Numerical Studies for the Characterization of Recoverable Resources from Methane Hydrate Deposits

FP00008138

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U.S. Department of Energy
National Energy Technology Laboratory

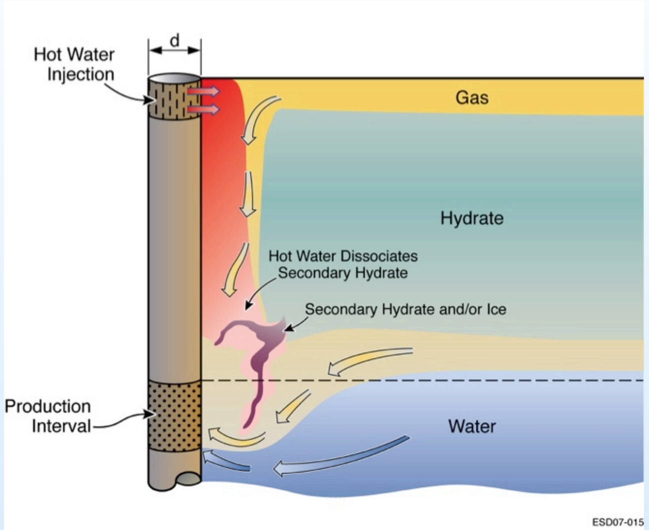
Oil & Natural Gas
2020 Integrated Review Webinar

Project Overview

Objective: To develop the knowledge base and quantitative predictive capability to describe the most important processes and phenomena associated with gas production from hydrate deposits

Project Components:

- **TOUGH+HYDRATE: simulator for hydrate-bearing reservoirs**
- **Design and evaluation of DOE and industry production tests**
- **Behavior of hydrates in the natural environment**
- **Coordinated laboratory work**
- **Collaborations and training**



This was the 2nd year ($400K) of a new project, FY19-FY21, part of a 20+-year DOE-funded hydrate program at LBNL

Technical Approach

FY20:

Task 6: Project Management and Planning

Task 7: Code Maintenance, Updates, and Support

Tasks 8-12: Design support for a DOE field test on the Alaska North Slope

Task 13: Support of DOE's Field Activities and Collaborations

Task 14: Participation in the Code Comparison Study of Coupled Flow, Thermal and Geomechanical Processes

Task 15: Publications, Tech Transfer and Reporting

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Code Maintenance and Upgrades

TOUGH+HYDRATE Codes

1. Components

(1) H_2O
(2) CH_4
(3) Hydrate (*)
(4) Salt
(5) Inhibitor
(6) Heat

(*): For kinetic dissociation

2. Phases

(1) Aqueous: H_2O, CH_4, S, I

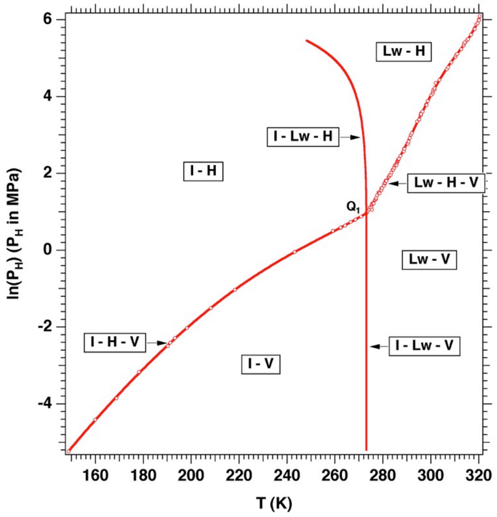
(2) Gas: CH_4, H_2O, I

(3) Solid-Hydrate: $CH_4.N_mH_20$

(4) Solid-Ice: H_2O

30 Possible phase combinations

3. *P-T* relationships



T+H is a fully compositional simulator capable of handling:

(a) Equilibrium or kinetic dissociation,

(b) Depressurization, thermal stimulation, inhibitor effects, and combinations

1. Moridis, G.J., Reagan, M.T., Queiruga, A.F., 2019. “Simulation of Gas Production from Multilayered Hydrate-Bearing Media with Fully Coupled Flow, Thermal, Chemical and Geomechanical Processes Using TOUGH+Millstone, Part I: The Hydrate Simulator,” *Transport in Porous Media*, **128**, 405-430, doi: 10.1007/s11242-019-01254-6.
2. Queiruga, A.F., Moridis, G.J., Reagan, M.T., 2019. “Simulation of Gas Production from Multilayered Hydrate-Bearing Media with Fully Coupled Flow, Thermal, Chemical and Geomechanical Processes Using TOUGH+Millstone, Part II: Geomechanical Formulation and Numerical Coupling” *Transport in Porous Media*, **128**, 221-241, doi: 10.1007/s11242-019-01242-w.
3. Reagan, M.T., Queiruga, A.F., Moridis, G.J., 2019. “Simulation of Gas Production from Multilayered Hydrate-Bearing Media with Fully Coupled Flow, Thermal, Chemical and Geomechanical Processes Using TOUGH+Millstone, Part III: Application to Production Simulation,” *Transport in Porous Media*, **129**, 179-202, doi: 10.1007/s11242-019-01283-1.

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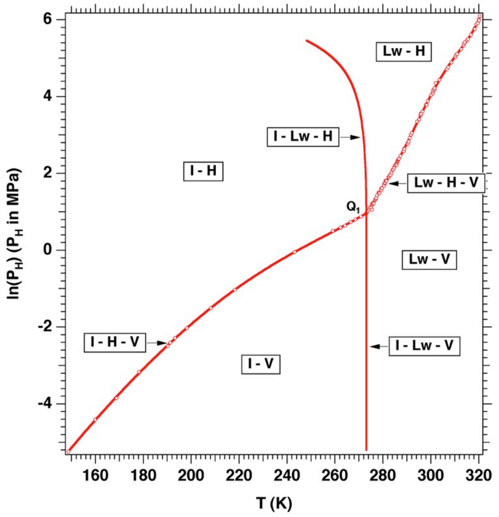

T+H is a fully compositional simulator capable of handling:
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- Used by **40+** research organizations in 18 countries
- Used by **8** international oil and gas companies

LBNL and/or T+H involved in the planning/design of nearly every international field test :

- **Mallik (DOE/Japan), PBU-L106 (DOE), “Mt. Elbert” Unit-D (DOE), Ignik Sikumi (DOE/ConocoPhillips), AC818/“Tigershark” (DOE/Chevron)**
- **Ulleung Basin (DOE/KIGAM), India NGHP-02 (DOE/India)**
- **Shenhu (China)** (T+H code)

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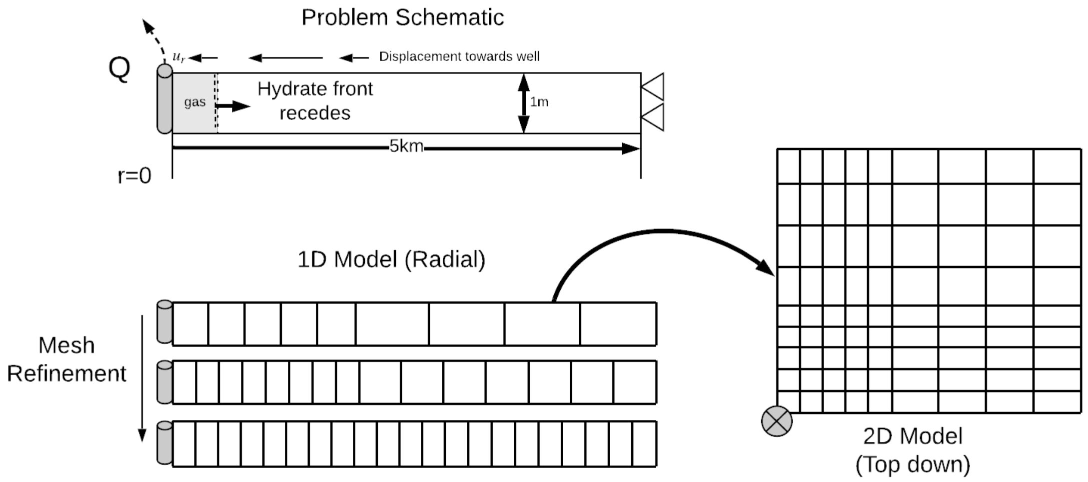
LBNL & The International Code Comparison Study 2

International effort comparing T-H-M simulators for gas hydrate production

- 5 test problems ranging from 0D to 1D flow to 3D T-H-M cases
- **LBNL lead Problem 4** (radially symmetric flow and geomechanics)
- Co-authors of IGHCCS2 paper

What else could we learn from this study?

