Ocean & Geohazard Analysis

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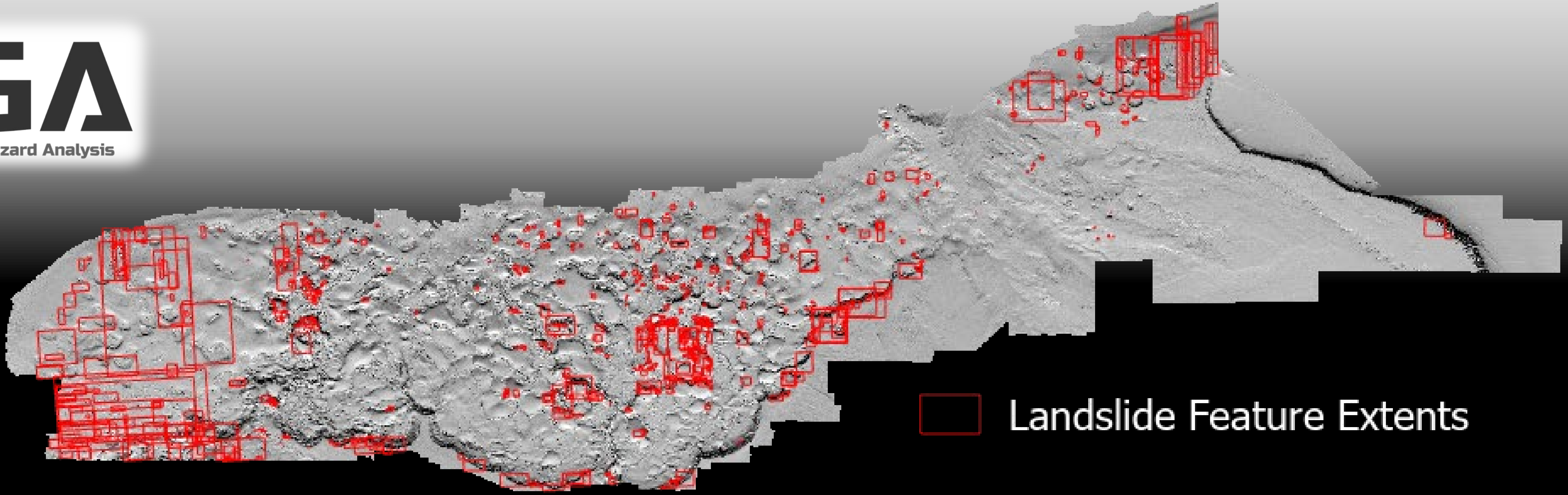

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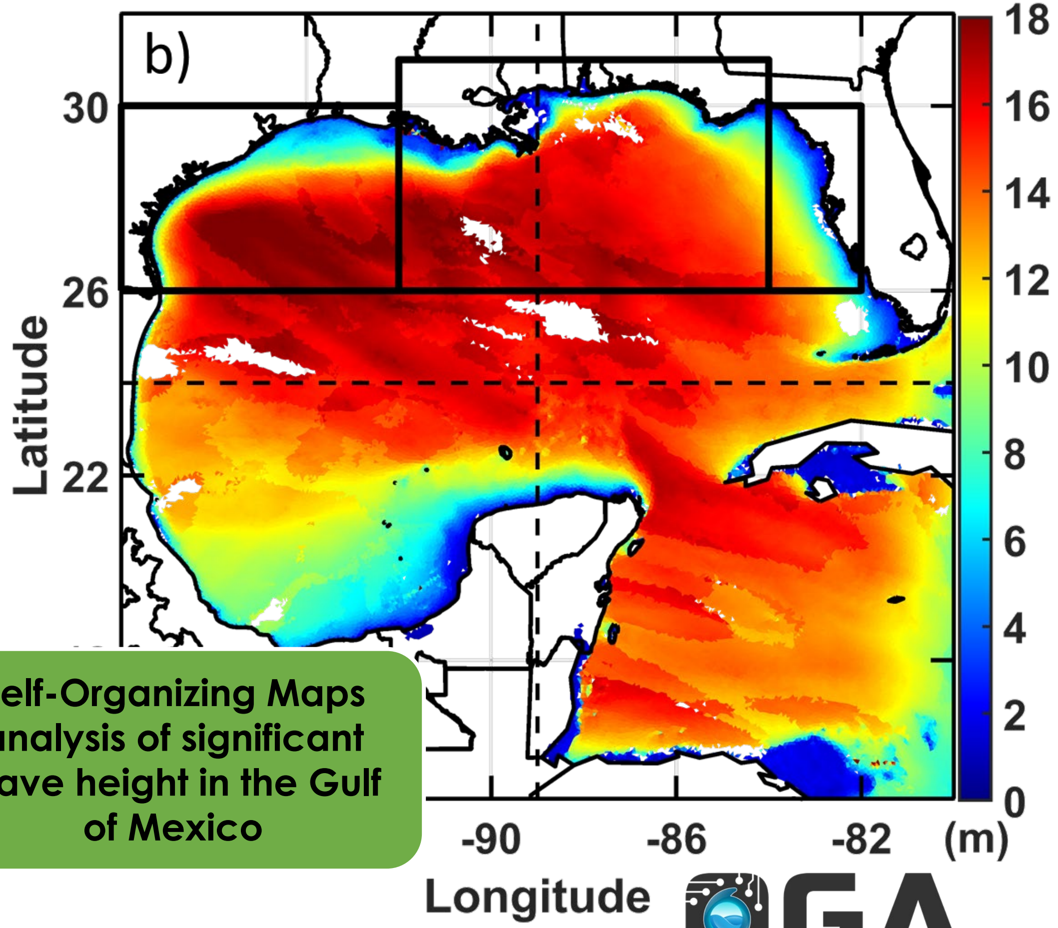
Ocean and Geohazard Analysis

Advanced Analytics to Predict Hazards to Offshore Infrastructure



Self-Organizing Maps analysis of significant wave height in the Gulf of Mexico

Ocean & Geohazard Analysis

Why is this work important?

Limiting environmental and community impact and improving safety of offshore operations and legacy infrastructure depends on forecasting and avoiding hazards.

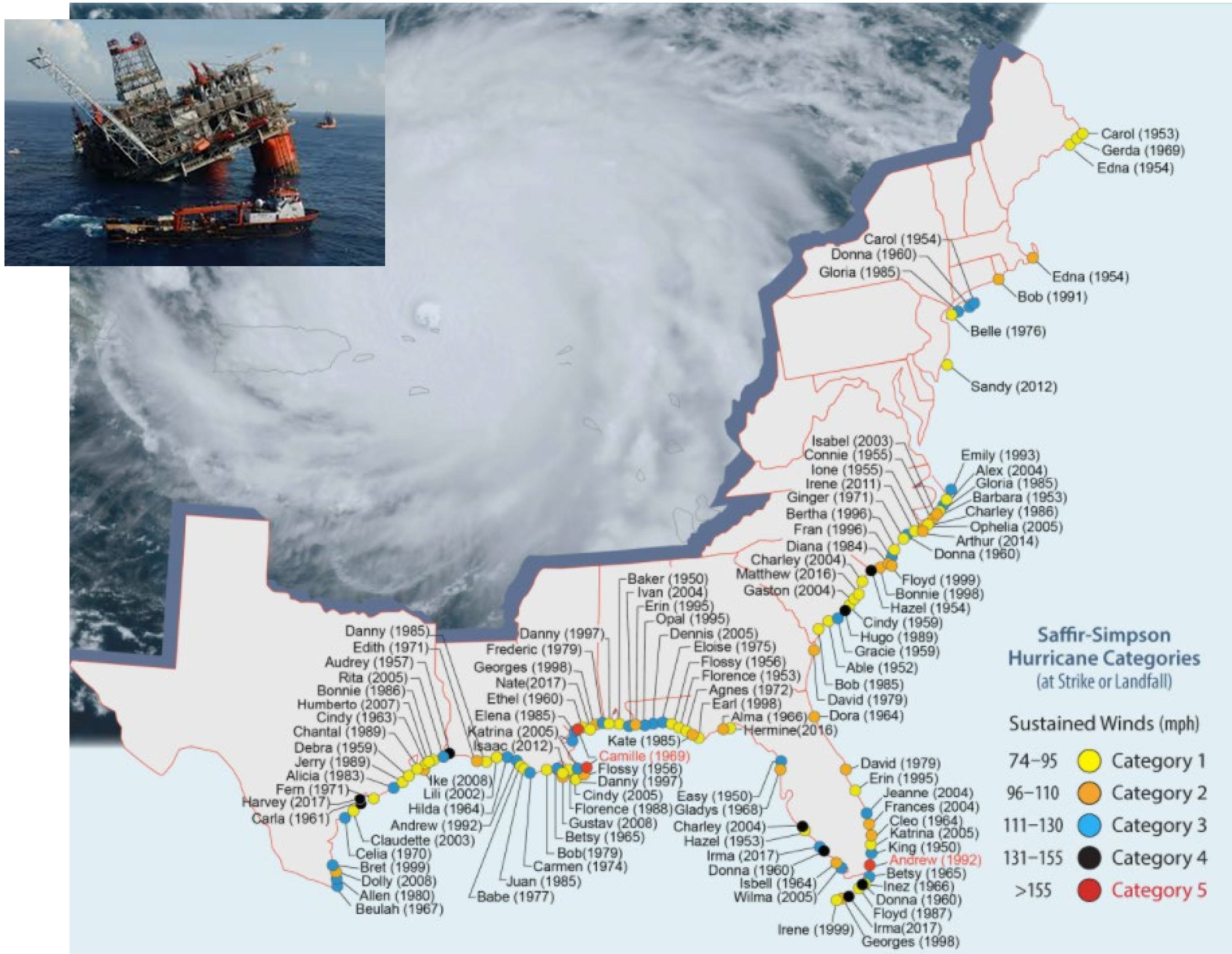
Issue/R&D Need

- Technology that integrates big data and science-based analytics for offshore hazards does not exist.
- Advanced analytics can offer near real-time assessment of risks, integrate different hazard types, and also forecast vulnerabilities.
- Packaging analytics in a flexible smart tool improves accessibility and forecasting at multiple scales.

Offshore Task 6: Infrastructure and Metocean Background

Motivation

- Demand on offshore Exclusive Economic Zone (EEZ) in the U.S. and around the world is increasing, with offshore infrastructure expected to increase 50–70% by 2028.
- Between 2004-2008, 181 structures and 1,673 wells in the Gulf of Mexico were destroyed by five hurricanes.
- Climate change is projected to intensify extreme events and increase their frequency.



