

A hybrid machine learning and reservoir simulation approach to estimating global gas hydrate occurrence using open-source software



PRESENTED BY

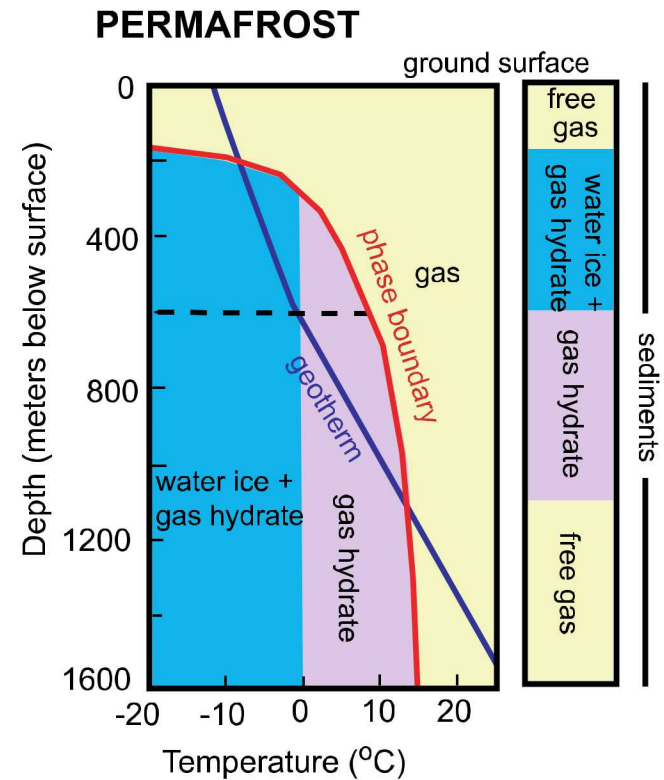
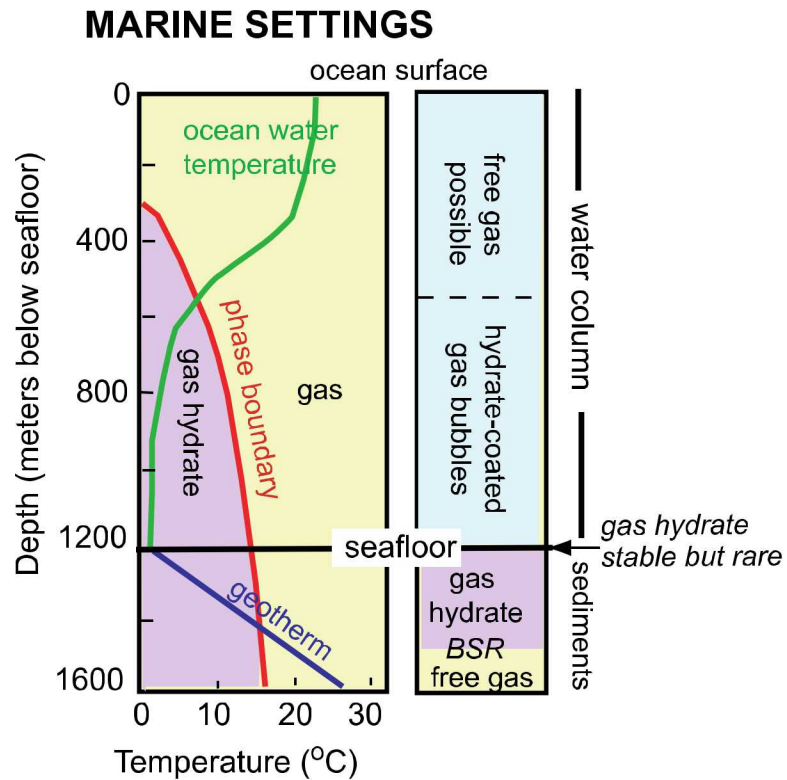
Michael Nole

Acknowledgements

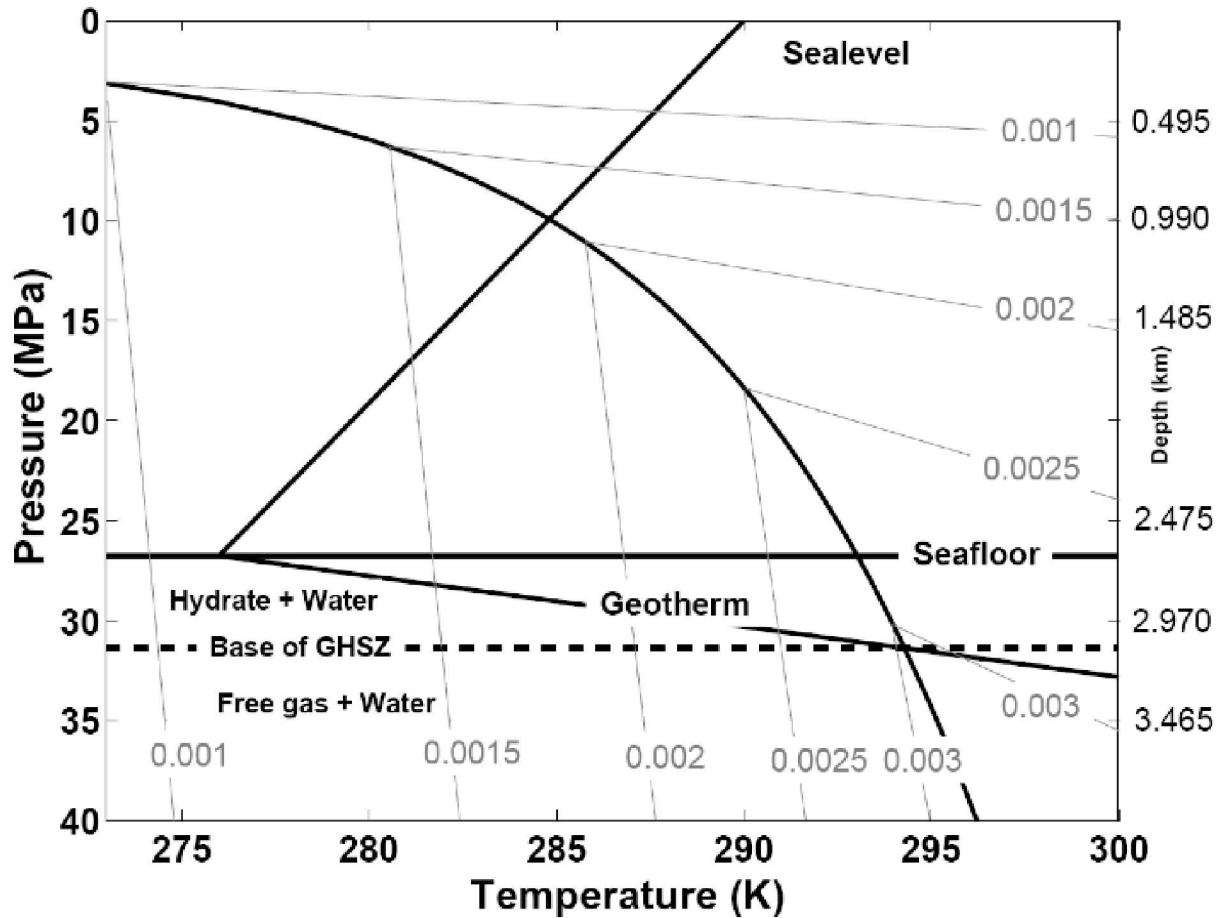
- Billy Eymold, The Ohio State University/Sandia National Labs
- Taylor Lee, Naval Research Laboratory
- Ben Phrampus, Naval Research Laboratory
- Warren Wood, Naval Research Laboratory
- Jenn Frederick, Sandia National Labs



