Infrastructure and Metocean Technology: The Ocean and Geohazard Analysis Tool

MacKenzie Mark-Moser
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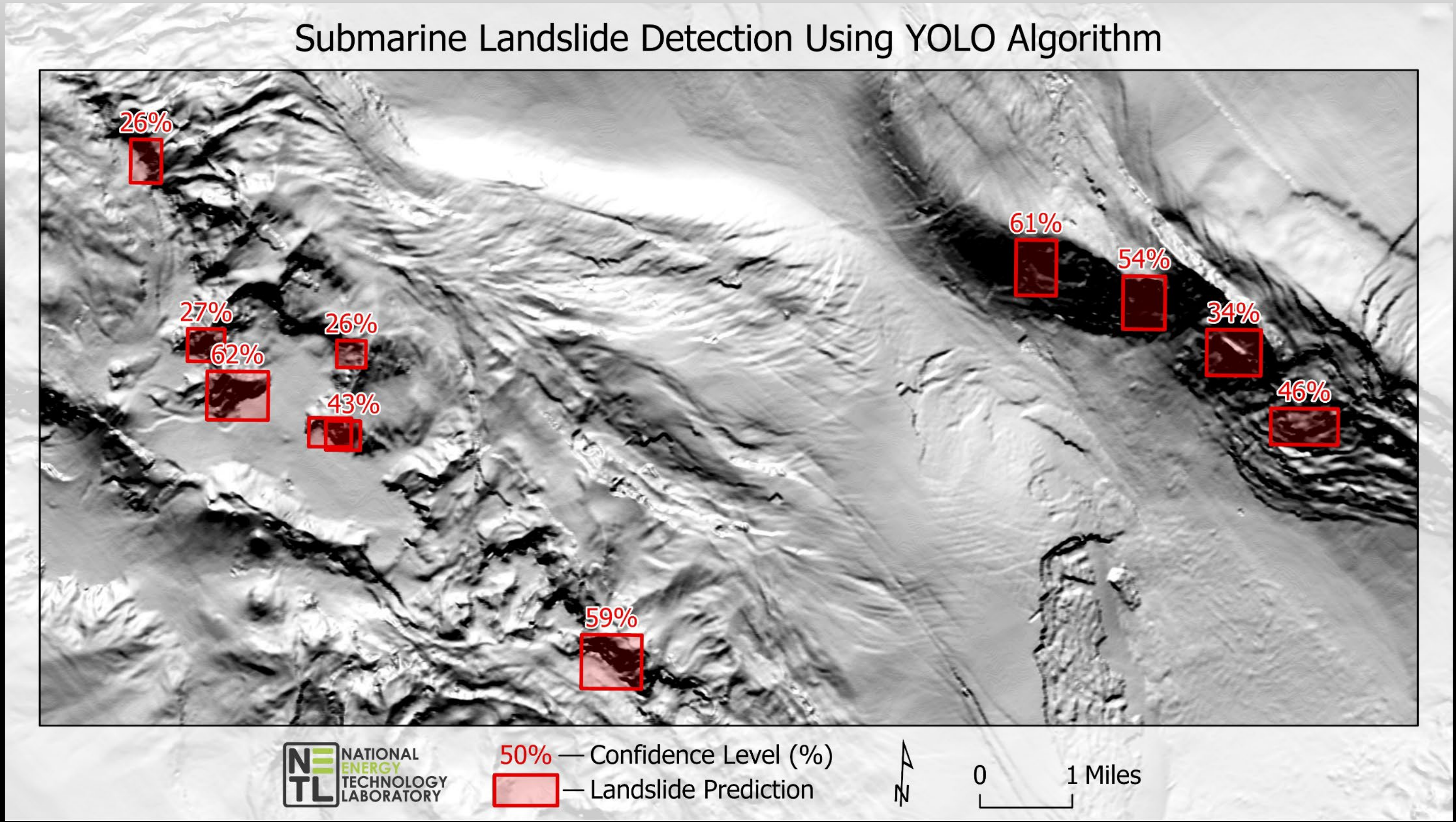
Co-PIs, Offshore FWP Task 6

Ocean & Geohazard Analysis



Offshore R&D

NETL Resource Sustainability Meeting
Oct. 27, 2022

U.S. DEPARTMENT OF ENERGY

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Offshore FWP, Task 6 Team

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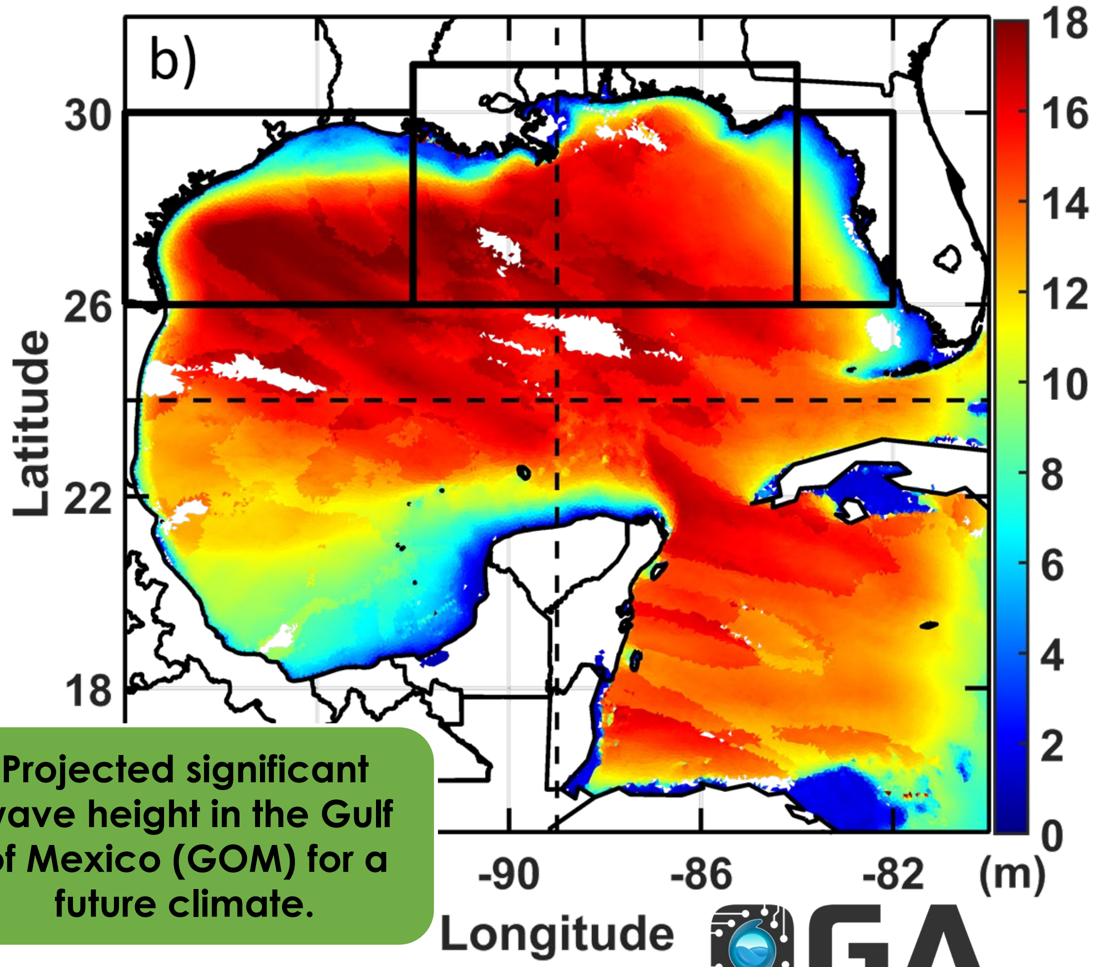
Infrastructure and Metocean Technology



Projected significant wave height in the Gulf of Mexico (GOM) for a future climate.

Why is this work important?

Limiting environmental and community impact and **improving safety** of offshore energy 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

Motivation for Artificial Intelligence/Machine Learning (AI/ML), Data-Driven Offshore Hazard Tools

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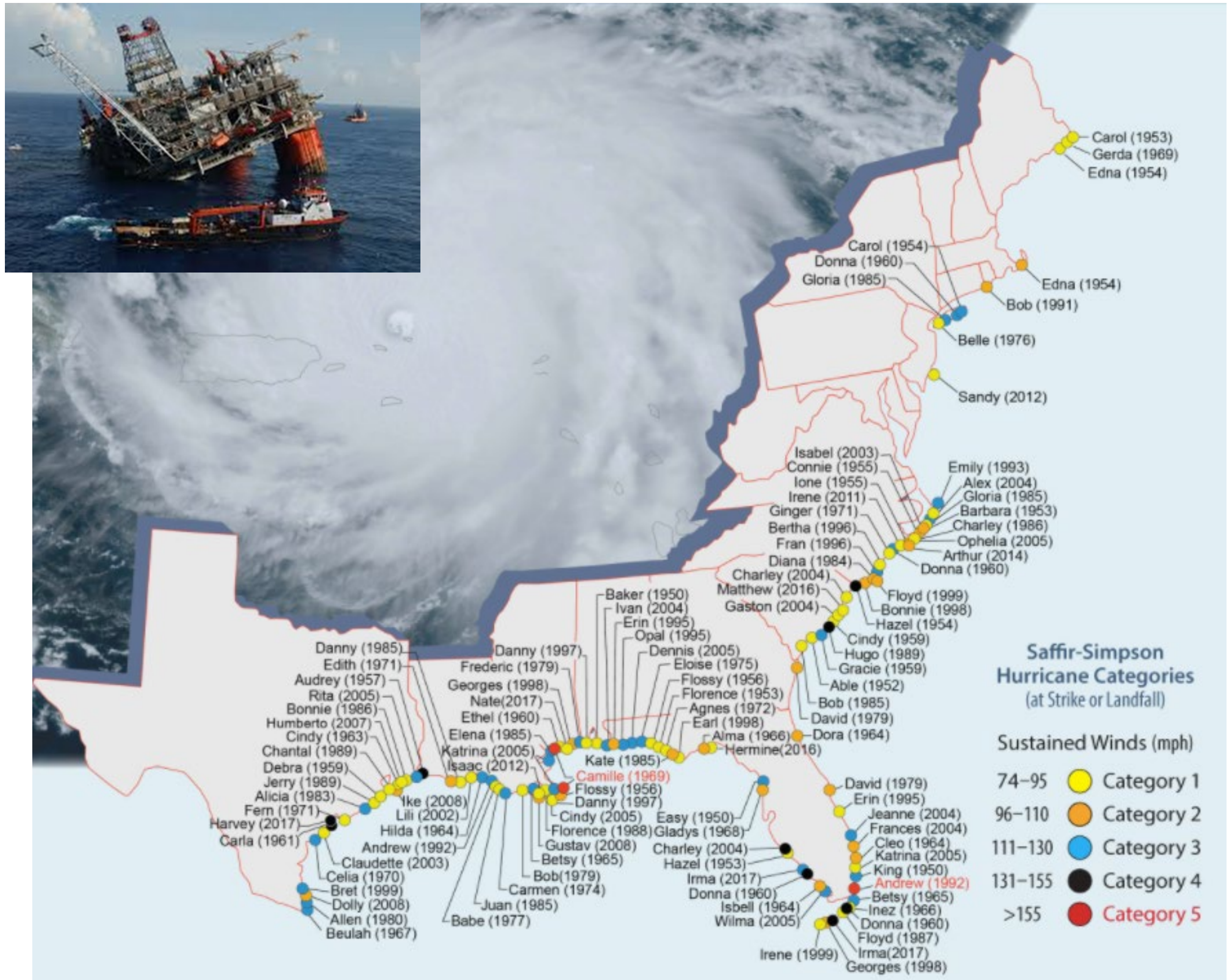
- Demand on offshore Exclusive Economic Zone (EEZ) in the U.S. and around the world is increasing, **with offshore infrastructure expected to increase 50–70% by 2028**

- **Between 2004–2008, 181 structures and 1,673 wells in the Gulf of Mexico were destroyed by five hurricanes**