- Tested **mesh convergence** for standard, Darcy-based hydrate simulation methods: **are we using “correct” discretization?**
- **Ongoing study: more complex than expected**



- **Coupled flow, geomechanics, and hydrate dissociation**
- **1D axisymmetric *r-z* mesh**, 5,000 m x 1 m, Δr = 0.02 m, around a well, t = 30 days
- Compare depressurization to an **analytical solution (Rudnicki, 1986)**

$$P = \frac{Q_S/h}{4\pi k/\eta} E_1(\xi(r,t)) \quad u_r = \frac{(Q_S/h)\alpha f(\xi(r,t))r}{8\pi(k/\eta)(K_d + 4G/3)}$$

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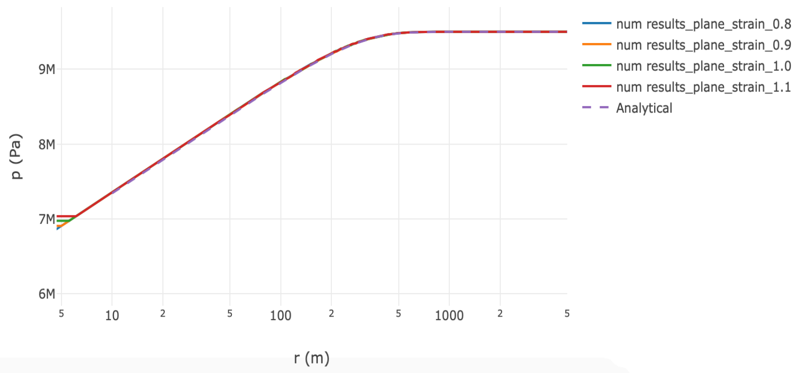

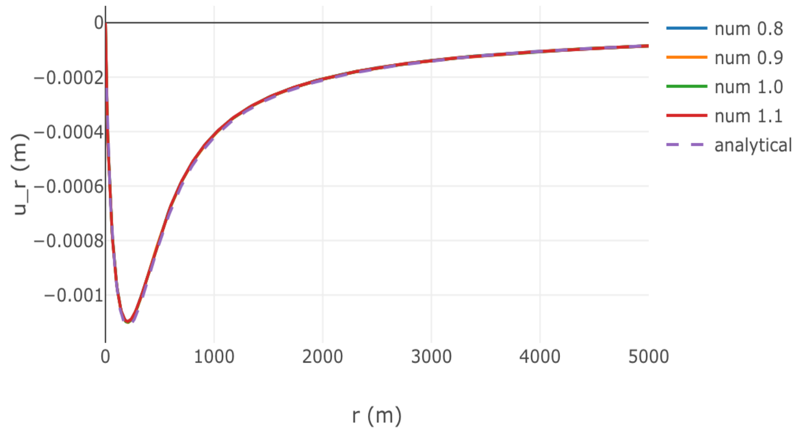

- Very close match between **TOUGH+HYDRATE/Millstone** and the analytical solution
- Other IGHCCS2 codes performed well, too

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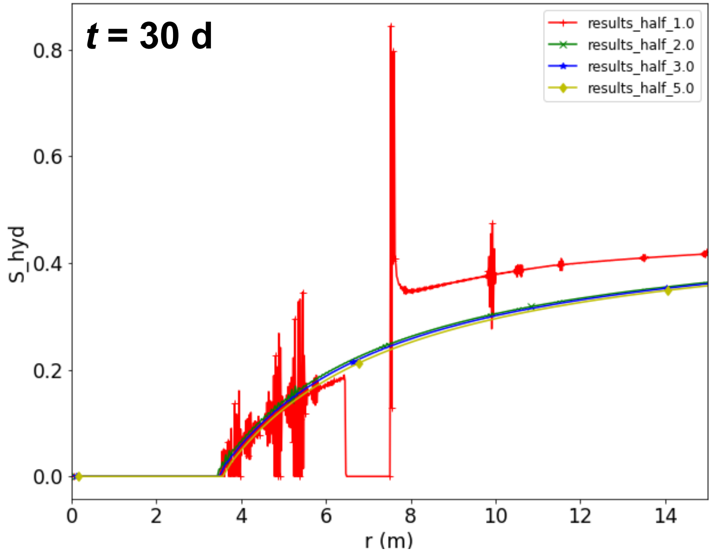
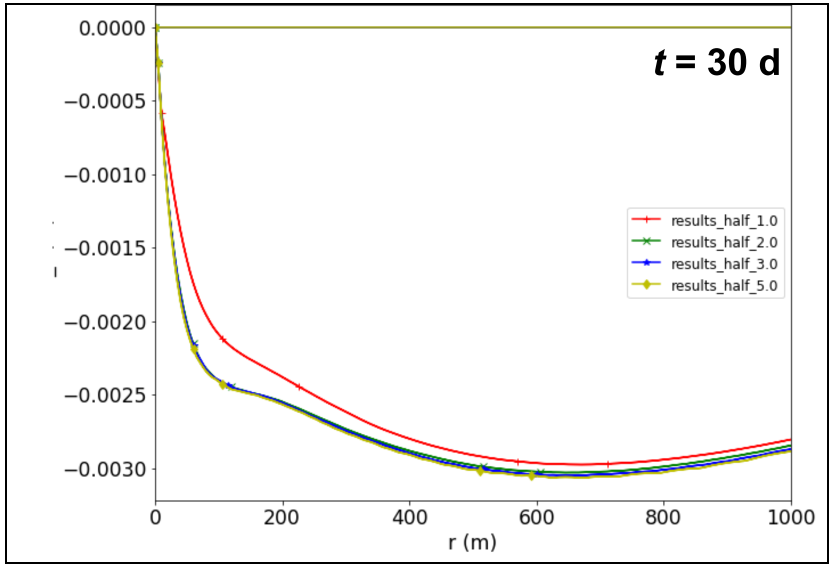
1D Mesh Convergence Study

Test Mesh Convergence in 1D Case

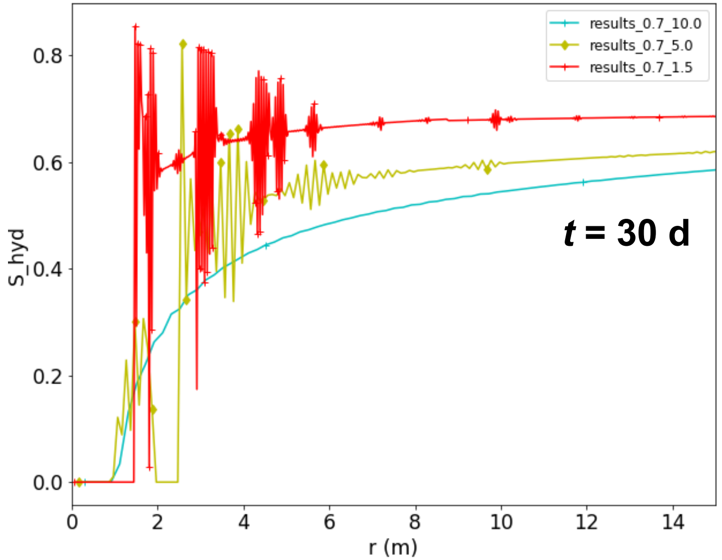
- 50% hydrate (initial)
- Scale discretization (Δr) by factor ***S***
- S = 1.0-10.0 → Δr = 0.02 m–0.2 m
- **Good convergence even for coarser meshes**
- Some lensing appears at S = 2.0 (Δr = 0.04 m)

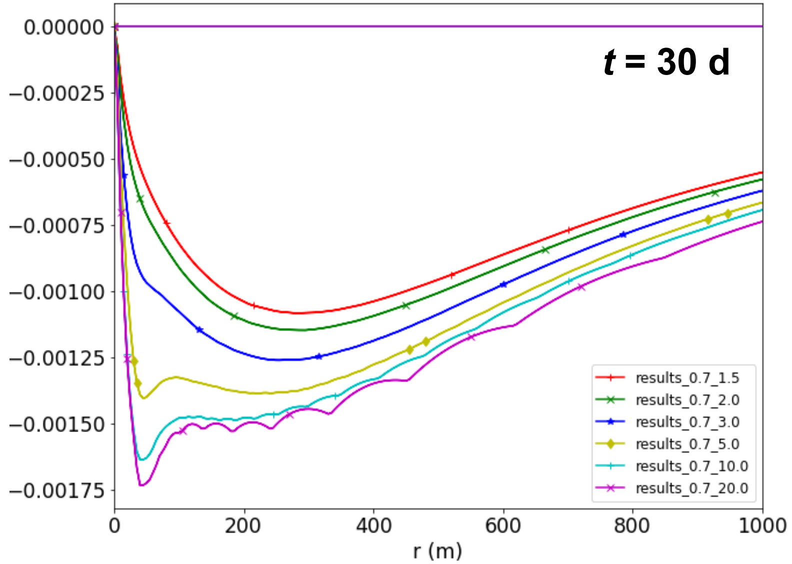




A Challenge: 70% Hydrate

- Lower effective permeability
- S = 1.5 - 20 → Δr = 0.03 m - 0.4 m
- Lensing appears at S < 10.0
- u_r varies with lensing (S_H vs. P)
- Lensing sensitive to initial heterogeneity and k_{eff}





