Infrastructure and Metocean Technology: The Ocean and Geohazard Analysis Tool
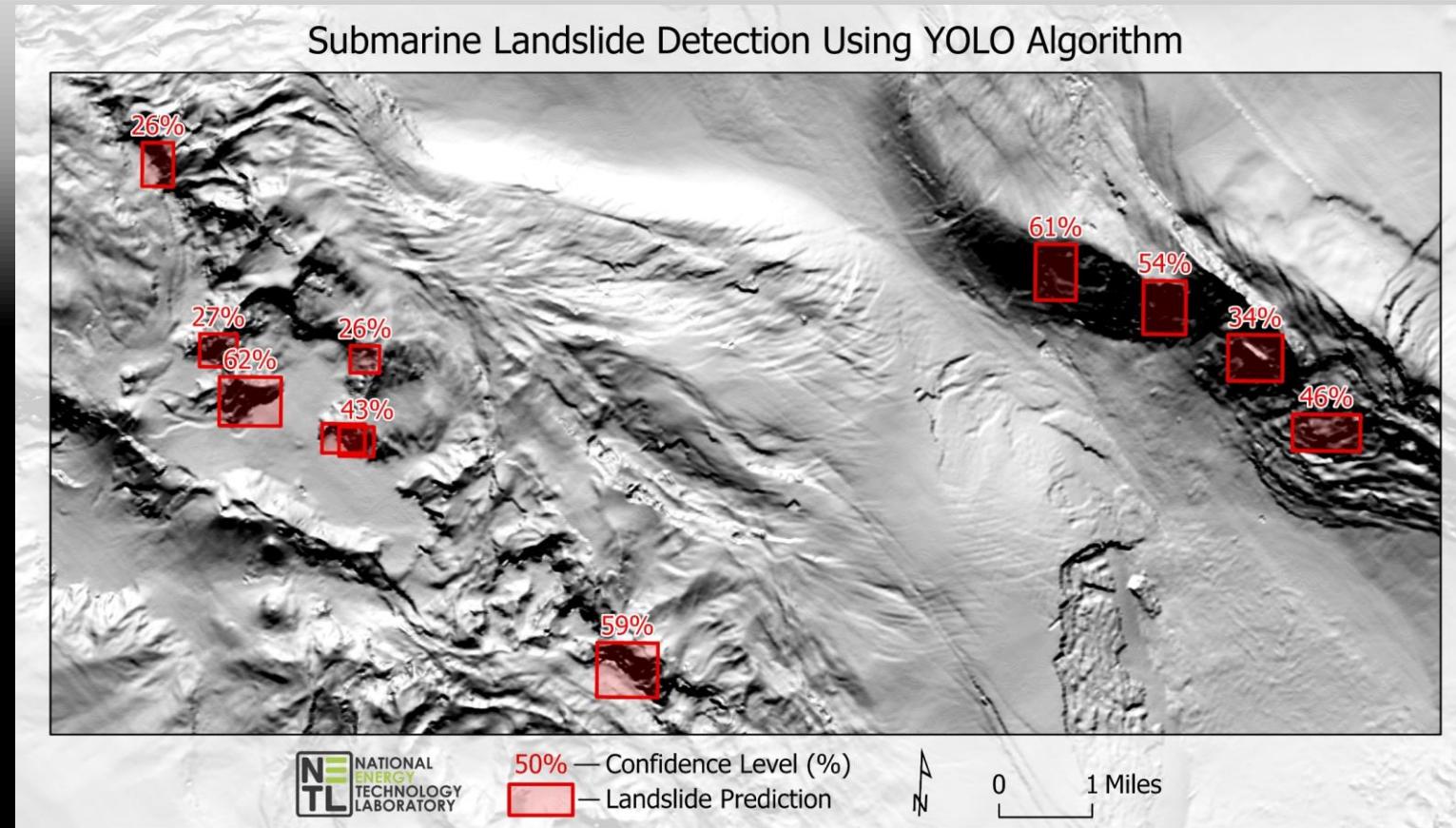
MacKenzie Mark-Moser
Rodrigo Duran
Co-PIs, Offshore FWP Task 6

NETL
NATIONAL ENERGY TECHNOLOGY LABORATORY

Submarine Landslide Detection Using YOLO Algorithm

NETL Resource Sustainability Meeting
Oct. 27, 2022

Disclaimer

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Offshore FWP, Task 6 Team

PIs: MacKenzie Mark-Moser[1,2], Rodrigo Duran[1,2,3], Jennifer Bauer[1]

Researchers: Patrick Wingo[1,2], Dakota Zaengle[1,2], Izzy Pfander[1,2], Cat Schooley[1,2], Chukwuemeka Okoli[1,2], Kelly Rose[1]

[1]*National Energy Technology Laboratory, 1450 Queen Avenue SW, Albany, OR 97321, USA*

[2]*NETL Support Contractor, 1450 Queen Avenue SW, Albany, OR 97321, USA*

[3]*Theiss Research, 7411 Eads Avenue, La Jolla, CA 92037, USA*

Offshore Task 6: Infrastructure and Metocean Technology

Projected significant wave height in the Gulf of Mexico (GOM) for a future climate.
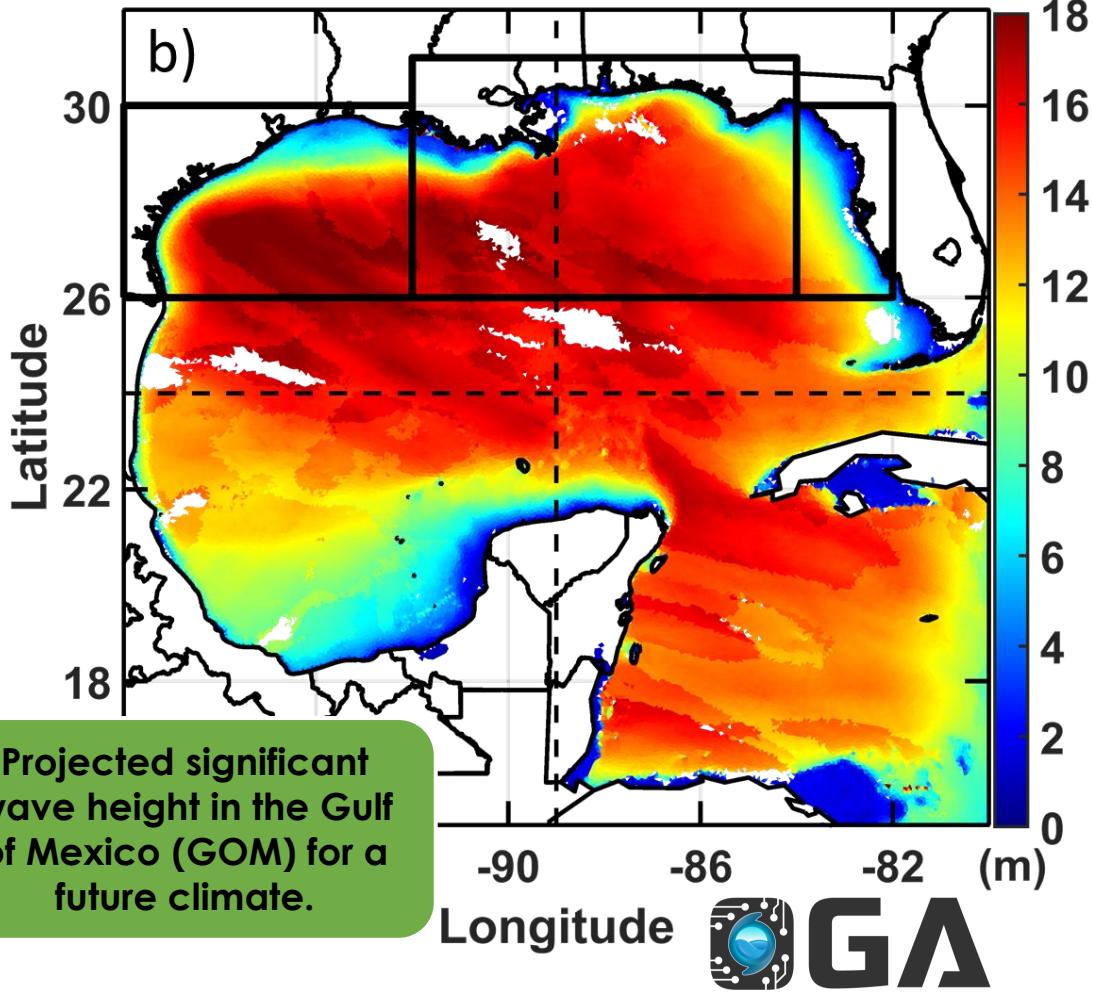
Why is this work important?

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.
- Packaging analytics in a **flexible smart tool** improves accessibility and forecasting at multiple scales.

