A PROBABILISTIC MODELING FRAMEWORK UTILIZING OCEAN DRILLING DATA TO FORECAST CURRENT & FUTURE THERMODYNAMIC CONDITIONS ON & BELOW THE SEAFLOOR

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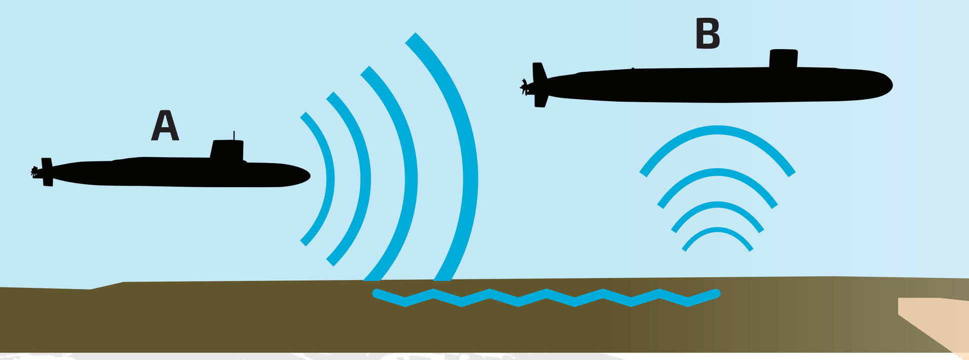
Naval Arctic Strategy now includes blue water operations, such as anti-submarine warfare, and mine warfare, requiring an accurate and reliable understanding of seafloor acoustics and seabed strength. Data on Arctic seafloor properties is extremely sparse, limiting our ability to predict mission critical geo-acoustical and geo-mechanical properties.

Sound travels through the water and through the sediments.

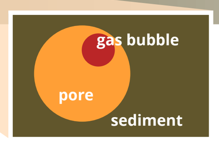


- Noise generated by submarine A can be heard by submarine B via sound propagation through the water column and the sediments.
- To reliably predict sound propagation pathways, we need an accurate understanding of seabed physical properties.
- We have very little knowledge on seafloor properties, limiting our ability to predict SONAR behavior through the seafloor.
- One of the largest influences on the speed of sound through the seabed is the distribution of free gas (i.e. gas bubbles).

compressional wave velocity (speed of sound)

$$V = \sqrt{\frac{B}{\rho}}$$

density — bulk modulus



Current SONAR algorithms do not take gas into account, because we can't reliably predict seafloor gas distribution.

Some example values

B_{air} = 0.000142 GPa

B_{water} = 2.2 Gpa

$B_{sediment}$ = 40 GPa

Geospatial Machine Learning (GML)

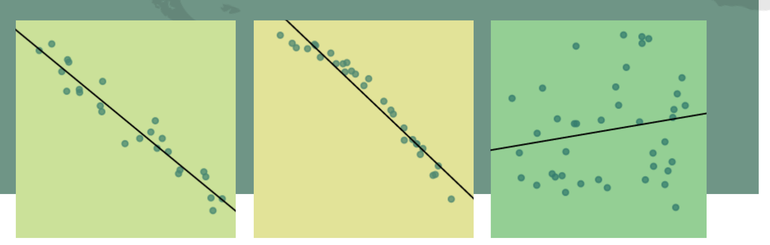
Can be used to build a system that predicts or forecasts seafloor properties like we forecast the weather. GML can produce maps of continuous seafloor properties with estimates of uncertainty, while also integrating physically consistent models. It is superior to traditional interpolation methods.

Global Observations (Data)

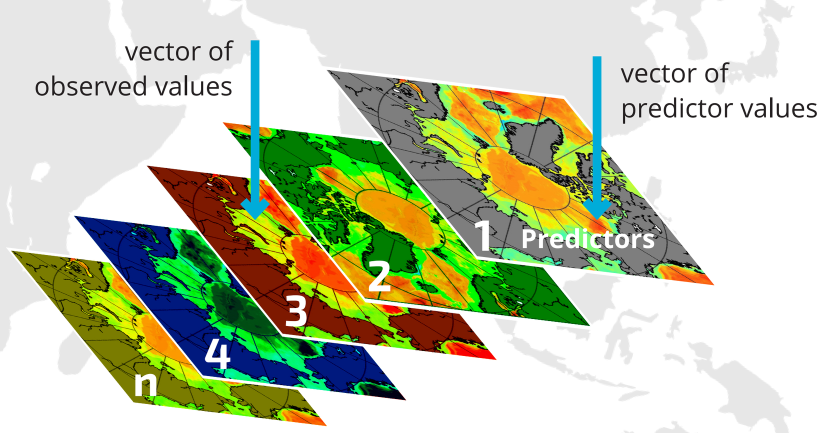
Collect and use all known data on seafloor, organized as a gridded dataset. Data outside of the Arctic can and should be used!