Offshore Task 6: Infrastructure and Metocean Approach

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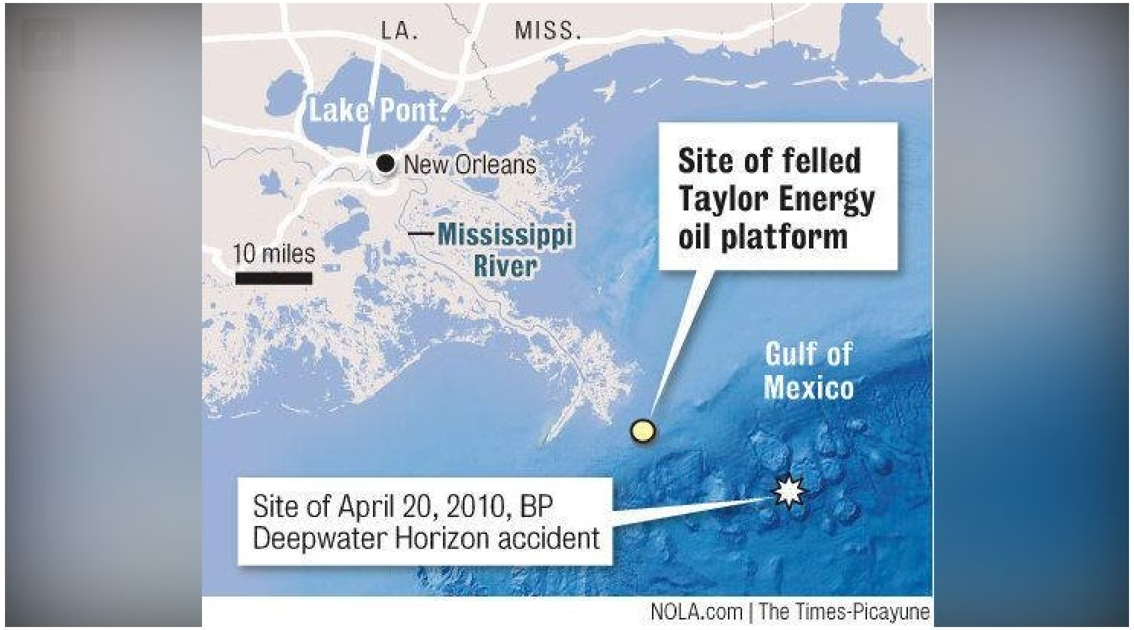
Approach: Assess and predict offshore hazards

- Hazards related to the metocean and seafloor environments include seabed instability, extreme wind/wave/current events, earthquakes, hazardous material spills
- Hazards are often interrelated. Example: Hurricanes are offshore hazards and drivers of other hazards, such as submarine landslides.
- Offshore structures impacted may include:
  - Petroleum and carbon storage platforms (both legacy and active)
  - wind energy
  - pipelines
  - bridges
  - tunnels
  - undersea internet cables

Taylor Energy oil platform, destroyed in 2004 during Hurricane Ivan, is still leaking in Gulf

Mark Schleifstein, NOLA.com | The Times-Picayune **JUL 1, 2013 - 5:05 PM**

5 min to read



Offshore Unconventional FWP

Task 6 - Infrastructure and Metocean Technology

Research Problem:

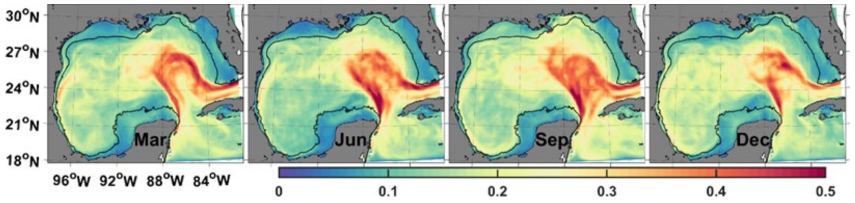
- Changes in the ocean environment (i.e., climate change, mudslides or burial from subsea currents, strong weather events or natural fluctuations) have been linked to billions of dollars of impacts.
- These events can have a significant effect on the success and longevity of offshore infrastructure, as well as affect safety and cost during exploration, production, and storage activities.

Research Approach:

- Determine current state of knowledge regarding hazardous metocean and bathymetric conditions, and data availability regarding these conditions and historic events.
- **EY19-EY20**: Evaluated if AI/ML models can be developed to better identify current hazardous metocean and bathymetric conditions. Developed, trained, and tested AI/ML models to identify conditions and forecast changes and vulnerabilities to offshore infrastructure.
- **EY21**: Refine Smart Tool to host AI/ML models and develop user interface. Develop forecasting and integrate selected hazard types into tool. Release desktop version at end of EY.
- **EY22+**: Refine analytical logic and functionalities through user testing. Build metocean and seabed hazard database for release on EDX. Report research in technical report or publication.

Benefit:

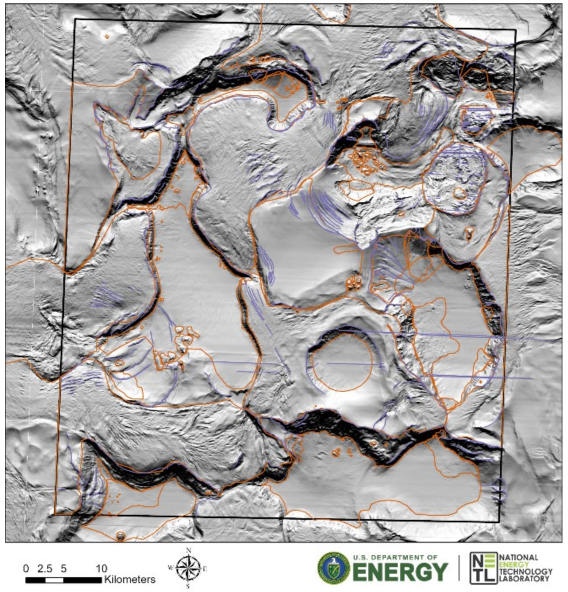
- Improved characterization of seabed-related hazards in the offshore can help prevent catastrophic incidents that impact the environment, coastal communities, and their economies.



Example of data collected:
Above - Avg. Bottom Current Velocity (12 yr. avg.)
Below – high-resolution bathymetric data and labeled hazards (in orange and purple)

Terrebonne Basin - Gulf of Mexico

High resolution bathymetry layer retrieved from BOEM (2017). Polyline (purple) and polygon (orange) layers resemble important subsurface features delineated by the NETL team.

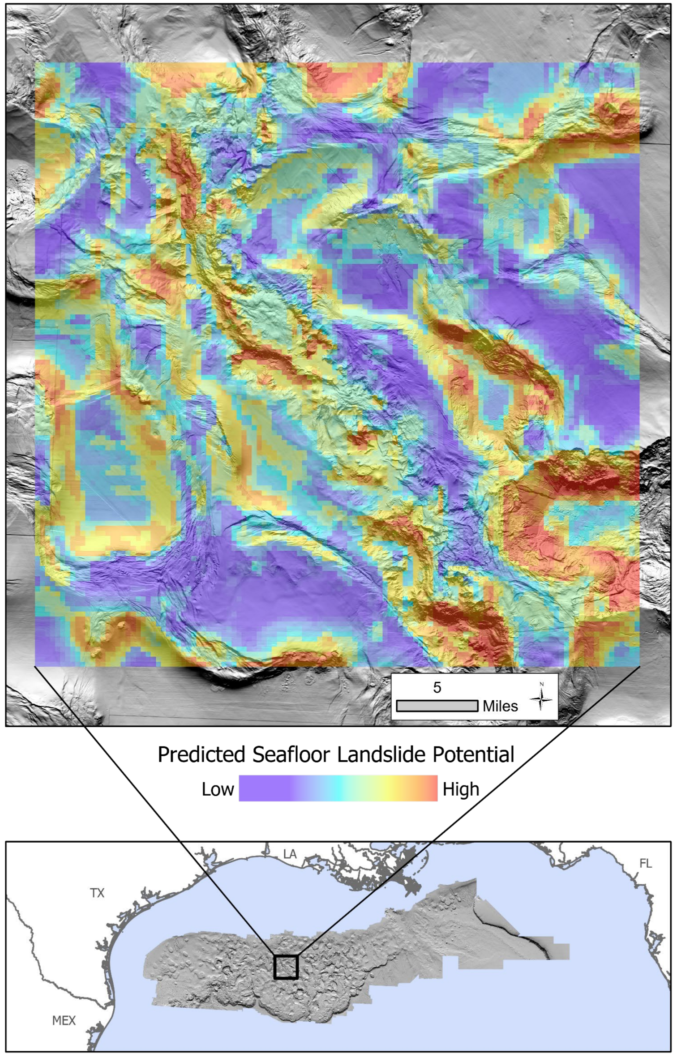


Ocean & Geohazard Analysis

The Ocean & Geohazard Analysis Smart Tool

Approach for Infrastructure and Metocean Technology

- Identify datasets for diverse hazard analyses
- Develop analytical framework for an **Ocean & Geohazard Analysis (OGA) Smart Tool**
- Train and validate AI/ML models
- MetOcean statistical and probabilistic analyses
- Release tool, data and models through the **online platform** hosted by **Energy Data eXchange (EDX)**



Ongoing work:

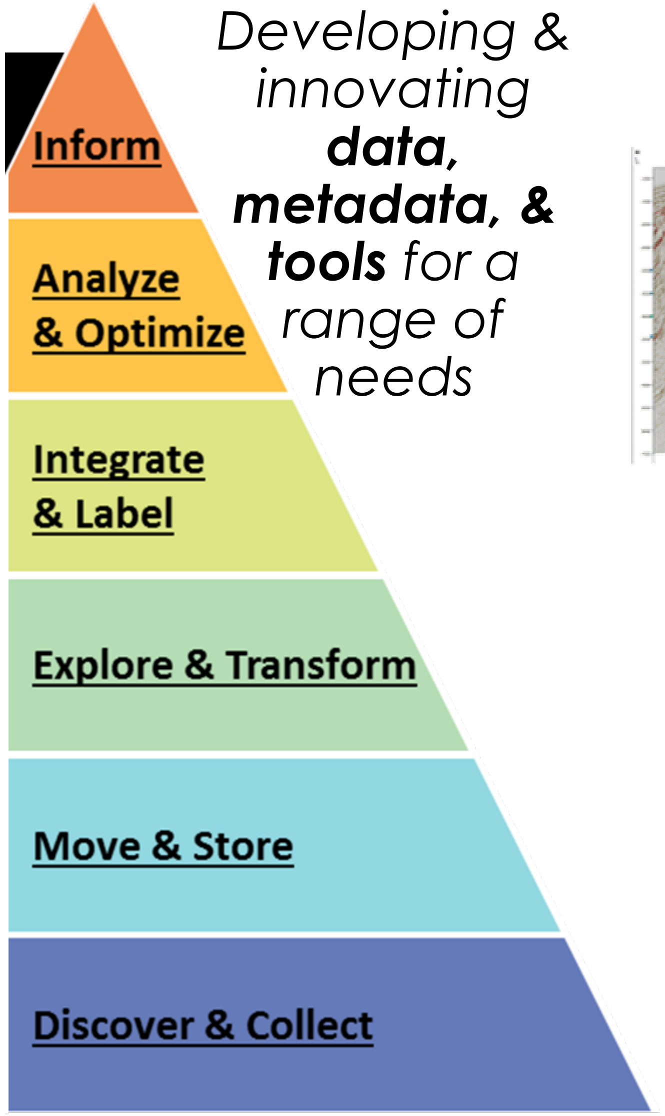
Collect large amounts of data, integrate from multiple sources to support analytics

