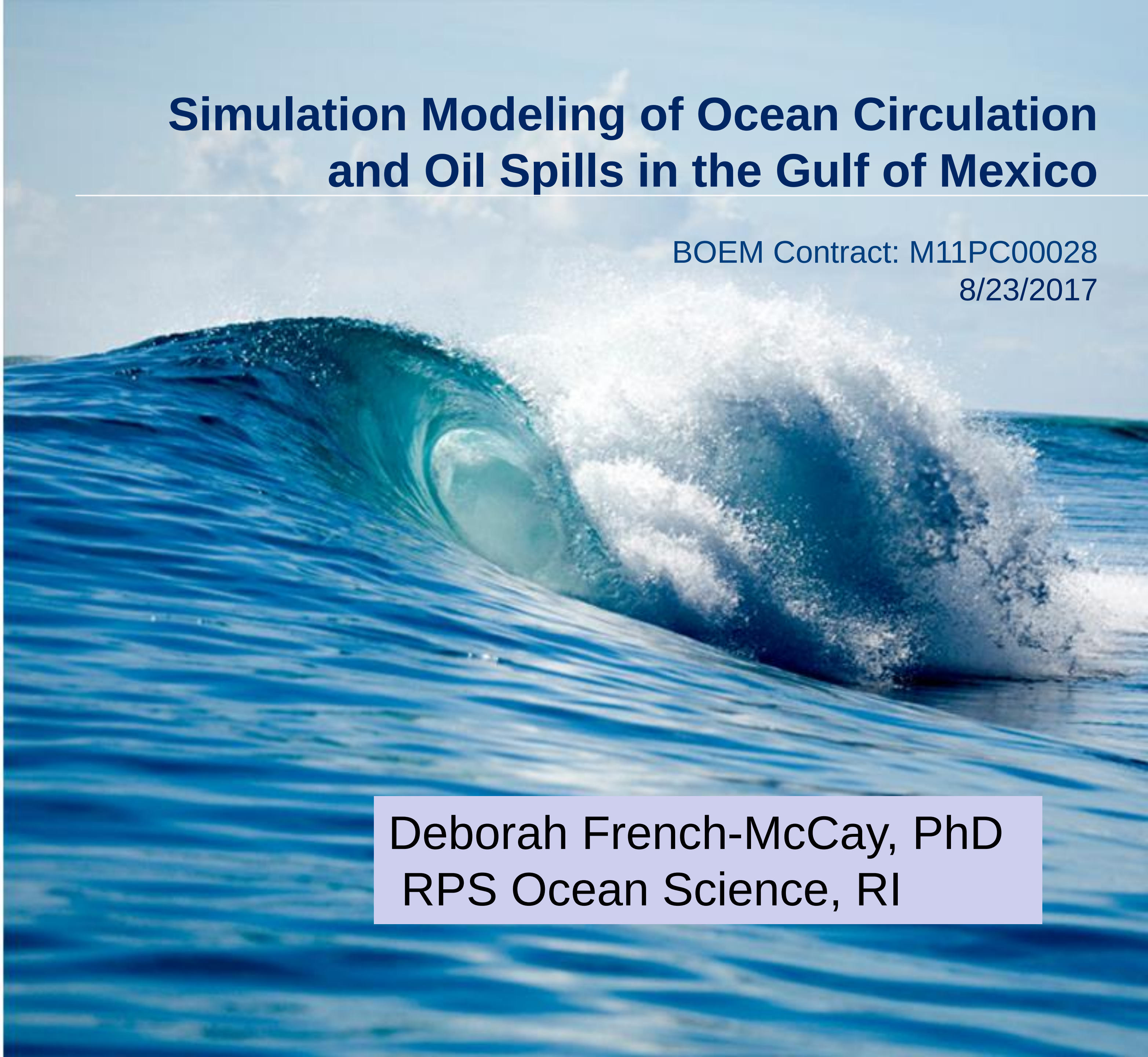
Simulation Modeling of Ocean Circulation and Oil Spills in the Gulf of Mexico

BOEM Contract: M11PC00028
8/23/2017



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RPS Ocean Science, RI

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Presentation Outline

- Project Background and Objectives
- Integrated Oil Spill Model System for Deepwater Blowouts
- Oil Spill Model Validation with Deepwater Horizon Spill Data
- Risk Assessment
  - Modeling Inputs
  - Model Results
- Overall Summary

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- **Overall Objectives**:
  - Develop an oil spill model that
    - Evaluates deep water blowouts,
    - Incorporates current knowledge, and
    - Integrates with existing environmental data and models.
  - Verify the oil spill model by comparison with field and other data.
  - Simulate long-term blowout releases from sites across a range of water depths and locations within the Gulf as part of a comprehensive spill risk assessment.

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Integrated Oil Spill Model

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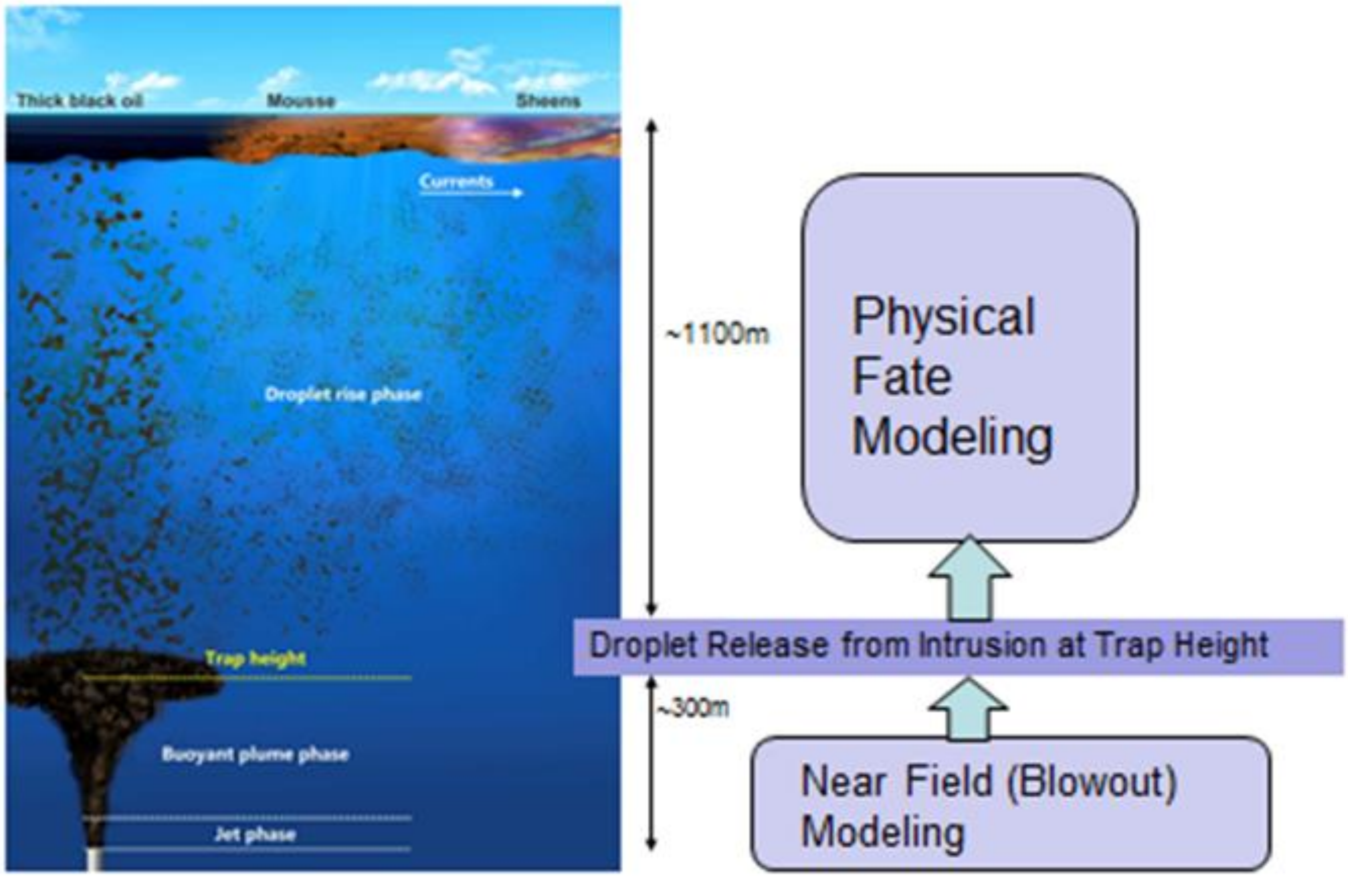
Modeling a Deepwater Oil and Gas Blowout



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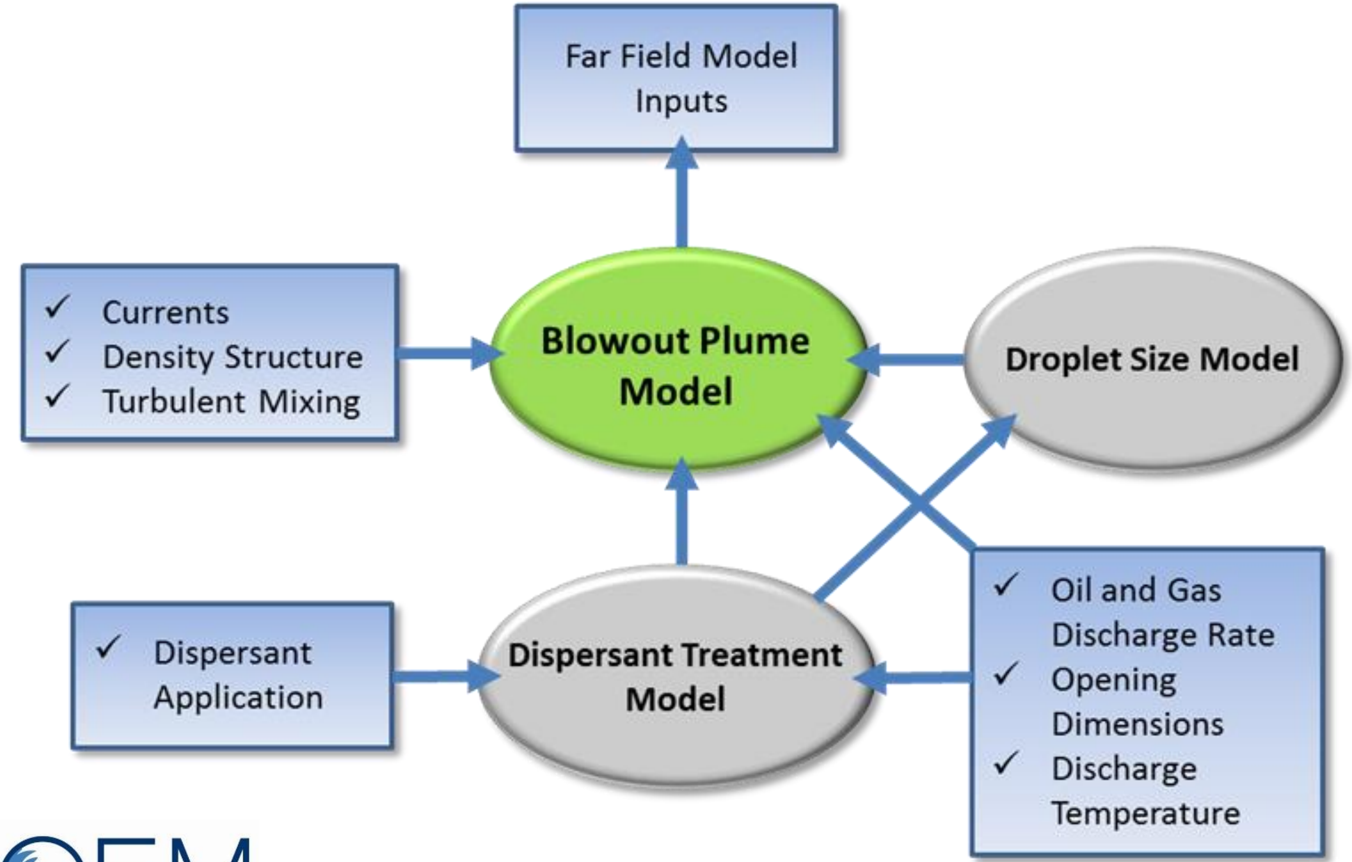
Integrated Oil Spill Model: Blowout Model (OILMAP DEEP)

Blowout Model (OILMAP-DEEP) simulates blowout plume dynamics for well blowouts, calculates the range of oil droplet sizes and provides inputs directly to the 3-D oil transport and fate model.