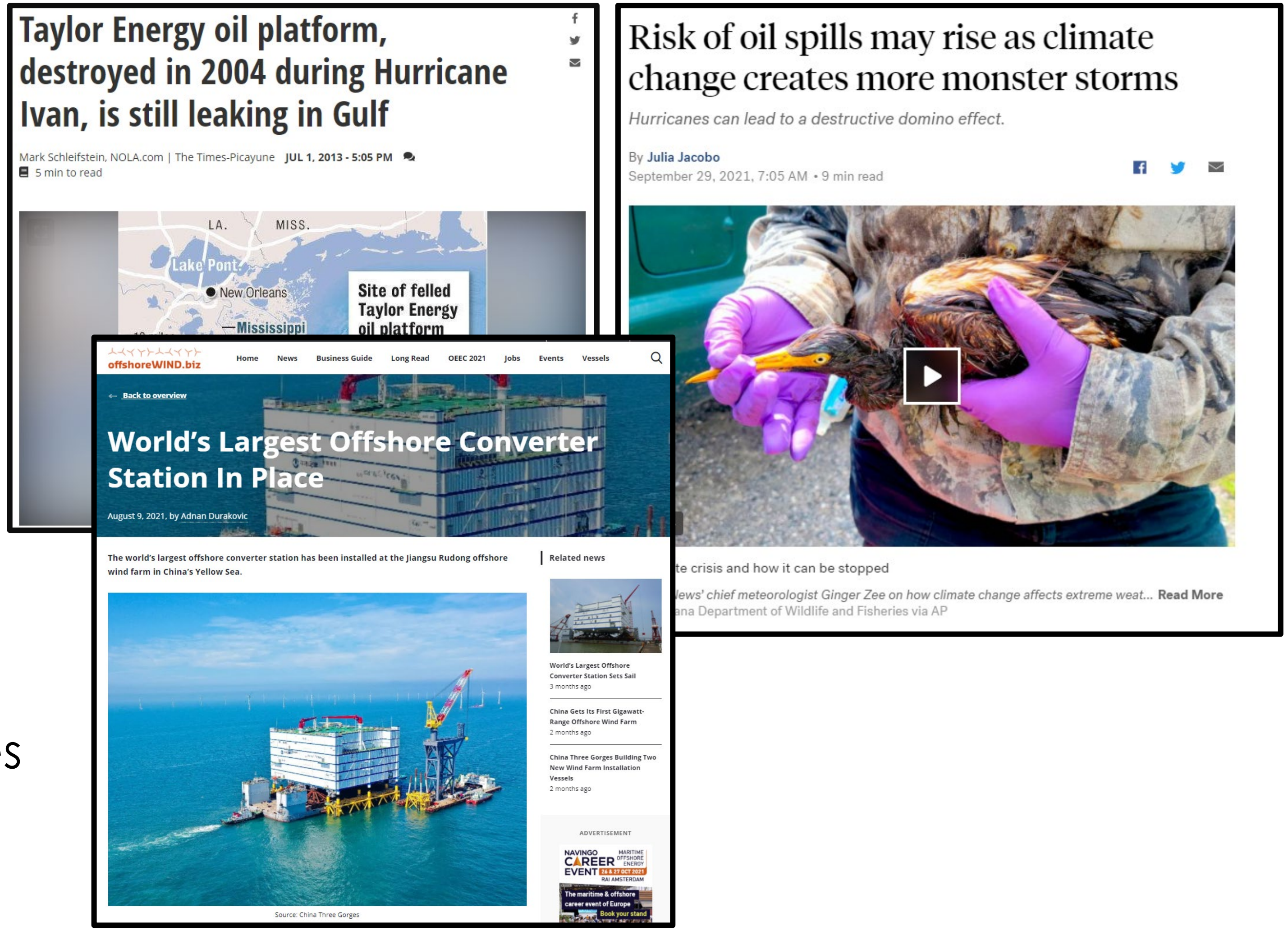
- Climate change is projected to intensify extreme events, increasing the frequency of major tropical cyclones



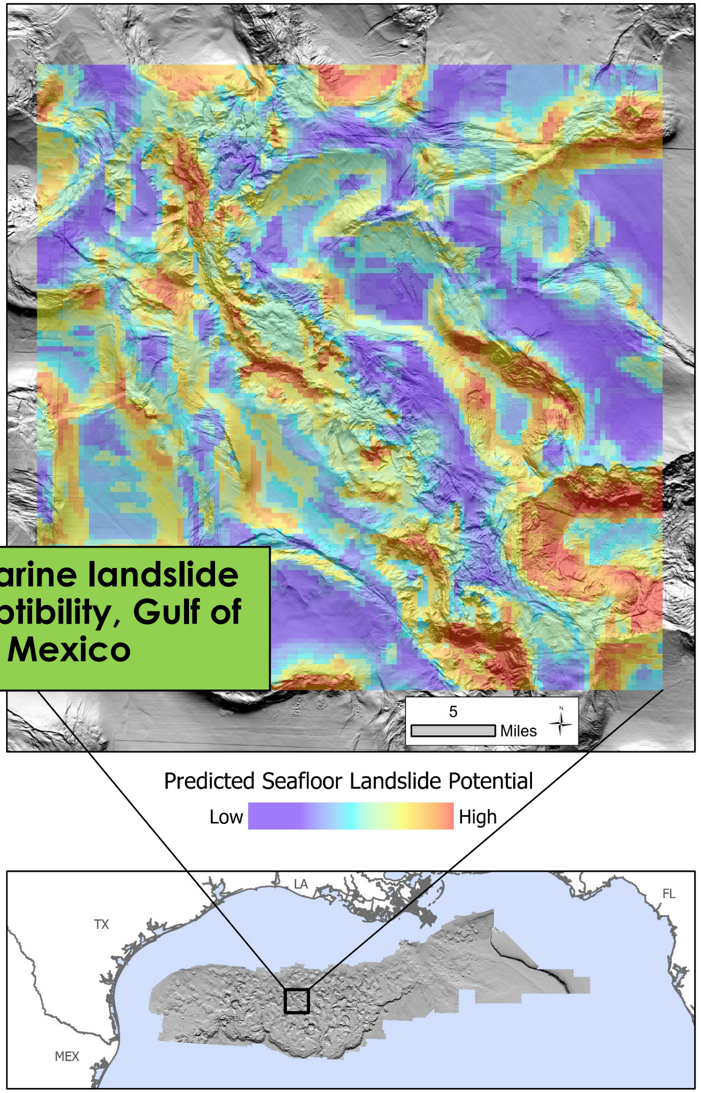
Motivation for AI/ML, Data-Driven Offshore Hazard Tools

- Hazards related to the metocean, seafloor, and subsurface environments include seabed instability, extreme wind/wave/current events, earthquakes, and hazardous material spills.

- **Hazards are often interrelated.** E.g., hurricanes and submarine landslides



Ocean & Geohazard Analysis Tool



Submarine landslide susceptibility, Gulf of Mexico

Ocean & Geohazard Analysis

- Assessing offshore hazards often requires massive amounts of data and length of time to assess the entire system
- Diverse offshore hazards require various approaches for analytics
- Packaging analytics in a flexible smart software tool improves accessibility and forecasting at multiple scales

Enabling efficient research for offshore metocean and seafloor hazard assessments

Ocean and Geohazard Analysis Smart Tool Workflow

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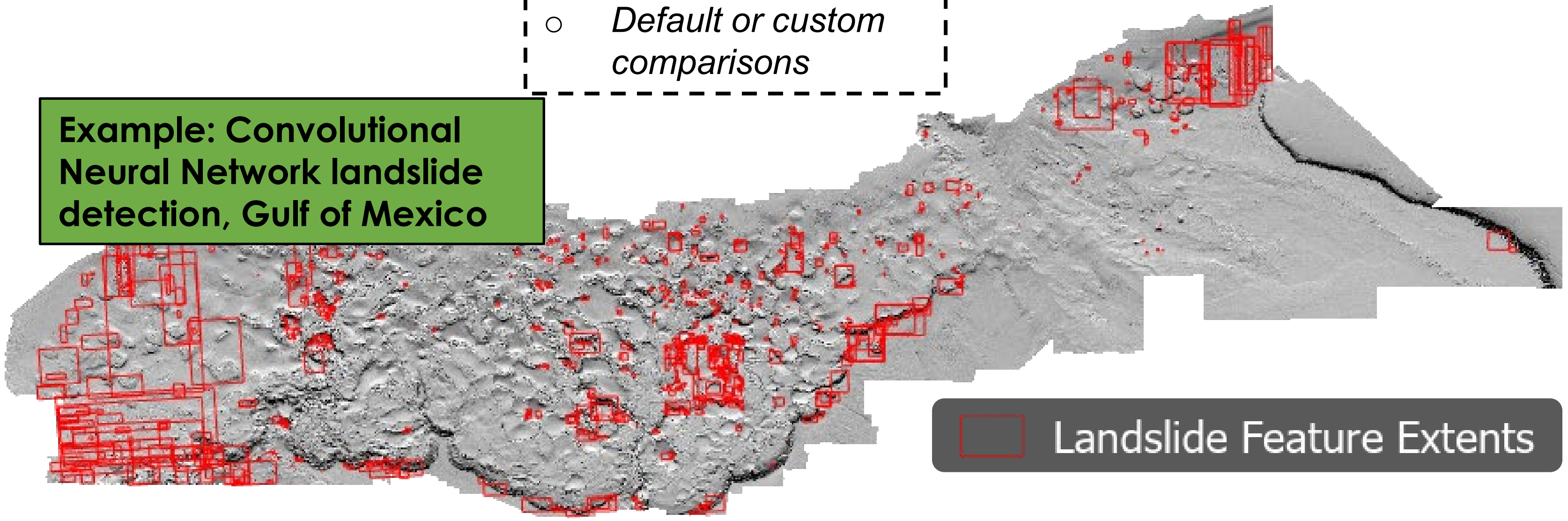
Choose offshore region of interest → *Select hazards for risk assessment* → *Select data & analyses* (AI/ML and Probabilistic) ⇄ *Advanced risk analytics and spatial visualization*

- *Determine hazards and hazard triggers to be analyzed*
- *Default or custom comparisons*

OGA
Ocean & Geohazard Analysis

Example: Convolutional Neural Network landslide detection, Gulf of Mexico



Selecting, training, testing AI/ML is key to an effective workflow

- **Identify datasets for diverse hazard analyses**
- **Develop analytical framework for smart modeling**
- **Train and validate AI/ML models**
- **Integrate metocean statistical and probabilistic analyses**

