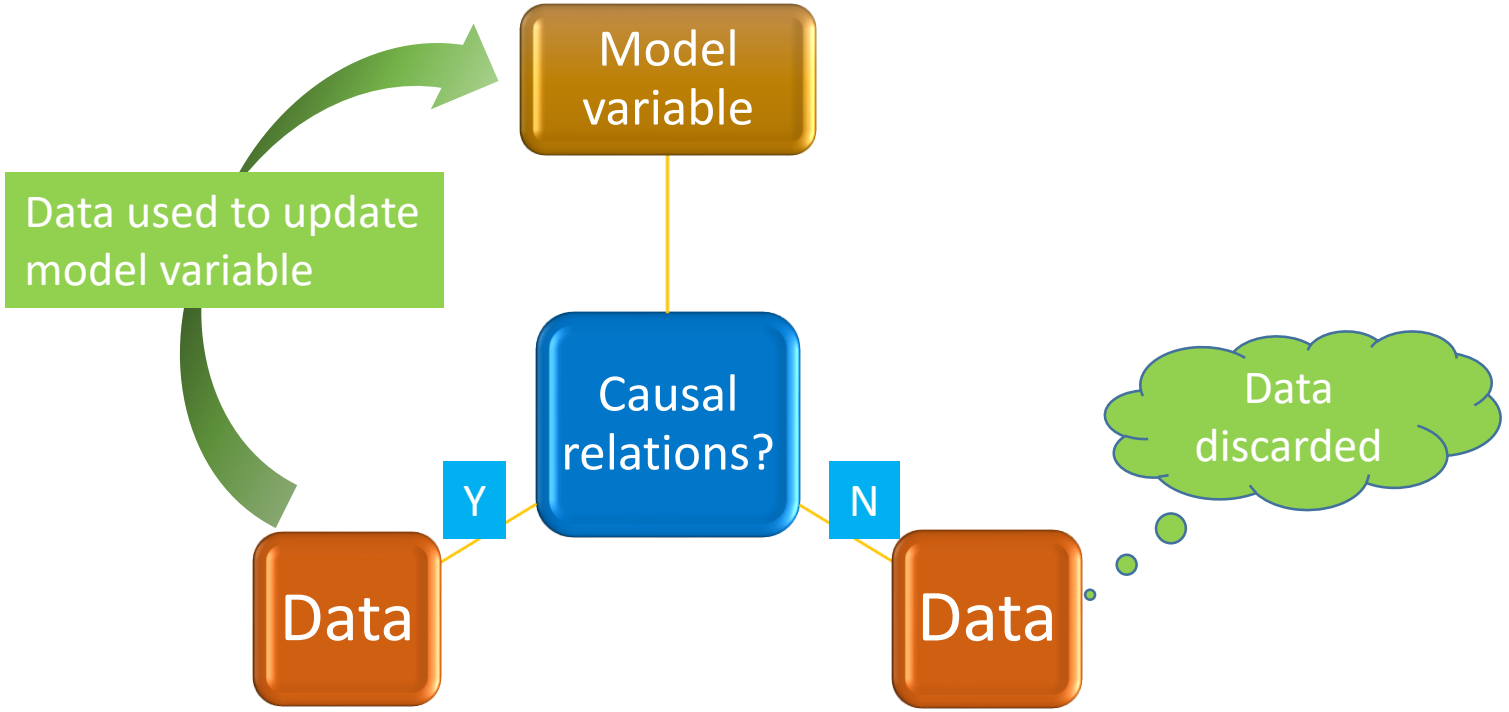
Improving UQ (input) performance through correlation-based adaptive localization*



*Luo, X., Bhakta, T., & Nævdal, G. (2018). Correlation-based adaptive localization with applications to ensemble-based 4D-seismic history matching. *SPE Journal,* 23, 396 – 427, 2018

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Overcoming some long-standing issues arising in conventional distance-based localization*§

*Luo, X., Bhakta, T., & Nævdal, G. (2018). Correlation-based adaptive localization with applications to ensemble-based 4D-seismic history matching. *SPE Journal,* 23, 396 – 427, 2018.

§Luo, X, Lorentzen, R., Valestrand, R. & Evensen, G. (2018). Correlation-based adaptive localization for ensemble-based history matching: Applied to the Norne field case study. SPE Norway One Day Seminar, SPE-191305-MS

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Additional enhancements are introduced to make correlation-based adaptive localization become simple and efficient in implementation, while avoiding empirical turnings.

