Smart Infrastructure Integrity Models to Support Remediation and Inform Safe Reuse Strategies

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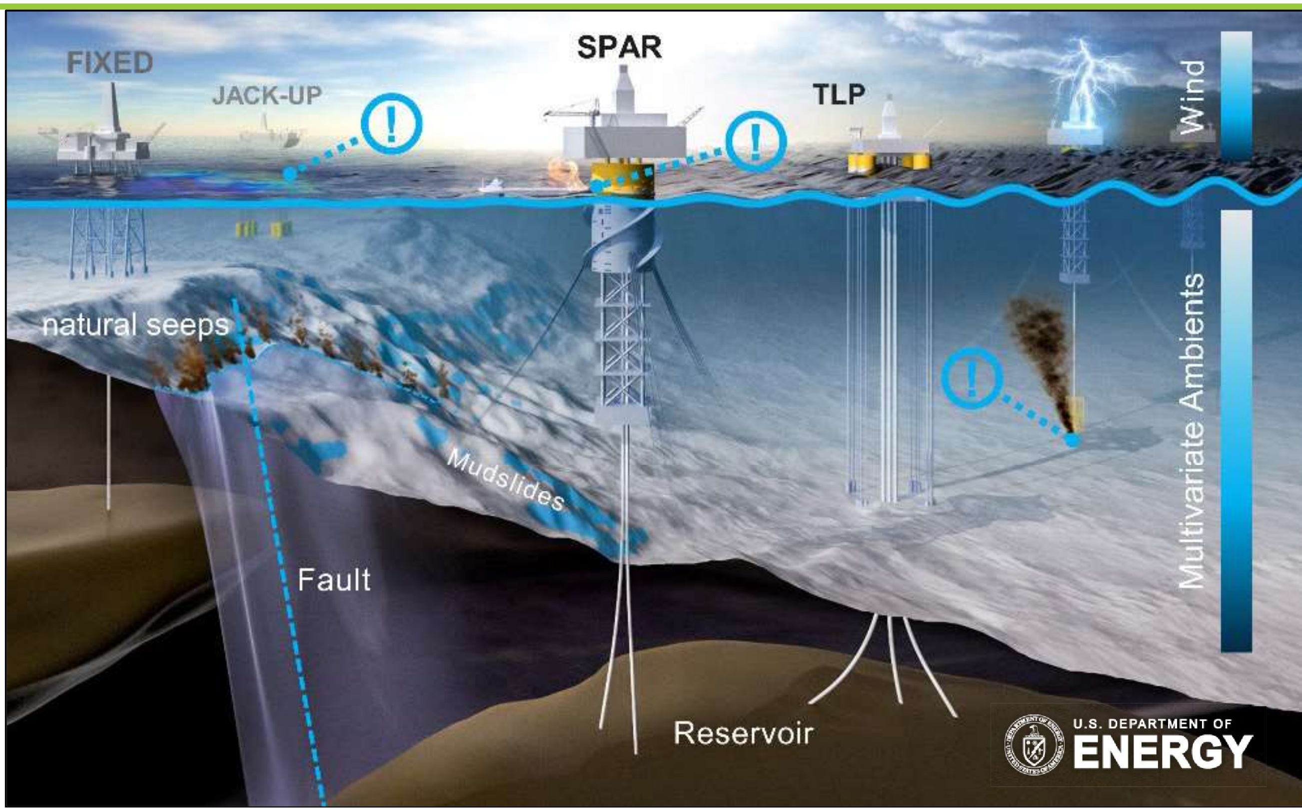
NATIONAL ENERGY TECHNOLOGY LABORATORY

Advanced Offshore Research Portfolio
- FWP 1022409
- Task 10 (EY21 – EY23)

Program Funding: Unconventional Fossil Energy Technologies

Program Number: 1611038

2022 Resource Sustainability Annual Project Review Meeting Oct. 27, 2022



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What is the need?

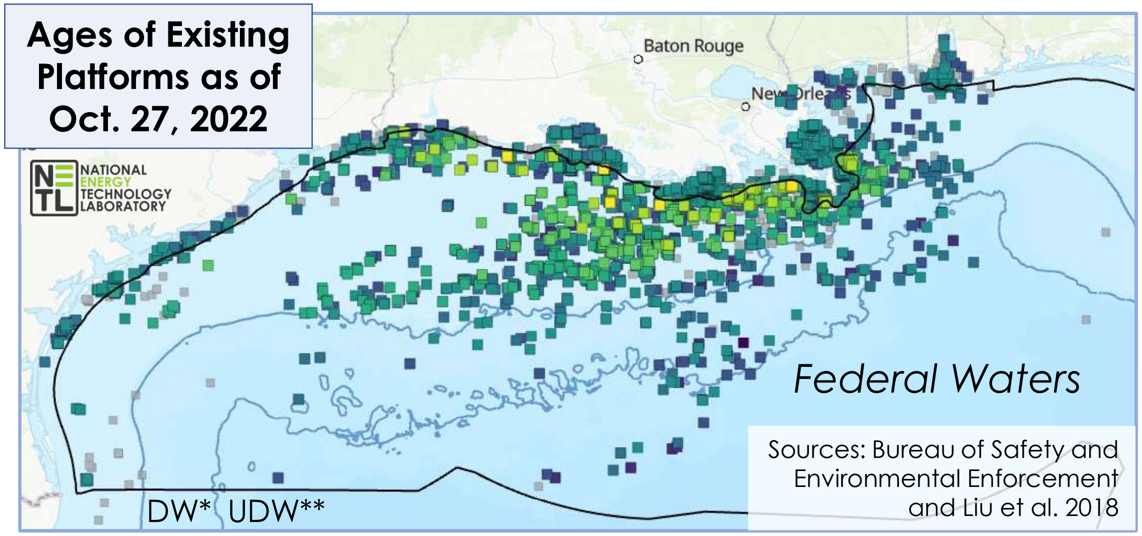
Offshore Energy Operations are Remote and Risky

Natural hazards

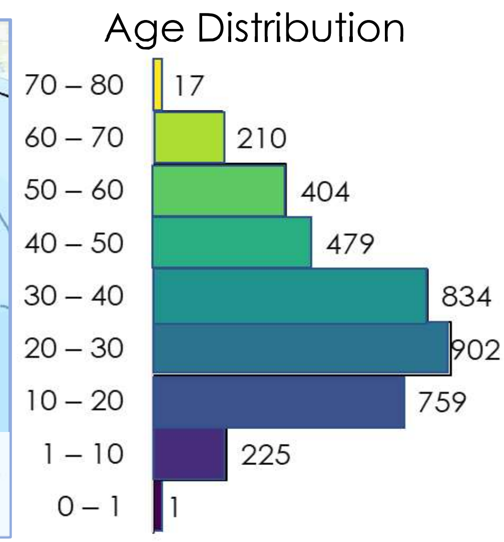
Integrity risks

Environmental impacts

Ages of Existing Platforms as of Oct. 27, 2022



Sources: Bureau of Safety and Environmental Enforcement and Liu et al. 2018



*Deepwater (1,000ft+)
**Ultra-deepwater (5,000ft+)

AIIM
Advanced Infrastructure Integrity Modeling

Values Delivered

- Identify **assets** vs. **liabilities**
- Inform **life extension**, **remediation**, **& safe use strategies**
  - Carbon storage, hydrogen storage, alternative energies
- Support **environmental** & **operational risk prevention**

Project Overview

AIIM: Advanced Infrastructure Integrity Modeling

AIIM applies **big data**, **big data computing**, and multiple **predictive machine learning (ML)**, **spatio-temporal**, and **advanced analyses**