Feature Selection & Validation

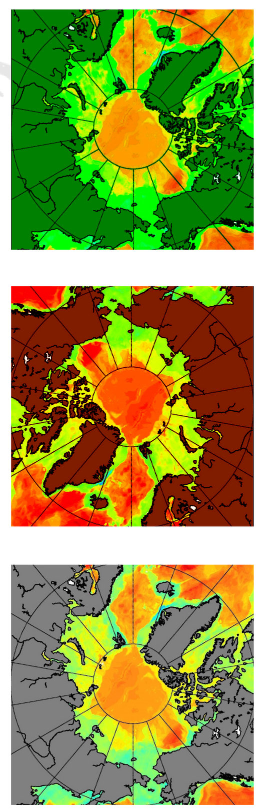
Only use the best predictors, based on individual predictive skill via 10-fold validation. Predictors must perform better than random noise.



Find Correlations in Geospatial Machine Learning Algorithm



GPSM: GLOBAL PREDICTIVE SEAFLOOR MODEL



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.

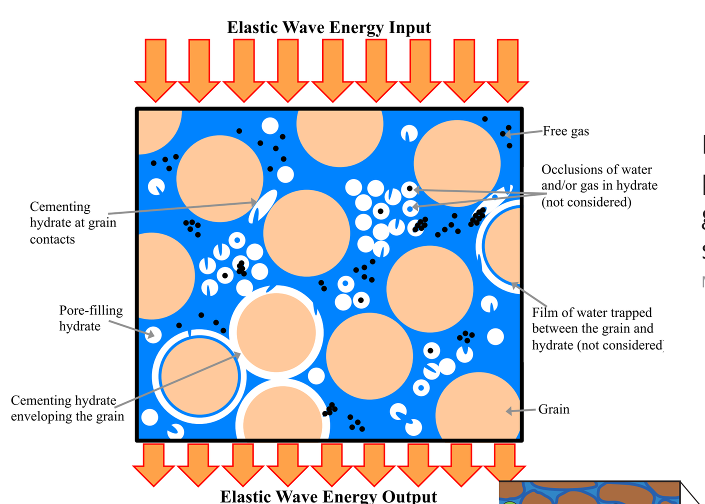
Uncertainty

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

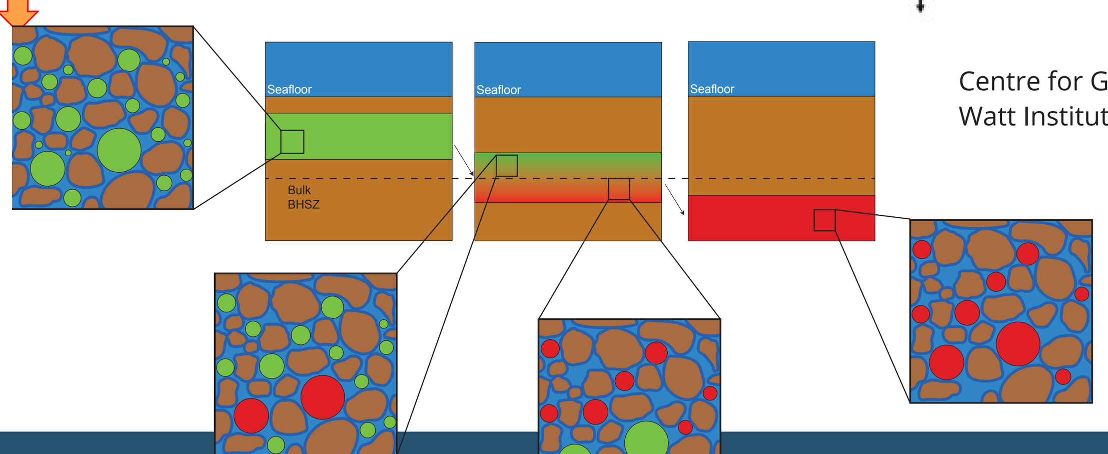
Uncertainty results can be used to guide future data acquisition campaigns. Increasing observations where prediction error (uncertainty) is high will benefit predictive skill globally.