See the poster on Monday, also to be presented in ECMOR, September 2018, Barcelona, Spain.

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Ensemble-based seismic history matching (SHM) workflow at IRIS

Handling challenges in SHM	Big data 
	Uncertainty quantification 
	Imperfection 

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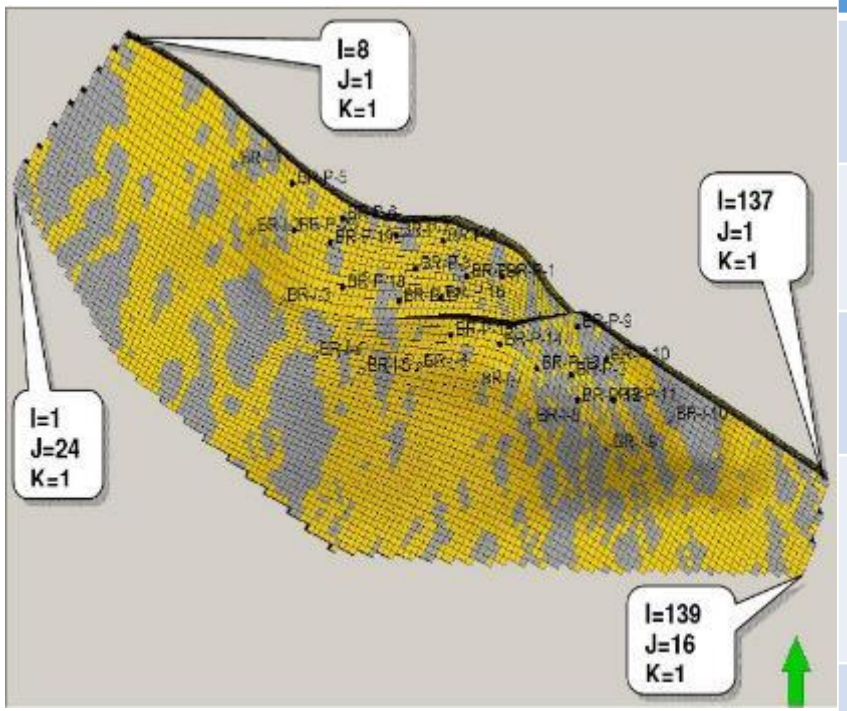
Example: Brugge benchmark case study*



Grid geometry of Brugge field

Experimental settings	
Model size	139x48x9, with 44550 out of 60048 being active gridcells
Parameters to estimate	PORO, PERMX, PERMY, PERMZ. Total number is 4x44550 = 178,200
Production data (~10 yrs)	BHP, OPR, WCT. Total number is 1400
4D seismic data (1 Base + 2 monitor surveys)	Near and far-offset AVA data. Total number is ~ 7 x 10^6 (needing too much computer memory to be used directly)
Leading wavelet coefficients	Two cases: 1. Total number is 178,332 (~2.5%); 100K case 2. Total number is 1665 (~0.02%). 1K case

*Luo, X., et al. (2016). An Ensemble 4D Seismic History Matching Framework with Sparse Representation and Noise Estimation: A 3D Benchmark Case Study. 15th European Conference on the Mathematics of Oil Recovery (ECMOR), Amsterdam, Netherlands, 29 August - 01 September, 2016.