Objectives

- Evaluate current state of **platform**, **pipeline**, and **wells** in the U.S. Federal Gulf of Mexico
- Integrate **pipeline** and **well-related data** and **fill gaps** identified in previous work
- Share information through the **AIIM Dashboard (EY23)**
  - Data visualization, analytics, and access

WATT The Power of Ai

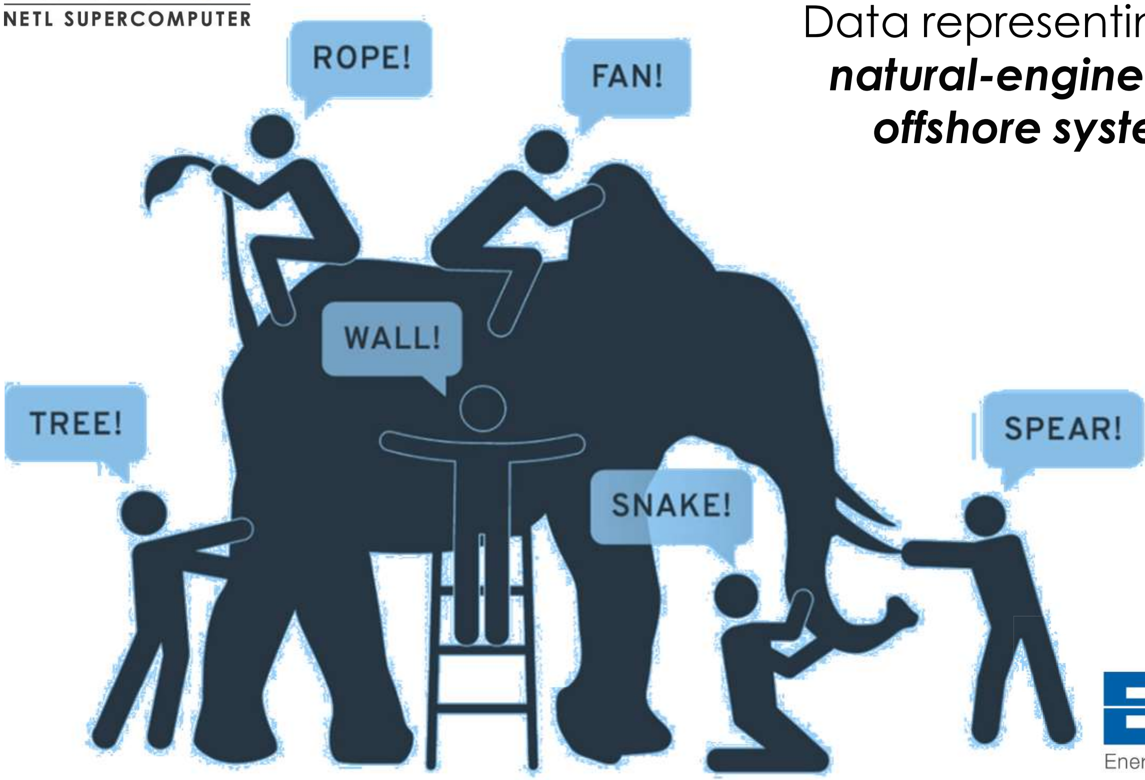
JOULE NETL SUPERCOMPUTER

AIIM Approach: Big Data & Big Data Computing-Driven Insights

NATIONAL ENERGY TECHNOLOGY LABORATORY

Using the Whole to Inform Local Trends & Predictions

JOULE NETL SUPERCOMPUTER



Data representing the ***natural-engineered offshore system***

- **11k+** platform records
- **26k+** miles of pipelines
- **68k+** well records
- **51k+** environmental layers
- Geohazard layers
  - Landslide prediction surface from **NETL's Ocean and Geohazard Analysis** smart tool
- **46GB+** biochemical data
- **Spatio-temporal production data** at the well, platform, and lease block level
- **70+** years of platform incidents
- **30+** years of pipeline incidents
- **50.6GB** of monthly ship trackline data

OGA Ocean & Geohazard Analysis

EDX Energy Data eXchange

AIIM Analytical Approach

Multiple Machine Learning (ML) and Advanced Modeling

Machine Learning Models (Dyer et al. 2022)

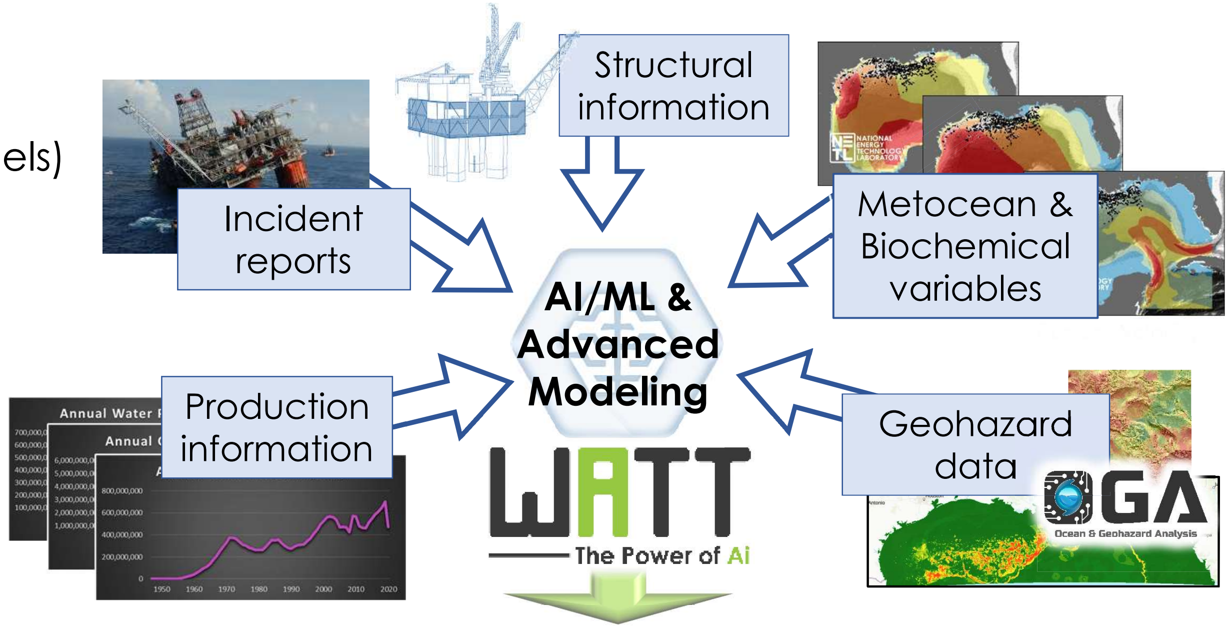
- Gradient Boosted Decision Trees (2 models)
- Artificial Neural Network (2 models)
- Bayesian Network

Advanced Analytics

- Geographically Weighted Regression
  (Nelson et al. 2021)
- Causality/Time Series Analytics

Why multiple models?

