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Title: An Integrated Framework for CO_2 Accounting and Risk Analysis in CO_2-EOR Sites

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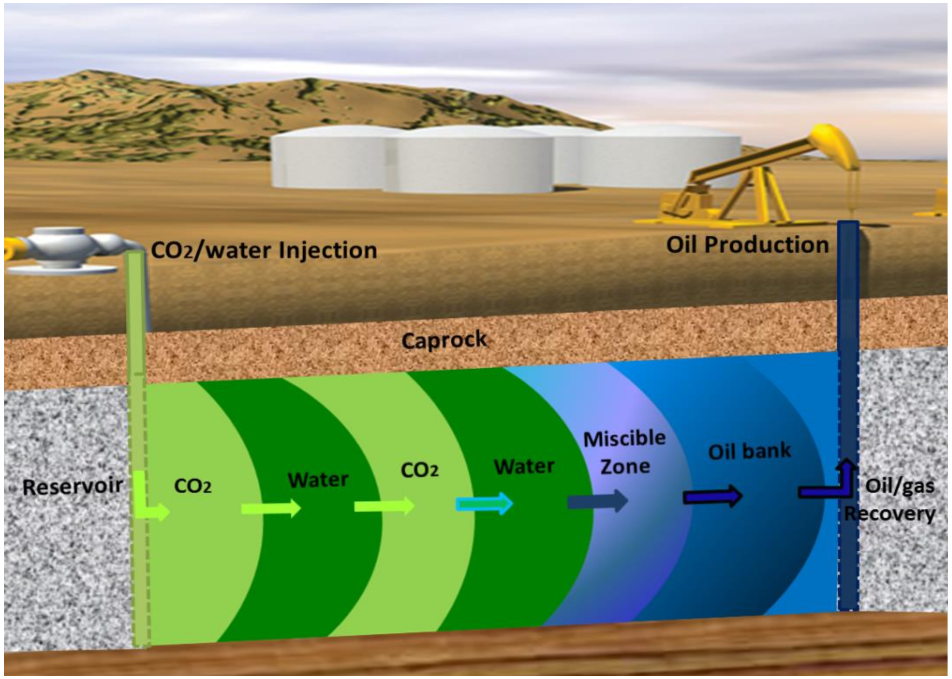
An Integrated Framework for CO_2 Accounting and Risk Analysis in CO_2-EOR Sites



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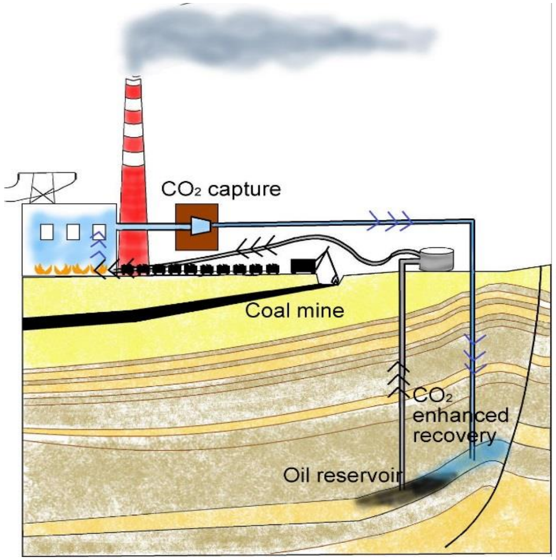
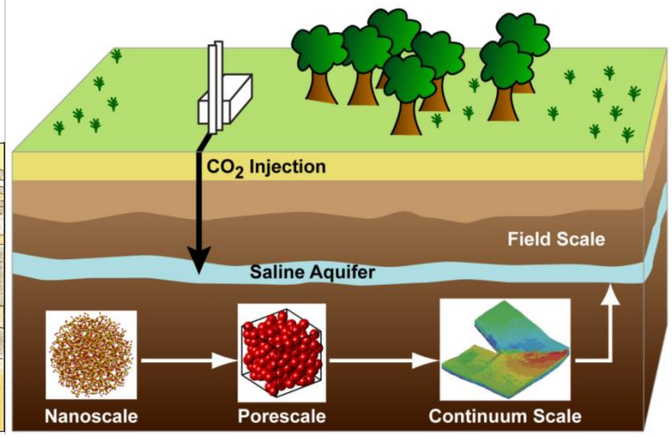
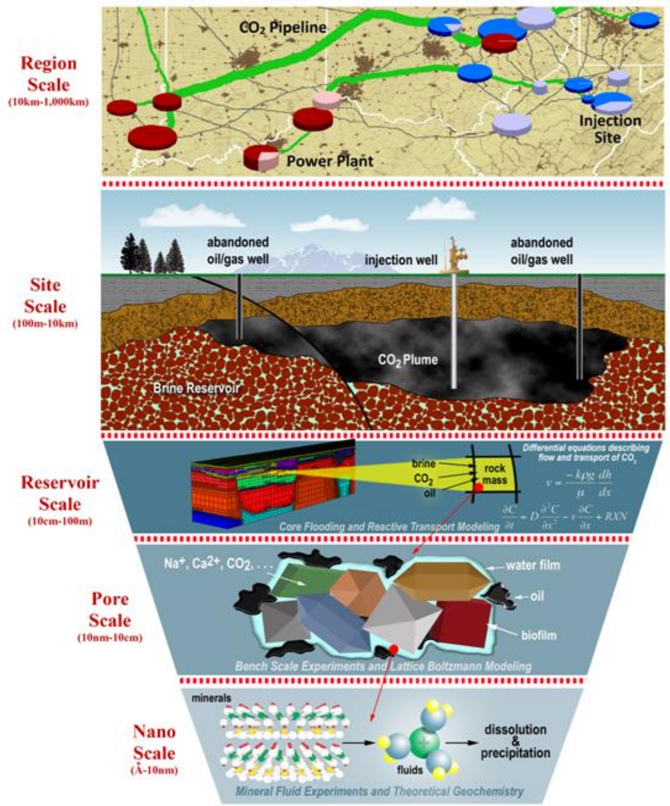
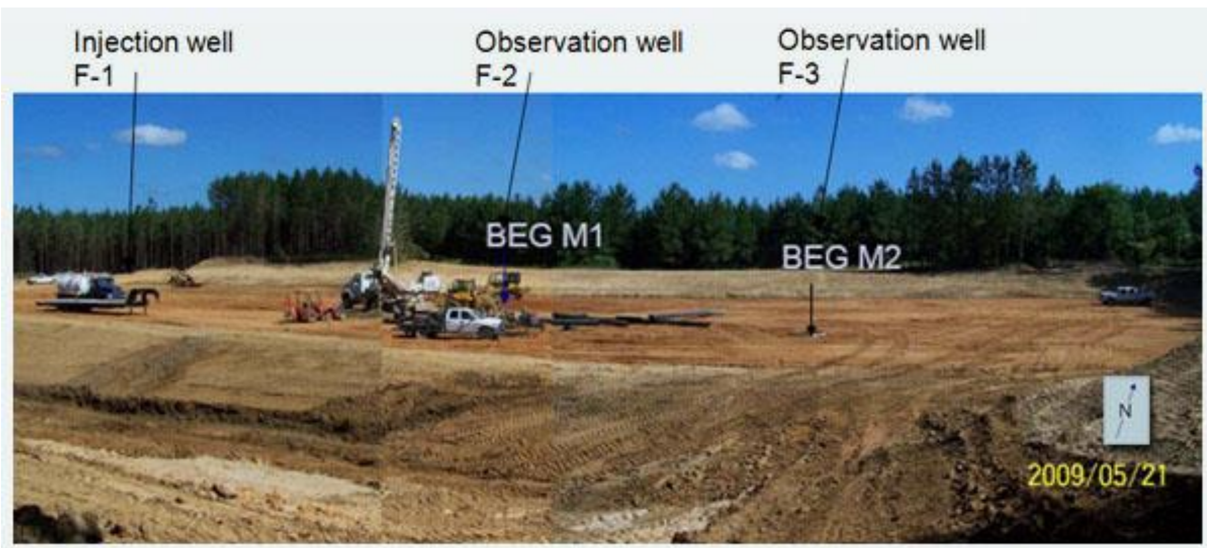
Carbon Sequestration





