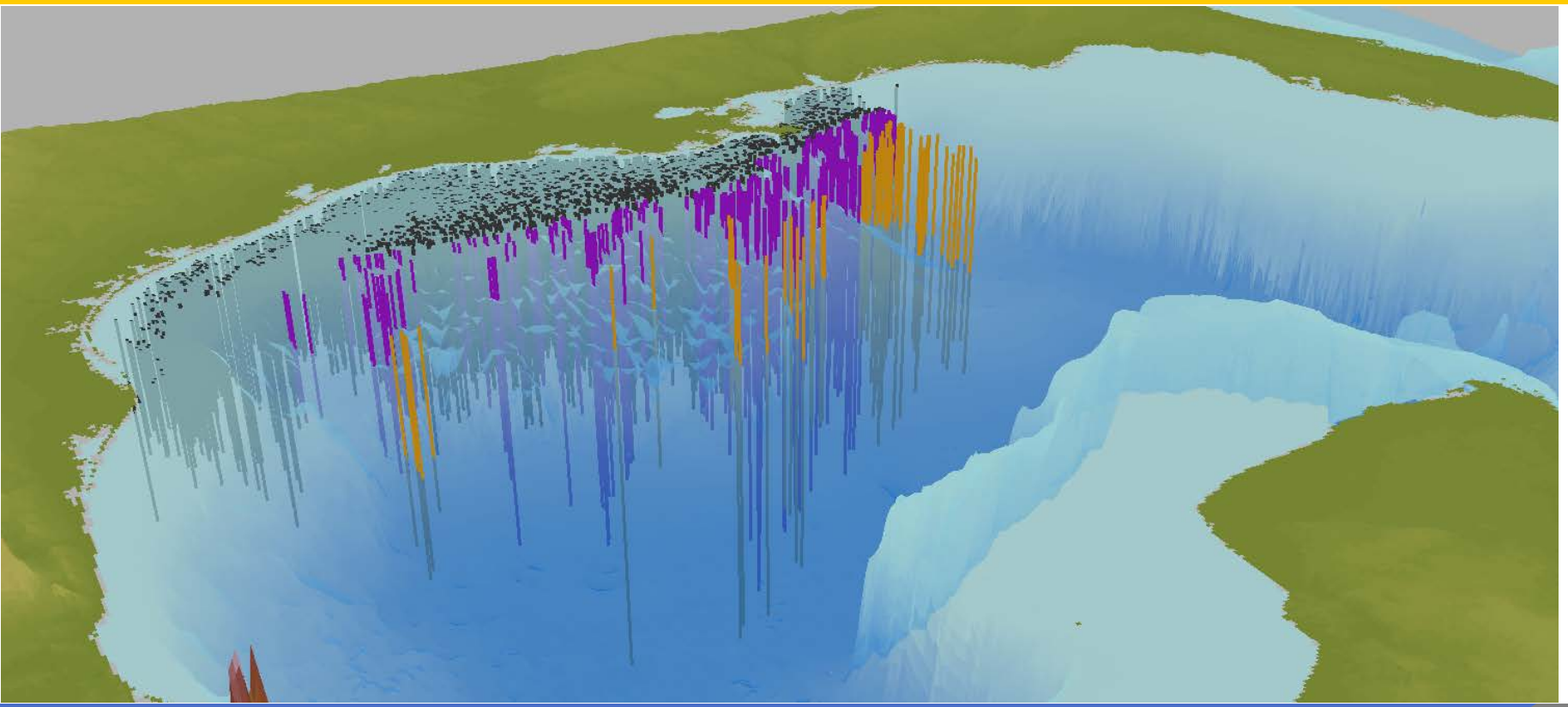
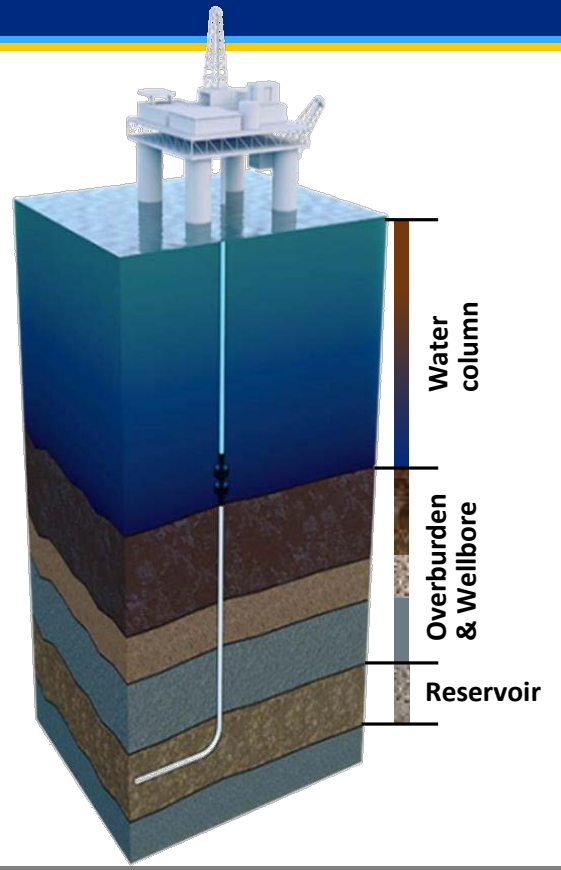
Driving Innovation ♦ Delivering Results





NETL's Offshore Integrated Assessment Model (IAM)

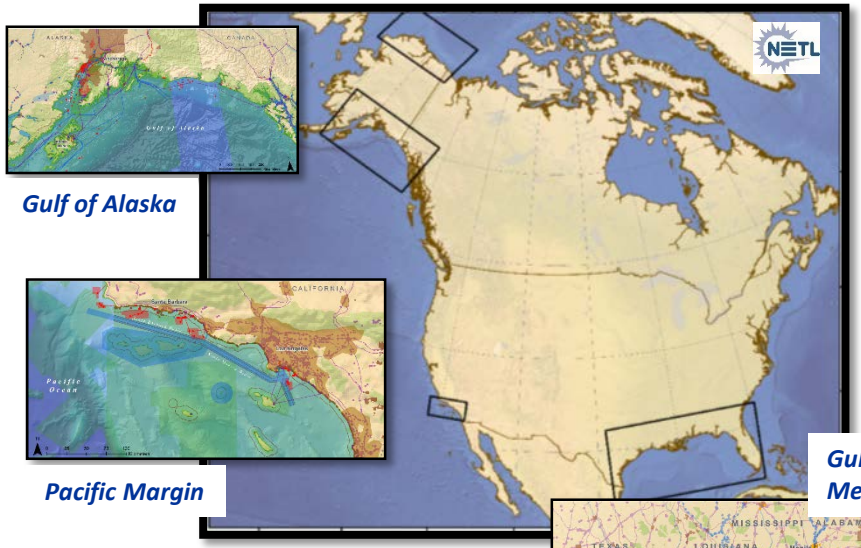
Offshore spill prevention, rapid response & risk reduction

Kelly Rose - Geology-Geospatial Scientist
U.S. Department of Energy, National Energy Technology Laboratory
Mastering the Subsurface Through Technology, Innovation and Collaboration: Carbon Storage and Oil and Natural Gas Technologies Review Meeting
August 16-18, 2016

R&D for Offshore Spill Prevention

- **DOE goals align to:**
  - Domestic supply
  - Environmental custodianship
  - Legacy management

Deepwater Horizon



- **Wells: ~56,886 offshore wells in federal waters**
- **Platforms: ~7,171 platforms in federal waters**
- **Pipelines: ~18,343 pipelines in federal waters**
- **Tankers: ~23,678 tankers dock at U.S. ports per year**

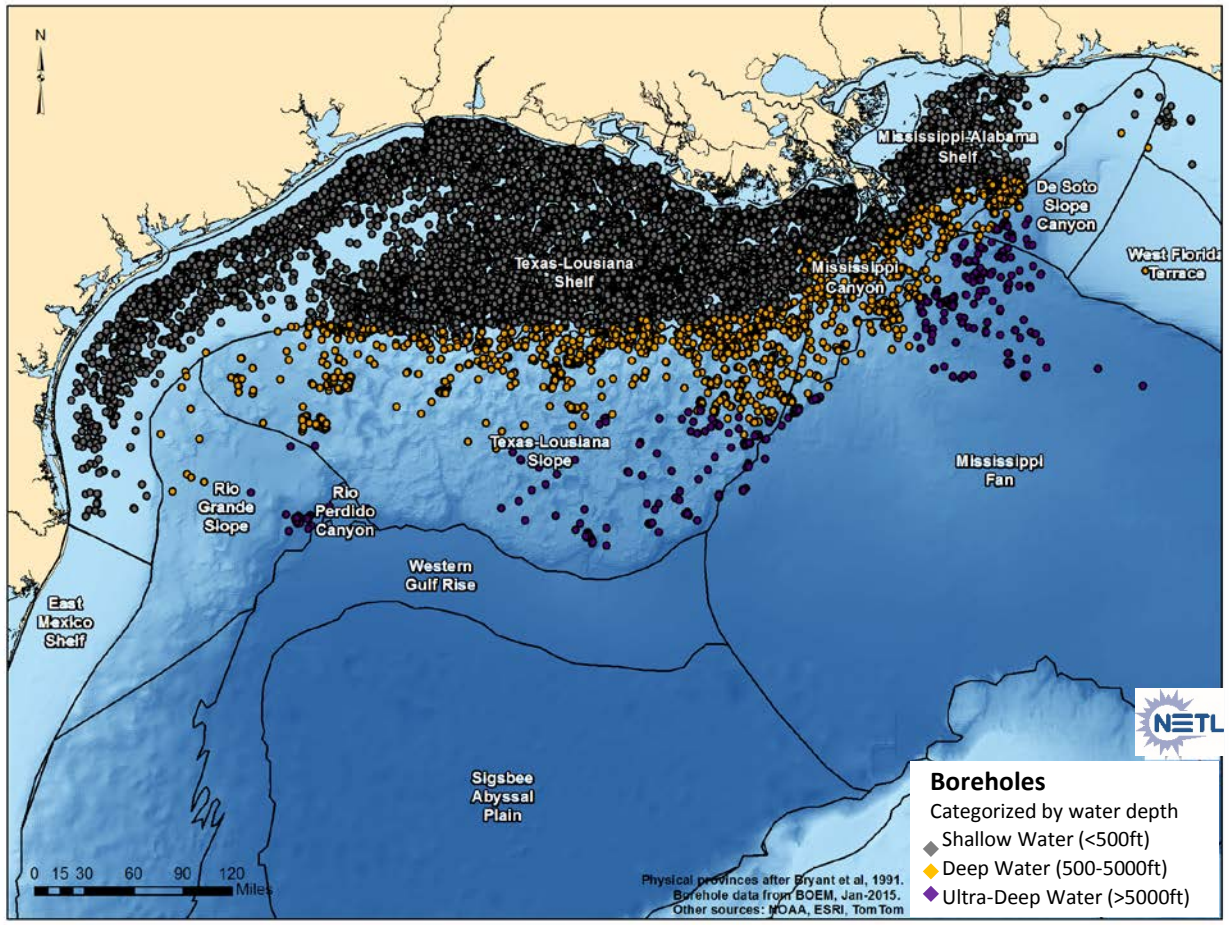
Key Drivers for the Offshore Portfolio:

- Recent offshore events, such as Hurricanes Ivan (2004), Katrina/Rita (2005) & DWH spill (2010)
- 2010 Executive Order 13547, Interagency Ocean Policy Task Force (IOPTF)
  - Executive agencies (including DOE) challenged to enhance national stewardship of the ocean, coasts, & Great Lakes
- 2012 Challenges Identified by DOI's OESAC Spill Prevention Subcommittee
  - Deep water and offshore frontier areas face production risks that are fundamentally distinct from onshore operations

Mississippi Canyon 20

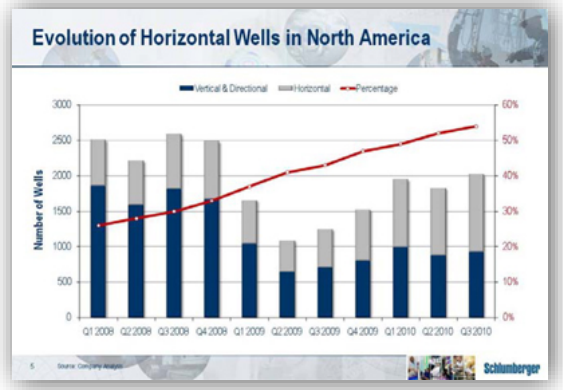
Offshore Drilling Risks Often Tied to Uncertainty

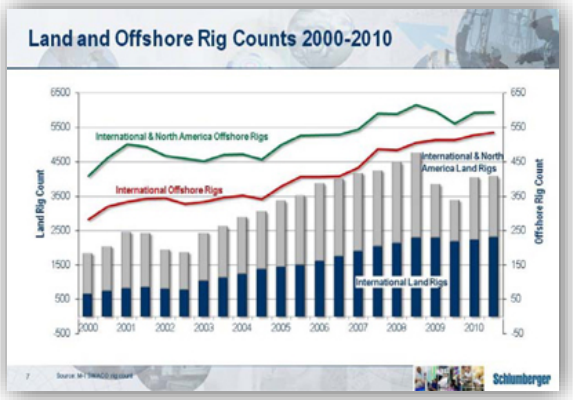
Uncertainty Reduction = Spill Prevention



One study cited that 44% of non-productive time was associated with geopressure and wellbore instability related problems

(source: Halliburton, https://www.landmarksoftware.com/Pages/DrillWorks.aspx)



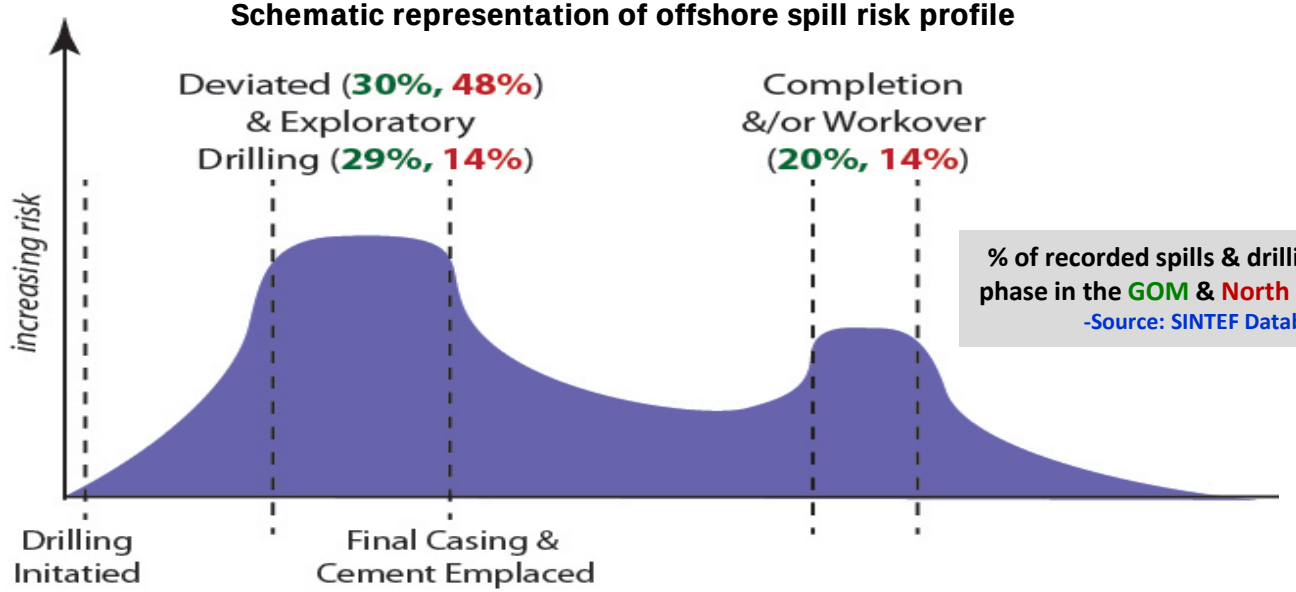


Drilling challenges from abnormal formation pore pressure and wellbore instability related events cost the industry **almost $8 billion every year**

