Assessing Current & Future Infrastructure Hazards:
Forecasting Platform Integrity with Machine Learning & Advanced Analytics for Reuse Optimization Strategies and Risk Prevention

PIs: Lucy Romeo[1,2] and Jennifer Bauer[1]

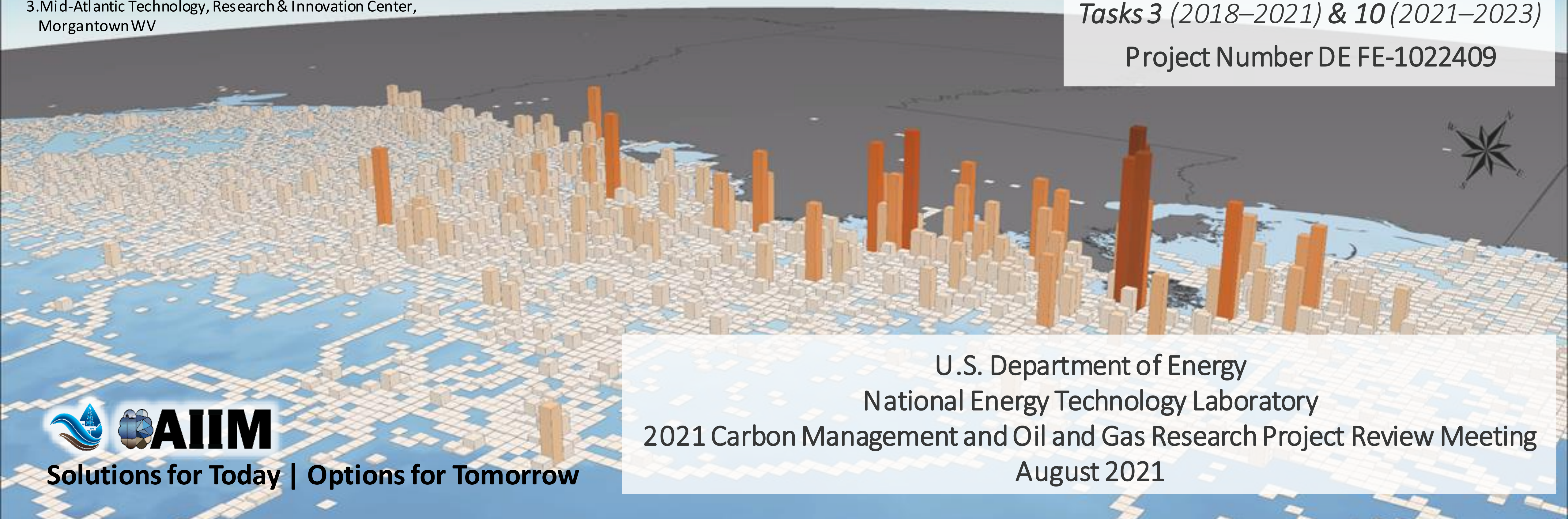
Key Personnel: Aaron Barkhurst[3], Rodrigo Duran[4], Alec Dyer[1,2], Jake Nelson[5], Kelly Rose[1], Michael Sabbatino[1,2], Madison Wenzlick[1,2], Patrick Wingo[1,2], Dakota Zaengle[1,2]

1. National Energy Technology Laboratory, Morgantown WV and Albany OR
2. NETL Support Staff, Morgantown WV and Albany OR
3. Mid-Atlantic Technology, Research & Innovation Center, Morgantown WV
4. Theiss Research, San Diego CA
5. Oak Ridge Institute of Science and Technology, Auburn AL

Offshore Unconventional Resources

Tasks 3 (2018–2021) & 10 (2021–2023)

Project Number DE FE-1022409



U.S. Department of Energy

National Energy Technology Laboratory

2021 Carbon Management and Oil and Gas Research Project Review Meeting

August 2021

AIIM

Solutions for Today | Options for Tomorrow

AIIM: Advanced Infrastructure Integrity Modeling

Applying smart, data-driven analytics to identify infrastructure opportunities and risks

Assessing Current and Future Infrastructure Hazards

- Built and cross-validated **machine learning (ML)** and advanced analytical models forecasting platform **remaining lifespan** & **risk**
- Develop, applied, and released **AIIM** framework data and results through **NETL Common Operating Platform** (COP)

Task 3: **Completed, June 2021**

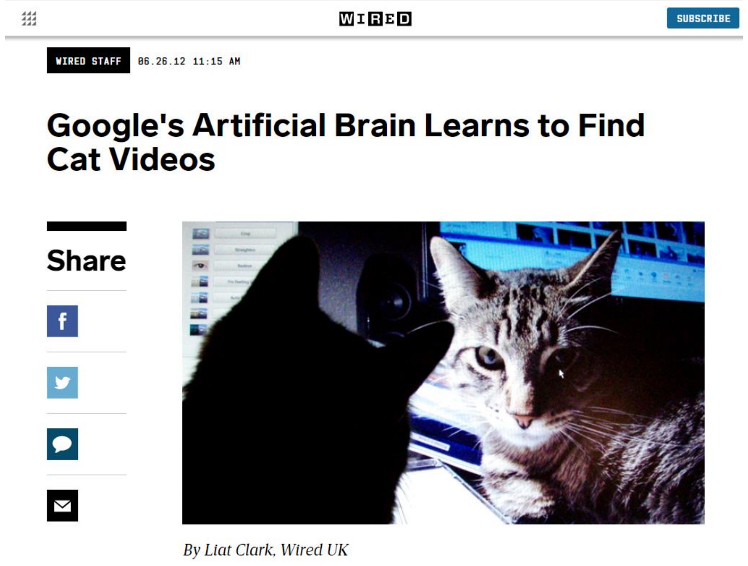
Smart Models to Optimize Use or Reuse of Production & Transport Infrastructure

- **Building off Task 3**, analyze permanent, semi-permanent, high-risk infrastructure (platforms, pipelines)
- Build a **smart modeling tool** to evaluate long-term integrity
- Assess **environmental** & **operational impacts** for more environmentally prudent planning

Task 10: **New Start, April 2021**

A few definitions to set the stage…

- **Artificial Intelligence (AI)**
  - “Programmed” intelligence
- **Machine Learning (ML)**
  - **Supervised ML**, the machine is trained, taught
  - **Unsupervised ML**, the machine learns on it’s own (Google’s cat video experiment)
- **Big Data**
  - Large volumes, variety, variability, velocity of data
- **Big Data Computing**
  - Computing engineering & systems to handle big data


WIRED SUBSCRIBE

WIRED STAFF 06.26.12 11:15 AM

Google's Artificial Brain Learns to Find Cat Videos

Share

By Liat Clark, Wired UK

JOULE NETL SUPERCOMPUTER

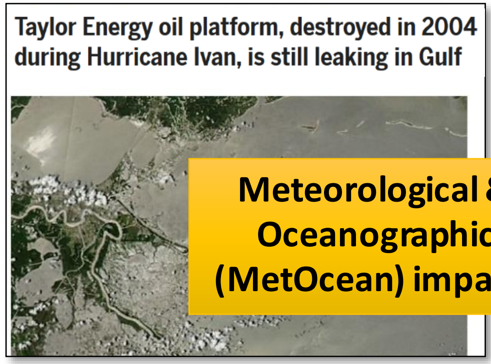
WATT The Power of Ai

What are the needs?

- We are asking **more** from aging infrastructure
- Offshore operations can be hazardous
  - **Environment**
  - **Operational wear and tear**