- Digitizing old & unstructured data sets
- Aggregating all open-source data available nationally and internationally

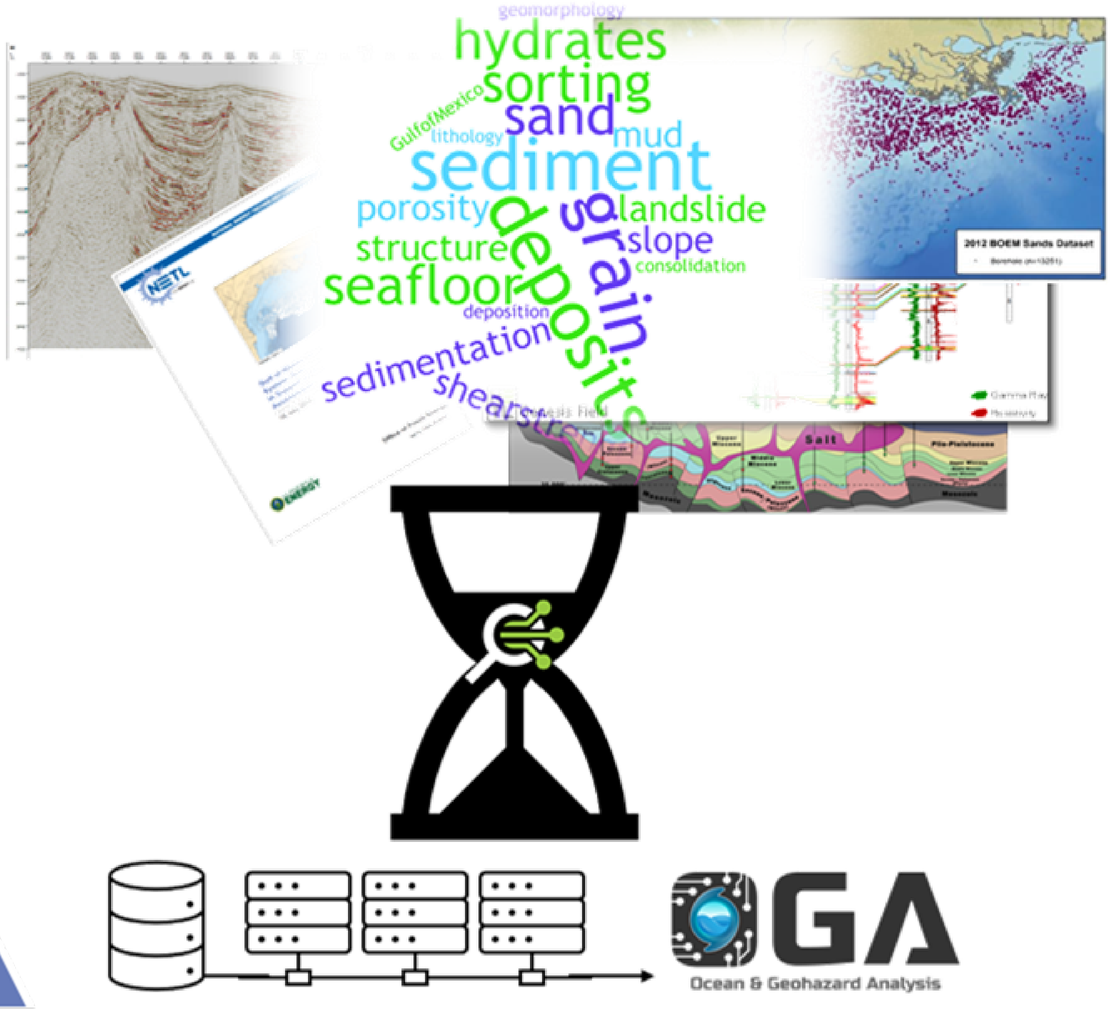
Novel analyses of these datasets using:

- Machine Learning
- Nonlinear Dynamics
- Prediction Statistical Intervals
- Monte Carlo simulations
- Dimensionality reduction methods
- Liang causality

NETL's Geo-Data Science & Discovery



*Developing & innovating **data, metadata, & tools** for a range of needs*

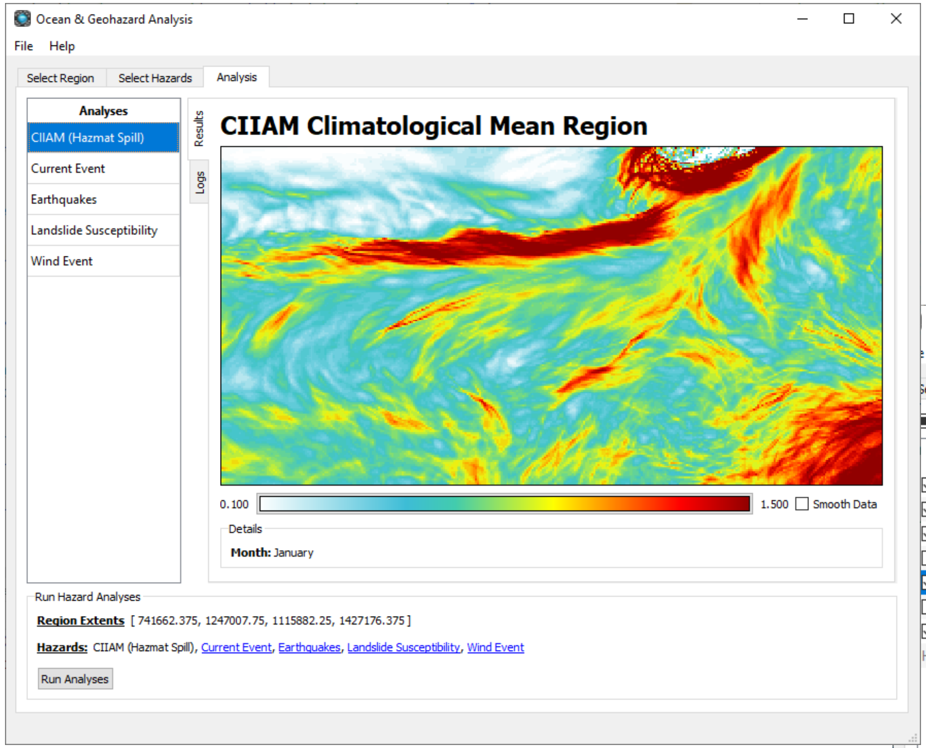


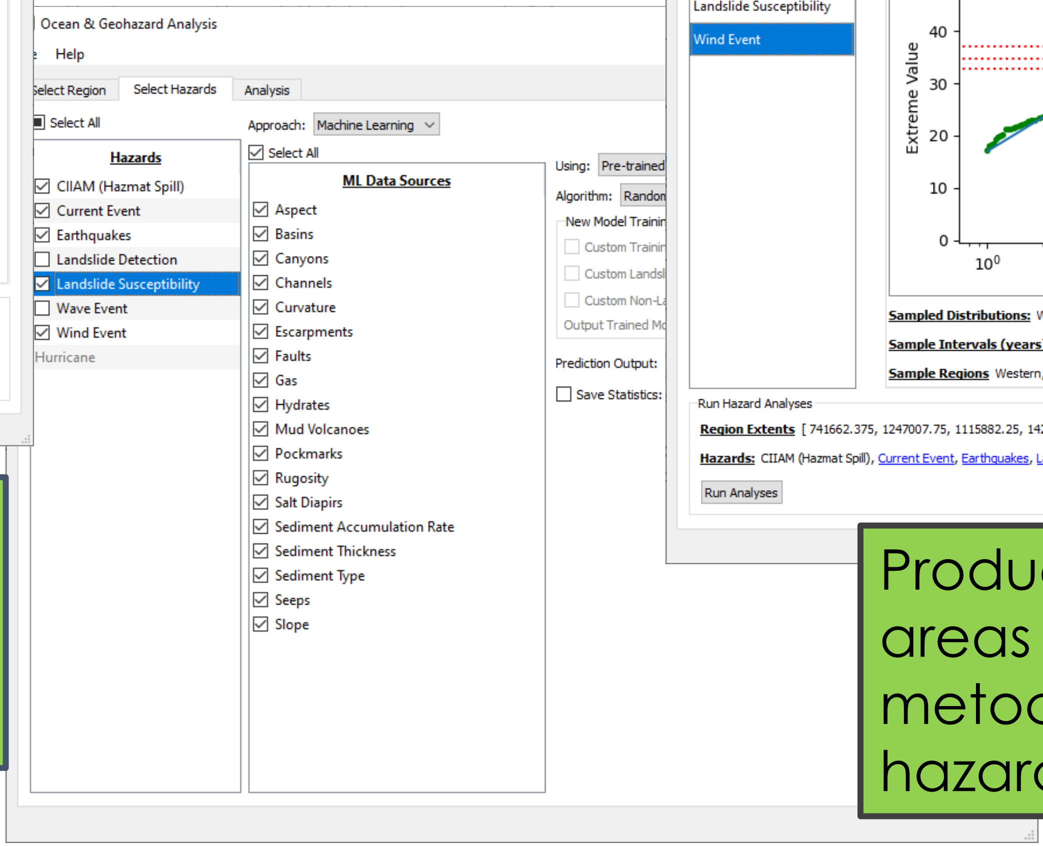
EDX Energy Data eXchange

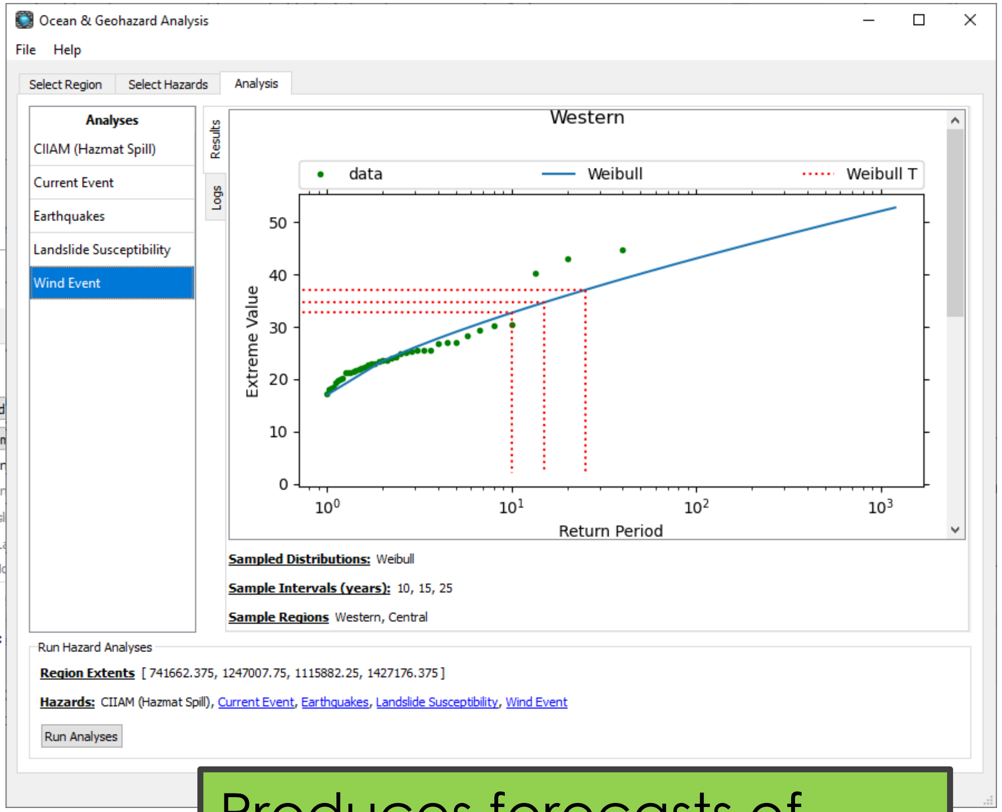
NETL SmartSearch

- SmartSearch automates data discovery through user preferences, web searching, and analyzing data relevance
- NETL's SmartSearch used to build a seafloor sediments database to support analyses