- Evaluate strengths vs. weaknesses
- Internal cross-validation



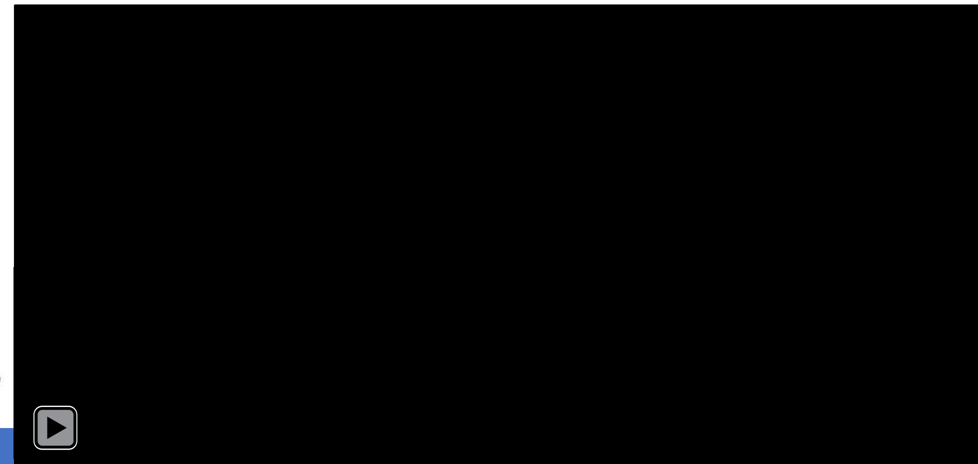
Identified **significant connections** among **biochemical** variables and **incidents**

Corroborated results with **news** and **reports**

ML models capable of predicting **removal age <u>< 3 years</u>**

Enhanced Environmental Factors

Integrating 46GB+ BioChemical Data & Seafloor Data



- Developed visualization to support **Metocean Big Data Processing Program** quality control
- **Time series processing** option
- At-depth data extraction to better support **pipelines** and **wells** analytics

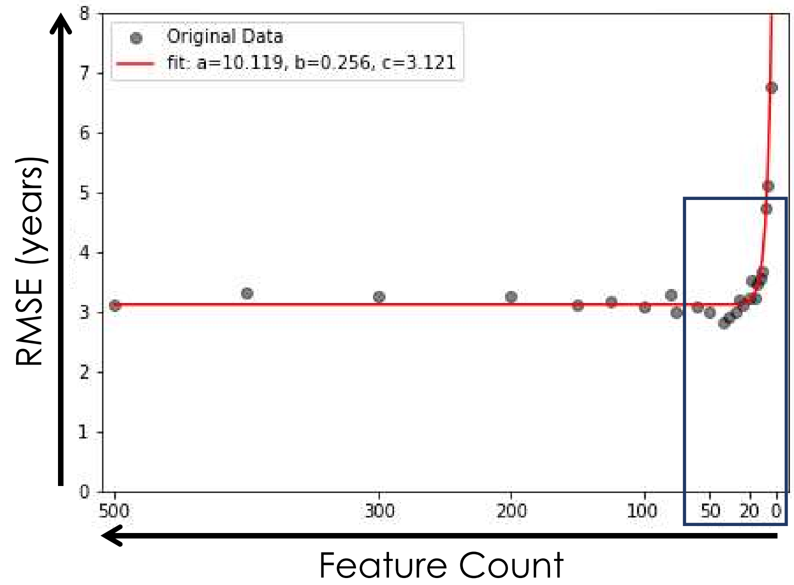
EDX Energy Data eXchange

Model	Variables
International Best Track Archive for Climate Stewardship	Storm category, max sustained wind speed, sea height, max gust, minimum central pressure
Medusa/Orca	Alkaline, diatom chlorophyll, nondiatom chlorophyll, detritus, inorganic carbon, inorganic nitrogen, detritic carbon, dissolved iron, dissolved oxygen, biologenic silicon, silicon, diatom phytoplankton, non-diatom phytoplankton, silicate, meso zooplankton, micro zooplankton
Texas Louisiana Shelf	Floor current direction and magnitude
Hybrid Coordinate Model	Floor current direction & magnitude; Surface current direction magnitude
Wavewatch III	Wave height, period, direction, and power; Wind direction and magnitude

Understanding Platform Lifespan & Risk

Expanding Analytics: *Predicting Platform Age at Removal*

- Integrated ***70+ years*** of data
  - **11k+ structure records**
  - **1,700+ features**
- Added **292 incidents** from **hurricanes** and **239 incidents** from **Pipeline and Hazardous Materials Safety Administration** (**PHMSA**)
- Calculated incident severity based on **incident impact** (i.e., damage, cost)
- Applied **ML models** to **updated data**



Feature engineering to identify key stressors impacting **integrity & risk**

Ex. Reduced 100s of production features to less than 10 (i.e., peak production years, water-oil production)

Model WATT The Power of AI	**RMSE* (years)**
Gradient Boosted Decision Tree (CatBoost)	**3.1**
Gradient Boosted Decision Tree (XGBoost)	**3.4**
Artificial Neural Network	**5.3**

*Root Mean Square Error

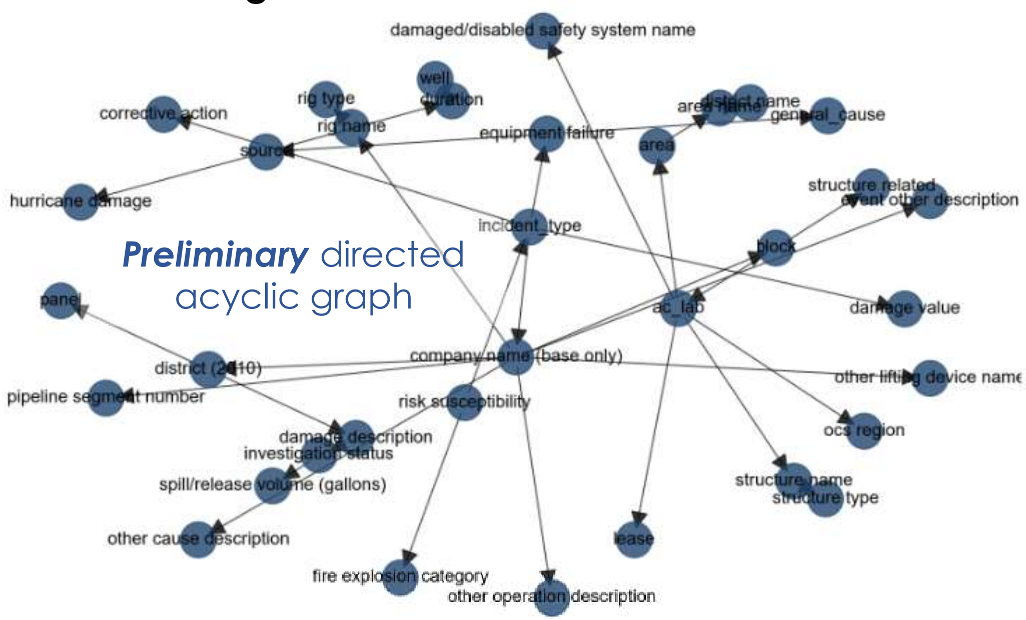
Applied machine learning model comparison: Predicting offshore platform integrity with gradient boosting algorithms and neural networks - ScienceDirect