Values Delivered

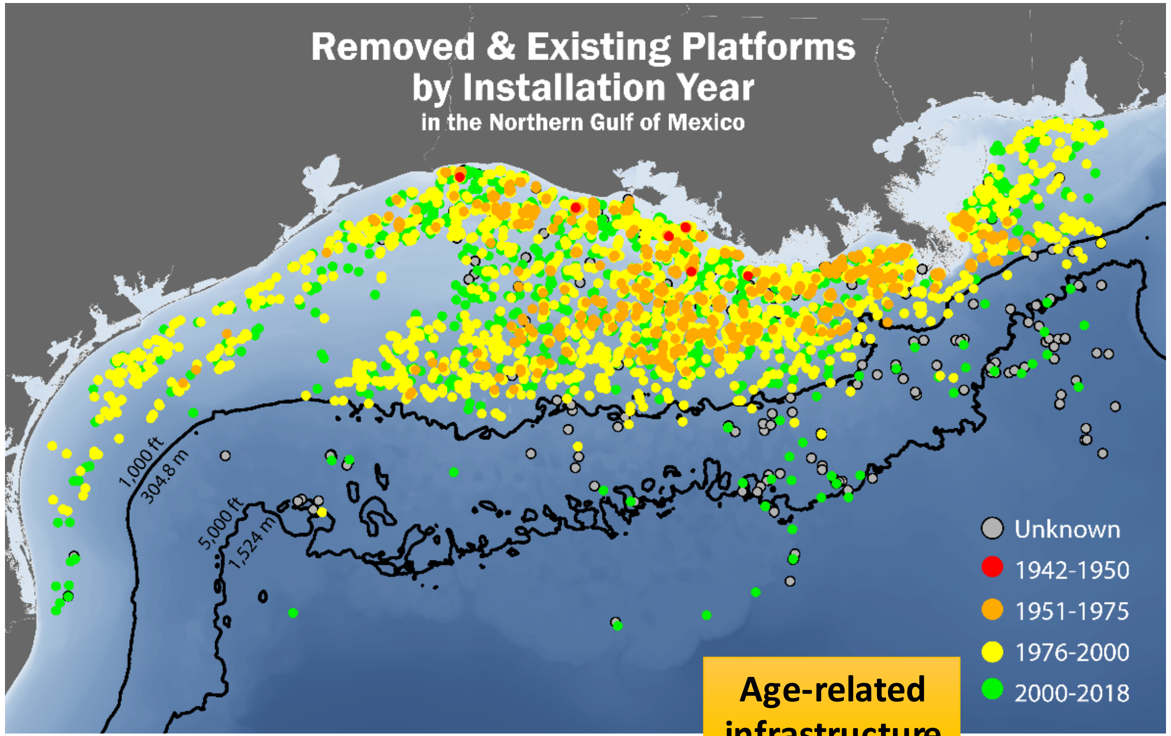
- Identify and address hazards
- Mitigate risk and cost
- Inform life extension & resource optimization strategies


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

Meteorological & Oceanographic (MetOcean) impacts

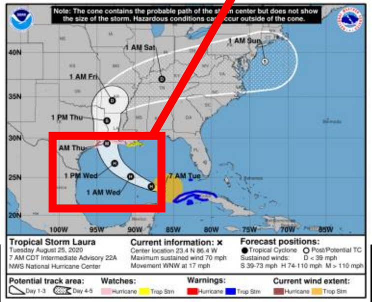

fuelfix
Offshore drilling regulator warns of bolt failures in Gulf of Mexico
Posted by James Osborne Date: May 03, 2016

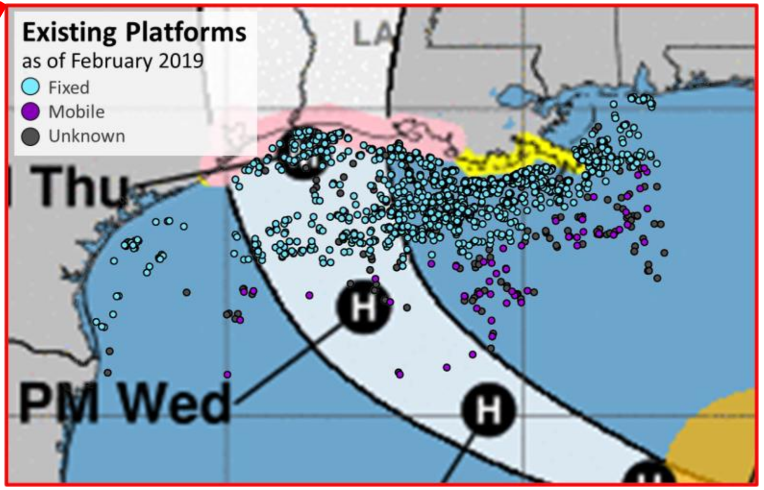
Integrity risks



Age-related infrastructure hazards

Hurricane Laura,
August 2020





***Need* to prevent hazards & support response planning**

Data-Driven Approach & Driving Insights

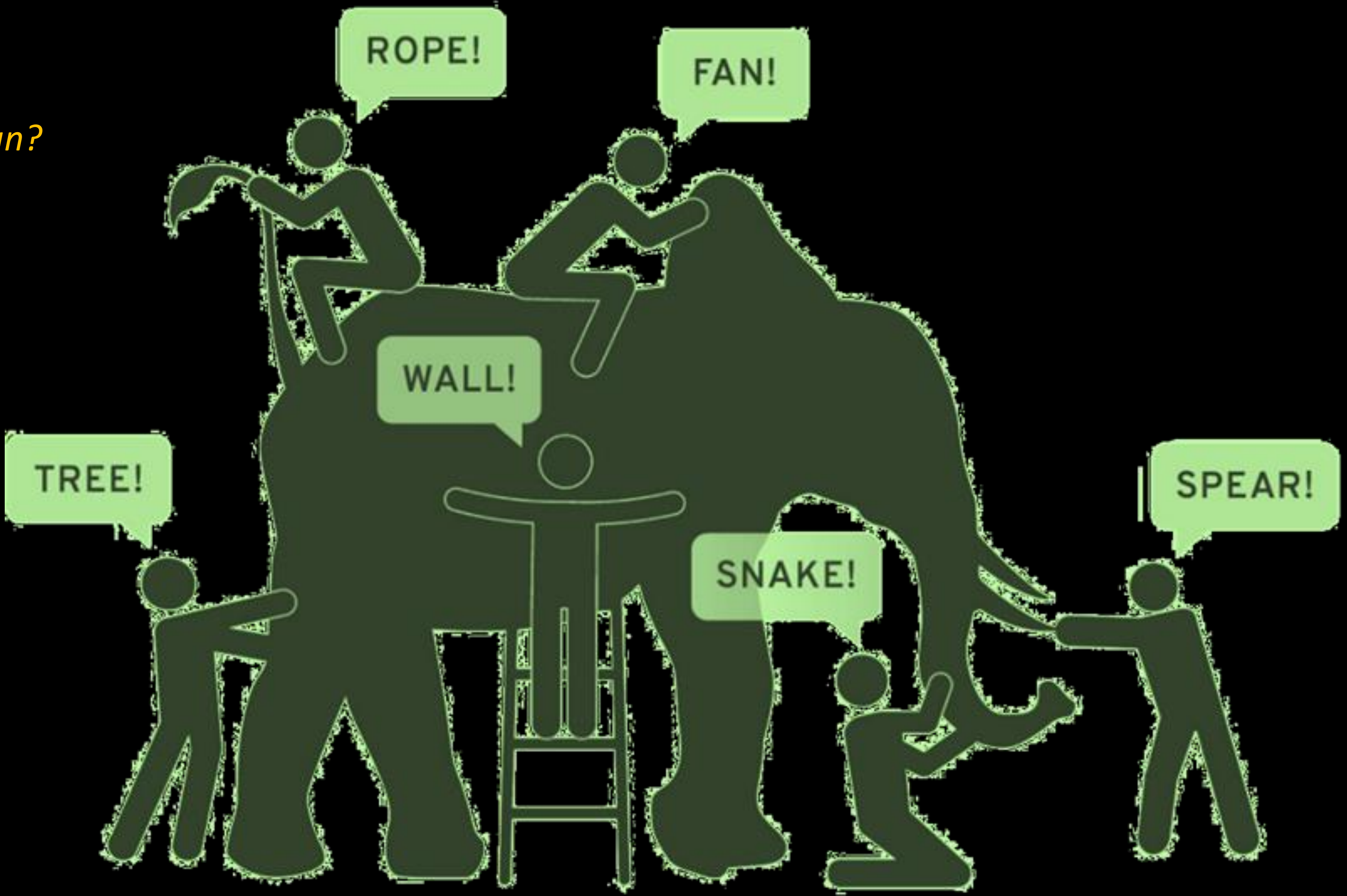
*Leveraging **Big Data** & **Big Data Computing** of the whole to inform the local*

Predicting Integrity

1. *What is the remaining lifespan?*
2. *Likelihood of future risk?*

Data representing the natural-engineered offshore system

- Structural platform records
- Incident reports
- Metocean* data
- Geohazard data
- Production information



*Meteorological & Oceanographic data

https://edx.netl.doe.gov/offshore/portfolio-items/assessing-current-and-future-infrastructure-hazards/

Dataset Development

7,065 platform records
1942-2020

>4,000 incident records
1956-2000, 2006-2018

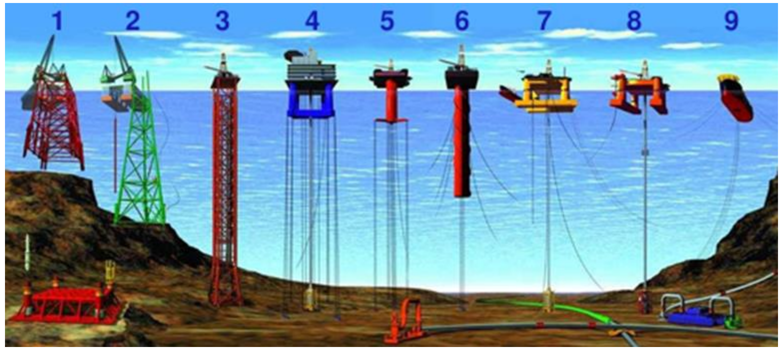
Evaluated **infrastructure integrity** based on:

- Location
- Use
- Operating condition
- Incident history
- Current velocity
- Wind speeds
- Wave height
- Storms
- External corrosion

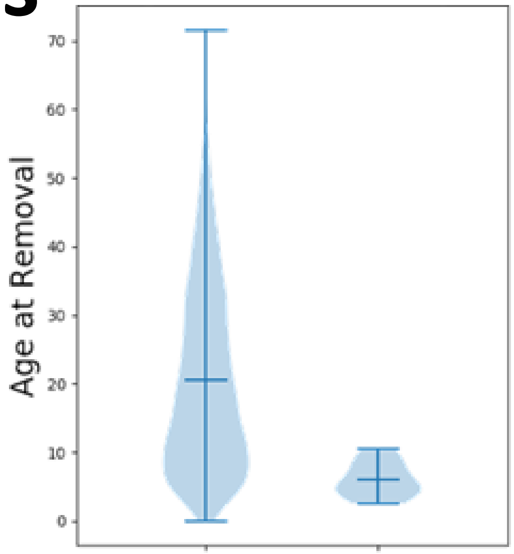
Structure & Incident Records

Offshore platform structure types:

Sources include BOEMRE, BSEE, USCG, MMS



“Fixed” “Mobile”



“Fixed” “Mobile”

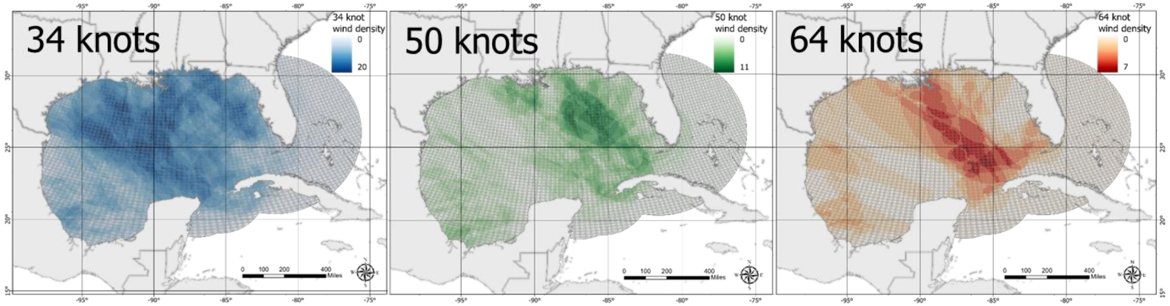
Metocean Big Data

NETL SUPERCOMPUTER

>51,000 layers
(**>130 GB**)

Sources include NOAA, US Navy, World Ocean Database, and external models

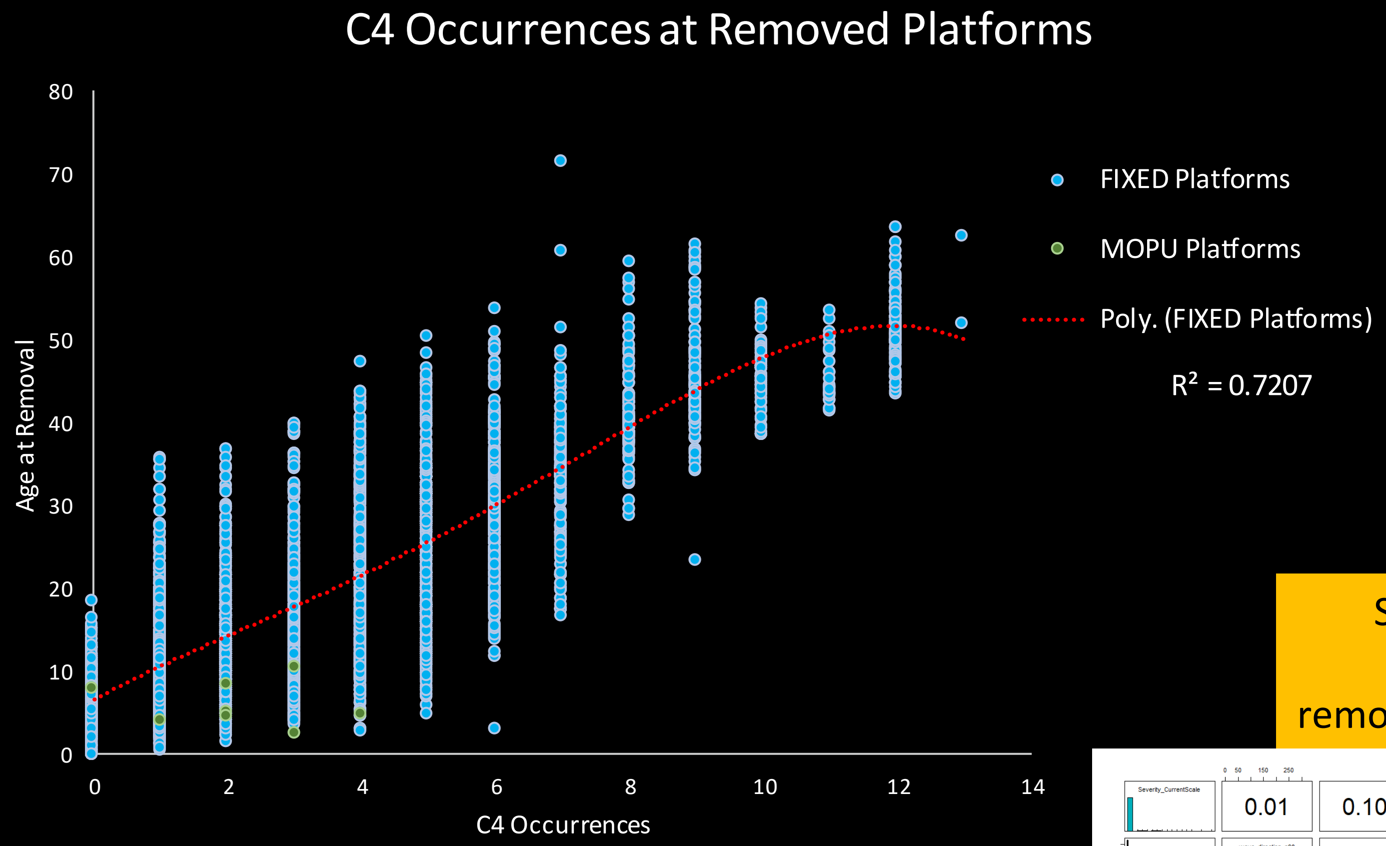
Data example: *Density of storm occurrences by wind speed*



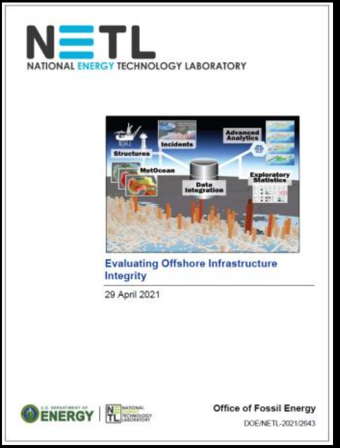
https://edx.netl.doe.gov/dataset/comprehensive-gom-federal-waters-platform-incident-metocean-and-geohazard-dataset

Exploratory Stats & Variable Analyses

- ***Understanding the data***
- Found relationships between age, incident severity, structural complexity, and environment
- Key variable selection improved understanding of ***operational platform integrity***

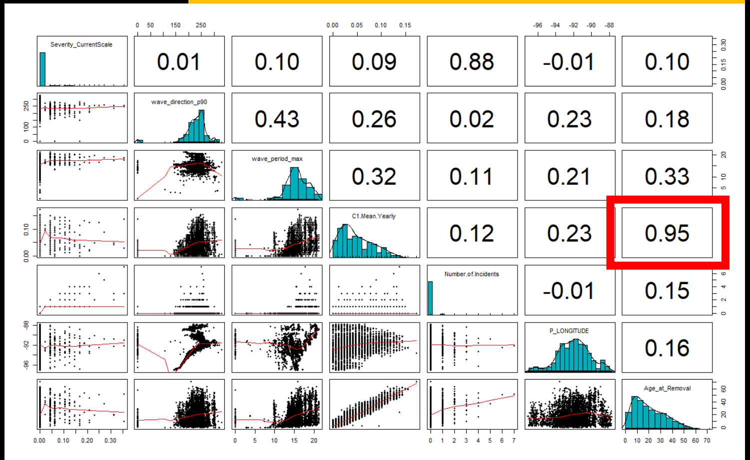


Potential plateau in the number of times a platform can sustain extreme hurricane conditions (Ordinary Least Squares regression)



Nelson et al., 2021

Strong relationship (0.95) between hurricanes and removal age (Pearson's Correlation)