Integrate physical models to produce predictions of seafloor geo-acoustic and geo-mechanical properties



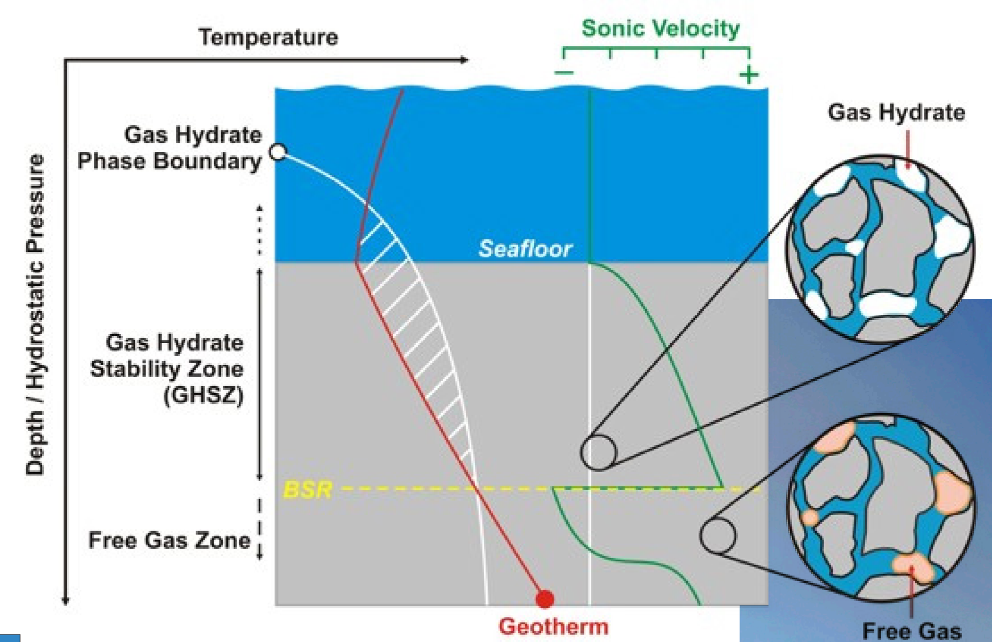
Rock physical models can use GML-predicted seafloor parameters to map geo-acoustic and geo-mechanical sediment properties.

Marin-Moreno, H. et al. (2017), J. Geophys. Res. Solid Earth



Better estimates of sediment grain size and thermal properties will help map methane gas phase diagrams.