Expanding Analytics for Platform Incidents

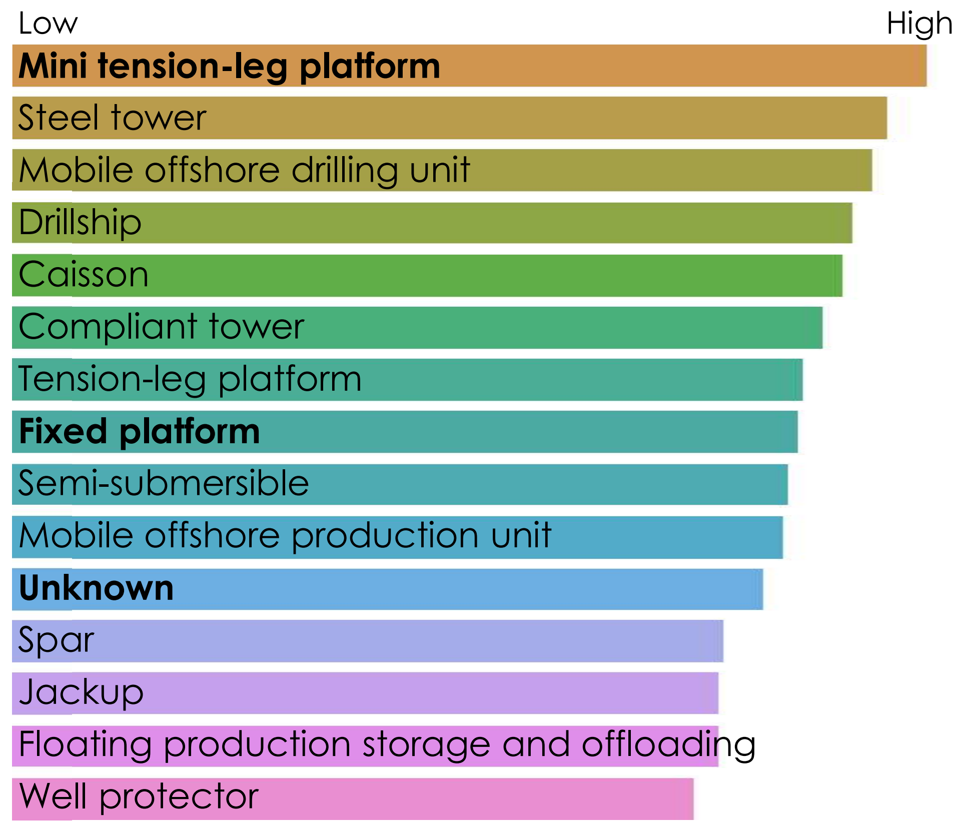
Examining Risk Cause and Effect

- Began development of **Bayesian Network** to correlate **incident attributes and causes** with incident severity

- Evaluating **trends** across **structure type**, **depth**, **installation age**, and **more**



Average Severity by Structure Type

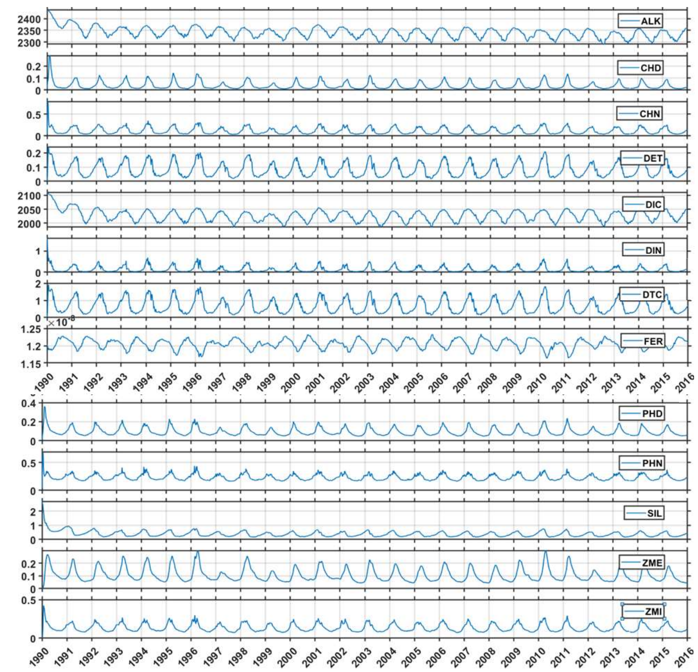


Time Series Analytics

Comparing Platform Incidents to Biochemical Variables

- Aggregated incidents and biochemical (Yool et al., 2013) time series to estimate **transfer of information**
- **Causal relationship was not found**
  - Biochemical variables → incident time series
- **Identified a causal relationship**
  - Biochemical variables → **rate of change** of incident time series

Biochemical properties cause incidents over **two main periods**: **10 years** and **20 years**



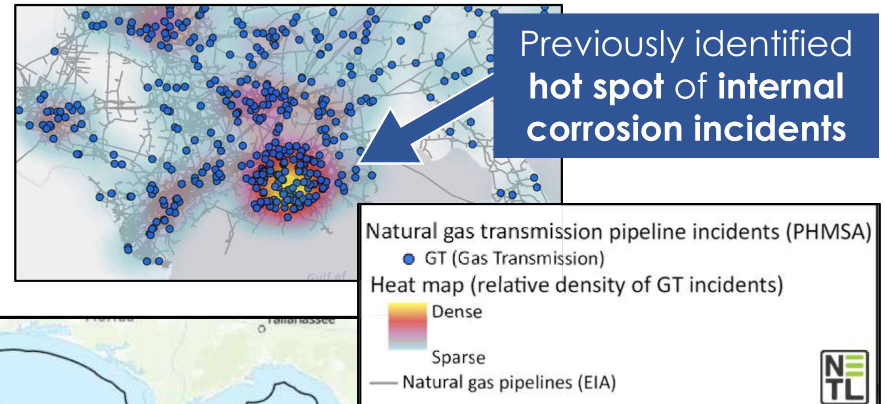
Example of biochemical time series

Model	Variables
Medusa/Orca (U.K. NOC)	Alkaline, diatom chlorophyll, nondiatom chlorophyll, detritus, inorganic carbon, inorganic nitrogen, detritic carbon, dissolved iron, dissolved oxygen, biologenic silicon, silicon, diatom phytoplankton, non-diatom phytoplankton, silicate, meso zooplankton, micro zooplankton

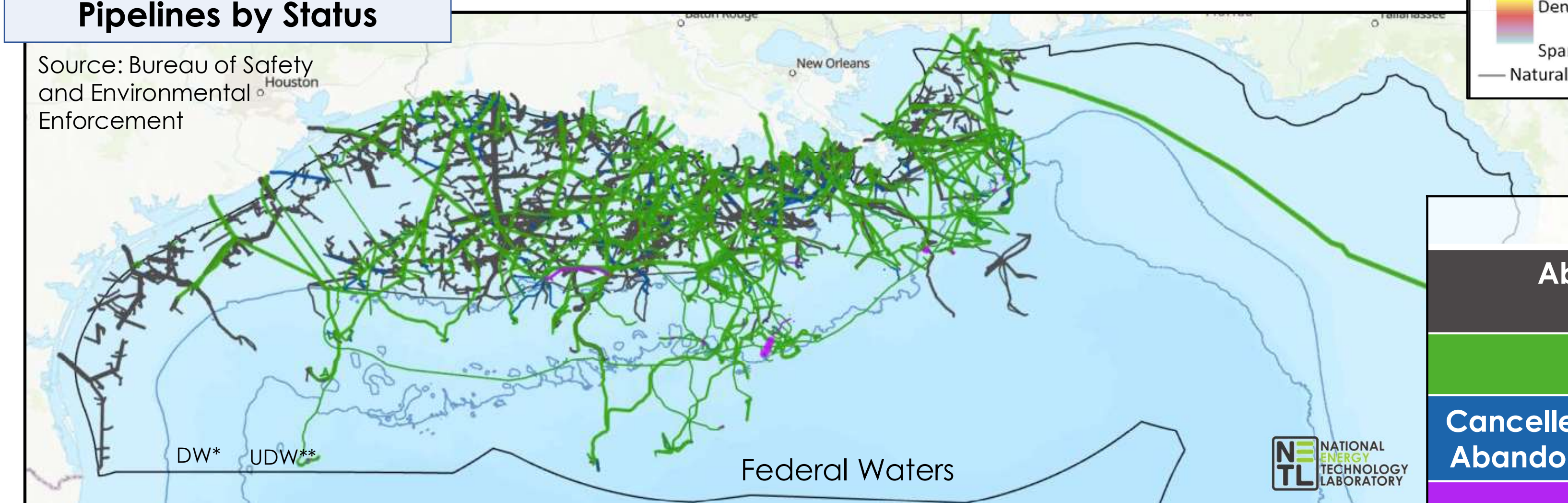
Integrating Pipeline Infrastructure

Utilizing Past Research to Inform New Insights

- Leveraging data and insights from **national pipeline R&D sensor placement**
- Applying AIIM to evaluate integrity of **existing** and **abandoned** pipelines