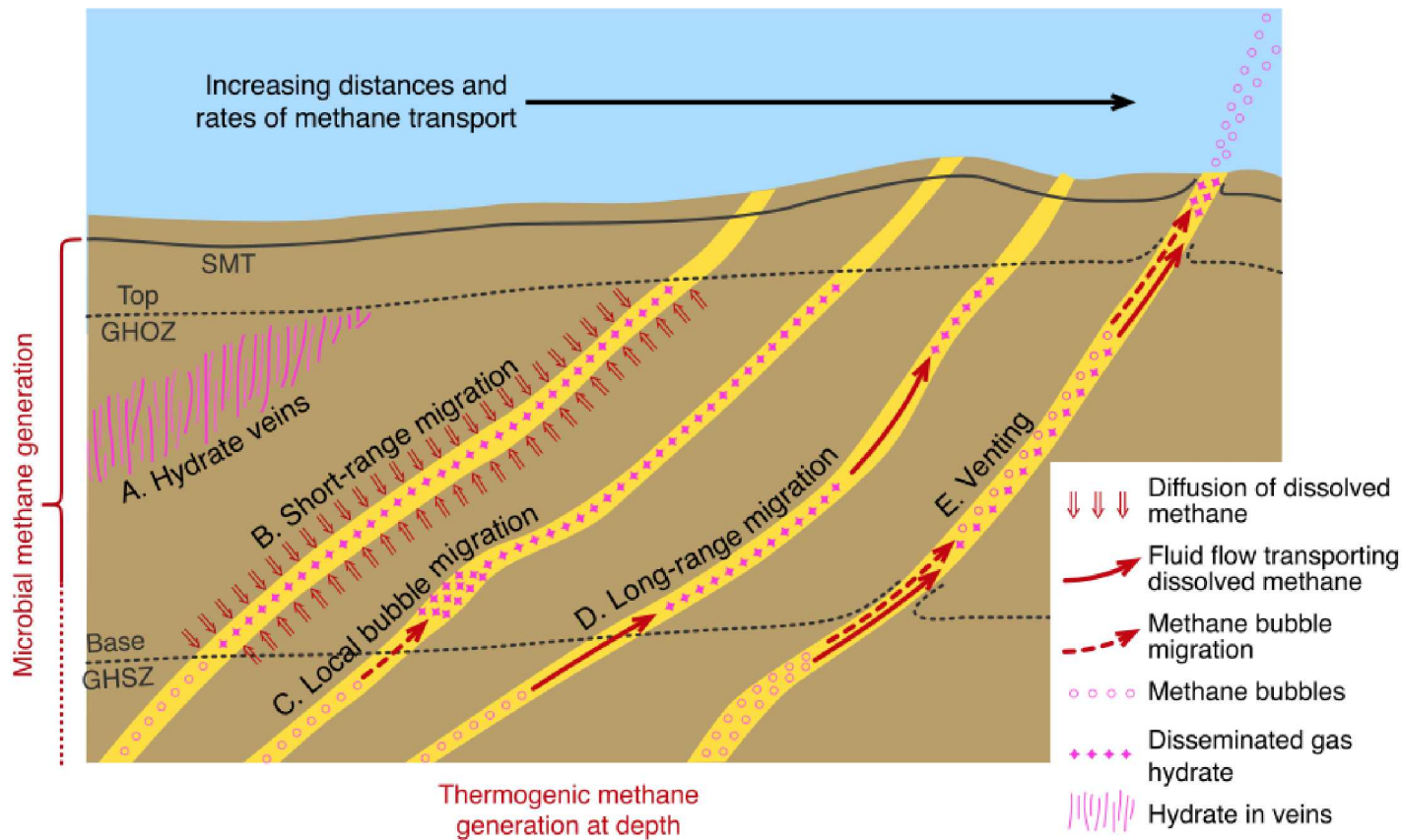
- The expression of gas hydrate in nature is controlled by complex interactions between gas sources, migration mechanisms, hydrate reservoirs, and (thermodynamic) seals
- Forward modeling these systems often requires:
 - Multi-phase, multi-component simulation
 - 3D capability to honor lateral heterogeneity and quantify competing influences of different migration mechanisms
- Predicting continuous distributions of inputs to a simulator is challenging when operating data-limited
 - How do we overcome this challenge, and can we quantify associated uncertainties?
- We can use machine learning to estimate the inputs to a simulator based off of proximity in geologic predictor space instead of simply spatial proximity



Methane Availability



Bhatnagar et al., 2007



Motivation



Sandia
National
Laboratories



- 1 Sandia National Laboratories
- 2 U.S. Naval Research Laboratory
- 3 University of Texas at Austin

Forecasting Marine Sediment Properties On and Near the Arctic Shelf with Geospatial Machine Learning

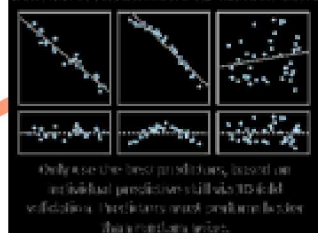
Jennifer M. Frederick¹, Warren Wood², Michael Nole¹, Ben Phrampus², Hugh Daigle³, Hongku Yoon¹, Brian Young¹, and Ken Sale¹

Global Observations (data)

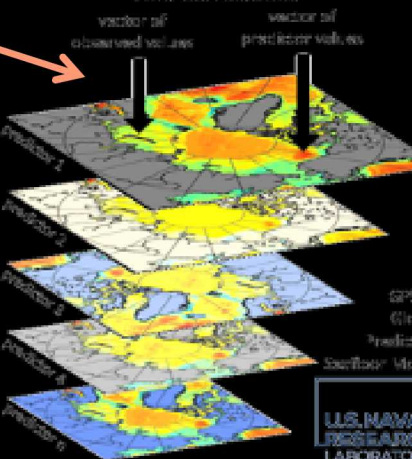


Collect and use all known data on seafloor, organized as a gridded dataset. Data outside of the Arctic can and should be used!

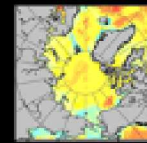
Feature Selection & Validation



Geospatial Machine Learning Algorithm Find Correlations



Features:



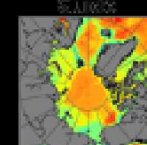
Global in space known data, and hundreds of derived calculated predictors. Data produces continuous maps of desired seafloor quantities, such as porosity, sediment type, local organic carbon content, etc.

Uncertainty:

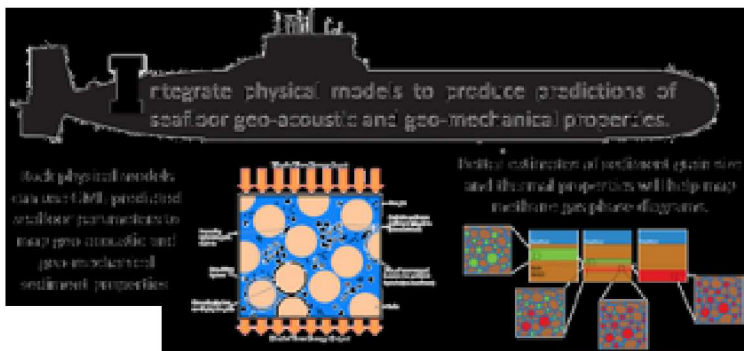


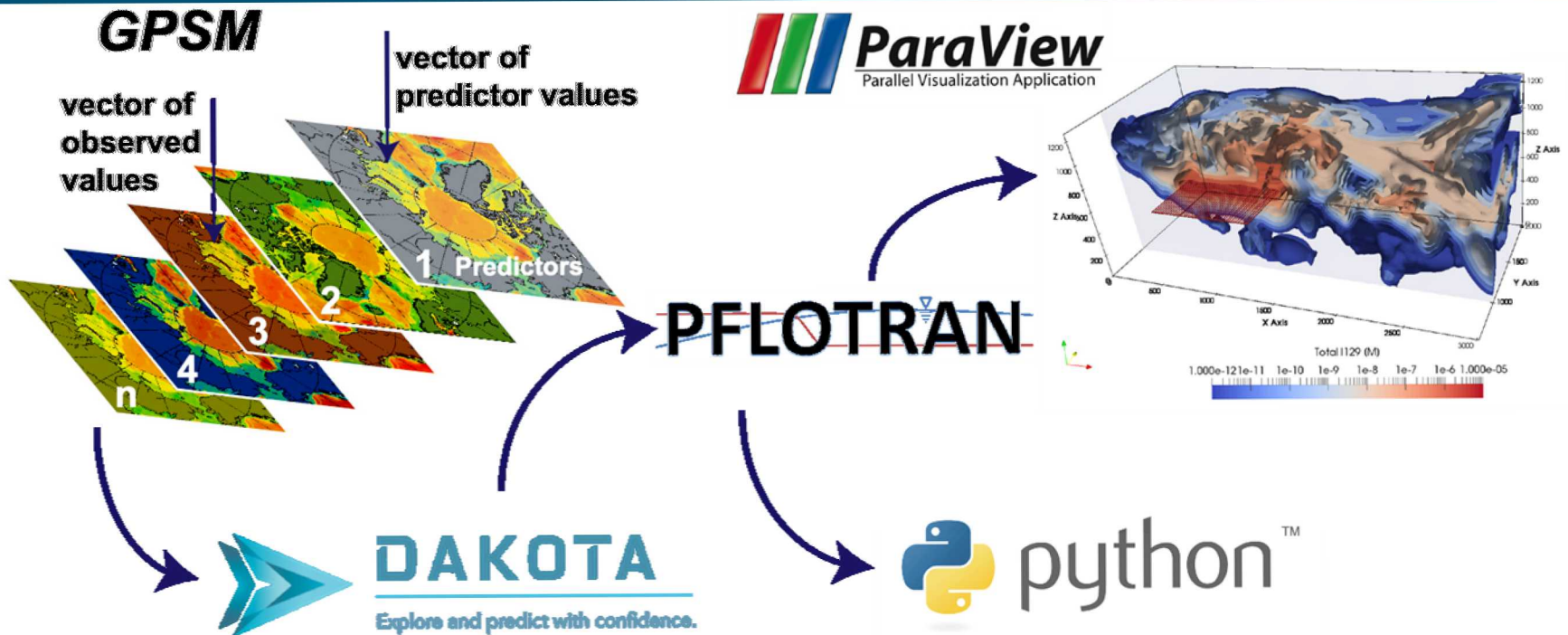
Data produces estimation of seafloor quantities and their uncertainty, which is based on predictor error. A well sampled parameter space will reduce parameter uncertainty.

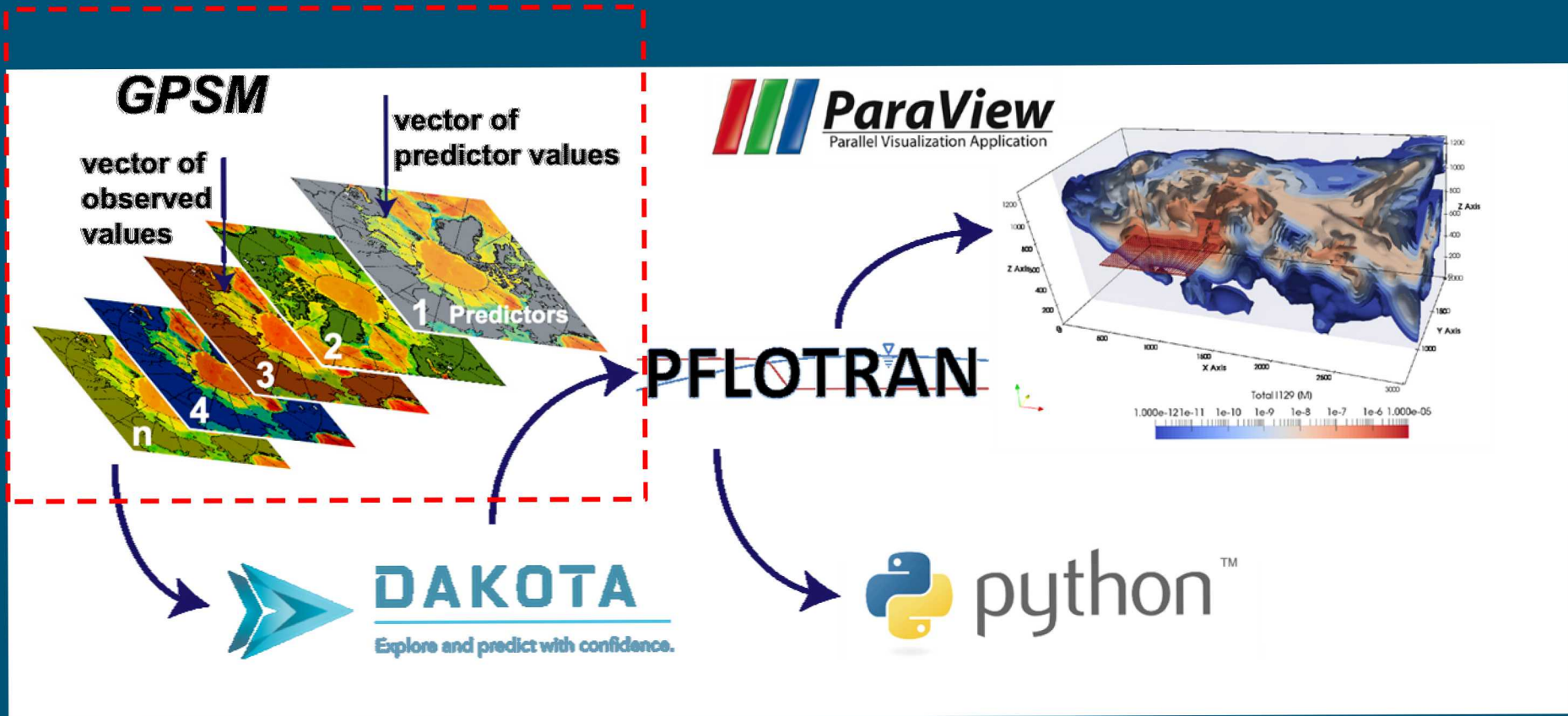
Skills:



Uncertainty models can be used to guide future data acquisition campaigns. Forecasting elevations where prediction error (uncertainty) is high will benefit prediction skill globally.

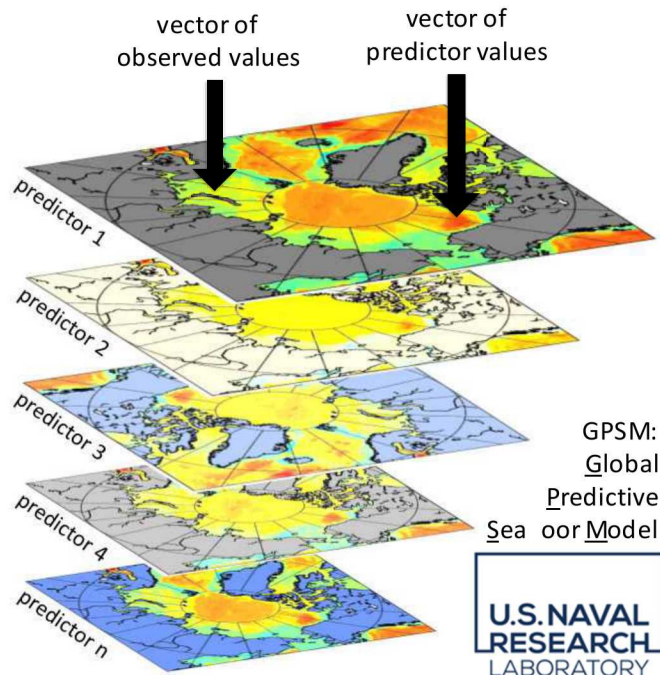




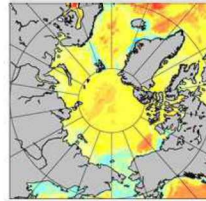


Geospatial Machine Learning Algorithm

Find Correlations

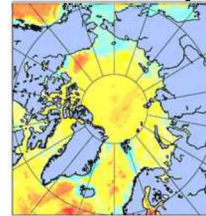


Forecast



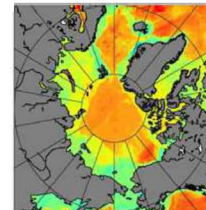
Based on sparse known data, and hundreds of dense calculated predictors, GML produces continuous maps of desired seafloor quantities, such as porosity, sediment type, total organic carbon content, etc.