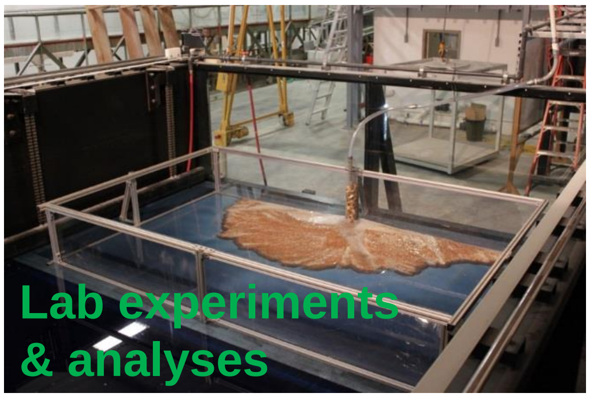


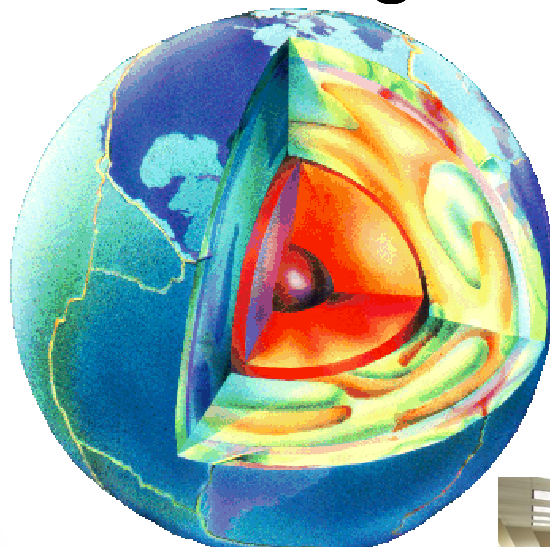


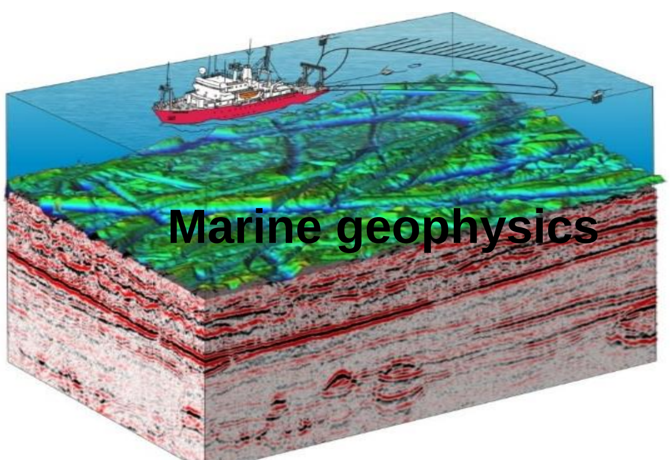
(Modified from Middleton et al. 2012, *Energy and Environ. Sci.*)