Pipelines by Status



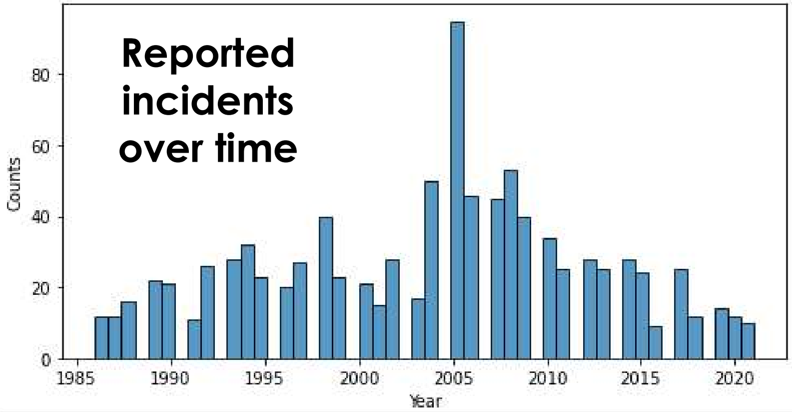
Status	Miles
Abandoned or Removed	23,838
Active	19,731
Cancelled, Proposed Abandon or Remove	3,914
Proposed	109

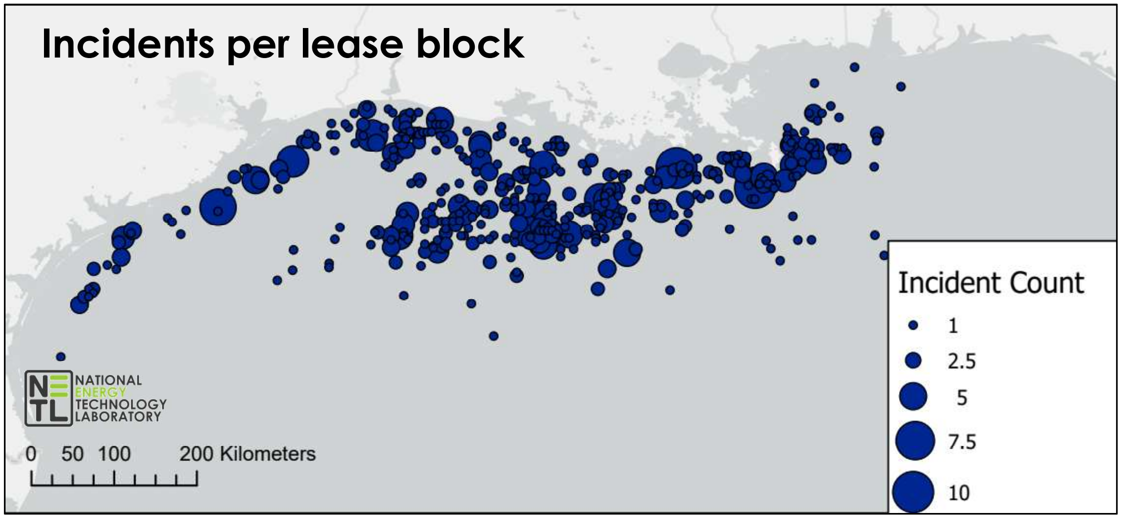
*Deepwater (1,000m+)
**Ultra-deepwater (5,000m+)

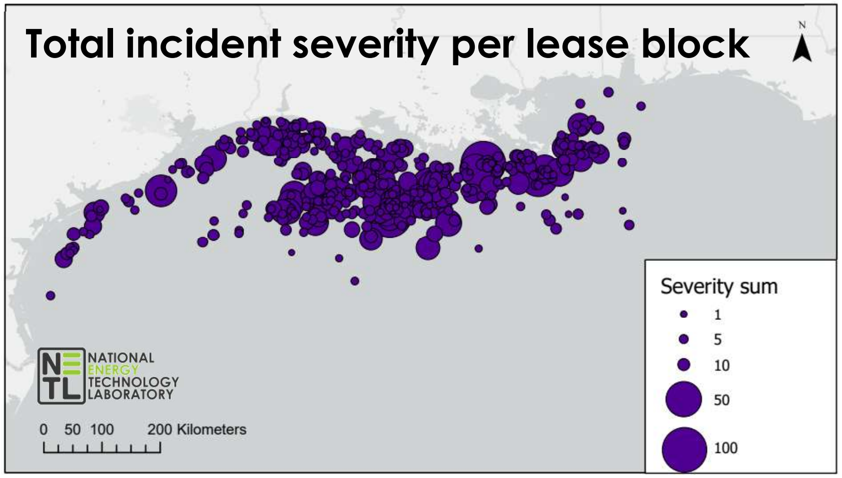
Preliminary Pipeline Incident Analytics

Understanding 30+ Years of PHMSA Incidents

- Compiled, cleaned, and mapped **970 PHMSA incidents** (Pipeline and Hazardous Materials Safety Administration)
- **30+ years** of incidents
- **Spatially mapped** more than **80%** to lease blocks
- Calculated **impact-based severity**



