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

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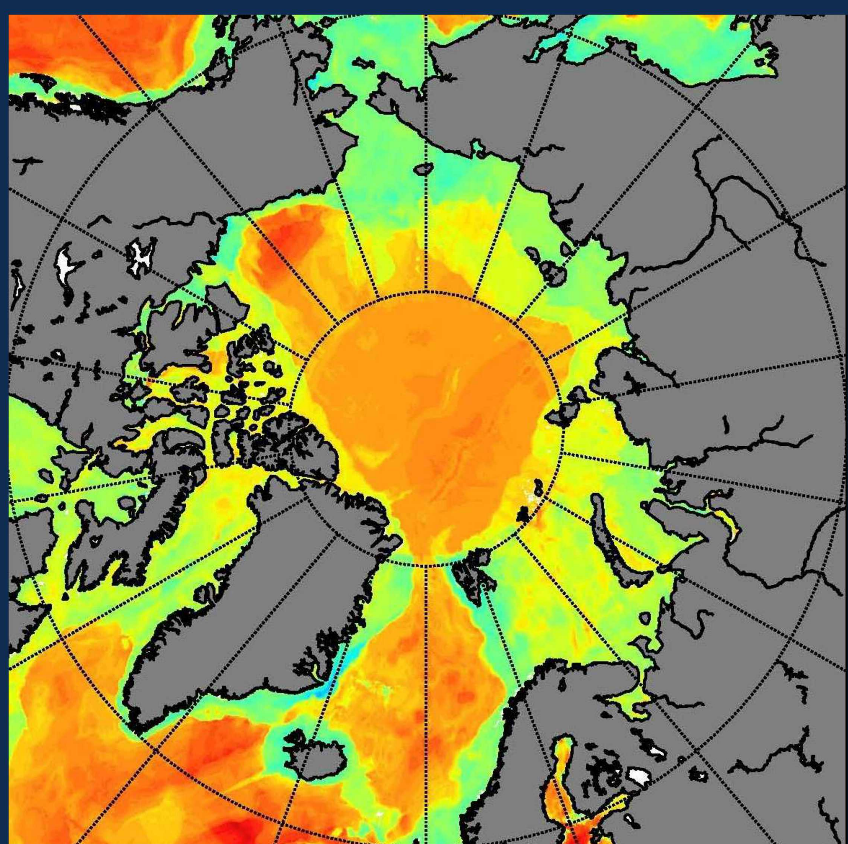
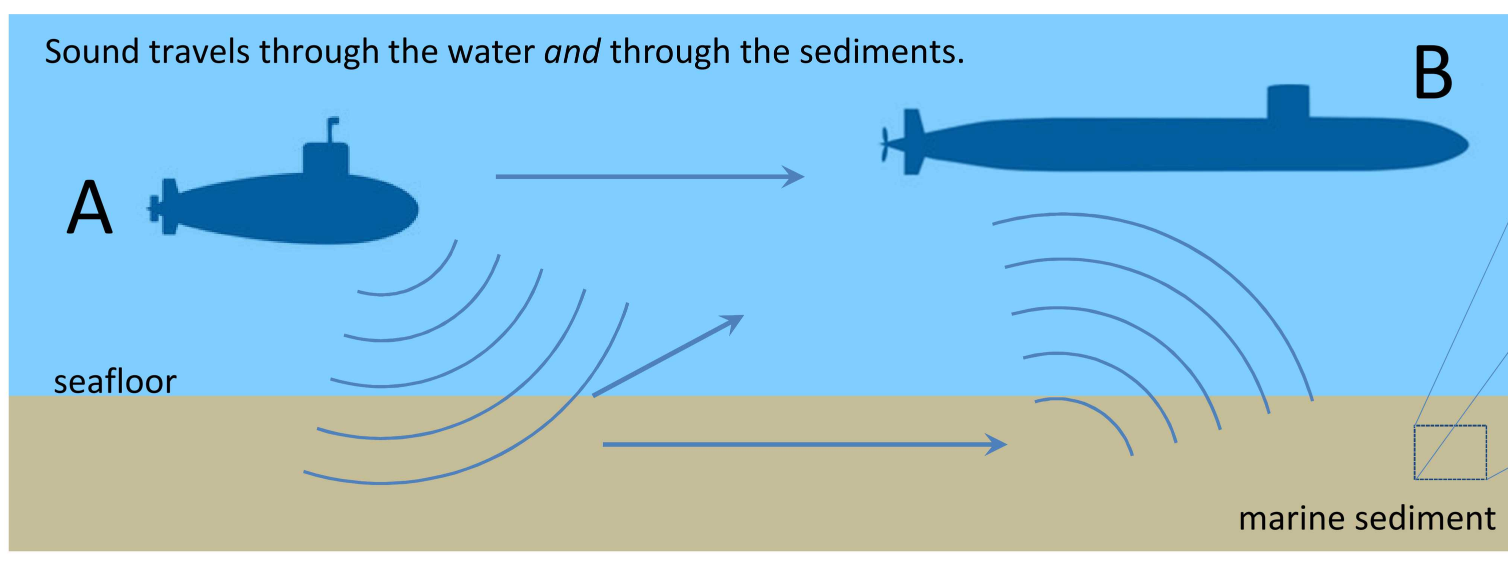