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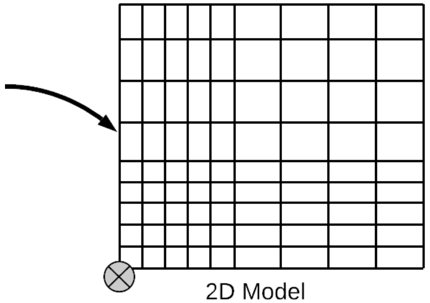
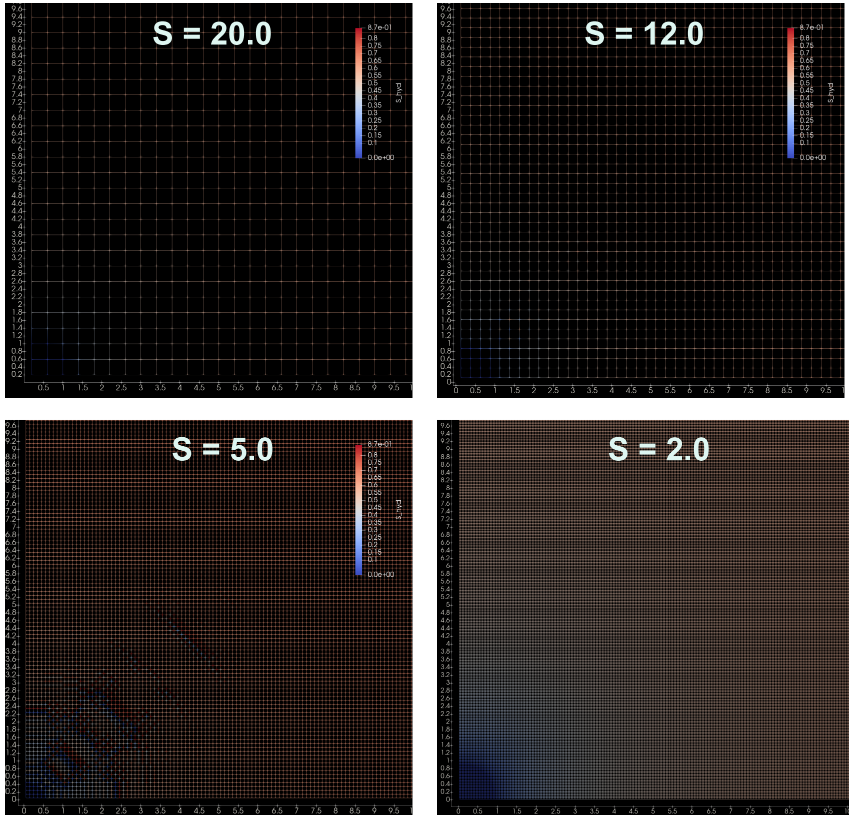
2D Mesh Convergence Study

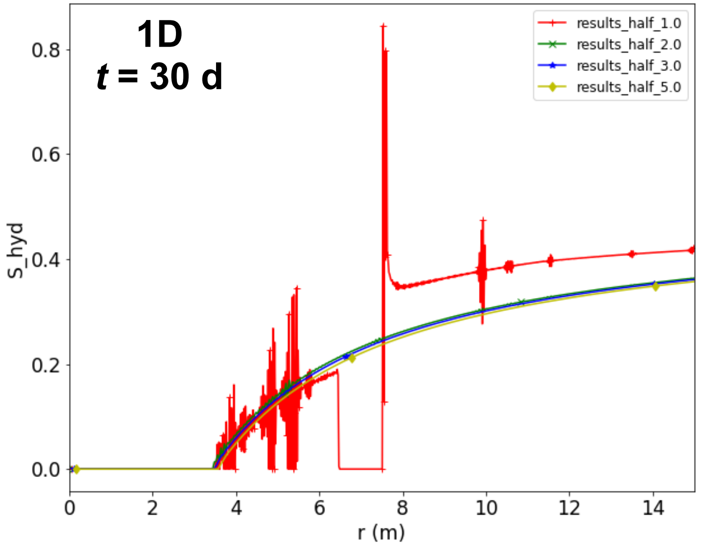


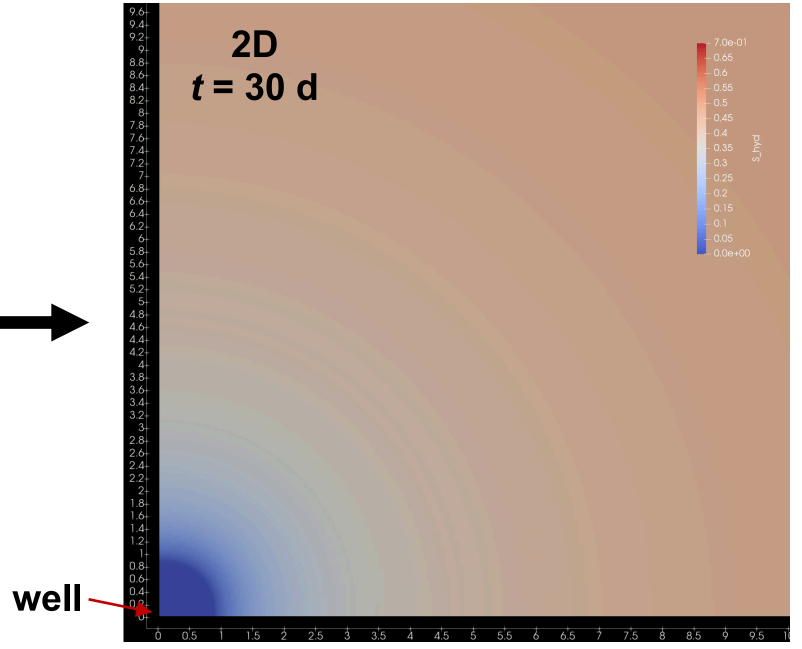
2D Model
(Top down)

- 1D *N*-element axisymmetric → *N* x *N* 2D
- Scale *S* from 2.0 to 50.0 (Δ*x*/Δ*y* → 4 cm to 1 m)
- Geomechanics disabled
- **Does the simulation still match axisymmetric behavior?**



- ***S* = 2.0, 50% hydrate,** 1D *r-z* vs. 2D *x-y*
- Mild lensing seen in both (4-7 m)
- Water and gas production similar
- **Clue: small variation w/o geomechanics**





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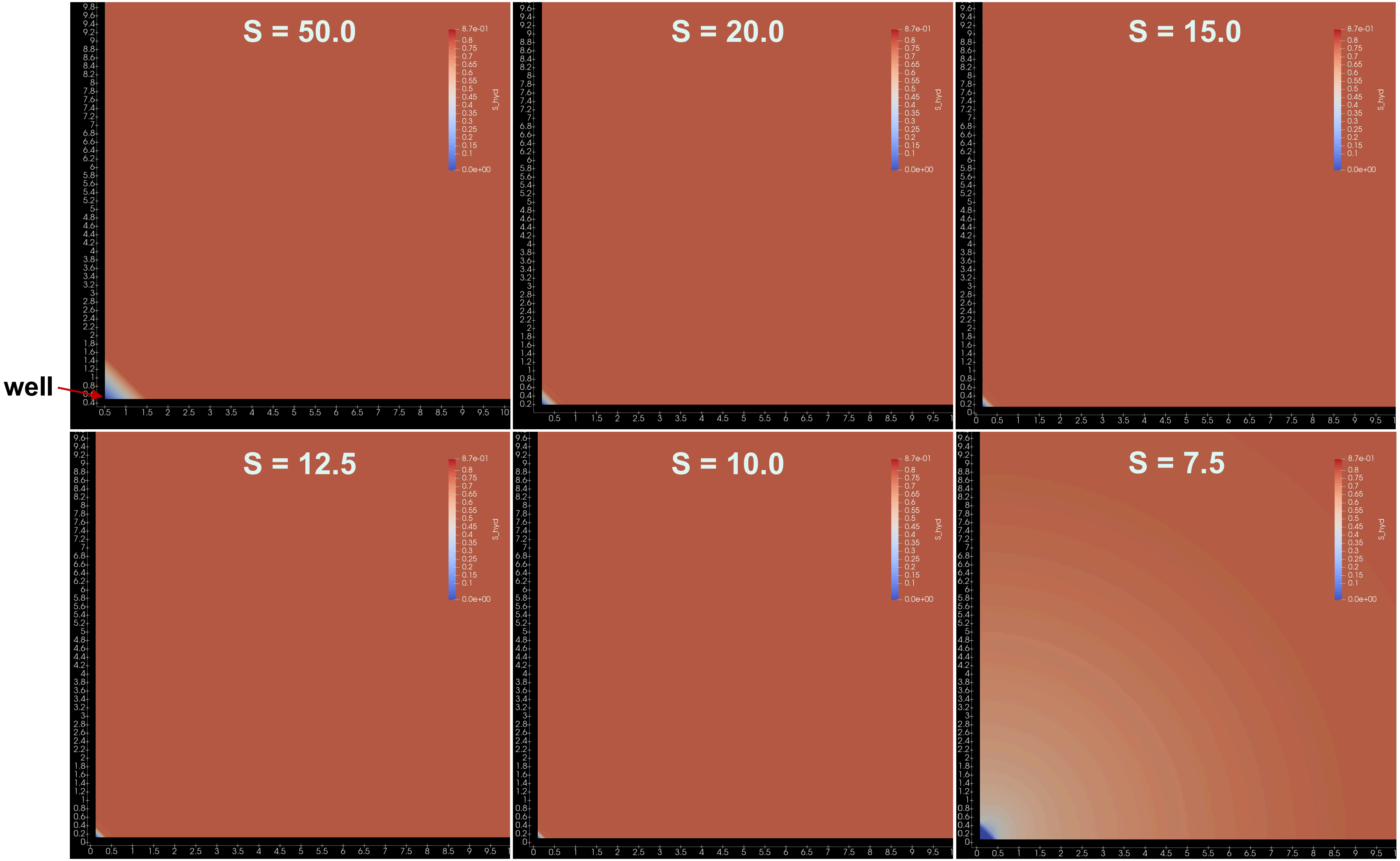
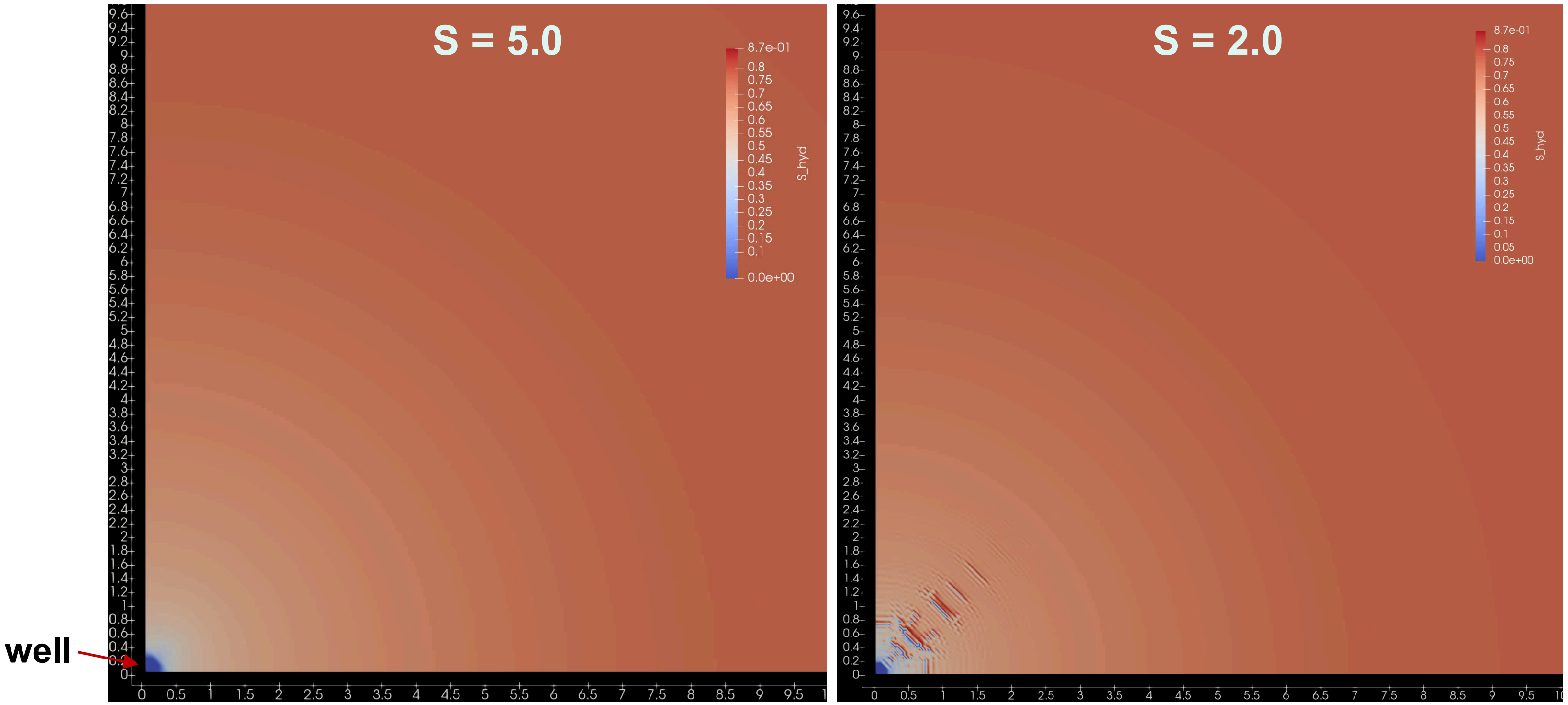
2D Discretization