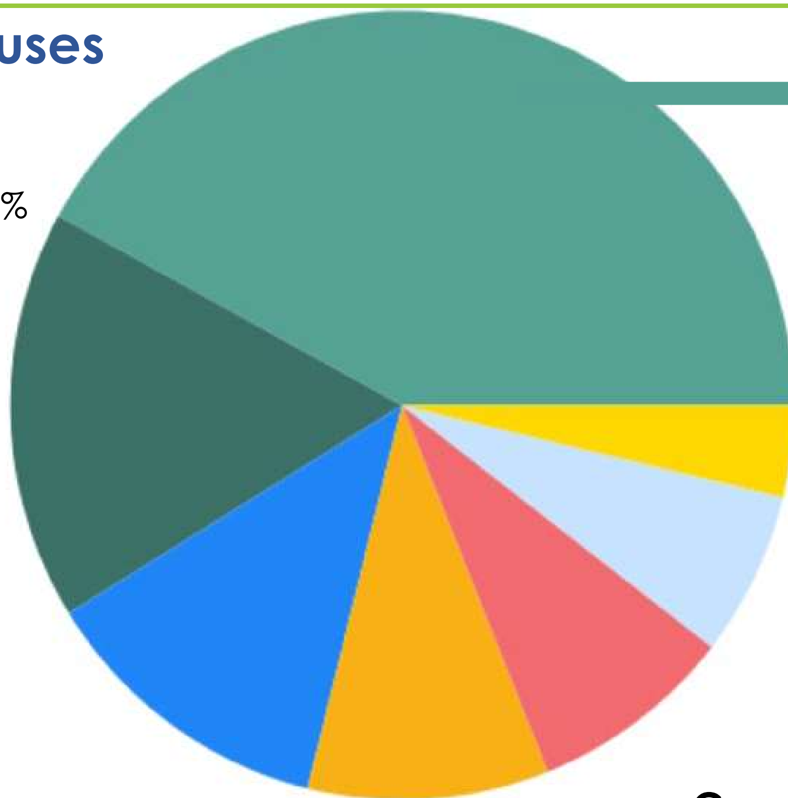


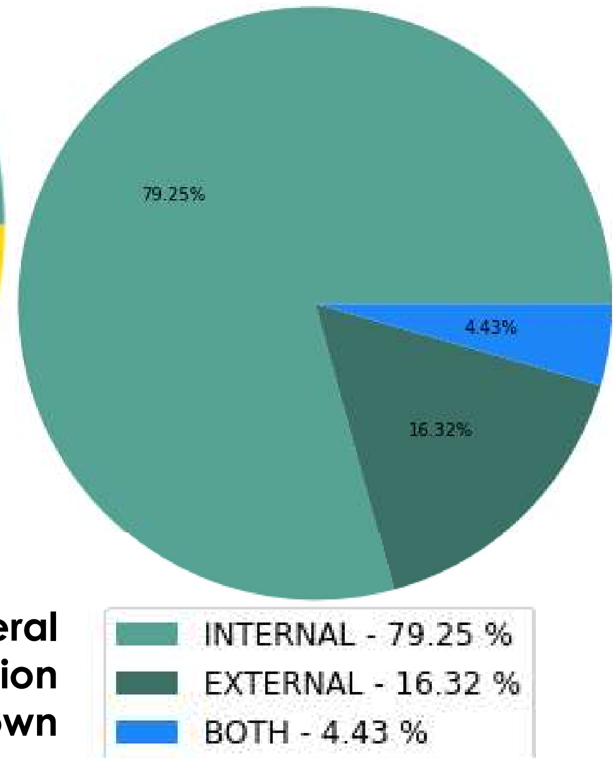


Preliminary Pipeline Incident Analytics Continued

Evaluating Incident Causes

- Corrosion Failure, 42.03%
- Outside Force Damage, 16.79%
- Natural Forces, 12.30%
- Other, 9.95%
- Material Failure, 8.45%
- Equipment Failure, 6.74%
- Incorrect Operation, 3.74%





General Corrosion Breakdown

Preliminary Pipeline Incident Analytics Continued

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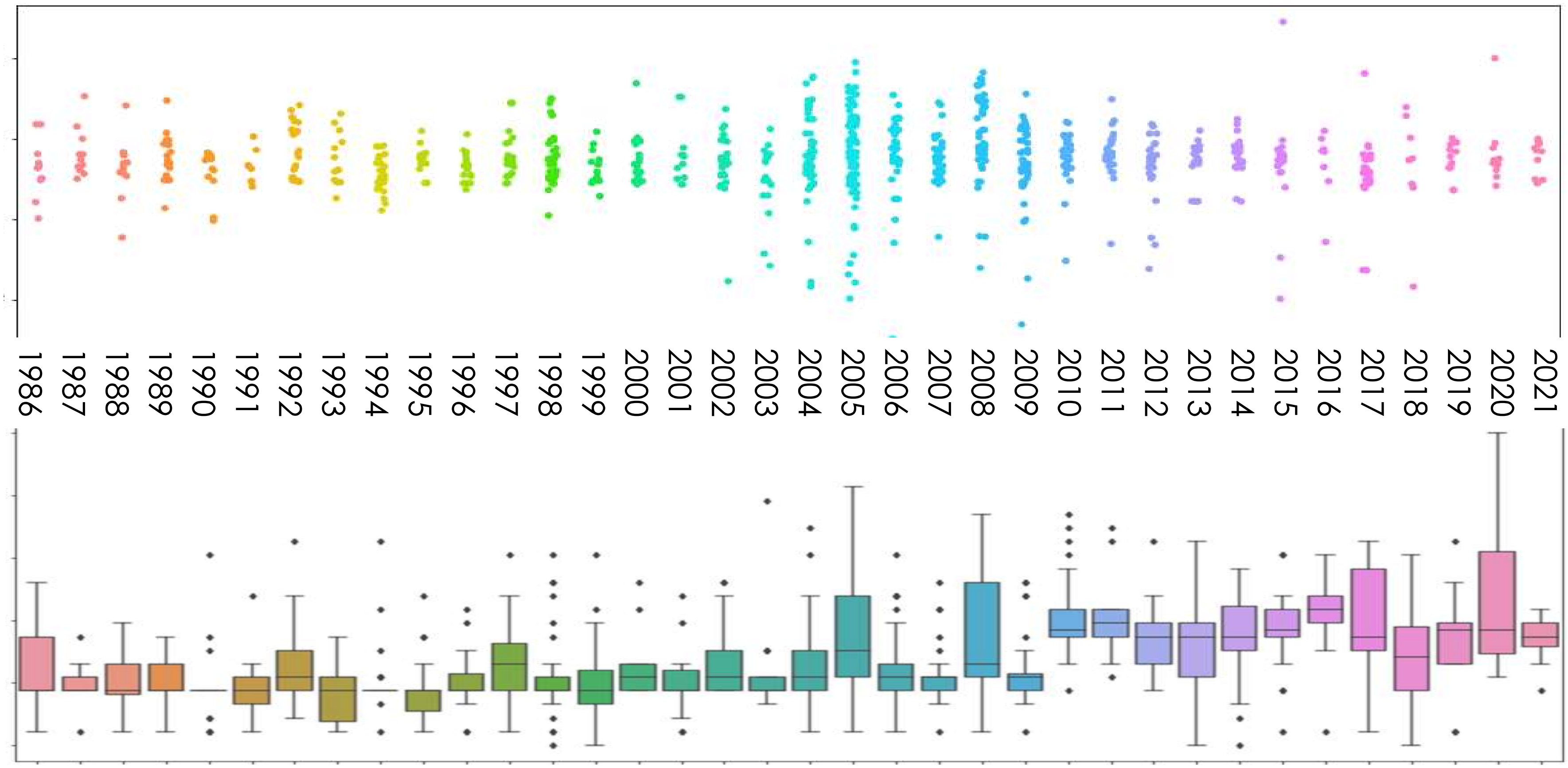
Evaluating Incident Consequences Over Time