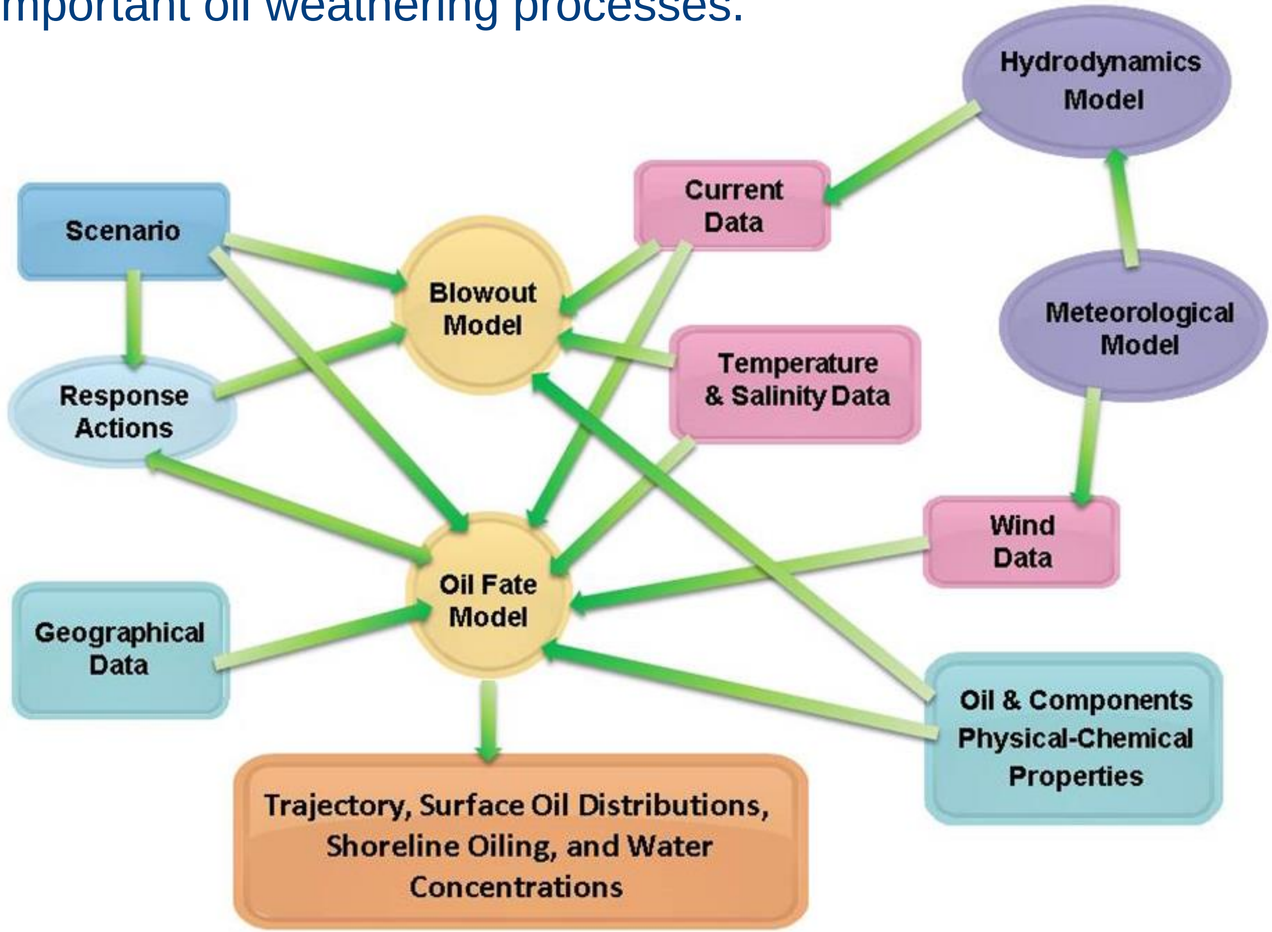


- **OILMAP DEEP blowout model originally developed by (Spaulding 2000).**
- **The model was enhanced based on lab studies and comparisons to data from DWH oil spill.**

  (Spaulding et al. 2015, 2017)

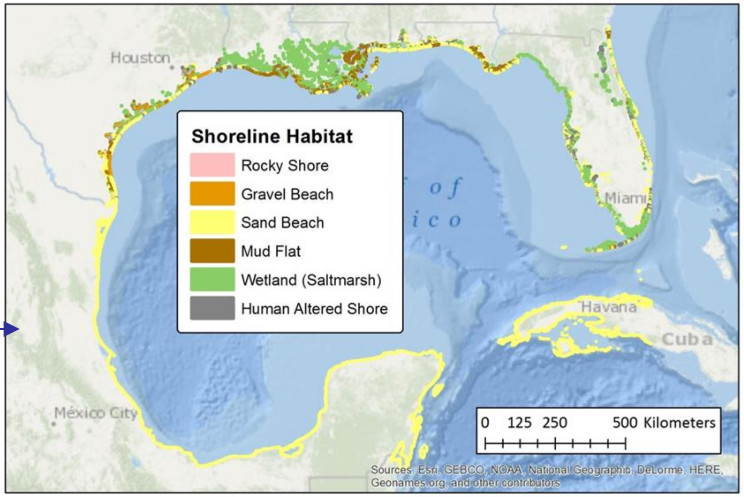
Integrated Oil Spill Model: SIMAP Trajectory and Fate Model

3-D Transport and Fate Model tracks surface and subsurface movement of oil, determines the oil's distribution in various environmental compartments and calculates important oil weathering processes.

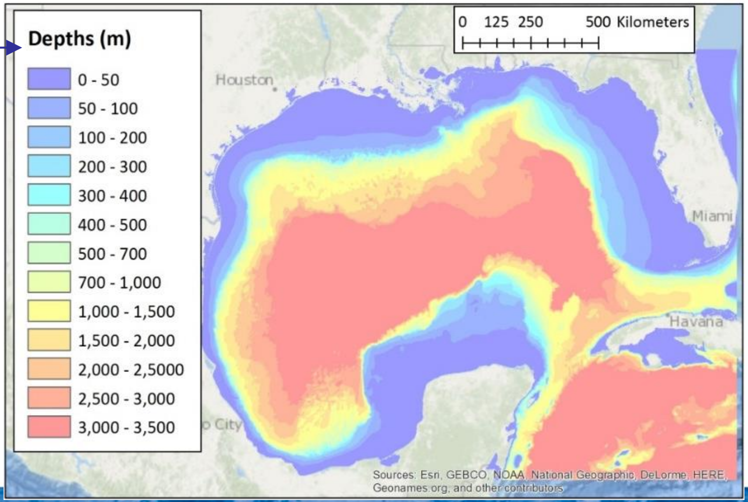


Integrated Oil Spill Model: Trajectory and Fate Model

- Movements of oil components tracked in space and time as parcels (Lagrangian elements, LEs, also called spillets)
  - Floating slicks, weathered oil
  - Droplets/particulates in the water
  - Dissolved components
  - In/on sediments and shorelines



- Model uses grids to define
  - Habitats
  - Bathymetry
  - Current vectors, water levels
  - Temperature, Salinity
  - Suspended Particulate Matter



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Integrated Oil Spill Model: Components of Oil Modeled Separately

C-C-C-C-C-C

Aliphatics:
- Alkanes – C10-C23 – volatile, negligible solubility
- Alkanes $\leq$ C10 & Cyclics – volatile & soluble

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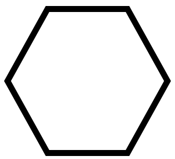
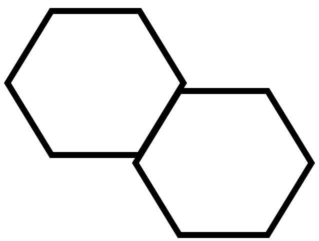
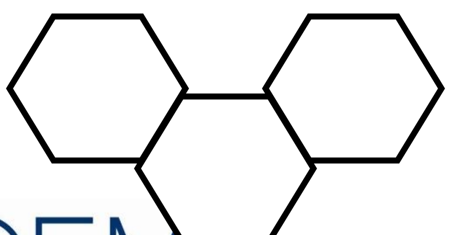


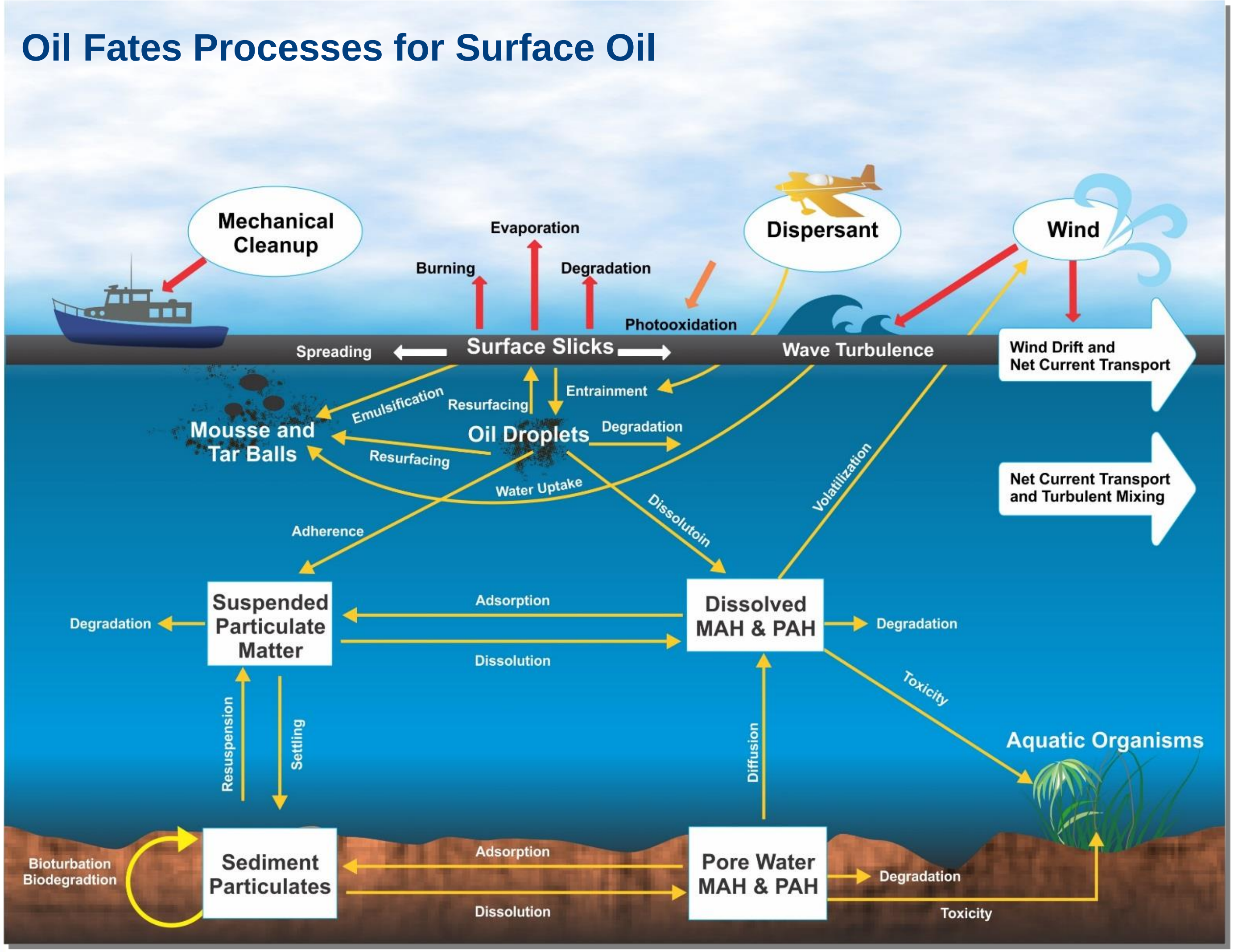
Monoaromatic Hydrocarbons (MAHs)
- Benzene, Toluene, Ethylbenzene and Xylenes = BTEX – highly soluble, highly volatile, moderately toxic
- Alkyl-substituted Benzenes – soluble, less volatile, more toxic