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

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, increasing the frequency of major tropical cyclones.
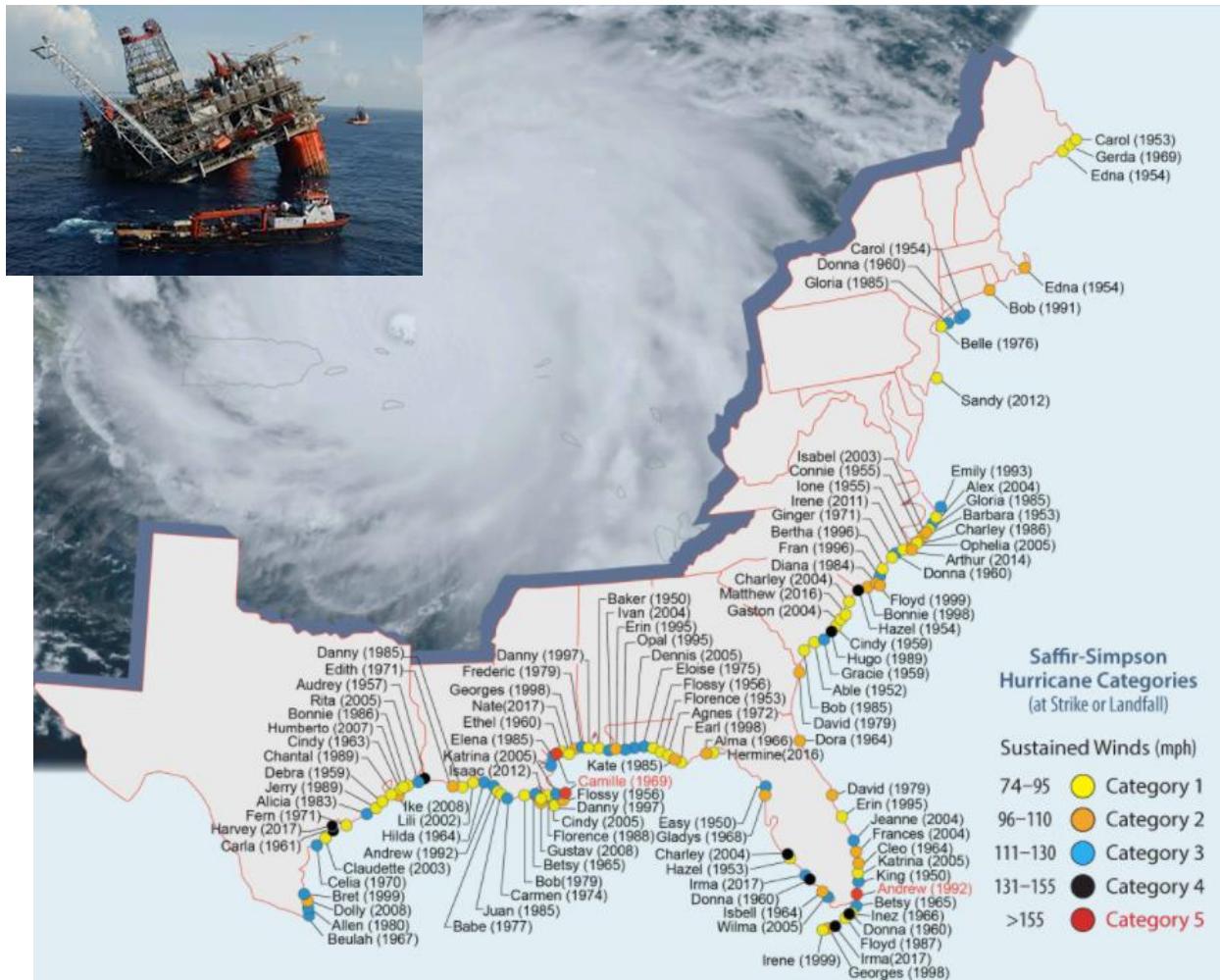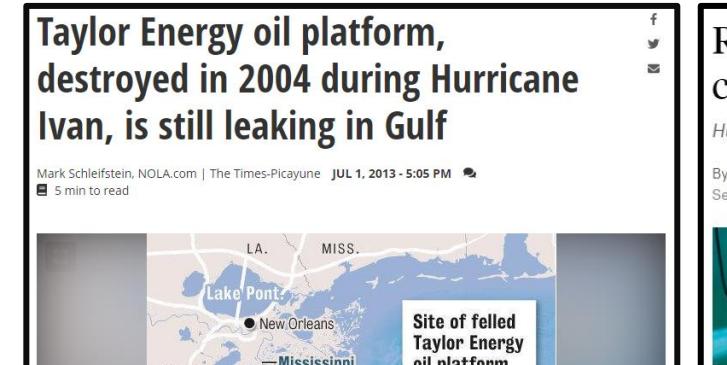
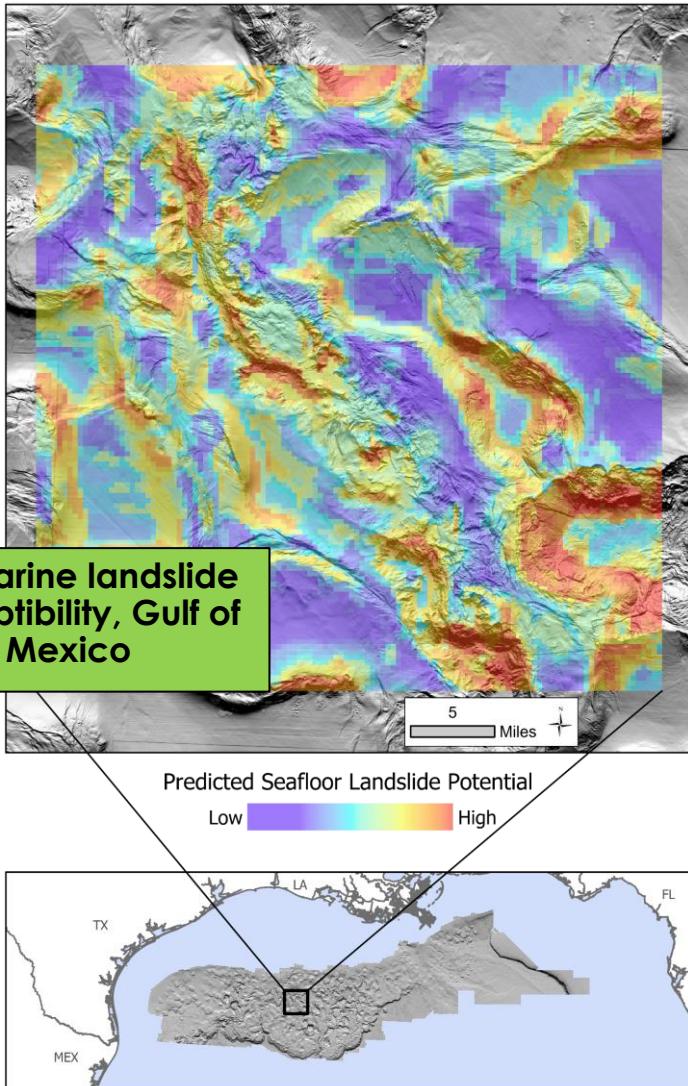# Motivation for AI/ML, Data-Driven Offshore Hazard Tools

- 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.** Example: Hurricanes are offshore hazards and drivers of other hazards, such as submarine landslides, that can, in turn, cause an oil spill.

Ongoing R&D for AI/ML Analyses

Submarine landslide susceptibility, Gulf of Mexico

Predicted Seafloor Landslide Potential
Low ——— High

5 Miles

OGA
Ocean & Geohazard Analysis

- Assessing offshore hazards often requires massive amounts of data and length of time to assess the entire system

- AI/ML analytics can offer near real-time assessment of risks, integrate different hazard types, and forecast vulnerabilities

- Selecting, training, and testing of AI/ML algorithms is key to an effective AI/ML-informed workflow

- 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

Choose offshore region of interest

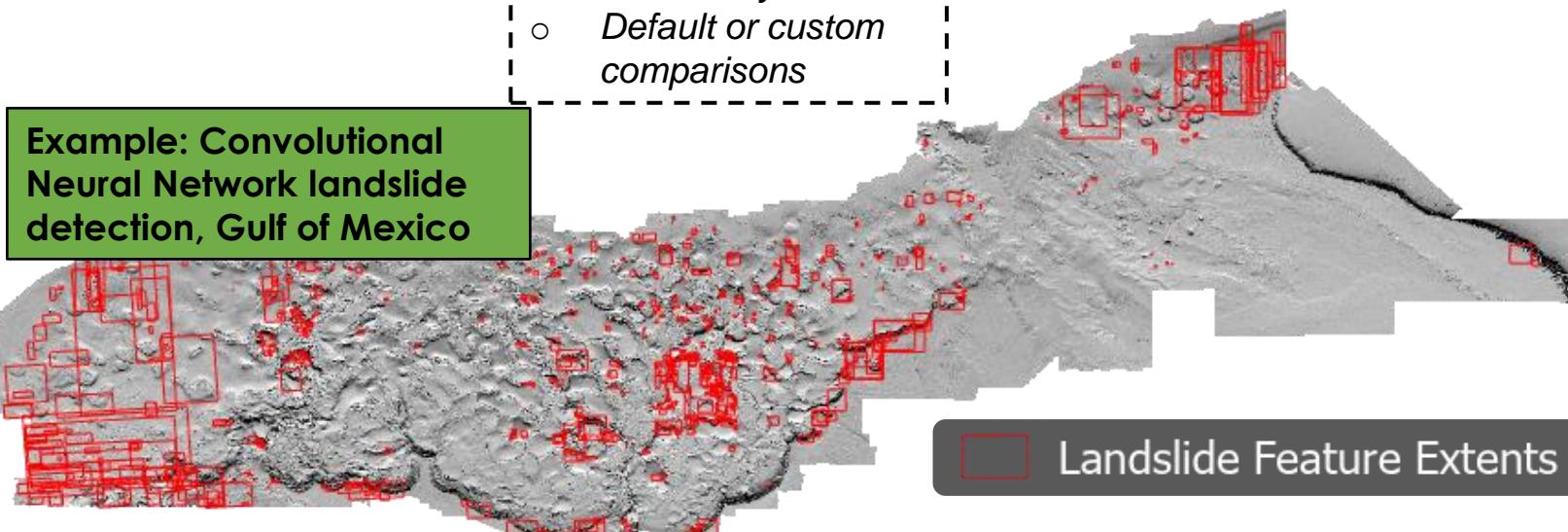Select hazards for risk assessment

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

Example: Convolutional Neural Network landslide detection, Gulf of Mexico

Landslide Feature Extents

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**
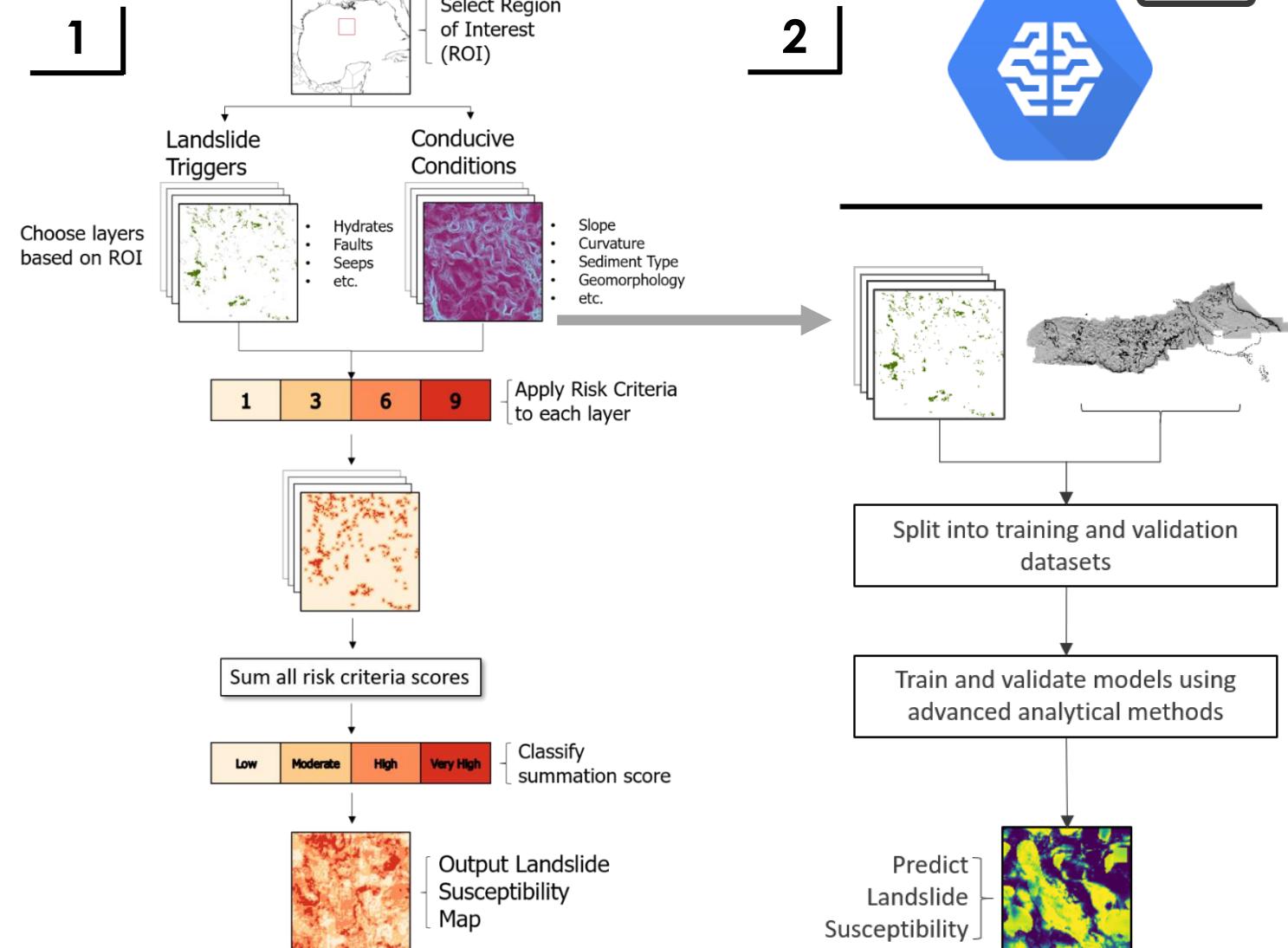
OGA Tool Hazard Components