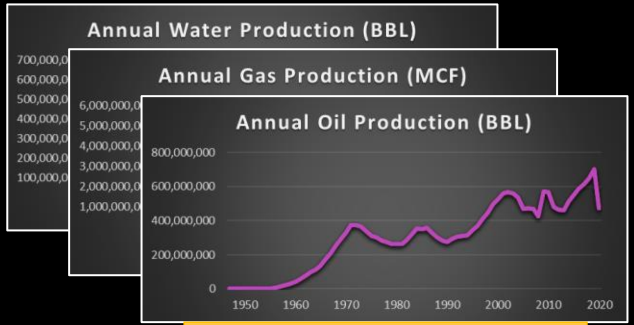
Machine Learning (ML) & Advanced Algorithms

Predicting Lifespan

1. Gradient Boosted Regression Tree
   Dyer et al. *in review*
2. Artificial Neural Network (ANN)
   Dyer et al. *in review*
3. Geographically Weighted Regression
   Nelson et al. *in review*

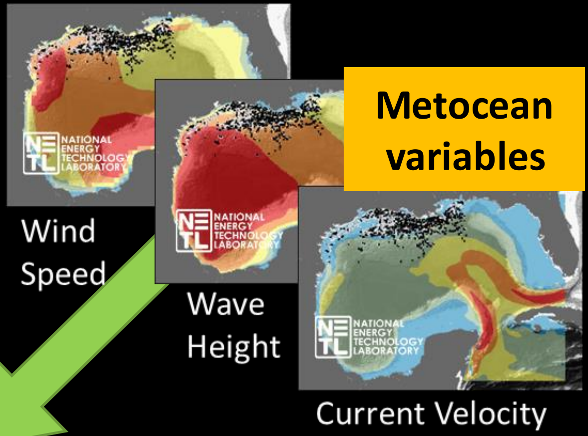
Risk Likelihood

- ANN Regression



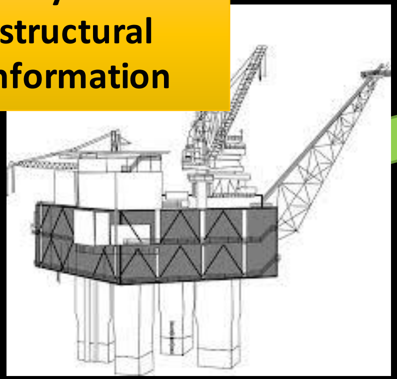
Production information

Structural- & weather-related incidents



Metocean variables

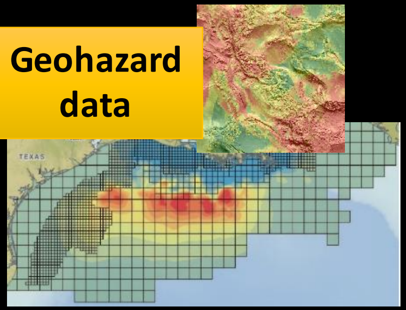
Publicly available structural information



Analyses through ML & advanced statistical models

WATT
The Power of Ai

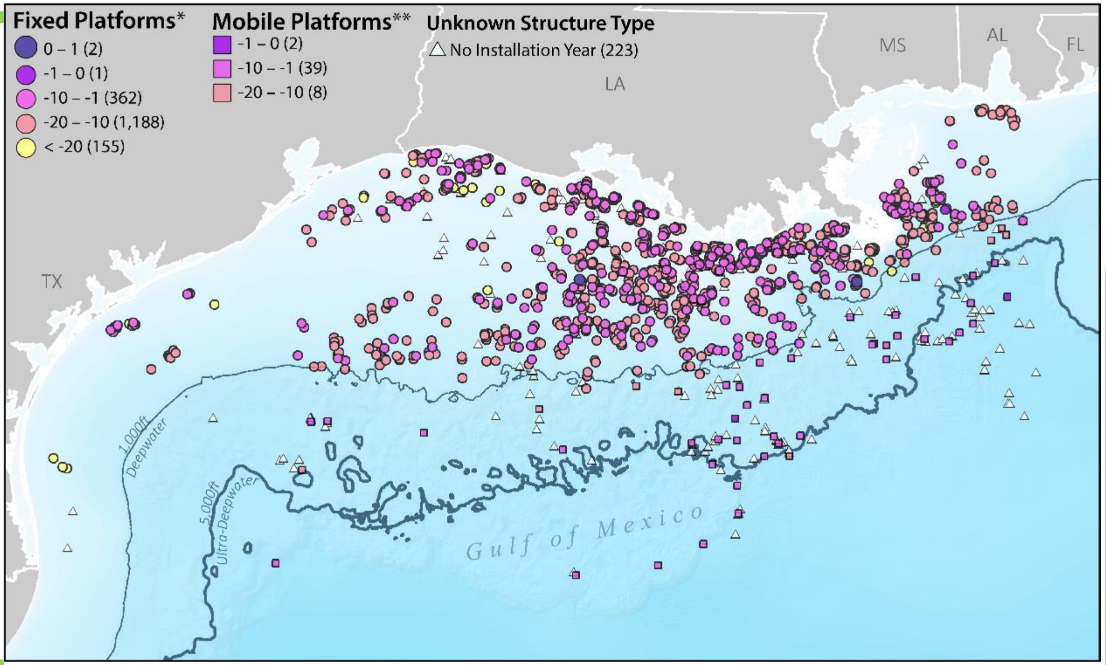
Geohazard data



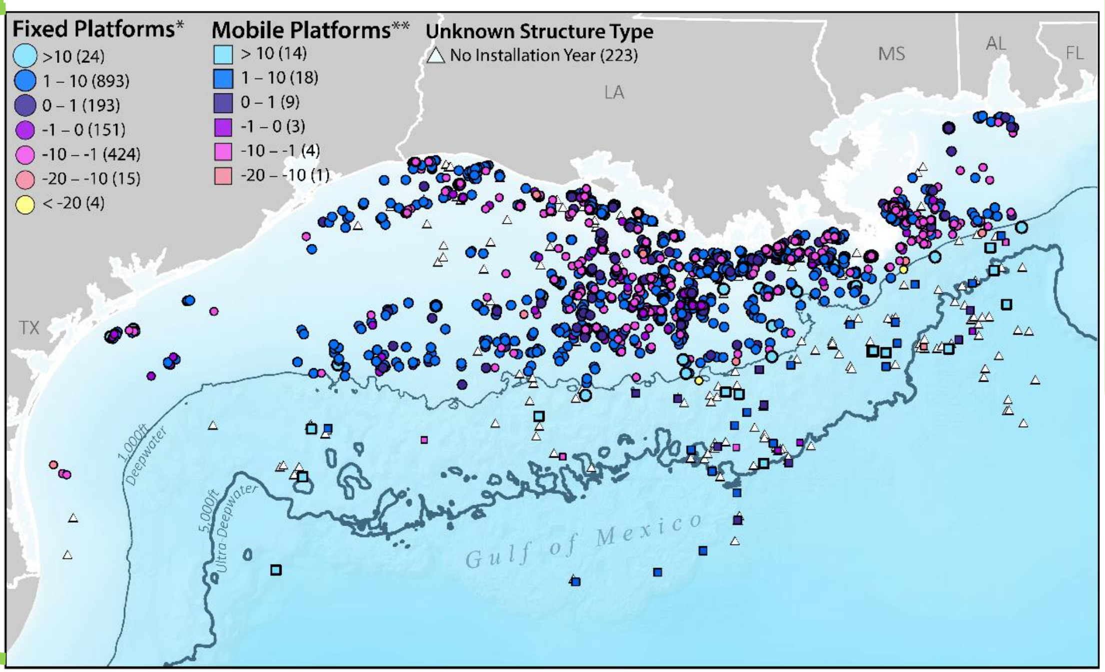
https://edx.netl.doe.gov/offshore/portfolio-items/assessing-current-and-future-infrastructure-hazards/

Predicting remaining lifespan

Gradient Boosted Regression Tree
97% accuracy



Artificial Neural Network
95% accuracy



Running ***multiple models*** allows us to better understand and ***internally validate results***

Values Delivered

- Helps to locally inform **use/reuse strategies**
- Inform **maintenance** and **monitoring** decisions

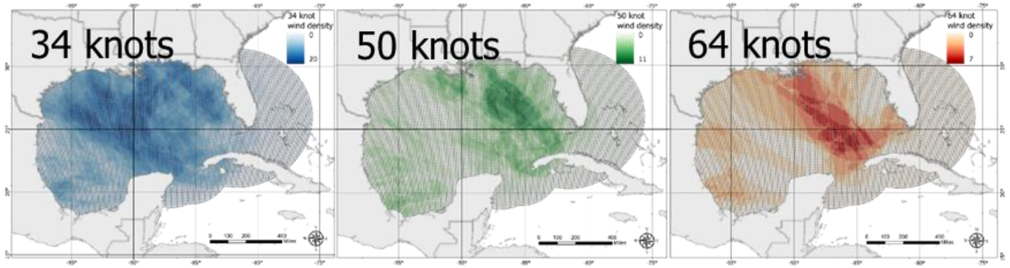
Dyer et al., in review

Explainable AI: *Understanding the predictions*

Which *attributes (features)* had predicting power?