OGA Smart Tool Interface







Smart Tool allows users to interact with their data and select or integrate appropriate models

Produces forecasts of areas more susceptible to metocean and seafloor hazards

Ocean & Geohazard Analysis Smart Tool Workflow

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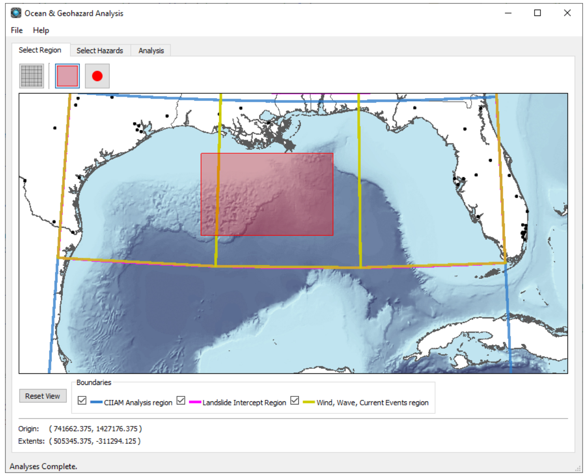
1. Choose offshore region of interest
2. Select hazards for risk assessment
   - ❑ All known hazards
   - ❑ Mudslide
   - ❑ Wind event
   - ❑ Wave event
   - ❑ Current event
   - ❑ Erosion
   - ❑ Earthquake
   - ❑ Hurricane
   - ❑ Hazmat spill
3. Select type of analysis
   - Default data, default analysis
   - Custom data, default analysis
   - Default data, custom analysis
   - Custom data, custom analysis
4. Advanced risk analytics and spatial visualization



OGA
Ocean & Geohazard Analysis

Landslide Detection

Locating Critical Parameters to Identify Mass Wasting Geohazards

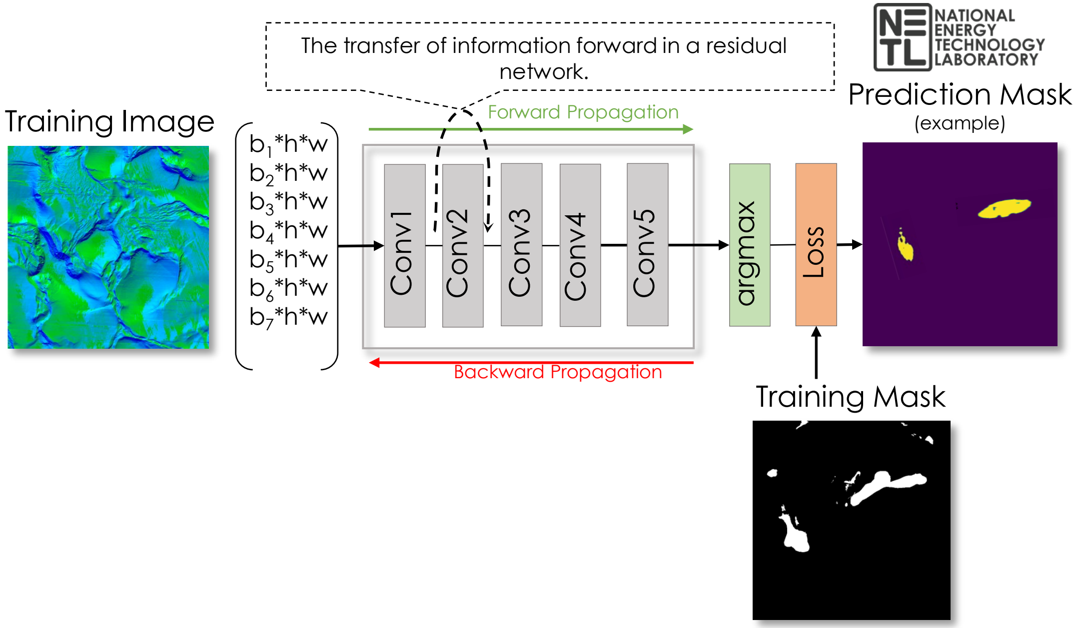
Objective: Using high-resolution seafloor images, develop a data driven neural network model to identify the locations of submarine landslides.

Model Design
- We use as a base the Fully Convolutional ResNet model, a prebuilt network available with the PyTorch framework.
- The model performs semantic segmentation to create an output mask highlighting landslides given an input image.

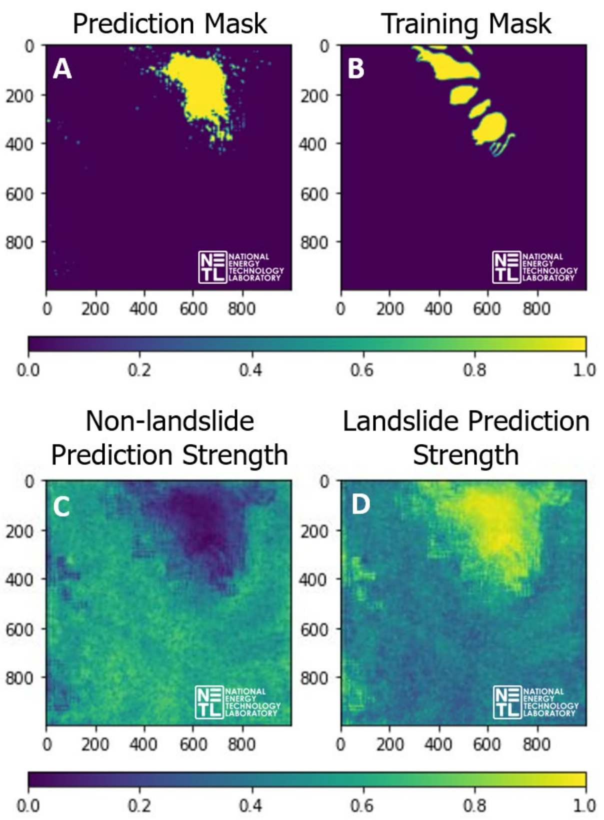
Challenges
- Inconsistent labeling, with different experts highlighting landslides at varied resolution the masks do not consistently encompass the same features. To overcome we have created a small scarp dataset with three reviewers to improve consistency and feature clarity.
- Small dataset, to improve the size we augment our dataset by flipping rotating and scaling existing images.
- Most models are designed for three band input images (Red/Green/Blue) while the images we use have seven bands. To solve this, we modify an existing model to accept the seven-band input image.

The model trains on Image and Mask pairs shown below.

It is given an input image and scored on how accurately it can produce a mask for the image.

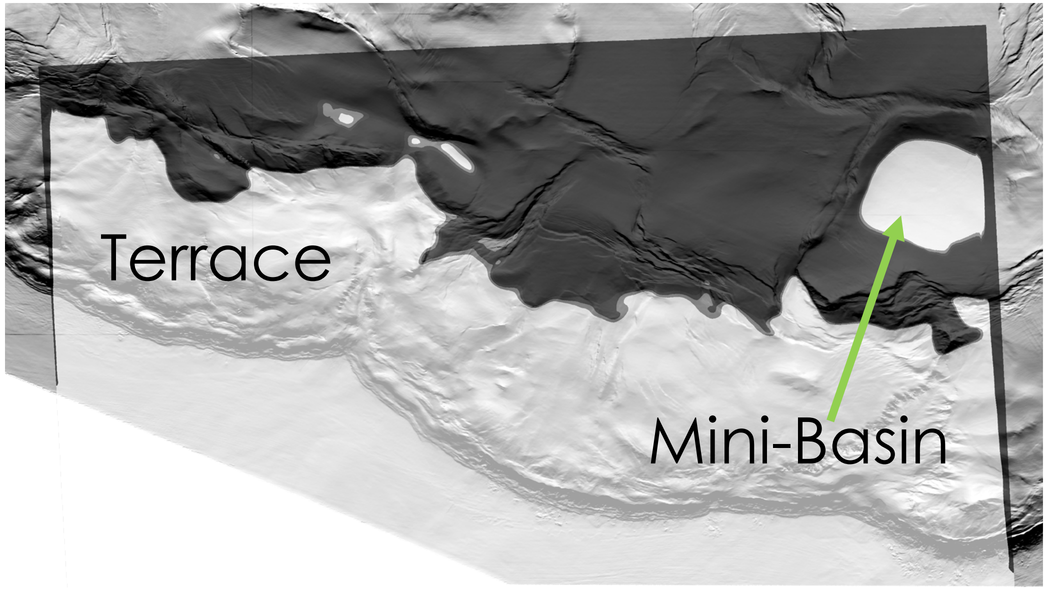


Landslide Detection Results



Most recent results (left) show the two output layers of the network (bottom C, D) which are combined to create the prediction mask (A) with the ground truth (B) for comparison.