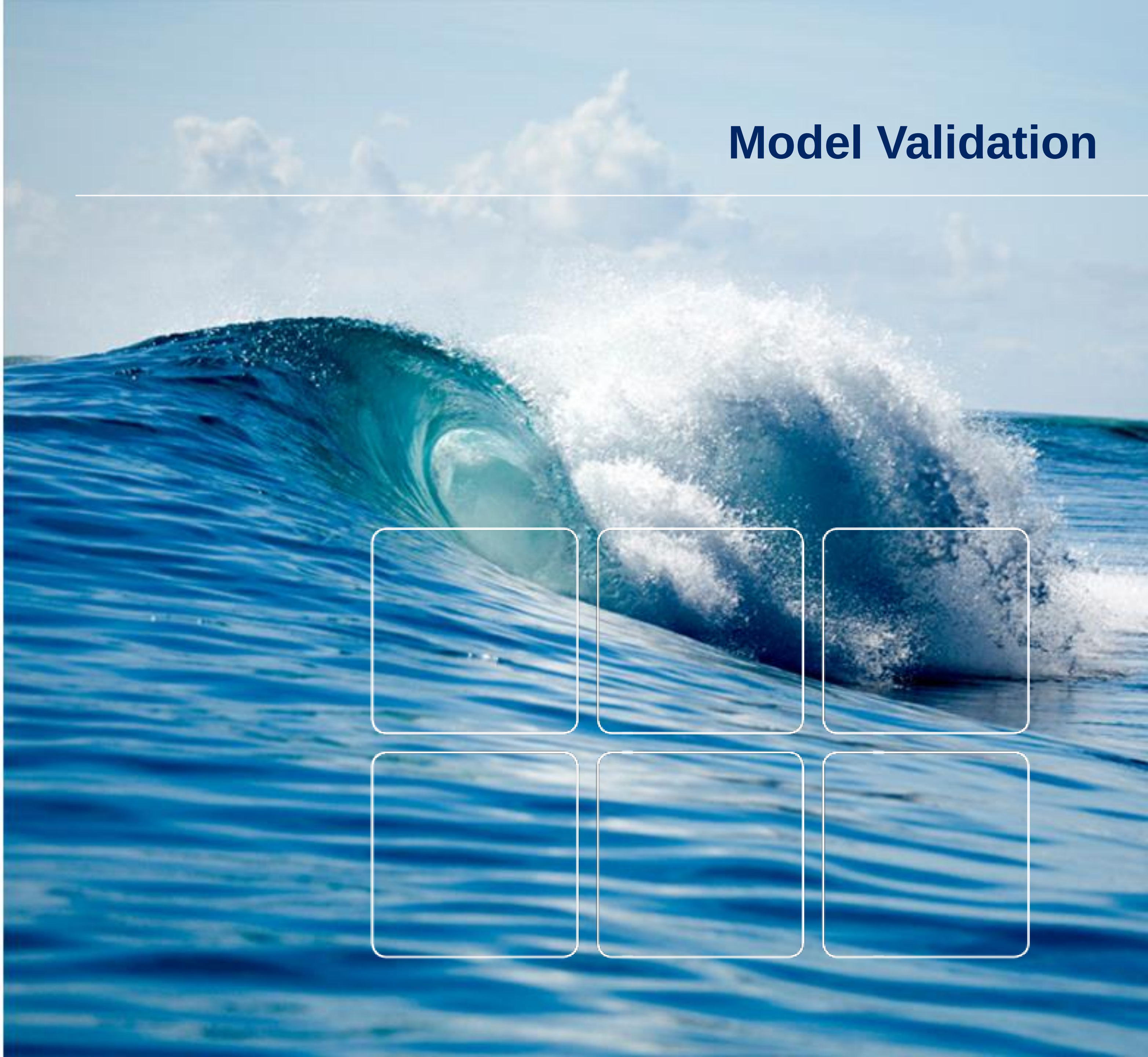
Polynuclear Aromatic Hydrocarbons (PAHs)
- Naphthalenes (2-ring PAHs)
  - soluble, less volatile, more toxic
  - with more alkyl chains, less soluble but more toxic
- 3 ring PAHs – semi-soluble, most toxic fractions
  - Phenanthrenes
  - Fluorenes
  - Dibenzothiophenes
- 4-ring PAHs – fluoranthenes, pyrenes, chrysenes
- larger PAHs insoluble



Integrated Oil Spill Model: Trajectory and Fate Model



Model Validation



Model Validation: DWH Spill Model/Data Comparisons

- Deepwater Horizon (DWH) oil spill – only deep water blowout where sufficient comparison data are available for validation
- Steps of the validation study:
  - **Collate data for use as input to the model.**
  - **Evaluate data available for validation of model results.**
  - **Apply model to DWH.**
  - **Compare model predictions to publicly available observations including:**
    - **buoyant plume trap depth, released oil droplet size distribution and rise velocities,**
    - **oil concentrations in the water column,**
    - **surface oil amounts and patterns, and**
    - **shoreline oiling.**
  - **Compare model-predicted mass balance to the NOAA Oil Budget Calculator and other studies.**
  - **Perform sensitivity (uncertainty) studies with particular focus on the key environmental input data sets (currents, winds) and the spill model algorithms.**

SIMAP Model Inputs

- Location of release – from end of riser and kink holes
- Date, time, and duration – considered daily releases and conditions
- Oil characteristics – had detailed analyses
- Amount of release – **Government**, BP and Court versions
- Geographical data (shoreline, habitat, depth)
- Environmental conditions
  - Winds & Currents – various model products used
  - Temperature & Salinity – NOAA NODC Climate Atlas
- Response activities
  - In-situ burning, but not enough data to model mechanic removal
  - Surface dispersants
  - Subsea dispersant application – in nearfield modeling – droplet sizes

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Model Validation: DWH Spill Model/Data Comparisons - Results

- **Subsurface Oil** – results show good comparison to observational data; sensitivity analyses shows most important input contributing to uncertainty was current data used
- **Mass Balance** – modeled amount of oil floating over time in good agreement with estimates from interpretation of remote sensing data (thus oil droplet distributions input to SIMAP and oil weathering and fate processes produce reasonable results)
- **Surface Floating Oil** – simulations using HYCOM-FSU (base case) show most similar results to remote sensing data, with floating oil in circular area near and just north of DWH wellhead; no-current simulations also result in realistic floating oil patterns created just north of well head – indicates importance of winds in transporting floating oil
- **Shoreline Oil** – modeled shoreline oiling for base case (2,000-2,700 km oiled) compares well with observations (2,100 km oiled)
- **Sediment Oil** – difference between model results and observations during spill due to oil-sediment settling from failed Top Kills not being included in modeling