OGA Tool Hazard Components

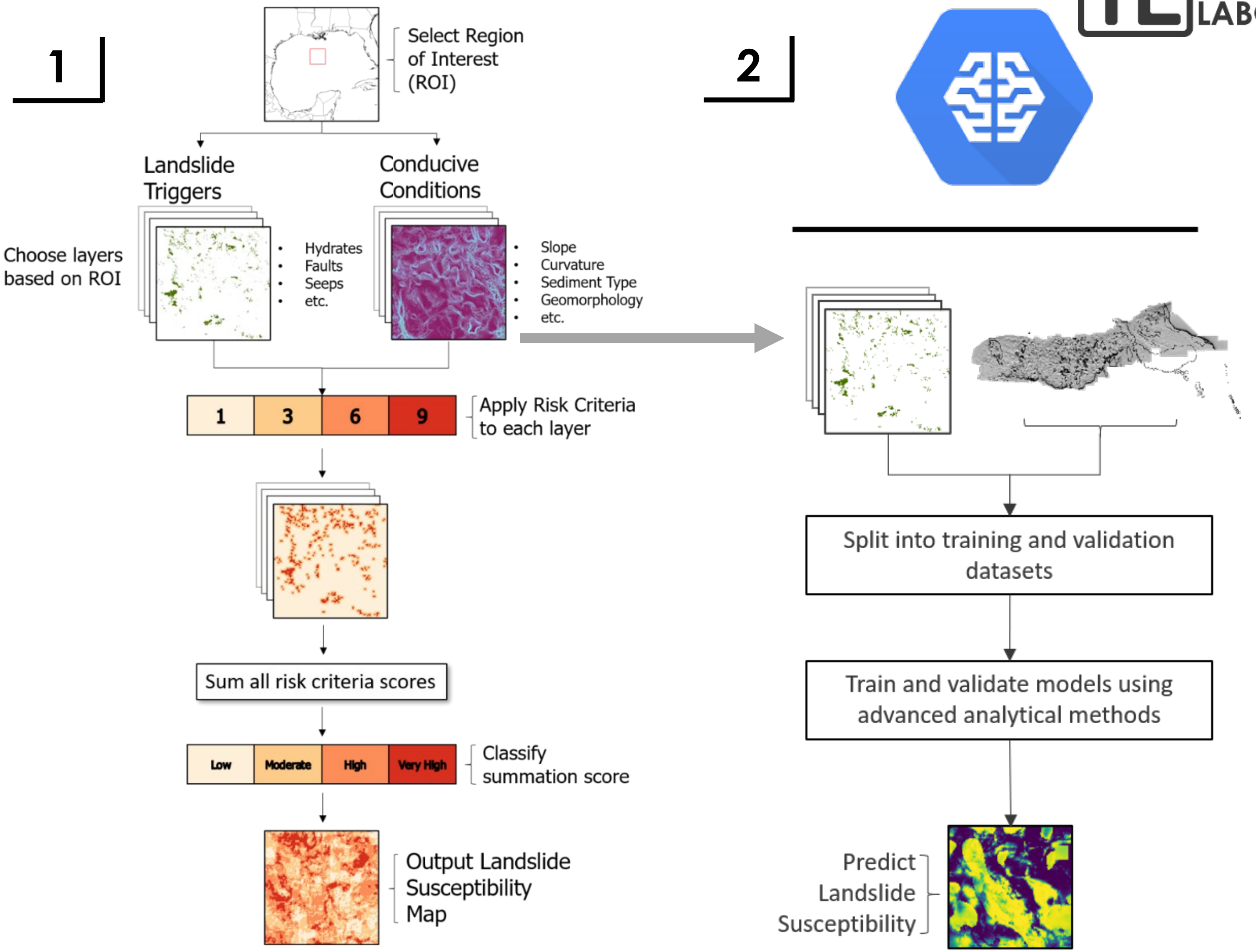
- Analyses are **selected for suitability** of predicting a given hazard or condition
- Each analysis is developed, validated, and prepped for **integration into OGA Tool**

Hazard and/or Process	Analysis Approach(s)
Landslide susceptibility	GIS (risk-based) Machine learning
Landslide detection	Convolutional neural network
Turbidity current susceptibility	GIS interpolation AI/ML spatial analysis
Wave height	Synthetic storm events simulate future extreme events under climate change Generalized extreme value
Wind speed	Generalized extreme value
Current speed	Generalized extreme value
Metocean	Lagrangian Coherent Structures (CIIAM)
Loop current eddy shedding	Self-organizing maps

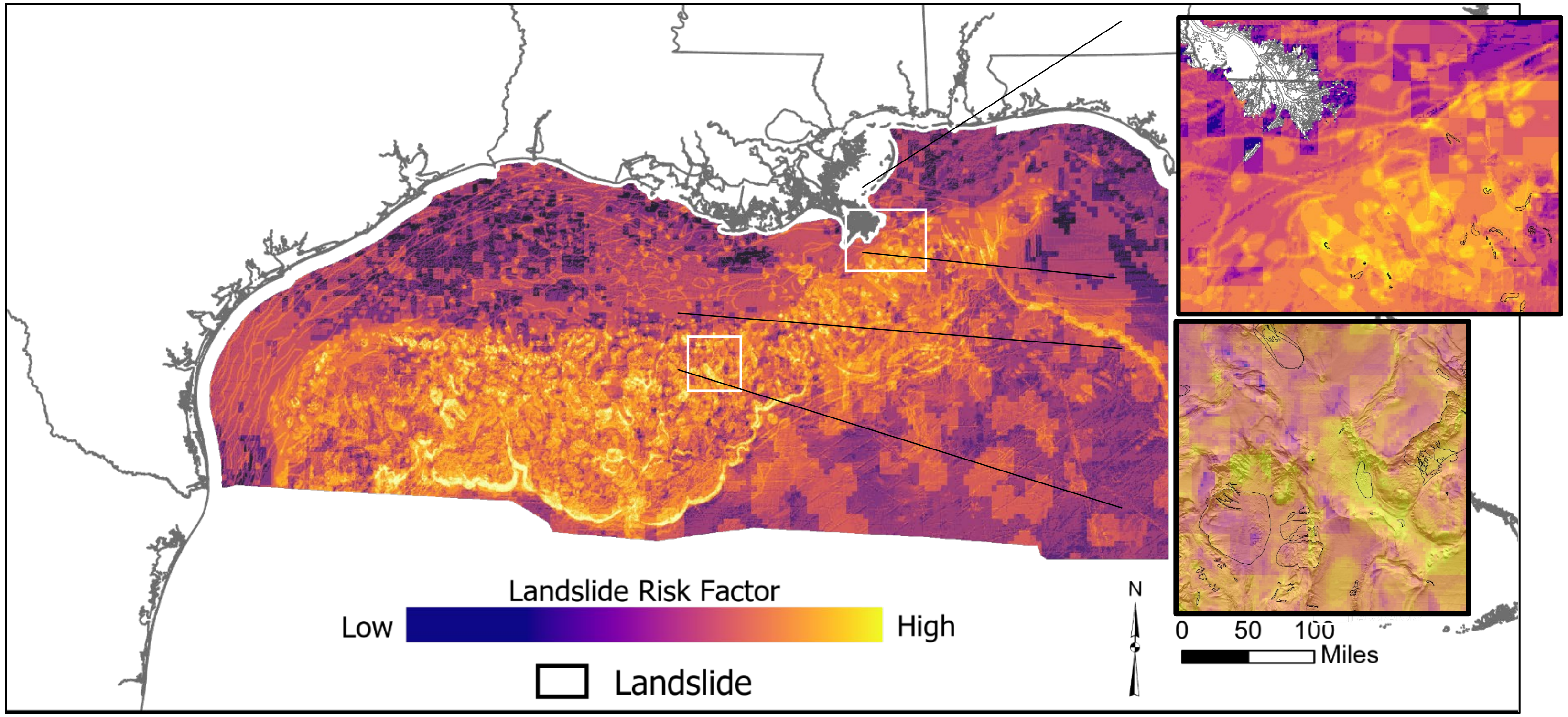
Submarine Landslide Susceptibility Mapping

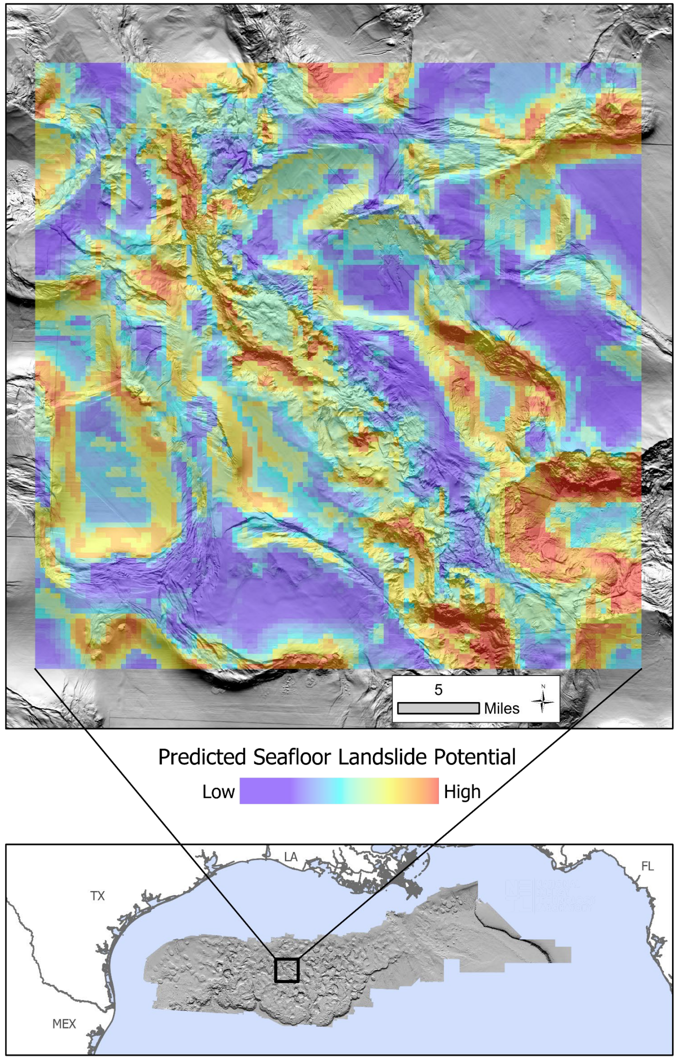
Two approaches for analyzing seafloor landslide potential in the GOM

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



Submarine Landslide Susceptibility Mapping





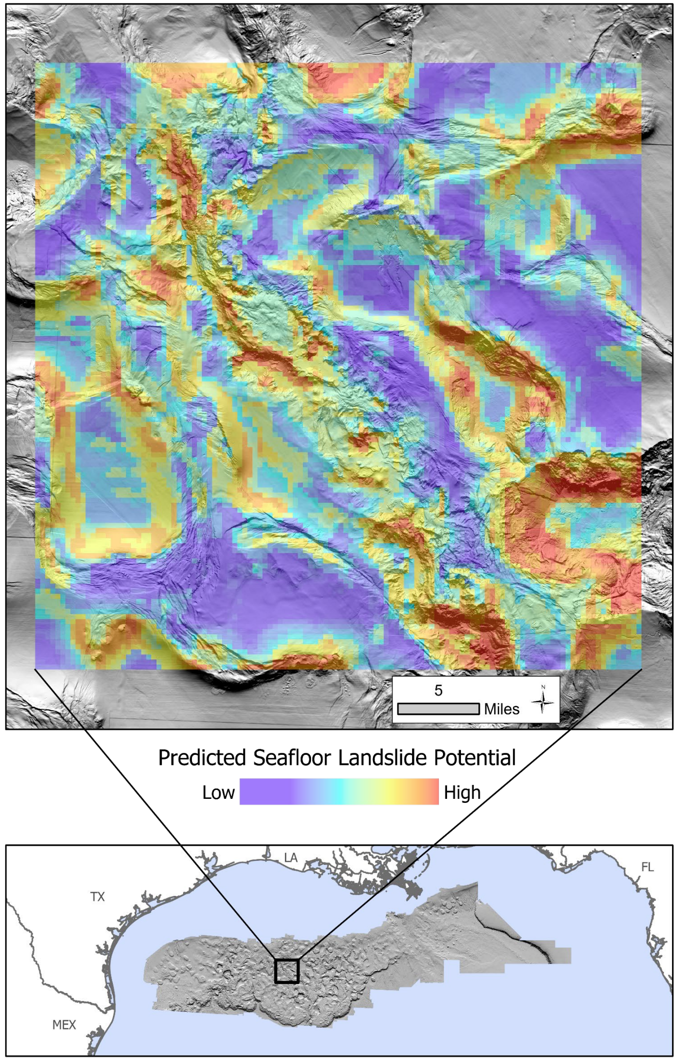
Two approaches for analyzing seafloor landslide susceptibility in the GOM

1. ***Risk-based GIS Approach (above)***
2. ***Machine Learning (ML) Approach (at right)***

Submarine Landslide Susceptibility Mapping

- Utilizing the same input criteria along with **robust ML models** to predict landslide potential
  - **Gradient Boosting Classifier (GBC)**
  - **Artificial Neural Network (ANN)**
- Improved accuracy using **tuning methods**
  - **Hyperparameter random search**
  - **Dimensionality reduction (SVD)**

GBC Model Output



Accuracy evaluated against validation dataset

GBC: 70.0%

ANN: 65.3%

Submitted to Natural Hazards for publication

Dyer, A.S., Mark-Moser, M., Duran, R., Bauer, J.R. (submitted) Submarine Landslide Susceptibility in the Northern Gulf of Mexico. Natural Hazards, Springer.