70 % Hydrate, 30 days



2D Discretization



- Lensing clearly initiated by mesh features (would 2D r-θ meshes look different?)
- Radially symmetric features appear by 30 days, larger r
- “Moving lenses” and “wormholing” **that appear in earlier studies** develop
- Discretization geometry around the well critical in seeding heterogeneity
- **Mild lensing doesn’t affect prediction of net production rates**

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Conclusions and Questions

- **Investigation ongoing** (part of FY21/BP3 Tasks 18 and 19)

- **Treatment of heterogeneity and lensing must be understood**
  - Effect of geomechanics?
  - Focus: **kinetic** vs. **equilibrium** when **mesh scale varies greatly** within a simulation
- **Effect on predicting overall production in 2.5D and 3D systems?**
  - More and more detail in geological models
  - System evolution vs. **system productivity**?
  - Numerics vs. physics?
- Core-scale studies and laboratory verification
- **Close attention to k_{rel} and k_{eff} (real data)**

Design support for a DOE field test on the Alaska North Slope

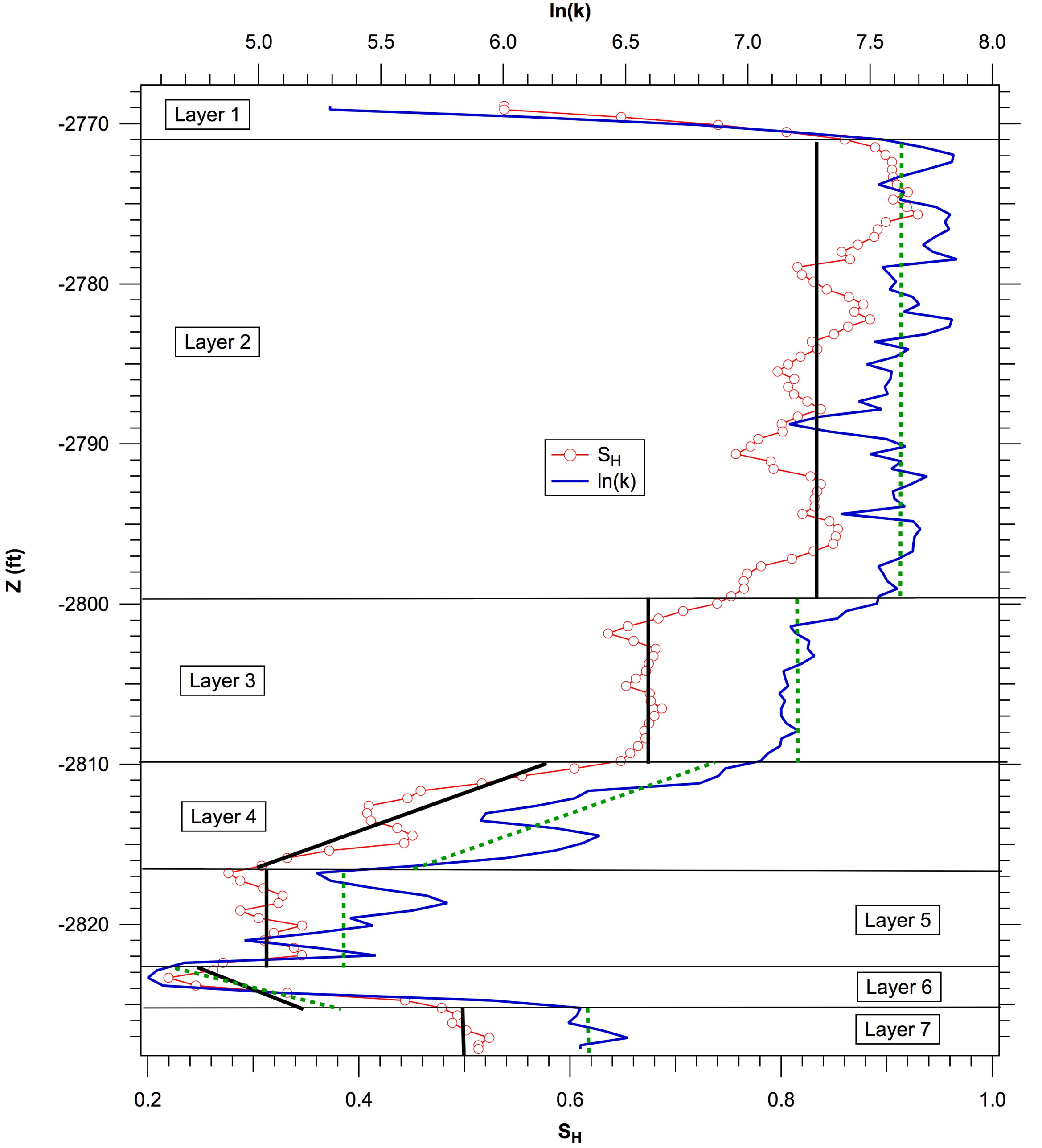
- **Assess the feasibility of production via numerical simulation**
- **Determine viable production strategies**

Need Geological Model

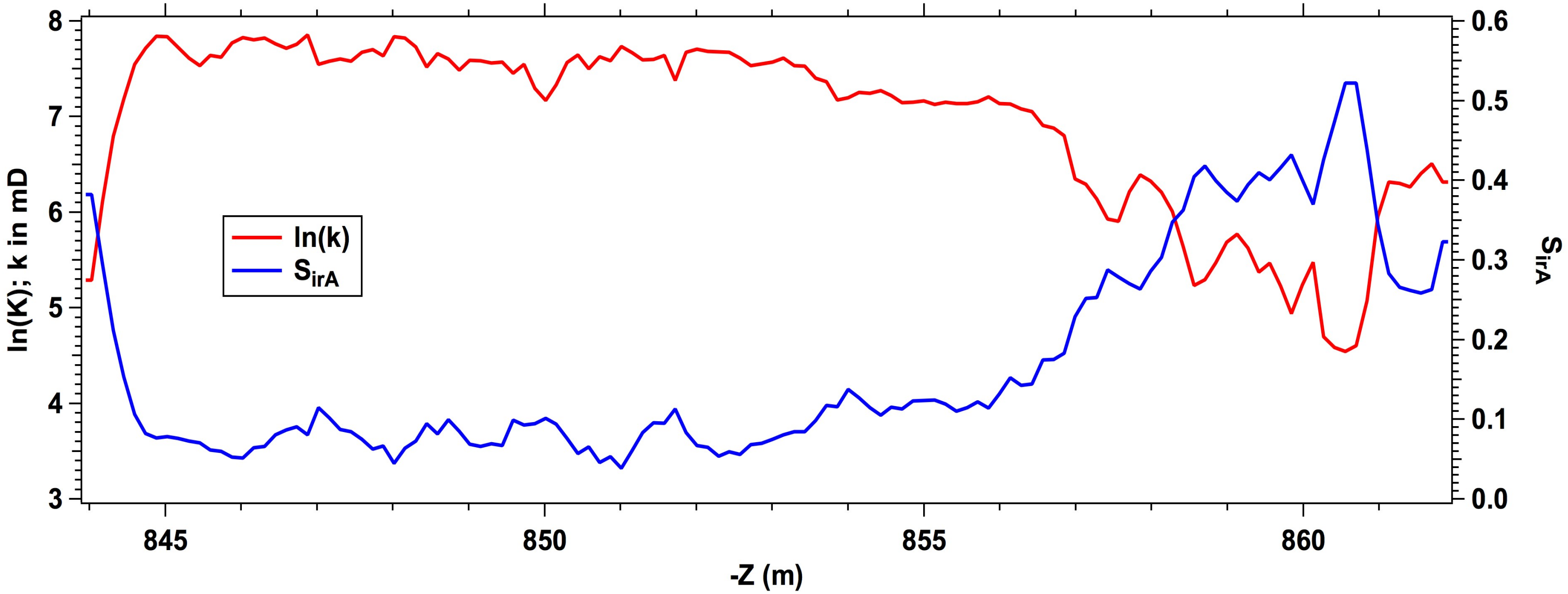
- System stratigraphy and geometry
- Reservoir boundaries, faults and aquifers
- Geologic model and data provided by project management and collaborators