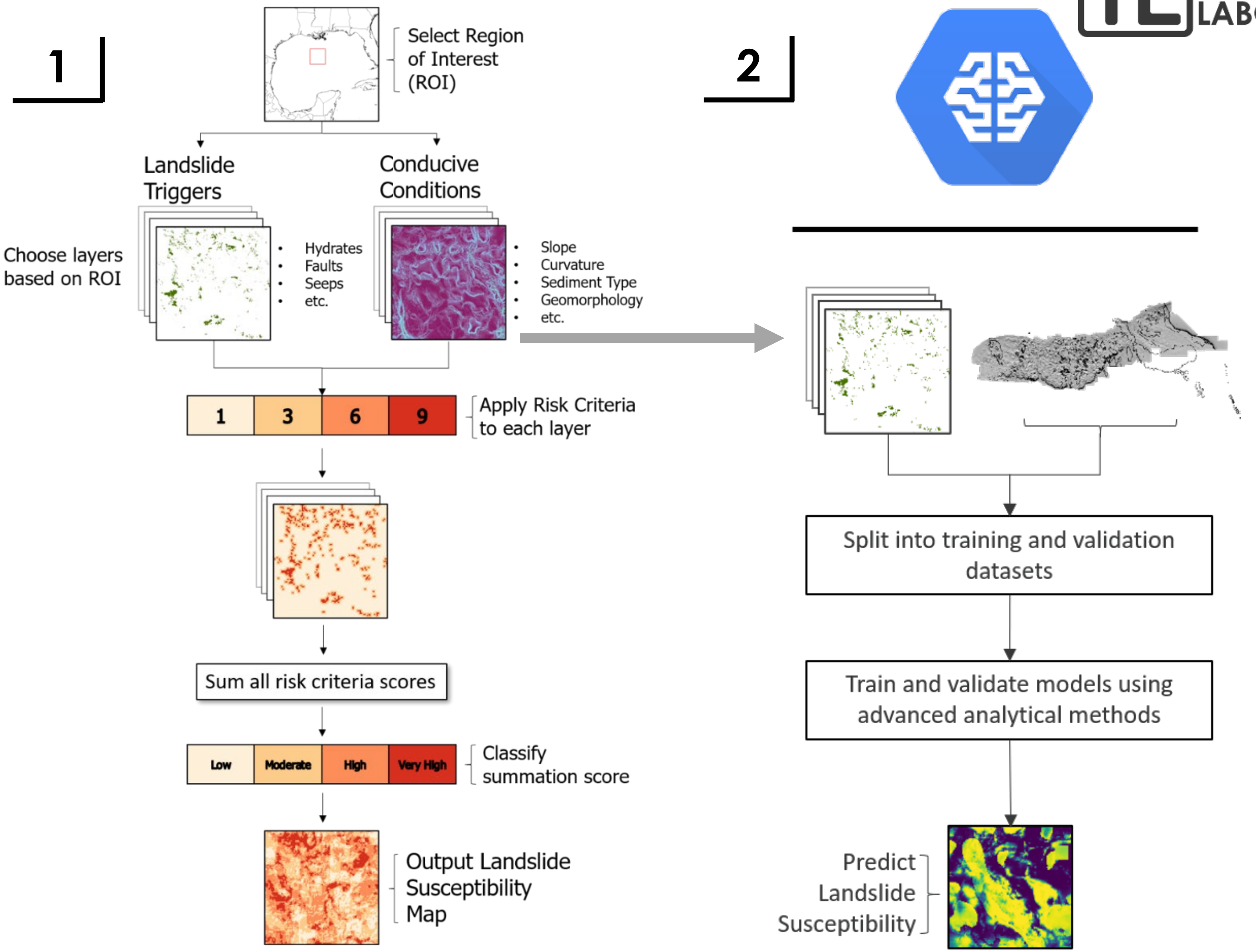
Early model output (right) showing low likelihood of landslide (black) and high likelihood of landslide (white). Results show model identifying terraces and basins as high likelihood of landslide areas.



Landslide Susceptibility

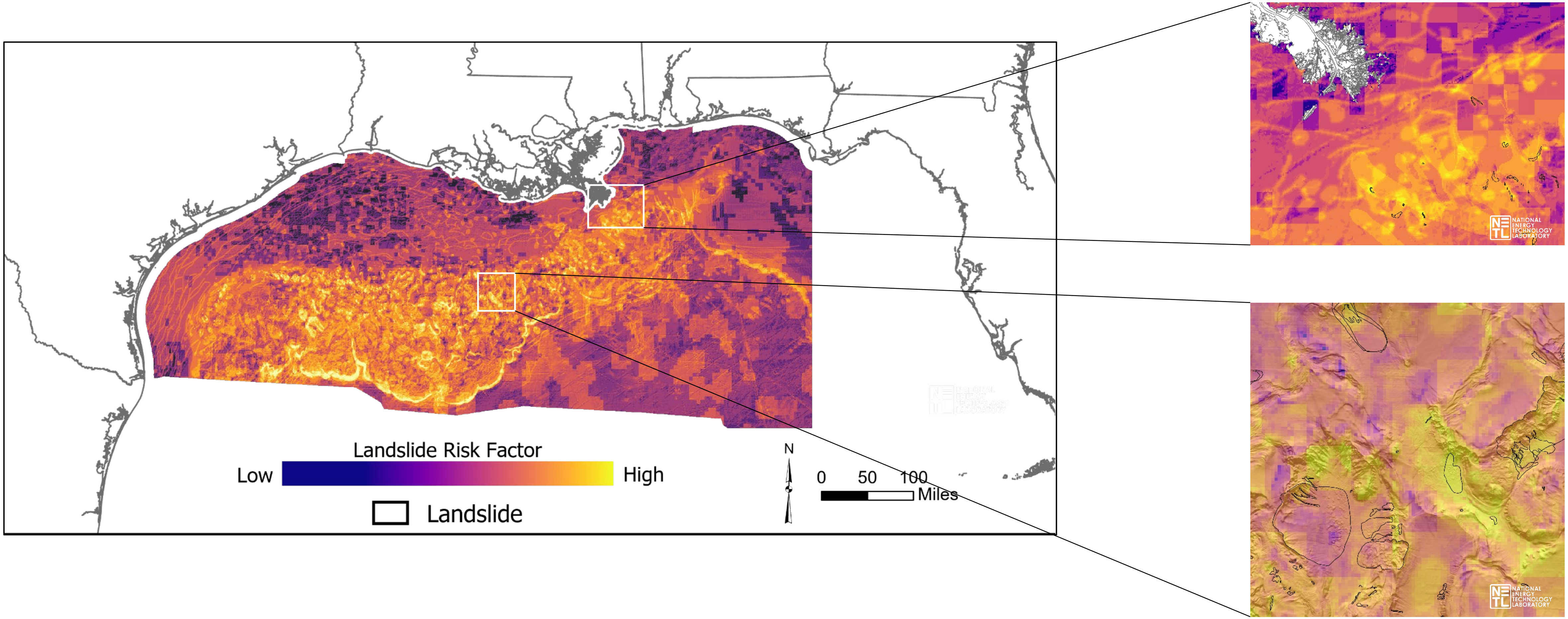
Two approaches for analyzing seafloor landslide potential in the GOM

1. ***Risk-based Approach***
2. ***Machine Learning (ML) Approach***



Landslide Susceptibility Results

Risk-Based Approach

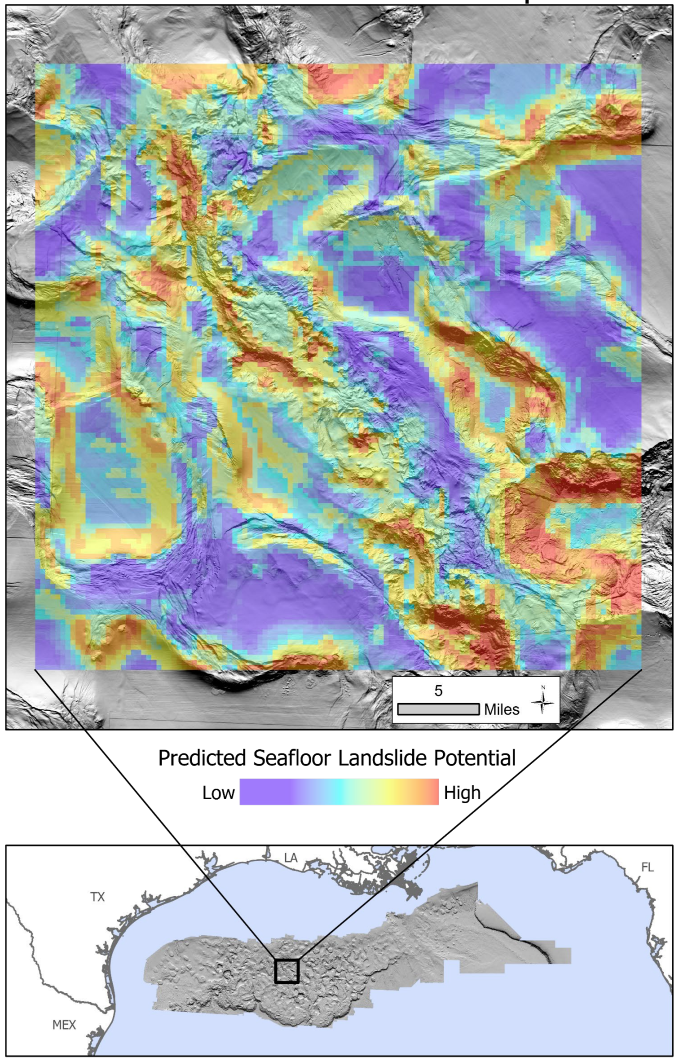


Landslide Susceptibility Results

ML Approach

- Utilizing the same input criteria along with **robust ML models** to predict landslide potential.
  - **Gradient Boosting Classifier (GBC)**
  - **Artificial Neural Network (ANN)**
- Improving accuracy using **tuning methods.**
  - **Hyperparameter random search**
  - **Dimensionality reduction (SVD)**
- Testing/validating models at various **spatial resolutions** (250 m, 500 m, 1,000 m, 2,000 m, 4,000 m).