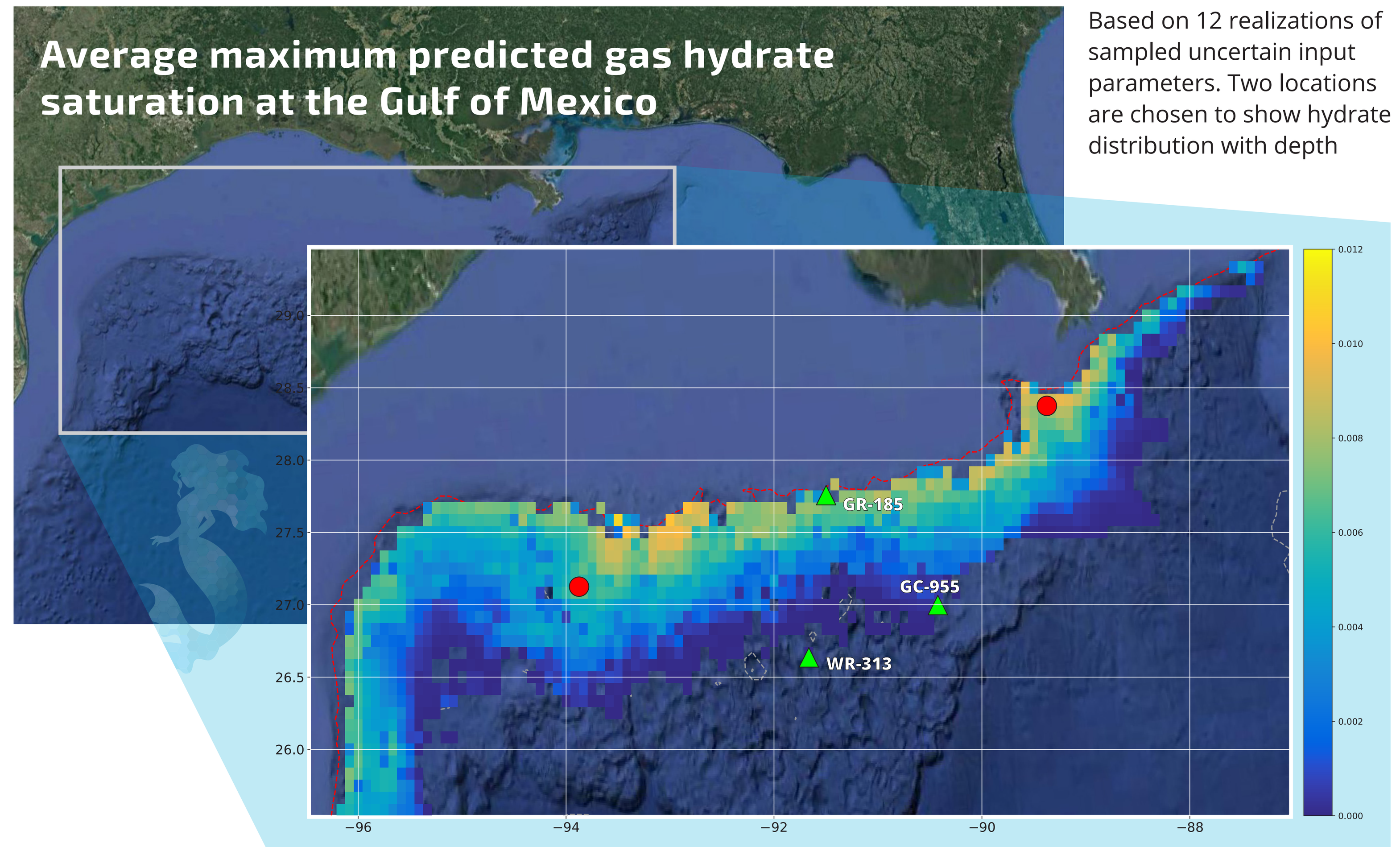
Nole, M. et al. (2018), EPSL



Centre for Gas Hydrate Research, Heriot Watt Institute of Petroleum Engineering.