- Analyses are **selected for suitability** of predicting a given hazard or condition

- Each analysis is developed, validated, and prepped for **integration into OGA Tool**

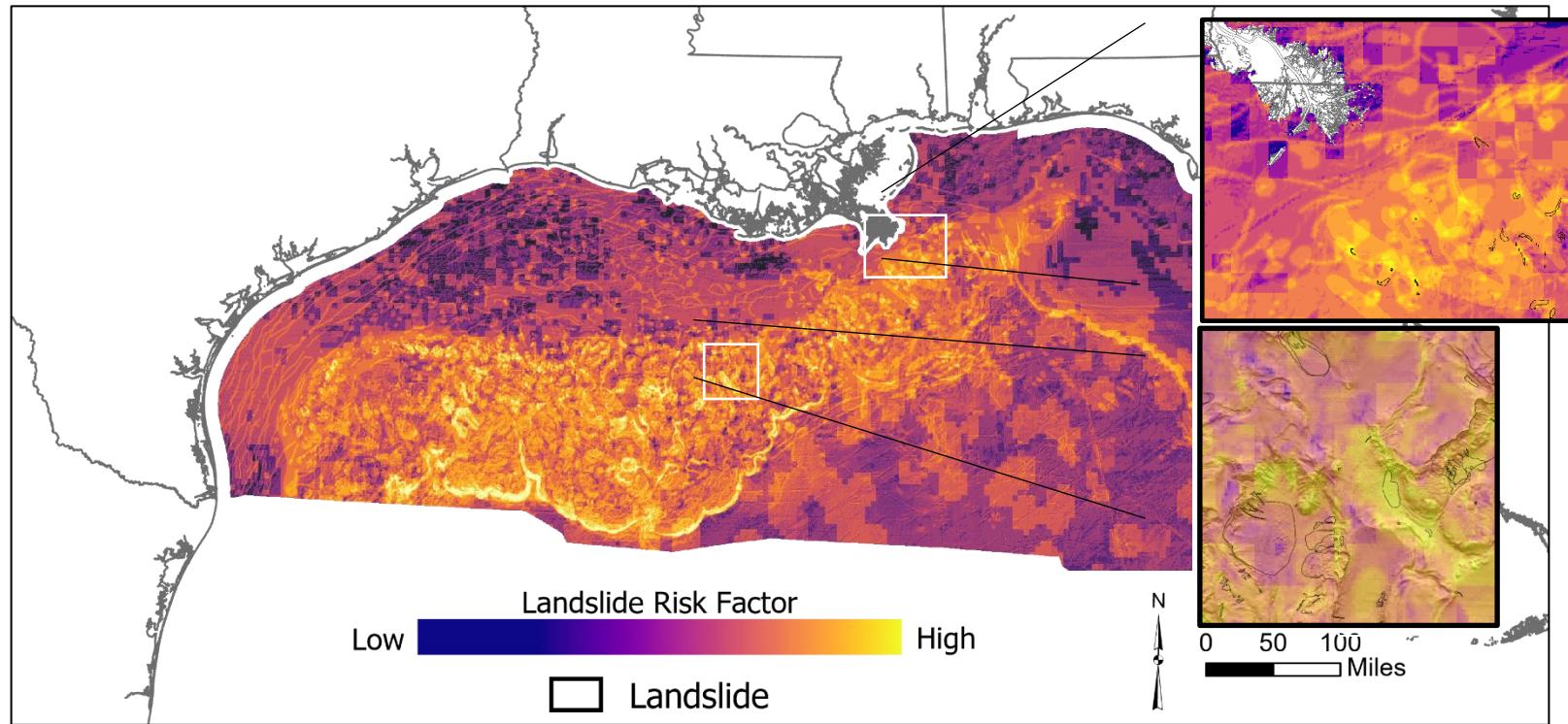| Hazard and/or Process	Analysis Approach(s)
Landslide susceptibility	GIS (risk-based) Machine learning
Landslide detection	Convolutional neural network
Turbidity current susceptibility	GIS interpolation AI/ML spatial analysis
Wave height	Synthetic storm events simulate future extreme events under climate 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

Landslide Susceptibility

Two approaches for analyzing seafloor landslide potential in the GOM

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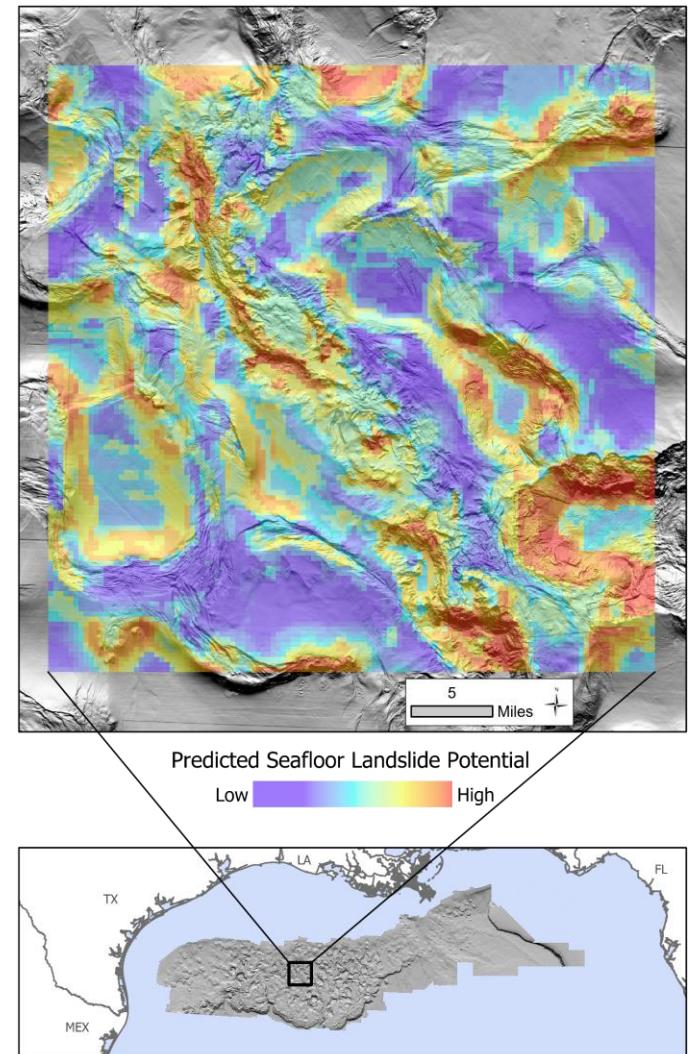
2. *Machine Learning (ML) Approach*

Landslide Susceptibility

Landslide Risk Factor

Low — High

☐ Landslide

N

0   50   100   Miles

Predicted Seafloor Landslide Potential

Low — High

5 Miles

**Two approaches** for analyzing seafloor landslide susceptibility in the GOM

1. *Risk-based GIS Approach (above)*

2. *Machine Learning (ML) Approach (at right)*

Landslide Susceptibility

- 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

Predicted Seafloor Landslide Potential
Low — High
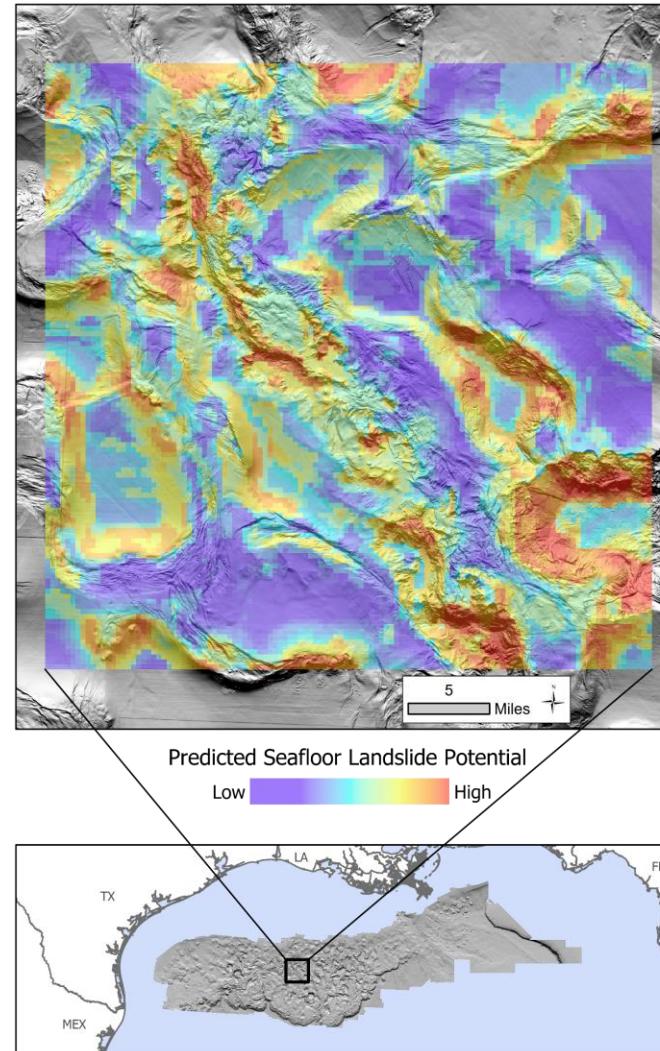
Accuracy evaluated against validation dataset
GBC: 70.0%
ANN: 65.3%

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 1950s, primarily studied in 1970s and 1980s.