- Do they make sense?
- Do they agree between the models?
- How do they differ?

Dyer et al., in review



<u>GBRT</u> *(10 out of 23)*

1. Category 1 hurricane yearly mean
2. Category 3 hurricane yearly mean
3. Category 4 hurricane yearly mean
4. Min. central pressure, 25th percentile
5. Min. central pressure, std. dev.
6. Tropical storm yearly mean
7. Wave direction, 90th percentile
8. Mean meridional wind
9. Category 2 hurricane yearly mean
10. Category 1 hurricane max. days yearly

Metocean
Production
Structural
Location

ANN also includes
Incidents
Geohazards

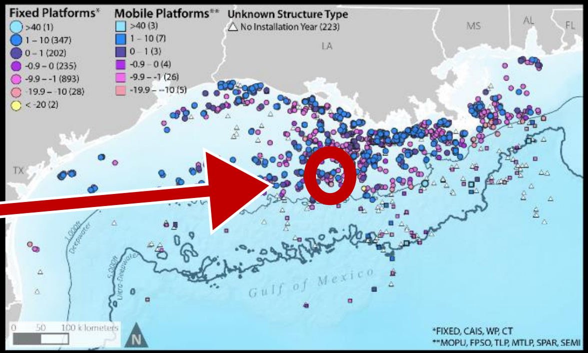
<u>ANN</u> *(10 out of **792**)*

1. Category 1 hurricane yearly mean
2. Category 3 hurricane yearly mean
3. Category 4 hurricane yearly mean
4. Tropical storm yearly mean
5. Max. reported wind gust, 25th percentile
6. Category 2 hurricane yearly mean
7. Area code
8. Category 1 hurricane max. days yearly
9. Category 4 hurricane yearly max.
10. Zonal wind minimum

Example: *Using the whole to inform the local*

B Fixed Platform

Installed 1972 (~49 years old)



*Both models found platform to be **past** the predicted removal age.*

Poor Risk Communication, Inadequate Maintenance Behind Fatal Gulf of Mexico Platform Incident

OE Staff • *March 12, 2021*

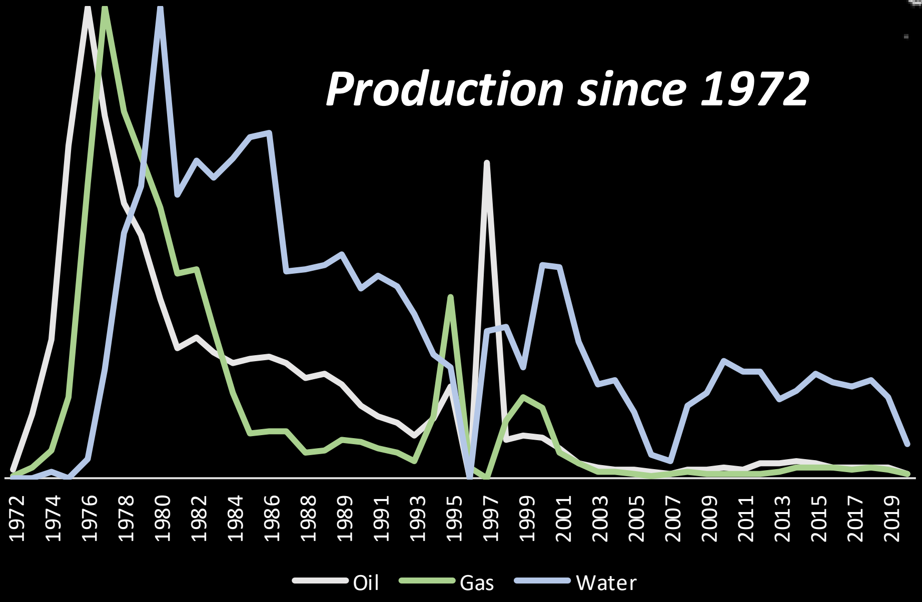
Aerial Photograph of EI-331 Platform "B" - Credit: BSEE

OE OFFSHORE ENGINEER

THE FUTURE OF OFFSHORE ENERGY & TECHNOLOGY.

Post-Incident Photograph of Hazardous Grating Section Suspended in Open Hole with Red "DANGER" Marking Tape Affixed - Credit: BSEE

Production since 1972



BSEE. *Investigation of May 29, 2019, Fatality.* BSEE Panel Report 2021-001.

Offshore Engineer. March 12, 2021. *Poor Risk Communication, Inadequate Maintenance Behind Fatal Gulf of Mexico Platform Incident.*

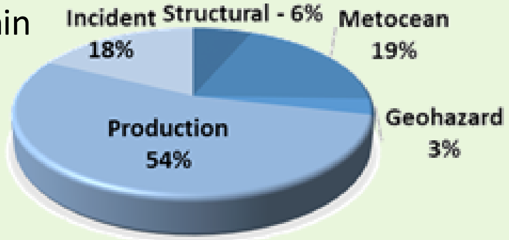
4 reported incidents
272 storms
11 tropical storms
53 hurricanes, including 2 C5

Models can *adapt* to answer a range of questions

Currently models are forecasting:

- Remaining lifespan *(age at removal)*
- Future Risk *(incident severity)*

Attribute breakdown within comprehensive dataset:



Modeling Framework

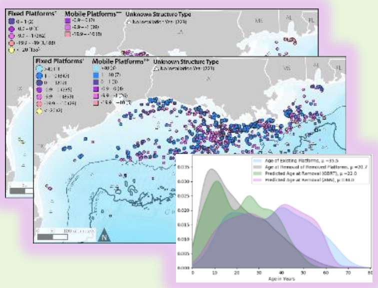
Inputs

↓

Pre-processing, training and scoring iterations

↓

Outputs



Given the right

input data and training…

…models can **predict other variables**

Potential Outputs

- Environmental load preparedness
- Decommissioning
- Incidents
- Maintenance needs
- Production potential