(source: Halliburton, https://www.landmarksoftware.com/Pages/DrillWorks.aspx)

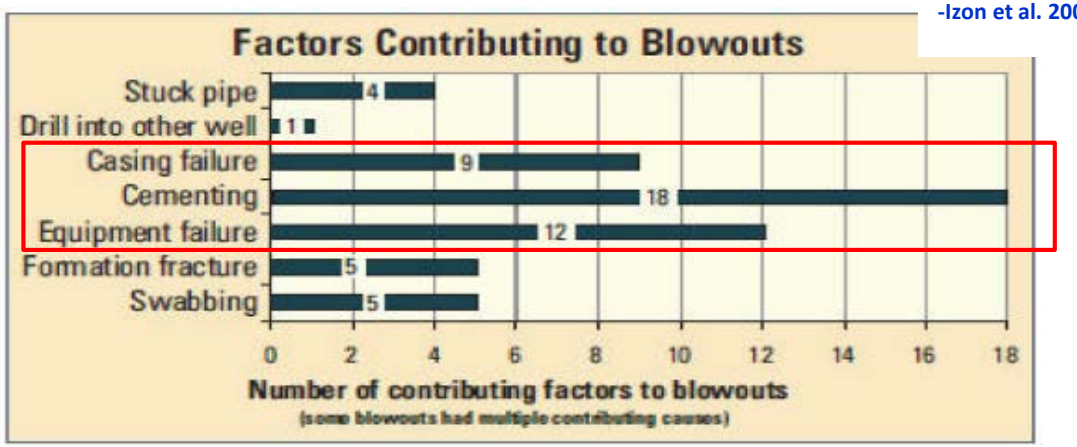
NETL's Offshore Portfolio & IAM-
Targeting Prevention of Top Offshore Spill Risks

Schematic representation of offshore spill risk profile



% of recorded spills & drilling phase in the GOM & North Sea
-Source: SINTEF Database

-Izon et al. 2007

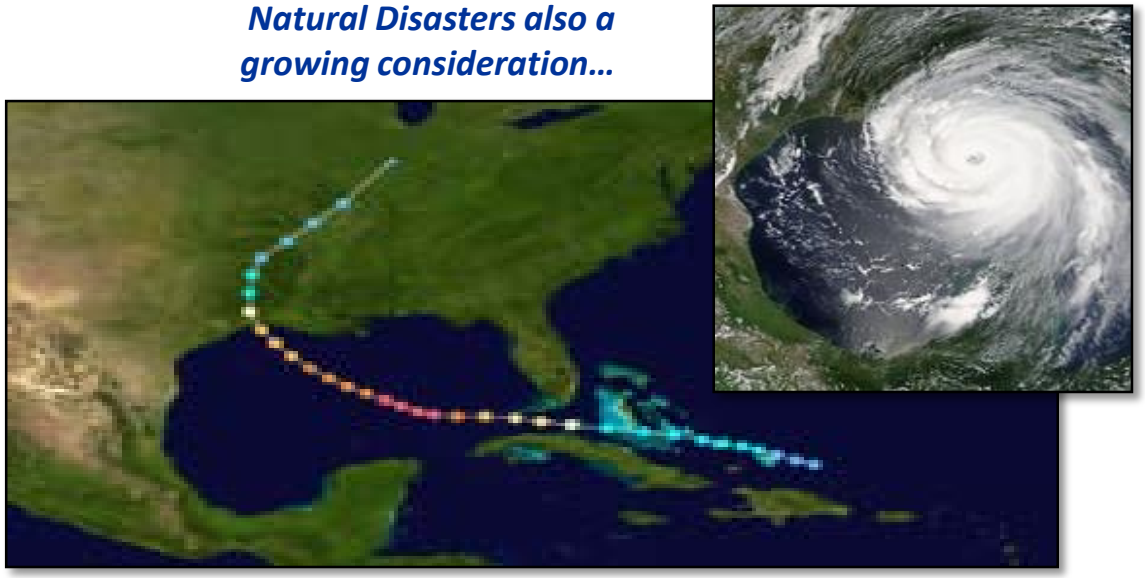


NETL ORD's Offshore IAM & Portfolio Target Key E&P Risks Associated with Extreme Offshore Hydrocarbons:

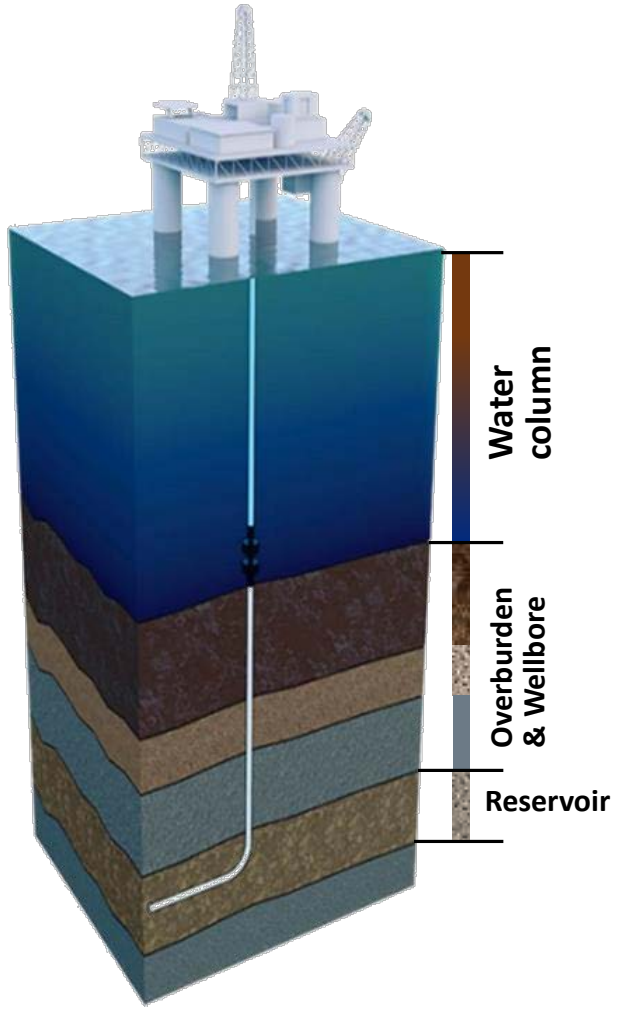
- Cementing Failures
- Equipment & Casing Failures
- Reducing geologic uncertainty
- Higher risk targets, "exploratory" systems

Through use of novel tools, models and big data

Natural Disasters also a growing consideration…



NETL ORD's Offshore Portfolio, 2011-present



Wellbore Integrity – Improved Science Base for Materials

- Characterizing the Behavior of Metal-Based Systems Used for Control Devices in Extreme Environments - *Hawk, J.* ***5:30pm Tuesday***
- Improving Science-Base for Wellbore Integrity, Foam Cements
- Evaluation of Lithology:Cement:Casing Barrier Integrity under UDW Subsurface Conditions , *Huerta, N.* ***4:05pm Wednesday***

56 presentations
22 publications

Rapid Detection and *In Situ* Characterization – Improving Safety

- Kick Detection at the Drill Bit - Adaptation of Existing Technology to Reduce Risks Associated with Deep and Ultra-Deep Drilling
- **Completed**: Improving Flow Assurance, Expediting Well Control, and Reducing Environmental Impacts Resulting from Blow-Outs in HPLT Environments

8 presentations
9 publications

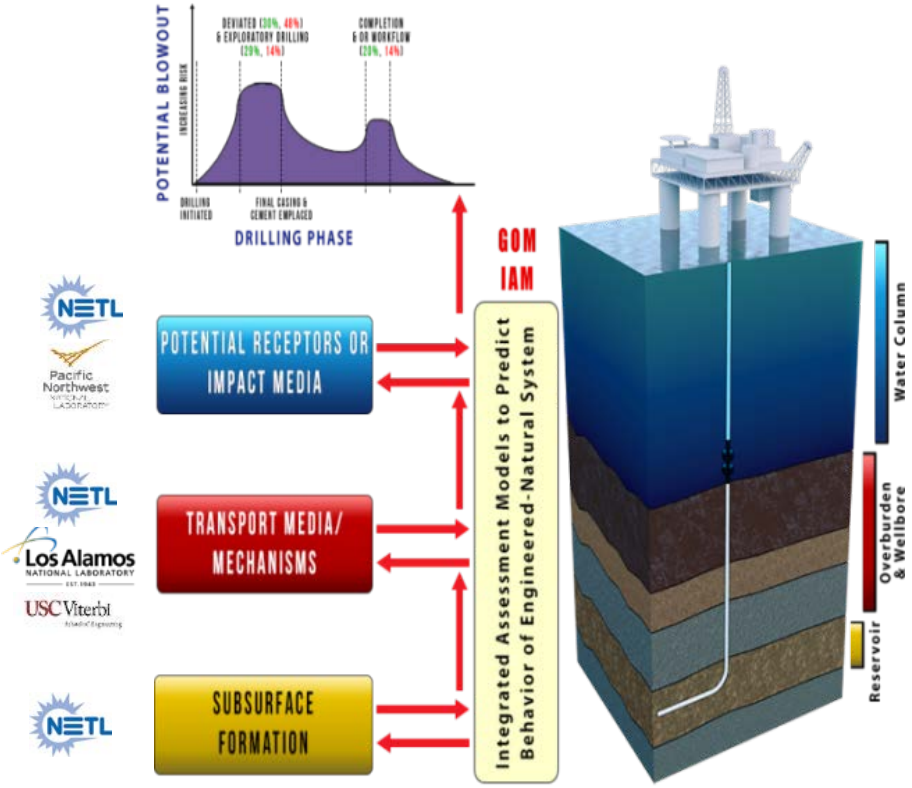
Risk Reduction - Mitigating Knowledge & Technology Gaps in Offshore Systems-

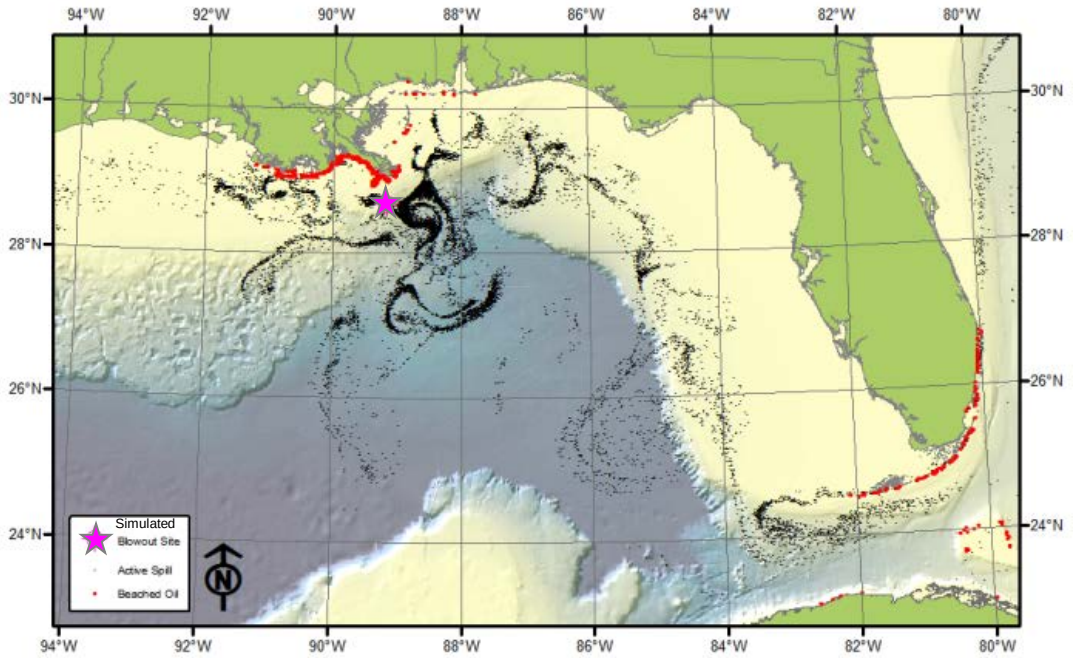
- Quantifying Complex Fluid-Phase Properties at High Pressure/High Temperature (HPHT)
- **Assessing Risks and the Potential for Environmental Impacts for Deepwater and Ultra-Deepwater GOM Resources**

58 presentations
34 publications
8 datasets
8 tools
2 patents pending

NETL's Offshore Integrated Assessment Model

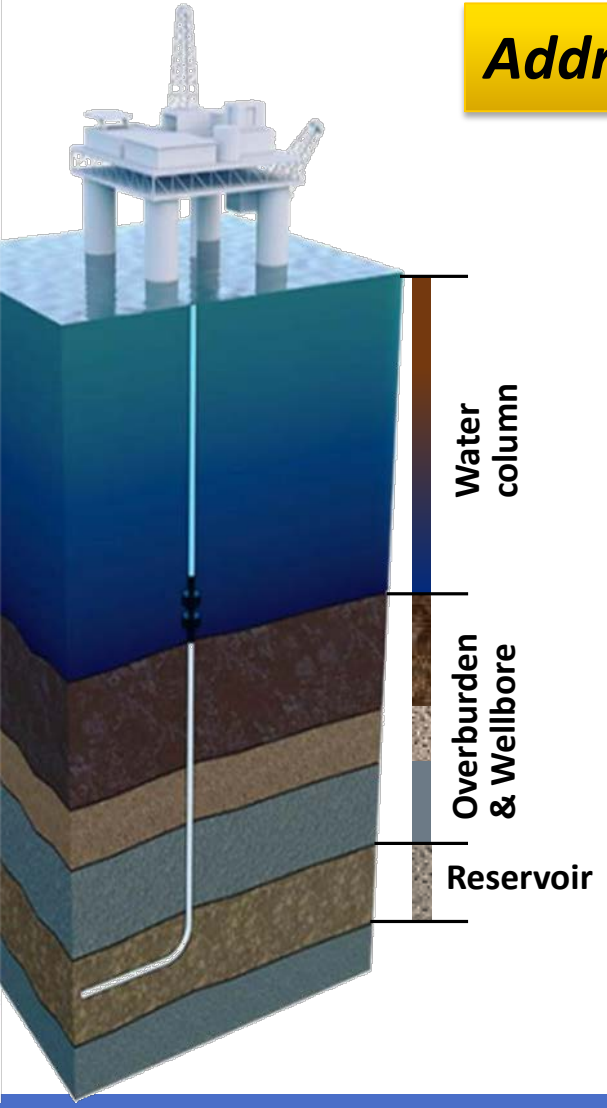
NETL's Offshore Integrated risk Assessment Model (IAM) is an integrated modeling and data system, from subsurface to the shore, **developed to identify knowledge & technology gaps for spill prevention**





- IAM combines GIS and Marine Spatial Planning techniques for oil spill prevention
- Designed with flexibility to adapt to a range of stakeholder needs and questions