MD	TVD	Porosity	Sh	Sw-irr	Sw-bound	Sw-free	K eff KC	K int KC
ft	*ft*	*model %*	*model*	*model*	*model*	*model*	*md*	*md*
	0	38%	0%	8%	50%	42%	1000	1000
	50	38%	0%	8%	50%	42%	1000	1000
	100	38%	0%	8%	50%	42%	1000	1000
	150	38%	0%	8%	50%	42%	1000	1000
	200	38%	0%	8%	50%	42%	1000	1000
	250	38%	0%	8%	50%	42%	1000	1000
	300	38%	0%	8%	50%	42%	1000	1000
	350	38%	0%	8%	50%	42%	1000	1000
	400	38%	0%	8%	50%	42%	1000	1000
	450	38%	0%	8%	50%	42%	1000	1000
	500	38%	0%	8%	50%	42%	1000	1000
	550	27%	0%	48%	48%	4%	15	15
	600	38%	0%	8%	70%	22%	800	800
	625	27%	0%	48%	48%	4%	15	15
	650	27%	0%	48%	48%	4%	15	15
	675	27%	0%	48%	48%	4%	15	15
	700	38%	0%	8%	70%	22%	800	800
	725	27%	0%	48%	48%	4%	15	15
	750	27%	0%	48%	48%	4%	15	15
	775	38%	0%	8%	70%	22%	800	800
	800	27%	0%	48%	48%	4%	15	15
	825	27%	0%	48%	48%	4%	15	15
	850	38%	0%	8%	70%	22%	800	800
	875	38%	0%	8%	70%	22%	800	800
	900	38%	0%	8%	70%	22%	800	800
	925	38%	0%	8%	70%	22%	800	800
	950	27%	0%	48%	48%	4%	15	15
	975	38%	0%	8%	70%	22%	800	800
	1000	38%	0%	8%	70%	22%	800	800
	1025	38%	0%	8%	70%	22%	800	800
	1050	38%	0%	8%	70%	22%	800	800
	1075	27%	0%	48%	48%	4%	15	15
	1100	27%	0%	48%	48%	4%	15	15
	1125	38%	0%	8%	70%	22%	800	800
	1150	27%	0%	48%	48%	4%	15	15
	1175	27%	0%	48%	48%	4%	15	15
	1200	27%	0%	48%	48%	4%	15	15
	1225	38%	0%	8%	70%	22%	800	800
	1250	27%	0%	48%	48%	4%	15	15
	1275	27%	0%	48%	48%	4%	15	15
	1300	27%	0%	48%	48%	4%	15	15
	1325	27%	0%	48%	48%	4%	15	15
	1350	38%	0%	8%	70%	22%	800	800

				SINGLE CASE FOR WATER DISTRIBUTION					ALTERNATIVE PERM CASES			
				sum of all components = 1					CASE A (core)		CASE B (NMR log)	
MD	TVDss	Porosity model	Sh	BOUND		FREE	NOT WATER		Keff	Kintrinsic	Keff	Kintrinsic
		PhiT	Hydrate saturation within PhiT	Clay Bound	Cap Bound	Free	Hydrate volume	Matrix volume	Add cutoff: Ki min (=0.001) set = Kintrinsic where Sh=0 Final Ki	Add cutoff: Ka min constrain (=0.001) Final Ka		Lower of TC and KC methods
		(2.69-Rho_c) /(2.69-1)	DMR method in reservoirs. Set to Zero elsewhere	<3ms	3ms-10ms	>10ms + "False hydrate"	PhiT*Sh	1-(CBW+BFW+FFW+Vmh)				
ft	ft	ft3/ft3	ft3/ft3	ft3/ft3	ft3/ft3	ft3/ft3	ft3/ft3	ft3/ft3	mD	mD	mD	mD
2537	2334.8	0.356	0.000	0.009	0.063	0.284	0.000	0.644	909.449	909.449	1036.456	1036.456
2537.5	2335.27	0.352	0.000	0.010	0.065	0.277	0.000	0.648	864.680	864.680	989.611	989.611
2538	2335.74	0.335	0.000	0.025	0.054	0.256	0.000	0.665	528.751	528.751	667.405	667.405
2538.5	2336.21	0.318	0.000	0.014	0.073	0.231	0.000	0.682	531.903	531.903	465.930	465.930
2539	2336.68	0.324	0.000	0.009	0.080	0.235	0.000	0.676	633.482	633.482	540.073	540.073
2539.5	2337.15	0.332	0.000	0.022	0.070	0.240	0.000	0.668	540.354	540.354	412.496	412.496
2540	2337.61	0.335	0.000	0.022	0.081	0.232	0.000	0.665	565.607	565.607	321.476	321.476
2540.5	2338.08	0.324	0.000	0.013	0.080	0.231	0.000	0.676	577.853	577.853	338.095	338.095
2541	2338.55	0.307	0.000	0.018	0.067	0.223	0.000	0.693	431.886	431.886	339.378	339.378
2541.5	2339.02	0.294	0.000	0.029	0.054	0.211	0.000	0.706	291.769	291.769	409.285	409.285
2542	2339.49	0.299	0.000	0.017	0.055	0.228	0.000	0.701	400.226	400.226	481.417	481.417
2542.5	2339.95	0.320	0.000	0.019	0.051	0.249	0.000	0.680	493.663	493.663	646.162	646.162
2543	2340.42	0.339	0.000	0.034	0.045	0.260	0.000	0.661	461.216	461.216	717.364	717.364
2543.5	2340.89	0.339	0.000	0.033	0.049	0.257	0.000	0.661	465.052	465.052	653.042	653.042
2544	2341.36	0.337	0.000	0.020	0.054	0.263	0.000	0.663	600.017	600.017	795.115	795.115
2544.5	2341.83	0.334	0.000	0.017	0.054	0.263	0.000	0.666	605.026	605.026	774.775	774.775
2545	2342.3	0.344	0.000	0.001	0.058	0.284	0.000	0.656	919.403	919.403	938.002	938.002
2545.5	2342.76	0.349	0.000	0.000	0.058	0.291	0.000	0.651	1001.196	1001.196	1006.569	1006.569
2546	2343.23	0.353	0.000	0.001	0.064	0.288	0.000	0.647	1037.188	1037.188	1044.631	1044.631
2546.5	2343.7	0.356	0.000	0.002	0.075	0.279	0.000	0.644	1050.342	1050.342	1045.342	1045.342
2547	2344.17	0.345	0.000	0.004	0.084	0.257	0.000	0.655	895.531	895.531	629.653	629.653
2547.5	2344.64	0.339	0.000	0.012	0.077	0.251	0.000	0.661	719.507	719.507	563.898	563.898
2548	2345.1	0.322	0.000	0.010	0.083	0.229	0.000	0.678	605.244	605.244	486.025	486.025
2548.5	2345.57	0.323	0.000	0.009	0.073	0.241	0.000	0.677	620.966	620.966	611.213	611.213
2549	2346.04	0.325	0.000	0.006	0.066	0.253	0.000	0.675	674.750	674.750	694.792	694.792
2549.5	2346.51	0.325	0.000	0.005	0.060	0.260	0.000	0.675	687.323	687.323	736.016	736.016
2550	2346.98	0.316	0.000	0.005	0.068	0.242	0.000	0.684	609.498	609.498	642.261	642.261
2550.5	2347.45	0.325	0.000	0.011	0.056	0.257	0.000	0.675	610.687	610.687	714.664	714.664
2551	2347.91	0.325	0.000	0.015	0.055	0.255	0.000	0.675	568.641	568.641	699.050	699.050
2551.5	2348.38	0.326	0.000	0.007	0.057	0.262	0.000	0.674	668.879	668.879	737.736	737.736
2552	2348.85	0.320	0.000	0.005	0.060	0.255	0.000	0.680	642.156	642.156	691.312	691.312
2552.5	2349.32	0.317	0.000	0.002	0.051	0.265	0.000	0.683	664.669	664.669	679.747	679.747
2553	2349.79	0.321	0.000	0.000	0.056	0.264	0.000	0.679	711.893	711.893	714.786	714.786
2553.5	2350.26	0.328	0.000	0.001	0.078	0.249	0.000	0.672	769.530	769.530	571.267	571.267
2554	2350.72	0.327	0.000	0.006	0.096	0.225	0.000	0.673	690.546	690.546	277.662	277.662
2554.5	2351.19	0.314	0.000	0.012	0.098	0.205	0.000	0.686	529.157	529.157	169.168	169.168
2555	2351.66	0.301	0.000	0.019	0.105	0.178	0.000	0.699	395.188	395.188	85.435	85.435
2555.5	2352.13	0.285	0.000	0.024	0.105	0.156	0.000	0.715	286.081	286.081	59.201	59.201
2556	2352.6	0.281	0.000	0.021	0.104	0.156	0.000	0.719	290.011	290.011	83.135	83.135
2556.5	2353.07	0.277	0.000	0.015	0.110	0.153	0.000	0.723	310.133	310.133	89.781	89.781