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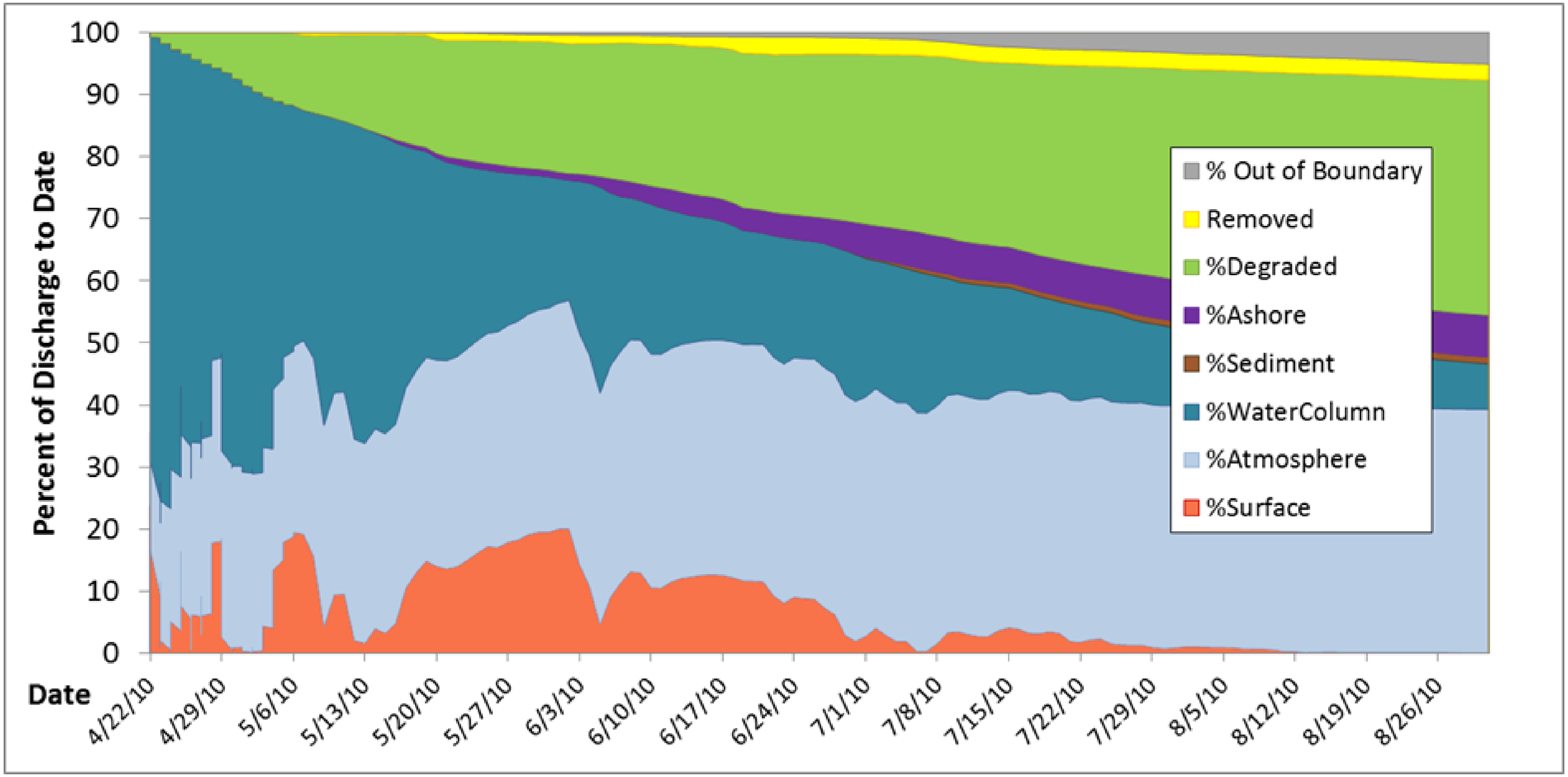
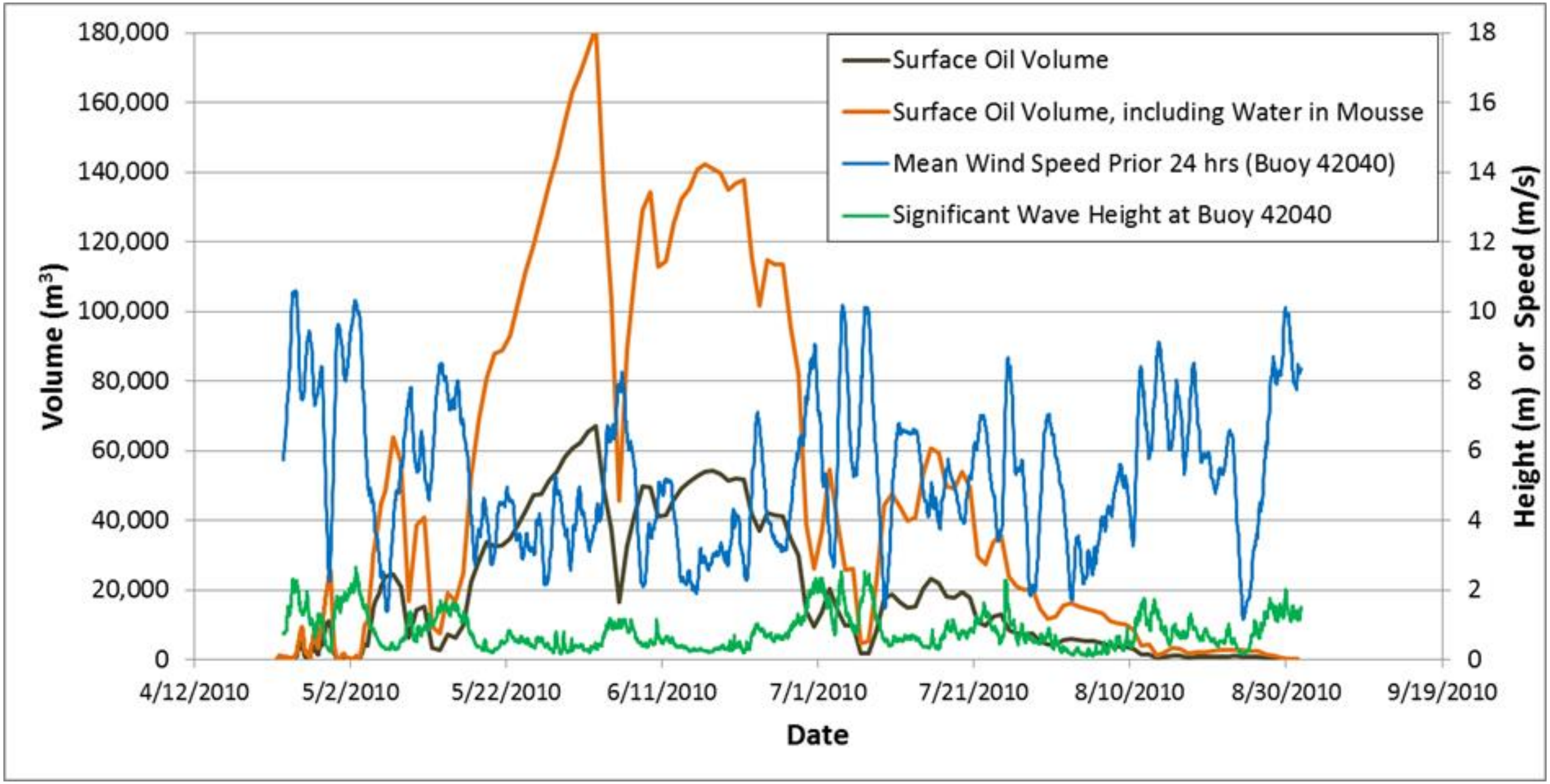
Model Validation: DWH Modeled Mass Balance over Time



Surface Oil Over Time
Reflected Winds & Waves



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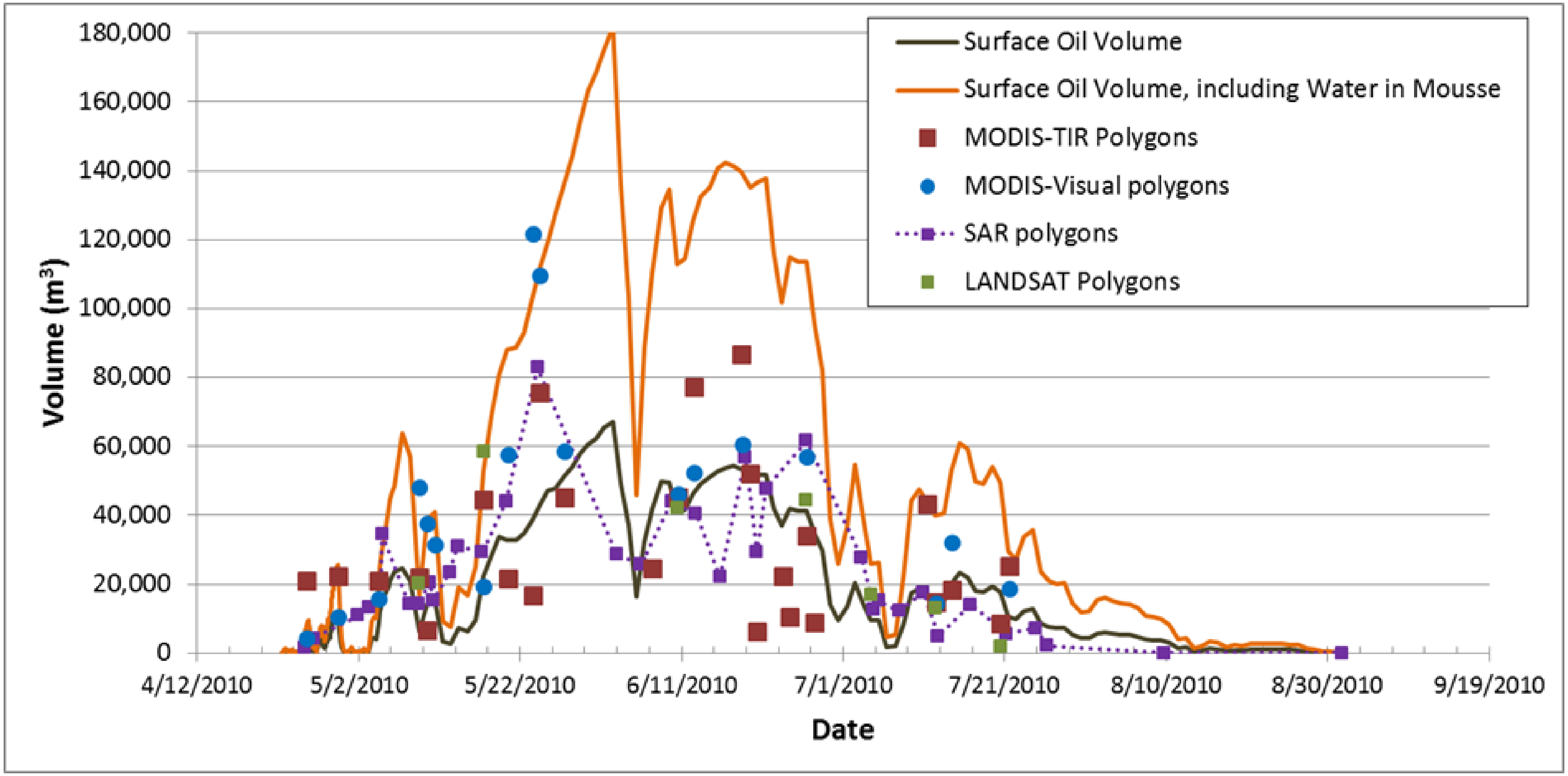
Model Validation: Floating Oil
DWH Model Compared to Remote Sensing Estimates



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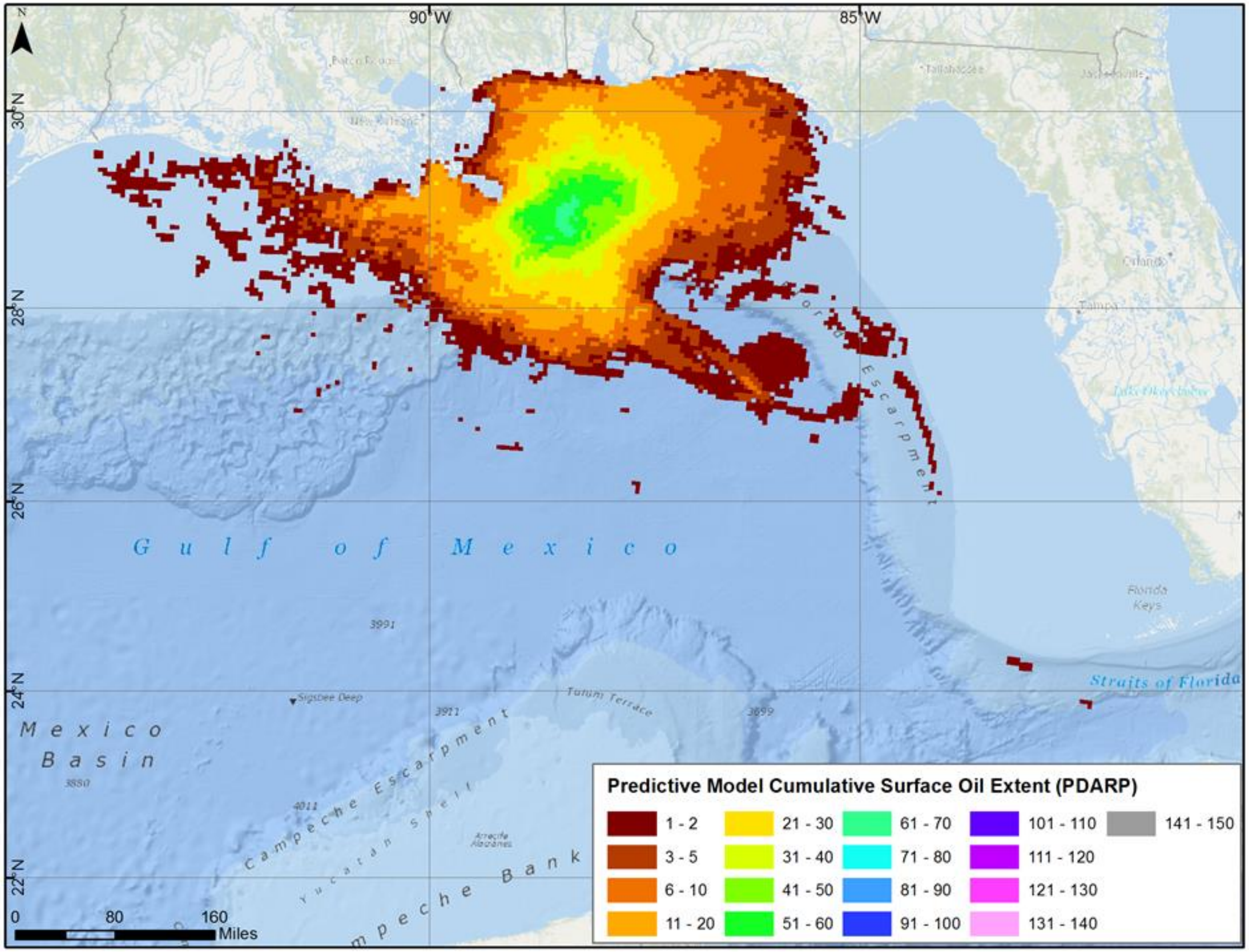
Model Validation:
DWH Cumulative Floating oil Coverage – Remote Sensing