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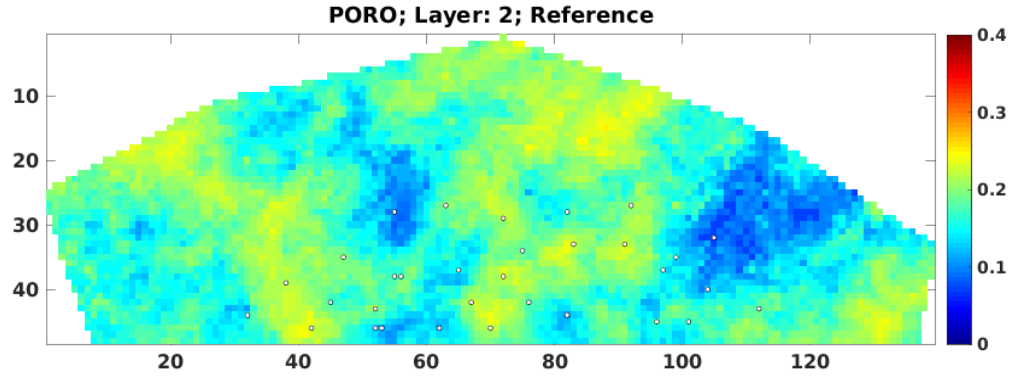
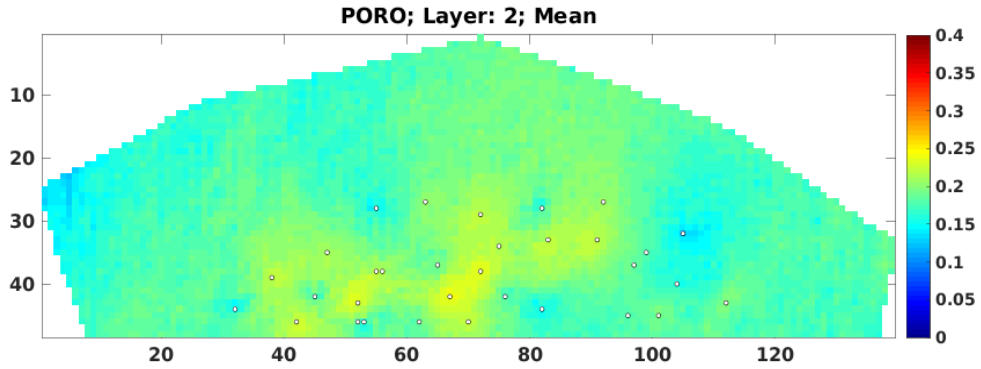
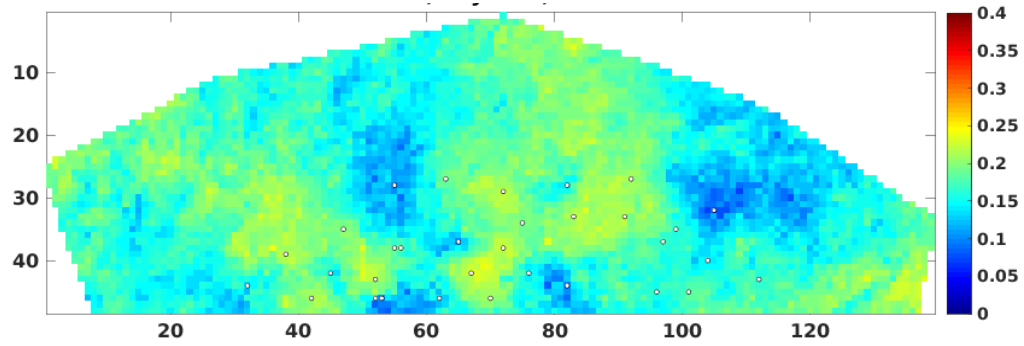
Reference PORO (at layer 2)



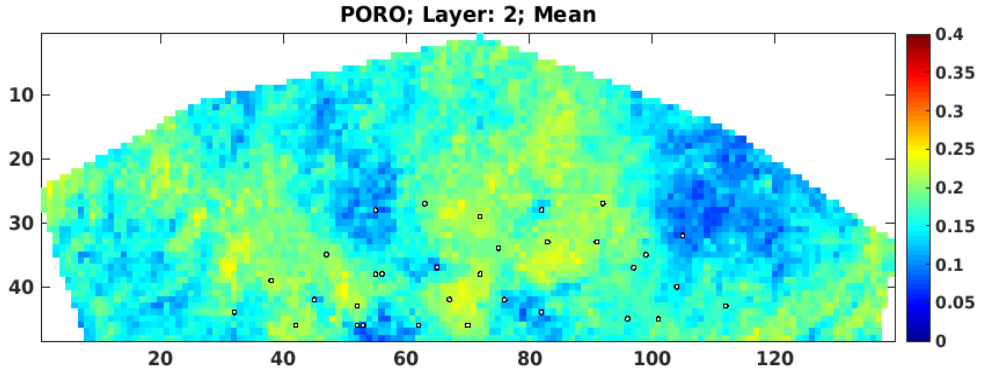
Mean PORO (at layer 2) of initial guess



Mean PORO (at layer 2) after history matching (100K)



Mean PORO (at layer 2) after history matching (1K)



Ongoing activities: Norne field case study using the SHM workflow with real seimsic data*

*Lorentzen, R. et al, to be presented in

- ❑ The 13th International EnKF Workshop, May 2018, Bergen, Norway
- ❑ ECMOR, September 2018, Barcelona, Spain.