- 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
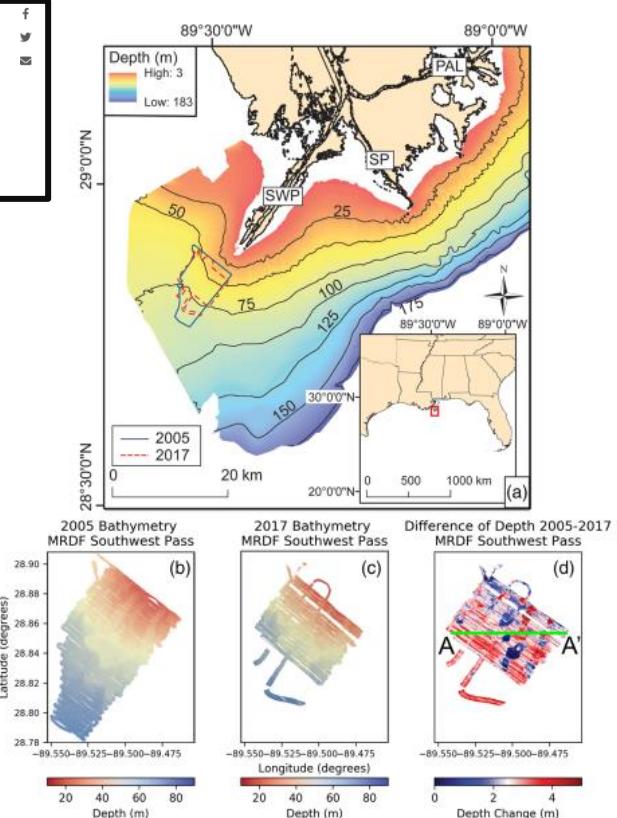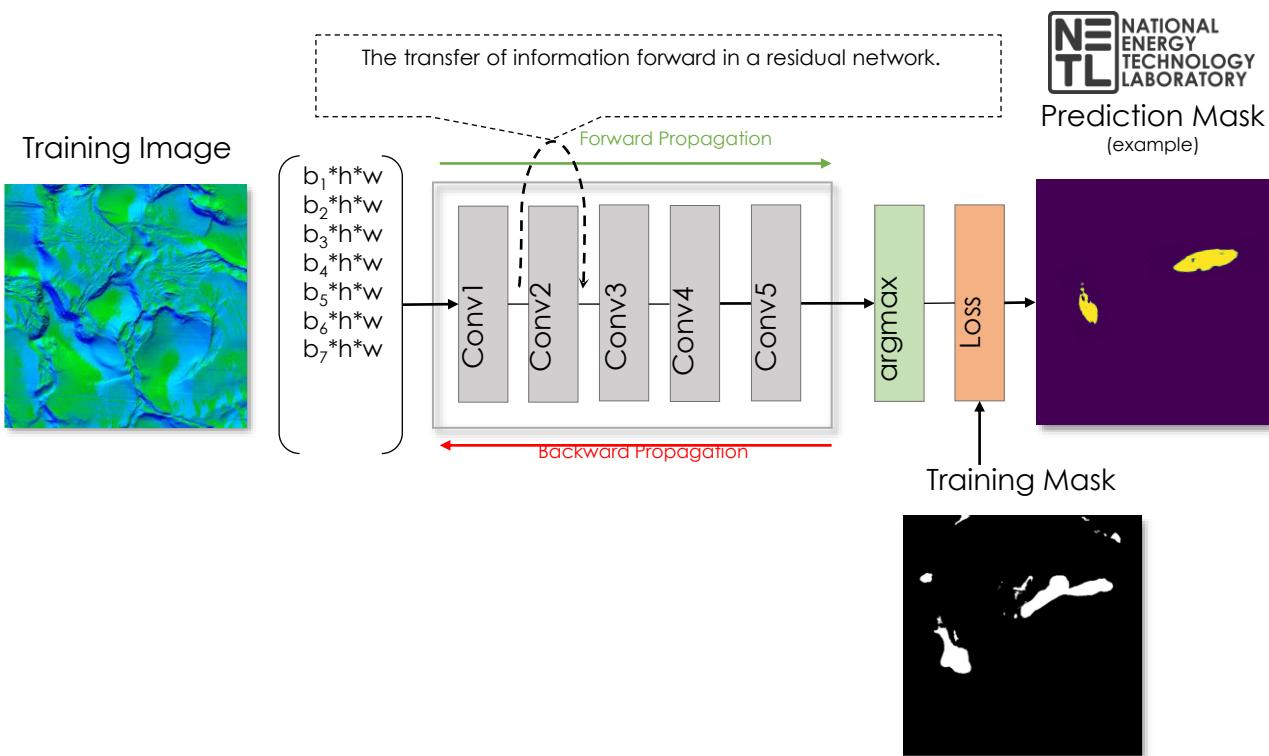
5 min to read

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

Landslide Detection

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

Training Image

The transfer of information forward in a residual network.

Forward Propagation

Backward Propagation

Conv1 Conv2 Conv3 Conv4 Conv5 argmax Loss

Prediction Mask (example)

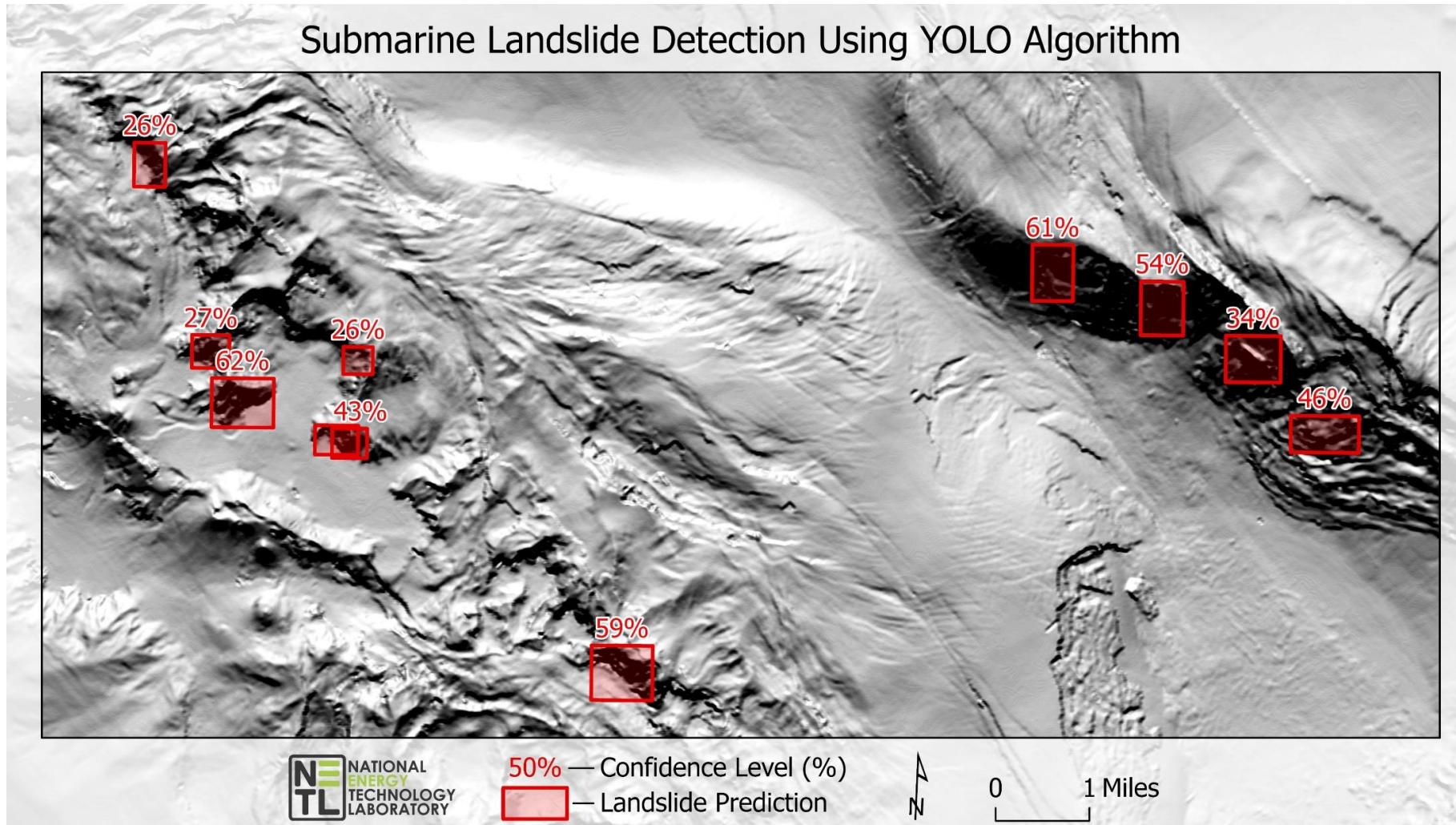Training Mask

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.
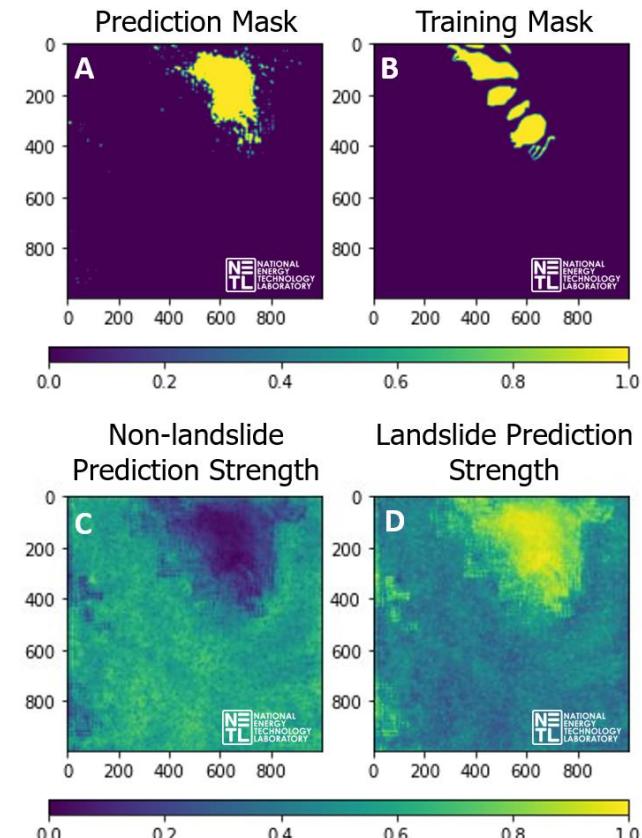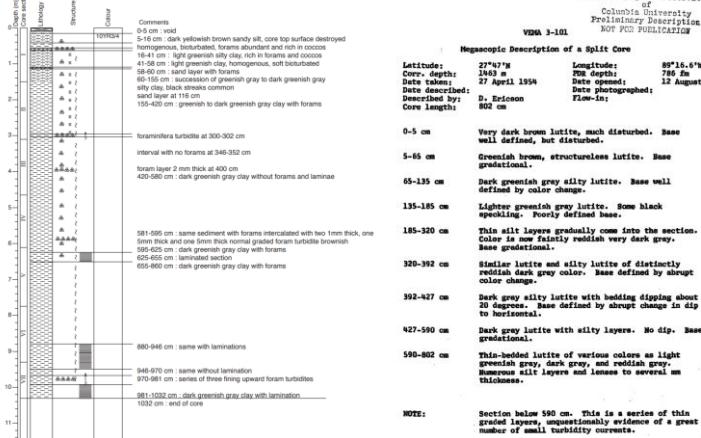
Landslide Detection Results