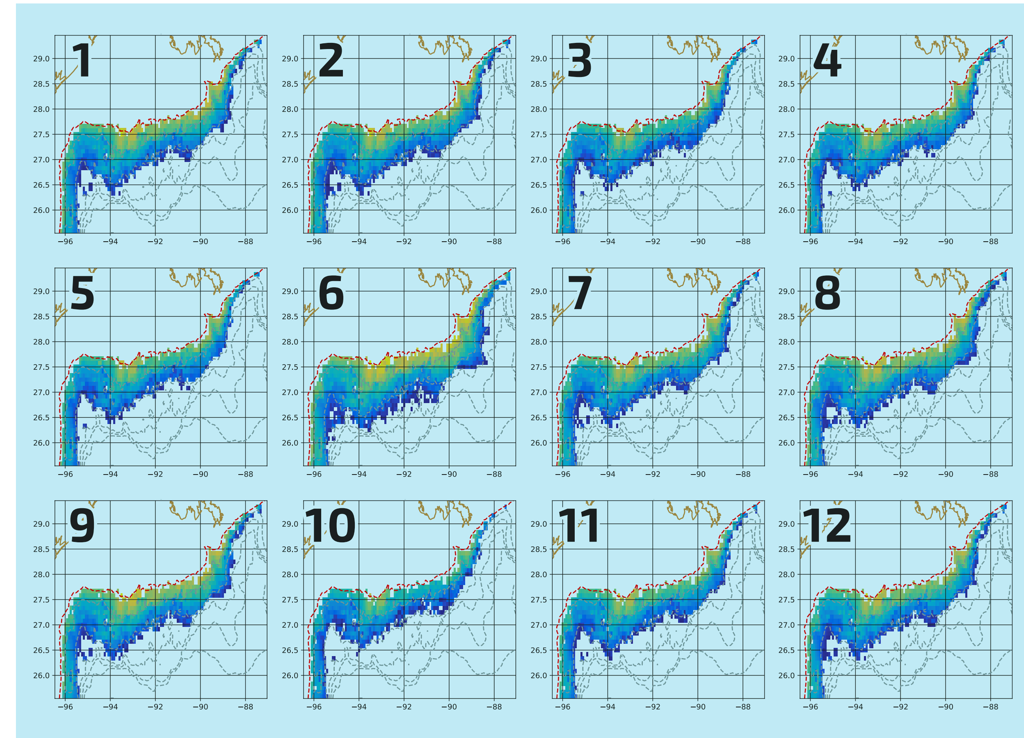
RESULTS

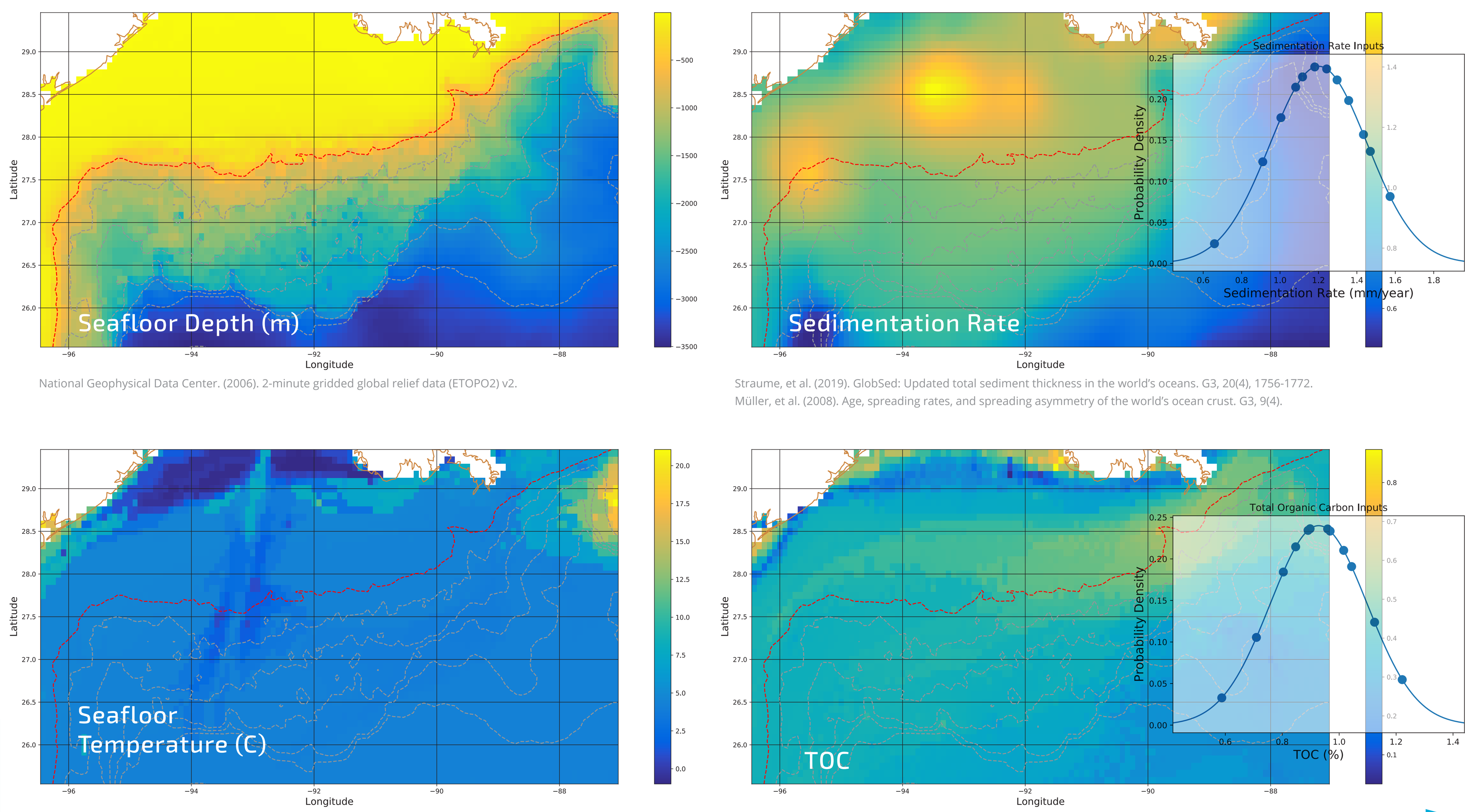
Average maximum predicted gas hydrate saturation at the Gulf of Mexico



Based on 12 realizations of sampled uncertain input parameters. Two locations are chosen to show hydrate distribution with depth