Modeling Framework

Comprehensive dataset

Supplemental information

↓

Pre-processing, training and scoring iterations

Altered hyperparameters

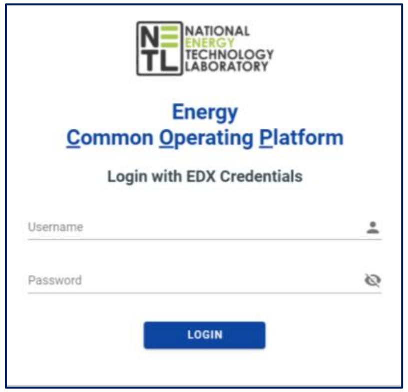
Learning something new

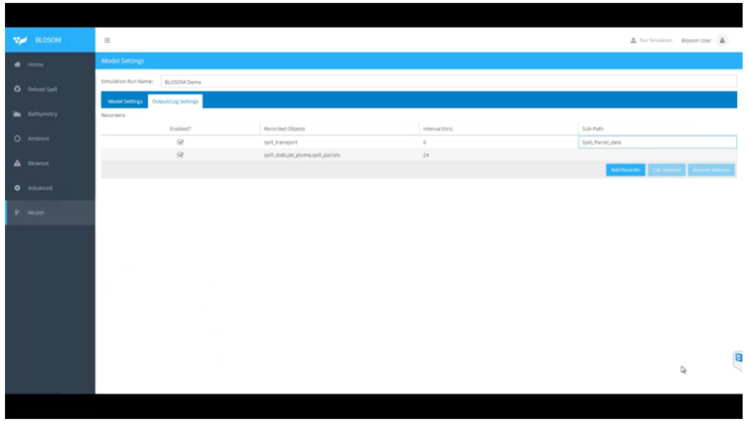
↓

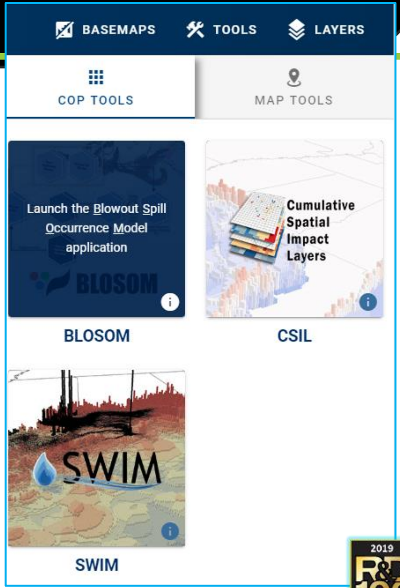
Outputs

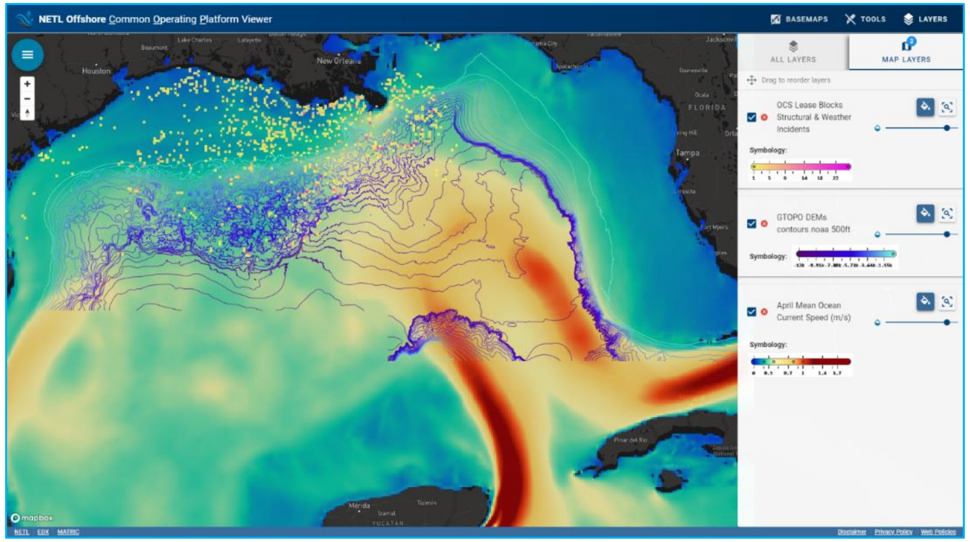
Increasing Access to Data & Models
Through NETL's Common Operating Platform

- Integrate **ML, big data, and analytical outputs** with **online platform**
- Platform securely released through **Energy Data eXchange®**
- Leverage **award-winning Offshore Risk Modeling Suite**
- **Real-time analyses** to **better understand offshore infrastructure integrity**





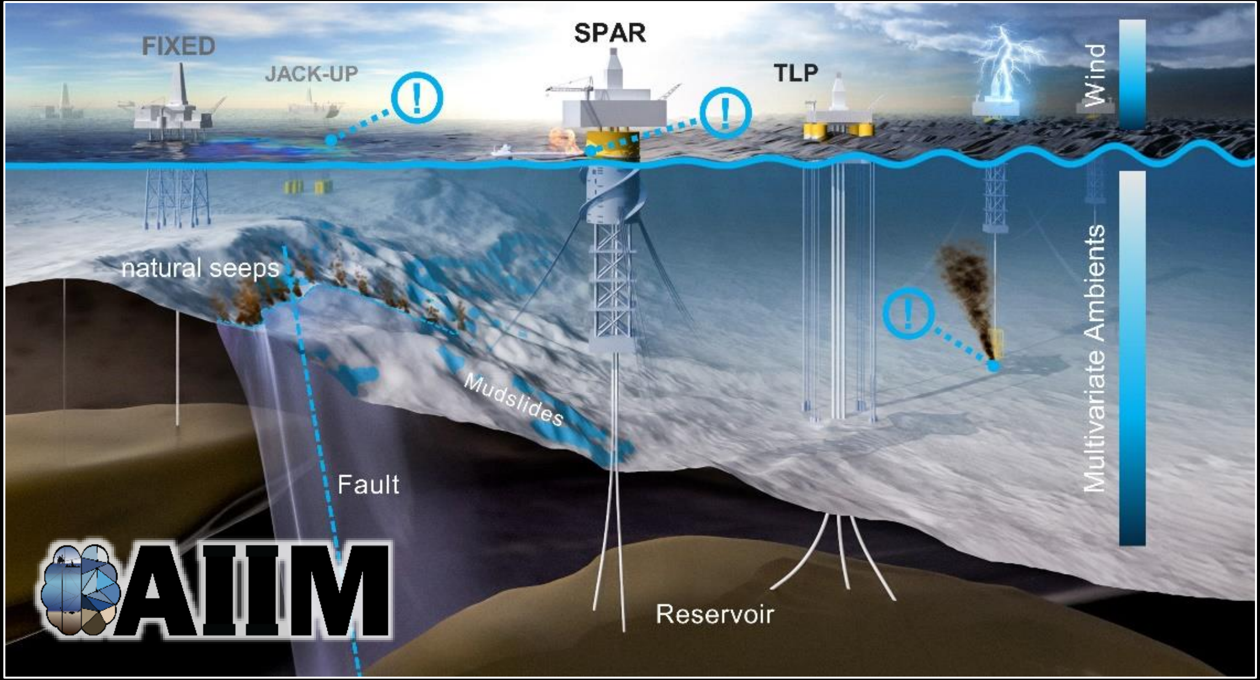




Energy Data eXchange

Synergy Opportunities

Internal collaboration and external interests

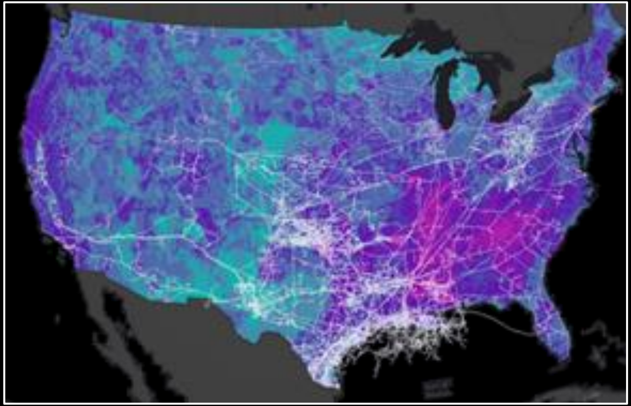


Work has been shared with

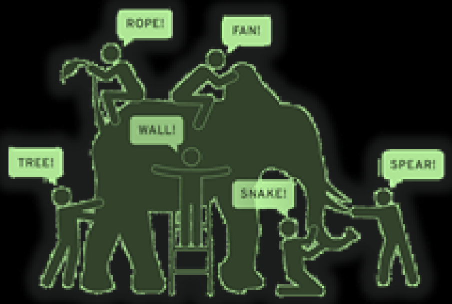
BSEE Bureau of Safety and Environmental Enforcement

BOEM Bureau of Ocean Energy Management

Lloyd's Register



National geospatial pipeline risk modelling analytics for sensor placement



Potential additional external interests

API American Petroleum Institute

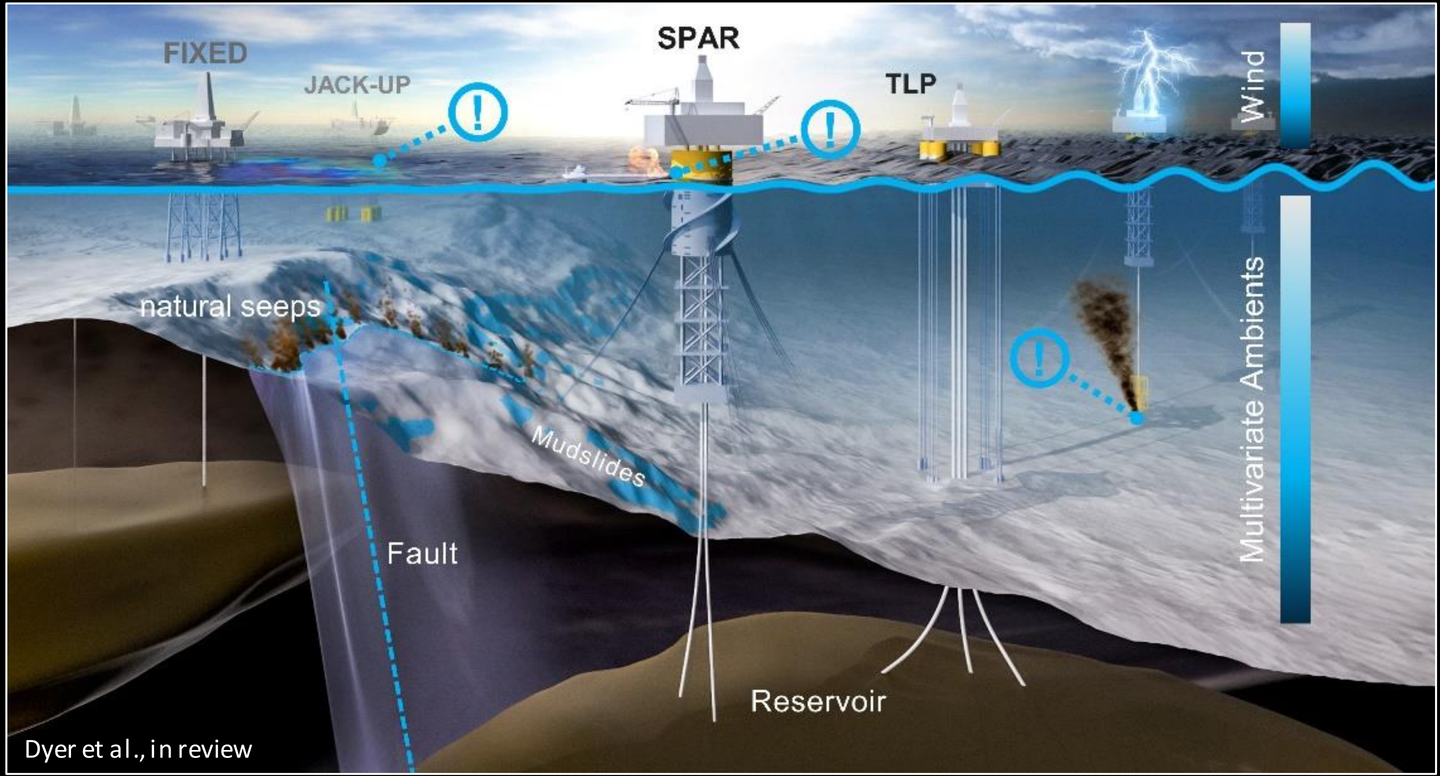
VALARIS

NOBLE

Transocean

Lessons Learned from Task 3

- **Big data, big data computing,** and **AI/ML** for solving complex problems
- **ML models** predicting existing platform longevity at ***95–97% accuracy***
- ***Full system analytics*** *enables us to* ***identify regional trends*** *and* ***explain our results locally***