Incident Cost Over Time

Costs based on 2021 USD value

Incident Severity Over Time



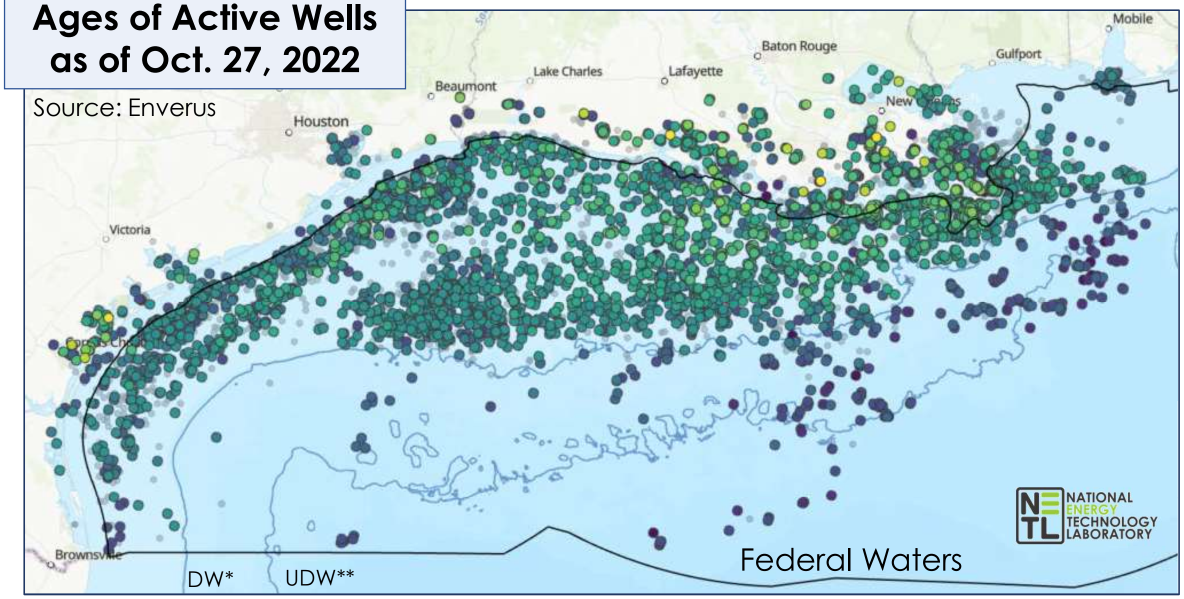
Integrating Well Infrastructure

Utilizing Past Research to Inform New Insights

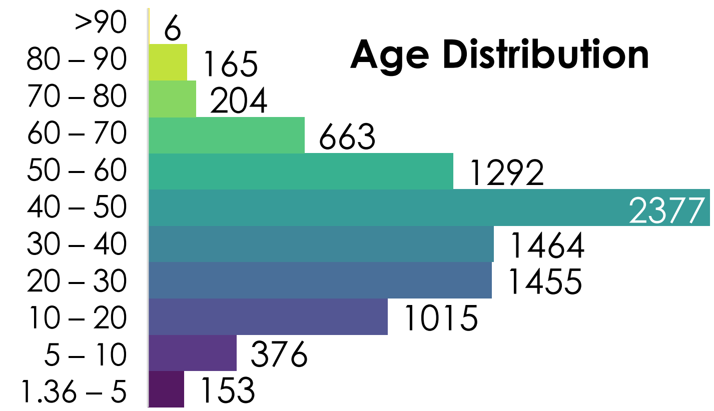
- Leveraging data and insights from **onshore well integrity testing**
- Evaluating **well integrity** for **reuse potential**

Ages of Active Wells as of Oct. 27, 2022

Source: Enverus



*Deepwater (1,000m+)
**Ultra-deepwater (5,000m+)



Stressors Identified

- Age (Dilmore et al, 2015)
- Type (Kiran et al., 2017)
- Concrete type and installation (Wang et al., 2016; Kiran et al., 2017; Wise et al., 2019; Rocha-Valadez et al., 2014)
- Water depth (Wise et al., 2019)
- Corrosion (Kiran et al., 2017)
- Direction (Lackey et al., 2021)
- Pressure and temperature (Rocha-Valadez et al., 2014; Wang et al., 2016; Kiran et al., 2017)
- Seismic/tectonic activity (Kiran et al., 2017)
- Geology (Dilmore et al, 2015; Kiran et al., 2017)

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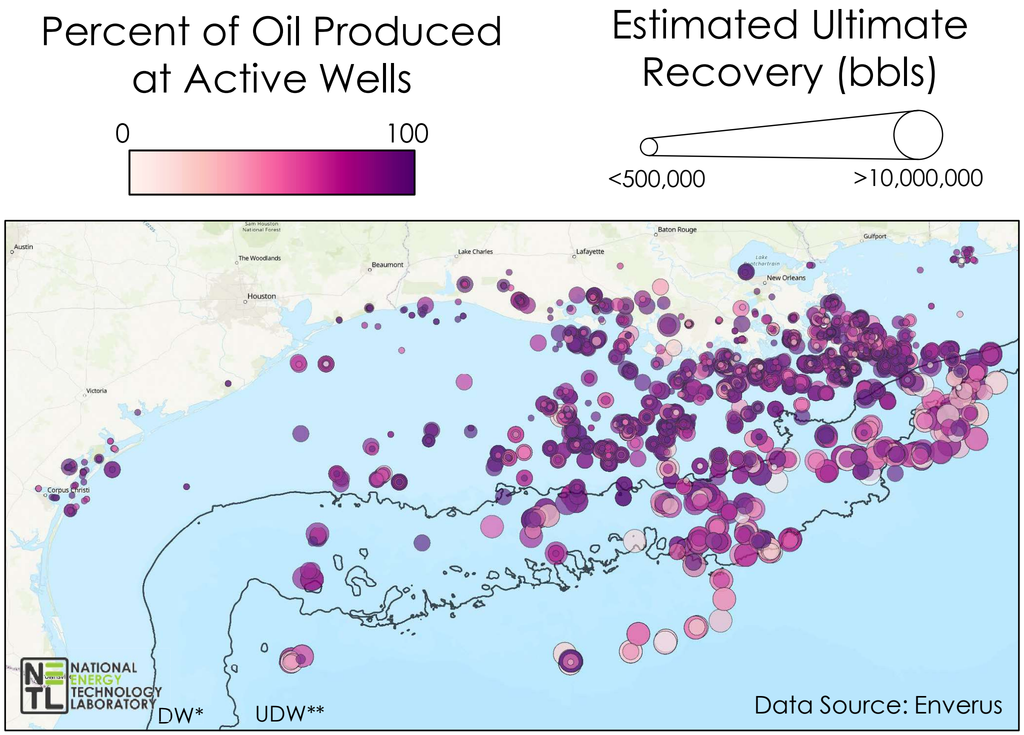
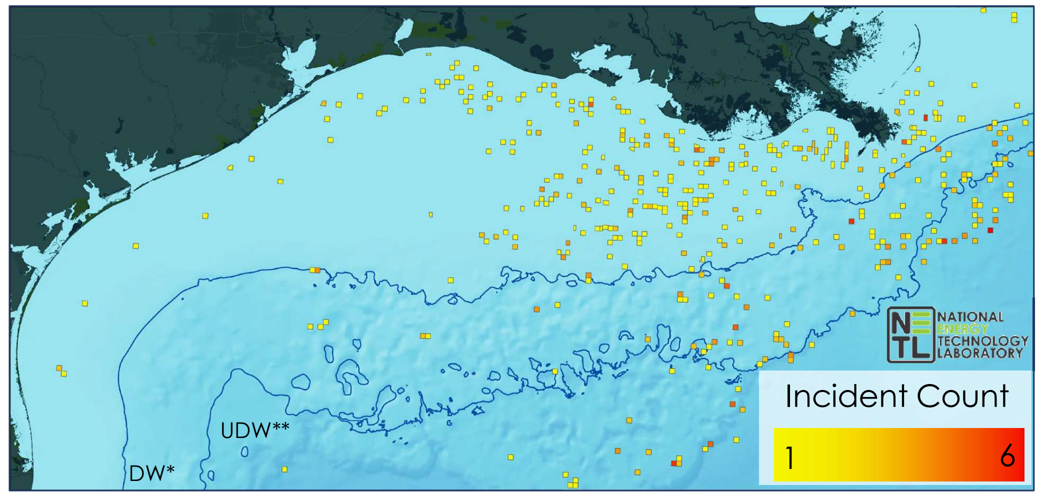
[Public data from three US states provide new insights into well integrity | PNAS]

Preliminary Well Integrity & Risk Analytics

Evaluating Production Life, Status, and Incidents





Well-Related Incidents from Pipeline & Platform Incident Reports (n = 603)

Count by Outer Continental Shelf Lease Block

*Deepwater (1,000m+)
**Ultra-deepwater (5,000m+)

Key Accomplishments

NATIONAL ENERGY TECHNOLOGY LABORATORY

TechConnect WORLD INNOVATION CONFERENCE & EXPO

[TechConnect Innovation Awardee]

- Published results and comparison of **ML infrastructure integrity models** in ***Marine Structures*** (Dyer et al. 2022)
- **Integrated 1.5TB+ of data**
- Enhanced **metocean big data processing program**
- Additional ML model **capable of predicting platform lifespan within 3 years on average**