GBC Model Output



Accuracy evaluated against validation dataset

GBC: 70.0%

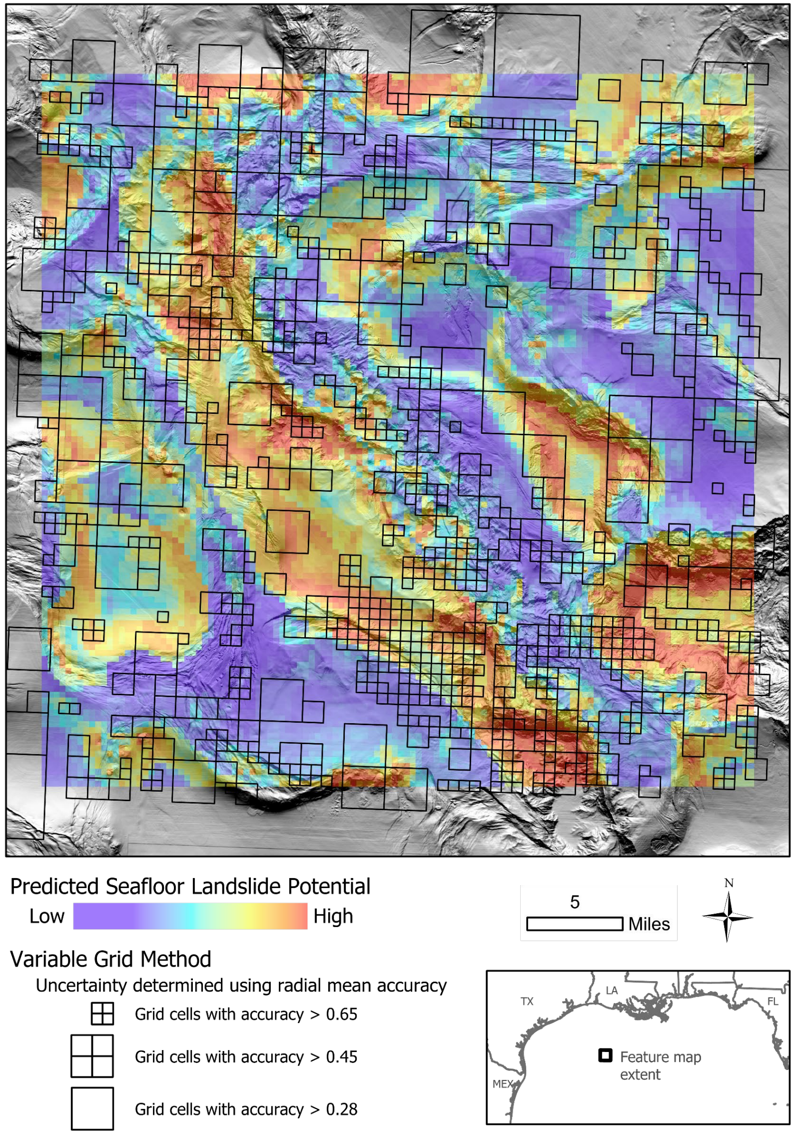
ANN: 65.3%

Landslide Susceptibility Results

ML Approach with Variable Grid Method

- The **Variable Grid Method** (VGM) (Bauer & Rose, 2015) utilized to visualize spatial uncertainty.
- **Smaller grid sizes** indicate a **higher certainty** of model predictions for that region while **larger grid sizes** indicate **lower certainty**.

VARIABLE GRID METHOD



Advanced Probability and Statistics

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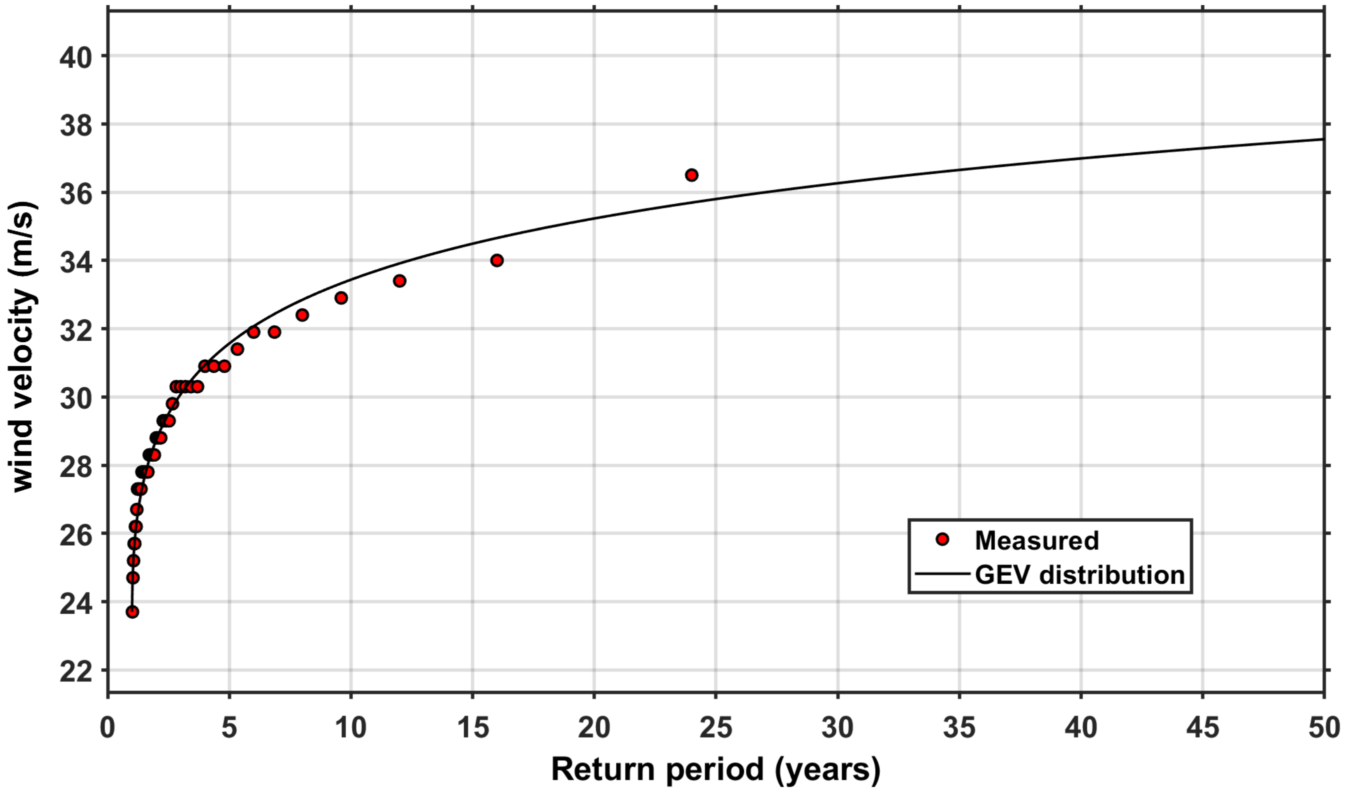
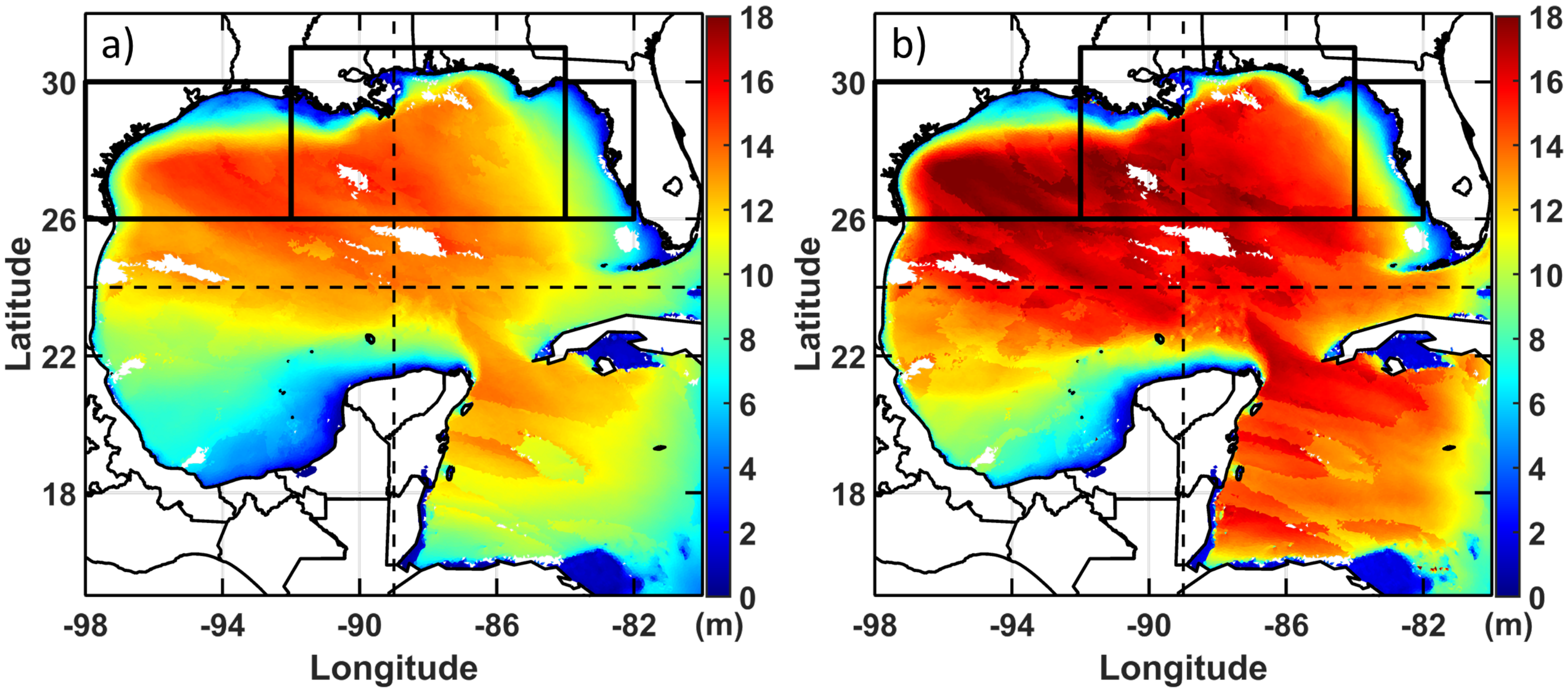
Generalized Extreme Value (GEV) distributions

$$G(z) = \exp\left\{-\left[1+\xi\left(\frac{z-\mu}{\sigma}\right)\right]^{-1/\xi}\right\}$$