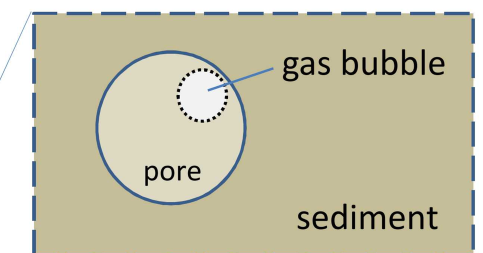
Arctic seafloor porosity predicted with geospatial machine learning by the U.S. Naval Research Lab. The spatial resolution is 5 x 5 arc minutes.

The harsh conditions in the Arctic make research and data acquisition difficult, if not impossible. We are stuck with data sparsity in the Arctic.

The U.S. Navy surfaces a submarine through the sea ice in the Beaufort Sea as part of the ICEX exercise that occurs every other year.

- Noise generated by submarine A can be heard by submarine B via sound propagation through the water column and the sediments.





- Sound actually travels faster through the sediments than it does through the water column, but only if sediments do not contain free gas.
- Submarine B will hear submarine A via sound that travels through the sediments before it hears the sound through the water column (if sediments do not contain free gas).
- We have very little knowledge on seafloor properties, limiting our ability to predict SONAR behavior through the seafloor.

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

V: compressional wave velocity (speed of sound); B: bulk modulus; ρ: density

Gas has a huge effect on the speed of sound, and it doesn't take a lot to make a difference.

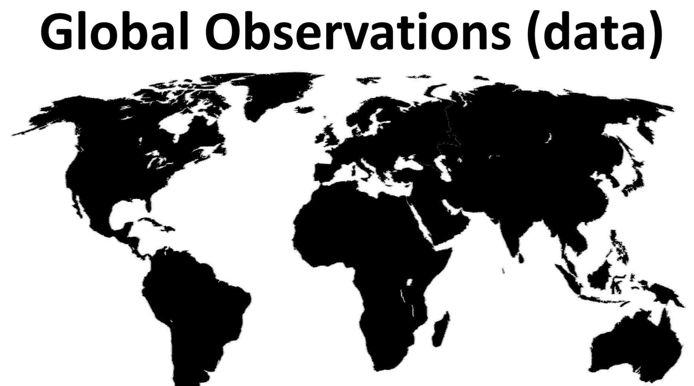
Some example values:

B_{air} = 0.000142 GPa
B_{water} = 2.2 Gpa
$B_{sediment}$ = 40 GPa

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

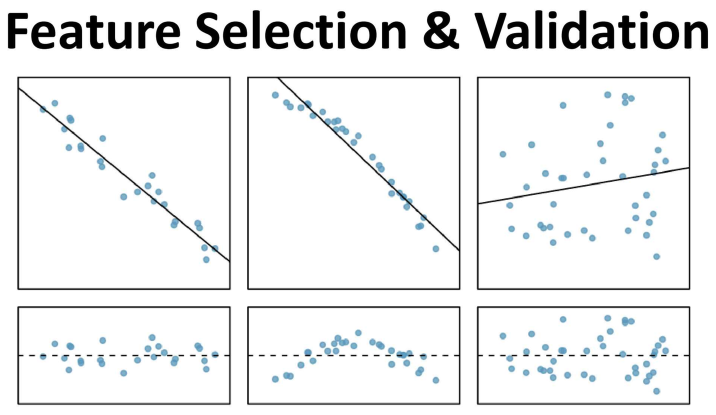
Geospatial machine learning (GML) can be used to build a system that predicts or forecasts seafloor properties like we forecast the weather. GML can produce maps of continuous seafloor properties with estimates of uncertainty, while also integrating physically consistent models. It is superior to traditional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