Design support for a DOE field test on the Alaska North Slope



Unit B: Very desirable properties (k_{int}, ϕ, n)

- Top boundary of simulated domain: top of Unit D above
- Bottom boundary of simulated domain: bottom of available dataset
- Radial/lateral boundary: at r = 800 m
- Flows across boundaries continuously monitored

Comments on Flow System of Unit B

- Significant variability of k, S_H, S_{irA}
- Remarkable consistency of k_{int}-S_{irA} relationship in the hydrate units
- k_{rel}: n_{min} from core studies vs. n_{max} from NMR studies
- We maintain maximum fidelity to data: properties and conditions layer by layer in the HBZ
- BOUNDARIES: Duration of test is 12-18 months

Design support for a DOE field test on the Alaska North Slope

- **Cylindrical system, vertical well**
  - Within Unit B: Δz = 0.1 m
  - Within Units C and D: Δz = 0.25 m
  - Within the rest of domain: Δz variable (log, 2-sided)
  - Radial: Δr from 0.1 to 0.25 m for r < 100 m, log distribution to r = 800m
- **Dimension 641x343 (r, z) = 220K elements, 880K eqs**

- **Every vertical subdivision/layer is considered a separate rock type with unique properties**
- **Properties derived from the team database**

- **All boundaries: permeable/flowing, monitored**

Initial Conditions

- *P/T* distribution (from Myshakin, personal communication)
- Initial saturations and spatial distribution (from database)
- Salinity of water: 0.5% (from database)
- **Account for salinity in simulations (useful indicator)**

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Design support for a DOE field test on the Alaska North Slope

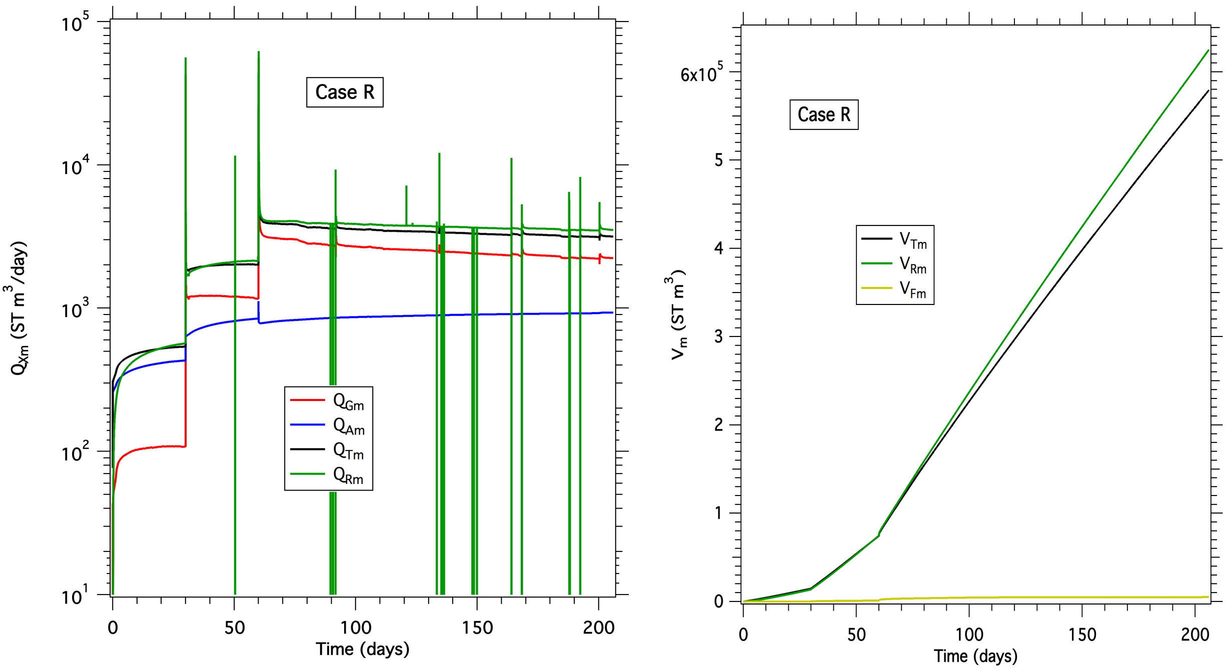
- **Assess the feasibility of production via numerical simulation**
- **Determine viable production strategies**

- **Reference case:**
  - Perforated interval: **10 m at top of formation**
  - BHP management: 2 MPa below P_0, **2 MPa decline every 30 days**, until P_{final} = 2.8 MPa
  - Anisotropy: k_r/k_z = 10
  - k_{rel}: Obtained from n_{min} (OPM)

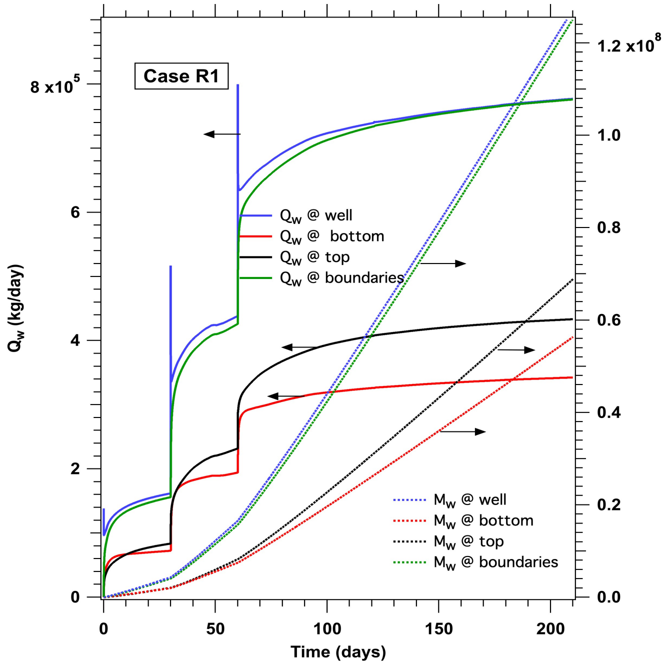
- **Exploratory cases:**
  - Assess k_{rel}: low k_{eff}, n_{max}
  - Vary length of perforated interval 5 m, 15 m, etc.
  - **"Low well": 10 m interval 3 m *below* top of formation**

Alaska North Slope: Reference Case

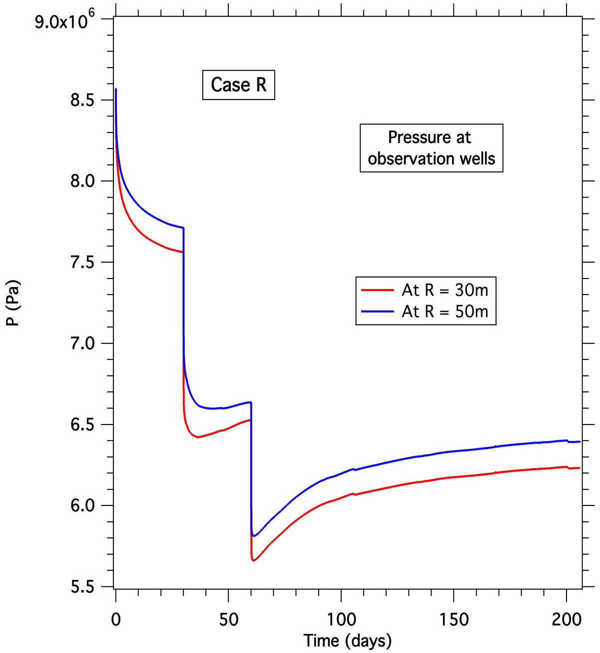
Gas Production



Water Production



Monitoring Wells



- Generation of gas by dissociation: weak
- Production rate: **flat to declining after 60 days!** (Especially gas rate)
- Water production: increasing, water production ~= water infiltration
- Monitoring wells: show pressure recovery/weak depressurization

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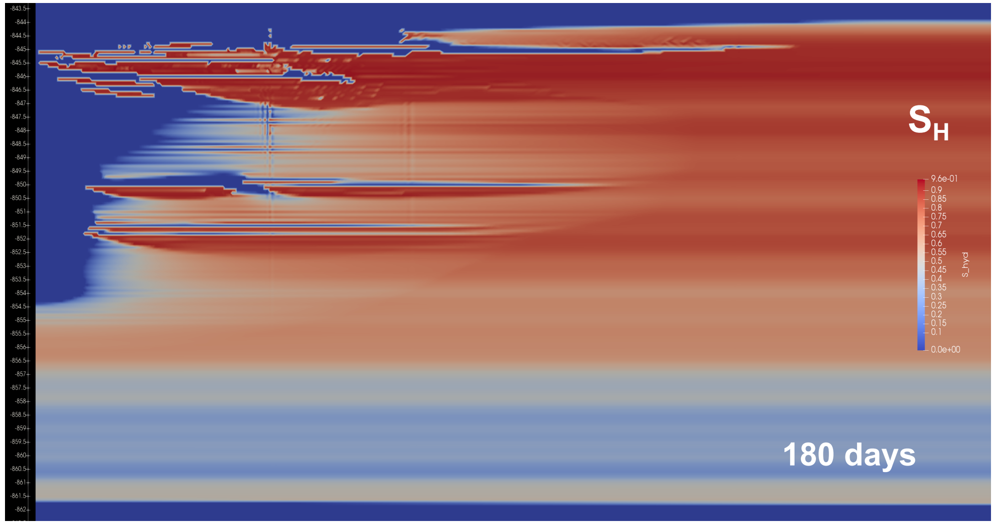
Alaska North Slope: Reference Case