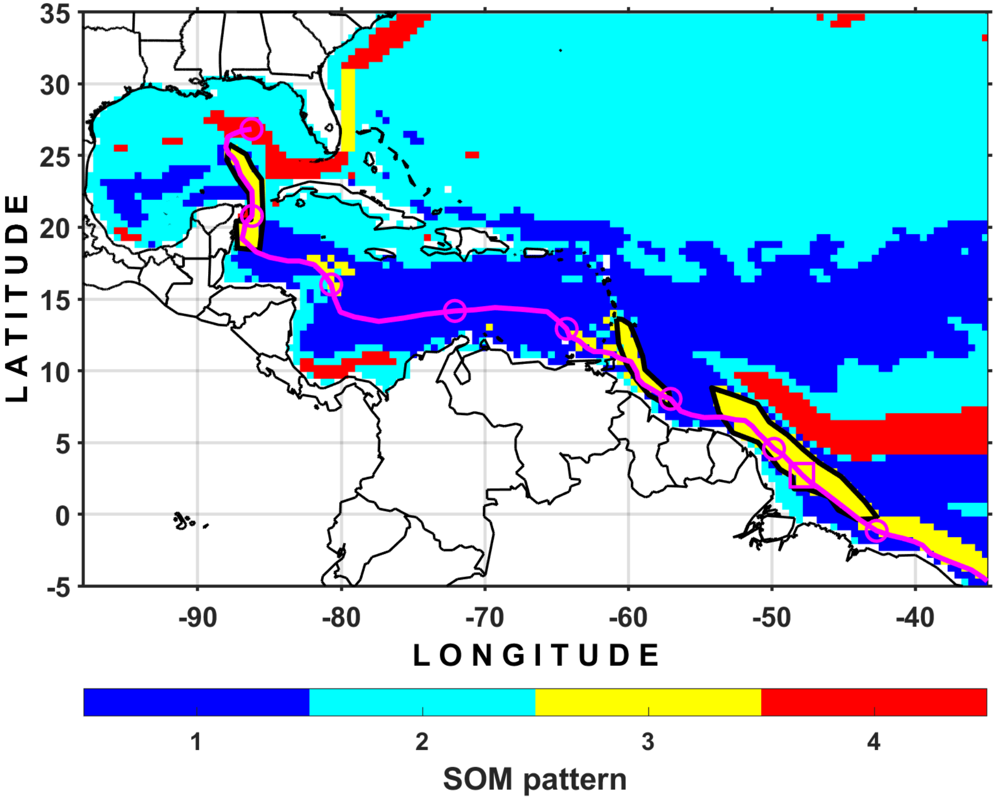
Wave Modeling Development

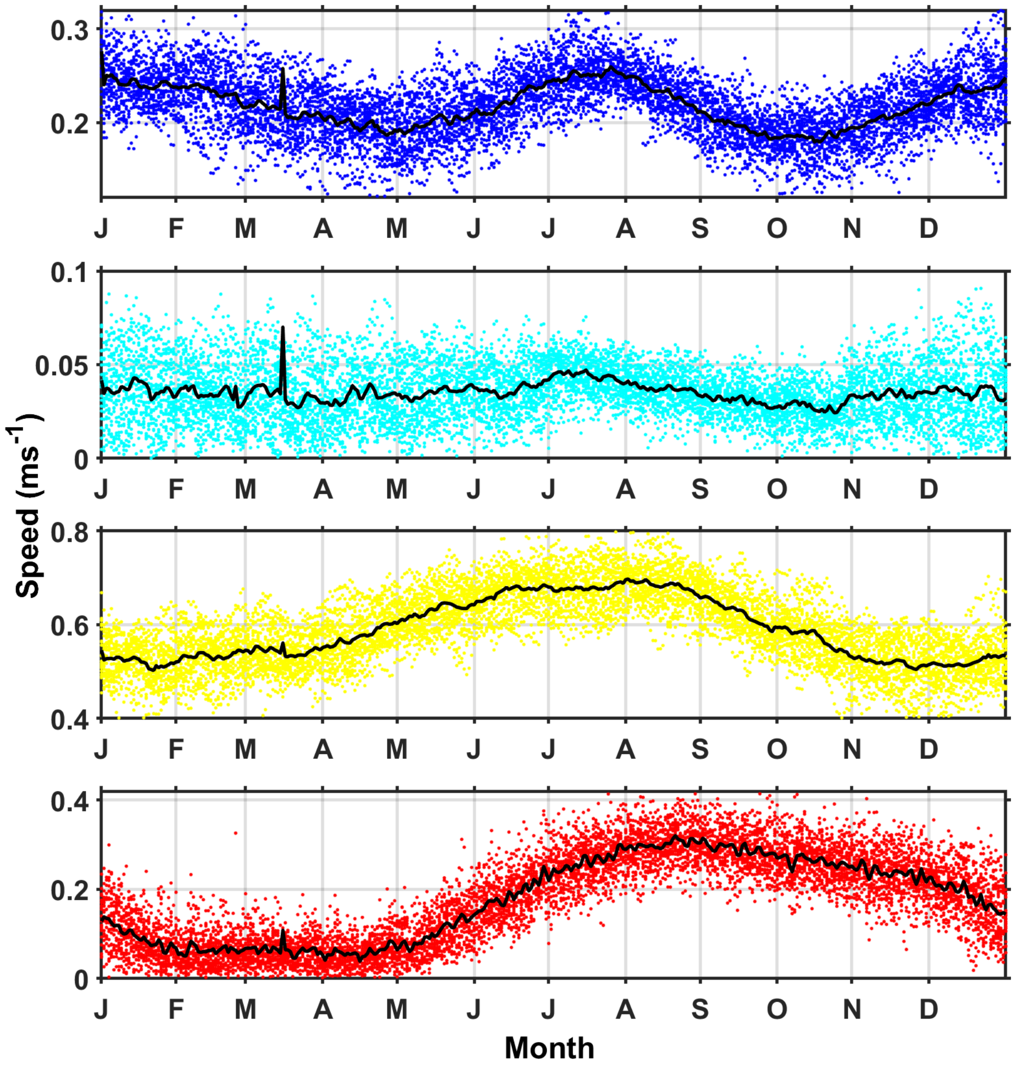
- Approach to wave modeling
- Creating synthetic physics-based tropical cyclone events in collaboration with MIT
- Critical for changing climate risk projections
- Waves are common catastrophic events to infrastructure, submarine landslide and mass movements
- Modeling and forecasting climate, ocean, and seafloor conditions within a flexible, AI/ML-informed Smart Tool can accelerate and integrate offshore hazard assessment.



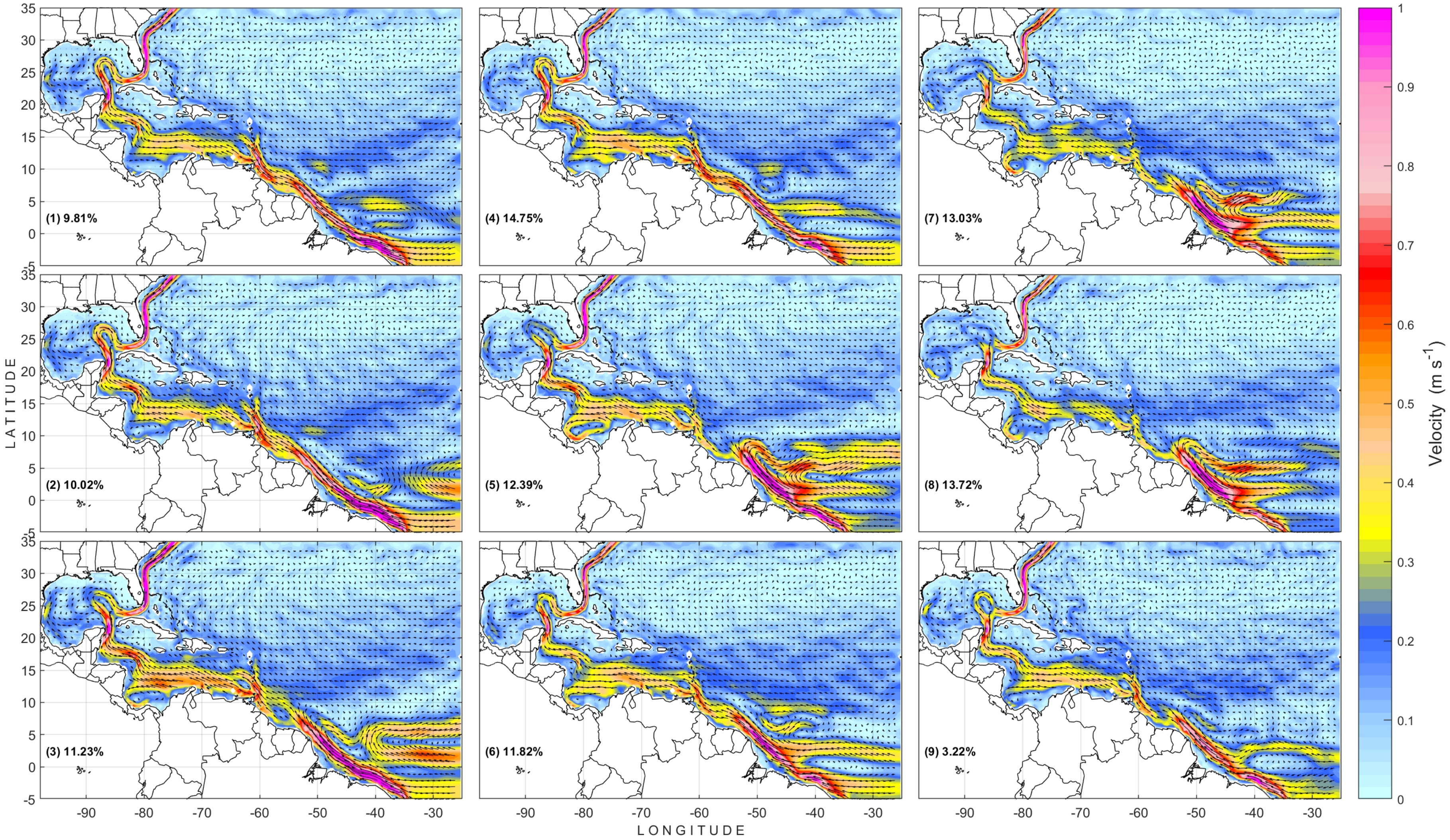
Significant wave height for the 100-years return period obtained from the GCM derived events ensemble for the (a) present and (b) future wave climates. Blank areas denote regions where less than 4 models show the same trend.