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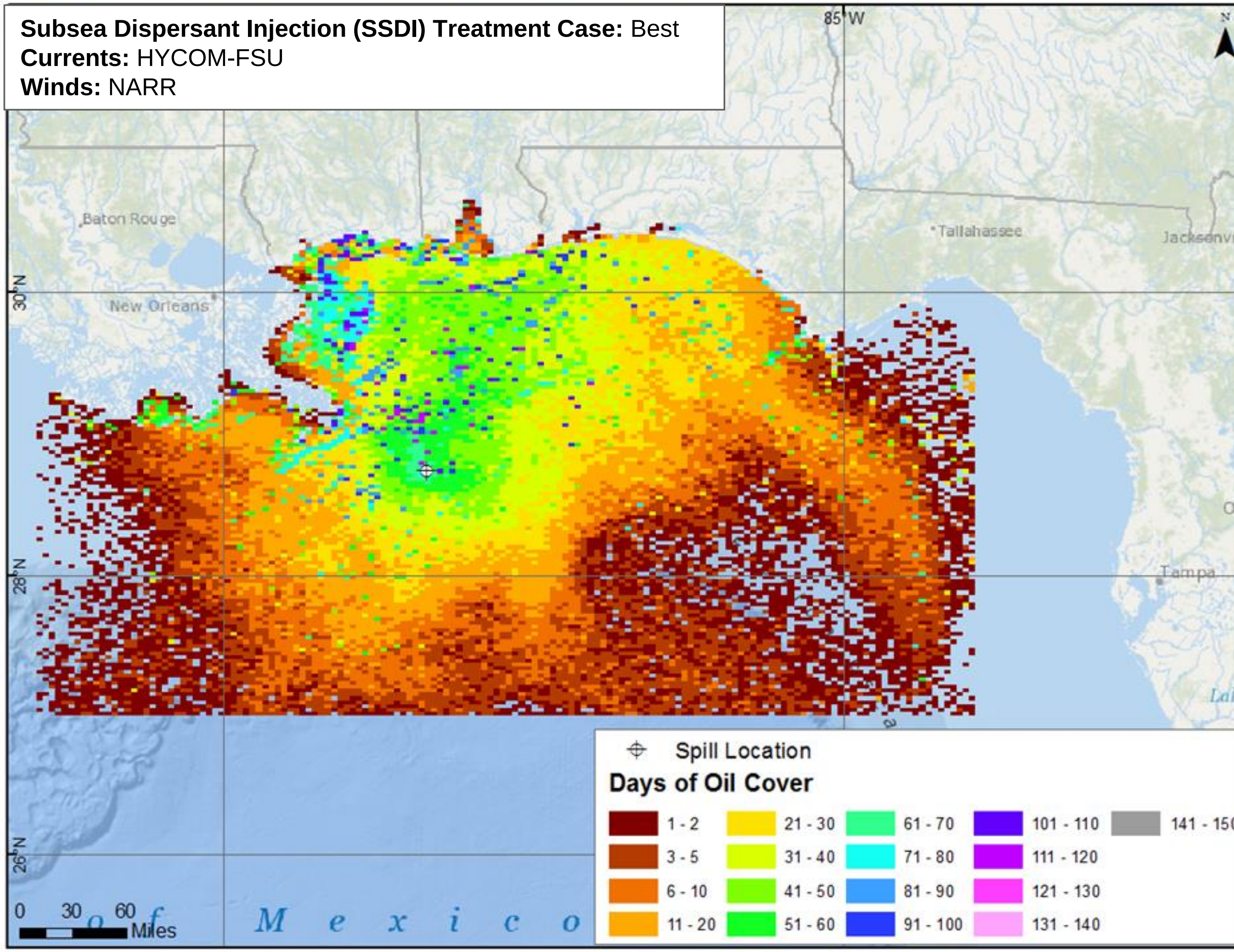
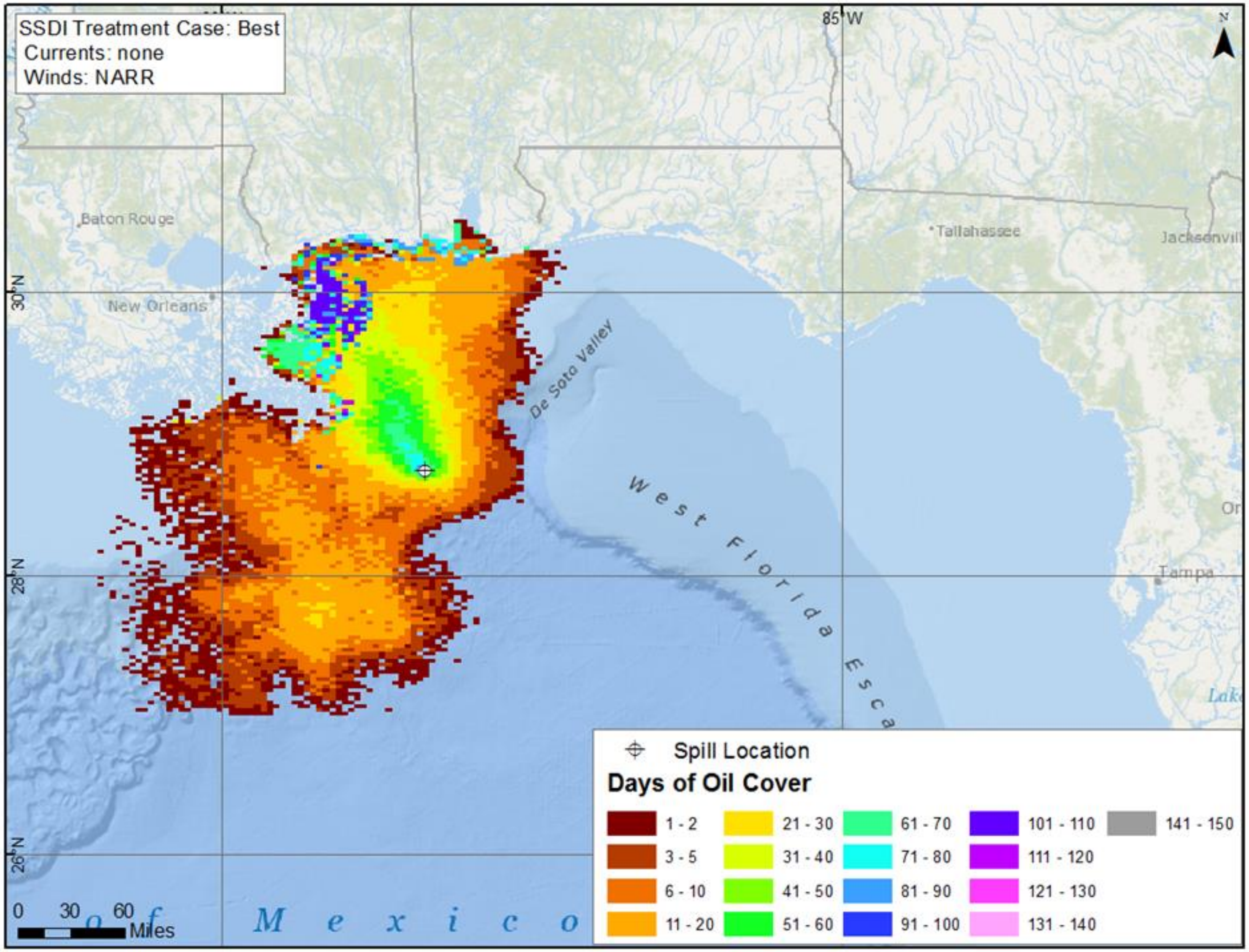
Model Validation:
Cumulative Floating Oil Coverage – Model Results

HYCOM-FSU currents and NARR winds



Model Validation:
Cumulative Floating Oil Coverage – Model Results

Negligible (ADCP) currents and NARR winds



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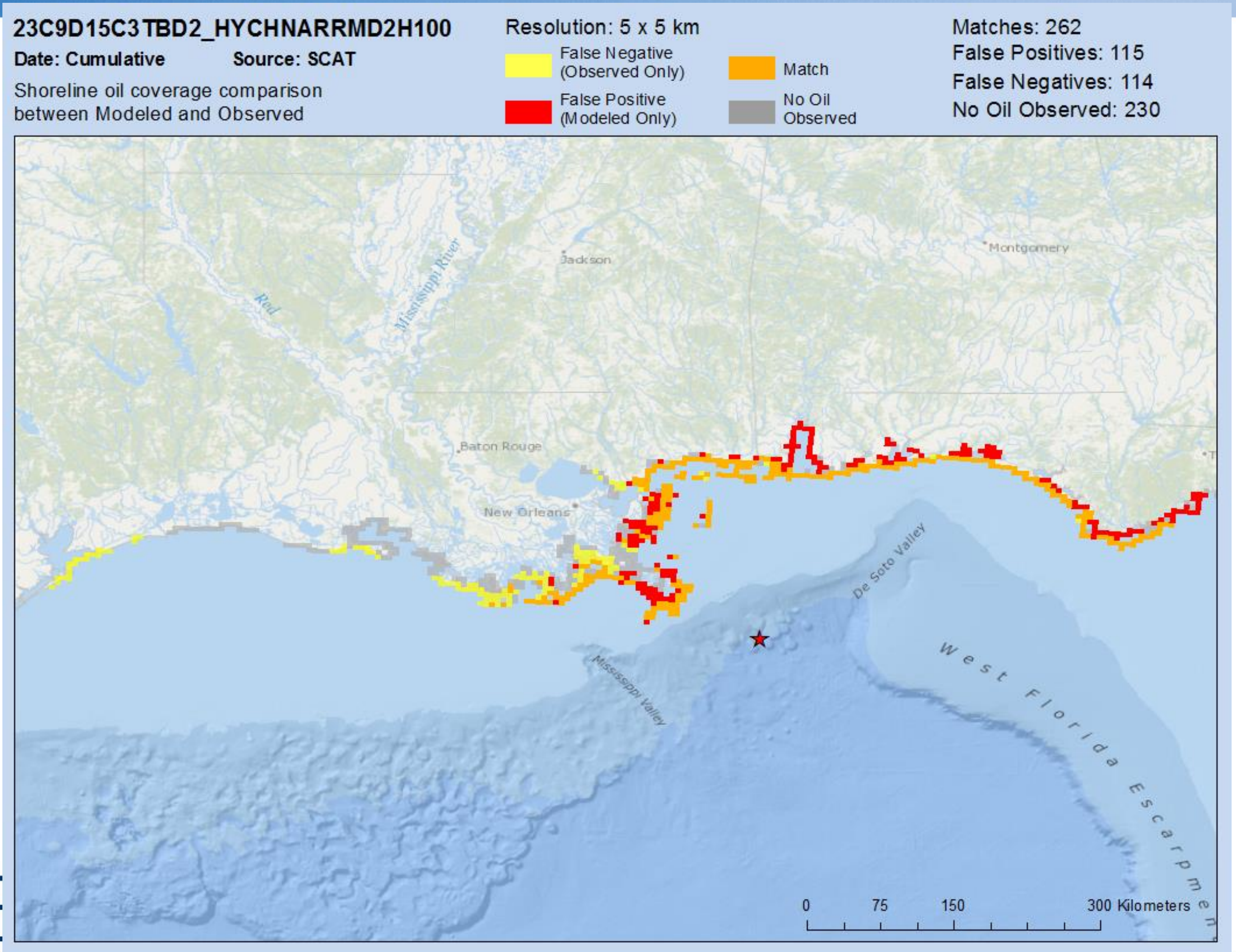
Shoreline Oil Distribution