Turbidity Current Hazard Modeling

- Turbidity currents are significant and powerful offshore hazards
- Core analysis accelerated using text extraction can assist in locating potential turbidity currents
- Locations can be used to inform ML for turbidity current susceptibility mapping and forecasting
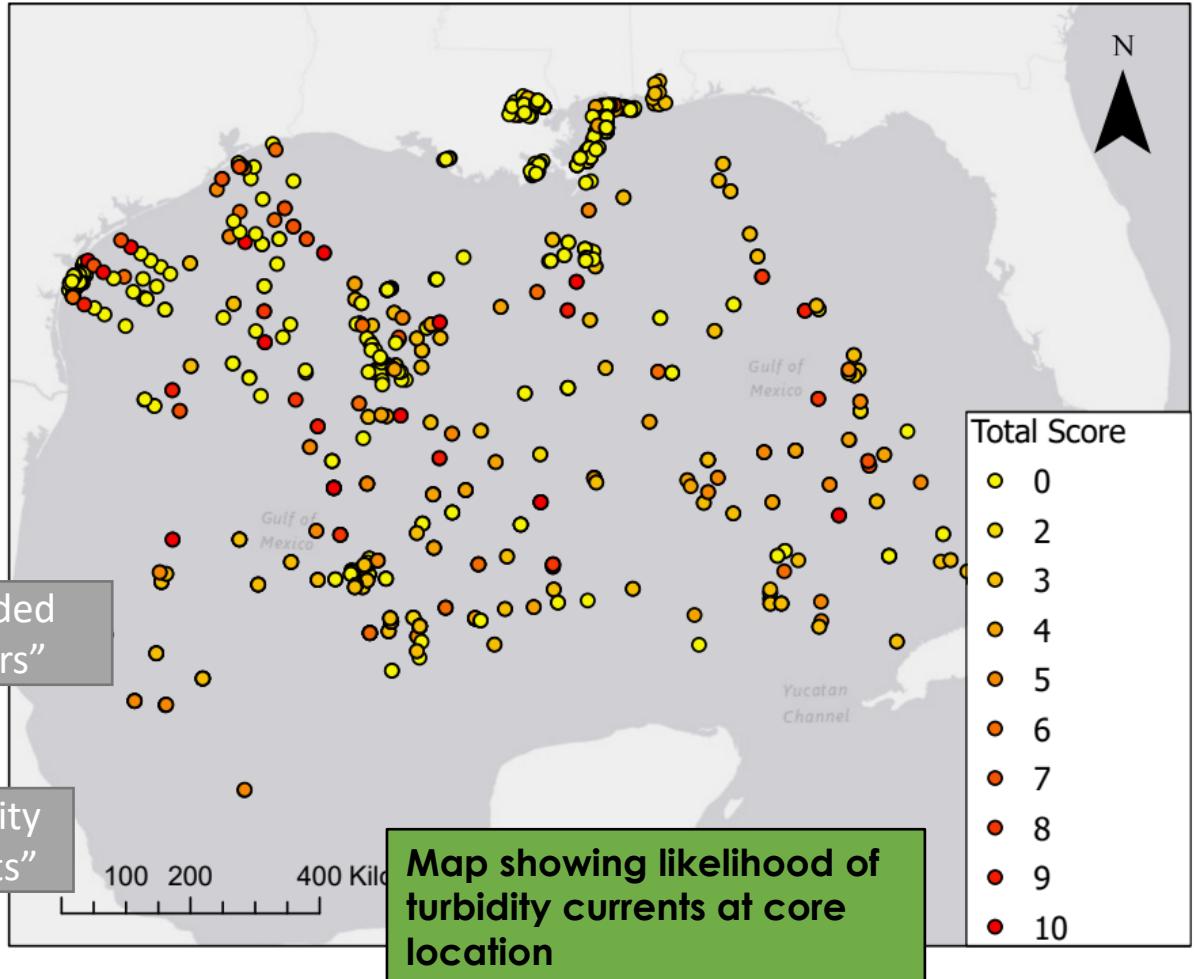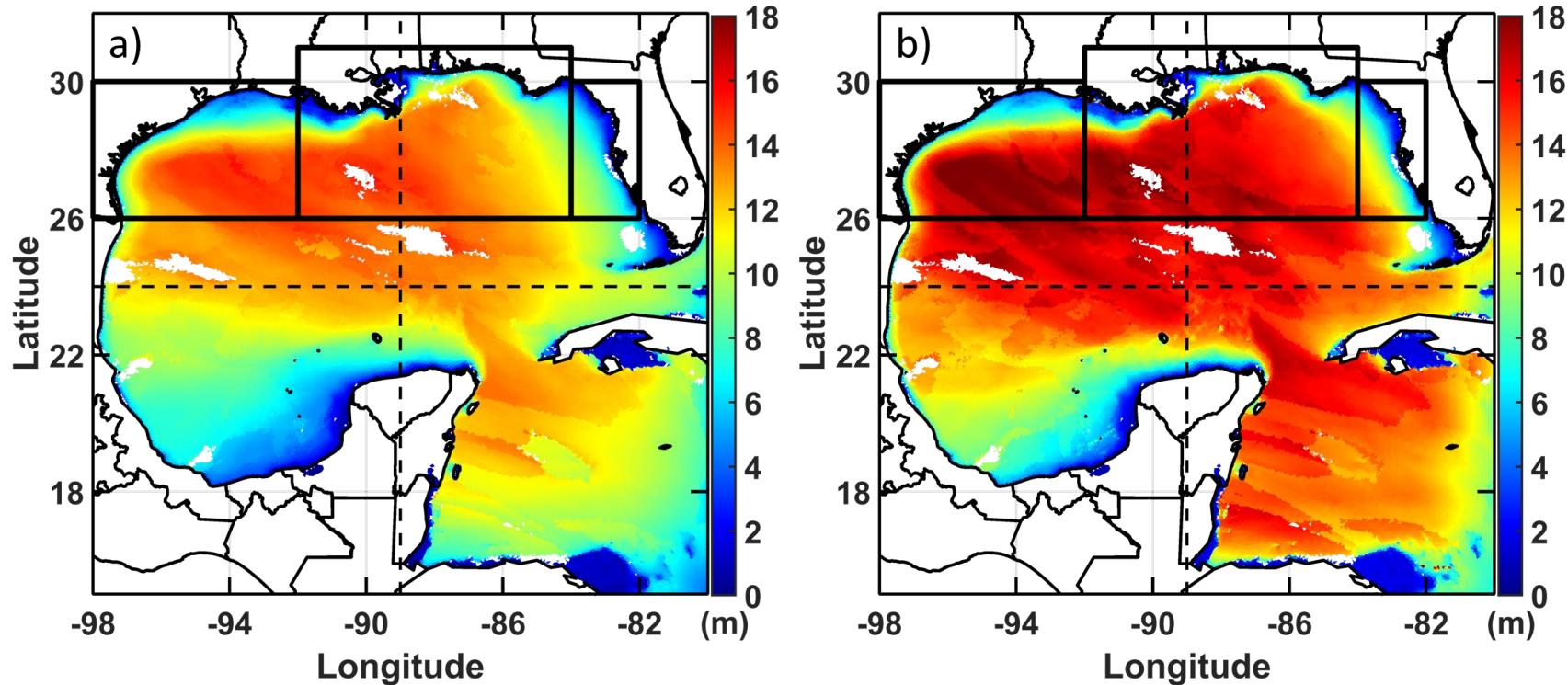

"turbidite"

"fining upward"

"foram turbidites"

"graded layers"

"turbidity currents"

Map showing likelihood of turbidity currents at core location

Total Score
- 0
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10

Wave Modeling Development

- Creating synthetic physics-based tropical cyclone events in collaboration with MIT

- 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.