Satellite & airborne observations

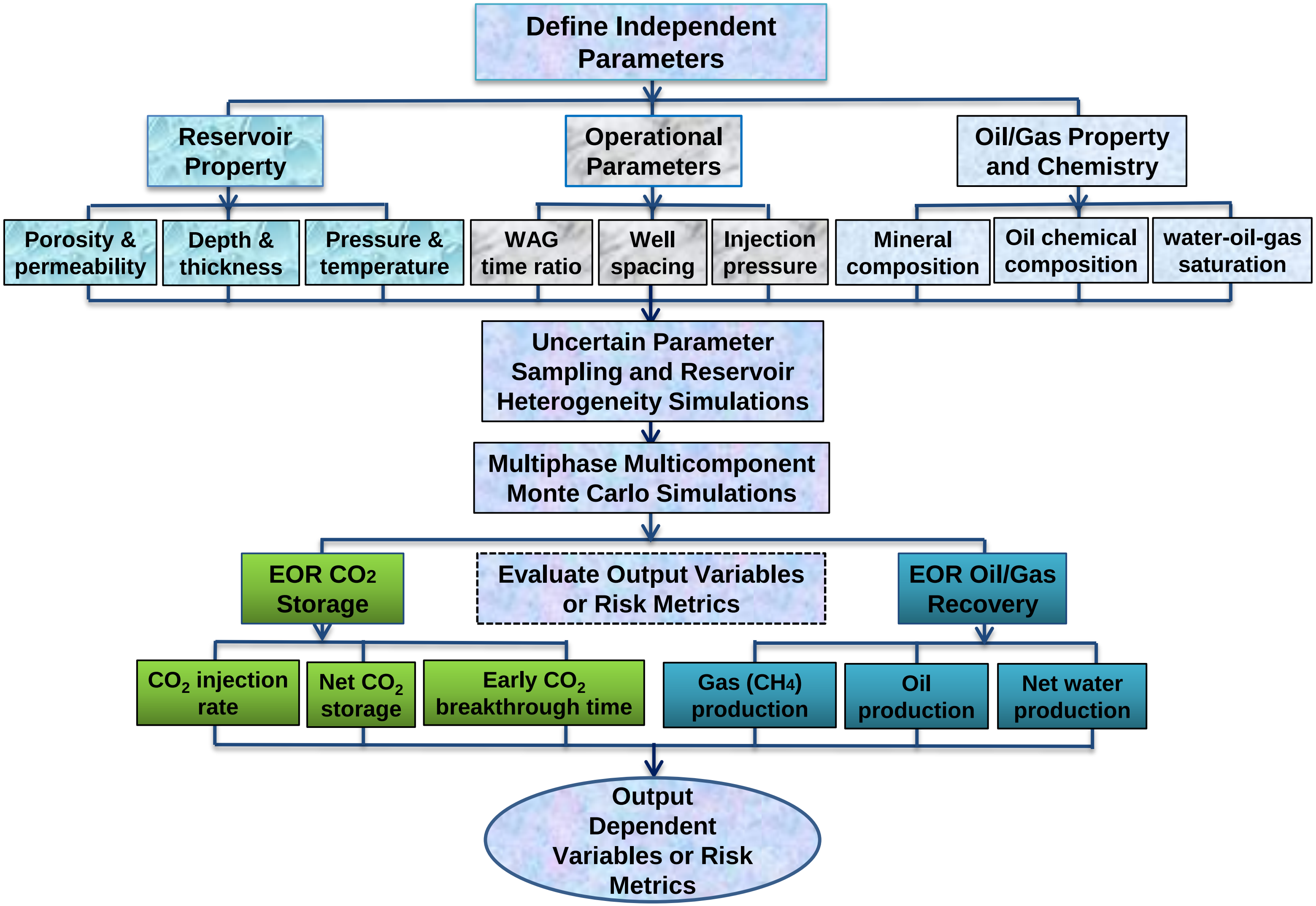
Research Integration



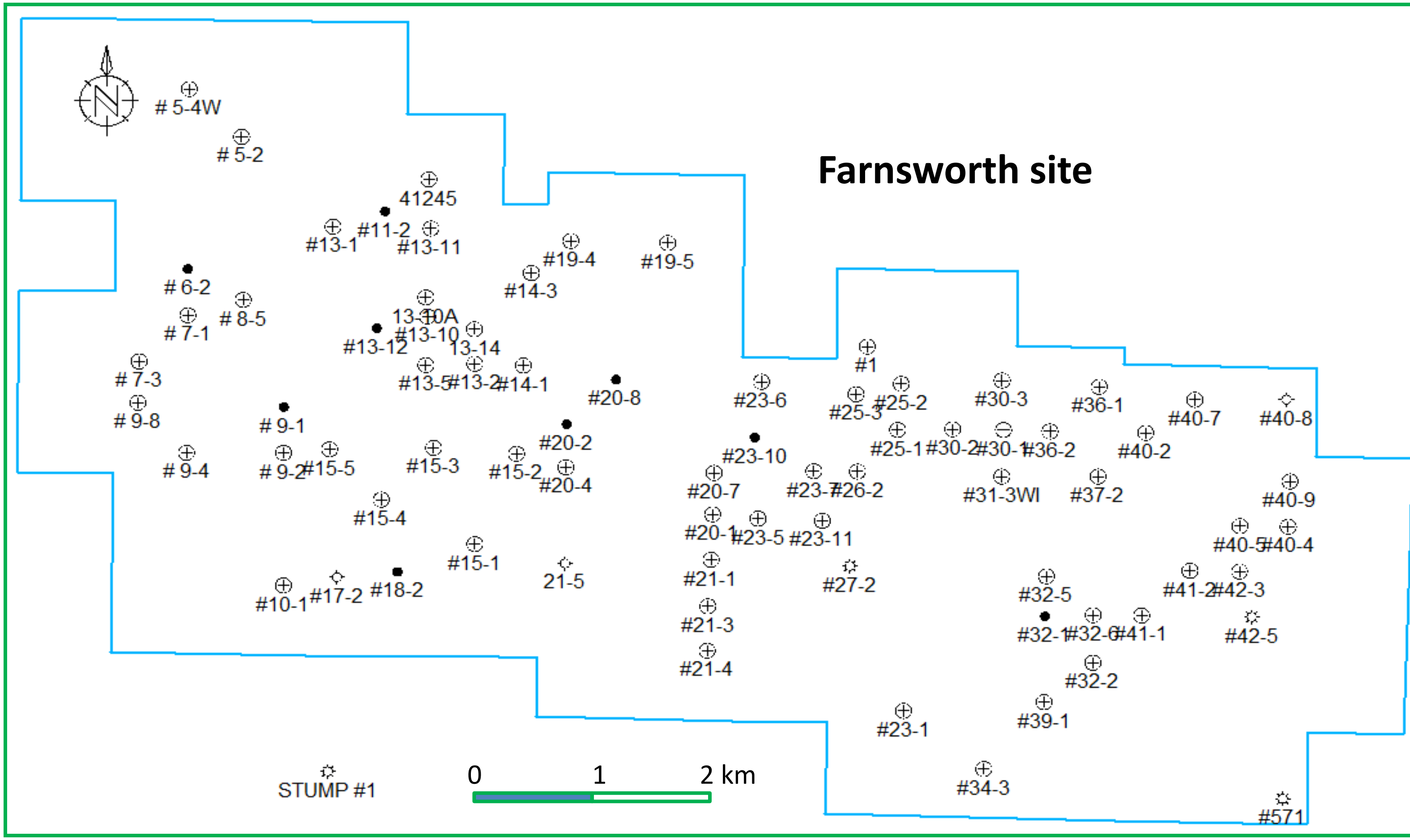




1. An integrated framework for CO_2 accounting and risk analysis in the Farnsworth site



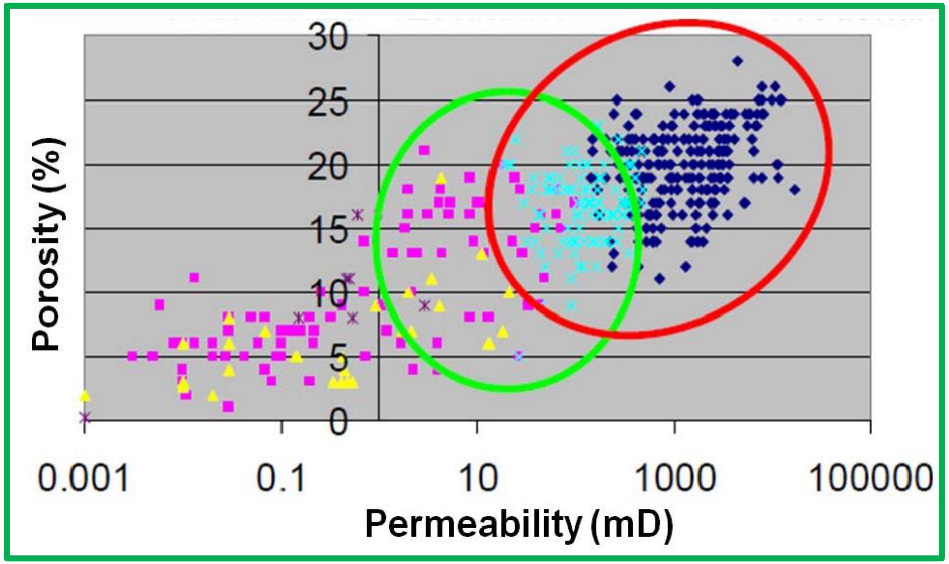
2. Permeability distribution and heterogeneity