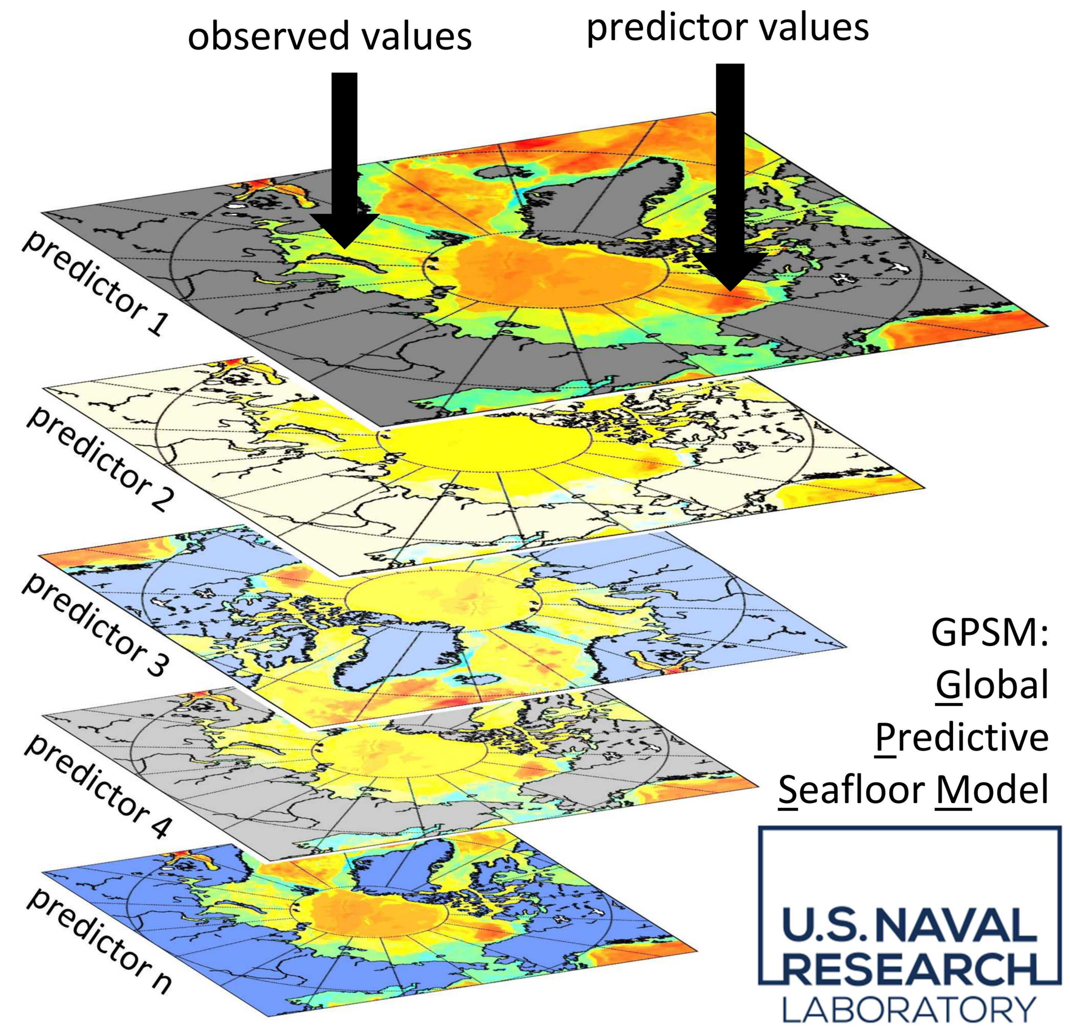
Feature Selection & Validation



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

Geospatial Machine Learning Algorithm

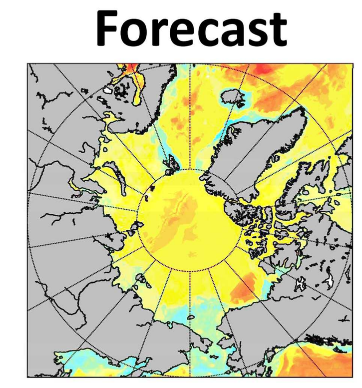
Find Correlations



GPSM: Global Predictive Seafloor Model

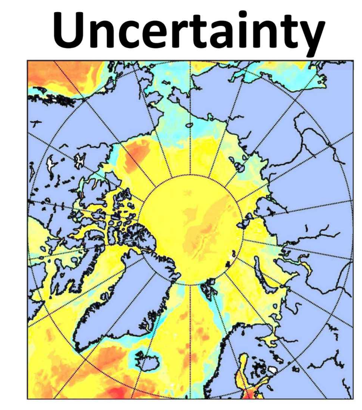
U.S. NAVAL RESEARCH LABORATORY

Forecast



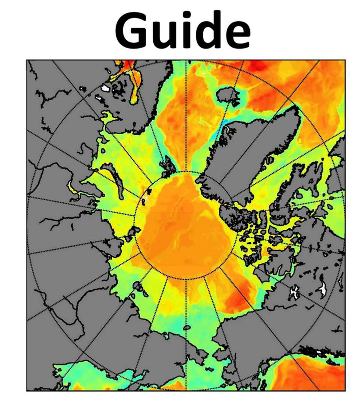
Based on sparse known data, and hundreds of dense calculated predictors, GML produces continuous maps of desired seafloor quantities, such as porosity, sediment type, total organic carbon content, etc.