Self-Organizing Maps – An Unsupervised Neural Network
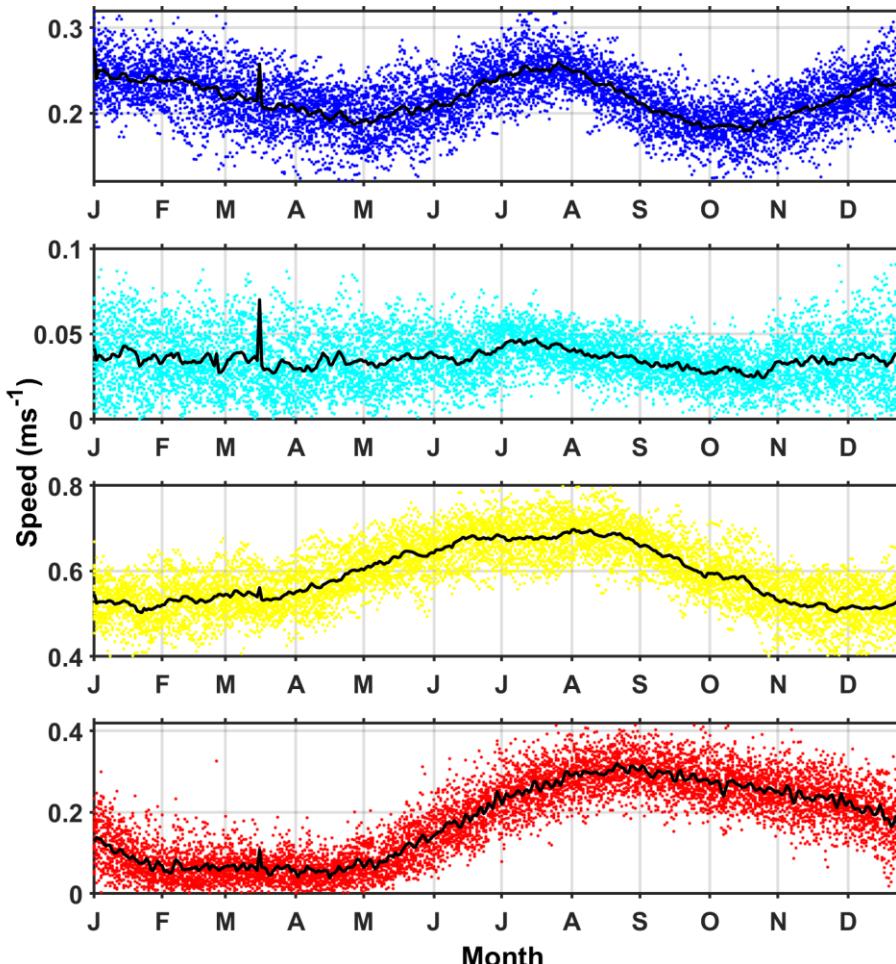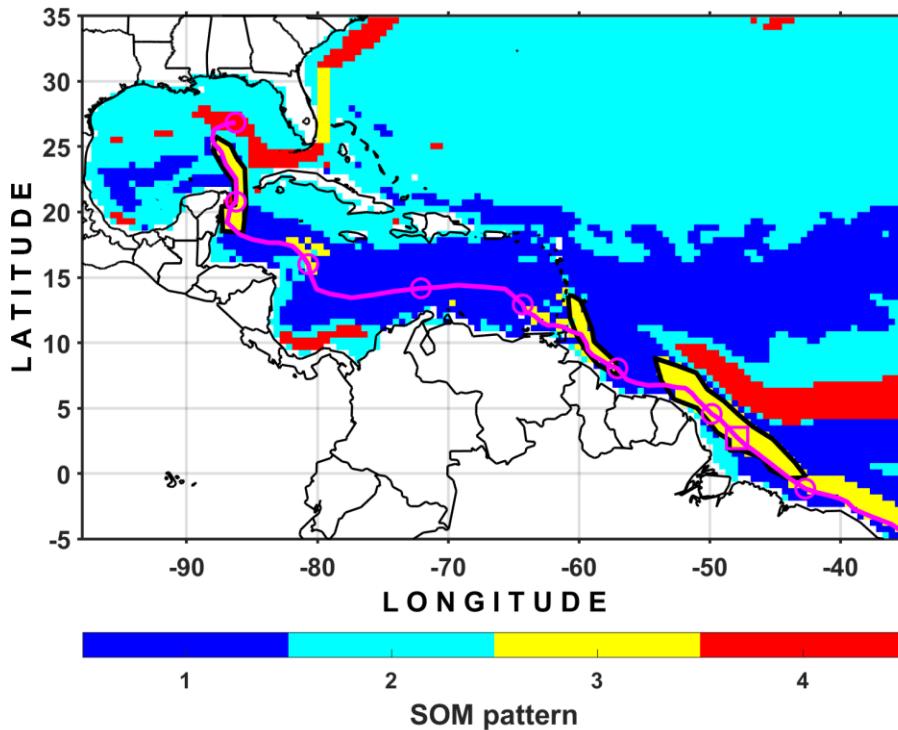
- Temporal patterns from self-organizing maps identifying predictable patterns in sea-surface velocity.

- 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
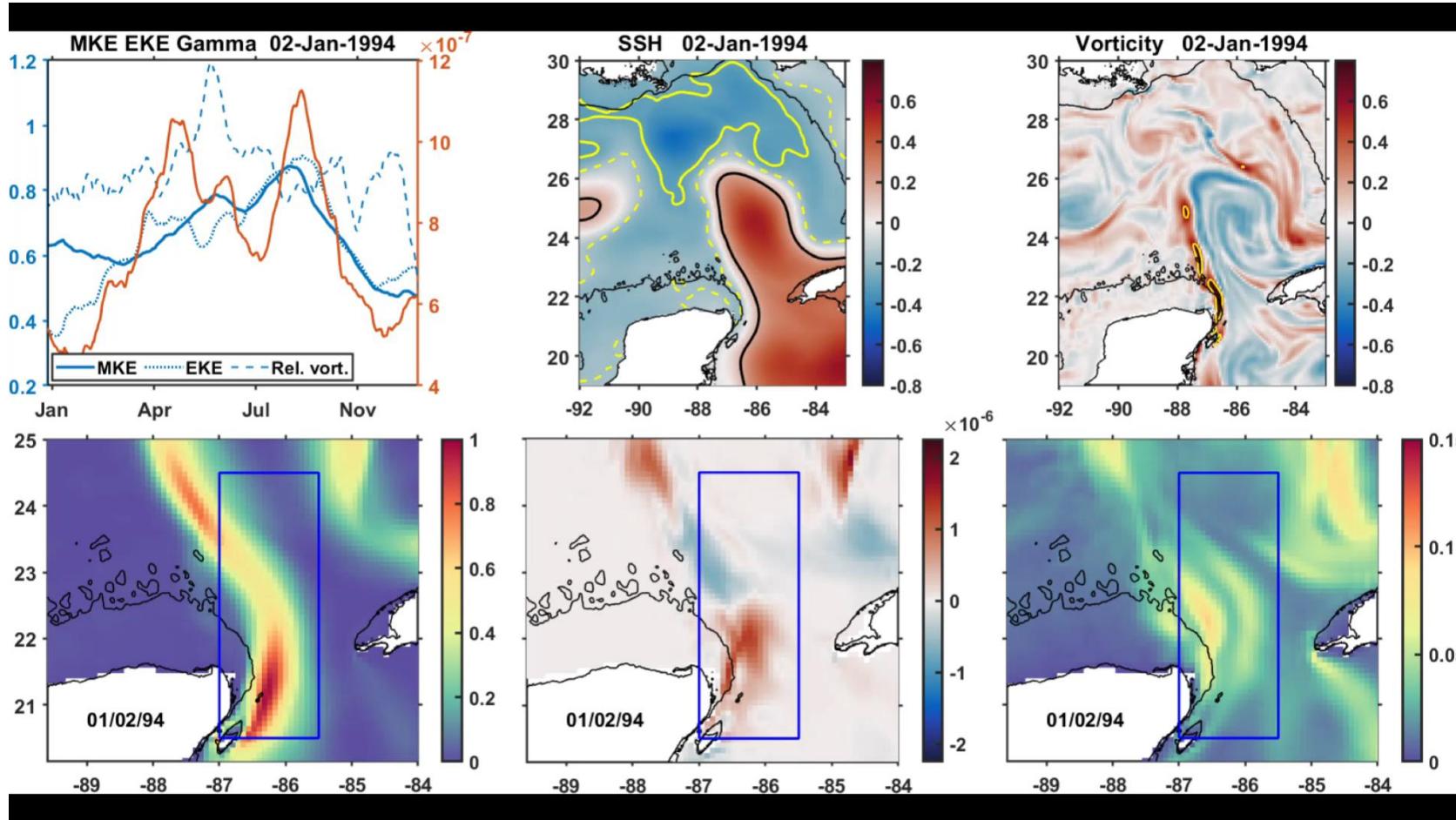
- The Loop Current (LC) and associated eddies are among the most intense currents in the world

- They 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
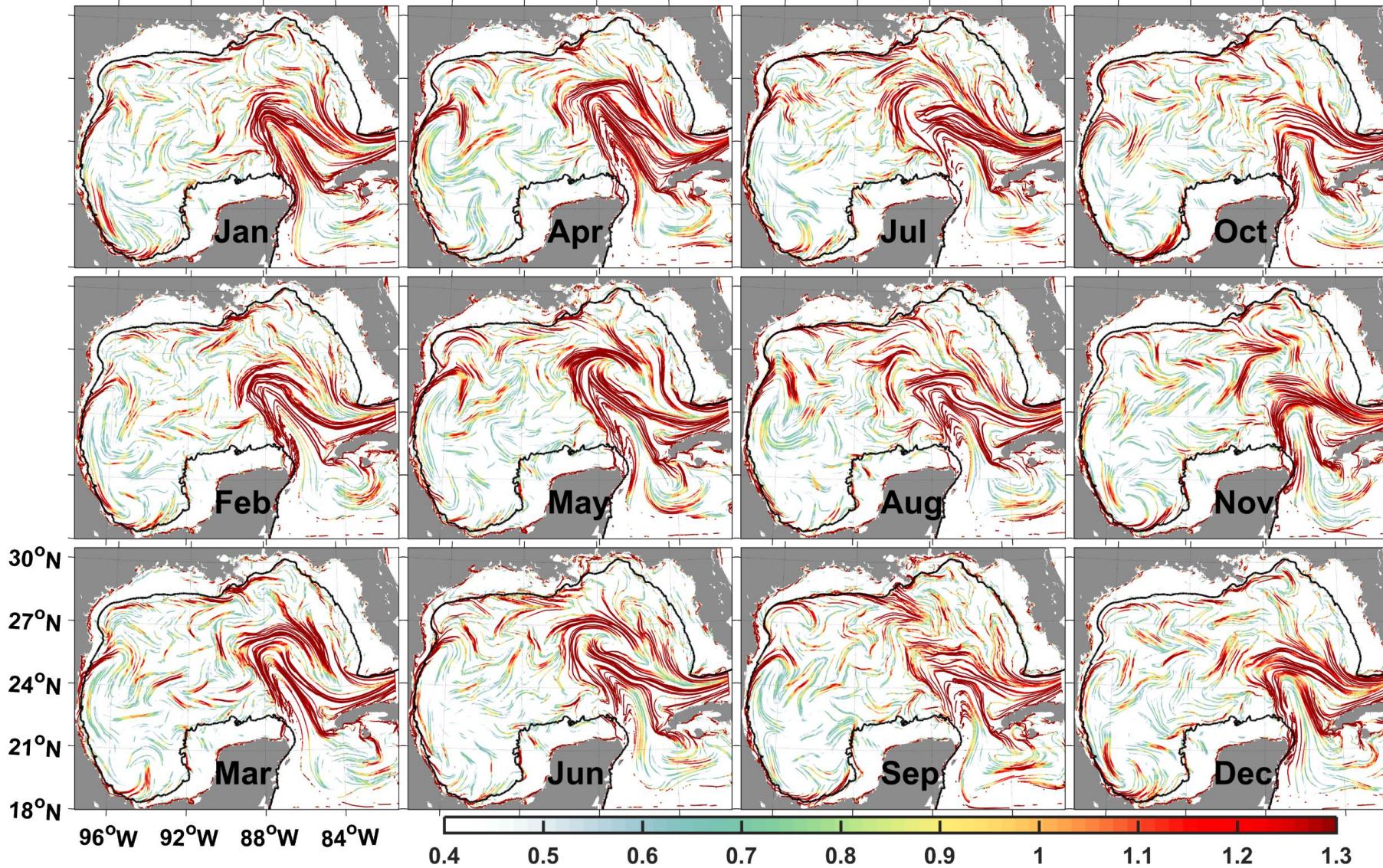
Metocean Pathways:
Red=attracting
White=isolated