Nearshore Adaptation for Submarine Landslide Susceptibility Mapping

- Landslides in the Mississippi River delta front have been recognized to threaten offshore infrastructure since the 1950s
- In 2004, Hurricane Ivan caused a landslide that resulted in the longest lasting spill in U.S. history, with heavy oil sheens still observed as late as 2019
- Our effort leverages big data and ML approaches to assess risk in the region after developing a ML model in deeper waters where the quality of data is favorable
- Nearshore submarine LSM considers shallow waters and effects of waves


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

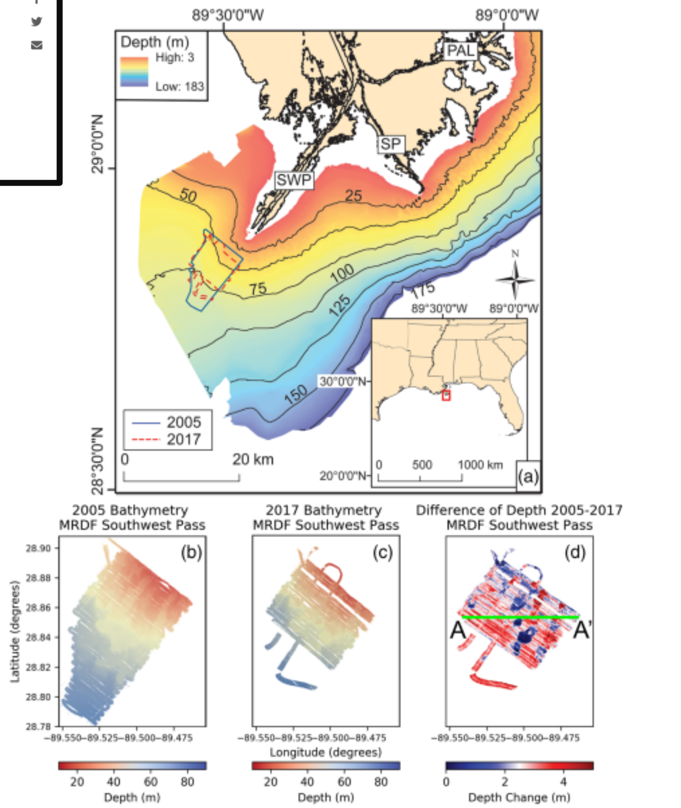
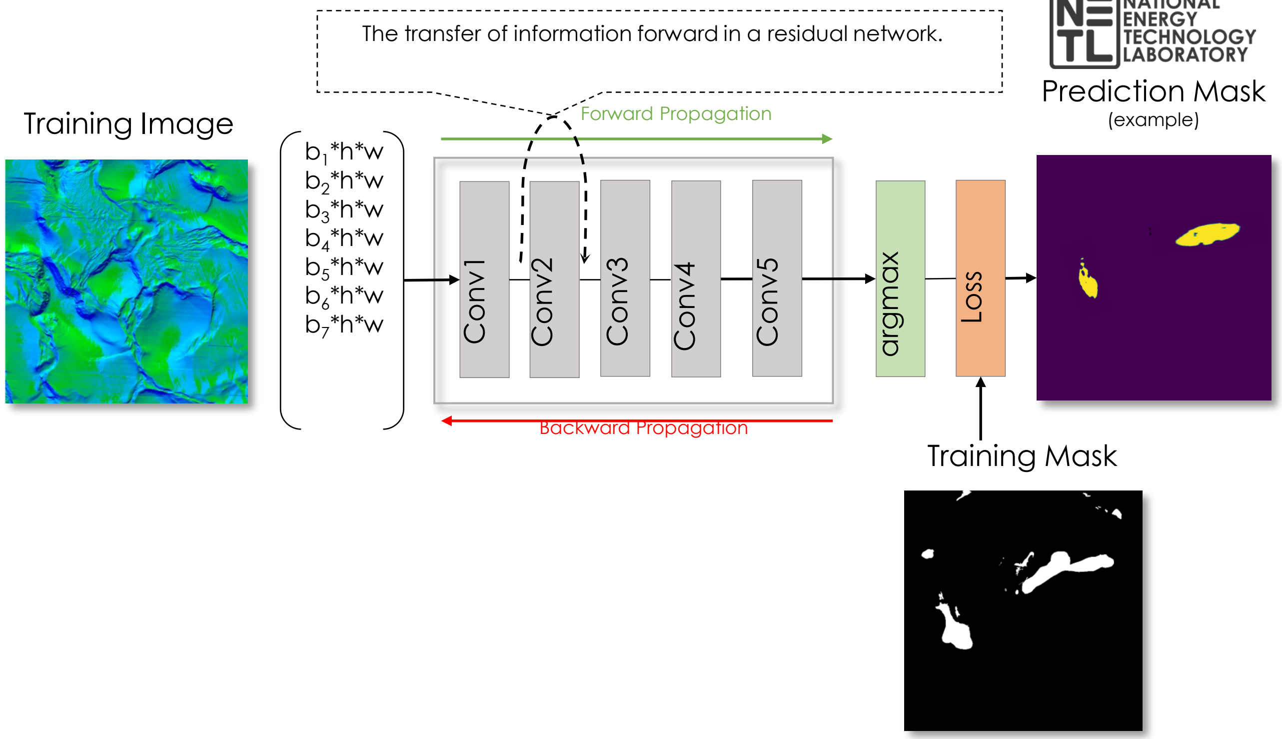


Figure 1. (a) The Mississippi River Delta Front region. Color shaded bathymetry derived from last full-coverage survey of the MRDF region in late 1970s. Blue and red polygons show locations of 2005 and 2017 multibeam surveys, respectively. Acronyms: PAL = Pass a Loutre; SP = South Pass; SWP = Southwest Pass. (b) 2005 25 m^2 resolution Southwest Pass multibeam bathymetric survey. (c) 2017 100 m^2 resolution multibeam Southwest Pass bathymetric survey. (d) Difference of depth between 2005 and 2017 bathymetric surveys; the entire area deepened by an average of ~2.6 m in 12 years, with more dynamic depth changes in mudflow zones. The green line represents the 1-D transect in Figure 5.

Obelcz et al., 2020

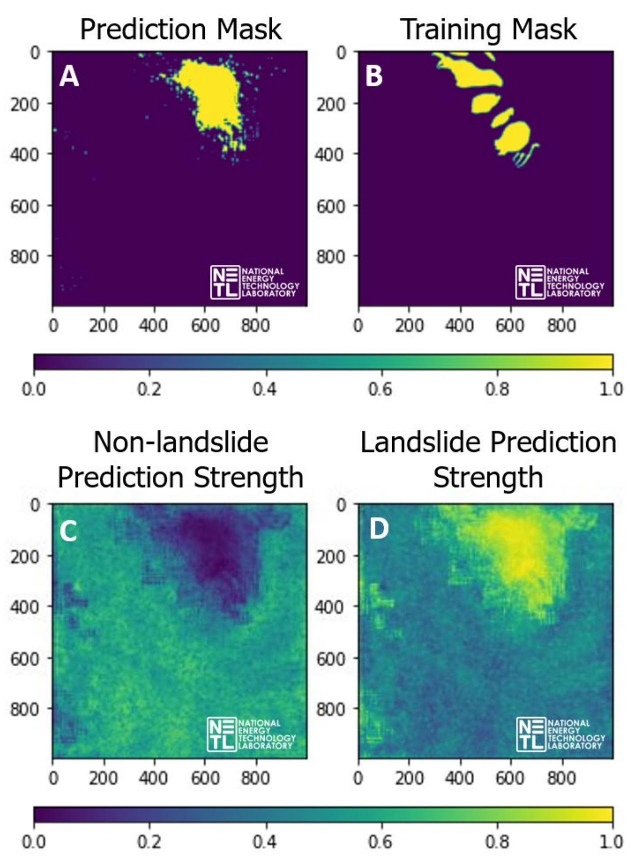
Submarine Landslide Detection

Using high-resolution seafloor images, a data-driven neural network model is used to identify the locations of submarine landslides

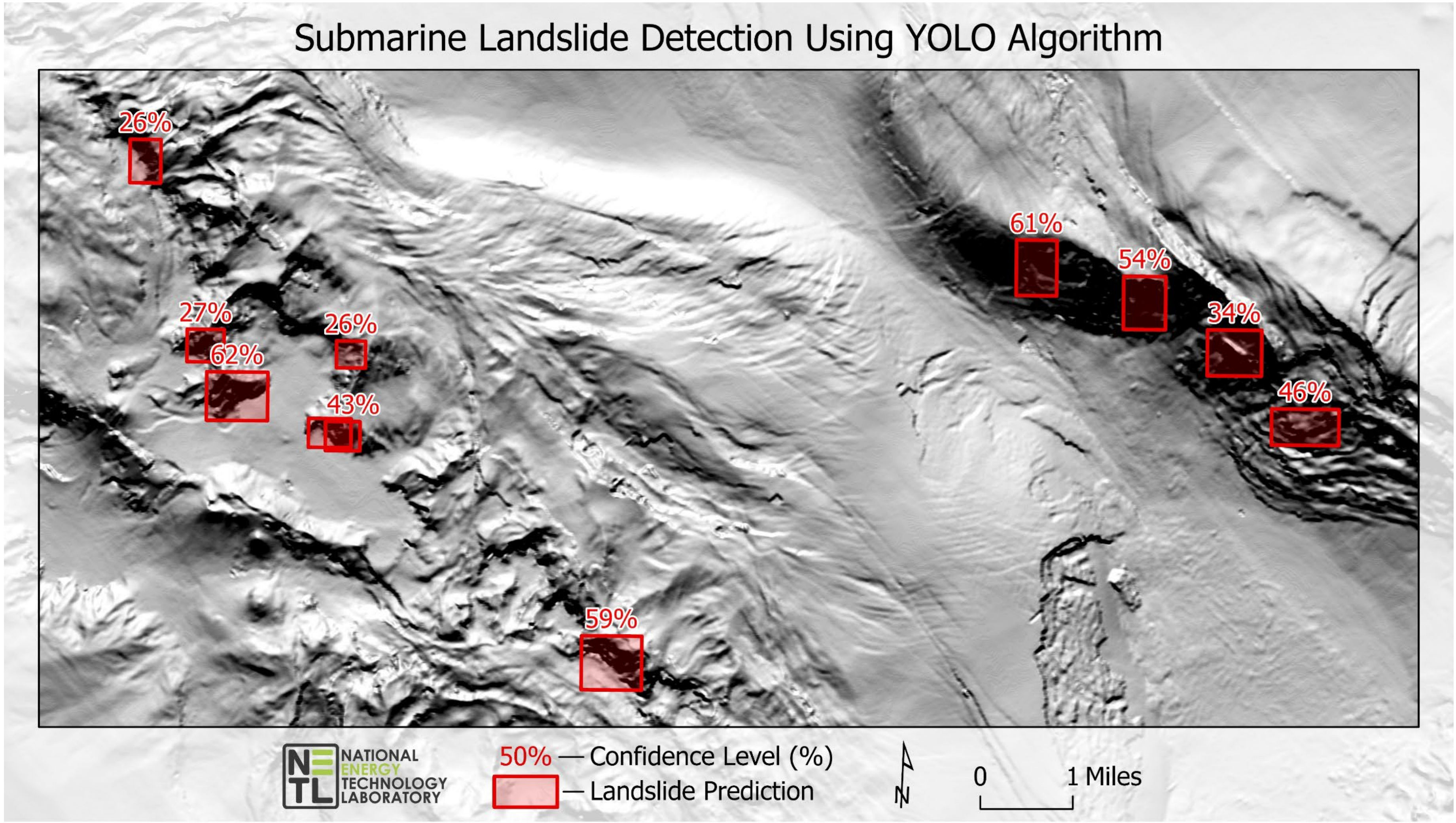


Model Design

- The Fully Convolutional ResNet model was used, a prebuilt network available with the PyTorch framework.
- The model performs semantic segmentation to create an output mask highlighting landslides given an input image.