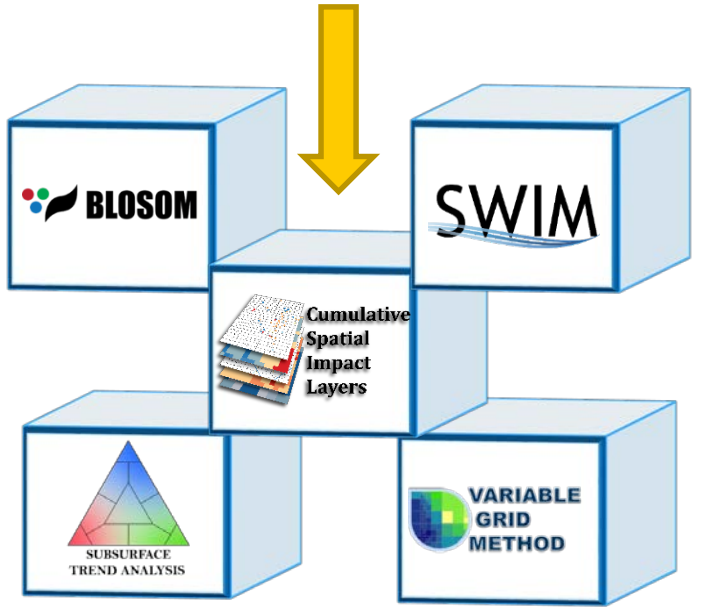
Offshore IAM – Components & Goals



Addressing Needs Highlighted in DWH Response

The Offshore IAM focused on developing:

1. A **framework** for future predictions, simulations & analyses of offshore E&P systems to ID vulnerabilities
2. A **"one-stop shop" for data** spanning the subsurface, water column, to the coast
3. Create a **secure, coordinated system** for inter-agency/entity assessment and evaluation
4. Develop an **open-source, adaptable suite of models** for simulating processes in the full system
5. Innovate **spatio-temporal approaches & tools** for assessing risks and reducing uncertainty



Accessing data and tools online

NETL's Energy Data Exchange (EDX) provides an ***innovative*** solution for data-driven efforts offering:

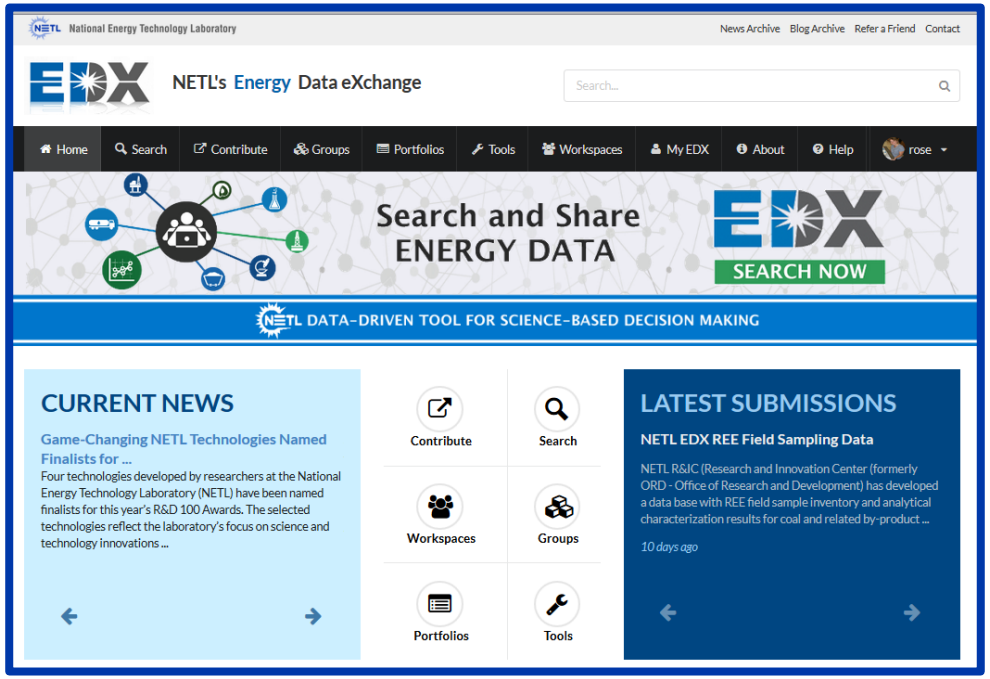
- A secure, online ***coordination and collaboration platform*** supporting energy research, knowledge transfer and data ***discovery*** needs
- Enduring and reliable ***access*** to historic and current R&D ***data, data driven products, and tools***
- Offers both ***public*** and ***secure, private*** functionalities

Public Side
Enables knowledge transfer, data preservation, reuse & discovery

Secure/Private Side
Supports research development, collaboration, & teamwork

EDX serves as a liaison between data resources and future needs

Geocube integrates key datasets through EDX or allows users to add their own, provides access to built-in geoprocessing tools to analyze and share products, as well as serve data for offshore IAM tools

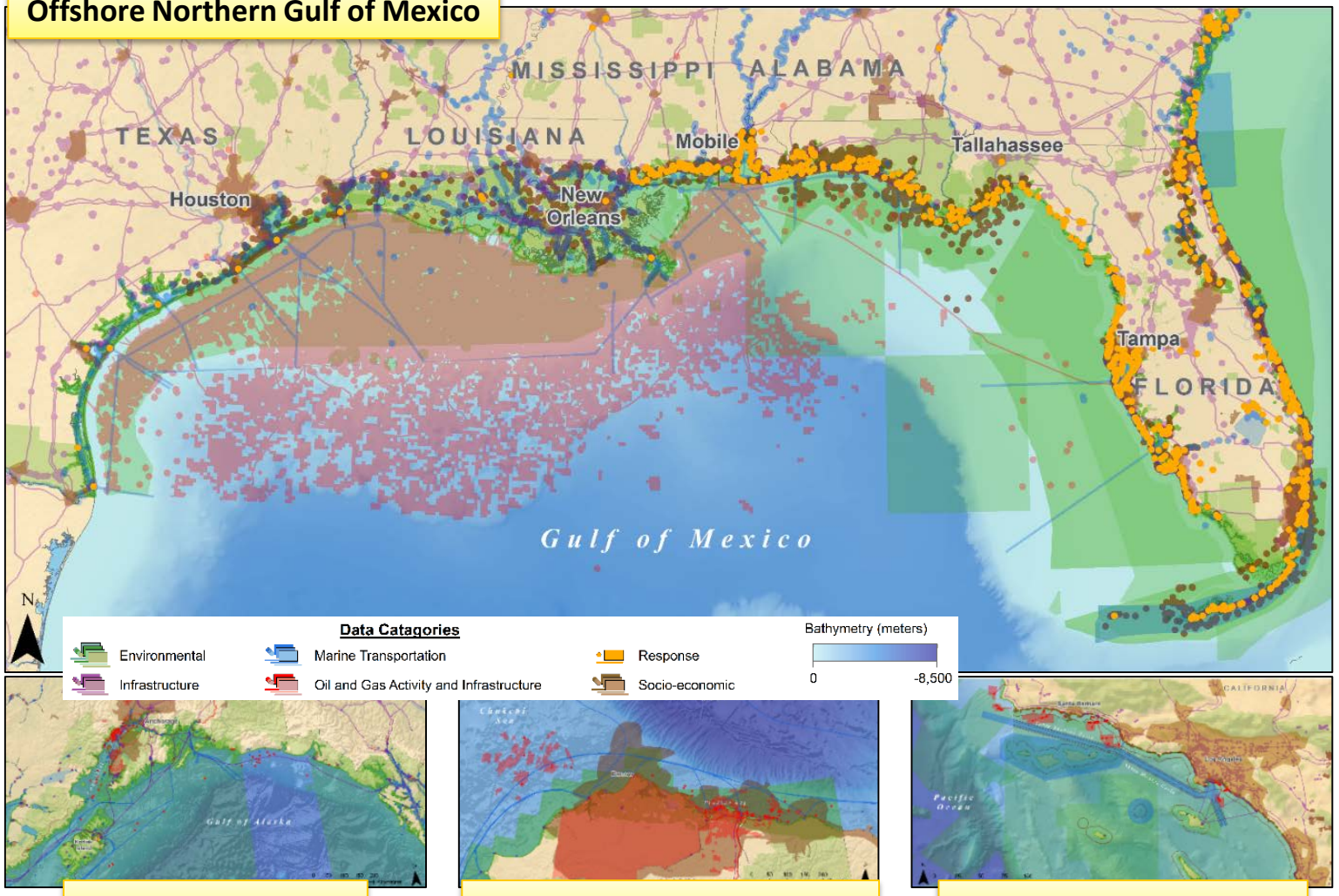


4 Regions - Complex, Multi-Source Big Data

- Accumulated almost 500,000 authoritative datasets for multiple offshore regions in the U.S., covering the subsurface, water column, and coastal regions
- Data are in numerous formats, dimensions & spatio-temporal extents
- These data drive the models, tools & approaches

GEO CUBE

Offshore Northern Gulf of Mexico



Offshore Gulf of Alaska

Offshore Arctic - North Slope

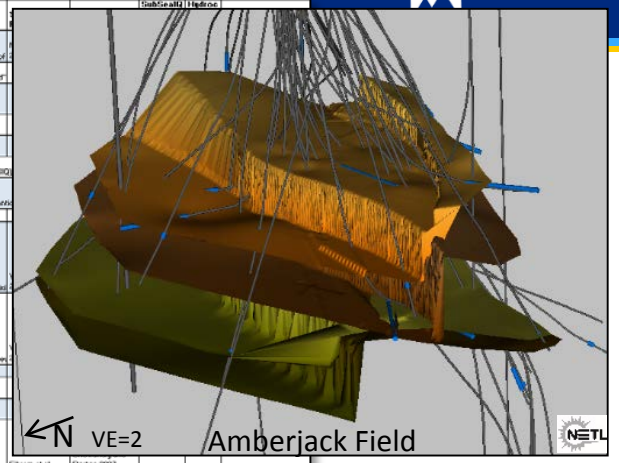
Offshore Southern California

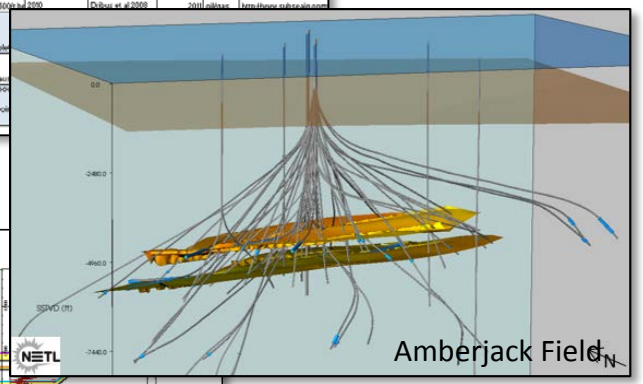
Subsurface Interpretation & Data

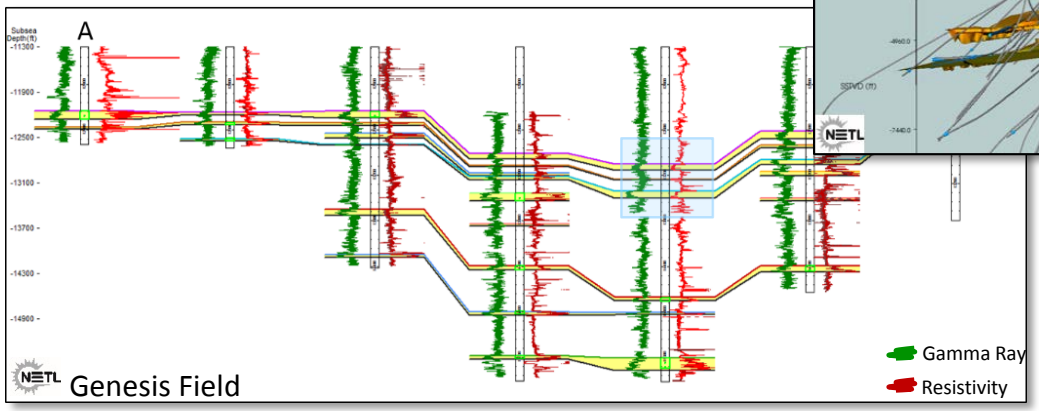
Currently have information on 127+ fields

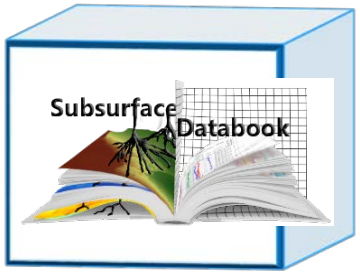
Data concatenating in Databook and NETL Database:

- Field
- Location
- Operator
- Water Depth
- Well depths
- Plays
- Age
- Geologic Province/Setting
- Reservoir Geology and Architecture
- Formation Names
- Reservoirs in each field
- Reservoir depths and depth ranges
- Gross/Net Thickness
- Traps
- Porosities
- Permeabilities
- Water Saturation
- Hydrocarbon Type
- Oil API/Gas SPGR
- GOR
- Pressure
- Temperature
- Oil Viscosity
- Flow Rates
- Reserves
- Faults
- Type logs
- Cross sections
- Seismic sections
- Formation tops
- Structure maps







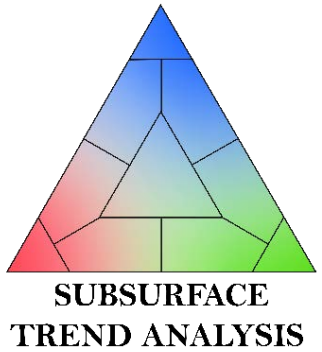


Subsurface Trend Analysis (STA) – Geologic uncertainty reduction

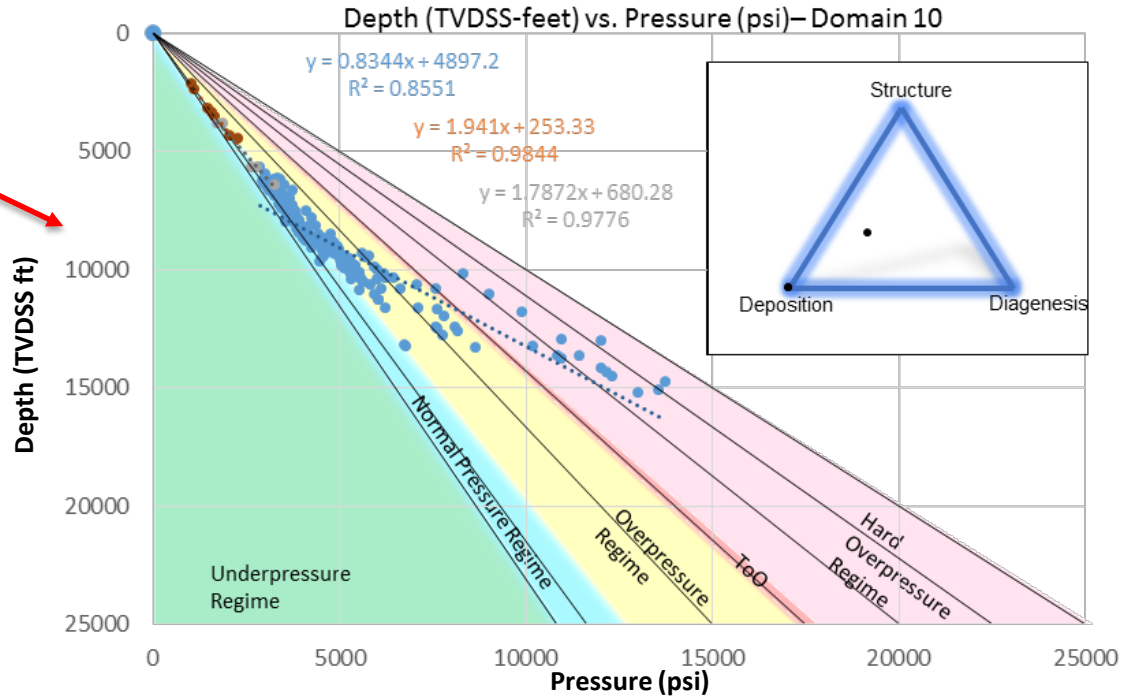
Goal – constrain subsurface property values using combination of deductive (*a priori*) knowledge & spatio-temporal statistical methods

- Provides a scientific base for predicting and quantifying potential risks associated with exploration and production in the subsurface
- Integrates basin analysis with geospatial and geostatistical methods to reduce uncertainty