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Conclusion

1. We have developed an efficient workflow to tackle the challenges of big data and UQ in SHM
2. Still lots of room for further enhancements and developments
3. The continuous long-term supports from NIORC, RCN and industrial partners are essential for us to come to this far

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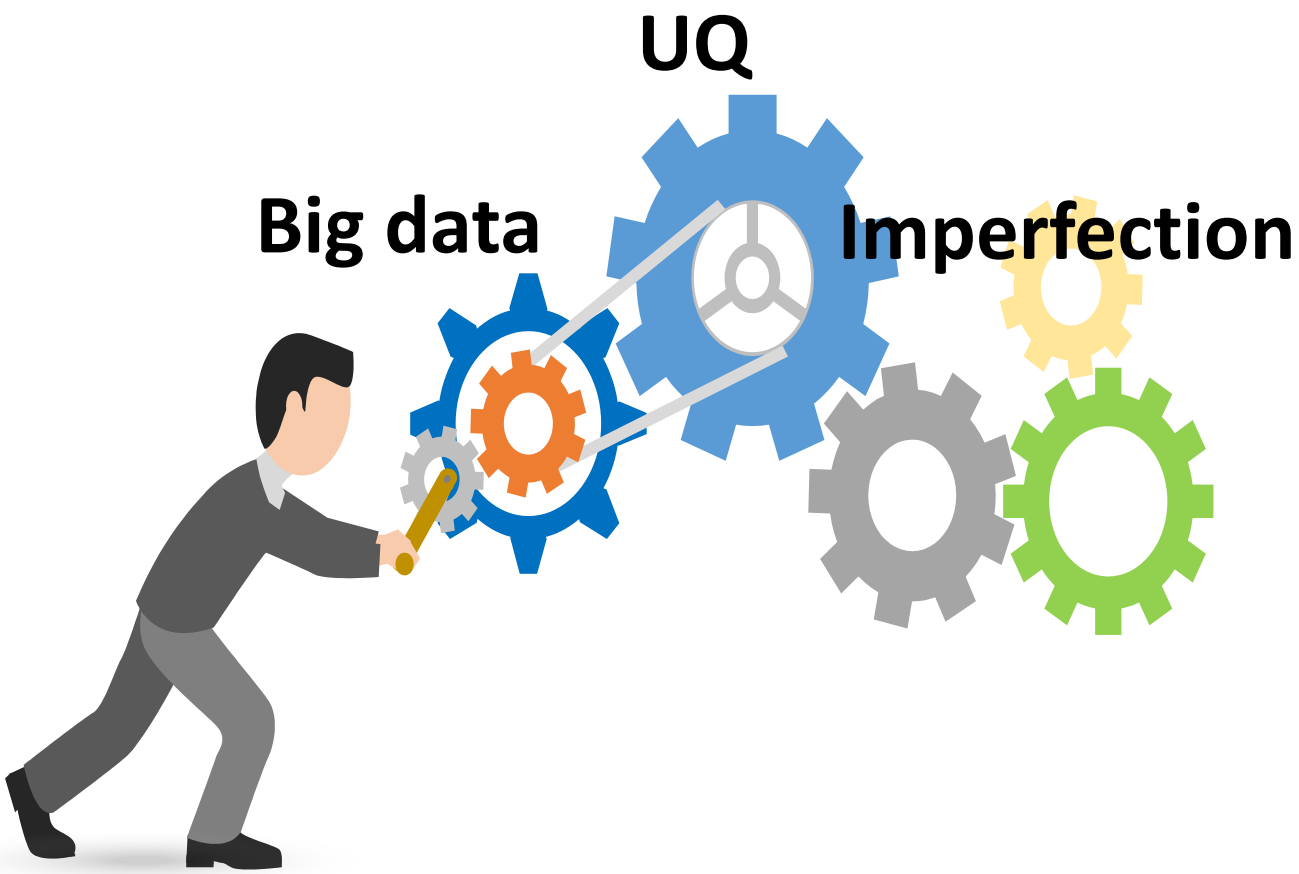
Future work



- More efficient solutions to tackling the challenges in SHM using multi-disciplinary approaches

- Possible improvements on the history matching algorithms

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The 2018 user partners and observers:

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Acknowledgements / Thank You / Questions

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