Large shelves are isolated:
- WFS
- LaTex
- Yucatan

Advanced Probability and Statistics

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

Generalized Extreme Value (GEV) distributions for wind velocity

Indicates likelihood of extreme wind event

Also applied extreme waves and currents
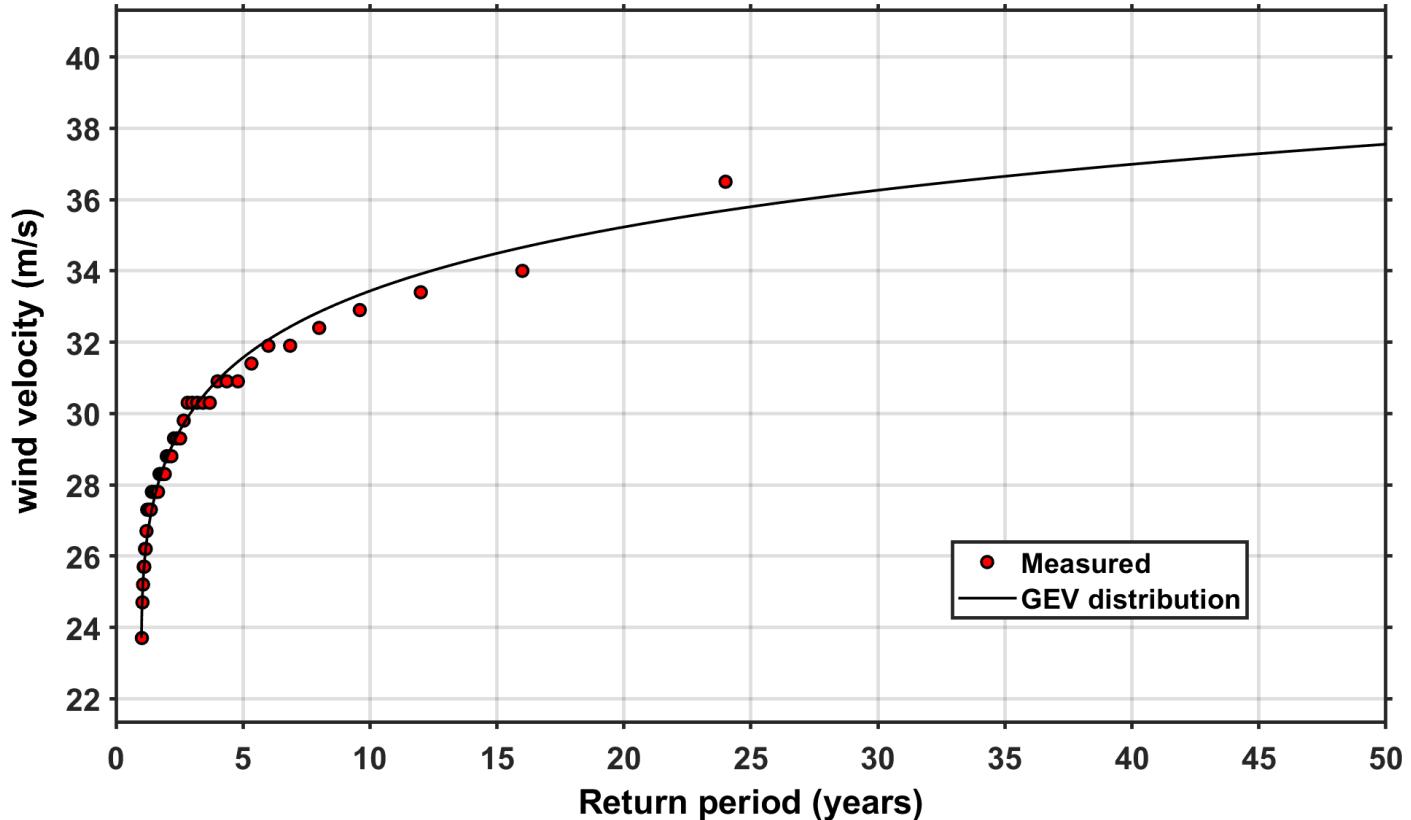
OGA Smart Tool Interface
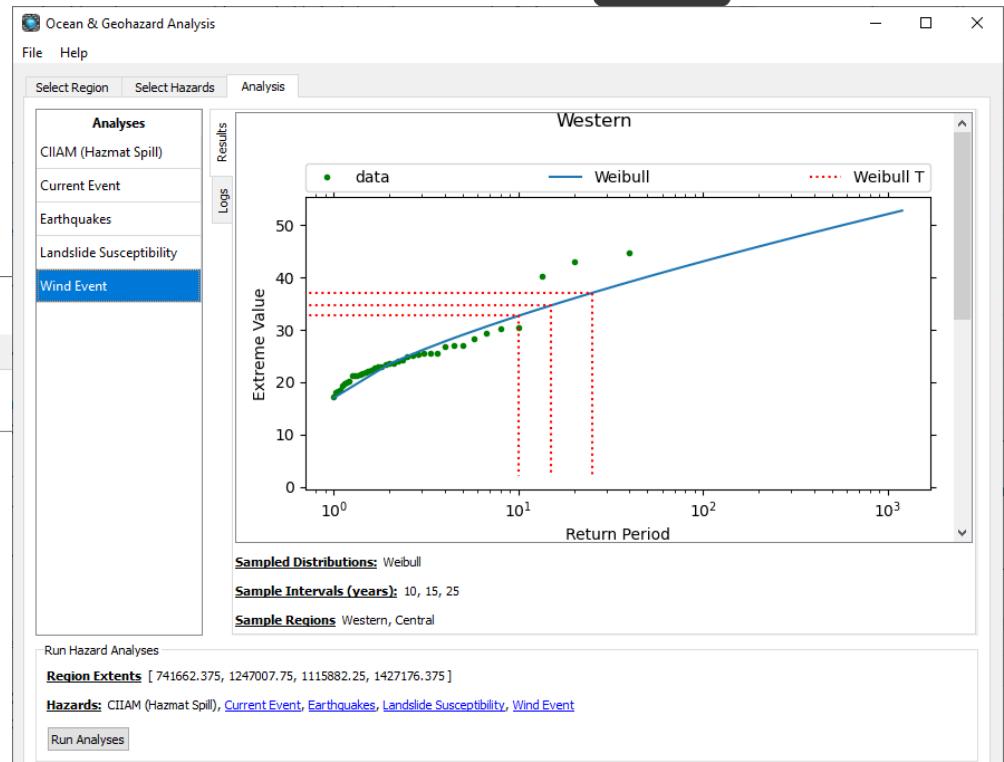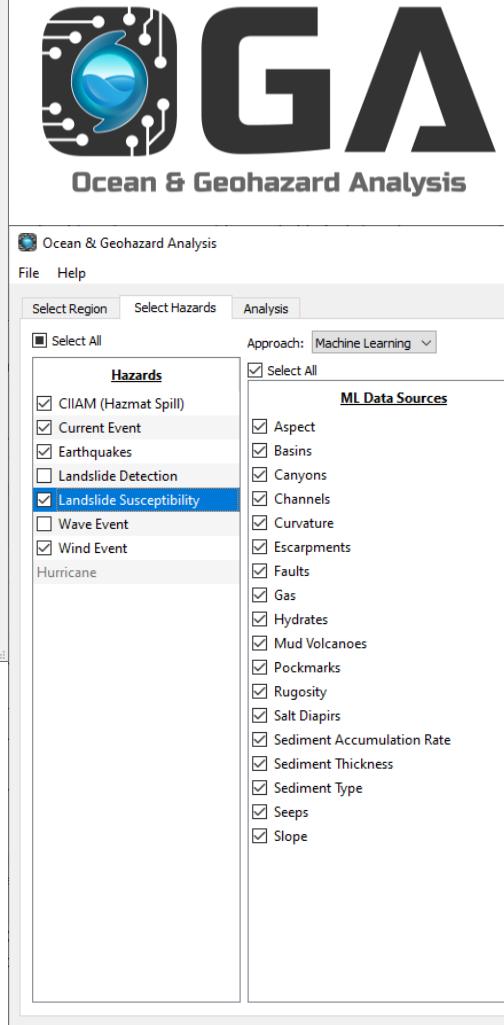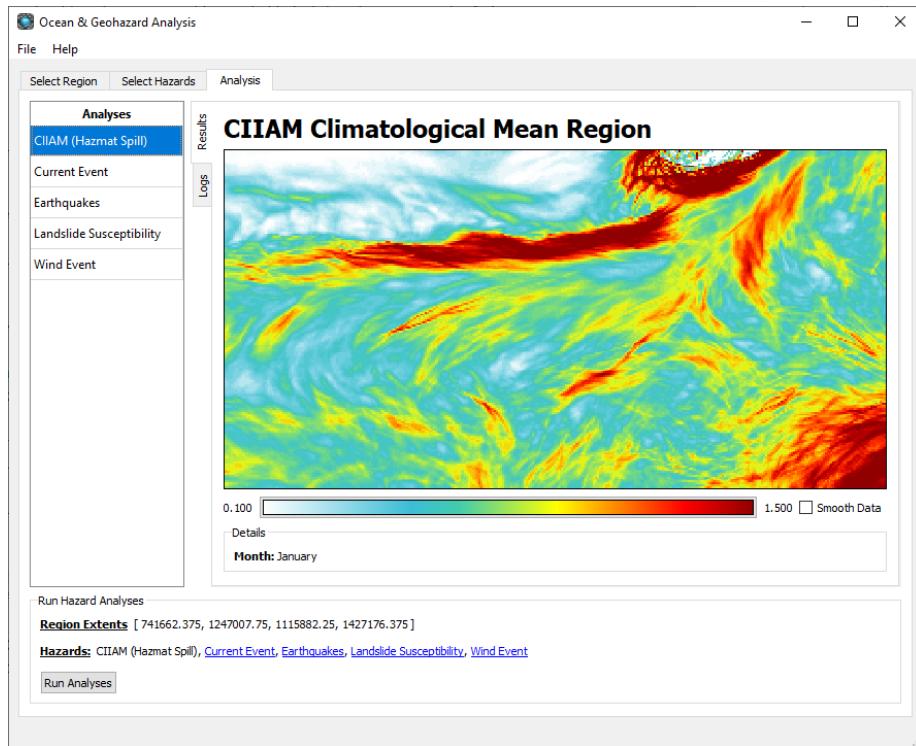
Smart Tool allows users to interact with their data and select or integrate appropriate models