Uncertainty

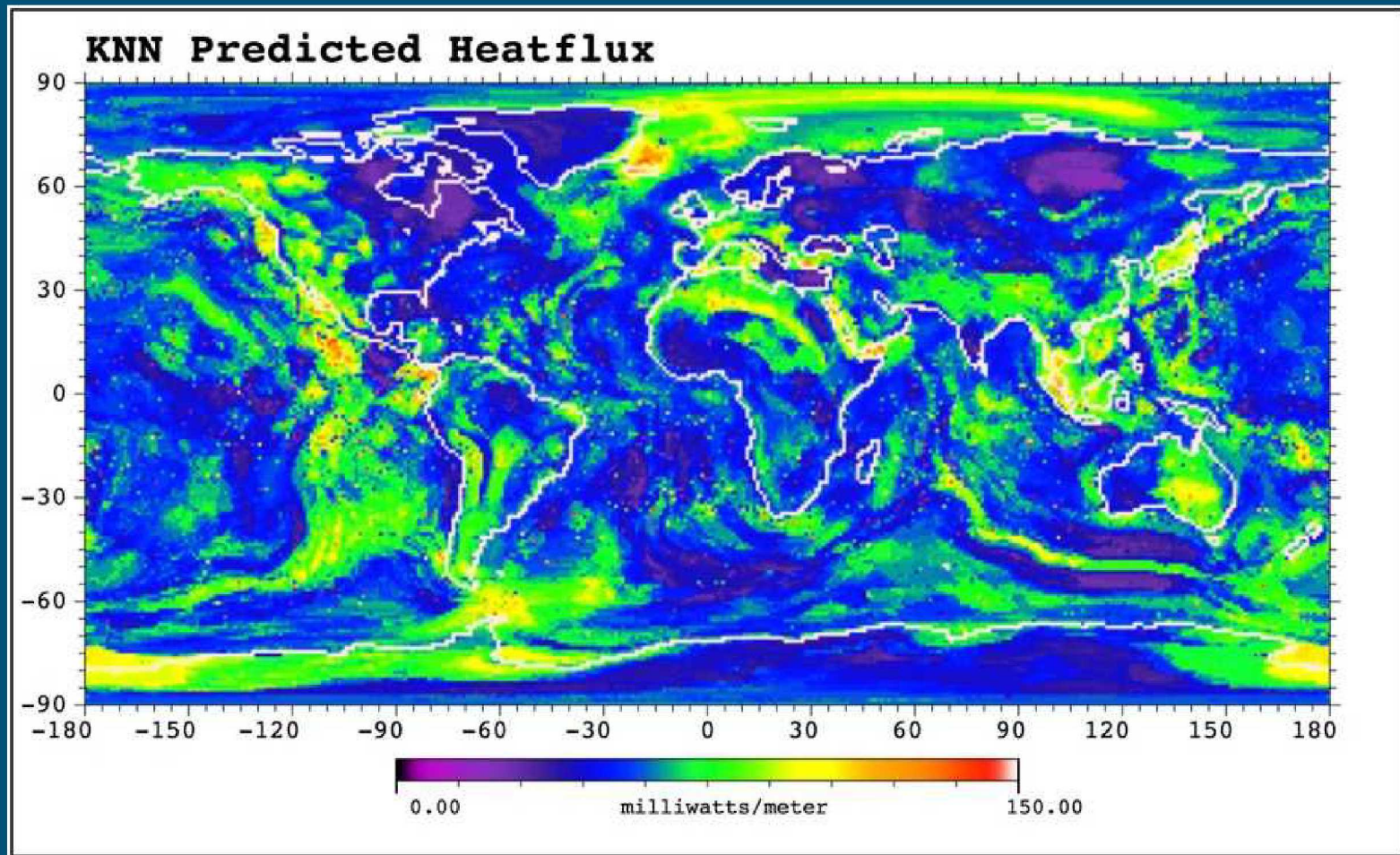


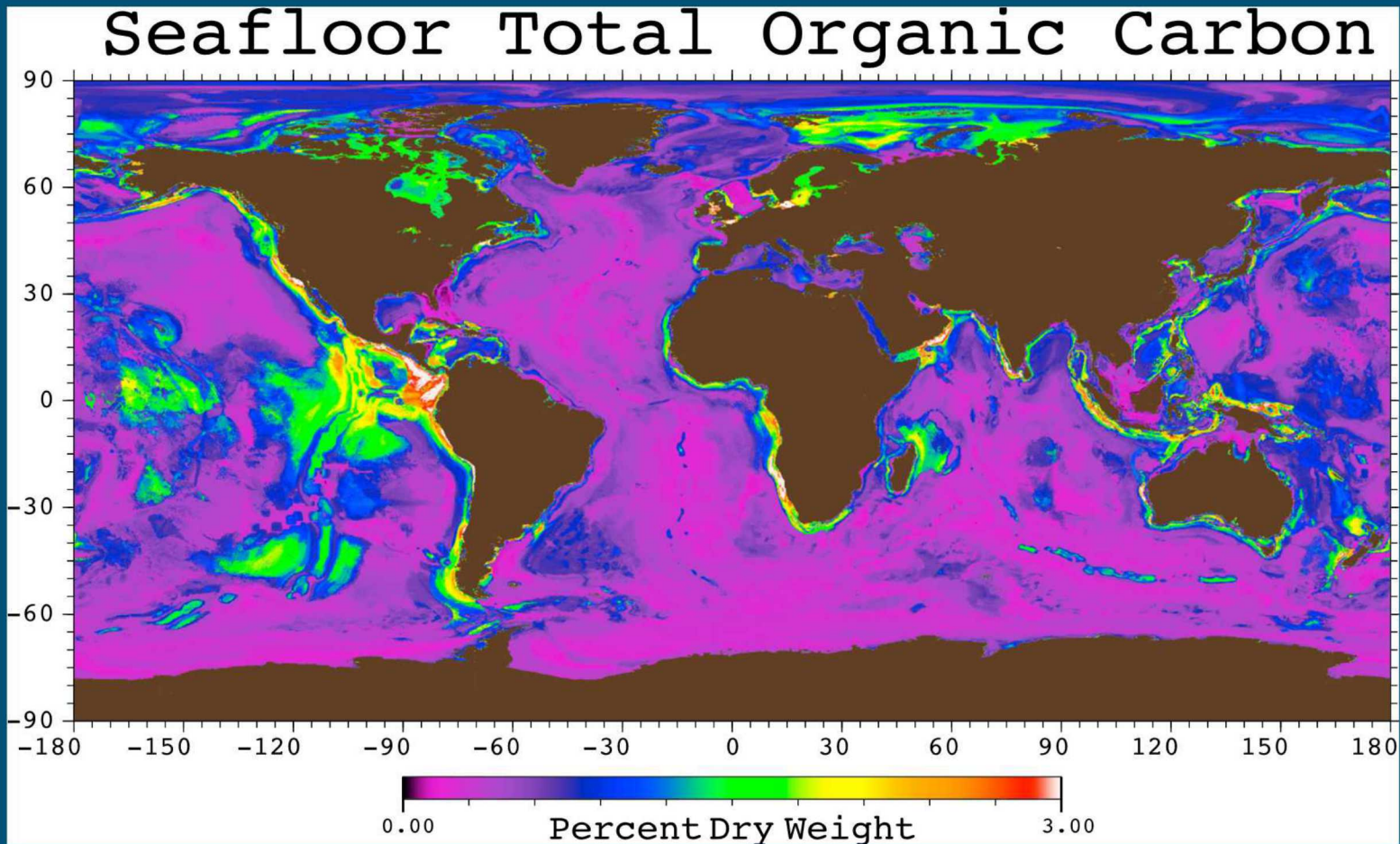
GML produces estimates of seafloor quantities and their uncertainty, which is based on prediction error. A well sampled parameter space will reduce parameter uncertainty.

Guide



Uncertainty results can be used to guide future data acquisition campaigns. Increasing observations where prediction error (uncertainty) is high will benefit predictive skill globally.