Reduction of Area
=
Reduction of Uncertainty

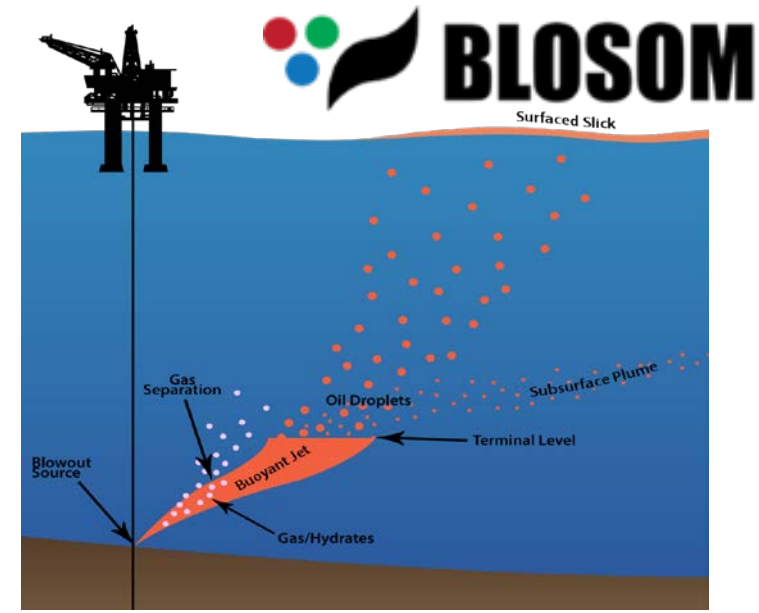


Multi-variate approach that combines *a priori* geologic knowledge with spatial and geostatistical analyses to offer high resolution insights about subsurface properties to help reduce geologic uncertainty

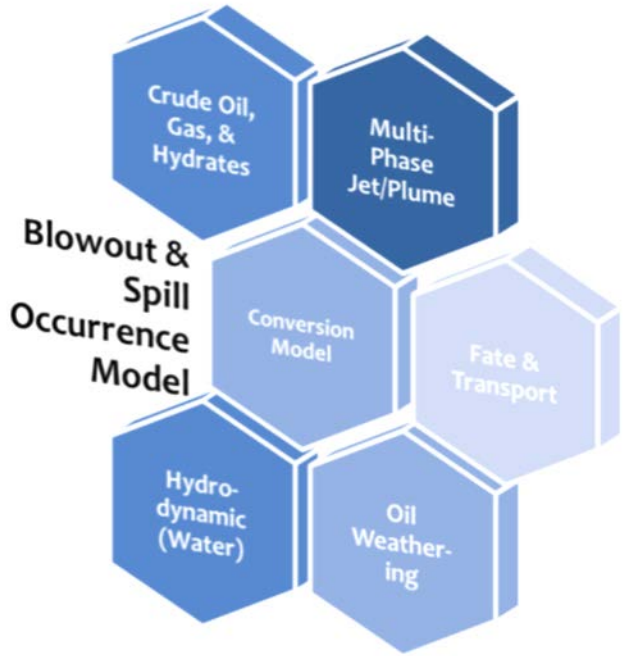


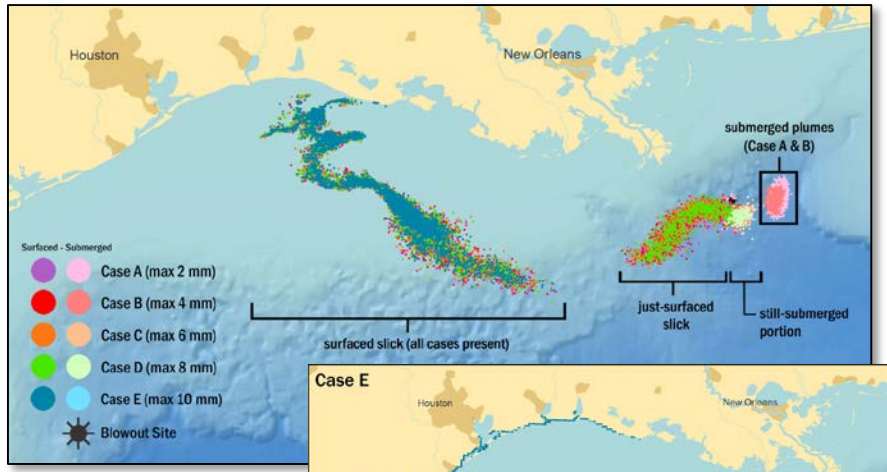
Rose et al., *in prep*, Subsurface Trend Analysis, a Multi-Variate Geospatial Approach for Evaluation of Geologic Properties and Uncertainty Reduction, *Interpretation*.

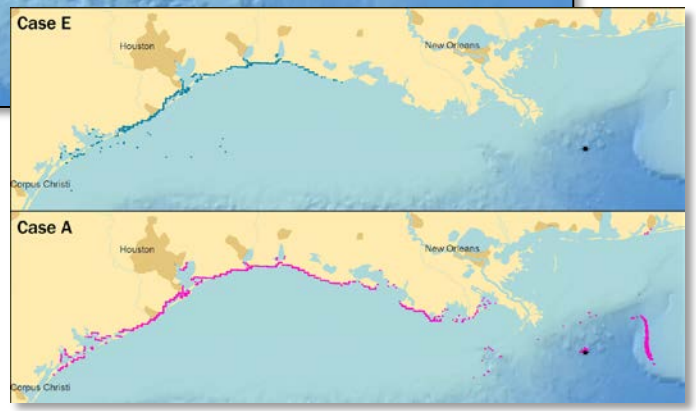
Blowout & Spill Occurrence Model (BLOSOM)



A comprehensive modeling suite for blowout & spill events, adapted for jet/plume behavior, high pressures, gas and hydrate dynamics, droplet-size distributions, and subsurface plume formation



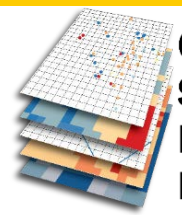




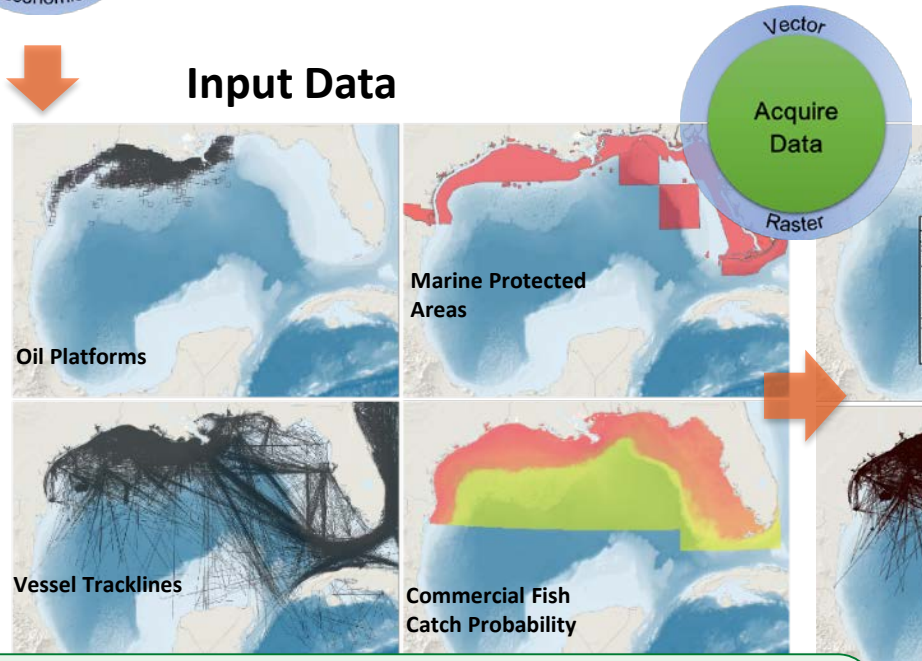
Sim, L.; Graham, J.; Rose, K.; Duran, R.; Nelson, J.; Umhoefer, J.; Vielma, J. ***Developing a Comprehensive Deepwater Blowout and Spill Model***; NETL-TRS-9-2015; EPAct Technical Report Series; U.S. Department of Energy, National Energy Technology Laboratory: Albany, OR, 2015; p 44.

Cumulative Spatial Impact Layers (CSIL)

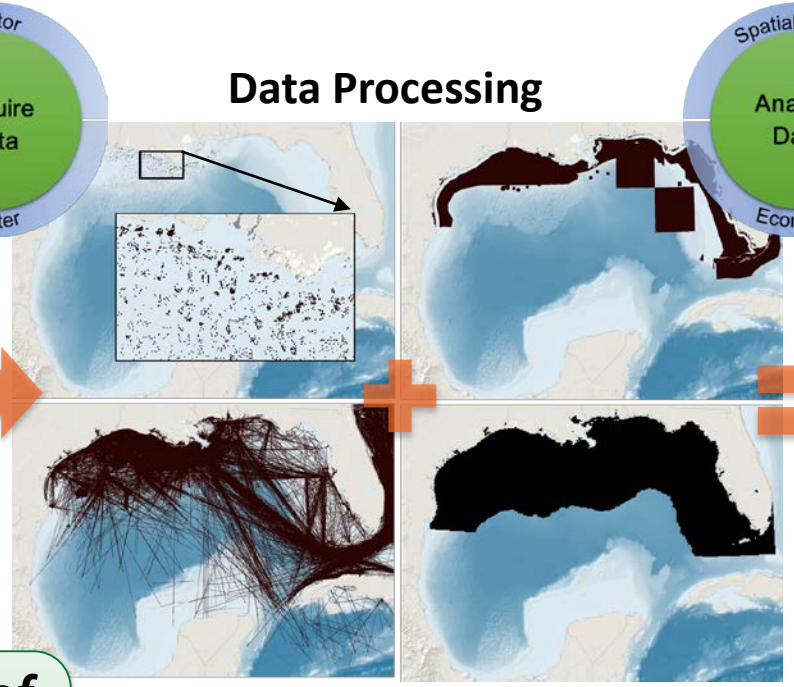
CSIL is a spatio-temporal approach that identifies potential impacts to various socio-economic and environmental actives within a region



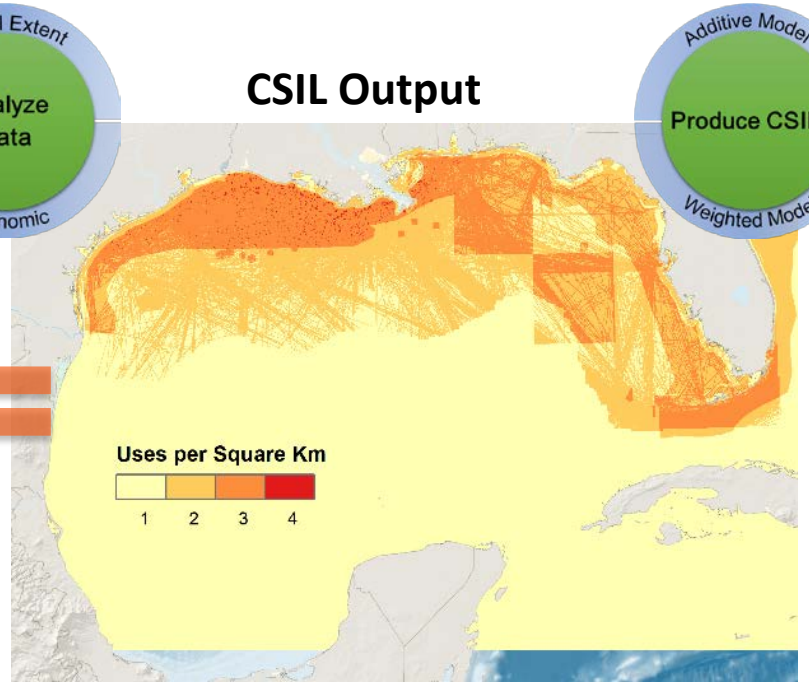
Input Data



Data Processing



CSIL Output



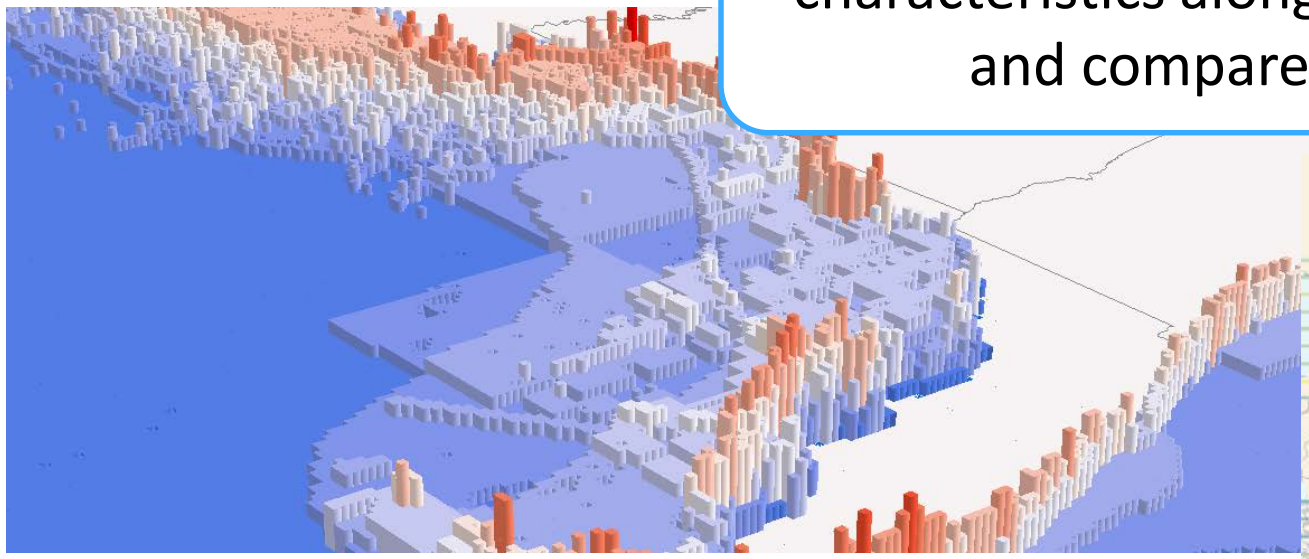
Quickly measures the total ***number of activities*** OR the ***estimated value*** (economic, etc.) per unit area (cell)

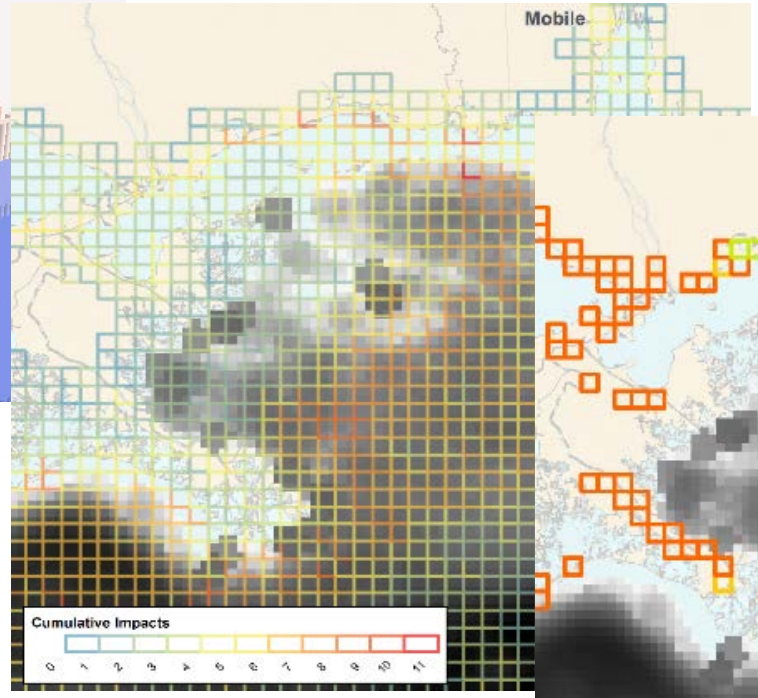
- Additive or Weighted design
- User-friendly
- Measures a variety of impacts
- Geographically robust

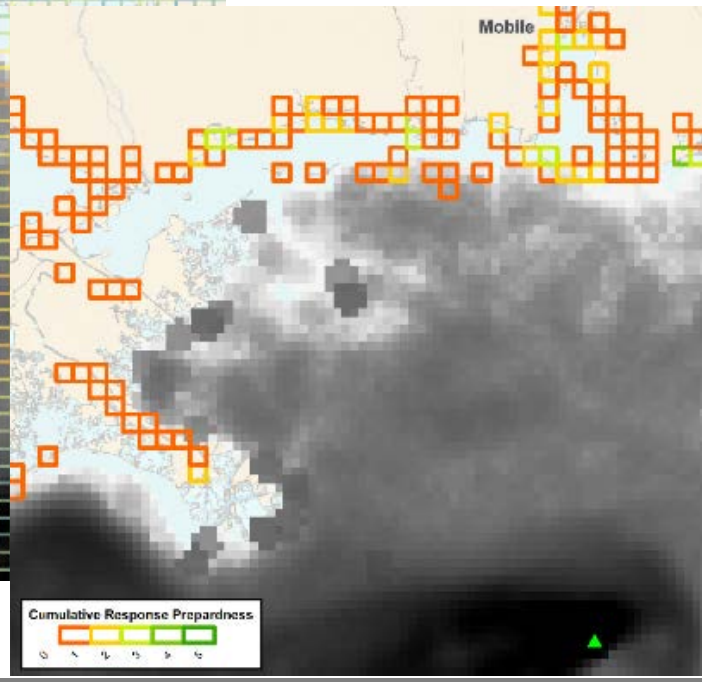
Bauer, J. R., et al., 2015. J. *A Spatio-Temporal Approach to Analyze Broad Risks and Potential Impacts Associated with Uncontrolled Hydrocarbon Release Events in the Offshore Gulf of Mexico*; NETL-TRS-2-2015, p 60.