Landslide Detection Results



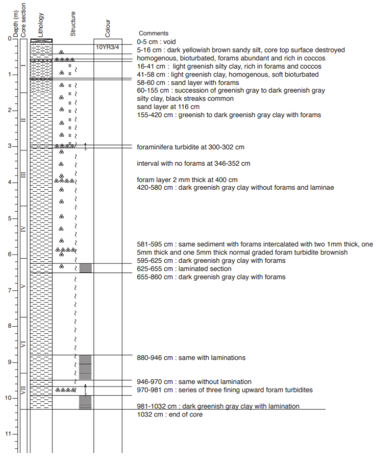
Turbidity Current Hazard Modeling

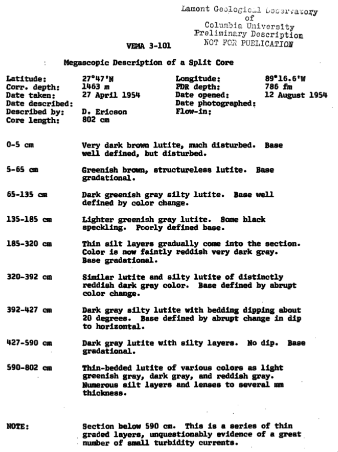
- Turbidity currents are significant and powerful offshore hazards that are similar but distinct from submarine landslides
- Core analysis is accelerated using automated text extraction and can assist in locating potential turbidity currents
- Locations can be used to inform ML for turbidity current susceptibility mapping and forecasting

“turbidite”

“fining upward”

“foram turbidites”





Lamont Geological Observatory
of
Columbia University
Preliminary Description
NOT FOR PUBLICATION

VEMA 3-101

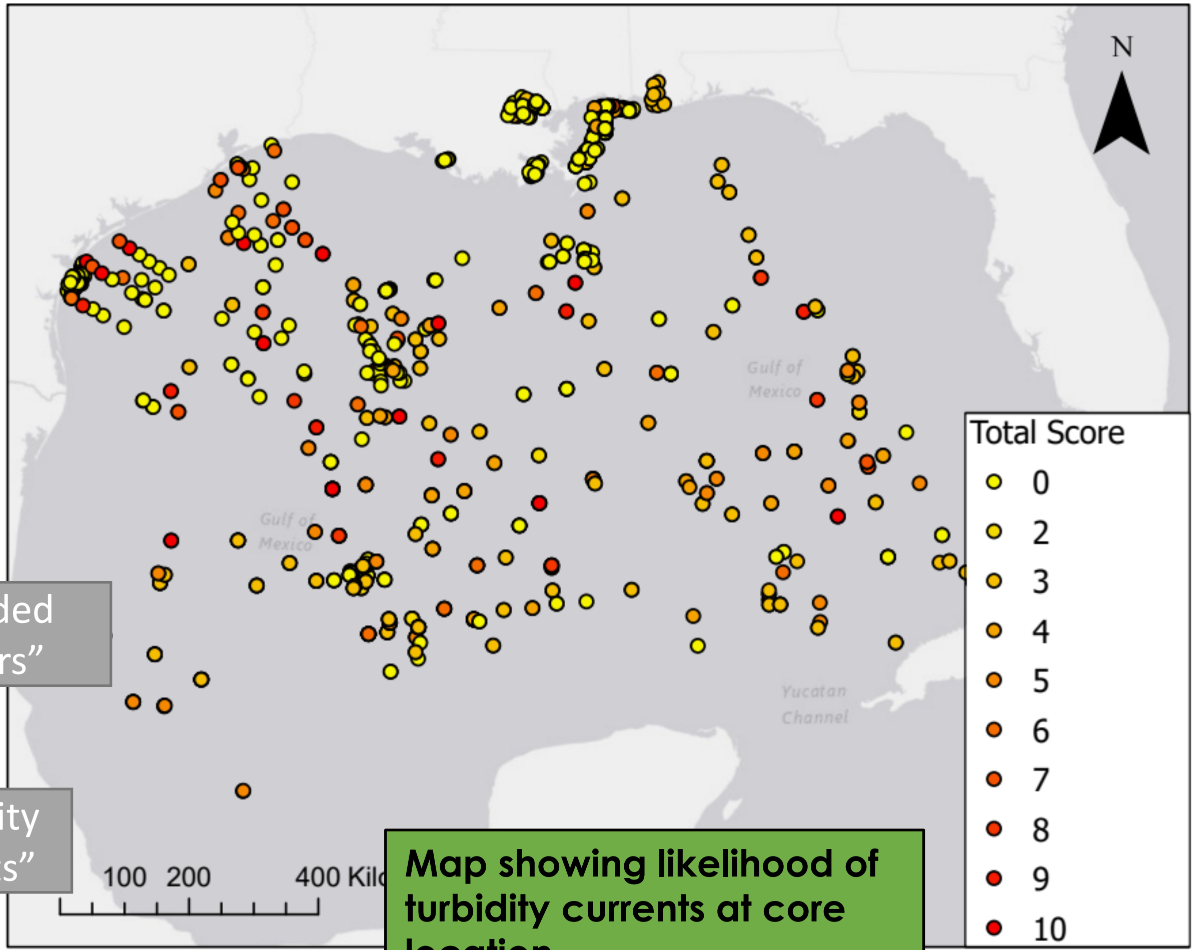
Megascopic Description of a Split Core

Latitude:	27°47'N	Longitude:	89°16.6'W
Corr. depth:	1463 m	PDR depth:	786 fm
Date taken:	27 April 1954	Date opened:	12 August 1954
Date described:		Date photographed:	
Described by:	D. Ericson	Flow-in:	
Core length:	802 cm		

0-5 cm	Very dark brown lutite, much disturbed. Base well defined, but disturbed.
5-65 cm	Greenish brown, structureless lutite. Base gradational.
65-135 cm	Dark greenish gray silty lutite. Base well defined by color change.
135-185 cm	Lighter greenish gray lutite. Some black speckling. Poorly defined base.
185-320 cm	Thin silt layers gradually come into the section. Color is now faintly reddish very dark gray. Base gradational.
320-392 cm	Similar lutite and silty lutite of distinctly reddish dark gray color. Base defined by abrupt color change.
392-427 cm	Dark gray silty lutite with bedding dipping about 20 degrees. Base defined by abrupt change in dip to horizontal.
427-590 cm	Dark gray lutite with silty layers. No dip. Base gradational.
590-802 cm	Thin-bedded lutite of various colors as light greenish gray, dark gray, and reddish gray. Numerous silt layers and lenses to several mm thickness.
NOTE:	Section below 590 cm. This is a series of thin graded layers, unquestionably evidence of a great number of small turbidity currents.

“graded layers”

“turbidity currents”



Map showing likelihood of turbidity currents at core location

Wave Modeling Development

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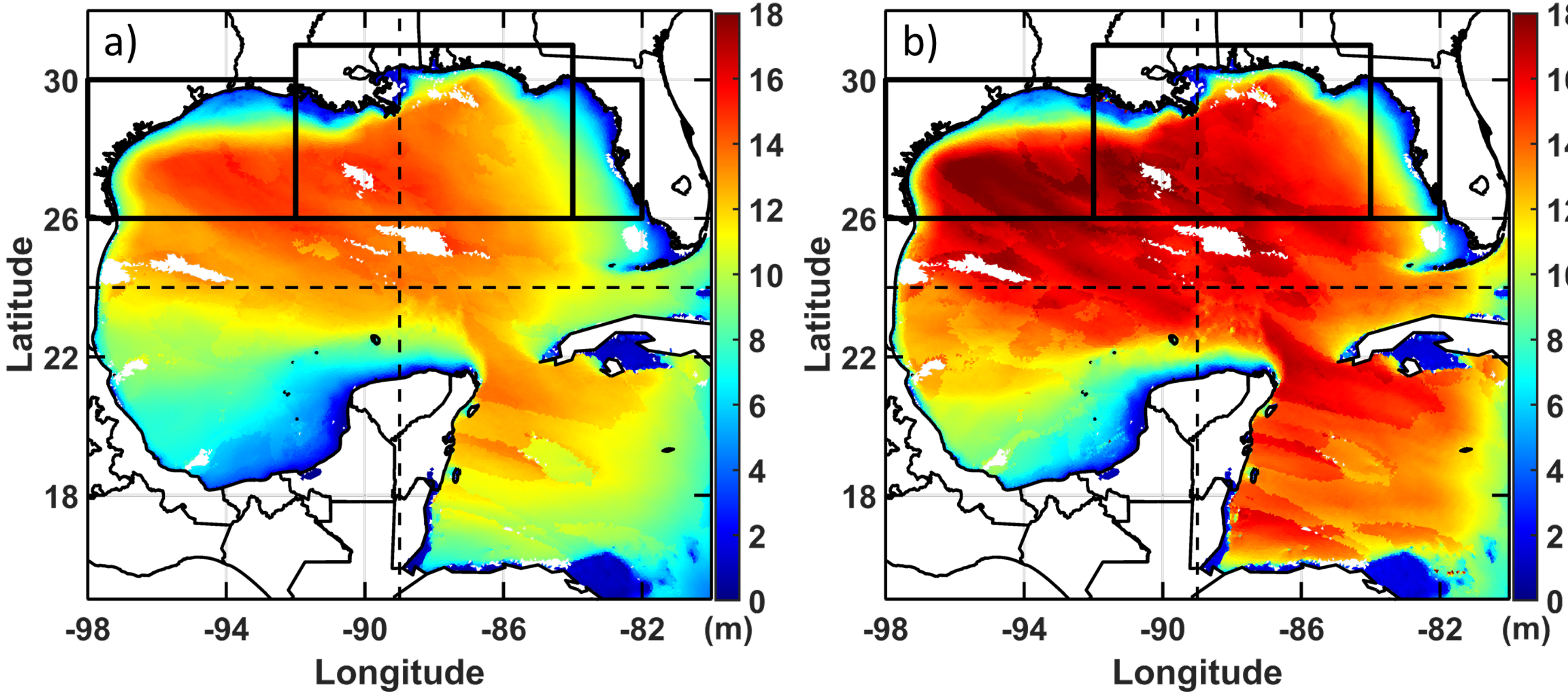
- API and industry have needed to revise platform design criteria due to unforeseen extreme waves
- We are creating wave data from synthetic physics-based tropical cyclones using Joule supercomputer
- Critical for risk projections in a changing climate