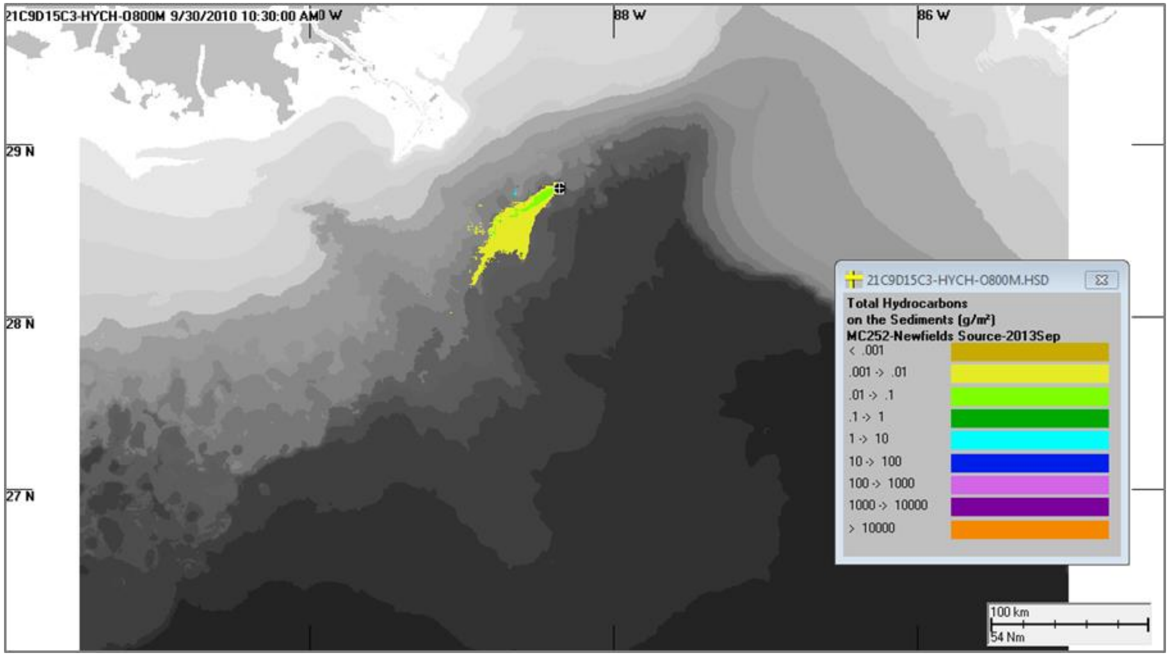
- Observed oiling
  - **Not all sections of shore visited every week**
  - **NRDA trustees only developed cumulative maps of relative oiling**
  - **RPS ASA evaluated the timing of oil arrival from SCAT and remote sensing (SAR) data**
- Modeled
  - **Compared timing and cumulative amount ashore to both SCAT and SAR-based data**

Shoreline Oil Distribution – HYCOM FSU



Sedimented Oil Distribution

- Observed oiling
  - Primarily within 20 km of wellhead and from failed Top Kills
  - Field data: about 7% of released oil
- Modeled
  - Top Kills not included, 1% of oil sediments
  - HYCOM FSU



Model Validation:
DWH - Modeled Mass Balance in Fall 2010

Fate	Low	Best Estimate	High
Evaporated	43%	39%	35%
Water column (dispersed or degraded)	38%	42%	47%
Burned	2.6%	2.6%	2.6%
Skimmed (based on Oil Budget Calculator by NOAA)	4%	4%	4%
Shoreline	5.2%	4.7%	4.6%
Sediment (based on field data analysis)	7.0%	7.0%	7.0%

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Conclusions – DWH Oil Fate Modeling

- Validation: Surface-Floating and Shoreline Oil
  - Good agreement, given uncertainty in currents
  - Transport mostly wind-driven
- Water concentrations – Model vs Observed
  - Considerable variation in space and time
  - Non-comprehensive sampling makes comparisons difficult
  - Modeled magnitudes agree with samples
  - Inclusions of currents shifts locations but magnitudes of concentrations similar between model and observed
- Subsea dispersant was effective on the treated oil
- Most of oil surfaced because only part was treated by subsea dispersant
- Concentrations – patterns evident in model agree with observations
  - Highest near trap height: 1050-1250 m
  - BTEX and soluble alkanes mostly dissolved at depth near trap height
  - PAHs only partially dissolved as oil rose

Model Validation: DWH Spill Model – Uncertainty in Results

- **Winds:**
  - Accounted for most of the transport of the floating oil.
  - Affect all of the surface weathering processes.
  - Most influential of all model inputs.
  - All models examined provided realistic model simulations of the event, as measured by comparisons to floating oil observations based on remote sensing.
- **Uncertainty:**
  - Majority - related to currents used, especially below 40 m.
  - HYCOM-FSU hydrodynamic model by Chassignet et al. - the most accurate transport as compared to remote sensing data and shoreline oiling observations.
- **Modeled mass balance of oil over time was relatively insensitive to:**
  - the floating oil dispersion coefficient
  - wind drift transport assumptions, and
  - current data used (to the degree that amount transported ashore was unaffected).
- **More variation in mass balance depending on the potential range of assumptions for subsea dispersant injection**
  - **Reflects differences in droplet size distributions and thus surfacing & weathering rates of the oil.**

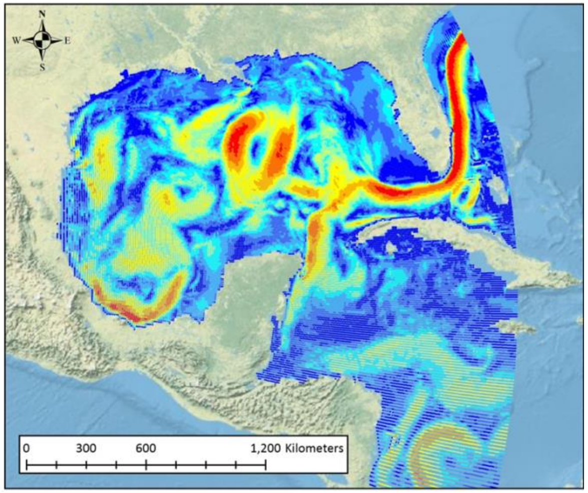
Risk Assessment – Model Inputs

Risk Assessment – Model Inputs

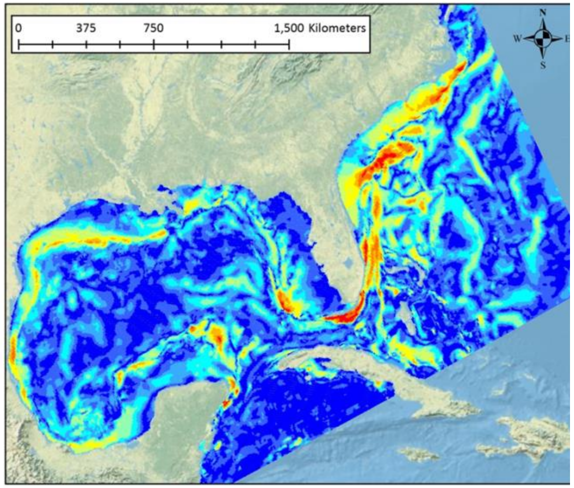
Hydrodynamics – 3D hydrodynamics for multiple years

Modeling Team	Model Name	Horizontal Resolution	Hindcast Period (# years)	Model Time Step
Lie-Yuaw Oey Princeton	POM	10 km	1998-2007 (10)	daily
Ruoying He NC State	SABGOM	5 km	2004-2010 (7)	daily
Eric Chassignet FSU	HYCOM	3-4 km	2001-2012 (13)	3 hours

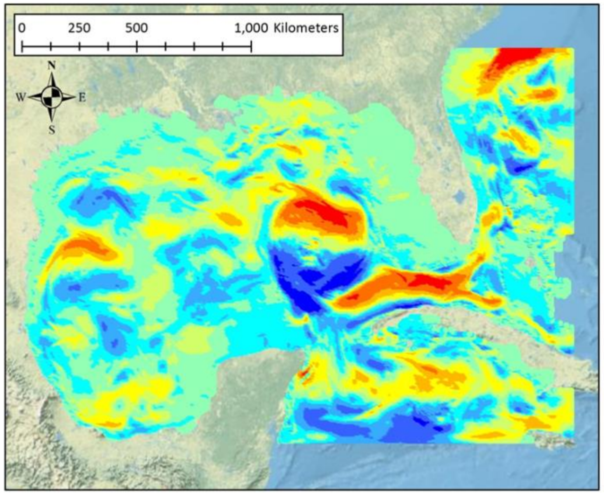
POM



SABGOM



HYCOM

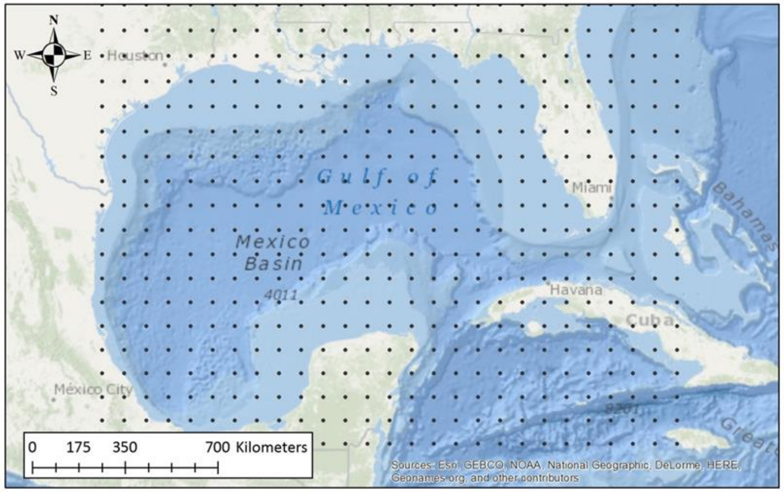


Risk Assessment – Model Inputs

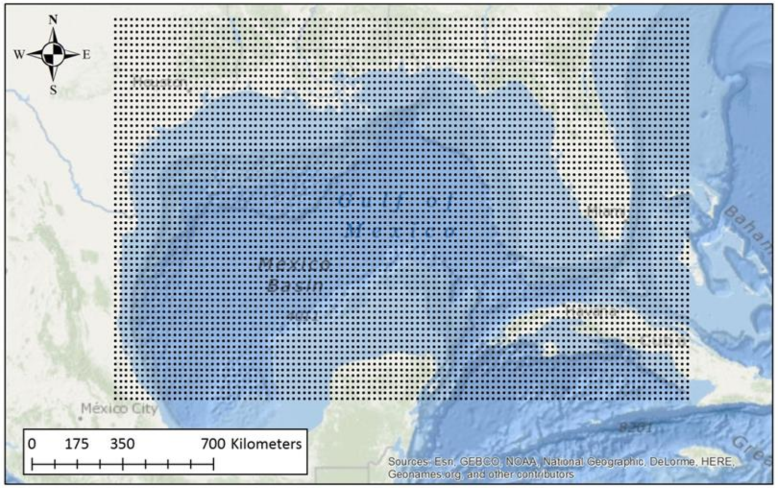
Winds – Multiple year time series of surface winds

Meteorological Model	Hindcast Period	Grid Resolution	Companion Hydrodynamic Model
ERA-Interim (ECMWF)	1993-2007	0.75° (approx. 80 km)	POM
NARR	2001-2012	0.3° (approx. 32 km)	SABGOM HYCOM