Samples



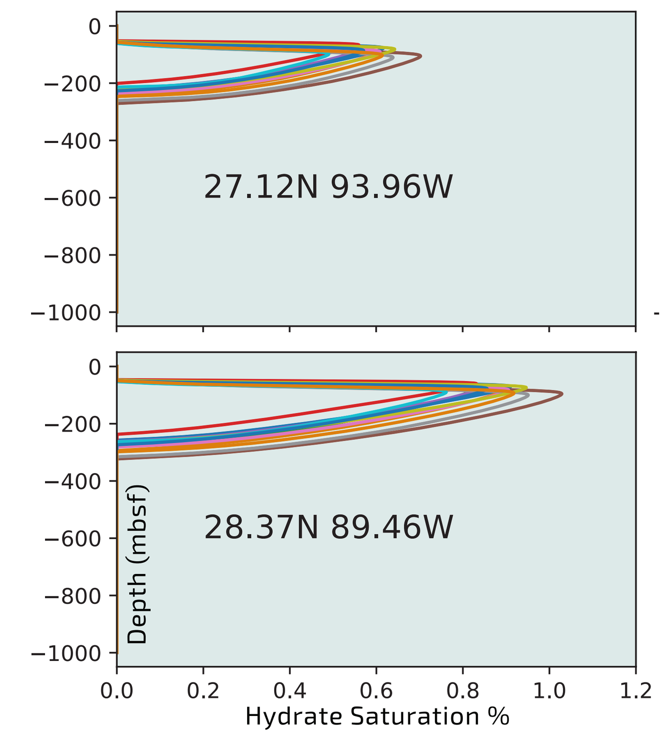


National Geophysical Data Center. (2006). 2-minute gridded global relief data (ETOPO2) v2.

Straume, et al. (2019). GlobSed: Updated total sediment thickness in the world's oceans. G3, 20(4), 1756-1772.
Müller, et al. (2008). Age, spreading rates, and spreading asymmetry of the world's ocean crust. G3, 9(4).

Locarnini, et al. (2013). World ocean atlas 2013. Volume 1, Temperature.

Lee, et al. (2019). Global Biogeochemical Cycles, 33(1), 37-46.

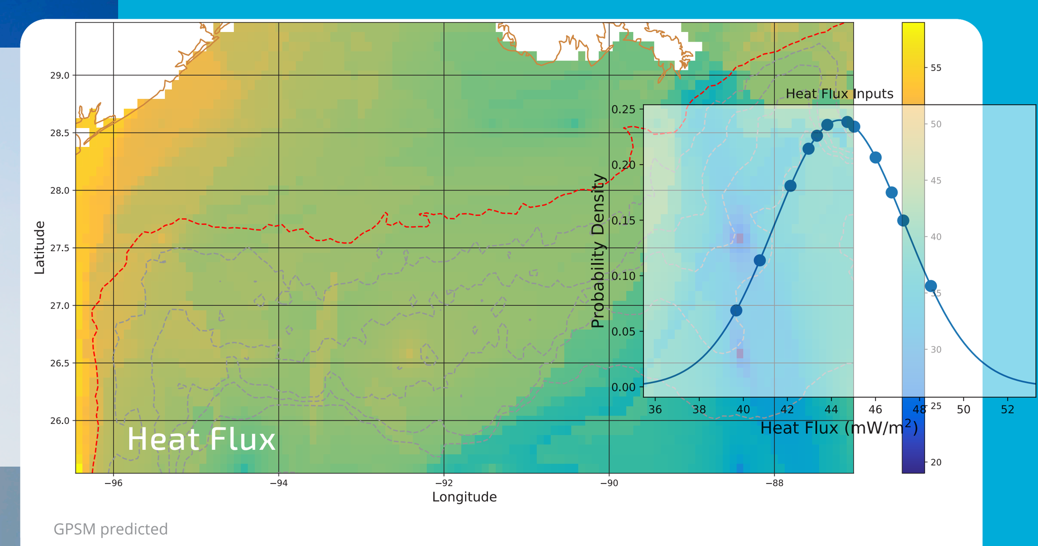


Profiles of gas hydrate saturation with depth at the 2 marked sites after 30kyrs

Each site shows the results of all 12 realizations. These profiles of gas hydrate saturation with depth correspond to the 2 sites marked on the main map figure.

Determined and uncertain model input parameters obtained from the Global Predictive Seabed Model (GPSM)[2]

These maps show the input parameters that were used to generate the modeled results in the main map. Sampling on these input parameters generates the 12 realizations. Uncertain parameters are assumed to be normally distributed with a mean value and standard deviation



GPSM predicted

Conclusions

Ensembles of stochastic simulations can produce maps of seafloor characteristics relevant to national security and defense, natural resource exploration, and climate change.

Future work will focus on integrating ensemble realizations to create probabilistic nowcasts and forecasts.

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