Produces forecasts of areas more susceptible to metocean and seafloor hazards

Next Steps for OGA Tool

- 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 Tool available for download from EDX upon request

Email: MacKenzie Mark-Moser
Mackenzie.mark-moser@netl.doe.gov

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	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
USA	UNC at Chapel Hill	Atlantic wind	Preliminary results obtained

MOU for Collaboration

BOEM — Bureau of Ocean Energy Management

U.S. NAVAL RESEARCH LABORATORY

Potential external interest

LR Lloyd's Register

CSIRO

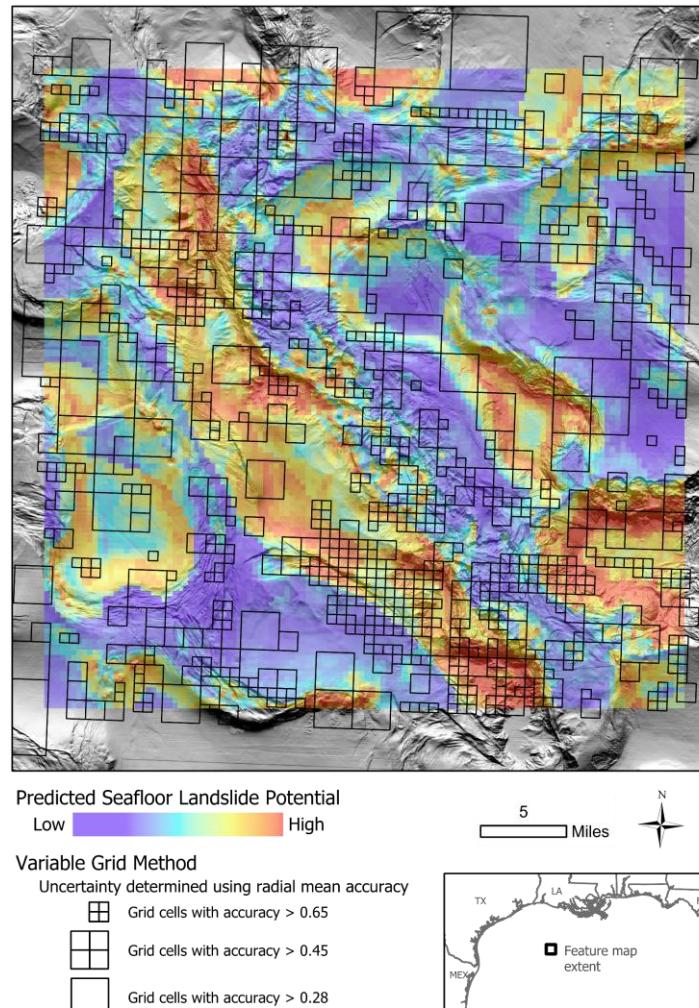CICESE

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 and 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

- Next steps are to integrate additional hazard analyses, validate tool, and strategize conversion to online tool

Predicted Seafloor Landslide Potential
Low — High

Variable Grid Method
Uncertainty determined using radial mean accuracy
- ⊞ Grid cells with accuracy > 0.65
- ⊞ Grid cells with accuracy > 0.45
- ☐ Grid cells with accuracy > 0.28

5 Miles

▢ Feature map extent

More information 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

OGA Ocean & Geohazard Analysis

NETL Resources

VISIT US AT: www.NETL.DOE.gov

(Twitter) @NETL_DOE

(Instagram) @NETL_DOE

(Facebook) @NationalEnergyTechnologyLaboratory

Contacts
r.duran@theissresearch.org
MacKenzie.Mark-Moser@netl.doe.gov
Jennifer.bauer@netl.doe.gov

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.
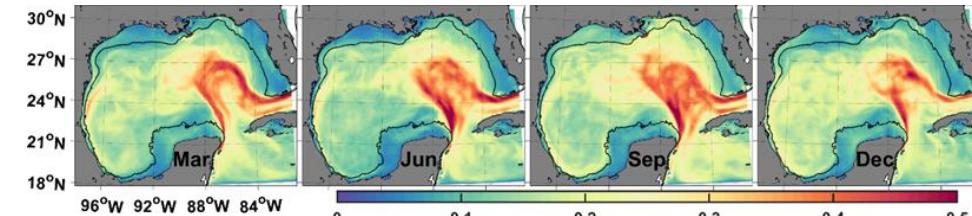
Average bottom current velocity (12 yr.)

OGA
Ocean & Geohazard Analysis
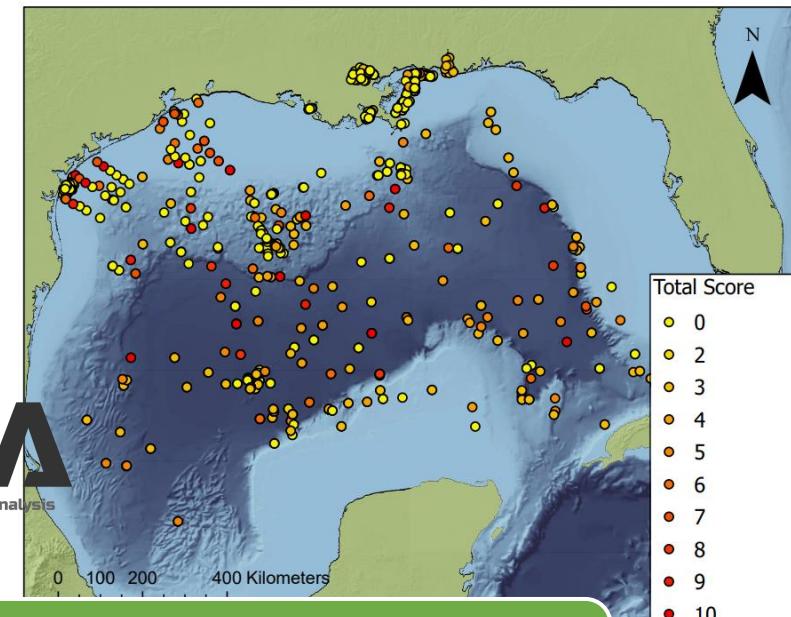
Potential locations of turbidity currents throughout the Gulf of Mexico based on text extraction core analysis

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

**NETL** NATIONAL ENERGY TECHNOLOGY LABORATORY

Task 6: Infrastructure and Metocean Technology

EY19	EY20	EY21	EY22
A B C D	E F G H	I J L M	N O P R

② ──→ ⑦
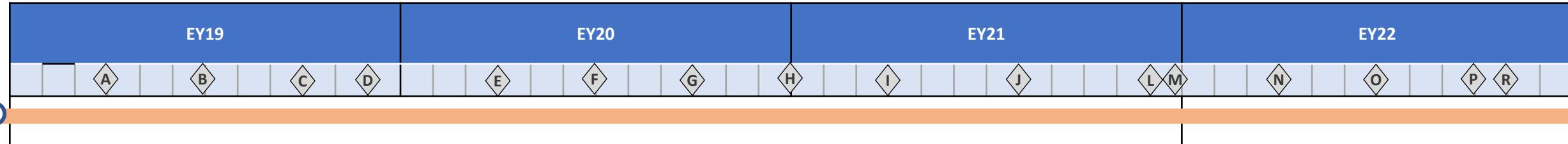
Milestones

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

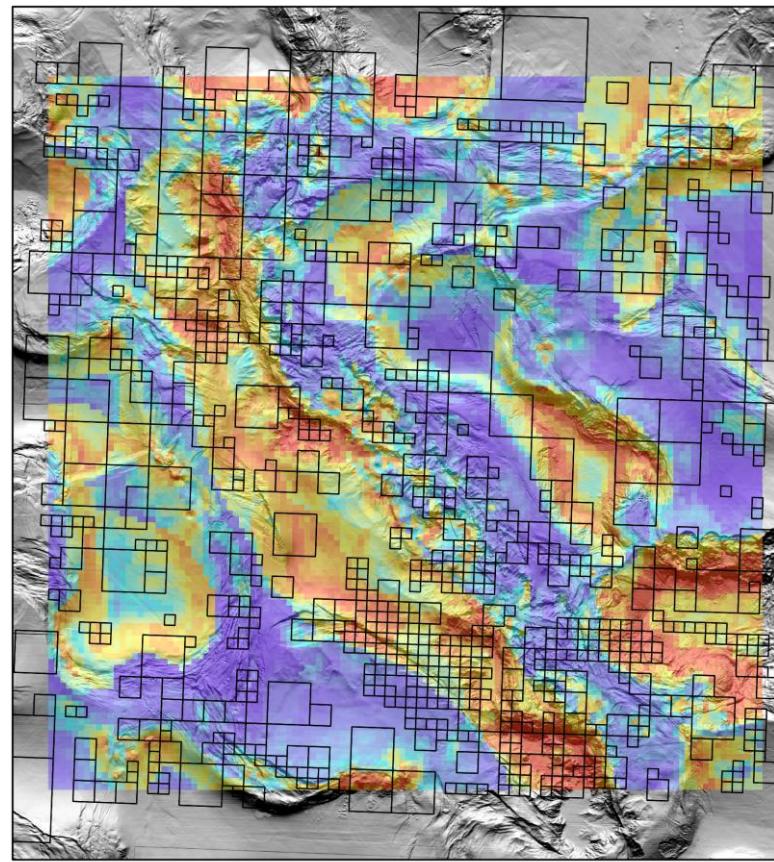⊕ # TRL Score | Go / No-Go Timeframe | Project Completion ◇ Milestone
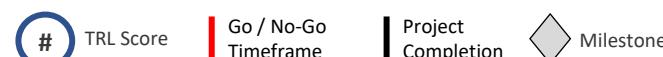
Landslide Susceptibility Results

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**.
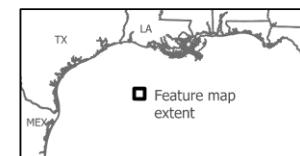

Predicted Seafloor Landslide Potential
Low — High

Variable Grid Method
Uncertainty determined using radial mean accuracy
- Grid cells with accuracy > 0.65
- Grid cells with accuracy > 0.45
- Grid cells with accuracy > 0.28

Publications, Datasets & Presentations

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.

- Alec Dyer, Scott Pantaleone, MacKenzie Mark-Moser, Andrew Bean, Paige Morkner, Samuel Walker, Jennifer Bauer, Historic Submarine Landslides in the Northern Gulf of Mexico, 8/8/2022, https://edx.netl.doe.gov/dataset/historic-submarine-landslides-in-the-northern-gulf-of-mexico, DOI: 10.18141/1879673

- Duran, R., T. Nordam, M. Serra and C. Barker (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 (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.

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