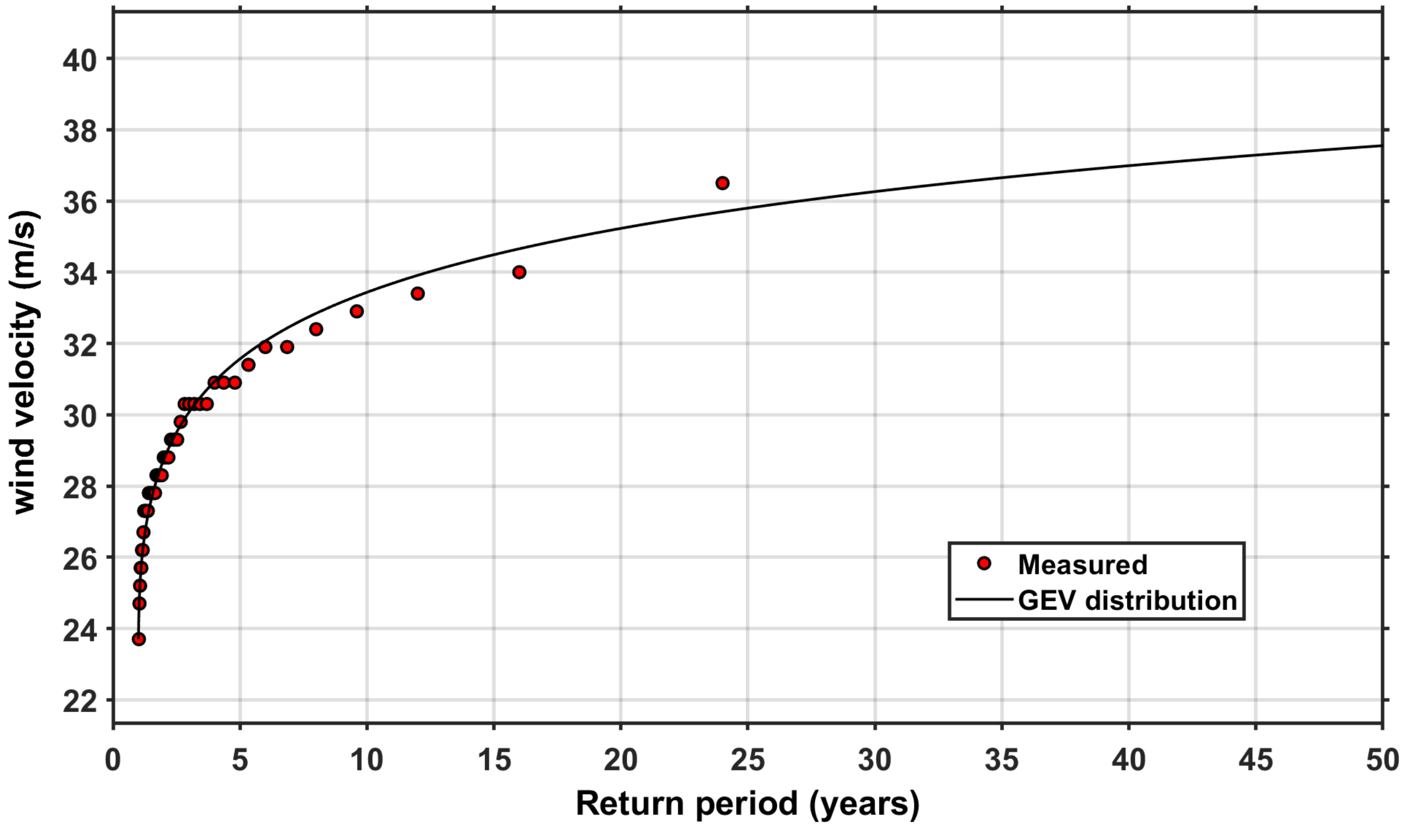
Significant wave height for the 100-years return period obtained from the general circulation model-derived events ensemble for the (a) present and (b) future wave climates. Blank areas denote regions where less than 4 models show the same trend.

Advanced Probability and Statistics

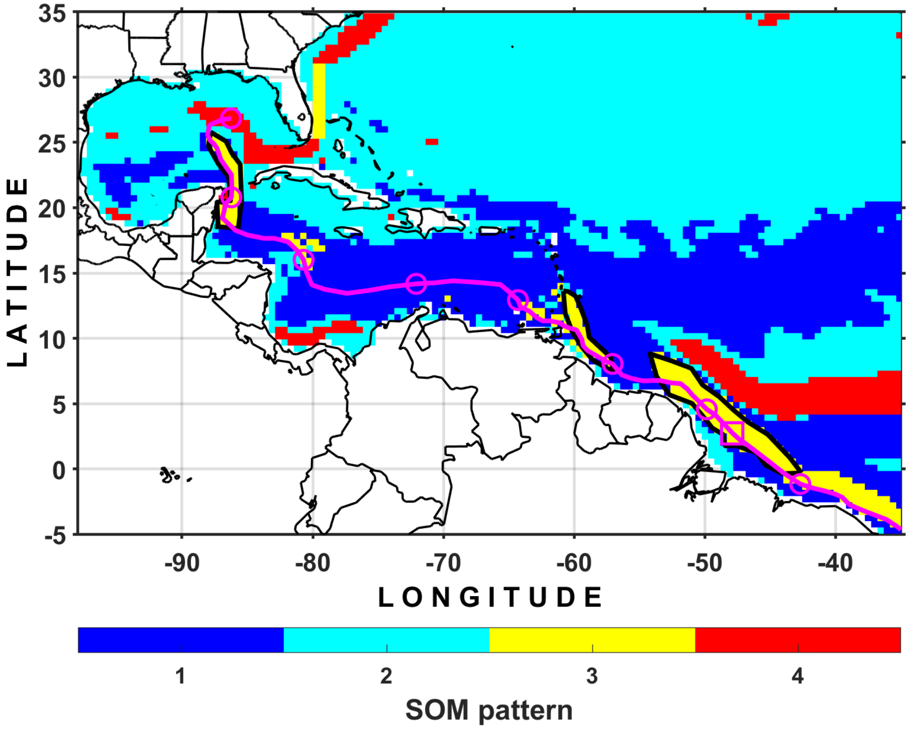
Generalized Extreme Value (GEV) distributions for wind velocity

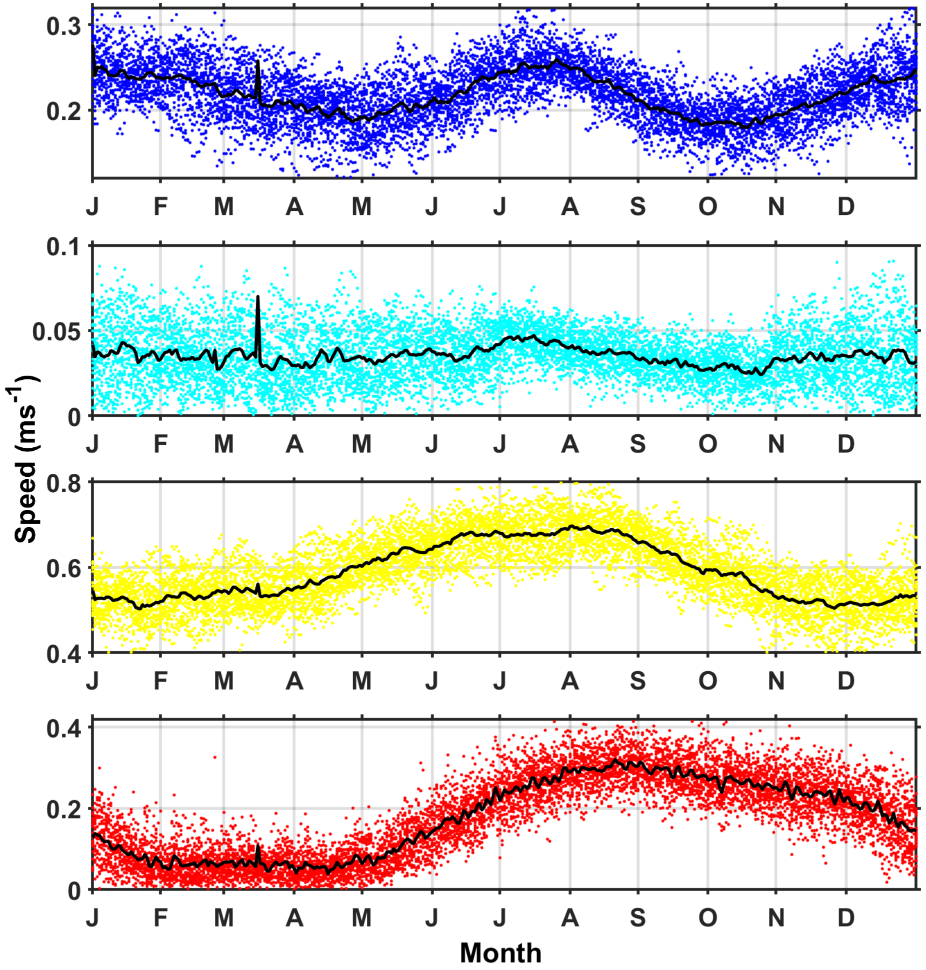
Indicates likelihood of future extreme events

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



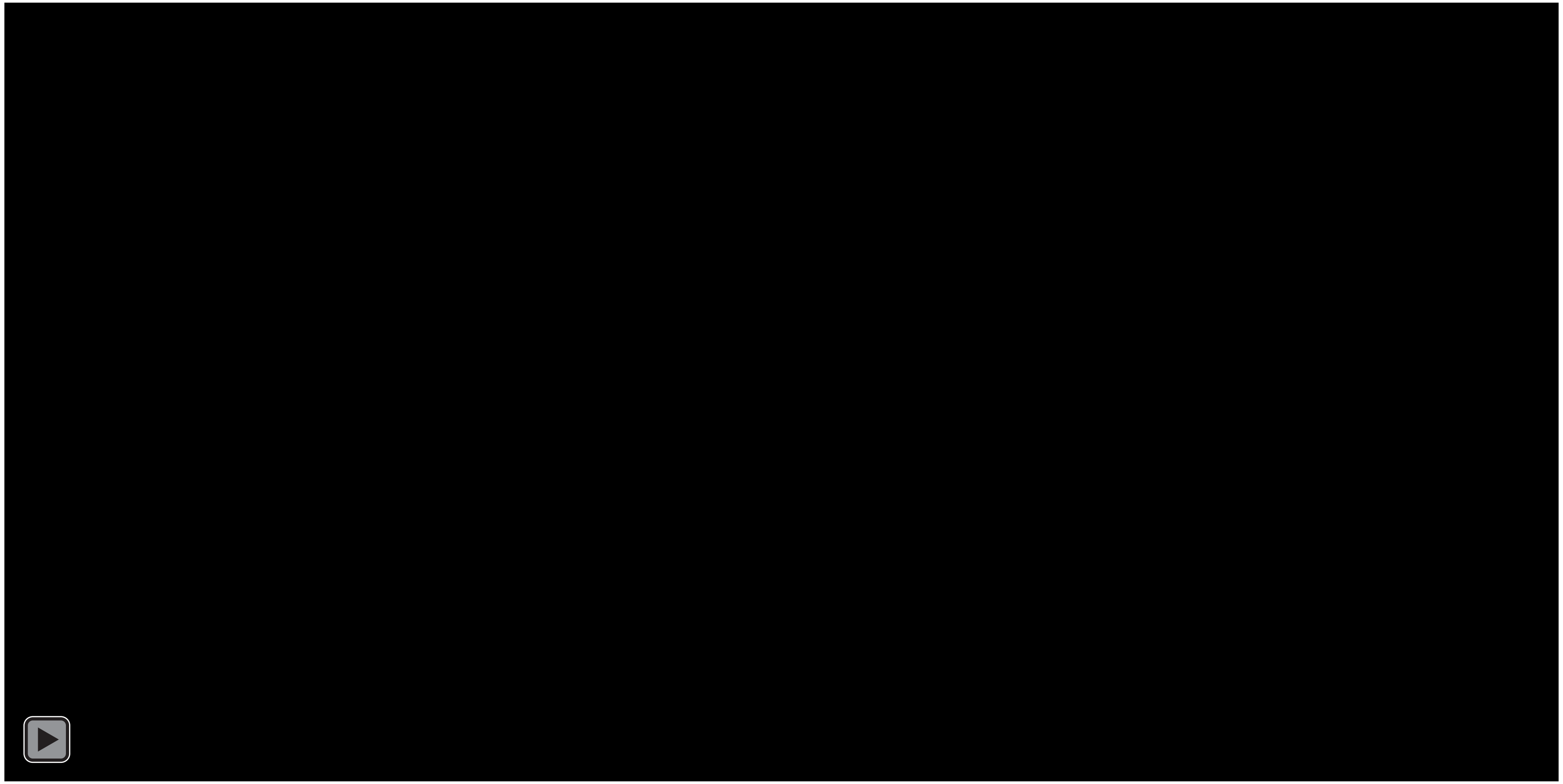
Self-Organizing Maps – An Unsupervised Neural Network





- Temporal patterns from self-organizing maps identifying predictable patterns in sea-surface velocity
- These insights, in combination with advanced analyses of energy and information transfers in the ocean are expected to improve Loop Current predictability

Loop Current Eddy Shedding



- The Loop Current (LC) and associated eddies are among the most intense currents in the world and are a major concern for offshore infrastructure
- Predicting LC eddy shedding has been intractable so far
- Insights from self-organizing maps are leading to novel analyses of Loop Current eddy shedding events using oceanic energy transfers