Spatially Weighted Impact Model (SWIM)

SWIM builds off of the CSIL approach, but uses the scenario characteristics along with potential impacts in an area to rank and compare various modeled oil spill scenarios





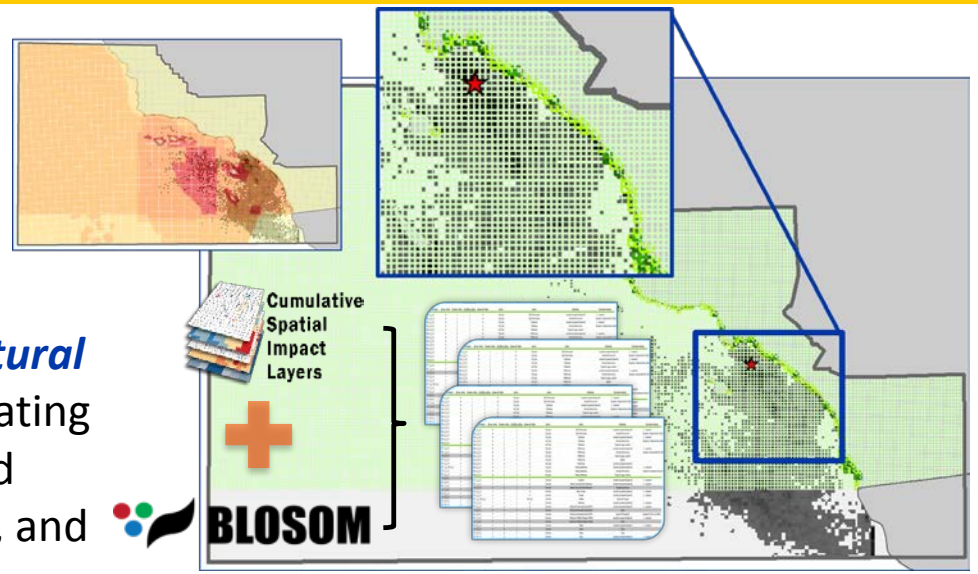


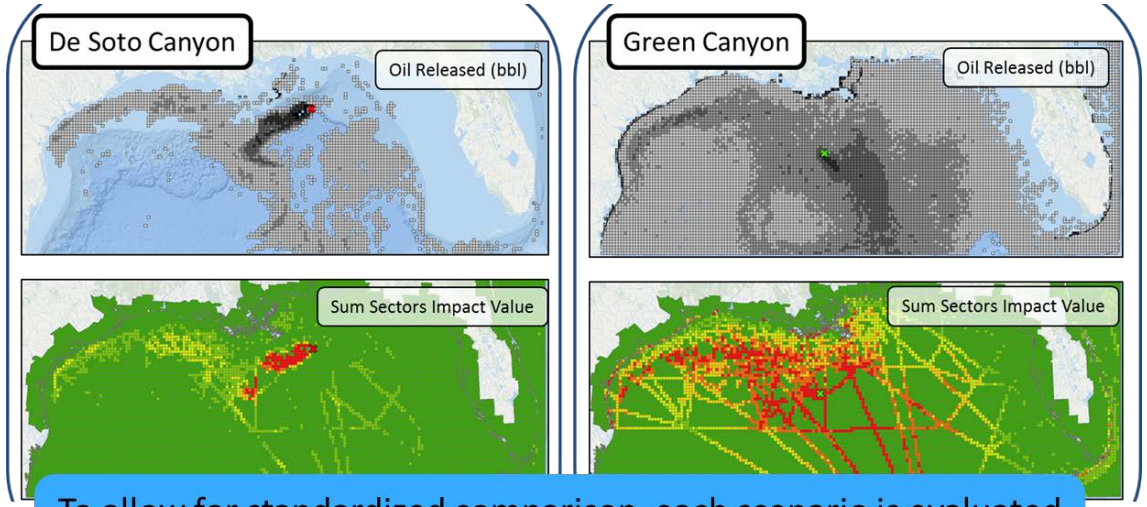
- Incorporates different user-defined weights
- Quantifies relationships between ‘event’ and potential ‘receptors’
- Uses spatial, temporal, and attribute variables and relationships to rank and compare modeled ‘events’

Spill modeled by BLOSOM

Example Application of SWIM

SWIM incorporates ***interactions within and between human and natural systems***, integrating modeled hazard scenarios, risks, and response





To allow for standardized comparison, each scenario is evaluated against an 'absolute worst case discharge scenario' (ABS WCDS)

Users can apply ***high-level ranks and weights*** that can be applied to each SWIM analysis

Scenario Evaluation Criteria	Absolute WCDS GOM	Alaminos Sept	DeSoto Sept	EastBreaksS ept	EugeneIslandS ept
Cumulative Impact Score	0.17	0.00	0.02	0.01	0.02
Max. Spill Volume	0.31	0.20	0.08	0.38	0.15
Max. Spill Duration	0.12	0.12	0.04	0.09	0.09
Total Spatial Extent	0.40	0.06	0.08	0.04	0.07
TOTAL SCORE	**1.00**	**0.38**	**0.23**	**0.52**	**0.33**

Rank (Scenarios)	Weight	Sliders for Scenario Rank Weights
1	16.7%	100
1	31.0%	100
1	11.9%	100
1	40.5%	100
	100.0%	Reset Scenario Rank Weights Sliders

	WCDS		WCDS w/Indicies	
	Modeled WCDS vs. ABS WCDS	Final Rank Value	Modeled WCDS vs. ABS WCDS	Final Rank Value
De Soto Canyon	11%	5	30%	4
Green Canyon	40%	3	76%	2

Results allow users to directly ***compare & rank various scenario outcomes*** to support a range of decision needs

Variable Grid Method (VGM)

R&D 100 2016 Finalist

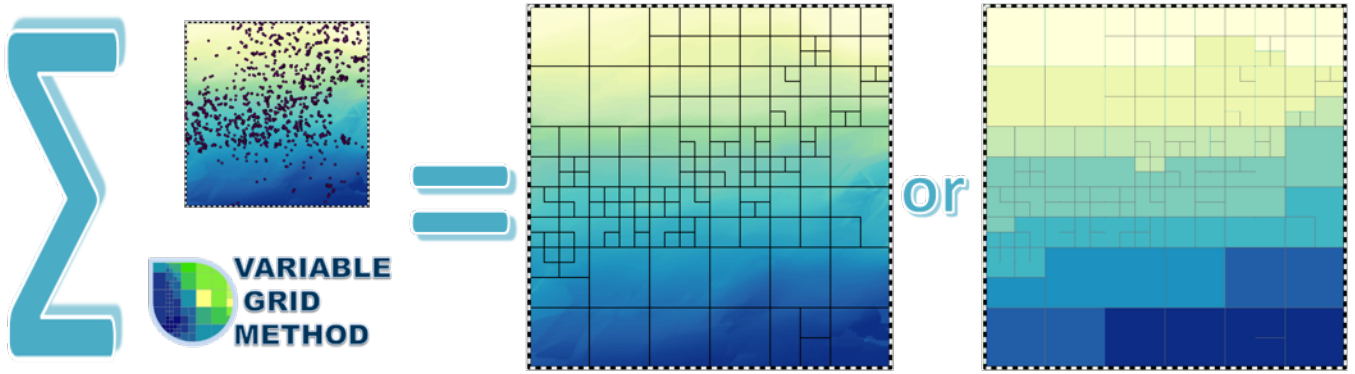
Failing to effectively include uncertainty in a geo-product can lead to ***false conclusions*** and ***poor decisions*** as well as ***affect the quality*** of current and future results

8 PM Sun, Jul 19		75°	75°	Cloudy	0%
9 PM Sun, Jul 19		74°	74°	Cloudy	0%
10 PM Sun, Jul 19		74°	74°	Cloudy	20%
11 PM Sun, Jul 19		74°	76°	Mostly Cloudy	10%
12 AM Mon, Jul 20		74°	75°	Mostly Cloudy	5%
1 AM Mon, Jul 20		73°	75°	Partly Cloudy	5%
2 AM Mon, Jul 20		73°	75°	Cloudy	5%
3 AM Mon, Jul 20		73°	74°	Cloudy	5%
4 AM Mon, Jul 20		73°	74°	Cloudy	5%
5 AM Mon, Jul 20		73°	74°	Cloudy	5%
6 AM Mon, Jul 20		72°	74°	Cloudy	5%

Height

VARIABLE GRID METHOD

Research surrounding offshore and subsurface systems are often plagued with uncertainty. The **Variable Grid Method (VGM)** was designed to ***better communicate uncertainty*** by presenting spatial data and uncertainty simultaneously…

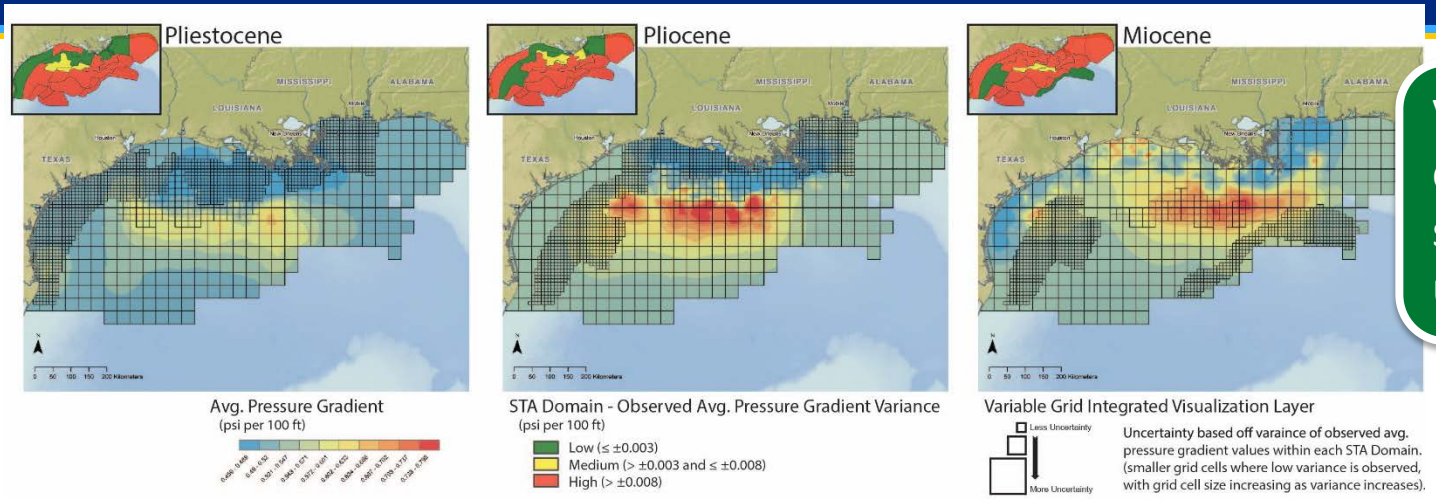


Communicates data (via colors) and uncertainty (via grid cell size)

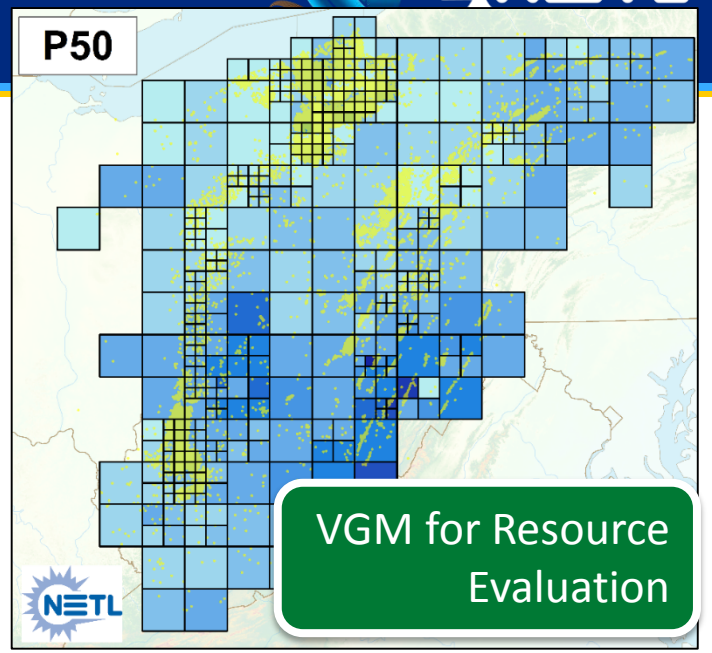
…whilst:

- allowing the ***flexibility*** to use different data types and uncertainty quantifications
- preserving ***overall spatial trends and patterns*** observed within the data, and
- enabling users to ***customize*** the final product to meet their needs and best communicate results in an ***intuitive manner***

Applications of the VGM



VGM for communicating subsurface uncertainty



VGM for Resource Evaluation

Hadoop-Based VGM Detailed Workflow

Well data from ArcMap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    "OR_Base_m_": 0.0,
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    "Salinity__": 0.0,
    "WSN": 1.0,
    "Surf_Lon": -80.103193,
    "Brine_Dens": 0.0,
    "OR_Gross_T": 0.0,
    "Porosity__": 0.0,
    "NET_THICKN": 0.0,
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},
"geometry": {
    "y": 5084098.520442895,
    "x": -8917047.03754837,
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        "wkid": 4326,
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    }
}
},
{
"attributes": {
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```


Example JSON from ArcMap

VGM-Step-0

Description: Convert 'enclosed-Json' ESRI feature class into 'feature-per-row' unenclosed-Json.

Input: 'Enclosed-Json' formatted data (i.e., ORWells-wgs84.json) uploaded from ArcMap using ESRI/Hadoop toolbox tools 'Features to Json' & 'Copy to HDFS'.

Output: Processed 'Unenclosed-Json' with 'feature per row' layout suitable for Mapper.

Mapper (Setup): Create EsriFeatureClass from input file and write each feature as a row represented as unenclosed-Json.