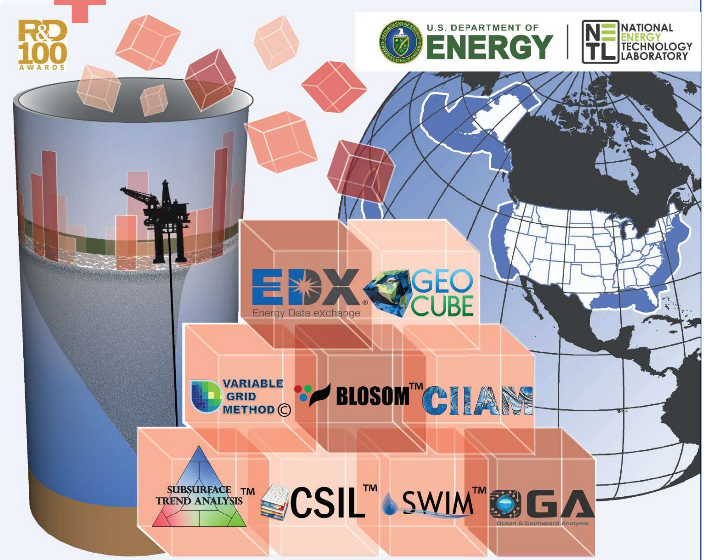
Next Steps

EDX Energy Data eXchange

- Apply **ML and advanced models** to **pipelines** and **wells**
- Integrate **operational** and **environmental risks** from **NETL's Offshore Risk Modeling Suite**

AIIM

- Present on risk analytics at **American Geophysical Union Fall Meeting, 2022**
- Papers in preparation on **incident processing** and **expanded analytics**
- Build **AIIM Dashboard** for **information visualization** and **interrogation**



AIIM Dashboard

Planned Capabilities

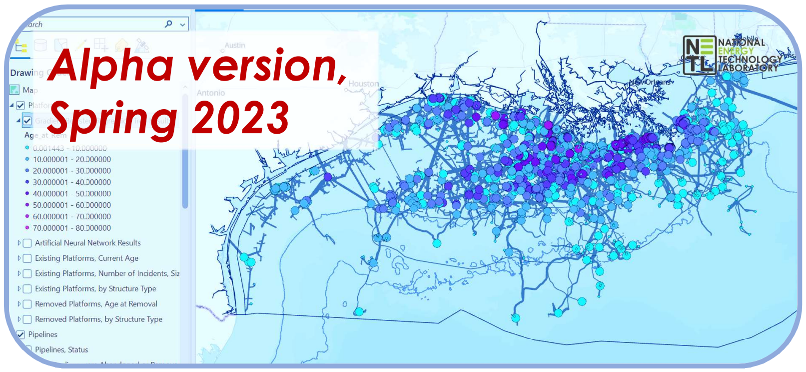
- **Fast access data** and **information**
- Map **infrastructure** and **key stressors**
- Identify **structural timelines** of **extreme** and **notable events**
- Evaluate **spatio-temporal trends** and **machine learning** results
- Visualize **infrastructure** and **metocean data** alongside **environmentally sensitive areas**

A **data-driven, smart, decision support system** to answer a variety of questions…

Offshore R&D

What are the most traversed lease blocks by ship traffic?

What is the remaining lifespan of a platform?



Where are operational risks more likely?

What is the history of a platform? Lease block? Pipeline?

Where are environmentally vulnerable areas?

Where are structures that could be reused for carbon storage?

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NETL RESOURCES

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Benefit to the Program

- **Tasks 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 10** 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 machine learning 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), Madison Wenzlick, Dakota Zaengle, Isabelle Pfander, Chukwuemeka Okoli, Catherine Schooley, Patrick Wingo, and Michael Sabbatino
  - Theiss Research: Rodrigo Duran, Ph.D.

Organization Chart

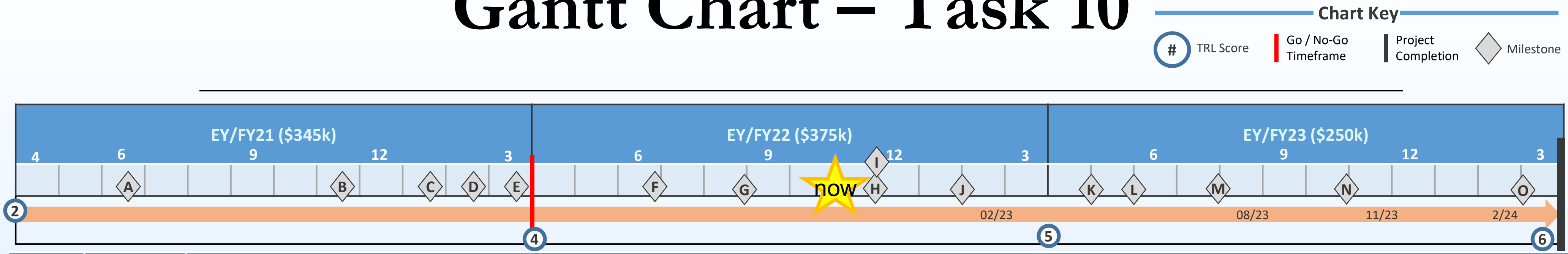
Lead Organization
NETL

Principal Investigators
Jennifer Bauer, Lucy Romeo

Task 10
Smart Infrastructure Integrity Models to Support Remediation and Inform Safe Reuse Strategies

Lead: Jennifer Bauer, Lucy Romeo
Team: Rodrigo Duran, Madison Wenzlick, Dakota Zaengle, Isabelle Pfander, Chukwuemeka Okoli, Catherine Schooley, Patrick Wingo, Michael Sabbatino, 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, 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	06/22	Apply smart models to evaluate the current state of production FE infrastructure in the U.S. GOM.
10.G	08/22	Integrate all pipeline structural, incident, metocean, and geohazard data into one dataset for analyses and modeling.
10.H	11/22	Apply smart models to evaluate the current state of energy transport infrastructure in the U.S. GOM.
10.I	11/22	Outline analytical framework for the development of the data-driven AIIM tool that uses smart logic to evaluate infrastructure, including tool needs and capabilities,
10.J	01/23	Acquire, process, and integrate wellbore data into a dataset for analyses.
10.K	04/23	Develop alpha version of AIIM tool and release for internal testing.
10.L	05/23	Analyze potential environmental and operational impacts using existing tools from the ORM suite.
10.M	07/23	Apply AIIM to evaluate existing wellbore integrity.
10.N	10/23	Provide demonstrable applications of novel tool for evaluating the current state of platform and pipeline infrastructure, streamlined with data-driven insights of potential environmental and operational risk.
10.O	02/24	Submit technical report or manuscript for publication.

Research Products from Offshore Task 10

- <u>Publications</u>
  - Dyer, Alec S., Dakota Zaengle, Jake R. Nelson, Rodrigo Duran, Madison Wenzlick, Patrick C. Wingo, Jennifer R. Bauer, Kelly Rose, and Lucy Romeo. (2022) "Applied machine learning model comparison: Predicting offshore platform integrity with gradient boosting algorithms and neural networks." *Marine Structures* 83: 103152.
  - Nelson, J. R., Romeo, L., & Duran, R. (2021). Exploring the Spatial Variations of Stressors Impacting Platform Removal in the Northern Gulf of Mexico. *Journal of Marine Science and Engineering*, 9(11), 1223.
  - Romeo, L., Wingo, P., Sabbatino, M., Bauer, J. (2021). Baseline data for spill assessments: Ambient conditions, Socioeconomic data, Sensitivity maps. In O. Makarynskyy (Ed.), *Marine Hydrocarbon Spill Assessment: From Baseline Information through to Decision Support Tools* (1 ed.). Amsterdam, Netherlands: Elsevier.