CIIAM Model Updates

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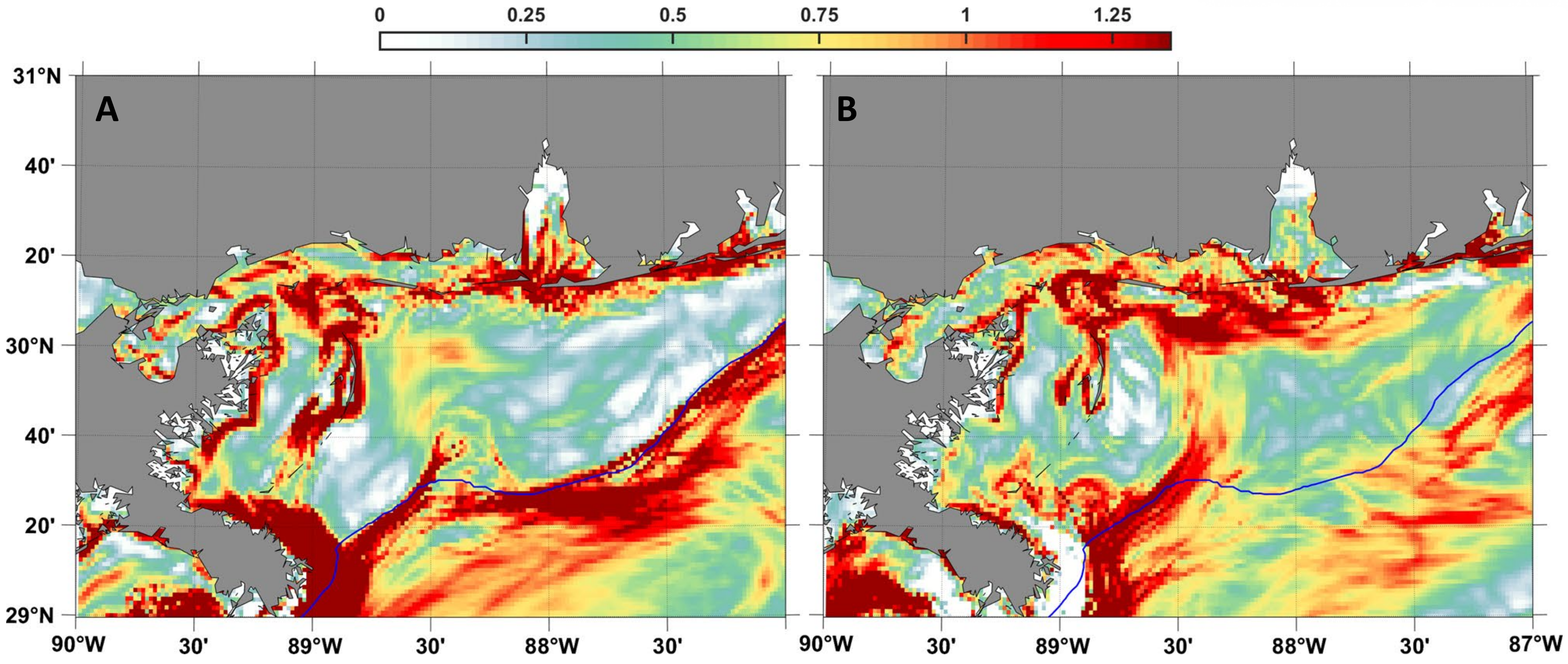
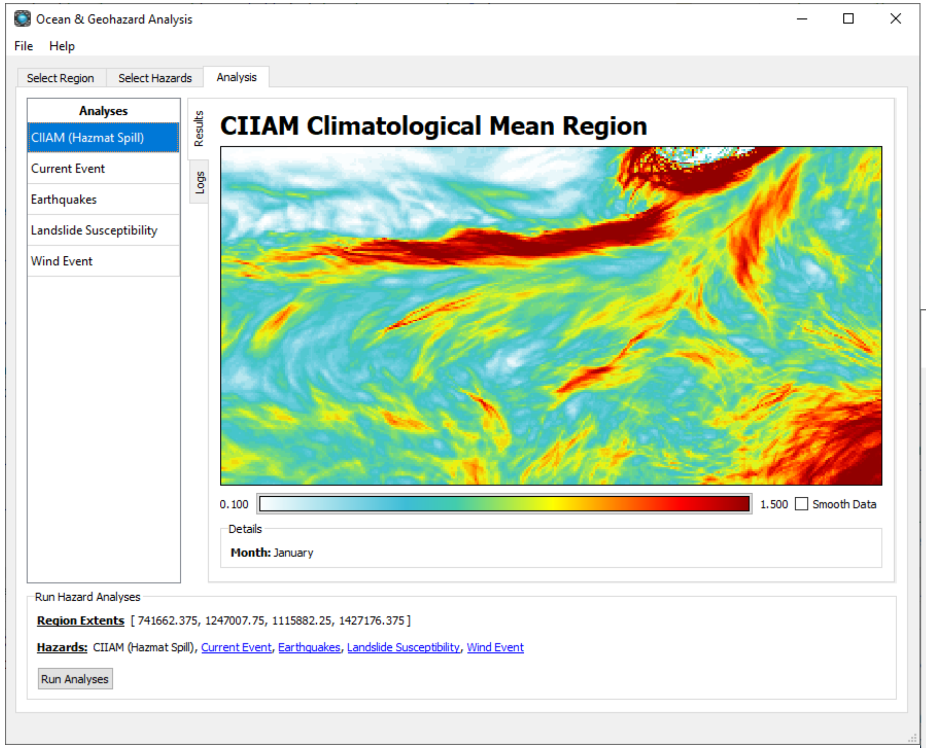
CIIAM

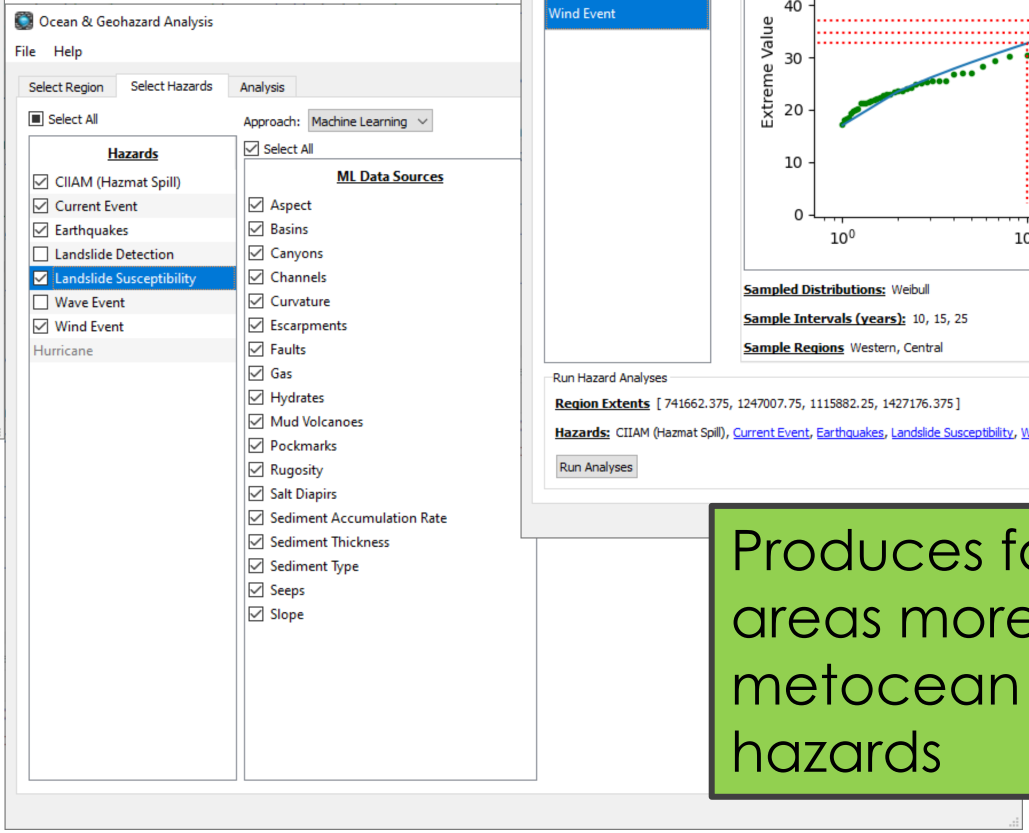


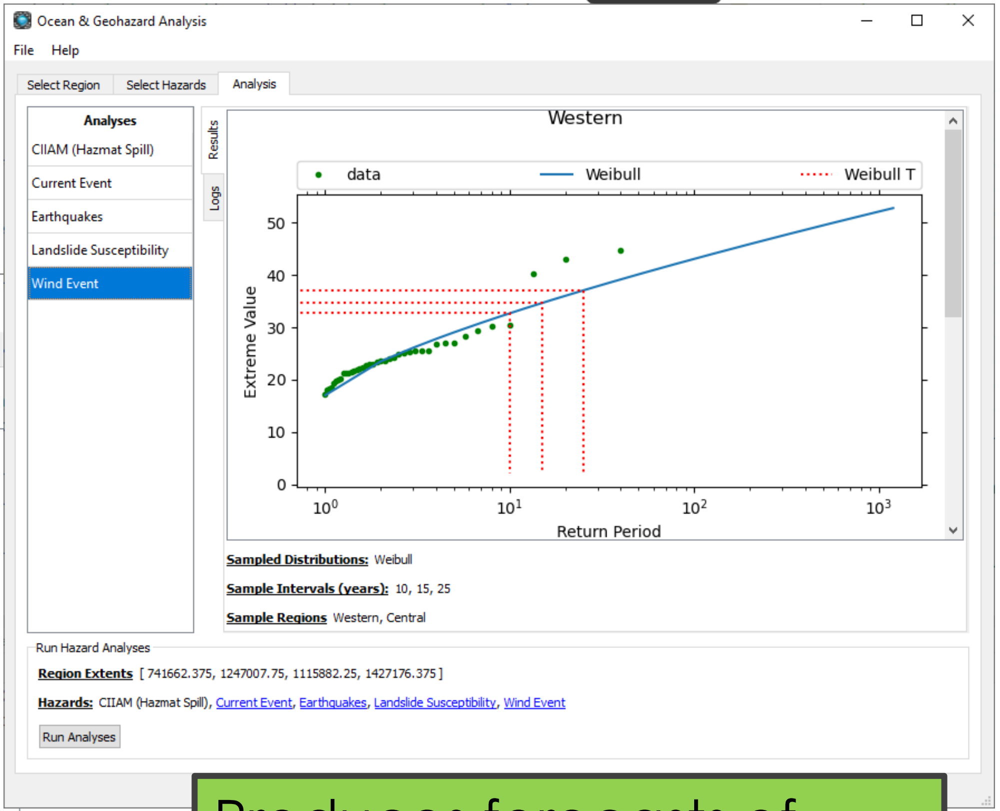
Metocean Pathways:
Red=attracting
White=isolated

CIIAM outputs for the ocean near southeastern Louisiana in (A) winter and (B) spring, showing transport barrier as open allowing particulate to reach coastline

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

Collaboration and External Interest

External CIIAM 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	Gouveia et al (2021). https://www.nature.com/articles/s41598-020-79386-9
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 and Caribbean	Preliminary results obtained
Saudi Arabia	Red Sea Modeling and Prediction Group KAUST	Red Sea	Preliminary results obtained
Mexico	Consortium for Sargassum forecasts (CICESE, UNAM, ECOSUR)	Caribbean and GOM	Preliminary results obtained

MOU for Collaboration OASIS:

BOEM and NETL MOU AGMT-1082.AMD1

Next Steps for OGA Tool

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- Integrating analyses for turbidity currents, nearshore submarine landslide susceptibility, extreme waves and wind in a changing climate, Loop Current predictability
- Assembly of database containing metocean and seabed datasets that feed OGA analyses
- Strategize conversion of OGA Tool to online-accessible web application