Reducer: Aggregate Mapper output into one or more files

'Feature per row' formatted data for MapReduce

VGM-Step-1

Description: Generate bounding quads for input ORWells-wgs84)

Input: vgm-step-0 output row-per-feature representation of orwells-wgs84 data

Output: Quads of varying extents with attribution (i.e., point count, max/min/avg salinity, porosity, brine density)

Mapper (Setup): Load point features from vgm-step-0 and use to generate quadtree node extents.

Mapper: Feed mapper each row of 'unenclosed-Json' from vgm-step-0 point data and query the quadtree for all quads that contain

Reducer: Aggregate Mapper output into one or more files and store in vgm/working/output-0/.

Overlapping attributed quads (shown via ArcMap)

VGM-Step-2

step-1 AND the point data generated from vgm-step-0

Output: Non-overlapping polygons as 'unenclosed-Json' features with attribution (point count, min/max/avg porosity, etc.)

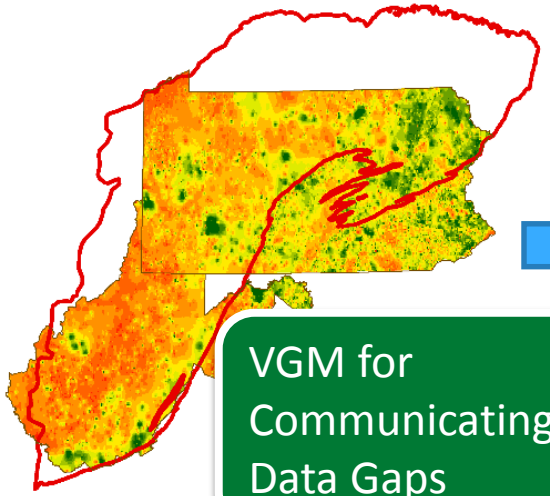
Mapper (Setup): Load vgm-step-1 output files representing attributed quads of varying resolutions to generate non-overlapping topology.

Mapper: Feed the Mapper with rows from the vgm-step-0 'unenclosed-Json' point feature data, query topology for 'point in polygon' to generate polygon's attributes, and perform geometry subtraction using ESRI Hadoop libs

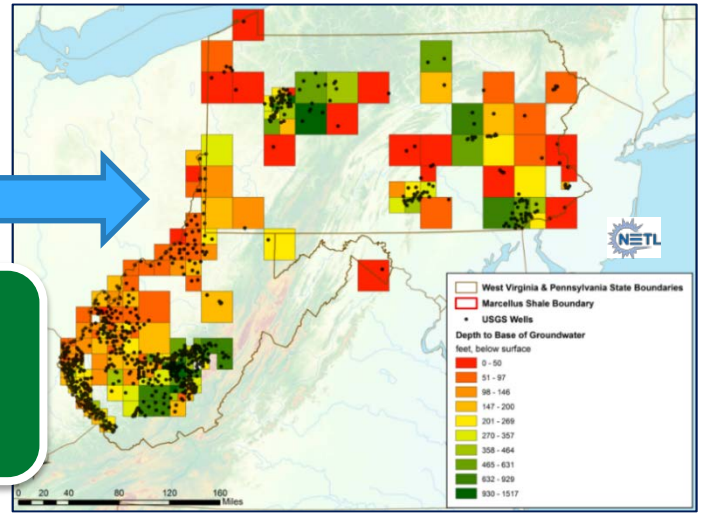
Reducer: Tally the attributes for each polygon and write attributed polygon as unenclosed-Json.

Attributed polygons for ArcMap

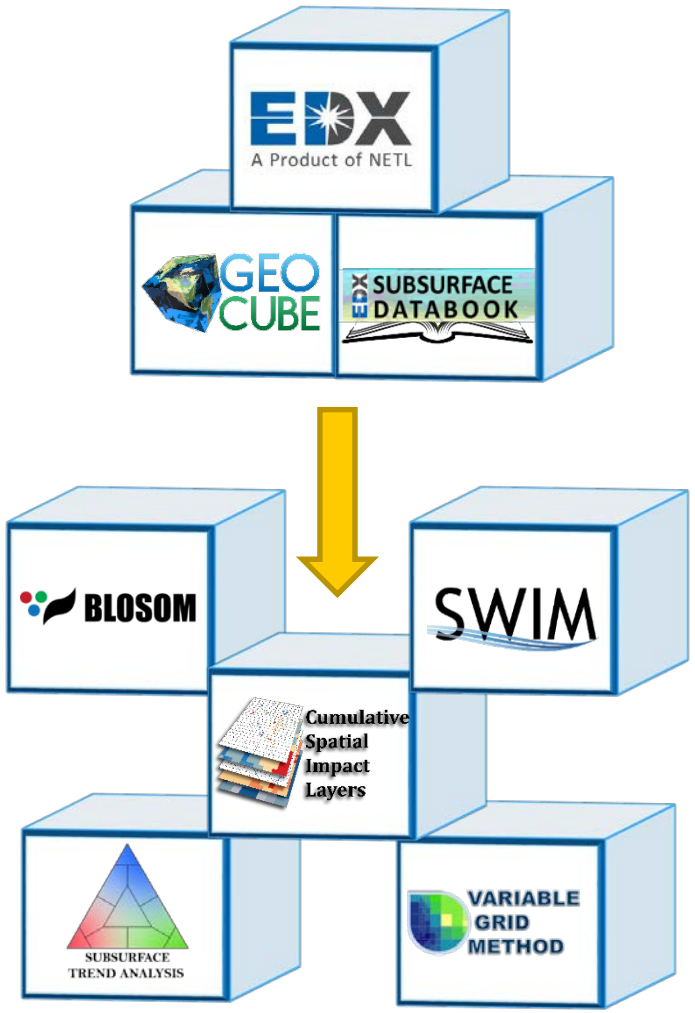
VGM for Big Data



VGM for Communicating Data Gaps



Using the 8 Offshore IAM Components



Configuring data + tools to ask and assess and ask if this

…time…

…place…

…material…

…reservoir…

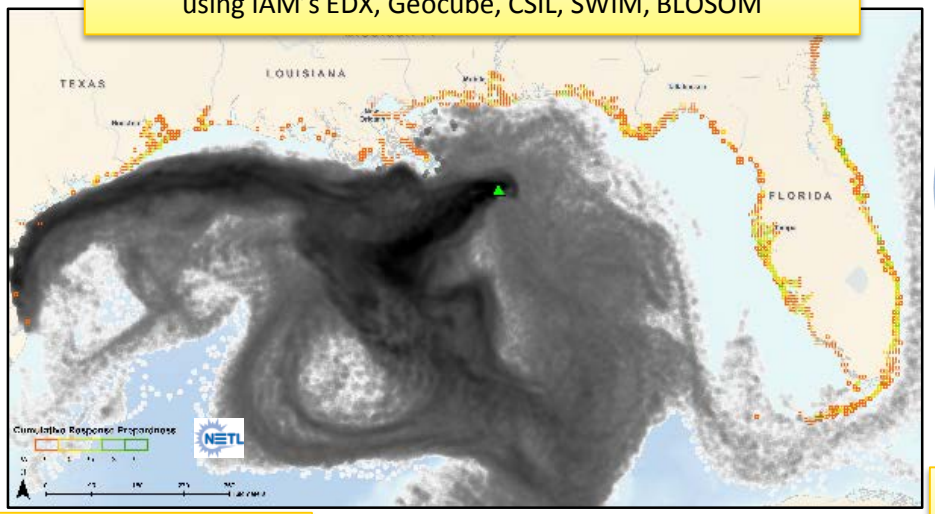
is risky?

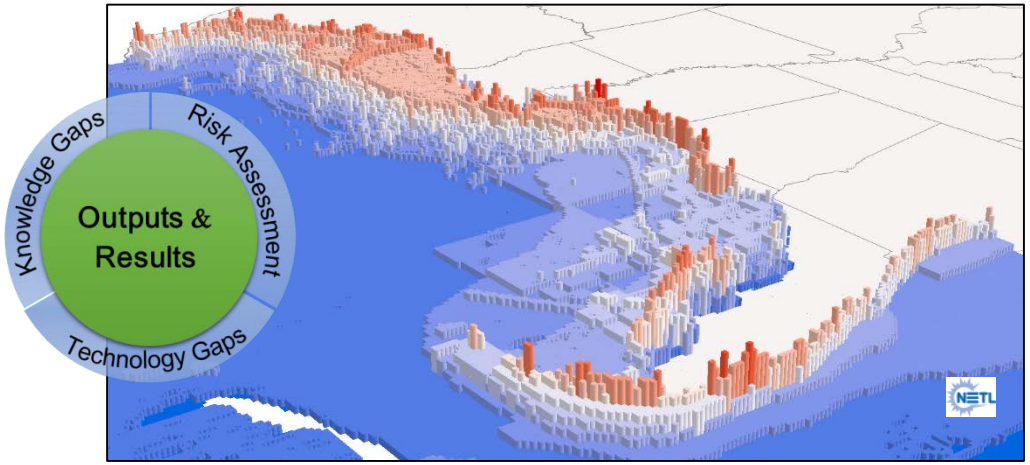
Let's review a couple analyses

NETL Offshore IAM Tools & Data Put to Use

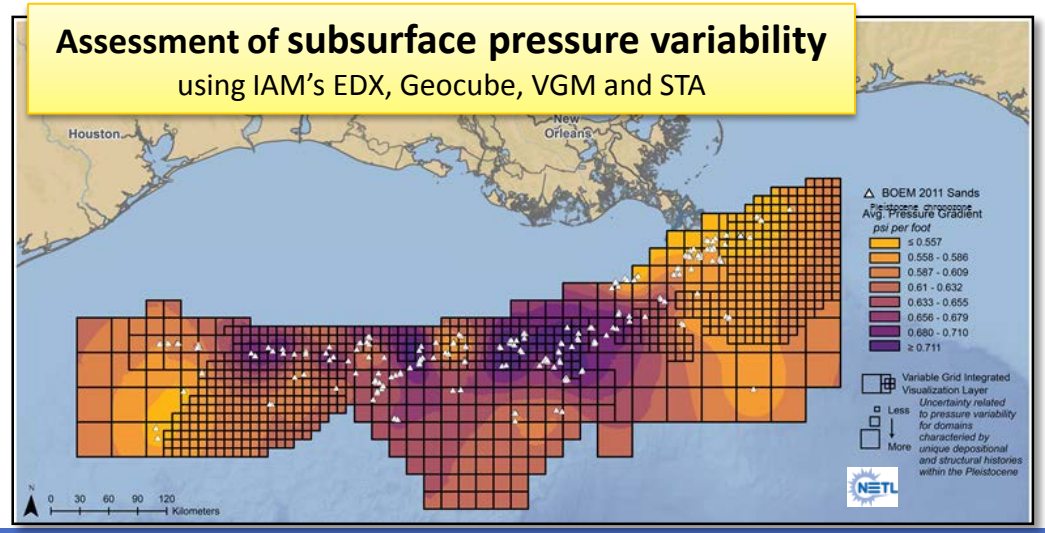
Offshore IAM **data & tools** are configurable for **multiple uses & scenarios** to answer a range of decision analysis & support questions

Evaluation spill & response resources relationships
using IAM's EDX, Geocube, CSIL, SWIM, BLOSOM

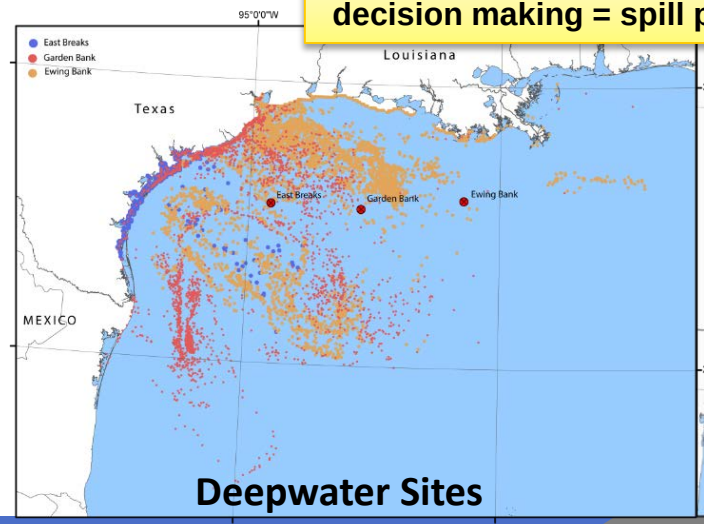


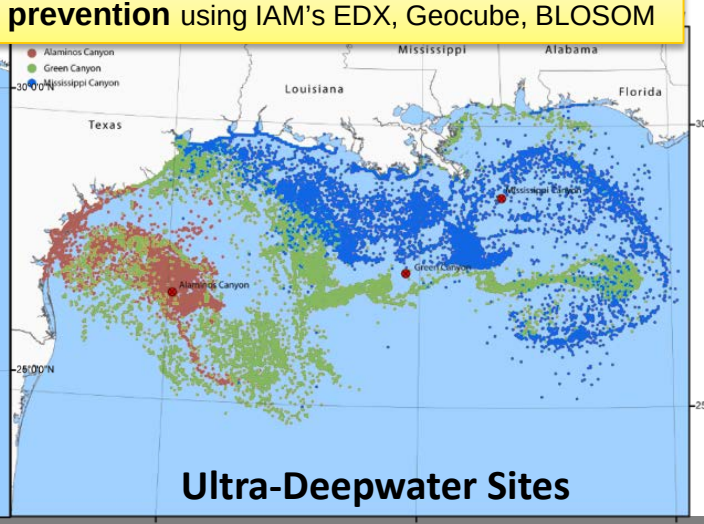


Assessment of subsurface pressure variability
using IAM's EDX, Geocube, VGM and STA



Ramifications for regulatory permitting & support industry decision making = spill prevention using IAM's EDX, Geocube, BLOSOM





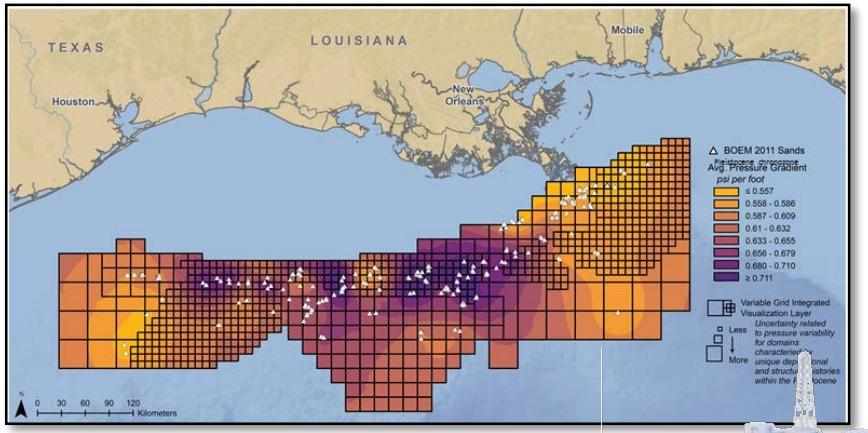
Results & Accomplishments to Date – Offshore IAM