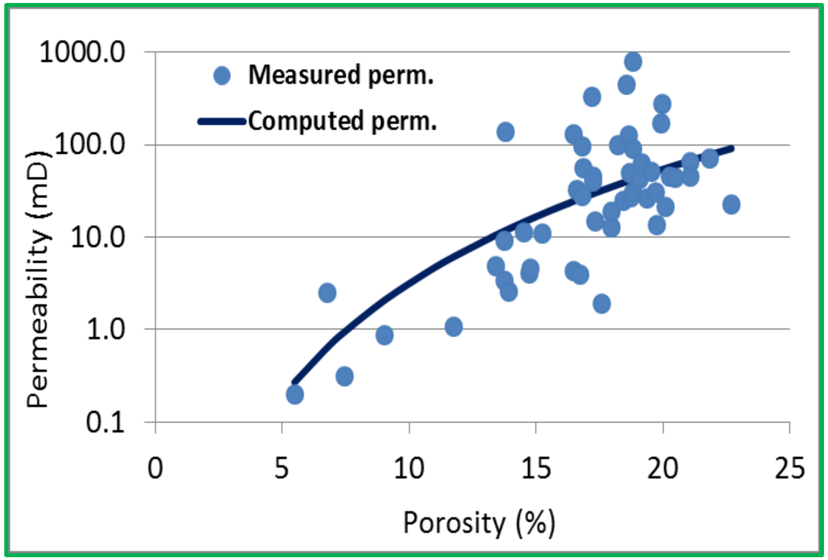


Borehole log data from about 70 wells in the Farnsworth site

Statistics of the measured Morrow reservoir parameters (SWP, February, 2014)

Statistics	Sample Depth (m)	Grain Density (g/cm^3)	Porosity (%)	Perm. (mD)	Perm. ($logm^2$)	Water Saturation (%)	Oil Saturation (%)
Minimum	2337.24	2.63	5.49	0.20	-15.71	10.68	8.69
Maximum	2348.73	2.92	22.69	783.50	-12.11	58.03	30.69
Mean	2343.02	2.67	16.78	69.21	-13.70	21.94	21.31
Standard Deviation	3.47	0.05	3.72	130.93	0.79	8.31	4.50

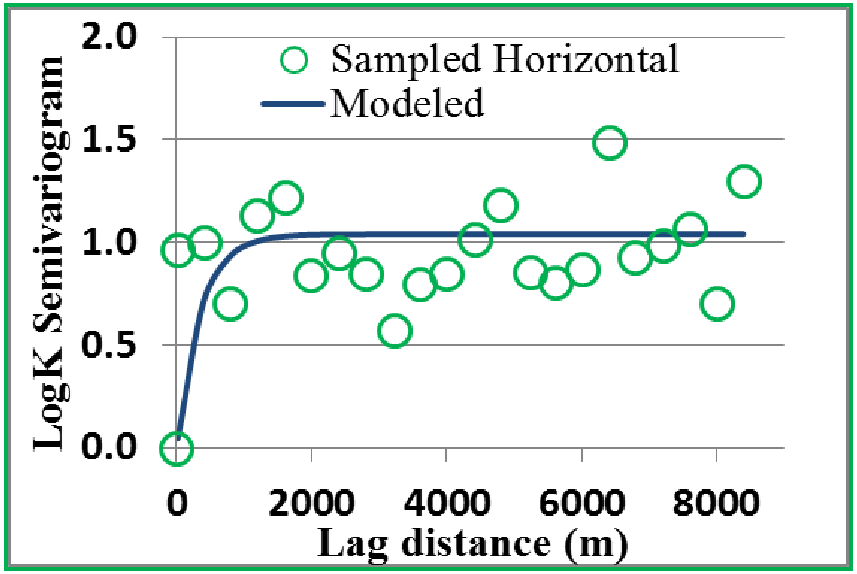


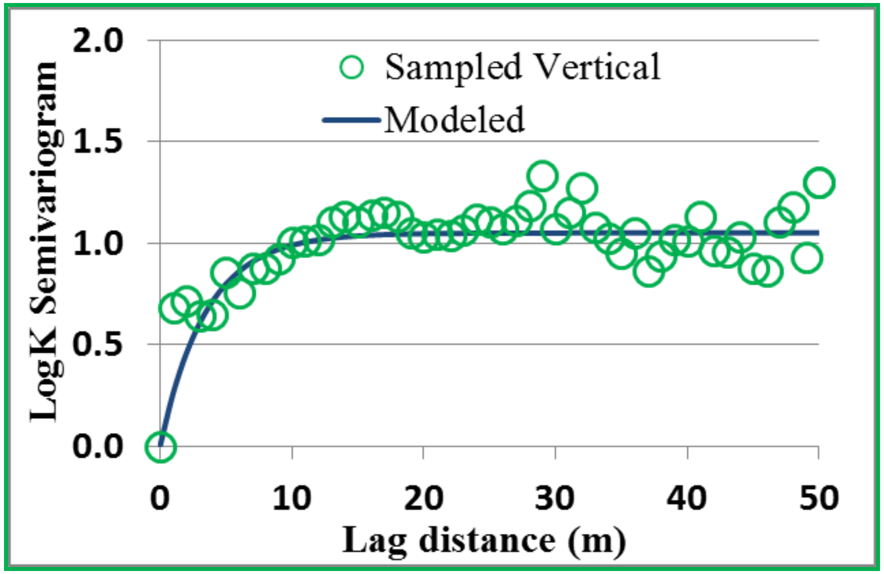


Permeability vs porosity in regional Marrow formation (left, modified from Bowen, 2005) and in Farnsworth site (right). The relationship equation for this site is obtained by inverse modeling of the site specific permeability and porosity data (modified from Bernabe et al. 2003).