Lee et al., 2019

Machine learning \leftrightarrow Mechanistic Simulation

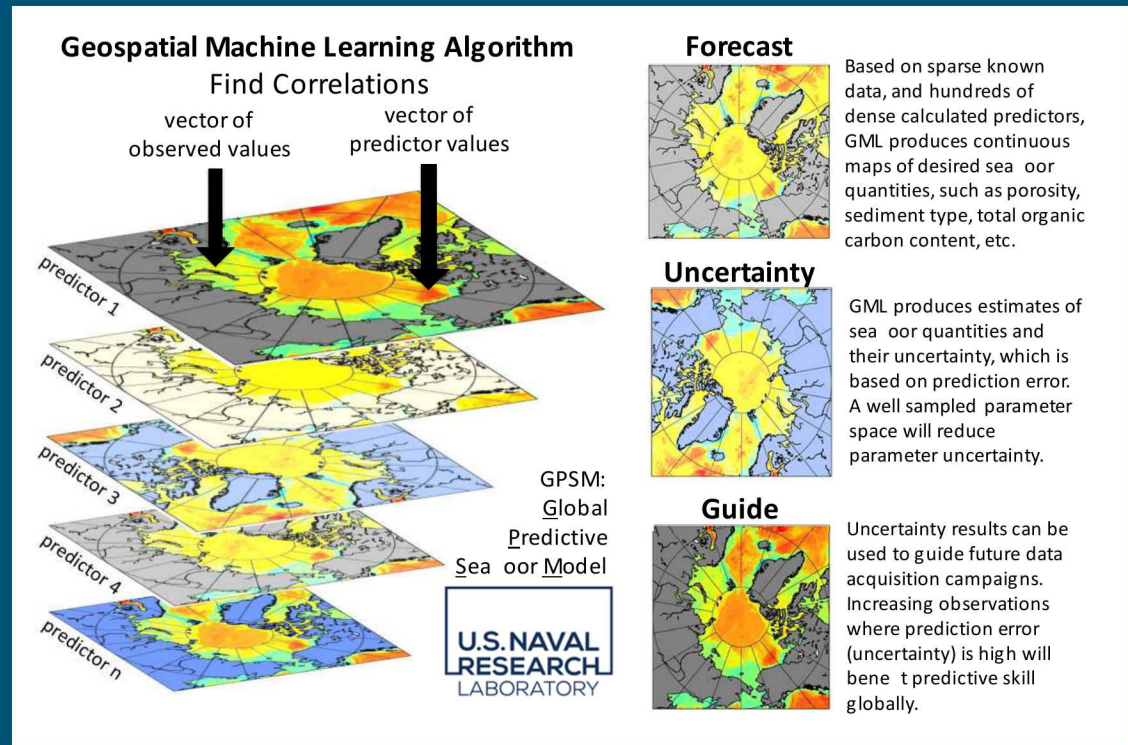
- Probabilistic maps quantify uncertainties in the seafloor parameters we are interested in
- How do these **uncertainties propagate** downward?
- What can confidence intervals on e.g. seafloor temperature, seafloor depth, seafloor organic carbon content, or heat flux tell us about the **likelihood of shallow gas or gas hydrate?**

Ex.

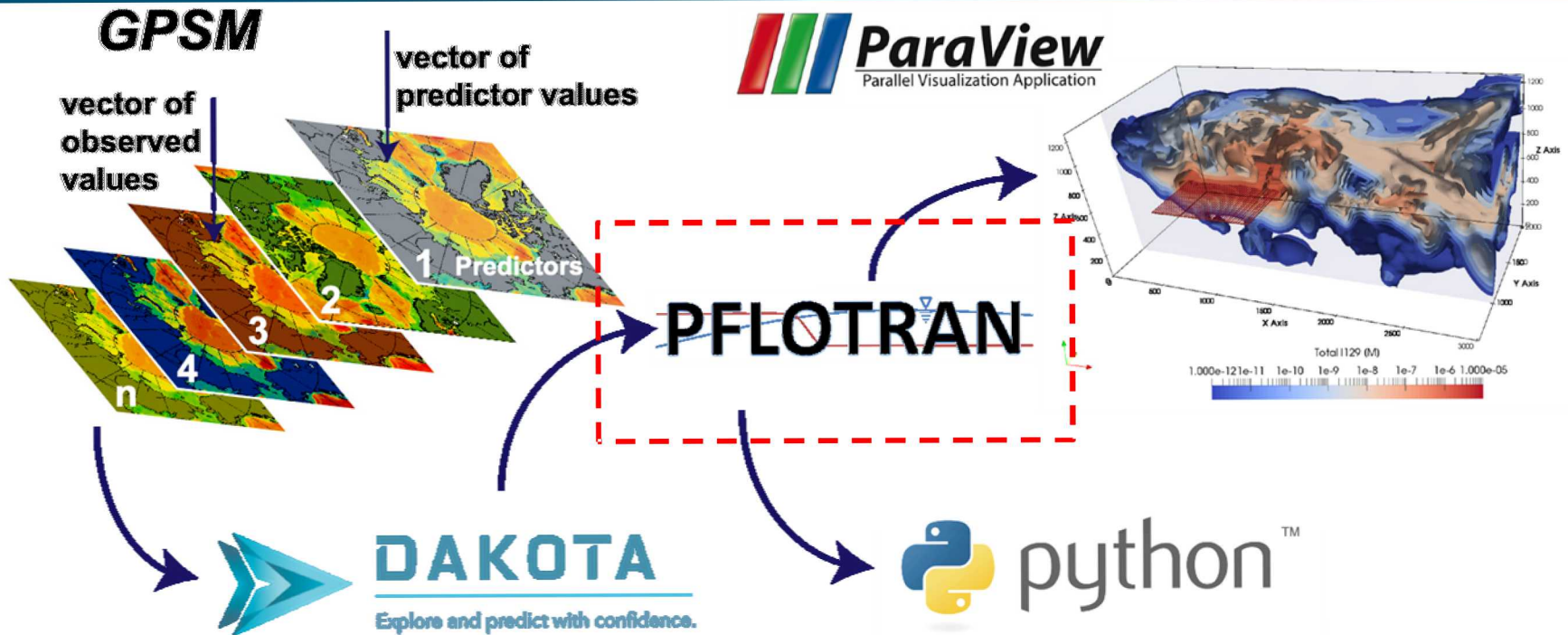
1. ϕ
2. α
3. v_{sed}
4. dist.
5. etc.

Observed Value
• e.g. permeability

Predicted value (predictand)
• e.g. permeability



We need thermodynamic models

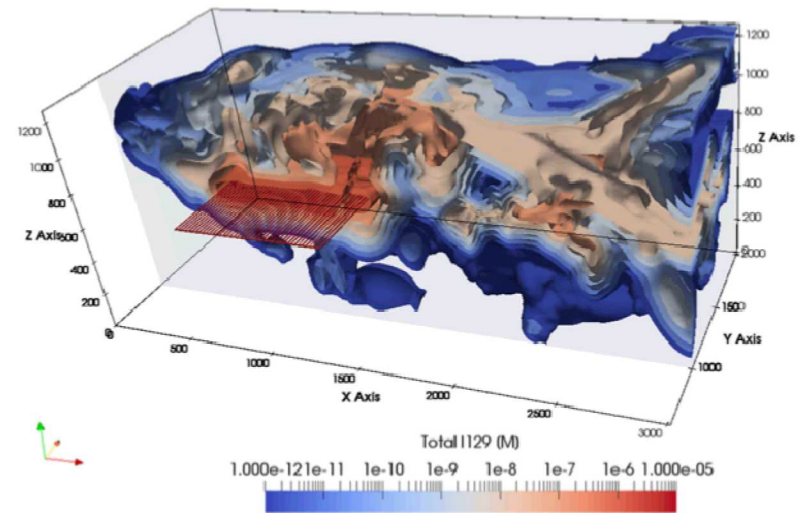


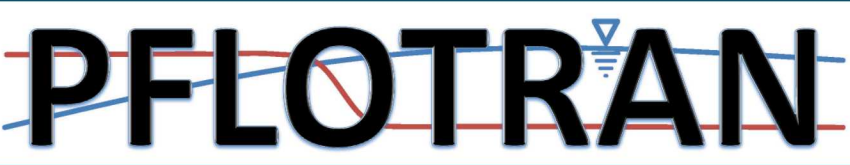
PFLOTRAN

$$\frac{\partial m_a}{\partial t} = -\nabla \cdot (\rho_l X_a^l \mathbf{q}_l + \rho_g X_a^g \mathbf{q}_g + \mathbf{J}_a^l + \mathbf{J}_a^g) + q_a^G,$$

$$\frac{\partial m_w}{\partial t} = -\nabla \cdot (\rho_l X_w^l \mathbf{q}_l + \rho_g X_w^g \mathbf{q}_g + \mathbf{J}_w^l + \mathbf{J}_w^g) + q_w^G,$$

$$\frac{\partial e}{\partial t} = -\nabla \cdot (\rho_l H_l \mathbf{q}_l + \rho_g H_g \mathbf{q}_g - \kappa_{\text{eff}} \nabla T) + q_e^G,$$