ERA-Interim



NARR



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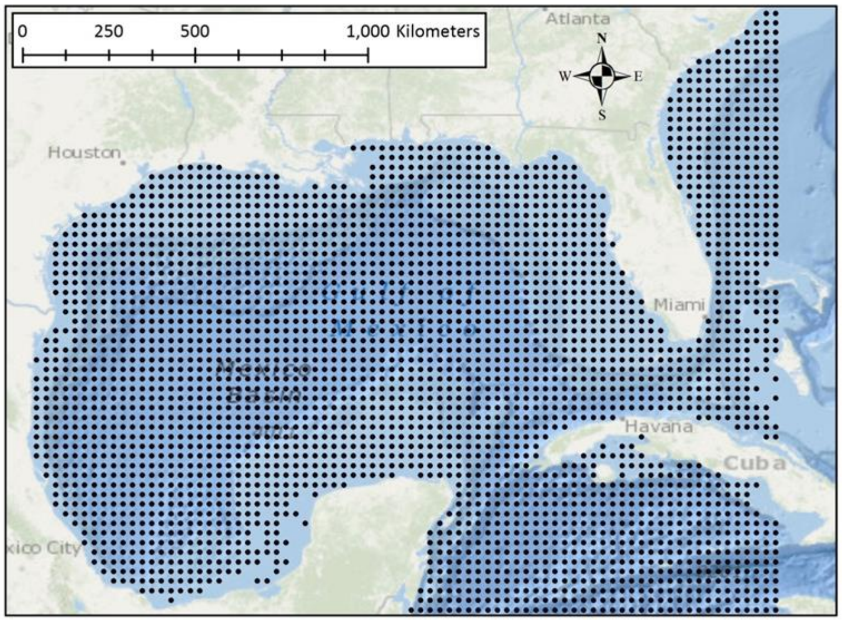
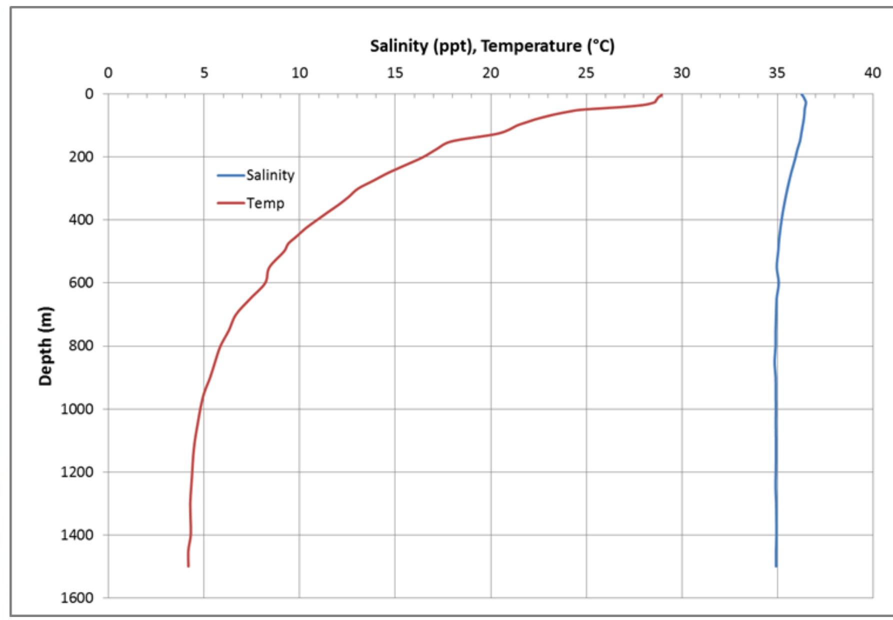
Risk Assessment – Model Inputs

Water Column

- Temperature and salinity profiles from the World Ocean Atlas 2013 (WOA13) high resolution, Version 2
- Average monthly from the period 1955-2012

World Ocean Atlas 2013 ¼° resolution

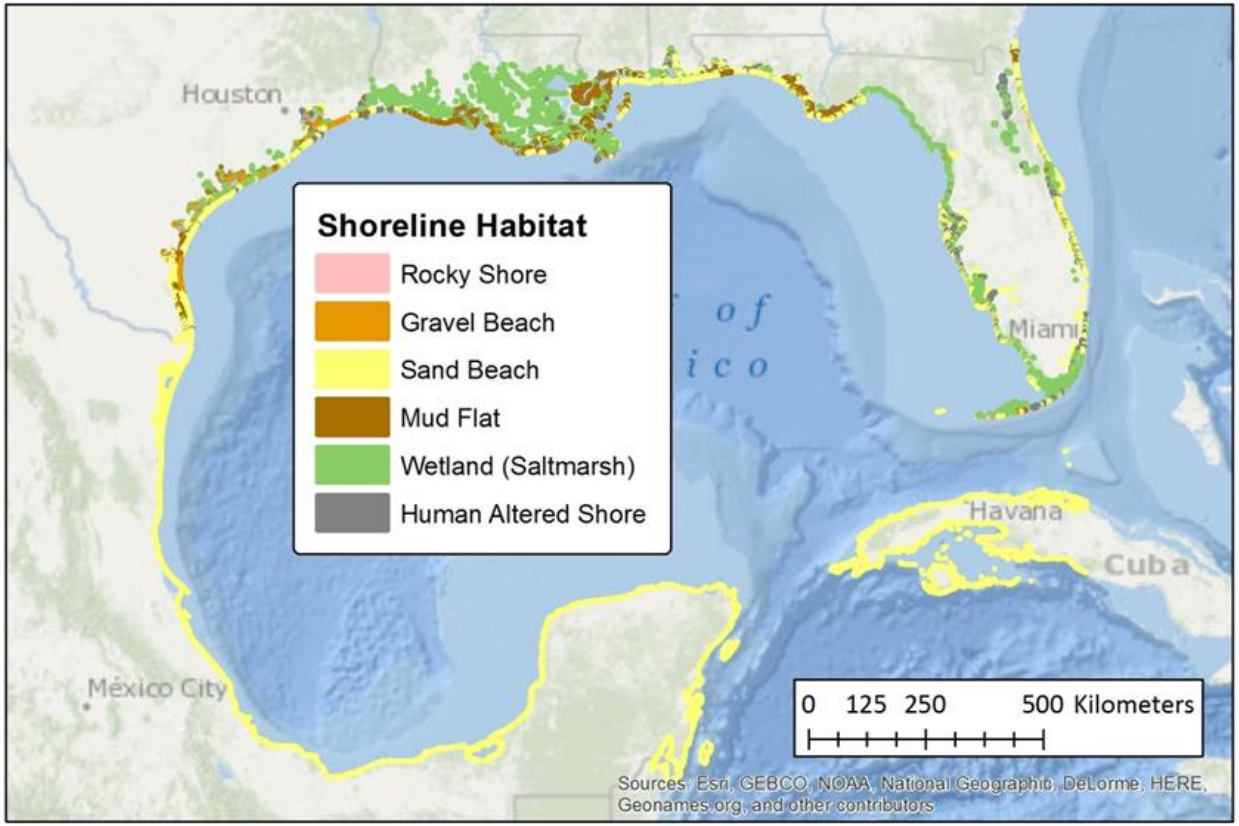




Risk Assessment – Model Inputs

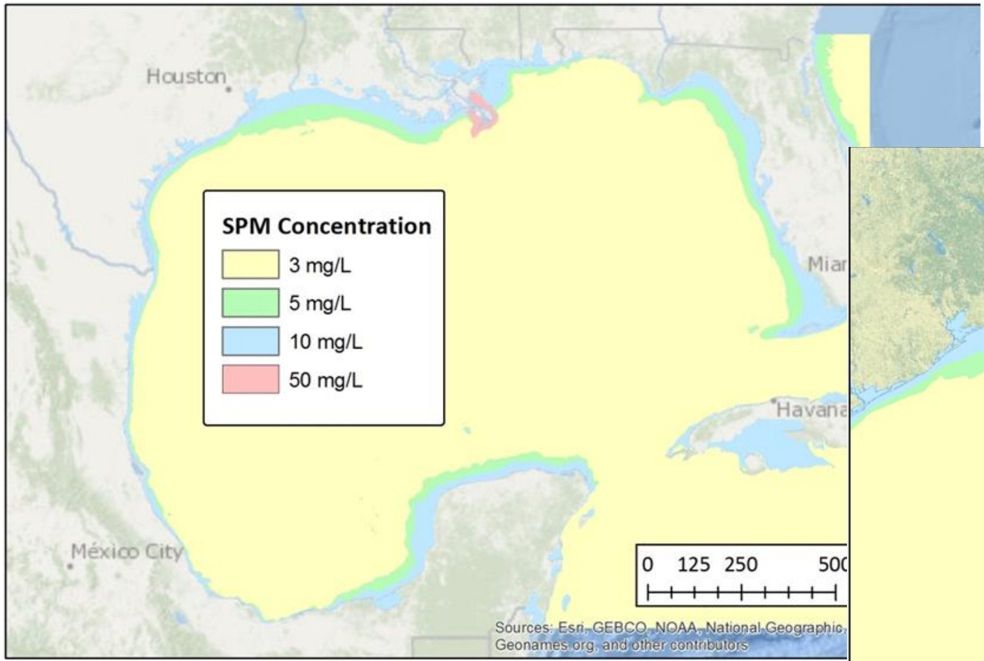
Habitats

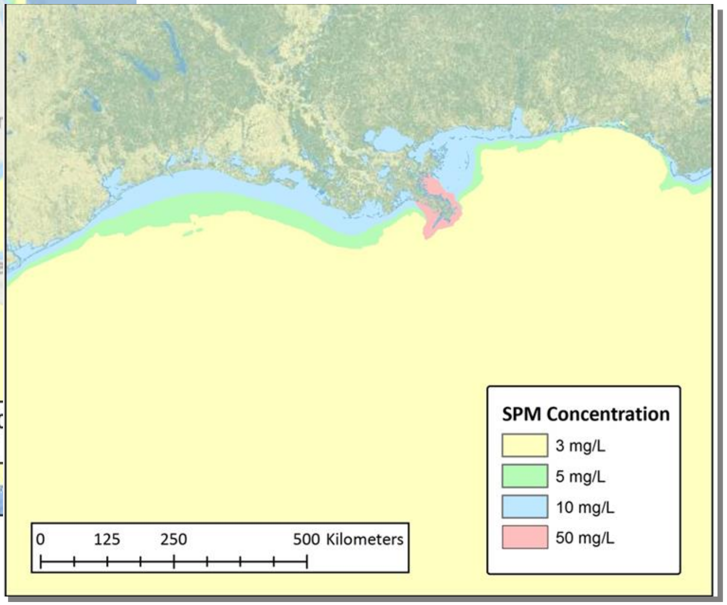
- Developed using NOAA Environmental Sensitivity Index (ESI) habitat data layers for applicable states (NOAA, 2012)
- Regions outside of the United States were assigned default shore and subtidal habitat



Suspended Particulate Matter (SPM) Concentration

- Three regions: Mississippi River discharge, nearshore shelf outside the area of river influence, remaining offshore locations
- Generalized distribution representative of concentrations during storm periods over the course of the year





Oil Physical and Chemical Properties

- Properties for the two crude oils used in the spill risk assessment – representative of many other crudes and refined products.