$$K = a\, \phi^{b}$$

Permeability semivariograms in horizontal and vertical directions



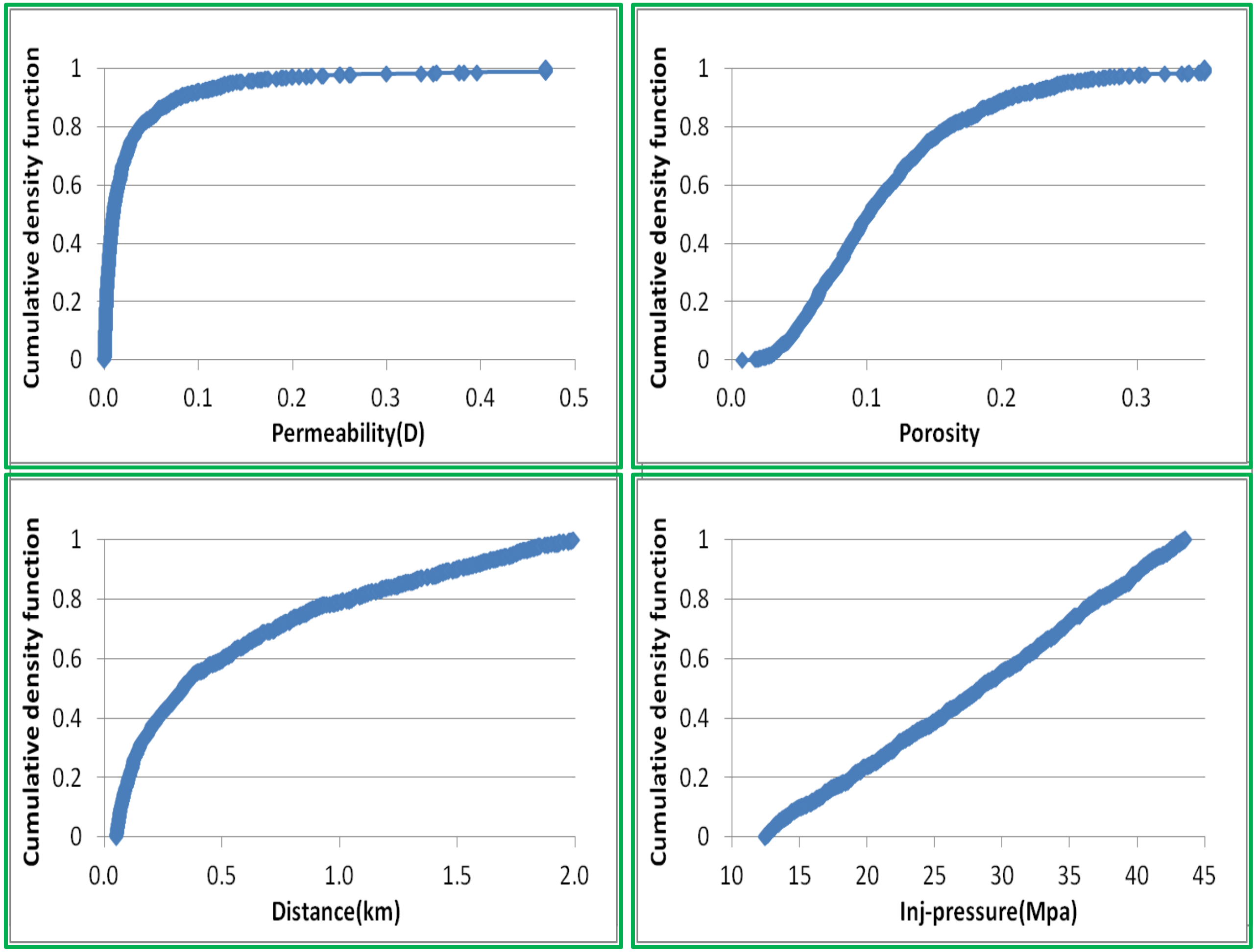


The variance of log permeability is 0.95 and the integral scales in horizontal and vertical directions are 350 and 3.5 meters, respectively. The horizontal integral scale is 100 times larger than the vertical integral scale.

Summarized uncertain parameters (independent parameters) and risk (or uncertainty) metrics for CO_2-EOR in the Farnsworth site

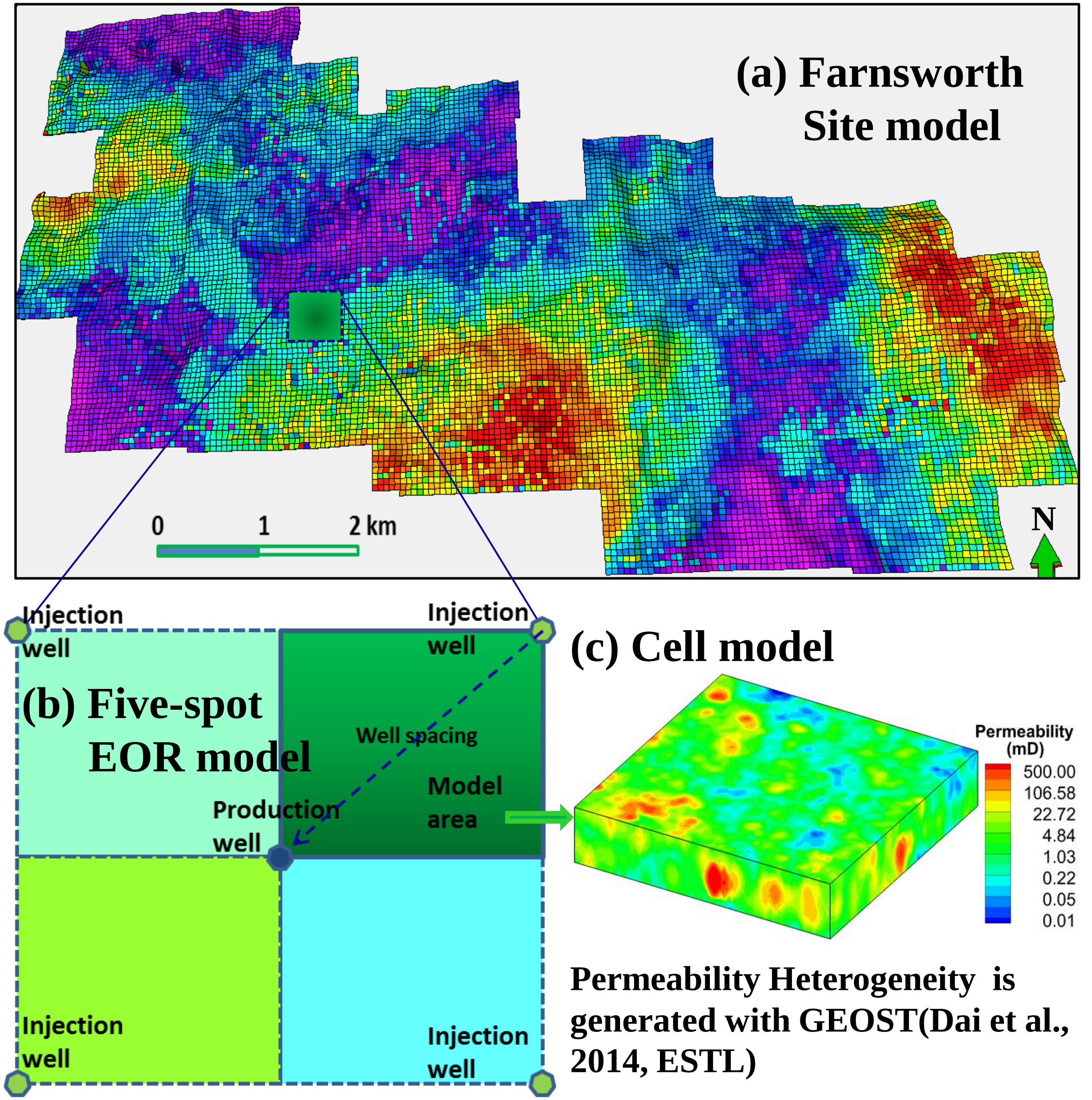
	Variables names	Min.	Max.	Mean
Uncertain Independent Parameters	Thickness(m)	5.0	50	27.5
	Permeability(mD)	0.2	783.5	69.2
	Porosity	0.05	0.23	correlated
	Initial water saturation	0.11	0.58	0.22
	Initial oil saturation	0.09	0.31	0.21
	Well spacing (m)	100	500	/
	Time ratio of WAG	0.0	10	/
Risk Metrics Or Dependent Variables	Net CO_2 injection(Mton)			
	Oil production(MMbbl)			
	Gas production(m^3)			
	Net water injection(Mton)			

Distributions of sampled uncertain parameters for MC simulations



Parameter distributions developed from 1000 realizations. The reservoir permeability is sampled with a log normal distribution and porosity is positively correlated with permeability. The well distance is a log uniform distribution. The others are uniform distributions.