Unit B: Hydrate-bearing zone, r = 0 - 40 m

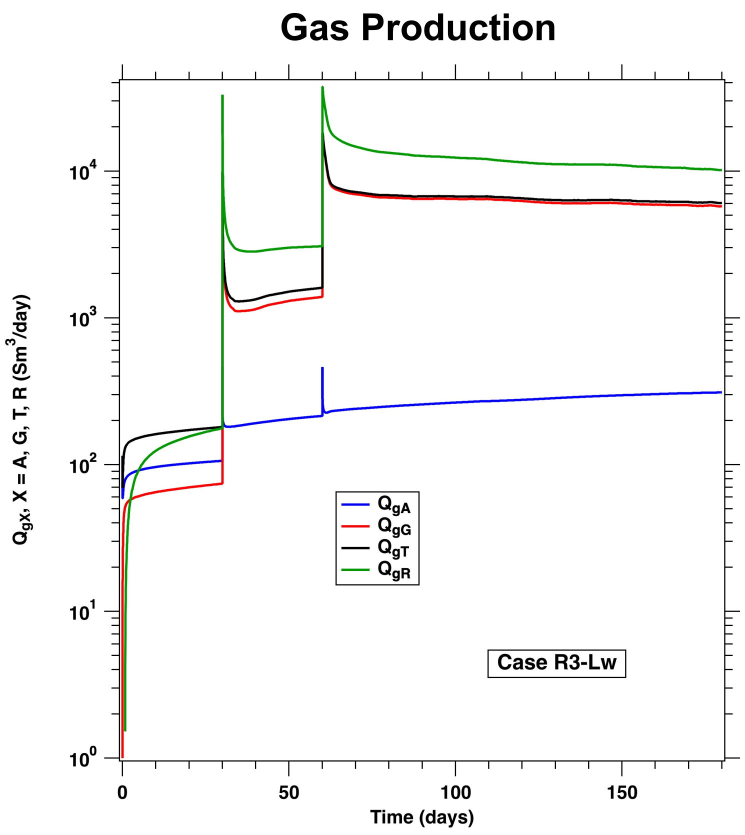


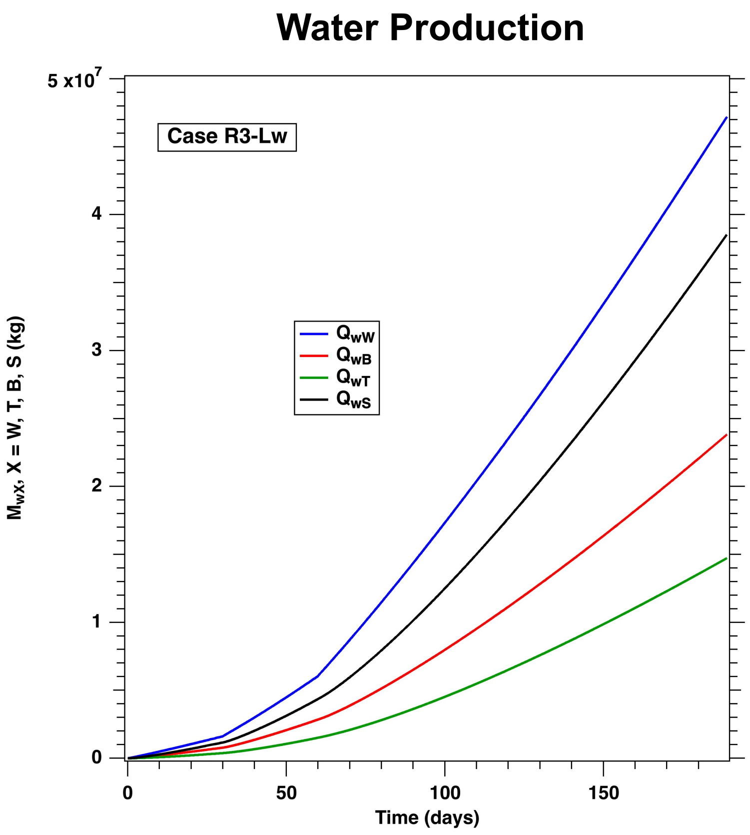
- Limited range of depressurization
- Dissociation focuses at top of HBZ
- Limited formation of gas→limited gas production

Alaska North Slope: Improved

Attempted improvement:

- **Move production interval 3 m down into hydrate zone ("low well")**
- **Maintain stepped depressurization, use most-likely properties (k_{rel})**

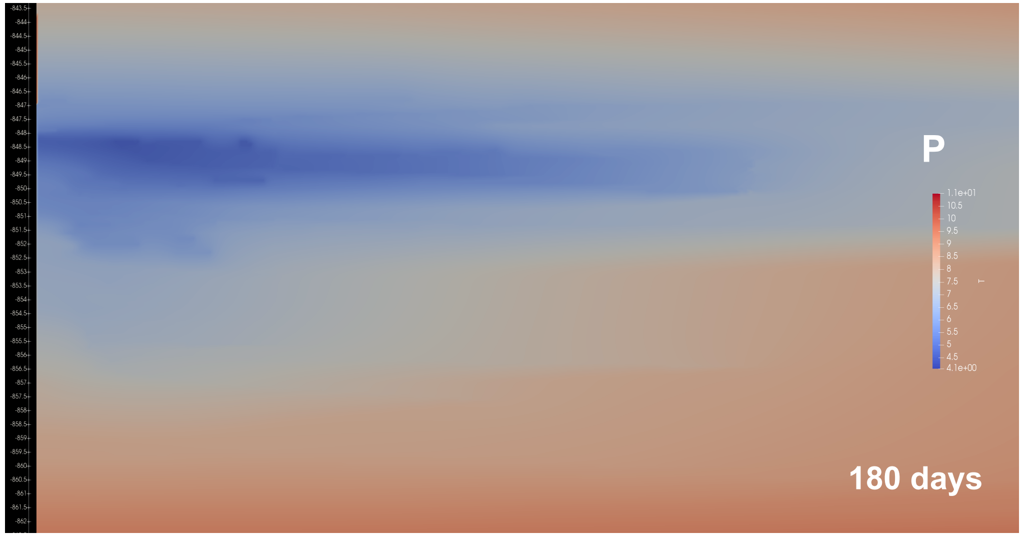


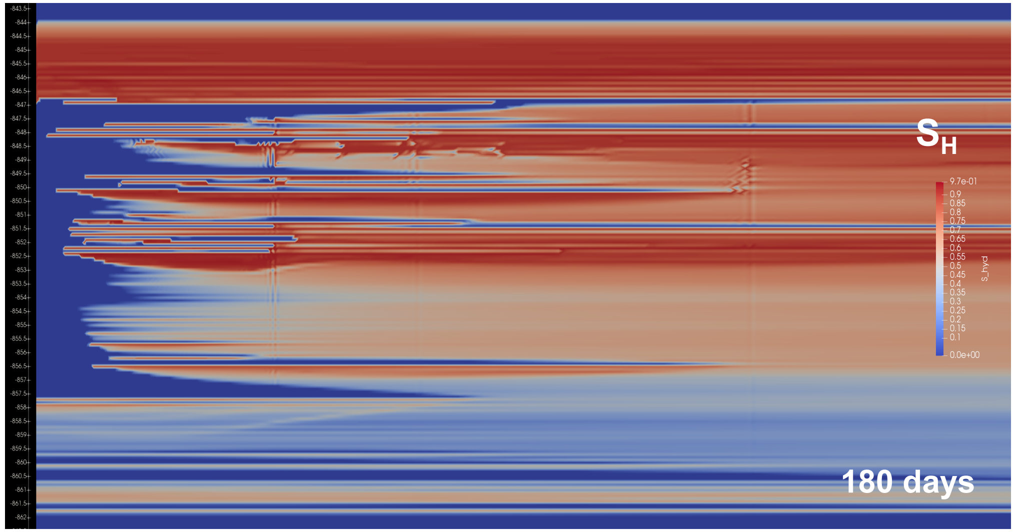


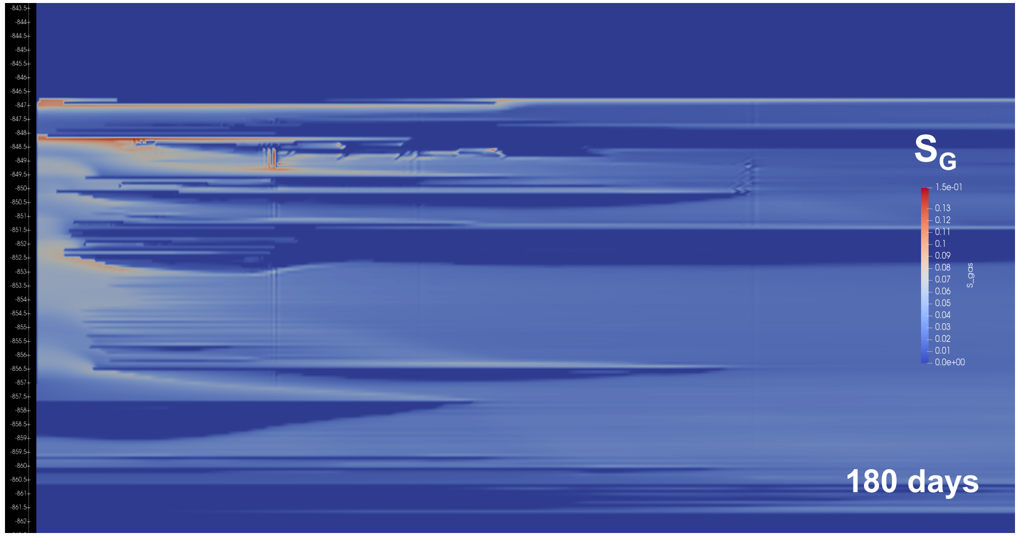
- Increased hydrate dissociation/gas generation (~3X)
- Increased gas production at well (~2.5X)