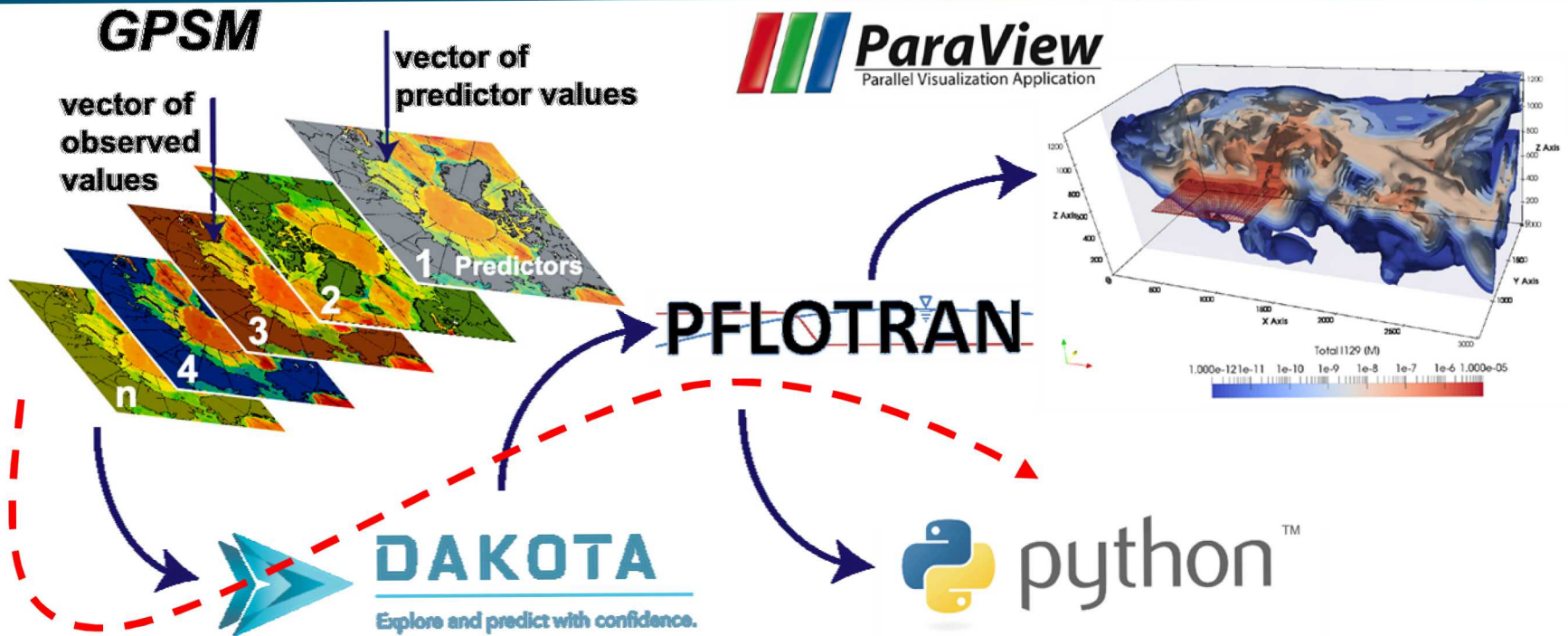




- Version control (git)
- Regression testing
- Online documentation/user's manual
- Continuous integration

The screenshot shows the GitHub repository page for PFLOTRAN. The left sidebar contains navigation links: Source, Commits (selected), Branches, Pull requests, Pipelines, Deployments, Issues, Wiki, and Downloads. The main content area is titled "Commits" and displays a list of recent commits. Each commit entry includes the author's name and profile picture, the commit hash, the commit message, and the date. A vertical timeline on the left of the commit list shows the progression of branches and merges.

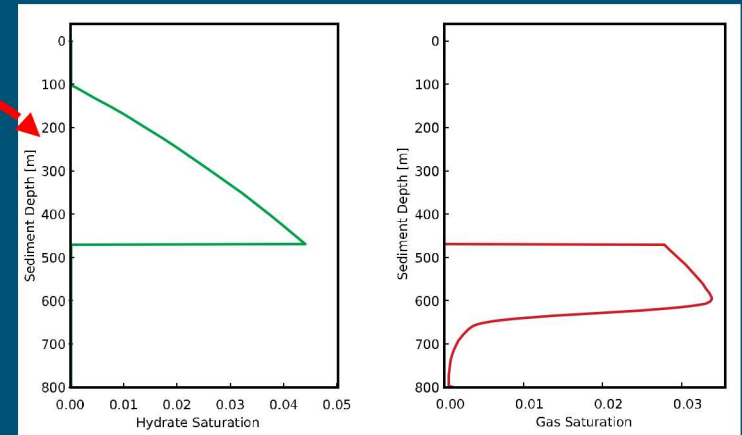
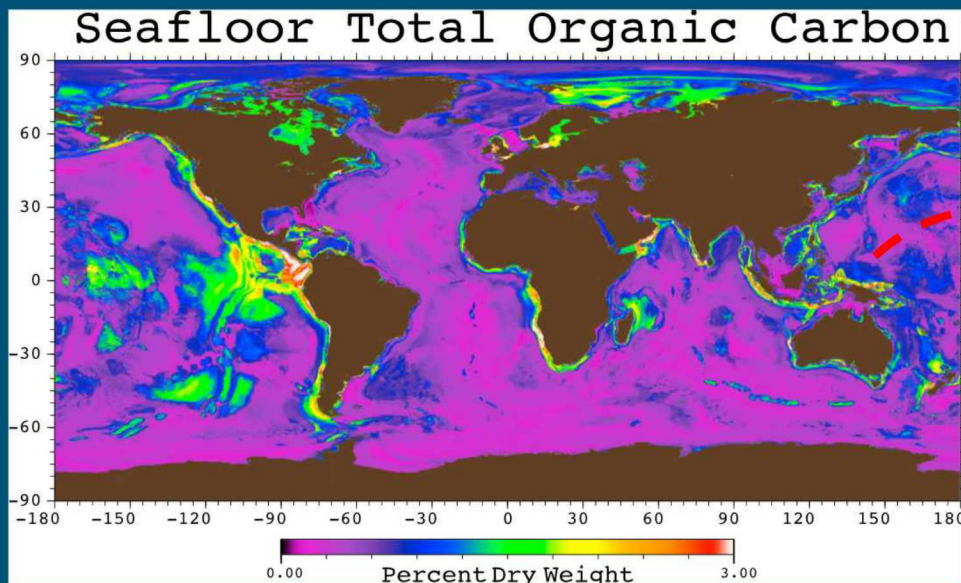
Author	Commit	Message	Date
Tom Seidl	c47ee89	Merged in dtseidl/pfioiran/tom/fmdm-surrogate (pull request #230) changed DECAY_TIME to use time units Approved-by: Gle...	2019-11-26
Tom Seidl	9937fd8	changed MECHANISM FMDMSURROGATE to FMDM_SURROGATE side note: time units for the DECAY_TIME sub-block assume...	2019-11-26
Tom Seidl	a227fec	changed DECAY_TIME to require time units	2019-11-25
Tom Seidl	6264747	Merged pfioiran/pfioiran into master	2019-11-25
Glenn Hammond	bbb42e3	Initial pass at fixing indexing of source/sink terms in general; still needs fix for numerical Jacobian	2019-11-22
Glenn Hammond	af4db21	fixed bug in regression script where timeout_error flag is uninitialized.	2019-11-22
Heeho Park	3815a2f	Merged in heeho/cpr-preconditioner-hypr-hypr-hypr (pull request #228) PETSC_HAVE_LIBHYPRE changed to PETSC_HAVE_LI...	2019-11-21
Michael Nole	5ef26c5	Minor changes following comments on pull request.	2019-11-21
Michael Nole	5d638b4	Tweak.	2019-11-21
Michael Nole	d1b8426	Refactor to have the PM hold all hydrate_parameters, to which others will point.	2019-11-21
Michael Nole	c282cf7	Move methanogenesis parameters into the PM and out of patch. Requires changes outside of HMODE.	2019-11-21
Glenn Hammond	c6e8b83	Merge branch 'master' of https://bitbucket.org/pfioiran/pfioiran	2019-11-20
Glenn Hammond	aa086d1	Changed -malloc 0 -> -malloc_debug no	2019-11-20
Glenn Hammond	c43ba1b	Merged in glenn/add-major-fail-to-regression (pull request #226) Addition of MAJOR FAIL category in regression tests; time o...	2019-11-20
Glenn Hammond	b32ed5c	Added T for time out error to regression testing legend	2019-11-20
Tom Seidl	8aedb97	Merged in dtseidl/pfioiran/tom/fmdm-surrogate (pull request #223) Tom/fmdm surrogate Approved-by: Glenn Hammond geha...	2019-11-20
Tom Seidl	114a2e3	Revisions for pull request #223: Changed tolerance for fmdm_ann_surrogate regression test. Replaced real, integer, and logical...	2019-11-20
Glenn Hammond	3df5b83	Merged in glenn/add-h5py-to-travis (pull request #225) Added python-h5py to apt-get Approved-by: Glenn Hammond geham...	2019-11-19
Glenn Hammond	47c3690	Added python-h5py to apt-get	2019-11-19
Michael Nole	8c92b6d	Merged in michael/hmode (pull request #224) Michael/hmode Approved-by: Glenn Hammond gehammo@sandia.gov	2019-11-19
Michael Nole	d4244af	hydrate regression test config file update.	2019-11-19
Michael Nole	70e45a6	Move Srg into rel_perm base	2019-11-19
Michael Nole	cdf8dbf	Working radiolysis model.	2019-11-19
Glenn Hammond	b34b282	Loosened major scale to 1.d6	2019-11-18
Glenn Hammond	3feda9e	Modified major failure of be a scaling of absolute/relative tolerance	2019-11-18