3. A five-spot EOR pattern and MC model setup

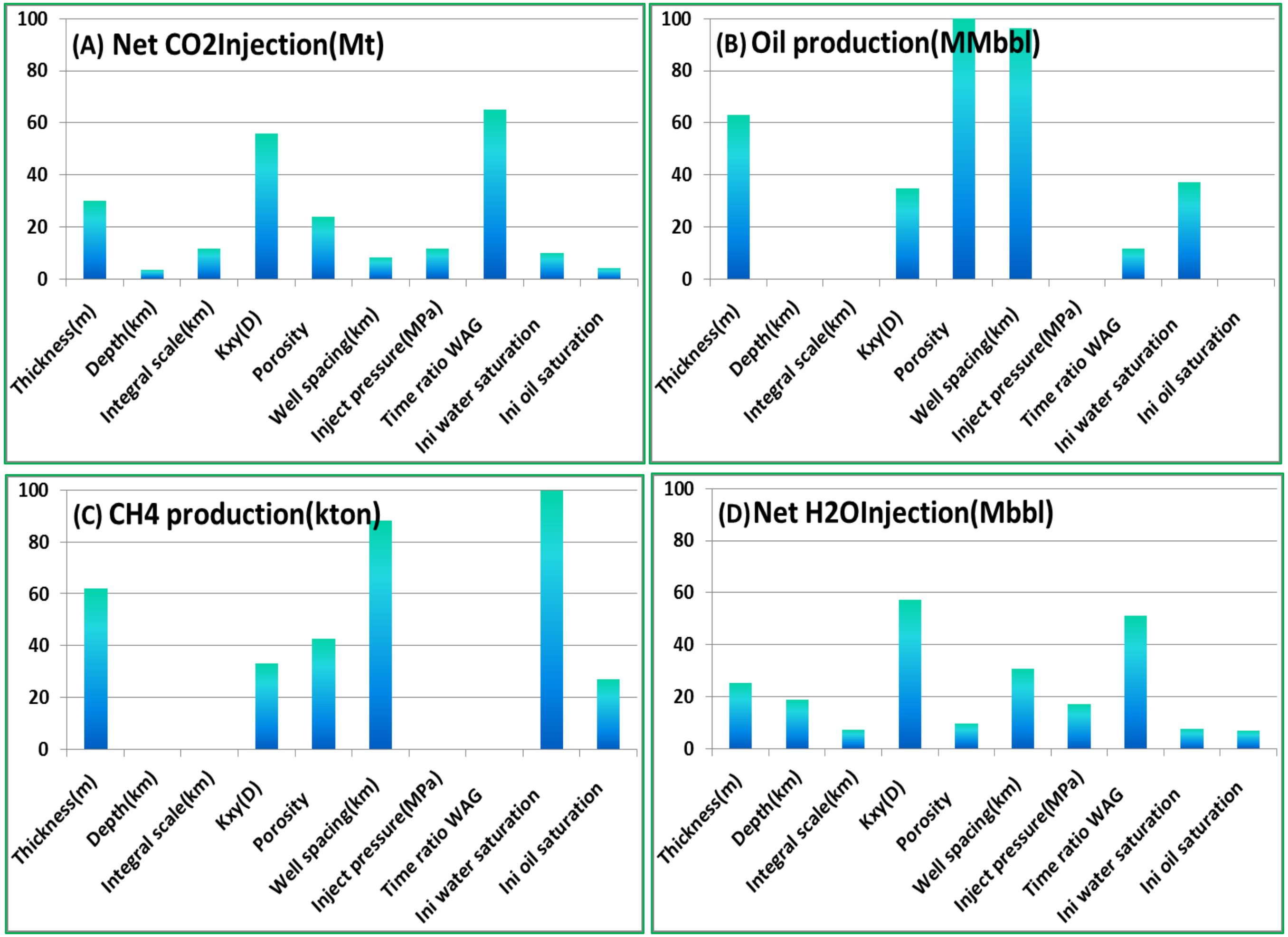


Permeability Heterogeneity is generated with GEOST(Dai et al., 2014, ESTL)

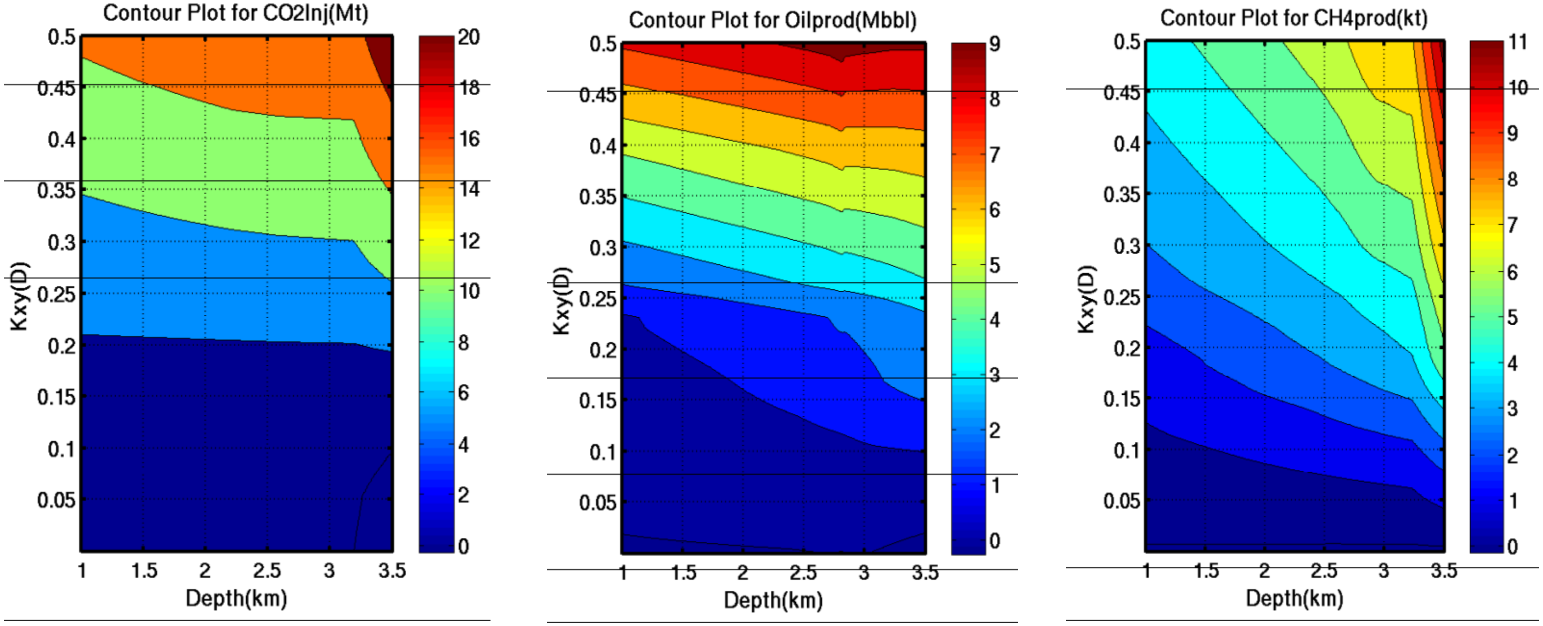
(Modified from Dai et al., 2014, *Environ. Sci. Technol. Lett.,* 1, 49-54)