Self-organizing Maps – An Unsupervised Neural Network

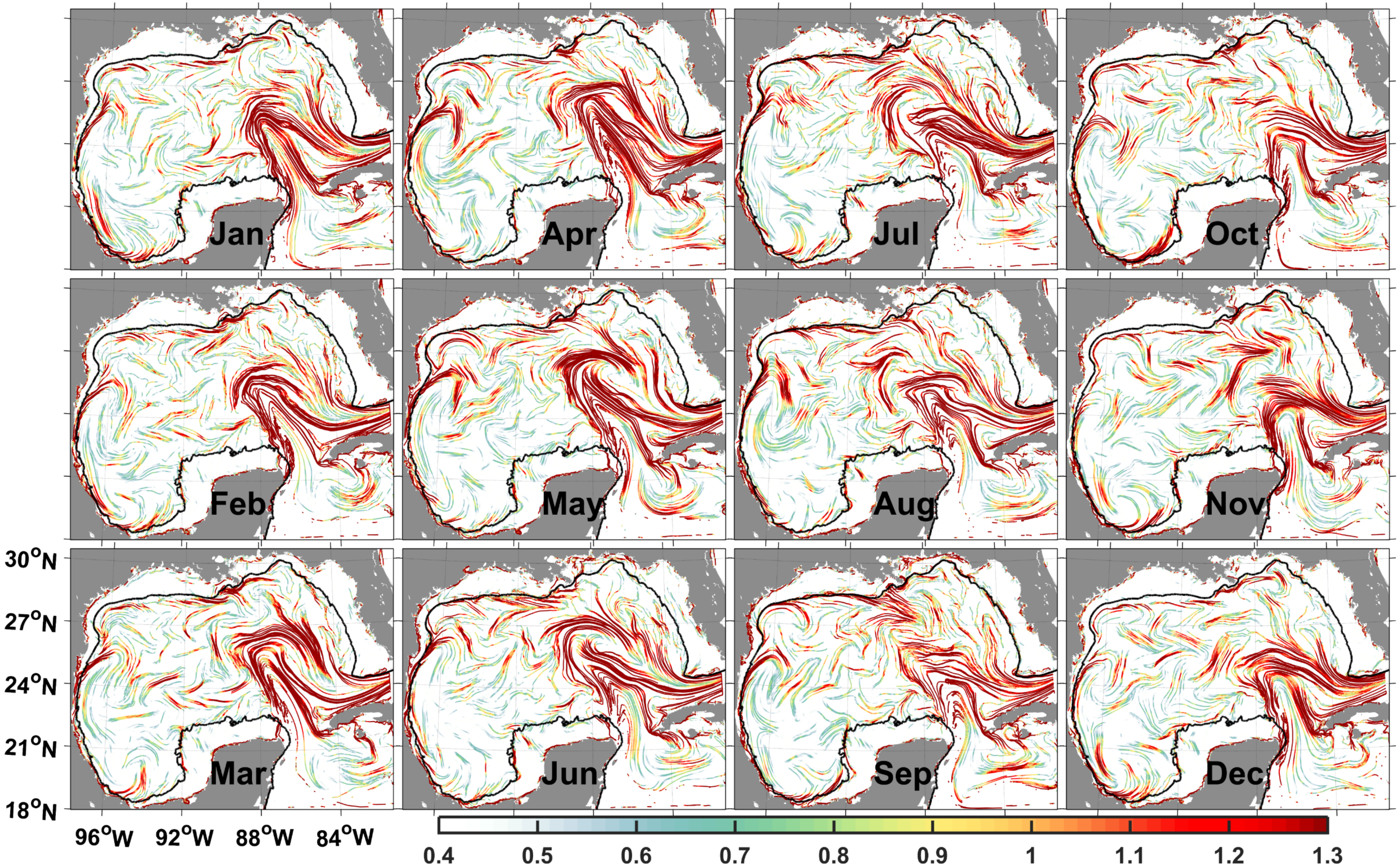




Self-organizing Maps – An Unsupervised Neural Network



CIIAM Model Updates



Pathways:
Red=attracting
White=isolated

Large shelves are isolated:
- WFS
- LaTex
- Yucatan

Collaboration and external interest

External CIAM Users			
Country	**Research Institute.**	**Study region**	**Status**
Spain	ICM Marine Science Institute Spain.	Mediterranean	Publication in progress
India	National Institute of Oceanography India	Gulf of Bengal	Publication in progress
Mexico	Engineering & Coastal Processes UNAM Mexico	Caribbean & Loop Current	Publication in progress
Brazil	National Institute for Space Research Brazil	Tropical Atlantic	Published by a Nature journal
Mexico	CICESE Ensenada Center for Scientific Research and Higher Education, Mexico	Deep GoM	Maslo, A., et al. (2020). https://doi.org/10.1016/j.jmarsys.2019.103267
Mexico	CICESE Ensenada Center for Scientific Research and Higher Education, Mexico	NW GoM	Gough, M. K., et al . (2019). https://doi.org/10.1175/JPO-D-17-0207.1
United Kingdom	National Oceanography Centre Marine Systems Modelling Group	North Sea	Preliminary results obtained
Saudi Arabia	Red Sea Modeling and Prediction Group KAUST	Red Sea	Work in progress
France	IRD/OCEANS/LOPS/IUEM	TBD	Planned for later this year
USA	UNC at Chapel Hill	Atlantic wind	Preliminary results obtained

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MOU for Collaboration

BOEM Bureau of Ocean Energy Management

U.S. NAVAL RESEARCH LABORATORY

Potential external interest

Lloyd's Register

CSIRO

CICESE

Publications & Presentations

Publications

- Duran, R., T. Nordam, M. Serra and C. Barker (in press, 2021). Horizontal transport in oil-spill modeling. Book chapter in Marine Hydrocarbon Spill Assessments, Elsevier. https://arxiv.org/abs/2009.12954
- Nordam T., J. Skancke, R. Duran and C. Barker (in press, 2021). Vertical transport in oil spill modeling. Book chapter in Marine Hydrocarbon Spill Assessments, Elsevier. https://arxiv.org/abs/2010.11890
- Nordam, T. & R. Duran (2020). Numerical integrators for Lagrangian oceanography. Geoscientific Model Development. https://gmd.copernicus.org/preprints/gmd-2020-154/.
- Gouveia, M. B., R. Duran, J. A. Lorenzzetti, A. T. Assireu, R. Toste, L. P. de F. Assad and D. F. M. Gherardi (submitted, revision in progress, 2020). Persistent meanders and eddies lead to quasi-steady Lagrangian transport patterns in a weak western boundary current. https://arxiv.org/abs/2008.07620
- Zhang, R., P. Wingo, R. Duran, K. Rose, J. Bauer, R. Ghanem (2020). Environmental Economics and Uncertainty: Review and a Machine Learning Outlook. Oxford Encyclopedia of Environmental Economics. https://doi.org/10.1093/acrefore/9780199389414.013.572.
- Gough M. K., F. J. Beron-Vera, M. J. Olascoaga, J. Sheinbaum, J. Jouenno, R. Duran (2019). Persistent Lagrangian transport patterns in the northwestern Gulf of Mexico. J. Phys. Oceanogr., 49, 353–367, https://doi.org/10.1175/JPO-D-17-0207.1
- Duran, R., F. J. Beron-Vera, M. J. Olascoaga (2018). Extracting quasi-steady Lagrangian transport patterns from the ocean circulation: An application to the Gulf of Mexico. Scientific Reports, 8(1), 5218. https://www.nature.com/articles/s41598-018-23121-y
- Appendini C. M., P. Ruiz-Salcines and R. Duran (in preparation). Tropical cyclone waves under climate change in the Gulf of Mexico: Implications in structure design.
- Kurczyn, J. A., R. Duran, E. Beier, and A. J. Souza (review revisions in progress, 2021). On the advection of upwelled water on the western Yucatan Shelf. Frontiers in Marine Science.
- https://doi.org/10.22541/au.162126717.71153804/v1

Presentations

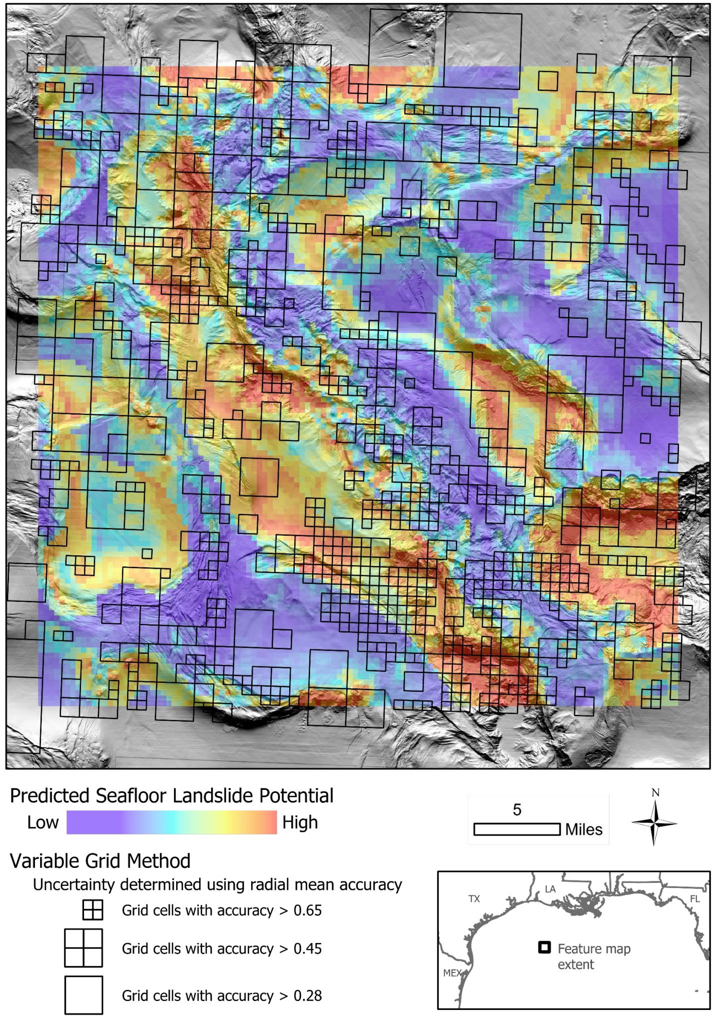
- Mark-Moser, M., Wingo, P., Duran, R., Dyer, A., Zaengle, D., Suhag, A., Hoover, B., Pantaleone, S., Shay, J., Bauer, J., Rose, K. **Submitted**. AI/ML integration for accelerated analysis and forecast of offshore hazards. AGU Fall Meeting 2021, Dec. 13-17, New Orleans, LA/Virtual. Session: EP027 - Proven AI/ML applications in the Earth Sciences
- Zaengle, D., Dyer, A., Duran, R., Mark-Moser, M., Rose, K., Bauer, J., Wingo, P. **Accepted**. Seafloor Landslide Detection in the Gulf of Mexico Using Computer Vision. IMAGE 2021
- Dyer, A., Duran, R., Mark-Moser, M., Rose, K., Bauer, J., Zaengle. D., Wingo, P. **2021**. Geohazard Analysis of Seafloor Landslide Potential for Infrastructure Protection. Esri User Conference. July 12-16, 2021.
- Duran, R., Dyer, A., Mark-Moser, M., Bauer, J., Rose, K., Zaengle. D., Wingo, P. **2020**. A Geospatial Analytical Framework to Identify Seafloor Geohazards in the Northern Gulf of Mexico. AGU Annual Meeting 2020, Session: NH010 - Geohazards in Marine and Lacustrine Environments
- Dyer, A., Zaengle, D., Mark-Moser, M., Duran, R., Bauer, J., Rose, K. **2020**. Deep Learning to Locate Seafloor Landslides in High Resolution Bathymetry. AGU Annual Fall Meeting (Virtual), 2020. Session: NH007 - Data Science and Machine Learning for Natural Hazard Sciences II Posters.
- Mark-Moser, M., Rose, K., Baker, V. D. **2020.** Developing a structured seafloor sediment database from disparate datasets using SmartSearch. AGU Annual Fall Meeting (Virtual), 2020. Session: IN042 – Utilizing unstructured data in earth science

Key Takeaways

- **Technology that integrates big data and science-based analytics for offshore hazards does not exist**

- **Advanced analytics can offer near-real time assessment of risks but also forecast vulnerabilities**

- **Smart Tool:**
  - **adapts to data availability/quality**
  - **adapts to different regions**
  - **incorporates new analytics and datasets**
  - **Flexible to integrate NETL tools and user tools for advanced predictive and spatial analysis**



Products available at https://edx.netl.doe.gov/offshore/

Values Delivered

Advancing the current state of knowledge, supporting offshore activities, forecasting risks to maintain environmental integrity that may evolve with a changing climate.

Improved characterization of metocean and seabed related hazards will help to prevent catastrophic incidents as human and engineered systems integrate with natural systems in the offshore environment.

Ocean & Geohazard Analysis

NETL RESOURCES

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Offshore R&D

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