- Production plateau after 60 days, but at a higher level
- Water production still high, but lower than reference case

Alaska North Slope: Improved







- Stronger depressurization, more extensive
- Dissociation focused at core of HBZ
- Low-k_{eff} hydrate zones “encase” depressurized zone
- Increased formation of gas → increased gas production

Design support for a DOE field test on the Alaska North Slope

- **Significant H_2O production and inefficient depressurization because of significant/persistent H_2O inflows**
- **Placement of the top of the well 3 m below the top of the target results in consistently optimal performance in all reservoir property cases**
  - Higher gas production due to more effective depressurization
- The most-likely permeability/relative permeability scenario has the best performance
- Effect of k, n, k_{rel}: Significant in terms of gas and H_2O production, not so in terms of water-to-gas ratio (defines the envelope of possible production estimates)
- Production interval length, anisotropy have a minor/negligible effect
- **Under this geological model, water production is a pervasive issue**
- **Simulations to be updated/expanded as data evolves**

Tech Transfer and Reporting

- **4 publications**

Journal Articles:

1. White, M.D., Kneafsey, T.J., Seol, Y., Waite, W.F., Uchida, S., Lin, J.-S., Myshakin, E.M., Gai, X., Gupta, S., Reagan, M.T., Queiruga, A.F., Kimoto, S., IGHCCS2 Participants, “An International Code Comparison Study on Coupled Thermal, Hydrologic and Geomechanical Processes of Natural Gas Hydrate-Bearing Sediments,” *J.Mar.Pet.Geo.*, **120**, 104566.
2. Moridis, G.J., Reagan, M.T., Queiruga, A.F., Collett, T.S., Boswell, R., Evaluation of the Performance of the Oceanic Hydrate Accumulation at the NGHP-02-9 Site of the Krishna-Godavari Basin During a Production Test and Under Full Production, *J.Mar.Pet.Geo.*, **108**, 680-696.

Conference Papers:

1. Moridis, G.J., Reagan, M.T., Queiruga, A.F., “Preliminary Predictions and Analysis of System Behavior During a Planned Long-Term Production Test from an Alaskan Permafrost-Associated Hydrate Deposit,” *Proc*. 10th International Conference on Gas Hydrates, Singapore, 21-26 June 2020. **(Conference Postponed)**
2. Reagan, M.T., Queiruga, A.F., Moridis, G.M., “Numerical Validation and Convergence Testing of Coupled Flow-Thermal-Mechanical Hydrate Reservoir Models and the Effect of Meshing on System Evolution,” *Proc*. 10th International Conference on Gas Hydrates, Singapore, 21-26 June 2020. **(Conference Postponed)**

- **6 presentations:**

1. Reagan, M.T., “Preliminary Analysis of System Behavior During a Planned Long-Term Production Test at a Permafrost-Associated Hydrate Deposit in Alaska,” (poster) 2020 Gordon Research Conference on Natural Gas Hydrate System, Galveston, TX, 23-28 Feb 2020.
2. Reagan, M.T., “Validation and Testing of Coupled Flow-Thermal-Mechanical Hydrate Reservoir Models,” H44B-07, AGU Fall Meeting 2019, San Francisco, CA, 9-13 Dec 2019.
3. Moridis, G.J., “Preliminary Analysis of Expected System Behavior During the Planned test of Gas Production From Hydrate Deposits in Alaska,” JOGMEC, Makuhari, Chiba, Japan, Nov 2019.
4. Reagan, M.T., “Numerical Studies for the Characterization of Recoverable Resources from Methane Hydrate Deposits,” 2019 Carbon Capture, Utilization, Storage, and Oil and Gas Technologies Integrated Review Meeting, Pittsburgh, PA, 26-30 Aug 2019.

Postponed:

1. Moridis, G.J., “Preliminary Predictions and Analysis of System Behavior During a Planned Long-Term Production Test from an Alaskan Permafrost-Associated Hydrate Deposit,” 10th International Conference on Gas Hydrates, Singapore, 21-26 June 2020.
2. Reagan, M.T., “Numerical Validation and Convergence Testing of Coupled Flow-Thermal-Mechanical Hydrate Reservoir Models and the Effect of Meshing on System Evolution,” 10th International Conference on Gas Hydrates, Singapore, 21-26 June 2020.

FY20-21 Tasks

Task 16: Project Management and Planning ($5K)

Task 17: Continuation of the Baseline Study for a DOE field test on the Alaska North Slope ($310K)

Task 18: Code Maintenance, Updates, and Support ($60K)

Task 19: Support of DOE's Field Activities and Collaborations ($5K)

- **IGHCCS2 Completion and Publication**

Task 20: Tech Transfer and Reporting ($10K)

Task 21: Publications and Travel ($10K)

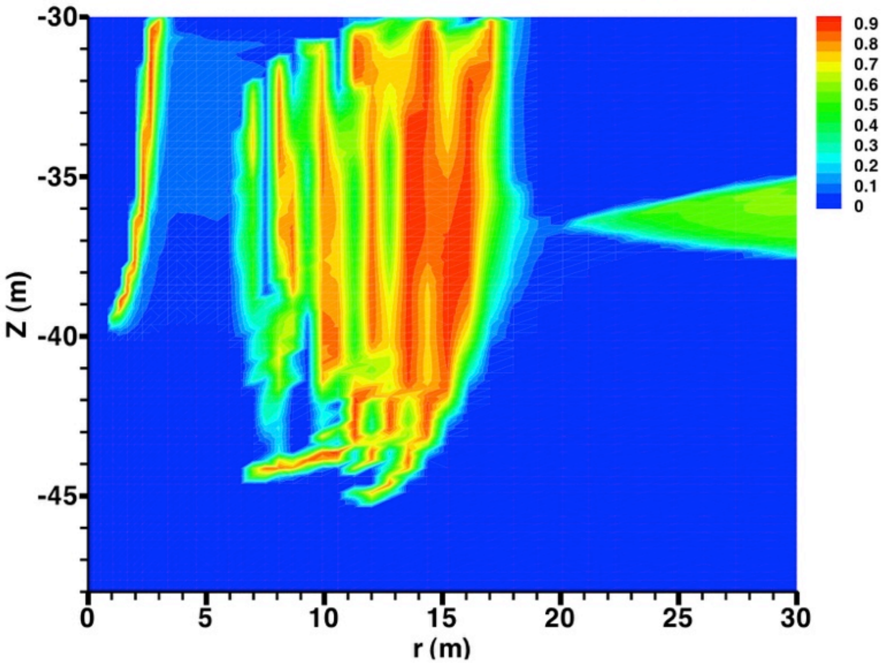
Accomplishments to Date

TOUGH+HYDRATE and pTOUGH+HYDRATE are used:

- by **40+** research organizations in 18 countries
- by **8** international oil and gas companies

LBNL and/or T+H have been involved in the planning and design of *nearly* every international field test or proposed field test:

- **Mallik (DOE/Japan)**
- **PBU-L106 (DOE)**
- **"Mt. Elbert" Unit-D (DOE)**
- **Ignik Sikumi (DOE/ConocoPhillips)**
- **AC818/"Tigershark" (DOE/Chevron)**
- **Ulleung Basin (DOE/KIGAM)**
- **India NGHP-02 (DOE/India)**
- **Shenhu (China)** (T+H code)



Appendix

Organization Chart

George Moridis,
PI

Reservoir Modeling

George Moridis,
Matthew Reagan,
Zhi Li

Gantt Chart

Milestone Title	Milestone Description	Planned Completion Date	Actual Completion Date	Status / Results
PMP	Maintenance and update of the Project Management Plan	November 30, 2019	Draft 11/13/2019 Revised 3/10/20	Submitted
Deliverable	Updated versions serial and parallel versions of the T+H/Millstone code	July 31, 2020	Ongoing	Ongoing
Deliverables	Reports describing in detail the evolution of the system behavior for the reference case and all sensitivity studies.	April 30, 2020 through September 30, 2020	Ongoing	Confidential reports submitted. Conference paper submitted. Two journal articles in preparation pending authorization
Deliverable	Updates reports and publications related to DOE international collaborations	September 30, 2020	November 21, 2019	Paper on India studies appeared in print (JMPG)
Deliverable	Completion of participation in the code comparison study; contributions to reports and publications	September 30, 2020	June 30, 2020	Paper accepted for publication (JMPG). Conference paper submitted (postponed).
Deliverable	Publications, Tech Transfer, Travel, and Reporting	Quarterly	Quarterly	Q1 and Q2 reports submitted