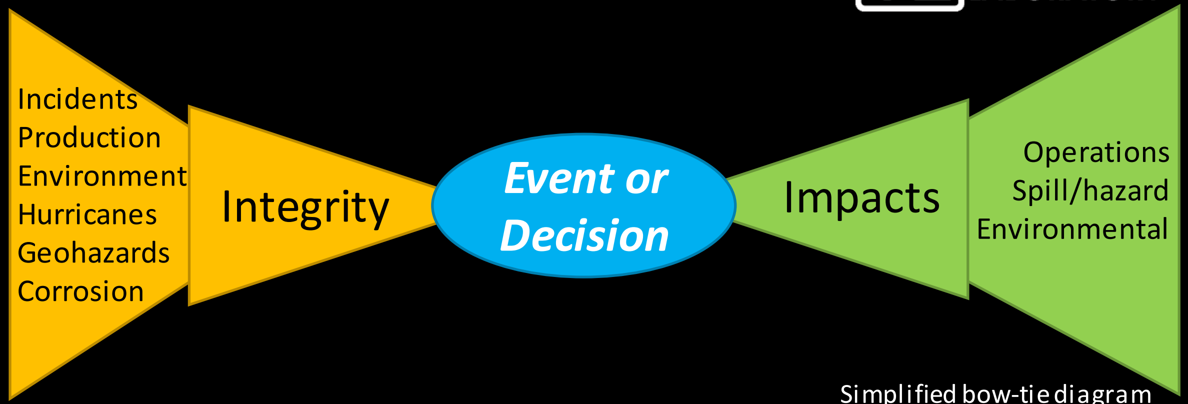


Dyer et al., in review

Next Steps – Task 10

- Build off Task 3 and fill in identified information gaps
- Apply **time series** and **causal analytics**
- Develop **smart tool** for **rapid evaluation** of **infrastructure integrity**

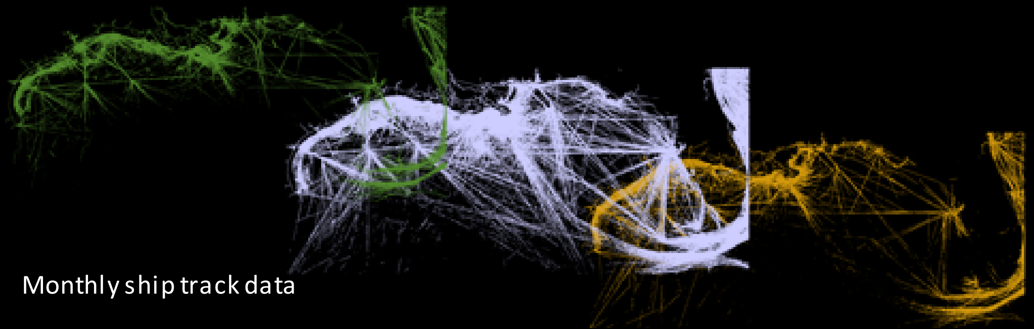
Task 10: **Smart Models to Optimize Use or Reuse of Production & Transport Infrastructure**



Simplified bow-tie diagram

Accomplishments

- Kick-off, April 2021
- Completed literature review of **>40 additional publications**
- Acquired **>1.2TB** of data
- Began planning evaluation methods to include *causality testing* and *time series analytics*


Monthly ship track data

Lessons Learned

- Big data ≠ better data
- Correlation ≠ causation
- Advanced models must be **explainable**

Challenges

- Historic data trapped in reports
- Access to maintenance and inspection records
- Limited equipment information

Disclaimer & Acknowledgement

- <u>Disclaimer:</u> This presentation was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference therein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed therein do not necessarily state or reflect those of the United States Government or any agency thereof.
- <u>Acknowledgement:</u> Parts of this technical effort were performed in support of the National Energy Technology Laboratory's ongoing research under the Offshore Unconventional Resources – DE FE-1022409 by NETL's Research and Innovation Center, including work performed by Leidos Research Support Team staff under the RSS contract 89243318CFE000003.

Questions?

Lucy.Romeo@netl.doe.gov

Jennifer.Bauer@netl.doe.gov

NATIONAL ENERGY TECHNOLOGY LABORATORY

Thank you!

Benefit to the Program

- **Tasks 3 and 10** supports the development of data, methods, models, and tools to support the evaluation of the current state of offshore oil and gas infrastructure in the U.S. Gulf of Mexico.
- **Task 3 (completed)** resulted in a novel analytical framework utilizing big data, big data computing, ML models, and an advanced geographic model to forecast the remaining lifespan and future risk of platforms. Resulting data and model outputs were hosted onto the newly developed NETL COP, also built as a result from this project.
- **Task 10 (new start)** will result in a multivariate, novel, and intelligent approach encompassing the full offshore natural-engineered system is needed to inform local use and reuse optimization strategies, minimize cost, and mitigate operational and environmental impacts. The application of big data, big data computing, causality testing, and ML will uncover key insights necessary for the safe and efficient offshore energy operations that are currently missing from existing approaches. Results from this project will improve predictive abilities to inform energy exploration and production strategies, prevent risk and promote safety, and help limit the already small FE offshore footprint while expanding energy resources.

Task 10 Project Overview

Goals and Objectives

- Funded by DOE as part of Offshore Unconventional Resources **DE FE-1022409**
- RSS Contract researchers
- Ongoing performance dates 2021-2023
- Project Participants
  - Federal: Jennifer Bauer (co-PI), Kelly Rose
  - LRST: Lucy Romeo (co-PI), Alec Dyer, Michael Sabbatino, Madison Wenzlick, Patrick Wingo, and Dakota Zaengle
  - Theiss Research: Rodrigo Duran, Ph.D.

Organization Chart

Lead Organization
NETL

Principal Investigators
Jennifer Bauer, Lucy Romeo

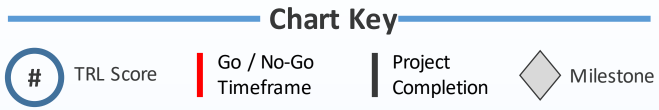
Task 3
Assessing Current a Future Infrastructure Hazards

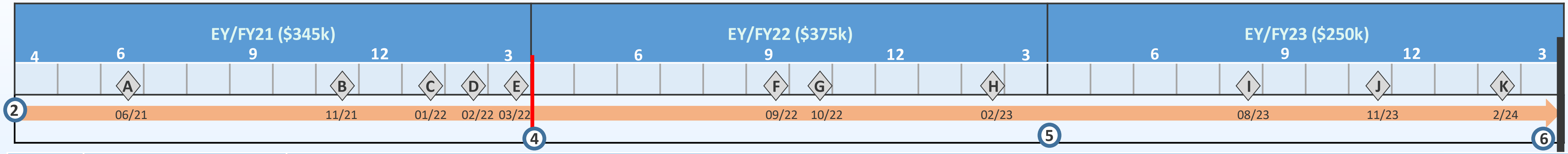
Leads: Jennifer Bauer, Lucy Romeo
Team: Aaron Barkhurst, Rodrigo Duran, Alec Dyer, Jake Nelson, Michael Sabbatino, Madison Wenzlick, Patrick Wingo, Dakota Zaengle, and Kelly Rose

Task 10
Smart Models to Optimize Use or Reuse of Production & Transport Infrastructure

Leads: Jennifer Bauer, Lucy Romeo
Team: Rodrigo Duran, Alec Dyer, Michael Sabbatino, Madison Wenzlick, Patrick Wingo, Dakota Zaengle, and Kelly Rose

Gantt Chart – Task 10





Milestones

Number	Expected Completion Date	Description
10.A	06/21	Complete a literature review on structural and external factors that influence offshore platform infrastructure operational capabilities, as well as past analytical techniques used to measure structural lifespan.
10.B	11/21	Acquire big, disparate data representing structural information, incident records, metocean variables, geohazard data, and well information. Integrate data into a comprehensive spatial dataset.
10.C	01/22	Complete preliminary analytics, including causality testing, on dataset to identify initial trends and patterns, as well as knowledge gaps. Identify potential advanced analytical techniques (machine learning [ML], geographic, statistical) for evaluating the current state of infrastructure for use and reuse optimization.
10.D	02/22	Outline technical report or manuscript covering data and methods for evaluating the current state of platform infrastructure for use and reuse optimization.
10.E	03/22	Determine if the preliminary analytics and current state of knowledge confirm that models can effectively analyze the integrity of offshore production infrastructure.
10.F	09/22	Apply smart models to evaluate the current state of production FE infrastructure in the U.S. GOM.
10.G	10/22	Develop analytical framework for a novel data-driven tool that uses smart tool logic to evaluate infrastructure.
10.H	02/23	Acquire data representing environmental and operational risk relating to exploration and production activities in the U.S. GOM.
10.I	08/23	Analyze potential environmental and operational impacts using existing tools from the ORM suite.
10.J	11/23	Provide demonstrable applications of novel tool for evaluating the current state of platform infrastructure, streamlined with environmental and operational impact assessments.
10.K	02/24	Submit technical report or manuscript for publication.