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.

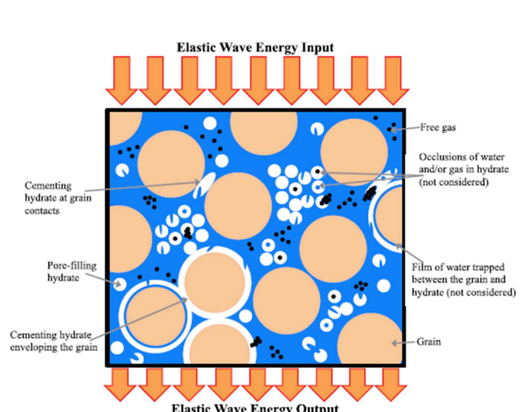
Guide



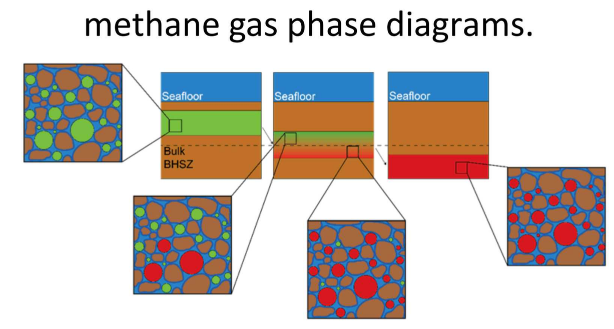
Uncertainty results can be used to guide future data acquisition campaigns. Increasing observations where prediction error (uncertainty) is high will benefit predictive skill globally.

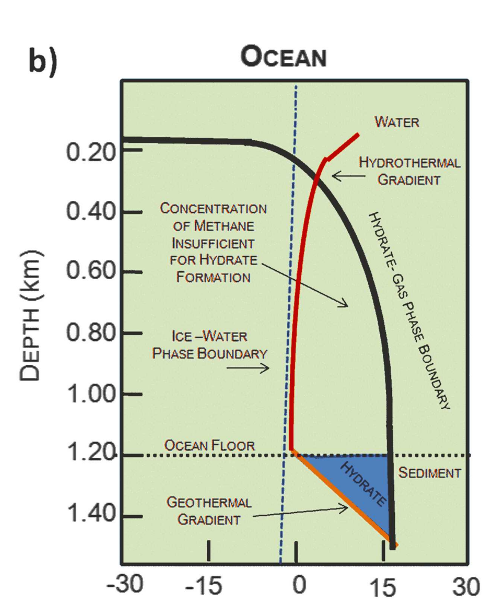
Integrate physical models to produce predictions of seafloor geo-acoustic and geo-mechanical properties.

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



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





GML forecasts can constrain shallow tomography models, improving seismic wave models.

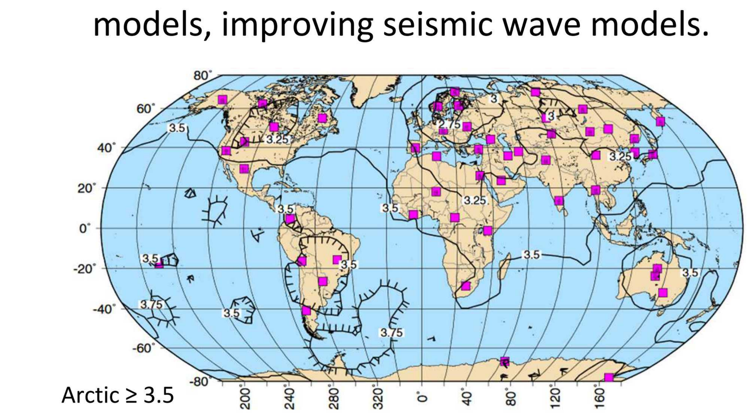


Figure 2-2 Contours of seismic magnitude for which signals would be expected (with signal-to-noise amplitude ratio greater than 3.2, i.e. 10 dB) at three or more stations of the IMS primary seismic network (solid squares), from 90 percent of the events at the contoured magnitude or larger. The contour interval is 0.25 magnitude units. The detection threshold for Europe, Asia, North America, and North Africa is in the magnitude range 3.5 to 3 or lower. (Figure provided by the Center for Monitoring Research)

Paul Richards, Columbia University,
TECHNICAL ISSUES RELATED TO THE COMPREHENSIVE NUCLEAR TEST BAN TREATY

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NNSA National Nuclear Security Administration