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An open-source framework for probabilistic gas hydrate systems modeling

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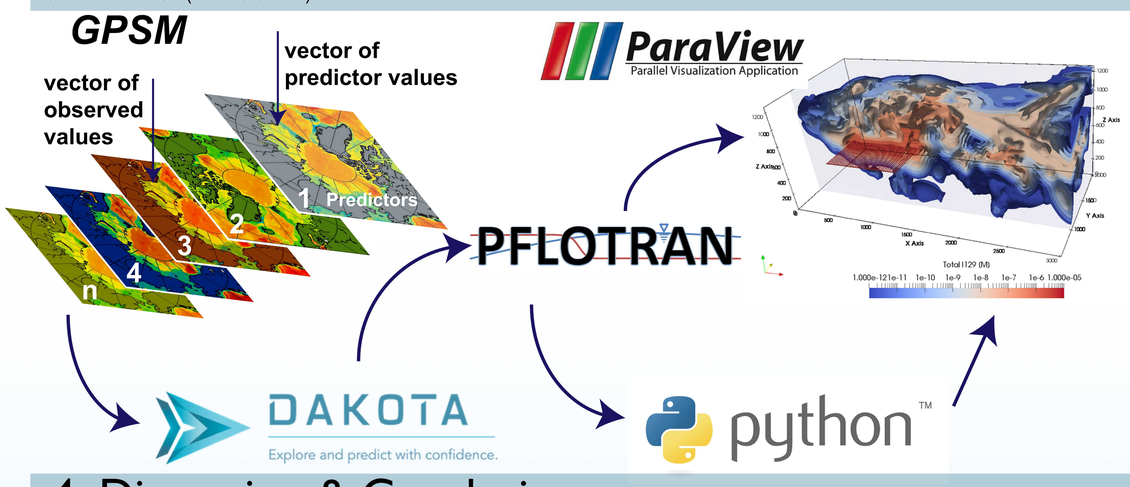
1. Abstract

Constraining spatio-temporal variation in environment conditions and sediment physical properties is of great importance to understanding gas migration in dynamic gas hydrate systems on continental margins, which are of interest to the scientific community from perspectives ranging from global climate change to natural gas production and to carbon sequestration. As simulation capabilities become more sophisticated, more uncertainties can be introduced into models because of an expansion of the processes being considered. These uncertainties arise from sparse and spatially biased sampling of sub-seafloor environments and must be honored when attempting to forward model the behavior of a gas hydrate system.

2. Open-source Framework

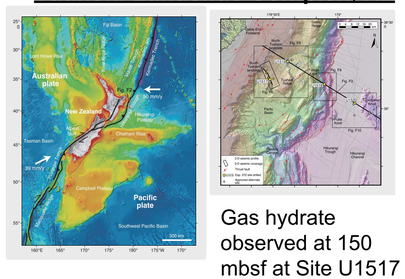
We introduce an open-source, open-development framework for integrated probabilistic gas hydrate systems modeling, which includes:
- ***parameter distribution prediction*** (e.g. using maching learning with the Global Predictive Seabed Model [GPSM])
- ***parameter sampling*** (using Dakota)
- ***mechanistic simulation*** (using the massively parallel flow and reactive transport simulator PFLOTRAN)
- ***statistical analysis*** (using Python packages)
- ***3D visualization*** (with ParaView).



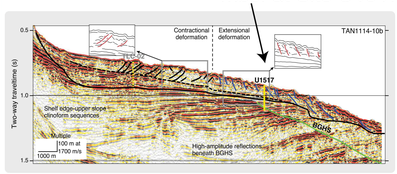
3. Applications

We demonstrate use of this framework by simulating microbially-sourced gas hydrate accumulation at two sites: the Tuaheni Landslide Complex and the Gulf of Mexico. Simulations are nonisothermal, multiphase, and consider sedimentation and methane production via microbial methanogenesis. PFLOTRAN, is open-source, open-development, and freely available; we encourage collaborative development of more advanced capabilities relevant to gas hydrate systems.