Physical Parameters	Mars TLP 2004	Ship Shoal Block 269
Oil Type	Medium crude	Light crude
Minimum Slick Thickness (µm)	0.1	0.1
Surface tension (dyne/cm)	26.2	25.6
Pour Point (°C)	-28°	-42°
API Gravity	26.8	38.7
Density at 25°C (g/cm^3)	0.8817	0.8236
Viscosity (cP) at 25°C	24	4

Risk Assessment – Results

Risk Assessment: Scenarios

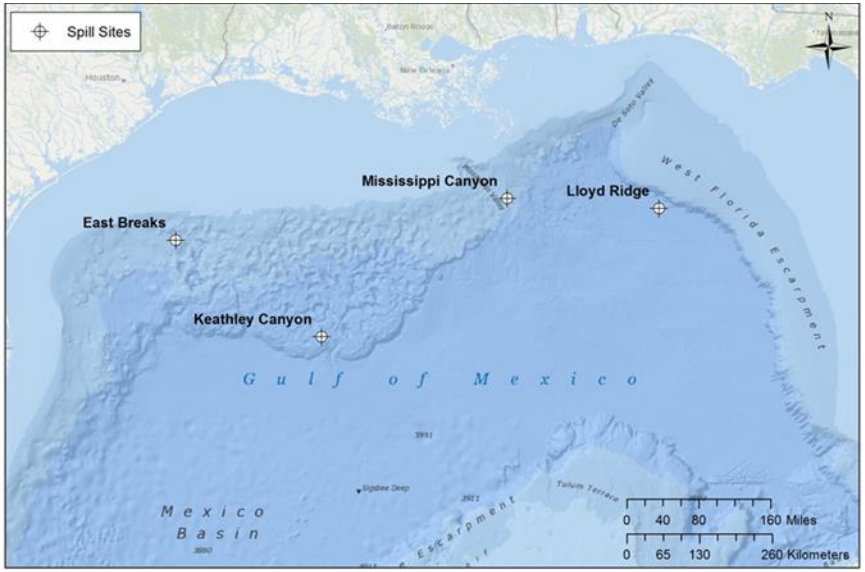
Spill Scenario

- 45,000 bbl/day over 30 days decreasing by 113.1 bbl/day
- Total Release = 1,300,802 bbl
- Simulation Length = 75 days

Parameters Considered

- 4 Release Locations (680 – 2,950 m depth)
- 2 GOR's (100 and 1,500 scf/stb)
- 2 Crude Oil types (light and medium)
- 3 Dispersant Options:
  none, 50% and 100% effectiveness
- 3 Hydrodynamic/wind model pairs
  - POM/ECMWF
  - ROMS/NARR
  - HYCOM/NARR

144 possible spill scenarios distilled to 72



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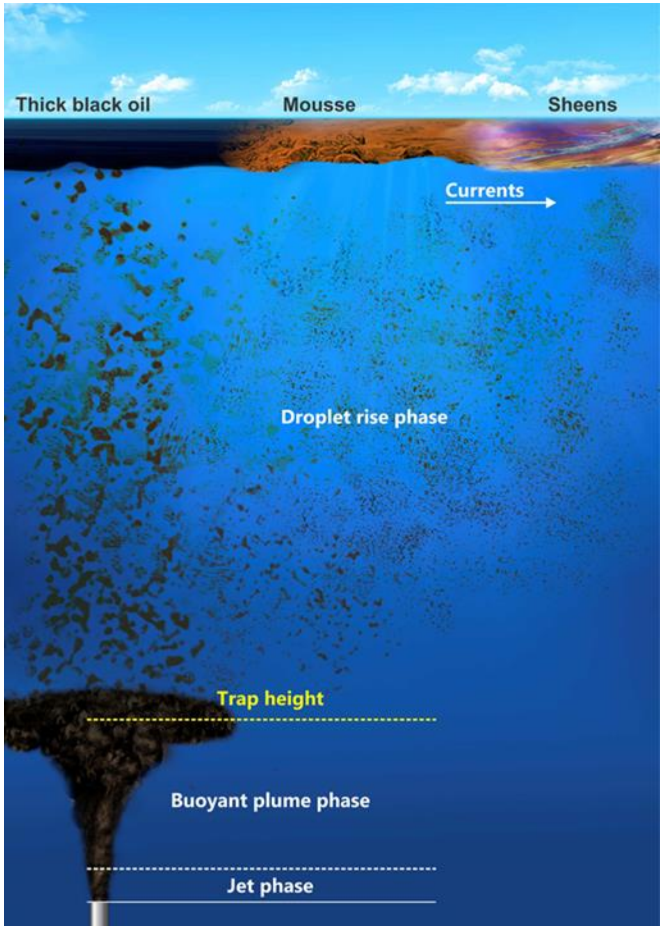
Risk Assessment: Blowout Model Results

Plume Height and Diameter



Scenario	Spill Site	Plume Trap Height (m)	Plume Diameter at Trap Height (m)
1	**East Breaks** (680 m depth)	186	124
2		186	124
3		195	100
4		320	167
5		320	167
6		320	167
7	**Keathley Canyon** (2,150 m depth)	536	269
8		536	269
9		494	256
10		620	298
11		620	298
12		620	298
13	**Mississippi Canyon** (1,150 m depth)	204	94
14		204	94
15		194	93
16		321	139
17		321	139
18		321	139
19	**Lloyd Ridge** (2,950 m depth)	498	235
20		498	235
21		527	242
22		586	257
23		586	257
24		586	257

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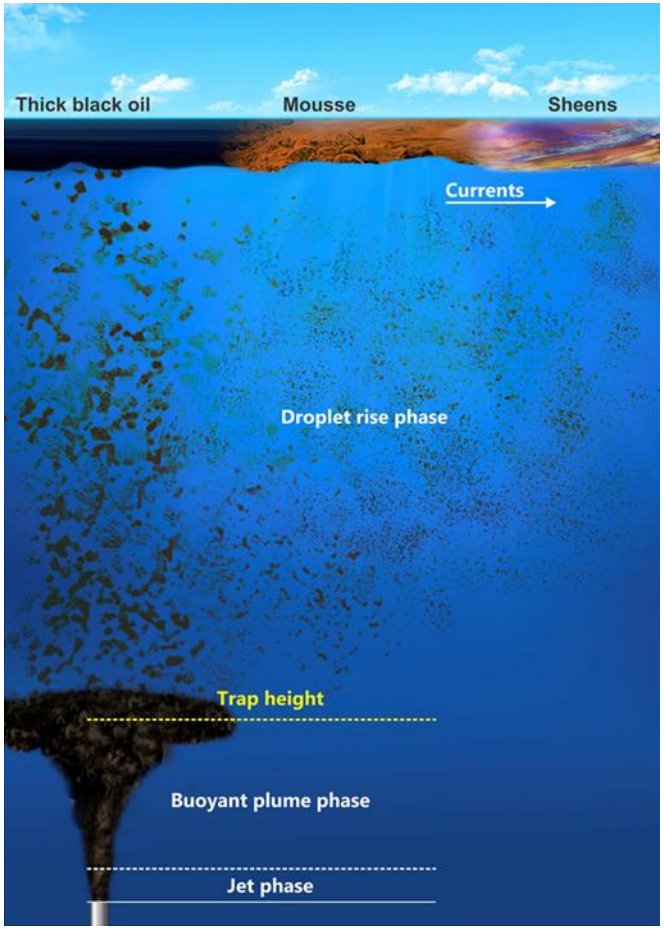
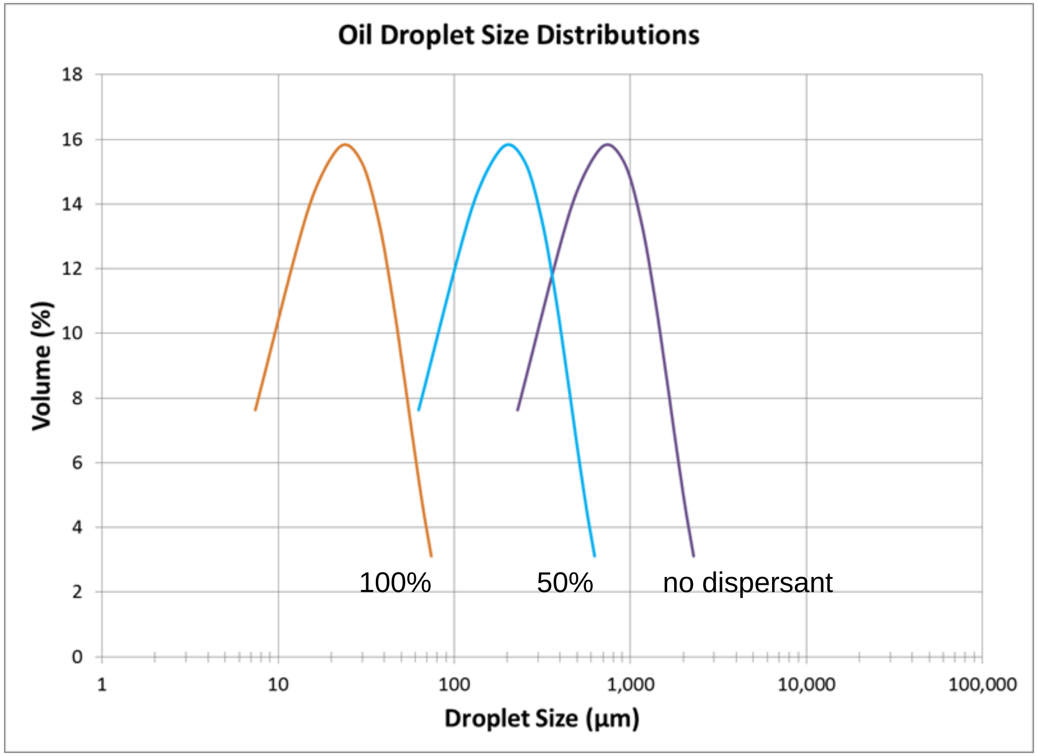
Risk Assessment: Blowout Model Results

Oil Droplet Size Distributions





Time varying oil location in the water column and droplet size data were used as input to the transport and fate model simulations.

Risk Assessment: Model Results – Summary

Effects of Dispersant Injection at Source:

- Regardless of whether exposure areas are calculated by averaging on a grid or based on area covered by LE's over duration of spill simulation, use of dispersant with 100% effectiveness decreased area covered by surface oil > 10 g/m^2.
- Swept areas at all thresholds decreased when dispersant was applied with 50% effectiveness and decreased again from 50% to 100% effectiveness.
- Mass balance numbers show clear trends in effect of dispersant injection in reducing the quantity of oil on sea surface and shoreline and increasing potential exposure in the water column to elevated THC concentrations.

Risk Assessment: Model Results - Summary

Most significant drivers of exposure to elevated dissolved hydrocarbon concentrations (in decreasing order of importance):

- **Oil droplet size – smaller Volume Mean Diameter (via more oil & gas volume flow, more energy and/or dispersant use) leads to more water column exposure**
- **Blowout Water Depth and Proximity to Shore (due to variation in rise time to surface and transport time to shore) – more water column exposure for deeper discharges offshore**
- **Blowout Location (due to varying transport and dilution)**
- **Oil Type – influence smaller than and masked by above effects**

As oil droplet size decreases, rate of degradation increases, since hydrocarbons become more bioavailable to microbes

Risk Assessment: Overall Conclusions

- Depth of blowout location and proximity to the Loop Current are two factors driving largest surface and subsurface oil contamination footprints.
- Proximity to shoreline drives length of shoreline oiled
- Influence of current data used
  - SABGOM hydrodynamics display weaker currents, in general, resulting in generally less surface floating oil area at both thresholds as compared to POM and HYCOM.
  - Magnitude of currents is faster in POM and slower in SABGOM, on average; thus, scenarios simulated with POM had larger volume of water contaminated.
- Droplet size distribution – most influential, a function of:
  - Oil & gas flow rates
  - Aperture size
  - Water depth
  - Dispersant use