Key Aspects of NETL IAM

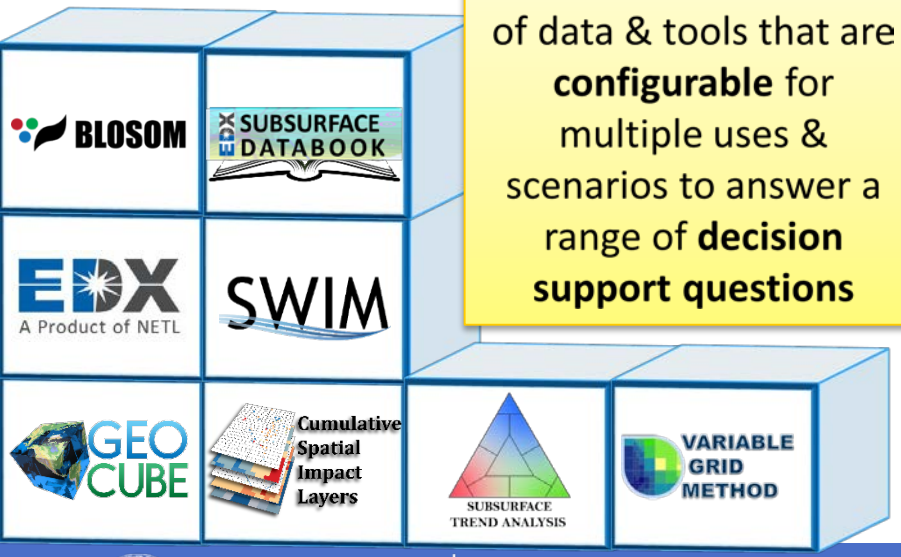
- Enable assessment of spatial & temporal trends
- Data in one place to support risk assessment
- Unique & novel tools and models spanning full system
- Integrate of findings from other Offshore Portfolio projects
- Culminating in suite of data & tools that are **adaptable** for multiple uses & scenarios
- Use to identify risks and knowledge/technology gaps

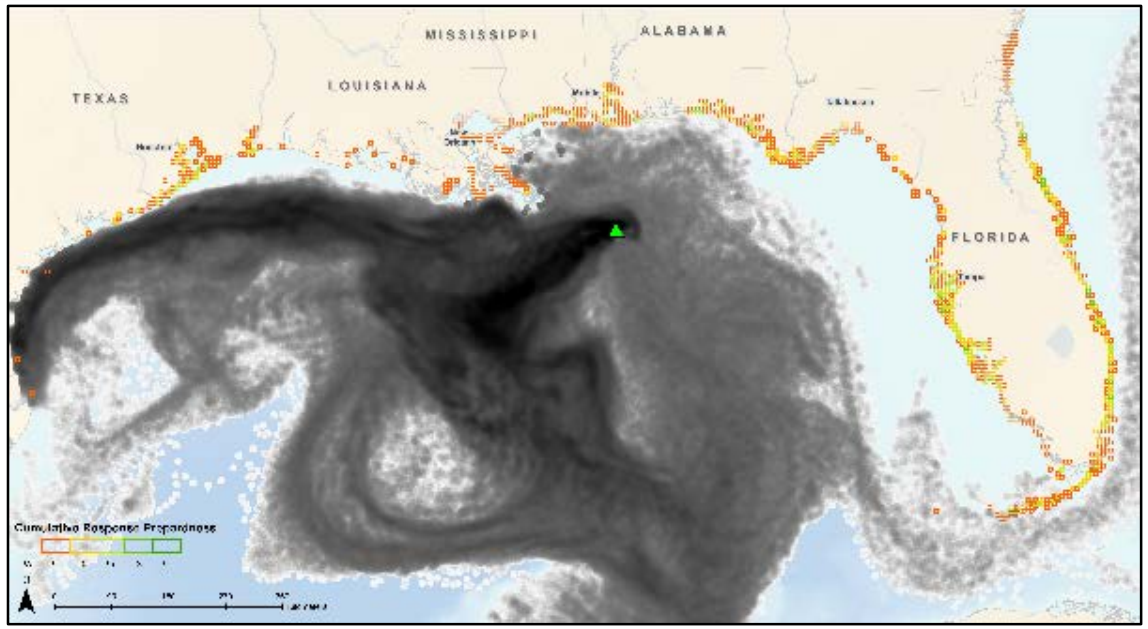
IAM Accomplishments

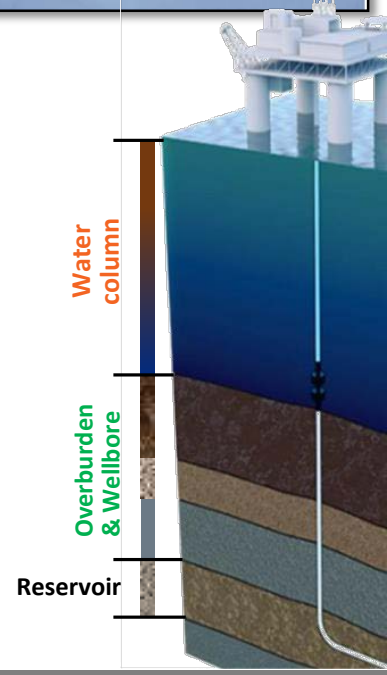
- 20+ Publications
- 25+ Conference Presentations
- 8 Tools
- 60+ TB of Data
- 8 External New Articles
- 1 Patent Application Filed
- 2 Extramural Projects



Offshore IAM is a suite of data & tools that are **configurable** for multiple uses & scenarios to answer a range of **decision support questions**

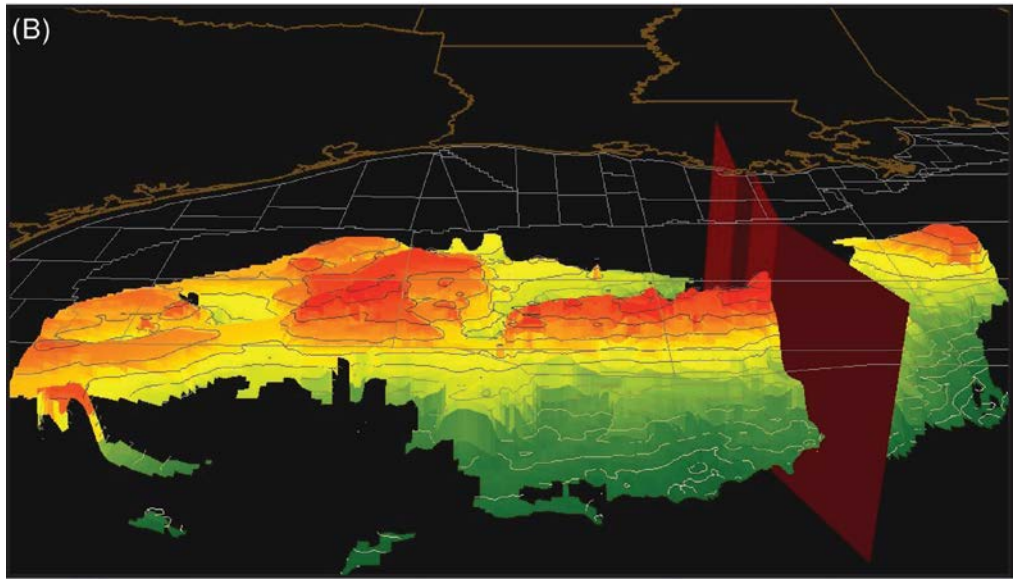






Next steps – Advanced Geoscience Computing

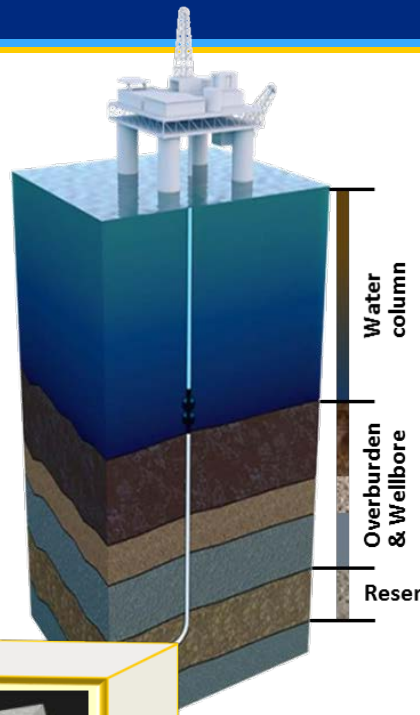
As studies evolve the need to efficiently & effectively incorporate, analyze & visualize multi-dimensional data becomes even more important

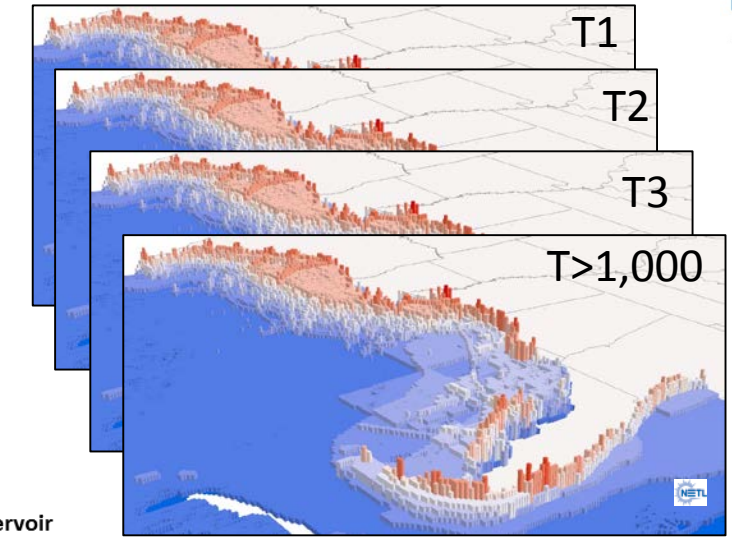


Our next steps focus on integrating advanced computational approaches, and pushing the boundaries of existing 3D/4D analytical techniques to address questions within engineered-natural systems

Next Steps –

Integrating material performance data to support informed decision making & analyses





- Utilize IAM suite for monte carlo-style assessments of GOM spatio-temporal risks
- Potential partnership with BOEM to utilize NETL IAM tools with BOEM data & expertise for advanced decision making support for:
  - Resource evaluation
  - NEPA
  - Offshore spill

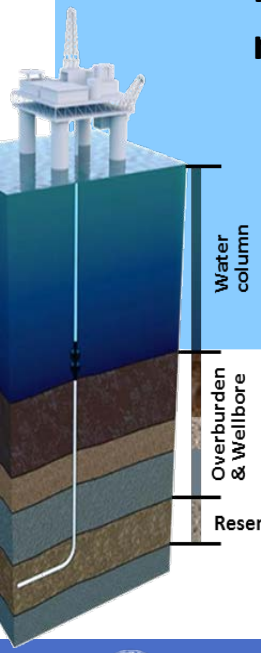
BOEM Bureau of Ocean Energy Management

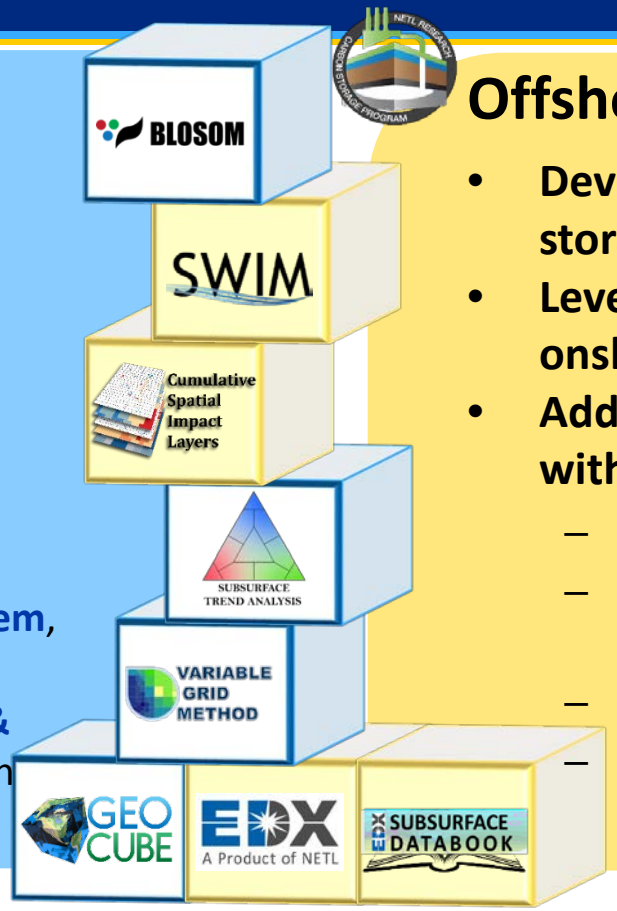
In FY17 these tools & data are being developed into an **online, common operating platform,** serving web-based tools, **big data geoprocessing and analytics**

Synergies with Other Areas

Offshore Spill Prevention

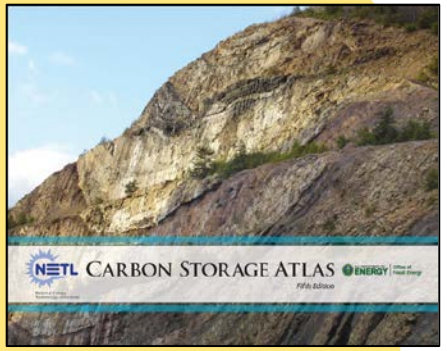
- **Ties to Offshore Portfolio projects (2011-2016):**
  - Wellbore integrity
  - Rapid detection and in situ characterization
  - Risk reduction
- **Feeding NETL's Offshore Integrated risk Assessment Model (IAM)**
  - Integrated **modeling and data system**, from subsurface to the shore, developed to **identify knowledge & technology gaps** for spill prevention
  - 8 IAM component tools to date





Offshore Carbon Storage

- **Developing an offshore CO_2 storage methodology**
- **Leveraging off of NETL/DOE's onshore methodology**
- **Addressing key differences with offshore systems including:**
  - Young, immature basin conditions
  - Unconsolidated/unlithified sediments
  - Over-pressured conditions
  - Presence/behavior of natural seeps



$$G_{CO_2} = Ah\phi\rho E$$

Interest from:

BOEM Bureau of Ocean Energy Management

NOAA National Oceanic and Atmospheric Administration, U.S. Department of Commerce

2 Spin Off WFO Projects Funded by BSEE
PNNL is collaborator/partner

BSEE Bureau of Safety and Environmental Enforcement

Pacific Northwest National Laboratory

Tools & Data Leveraged Towards Projects in:

NETL Research Carbon Storage Program

NRAP National Risk Assessment Partnership

UCR Unconventional Resources

TUESDAY, AUGUST 16, 2016

- 12:40 PM Monitoring Groundwater Impacts - Christina Lopano
- 1:55 PM Multi Variate Examination of the Cause of Increasing Induced Seismicity – Kelly Rose
- 4:40 PM Exploring the Behavior of Shales as Seals and Storage Reservoirs for CO_2 – Ernest Lindner
- 5:05 PM Risk Assessment for Offshore Systems – Kelly Rose
- 5:30 PM Metal-based systems in Extreme Environments – Jeff Hawk
- 6:15 p.m. Poster Session
  - Kelly Rose - Developing a carbon storage resource assessment methodology for offshore systems
  - Doug Kauffman - Catalytic Conversion of CO2 to Ind. Chem. And eval. Of CO2 Use and Re-Use
  - Liwel Zhang - Numerical simulation of pressure and CO2 saturation above an imperfect seal as a result of CO2 injection: implications for CO2 migration detection