Using GPSM maps for:

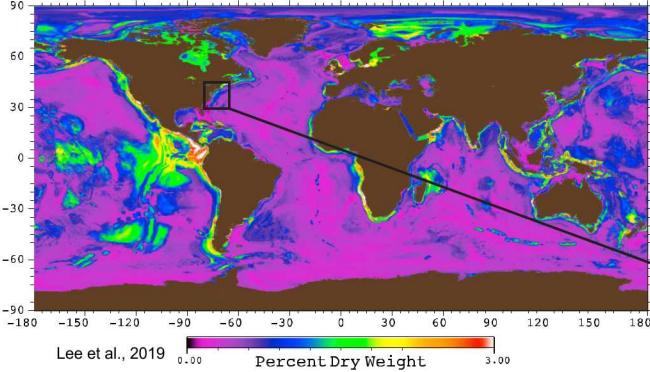
- TOC
- Sedimentation rate
- Heat flux
- Bathymetry
- Seafloor temperature

We can use mechanistic simulations to project downward into sediments



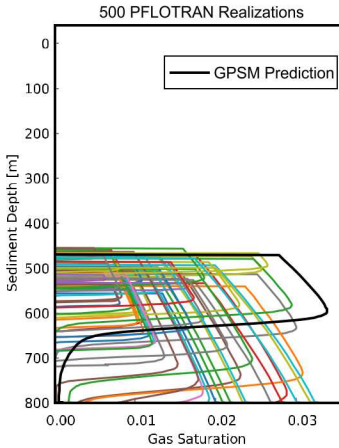
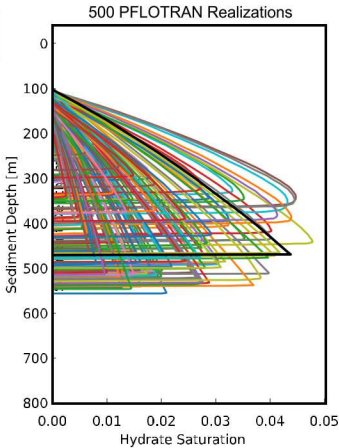
GPSM