Tuaheni Landslide Complex, NZ

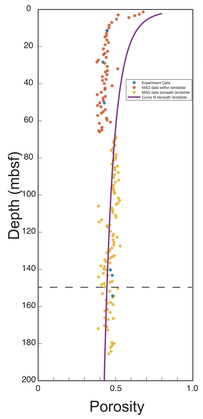


Gas hydrate observed at 150 mbsf at Site U1517



IODP 372 Preliminary Report

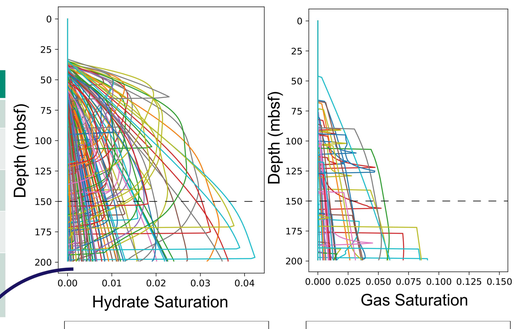
Data Vectors



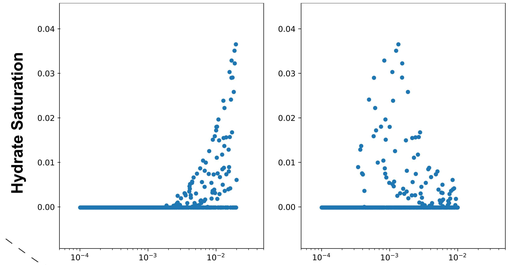
Uncertain Parameter Sampling

Parameter	Distribution	Min	Max	Current (approx.)
Seafloor Depth (m)	Uniform	710	740	725
Seafloor Temperature	Uniform	3	9	6
Heat Flux (W/m^2)	Uniform	0.03	0.1	0.038
Sedimentation Rate (m/yr)	Log-uniform	$1x10^{-4}$	$1x10^{-2}$	$8x10^{-4}$
Seafloor Organic Carbon Fraction	Log-Uniform	$1x10^{-4}$	$2x10^{-2}$	Machine-learned (GPSM maps)

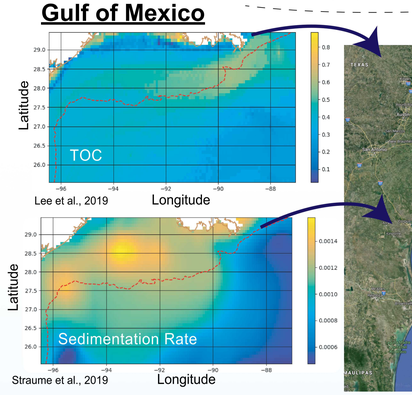
PFLOTRAN realizations (500)

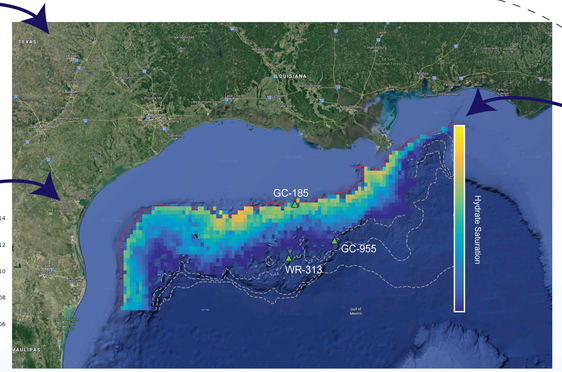


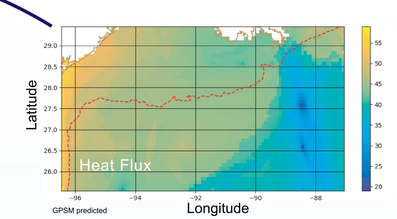
Sensitivity Analysis (at 150 mbsf)



Gulf of Mexico







4. Discussion & Conclusions

At the Tuaheni Landslide Complex: using current approximate values for the set of parameter inputs, gas hydrate growth appears to be favorable (hydrate saturation at steady state is 2.58%). But sampling a range of input results in 18.2% (91/500) of simulations being favorable for gas hydrate formation, indicating that ***future perturbations are likely to destabilize gas hydrate***. Similarly, gas formation was favorable in 7.2% (36/500) of realizations.

In the Gulf of Mexico: machine-learned maps were used to determine the distributions and uncertainties associated with parameter inputs such as organic carbon content, sedimentation rate, and heat flux. These maps fed parameter sampling for 1D simulations thoughout the Gulf of Mexico. The resulting map predicts that microbially-sourced hydrate should accumulate in the largest quantities in shallower areas up to 500 m water depth. Bulk average hydrate saturations are low in comparison to observations in the Gulf of Mexico and do not capture extensive localized hydrate formation seen in this area, suggesting that a simple diffusive migration mechanism is likely insufficient to explain hydrate growth here.

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6. References

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