4. Preliminary results

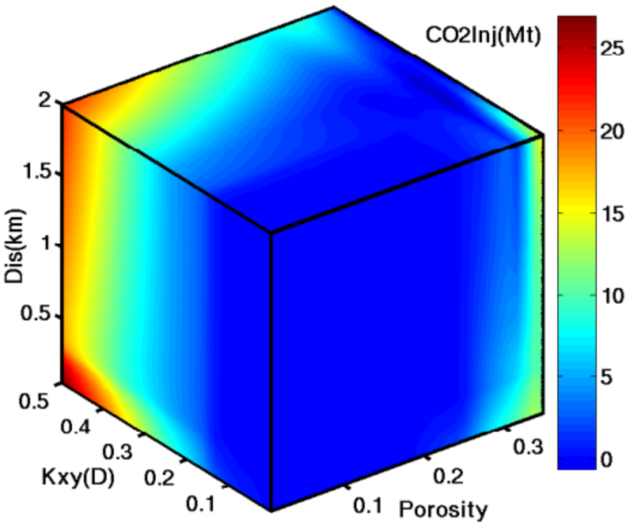
4.1 Global sensitivity analysis with ***multivariate adaptive regression spline*** (MARS) **method**

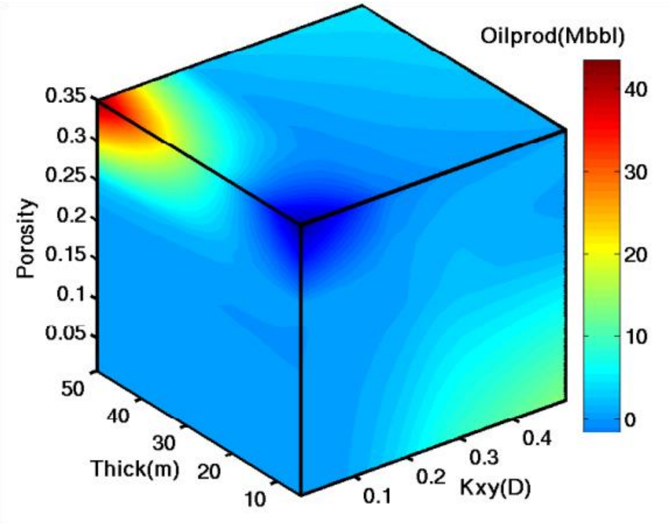


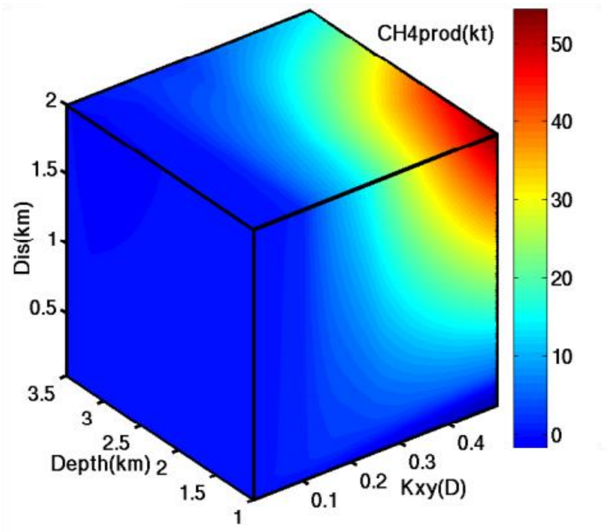
4.2 Response surfaces generated with PSUADE (2-D)



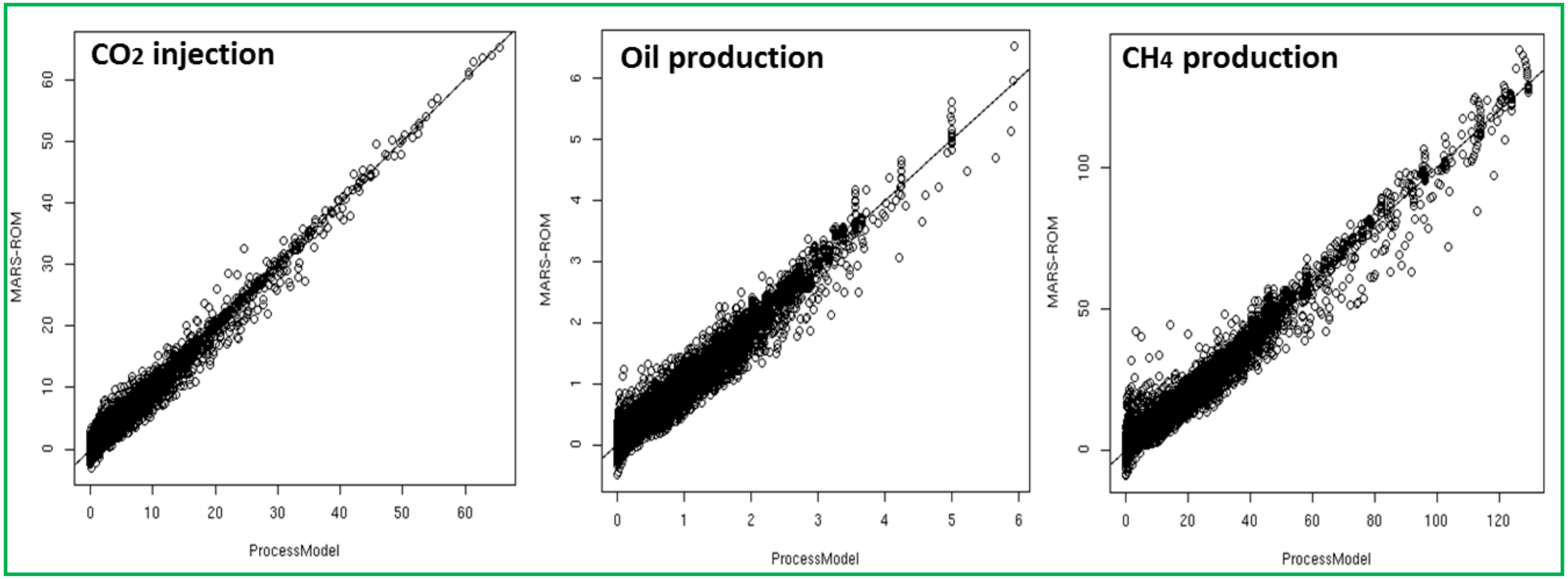
3-D Response surfaces generated with PSUADE