Seafloor Total Organic Carbon

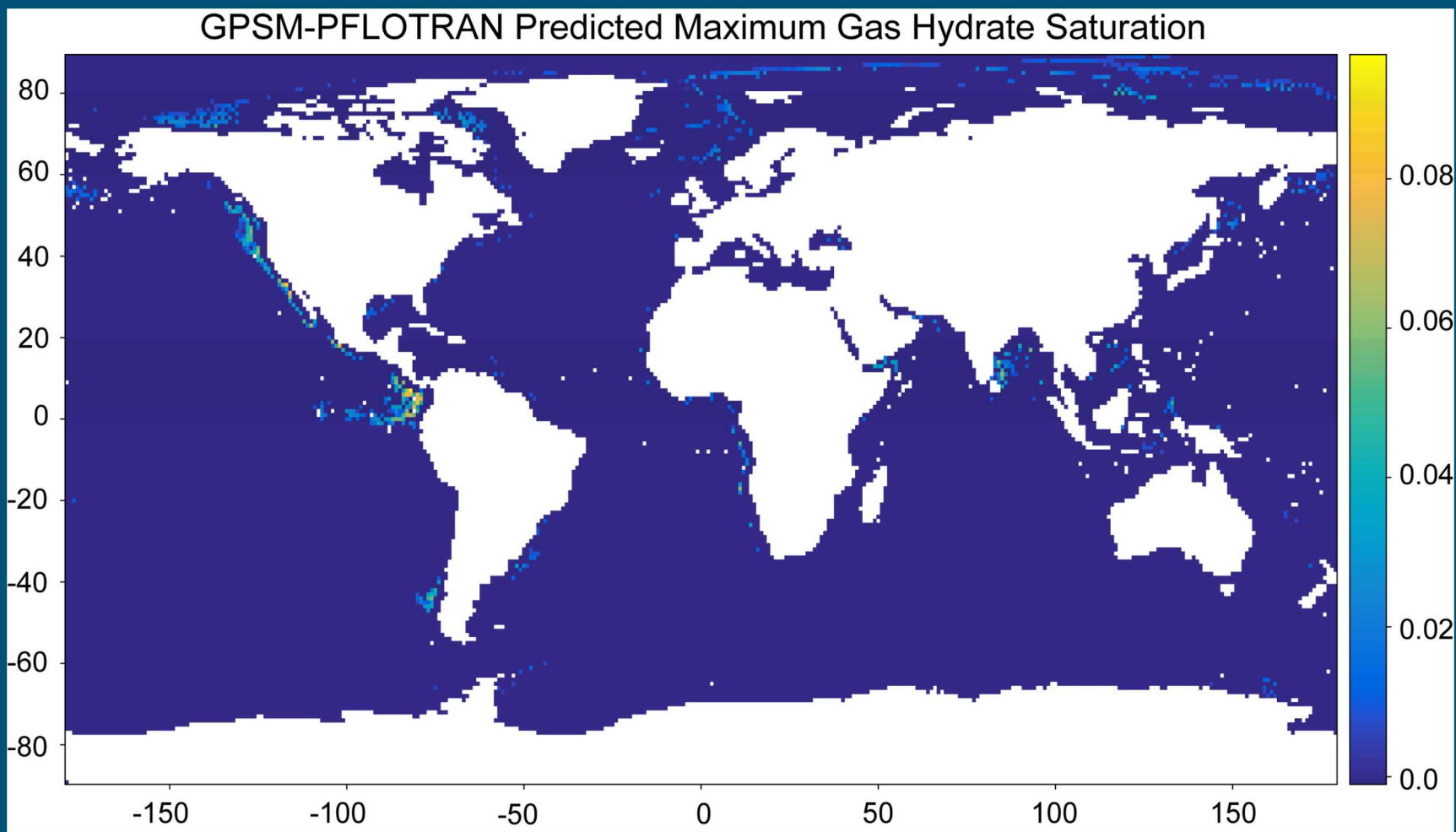


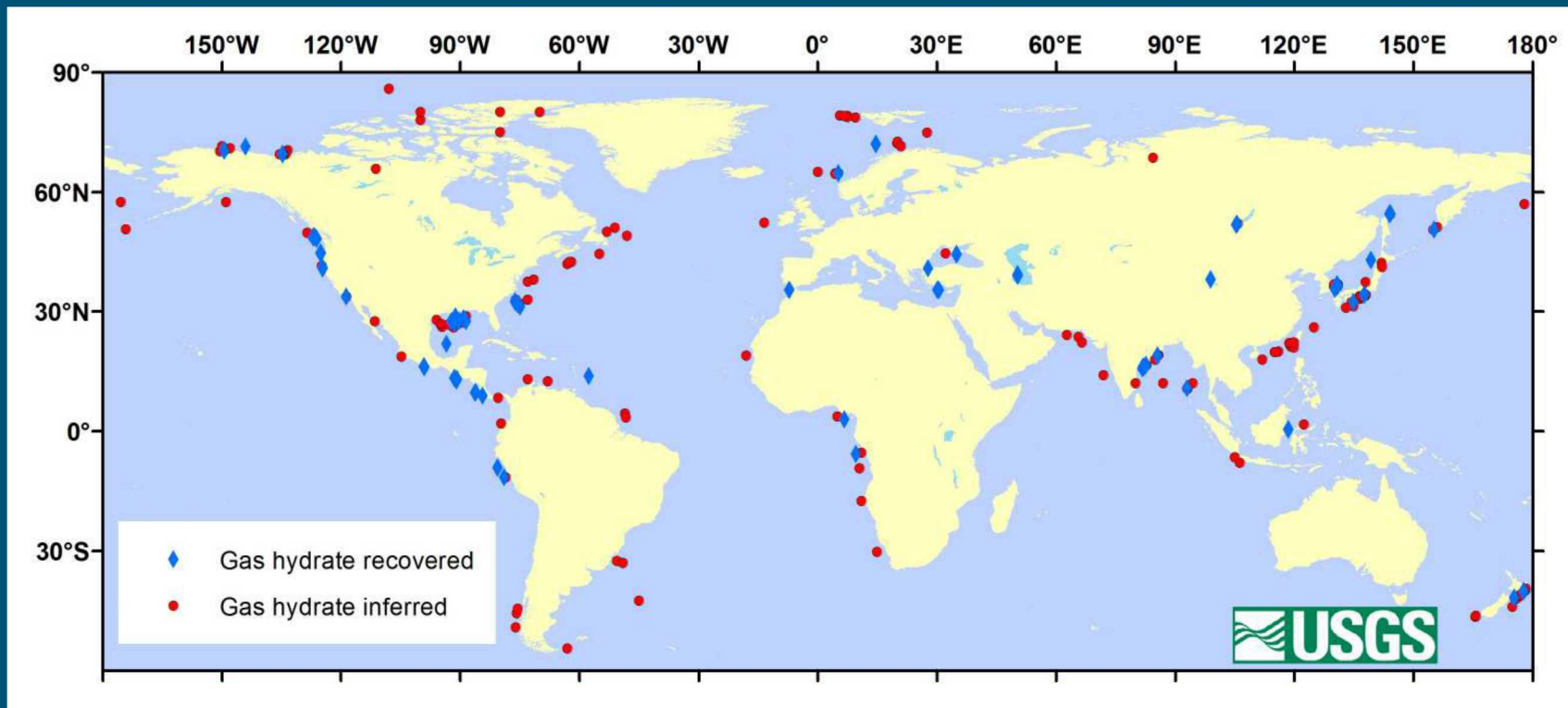
Parameter	Distribution	Min	Max	Current (GPSM)
Seafloor Depth (m)	Uniform	2760	2800	2780
Seafloor Temperature (C)	Uniform	3	5	4
Heat Flux (W/m ²)	Uniform	0.03	0.08	0.06
Sedimentation Rate (m/yr)	Log-uniform	1x10 ⁻⁴	1x10 ⁻³	2x10 ⁻⁴
Seafloor Organic Carbon Fraction	Log-Uniform	1x10 ⁻³	2x10 ⁻²	1x10 ⁻²

PFLOTTRAN



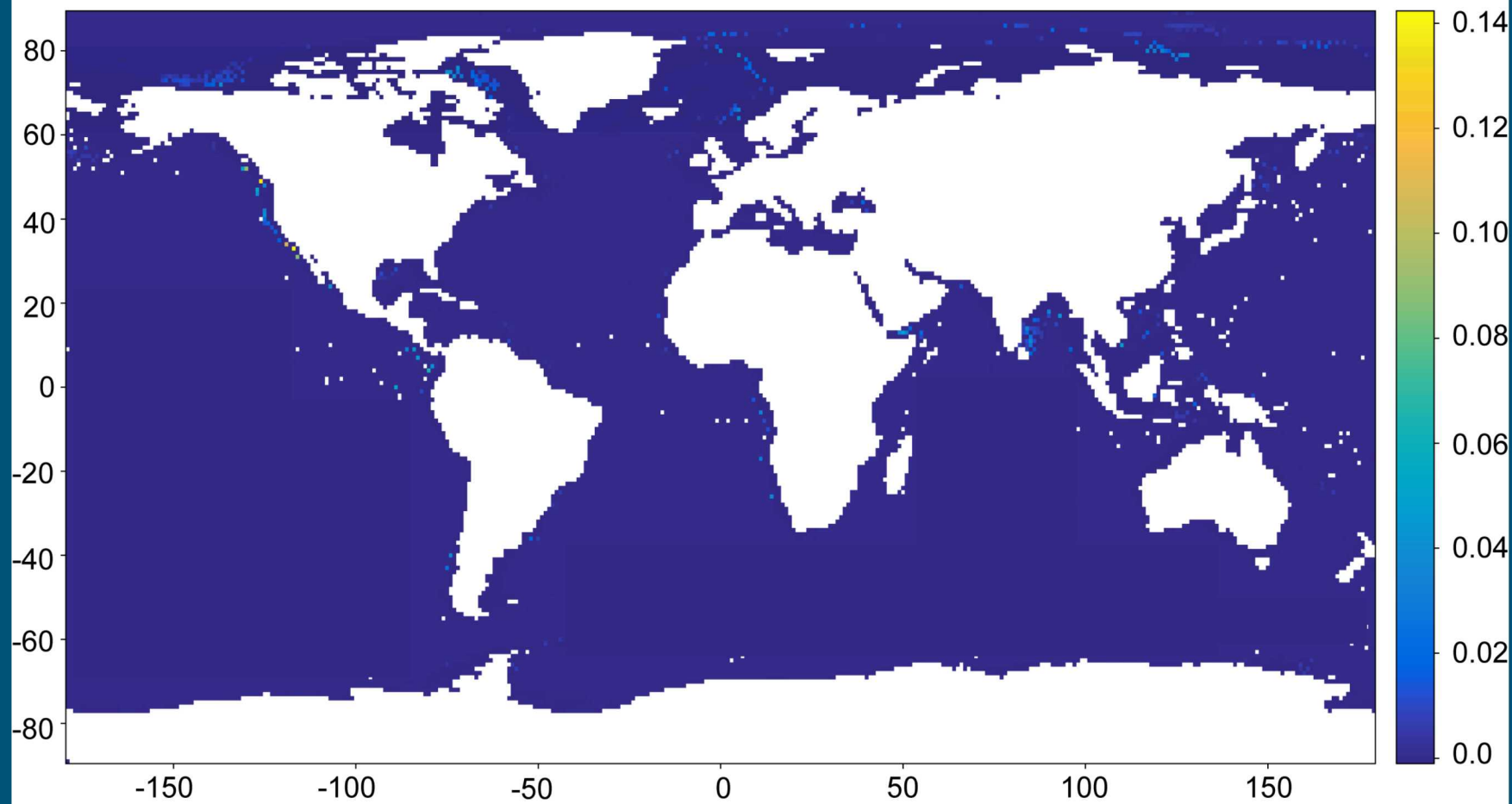
*See Frederick et al. poster at the GRC!







GPSM-PFLOTTRAN Predicted Maximum Gas Saturation



- Higher-resolution maps, zoomed in sub-sampling
- Quantify uncertainty
- Sub-sample, do 3D
- Mixed migration mechanisms
- Expanded capabilities (mixed hydrates [with UT Austin], geomechanics/slope stability with CSM, etc)

Affiliated posters you should check out

- Jenn Frederick
- David Fukuyama