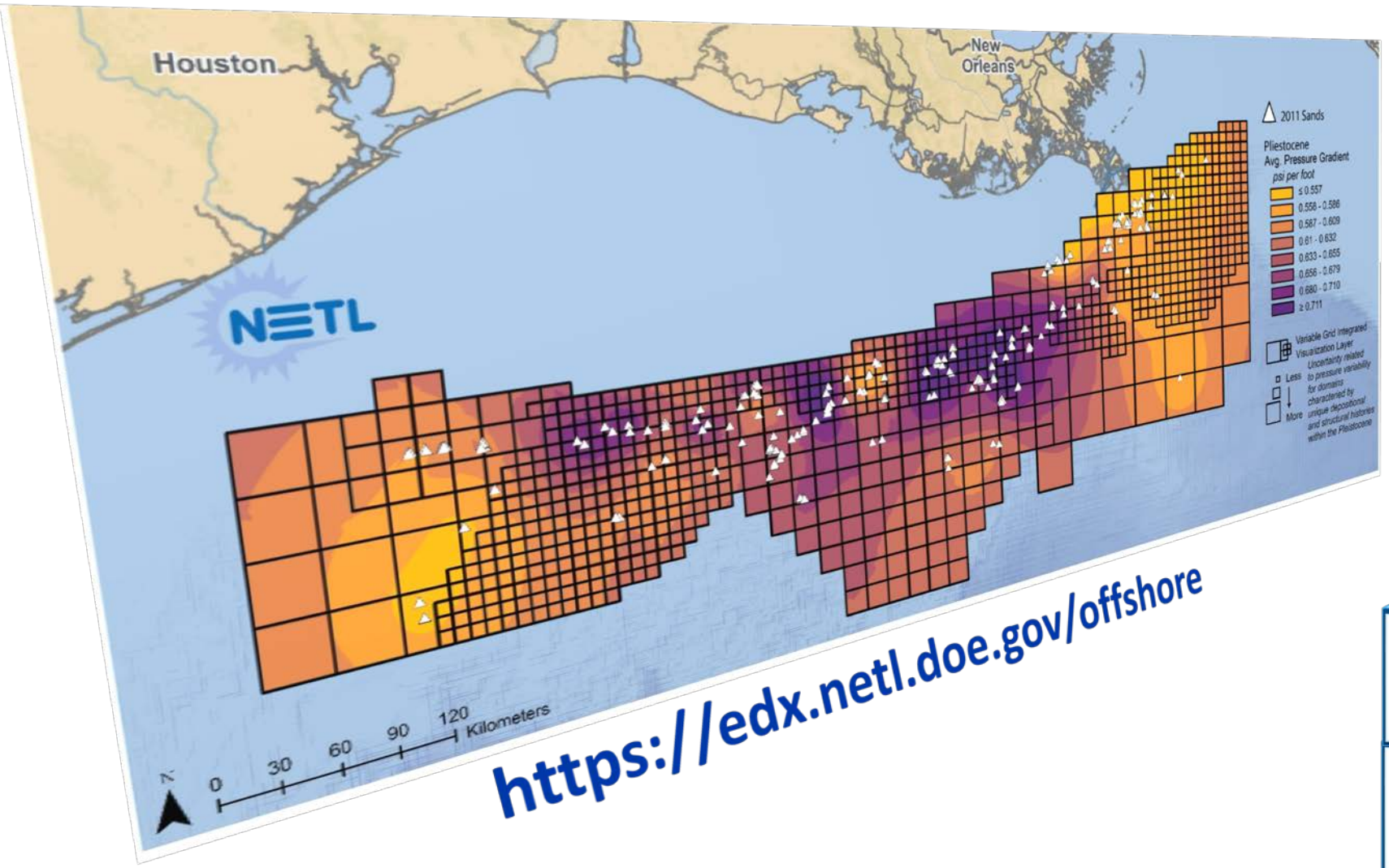
WEDNESDAY, AUGUST 17, 2016

- 12:30 PM MVA Field Activities – Hank Edenborn
- 1:20 PM Microseismicity –Erik Zorn
- 2:35 PM Resource Assessment – Angela Goodman
- 2:35 PM Understanding Impacts to Air Quality from Unconventional Natural Gas – Natalie Pekney
- 4:05 PM Improving Science-Base for Wellbore Integrity, Barrier Interface Performance – Nik Huerta
- 5:20 PM Wellbore Integrity and Mitigation – Barbara Kutchko

THURSDAY, AUGUST 18, 2016

- 1:00 PM Advances in Data Discovery, Mining, & Integration for Energy (EDX) – Vic Baker
- 1:25 PM Methods for Locating Legacy Wells – Garrett Veloski
- 2:40 PM Reservoir Performance – Johnathan Moore
- 3:05 PM Geochemical Evolution of Hydraulically-Fractured Shales – Ale Hakala

Thank you



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Acknowledgment: This work was funded by the Department of Energy, National Energy Technology Laboratory, an agency of the United States Government. Neither the United States Government nor any agency thereof, makes any warranty, expressed 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 herein 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 herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Appendix

- These slides will not be discussed during the presentation, but are mandatory

Organization Chart

Task 1 Project Coordination & Crosscutting R&D
- NETL, Rose PI

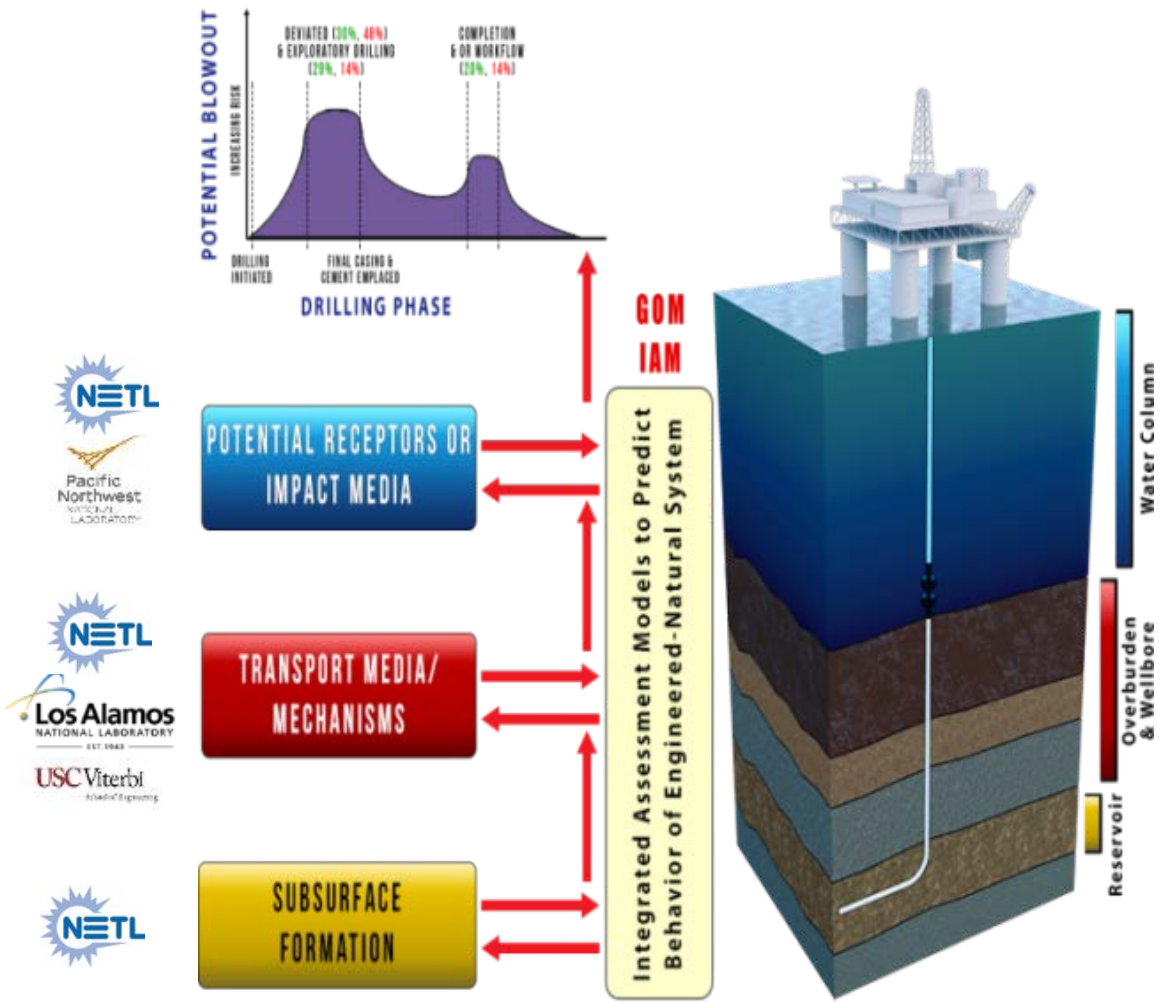
Task 2 - Water Column Sub-Team
- NETL, PNNL, OSU (previous years)

Task 3 - Wellbore Sub-Team
- NETL, LANL & USC (previous years)

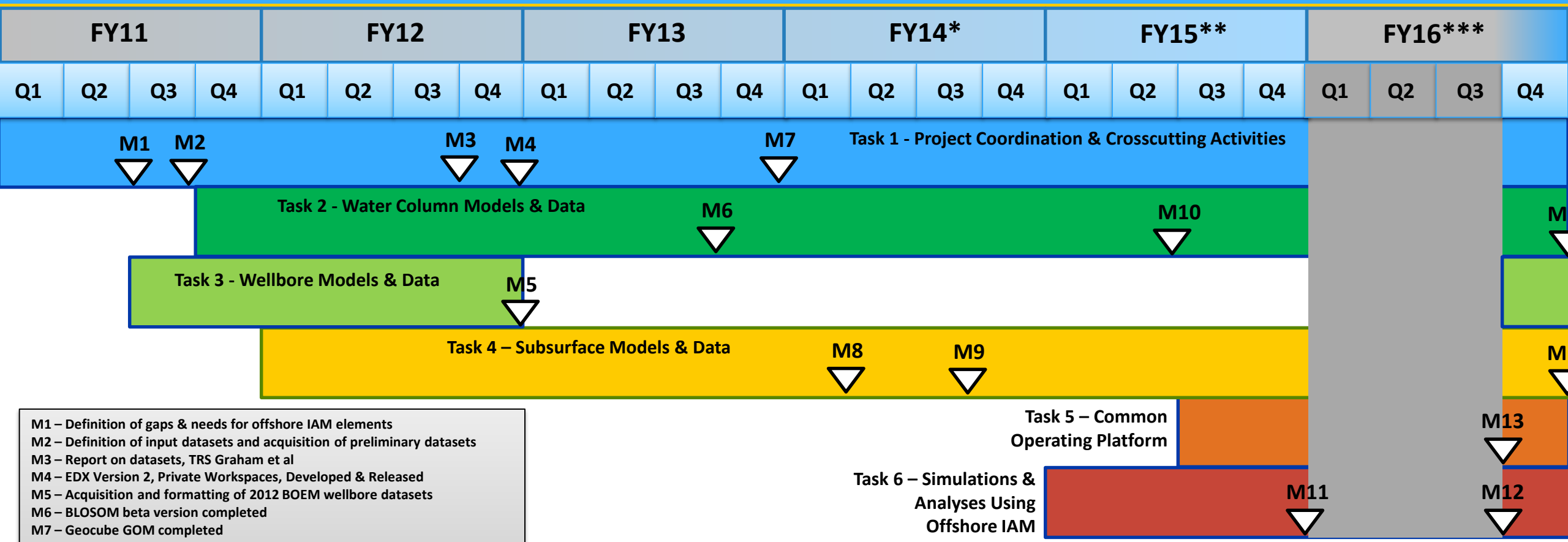
Task 4 - Subsurface Sub-Team
- NETL

Task 5 - Common Operating Platform Sub-Team
- NETL

Task 6 - Simulations & Analyses
- NETL, PNNL, USC (previous years)



Gantt Chart – Simplified with key milestones

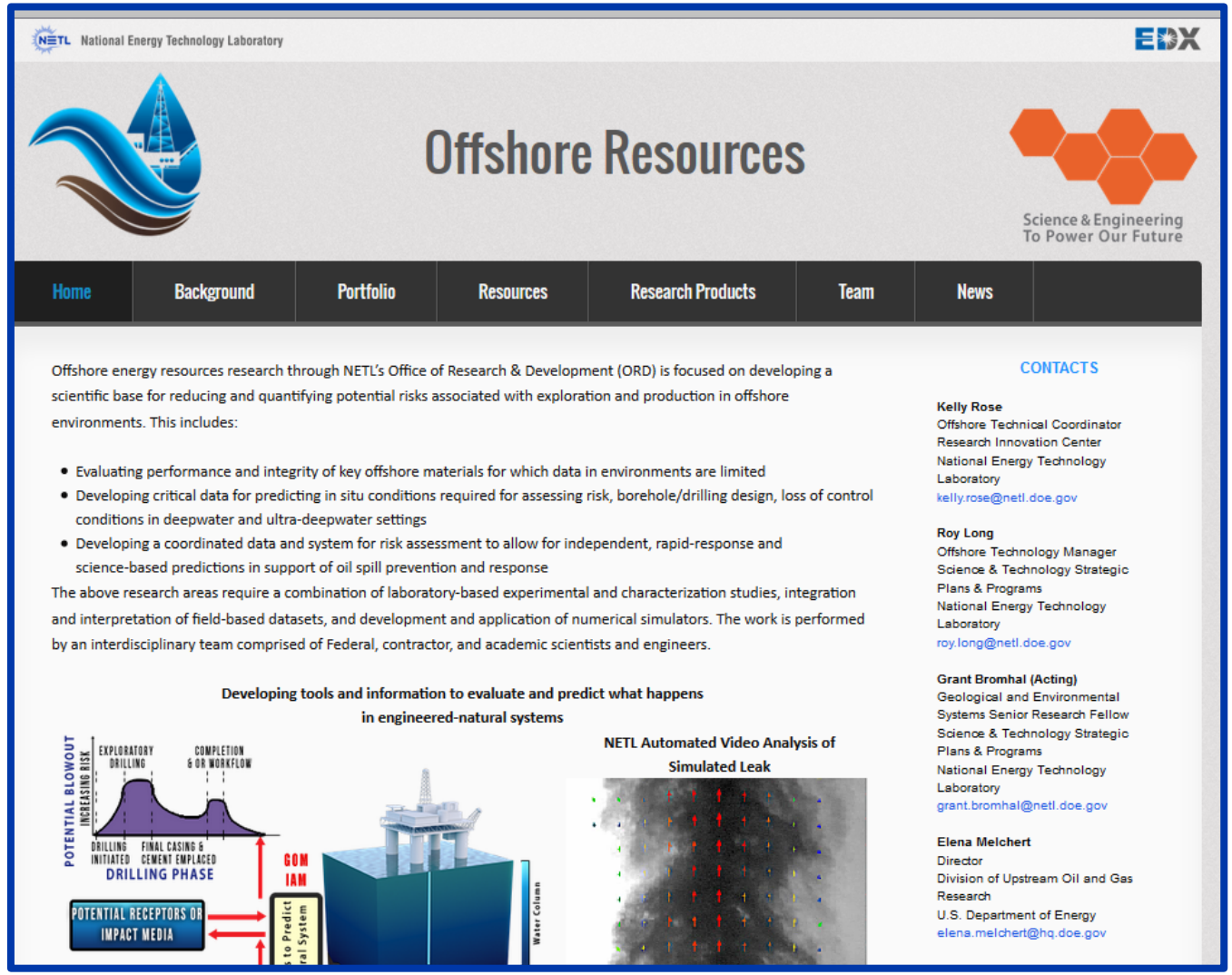


M1 – Definition of gaps & needs for offshore IAM elements
M2 – Definition of input datasets and acquisition of preliminary datasets
M3 – Report on datasets, TRS Graham et al
M4 – EDX Version 2, Private Workspaces, Developed & Released
M5 – Acquisition and formatting of 2012 BOEM wellbore datasets
M6 – BLOSOM beta version completed
M7 – Geocube GOM completed
M8 – Subsurface Databook for GOM initiated using PPT
M9 – Initiation of STA analysis for GOM using BOEM sands data
M10 – Completion of Cumulative Spatial Impact Layers (CSIL) tool, beta
M11– Analysis of impact trends in GOM using BLOSOM/CSIL/SWIM tools
M12 – Analysis of GOM subsurface initial pressure trends using STA and VGM
M13 – Initiate development of Offshore IAM Common Operating Platform
M14 – Beta version of SWIM tool completed
M15 – STA analysis of GOM and TRS draft publication completed

*EPACT 2005 oil/gas funding repealed
**Funding delays & budget reduction by 50%+
***No FY16 funds until Q4

Bibliography – Public Products

All publically released products from this portfolio can be access from here:
https://edx.netl.doe.gov/offshore



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