Research Products from Offshore Tasks 3 and 10

- <u>Publications</u>
  - Nelson, J., Dyer, A., Romeo, L., Wenzlick, M., Zaengle, D., Duran, R., Sabbatino, M., Wingo, P., Barkhurst, A., Rose, K., Bauer, J. Evaluating Offshore Infrastructure Integrity; DOE/NETL-2021/2643; NETL Technical Report Series; U.S. Department of Energy, National Energy Technology Laboratory: Albany, OR, 2020; p 70. doi.org/10.2172/1780656
  - Romeo, L., Wingo, P., Sabbatino, M., Bauer, J., Rose, K. "Baseline data for spill assessments: Ambient conditions, Socioeconomic data, Sensitivity maps." Marine Hydrocarbon Spill Assessments. **In Review.**
  - Dyer, A., Zaengle, D., Duran, R., Nelson, J., Wenzlick, M., Wingo, P., Bauer, J., Rose, K., and L. Romeo. **In Review.** Applied Machine Learning Model Comparison: Predicting Offshore Platform Integrity with Gradient Boosting Algorithms and Neural Networks. **Submitted to Marine Structures.**
  - Nelson, J., Romeo, L., and R. Duran. **In Review**. Exploring the Spatial Variations of Stressors Impacting Platform Removal in the Northern Gulf of Mexico. **Submitting to Marine Pollution Bulletin following internal approval**.
- <u>Data</u>
  - Romeo, L., Dyer, A., Wenzlick, M., Duran, R., Nelson, J., Sabbatino, M., Wingo, P., Rose, K., and J. Bauer. Comprehensive GOM Federal Waters Platform, Incident, Metocean, and Geohazard Dataset, 4/26/2021, https://edx.netl.doe.gov/dataset/comprehensive-gom-federal-waters-platform-incident-metocean-and-geohazard-dataset, DOI: 10.18141/1779221

Presentations from Offshore Tasks 3 and 10

- Romeo, L., Barkhurst, A., Bauer, J., Duran, R., Dyer, A., Rose, K., Wenzlick, M., and Zaengle, D. **In Review**. Applied Machine Learning and Geospatial Models to Forecast the Remaining Lifespan of Offshore Infrastructure in the Gulf of Mexico. AGU Fall Meeting. December, 2021.
- Romeo, L., Dyer, A., Bauer, J., Barkhurst, A., Duran, R., Nelson, J., Sabbatino, M., Wenzlick, M., Wingo, P., Zaengle, D. and Rose, K. 2021. Forecasting Offshore Platform Integrity: Applying Machine Learning Algorithms to Quantify Lifespan and Mitigate Risk. Machine Learning in Oil & Gas. April 15, 2021. Virtual.
- Romeo, L., Dyer, A., Zaengle, D., Nelson, J., Wenzlick, M., Duran, R., Sabbatino, M., Wingo, P., Barkhurst, A., Bauer, J., and Rose, K. Machine Learning Driven Forecasting of Offshore Infrastructure Integrity. in prep. Interagency Coordinating Committee on Oil Pollution Research (ICCOPAR) Quarterly Meeting. December, 2020. Virtual.
- Romeo, L., Dyer, A., Zaengle, D., Nelson, J., Wenzlick, M., Duran, R., Sabbatino, M., Wingo, P., Barkhurst, A., Bauer, J., and Rose, K. 2020. Assessing Current and Future Infrastructure Hazards: Forecasting Integrity using Machine Learning and Advanced Analytics. Oil and Gas Project Review Meeting. October 26, 2020. Virtual.
- Justman D., Romeo, L., Barkhurst, A., Bauer, J., Duran, R., Dyer, A., Nelson, J., Sabbatino, M., Wingo, P., Wenzlick, M., Zaengle, D., Rose, K. invited talk. Advanced geospatial analytics and machine learning for offshore and onshore oil & natural gas infrastructure. GIS Week 2020. October 6-7, 2020. Virtual.
- Romeo, L. and Barkhurst, A. Building Big Data Geospatial Tools for a Common Operating Platform: Cumulative Spatial Impact Layers. DOE GIS Users Group Meeting. September 10, 2020. Virtual. Invited presentation.
- Dyer, A., Romeo, L., Wenzlick, M., Bauer, J., Nelson, J., Duran, R., Zaengle, D., Wingo, P., and Sabbatino, M. 2020. Building an Analytical Framework to Measure Offshore Infrastructure Integrity, Identify Risk, and Strategize Future Use for Oil and Gas. Esri User Conference, San Diego, CA, July 13-15, 2020. https://www.esri.com/en-us/about/events/uc/overview
- Dyer, A., Rose, K., Bauer, J., Romeo, L., Barkhurst, A., Wingo, P., Sabbatino, M., Nelson, J., Wenzlick, M., Building an Analytical Framework to Measure Offshore Infrastructure Integrity, Identify Risk, and Strategize Future Use for Oil and Gas, AGU Ocean Sciences Meeting 2020, Oral Presentation. https://www.agu.org/Ocean-Sciences-Meeting
- Romeo, L., Dyer, A., Nelson, J., Bauer, J., Rose, K., Dao, A., Wingo, P., Creason, C.G., and Sabbatino, M. Building Regional Baselines and a Suite of Spatial Tools to Better Prepare for Oil Spills, AGU Ocean Sciences Meeting 2020, Poster Presentation. https://www.agu.org/Ocean-Sciences-Meeting
- Romeo, L. and Barkhurst, A. Building Big Data Geospatial Tools for a Common Operating Platform: Cumulative Spatial Impact Layers. DOE GIS Users Group Meeting. September 10, 2020. Virtual. Invited presentation.
- Romeo, L., Wenzlick, M., Dyer, A., Sabbatino, M., P. Wingo, Nelson, J., Barkhurst, A., Bauer, J., and Rose, K. 2019. Building Data-Driven Analytical Approaches and Tools to Evaluate Offshore Infrastructure Integrity. Addressing the nation's energy needs through technology innovation – 2019 carbon capture, utilization, storage, and oil and gas technologies integrated review meeting, Pittsburgh, PA, August 26-30, 2019.
- Rose, K., 2019. An Ounce of Prevention is Worth a Pound of Response, NETL's Big Data Technologies for Offshore Spill Prevention. Addressing the nation's energy needs through technology innovation – 2019 carbon capture, utilization, storage, and oil and gas technologies integrated review meeting, August 26-30, 2019
- Bauer, J., Romeo, L., Nelson, J., Wingo, P., Bunn, A., Barkhurst, A., Chittum, J., and Rose, K. Swimming through the data deluge to inform oil spill prevention needs. Gulf of Mexico Oil Spill and Ecosystem Science Conference, New Orleans, LA, February 5-8, 2018. http://www.cvent.com/events/2018-gulf-of-mexico-oil-spill-and-ecosystem-science-conference/event-summary-6ae61bf76b204d0392d48b8bf15ed1eb.aspx
- Romeo, L., Wingo, P., Barkhurst, A., Chittum, J., Bauer, J., Rose, K., 2018, Choose Your Own Adventure: NETL's Innovative Cumulative Spatial Impact Layers Tool for Processing, Analyzing, and Visualizing Spatio-Temporal Big Data. American Geophysical Union: Ocean Sciences. Portland, OR. February, 2018. https://osm.agu.org/2018/
- Romeo, L., Wingo, P., Justman, D., Barkhurst, A., Bauer, J., Rose, K., 2018, Cumulative Spatial Impact Layers - Choose Your Own Adventure: NETL's Innovative Tool for Processing, Analyzing, and Visualizing Spatio-Temporal Data. Computational Geosciences Meeting. NETL Albany, OR. January, 2018.