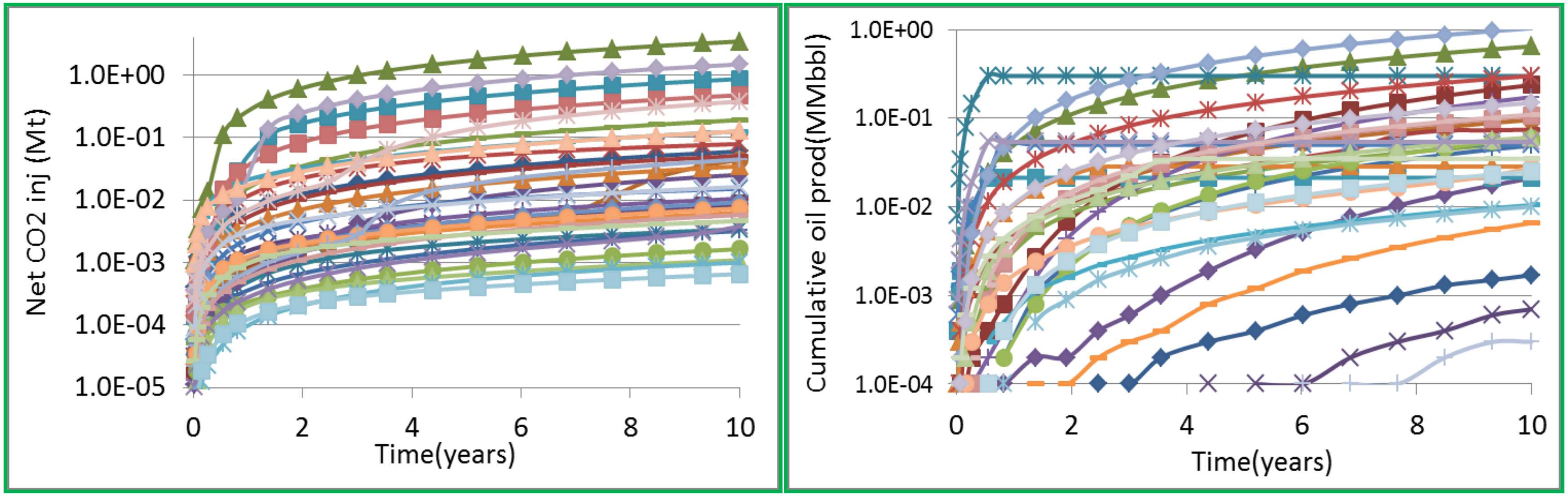


The fitting results for the developed response surfaces

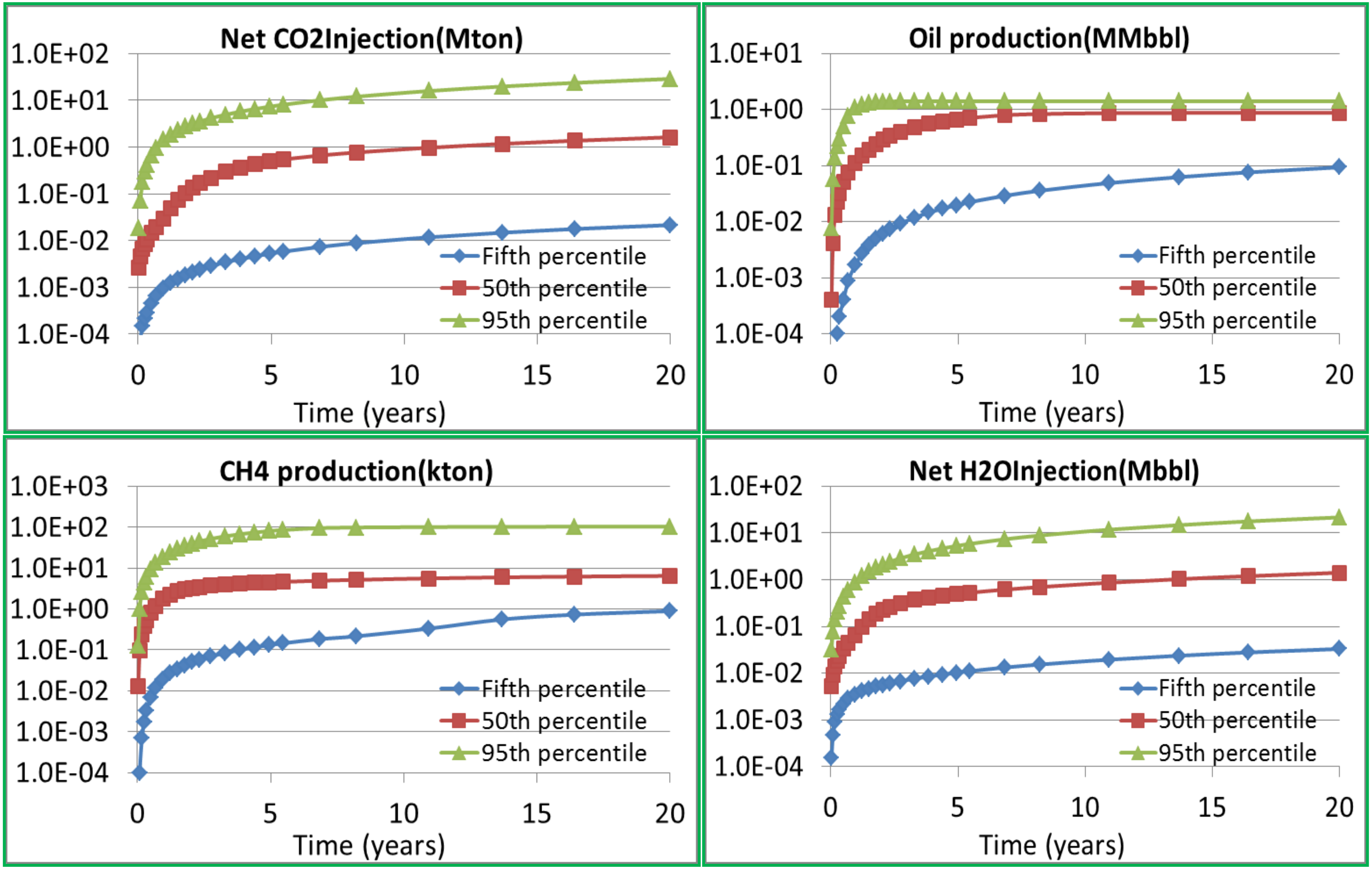


The R-squares for the three response surfaces are larger than 0.95.

4.3 Statistical analysis



Horsetail plots for net CO_2 injection and cumulative oil production



Statistical analysis of accumulative CO_2/water injection, oil/CH_4 production

5. Summary and Future Research

- **The global sensitivity results indicate that the reservoir permeability and porosity are the key parameters to control the CO_2/water injection, oil/gas production rates. The well spacing also has large impact on oil/gas production.**
- **The response surface analysis shows that CO_2 injection rate increases with increasing reservoir permeability and well spacing. The estimated well spacing from our preliminary calculations for maximizing CO_2 injection and oil/gas production is around 295 meters.**
- **Statistical analysis of the MC simulation results indicates that the Net CO_2/water injection will increase with time while the oil/gas production reaches to the peak around 5 years and then reduces very quickly to 0 in about 8 years.**
- **Next steps: we will incorporate the response surfaces into our risk assessment code CO_2-PENS to account for CO_2, oil, CH_4, and brine interactions at this site.**

Acknowledgements

This work is part of the Phase III of the SWP CO_2-EOR-Storage Project that is supported by the U.S. Department of Energy and managed by the National Energy Technology Laboratory. We gratefully acknowledge the assistance of Brian Coats of Coats Engineering, Inc. for providing the multi-phase flow and transport modeling code and discussing with us the multi-phase model setup.