OGA
Ocean & Geohazard Analysis

OGA Tool Version 2 release March '23

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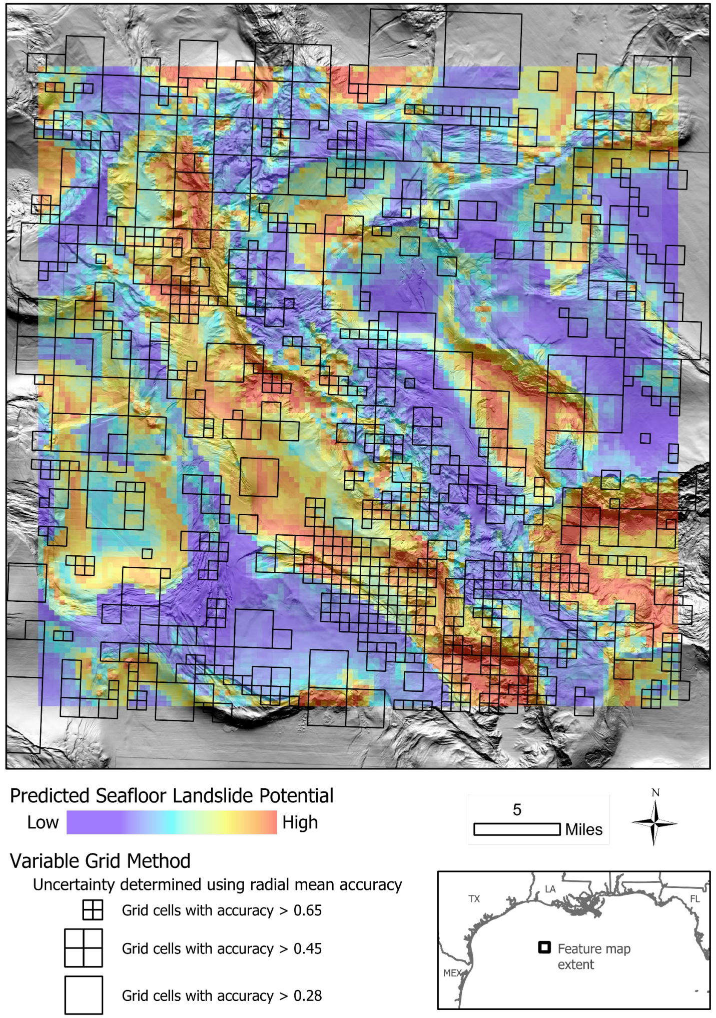
Key Takeaways

- **Technology that integrates big data and science-based analytics for offshore hazards**
- **Advanced analytics can offer near-real time assessment of risks and also forecast vulnerabilities**
- **Smart Tool:**
    - **adapts to data availability/quality**
    - **adapts to different regions**
    - **flexible to integrate NETL tools and user tools for advanced predictive and spatial analysis**
- **Next steps are to integrate additional hazard analyses, validate tool, and strategize conversion to online tool**



More information at https://edx.netl.doe.gov/offshore/

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Values Delivered

Advancing the current state of knowledge, supporting offshore activities, forecasting hazards 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

Offshore information available at https://edx.netl.doe.gov/offshore/

U.S. DEPARTMENT OF ENERGY

Advanced Offshore Research Task 6 Timeline

Research Problem:

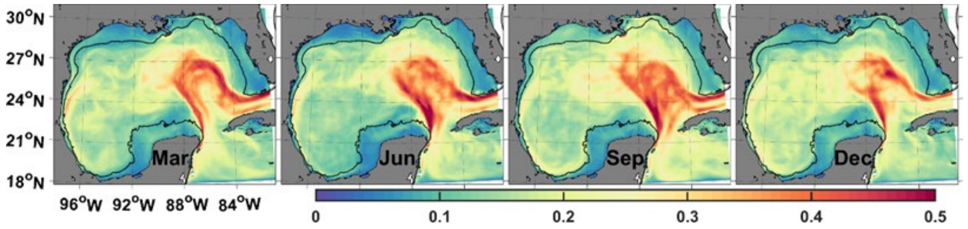
- Changes in the ocean environment (e.g., mudslides or burial from subsea currents, strong weather events or natural fluctuations) have been linked to billions of dollars of impacts. Climate change is expected to intensify many of these problems.
- These events can have a significant effect on the success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

Research Approach:

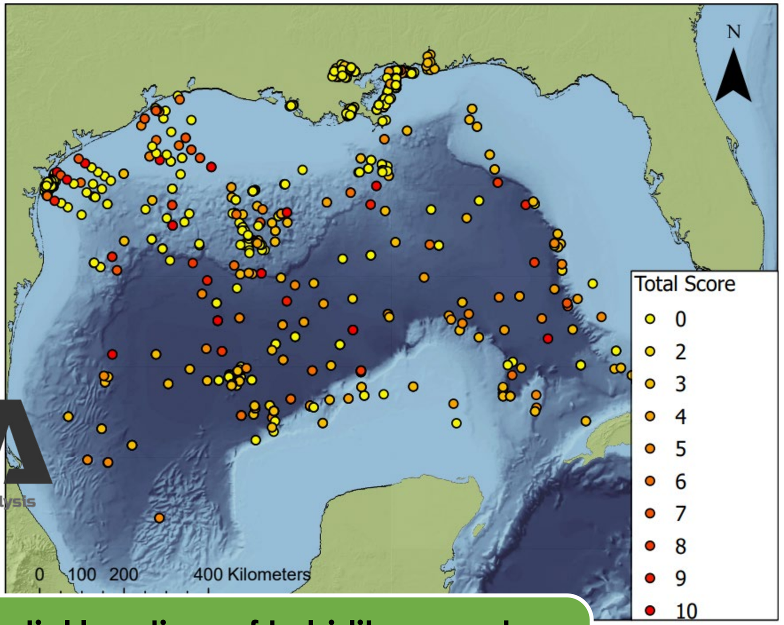
- Determine current state of knowledge regarding hazardous metocean and bathymetric conditions, and data availability regarding these conditions and historic events.
- **EY19-EY21**: Evaluated if AI/ML models can be developed to better identify current hazardous metocean and bathymetric conditions. Developed, trained, and tested AI/ML models to identify conditions and forecast changes and vulnerabilities to offshore infrastructure. Refined Smart Tool to host AI/ML models and develop user interface. Developed forecasting and integrated selected hazard types into tool. Released desktop version at end of EY.
- **EY22**: Refine analytical logic and smart tool functionalities through user testing and development. Build metocean and seabed hazard database for release on EDX. Report research in technical report or publication.
- **EY23+:** Strategize conversion of OGA Tool to online platform. Submit integrated seabed hazard database for release to EDX. Continue to produce technical publication(s).

Benefit:

- Improved characterization of metocean and seabed related hazards in the offshore can help prevent catastrophic incidents that impact the environment, coastal communities, and their economies while supporting offshore energy and carbon storage efforts.



Average bottom current velocity (12 yr.)

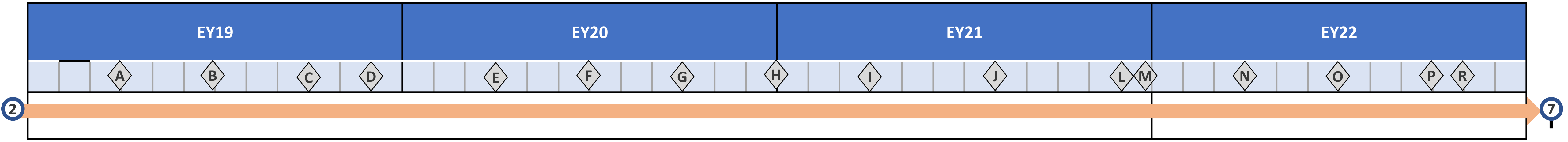


Potential locations of turbidity currents throughout the Gulf of Mexico based on text extraction core analysis

Offshore Unconventional FWP

Key Team Members: PI – Jennifer Bauer - CO-PI – Mackenzie Mark-Moser, Rodrigo Duran

Task 6: Infrastructure and Metocean Technology



Milestones

Number	Date	Description
EY21.6.I	06/2021	List summarizing identified improvements and enhancements for analytical logic and smart tool.
EY21.6.L	02/2022	Internal release of the Ocean & Geohazard Analysis tool, desktop version, to EDX.
EY21.6.M	03/2022	Evaluate TRL for smart tool and determine if additional development or enhancements are needed to obtain target TRL.
EY22.6.N	06/2022	List summarizing tool enhancements priorities identified by user testing on OGA Version 1.
EY22.6.O	09/2022	Draft manuscript(s) of individual smart tool model(s) or algorithm(s) completed
EY22.6.P	12/2022	List optimizations made to the Ocean & Geohazard Analysis tool.
EY22.6.Q	01/2023	Assemble metocean and seafloor database to support smart tool analysis.
EY22.6.R	06/2023	Strategize conversion of Ocean & Geohazard Analysis tool to online platform.
EY22.6.S	10/2023	Update integrated metocean and seabed hazard database for management review and approvals to release on EDX.
EY22.6.T	12/2023	Outline a technical report or additional publications.

Chart Key

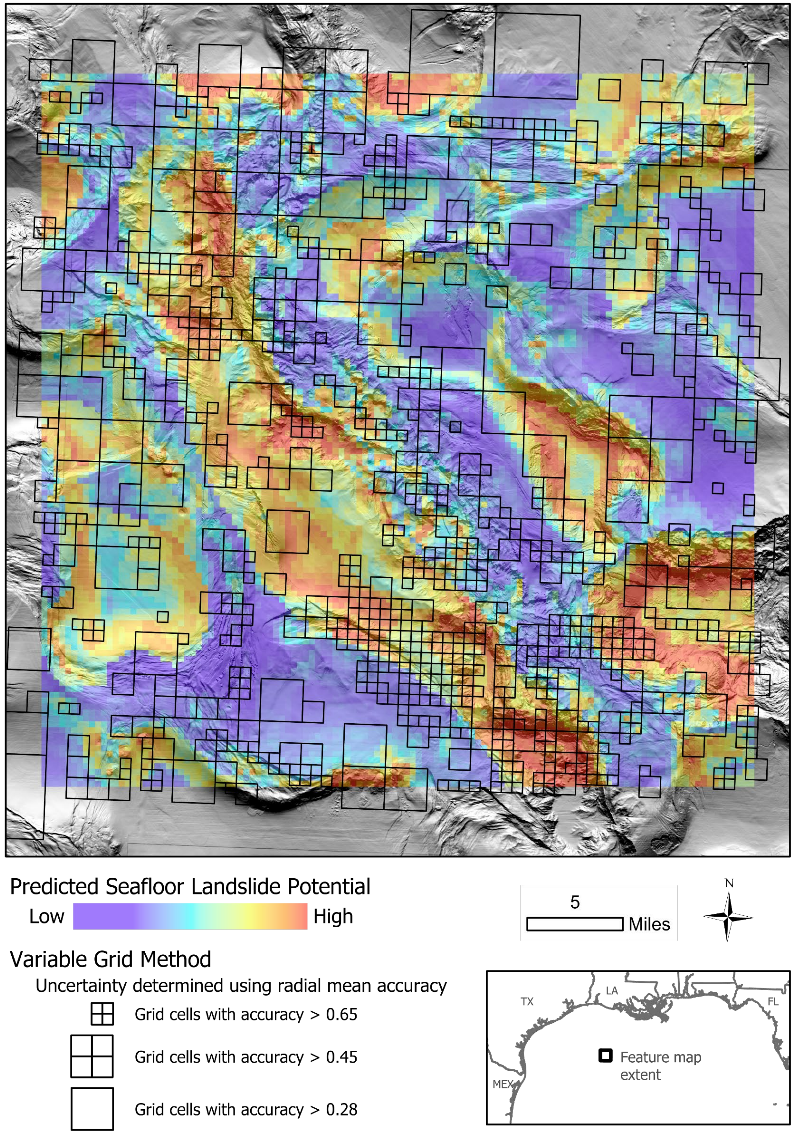
\# TRL Score | Go / No-Go Timeframe | Project Completion | Milestone

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



Publications, Datasets & Presentations

NATIONAL ENERGY TECHNOLOGY LABORATORY

Publications

- Dyer, A.S., Mark-Moser, M., Duran, R., Bauer, J.R. (submitted) Submarine Landslide Susceptibility in the Northern Gulf of Mexico. Natural Hazards, Springer.
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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
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