Oil Spill Modeling: State of the Art and Research Needs

TechSurge – Advancing Oil Spill Technology: Beyond the Horizon

Deborah French McCay, Ph.D.

Director, Research and Model Development
RPS ASA

South Kingstown, RI USA
Debbie.FrenchMcCay@rpsgroup.com

+1 (401) 789 - 6224 x331

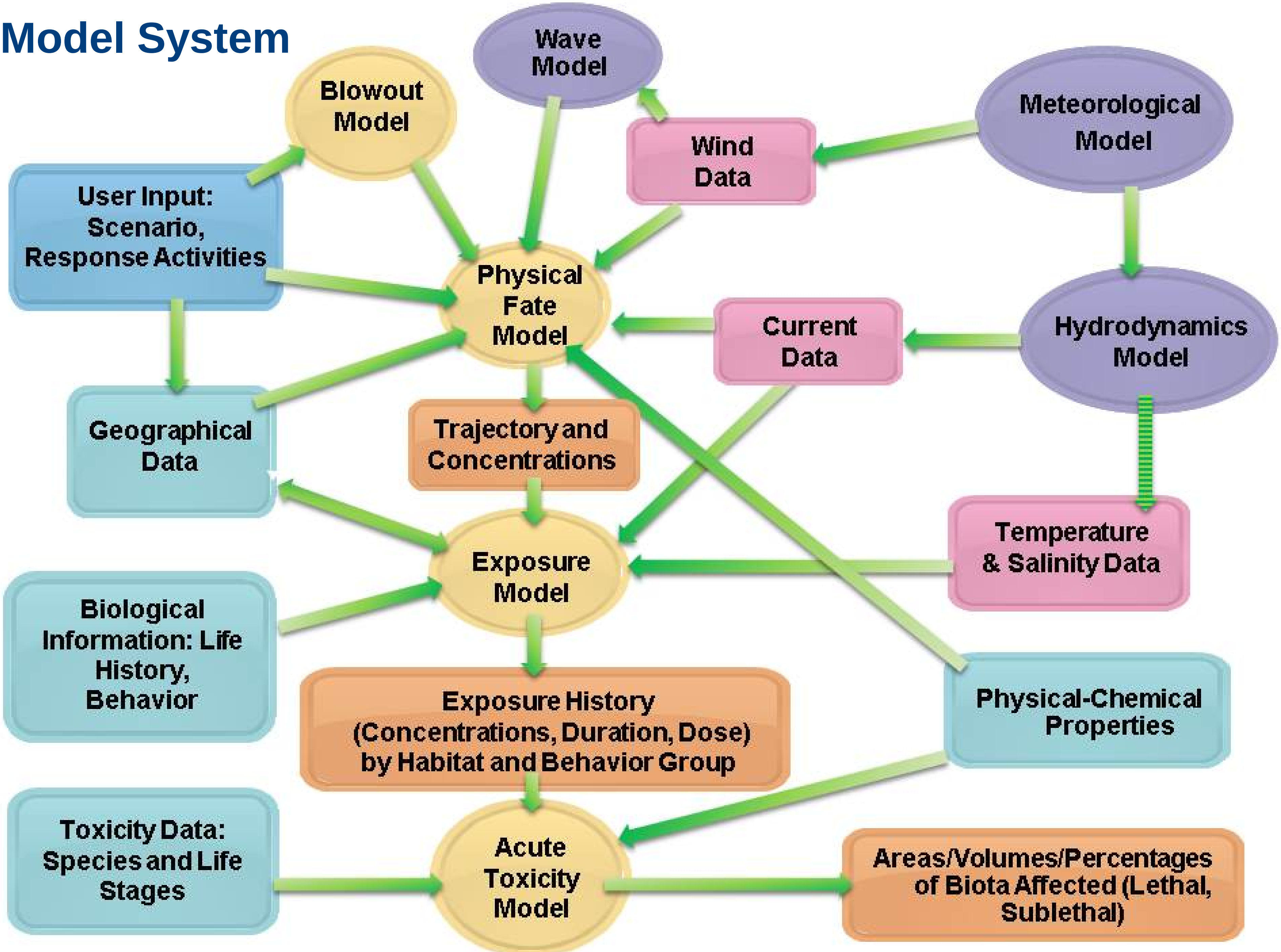
What Questions Do Response Decision-Makers and Managers Have?

- During a spill
  - Where is the oil going?
  - How soon will it get there?
  - What are the resources at risk?
  - To what degree with resources be exposed?
  - How will the resource exposures change if certain response alternatives are applied?
  - What are the uncertainties?
- Spill planning
  - What is the probability that oil will reach various locations and affect resources?
  - How will the resource exposures and impacts change if certain response alternatives are applied?
  - What are the uncertainties?

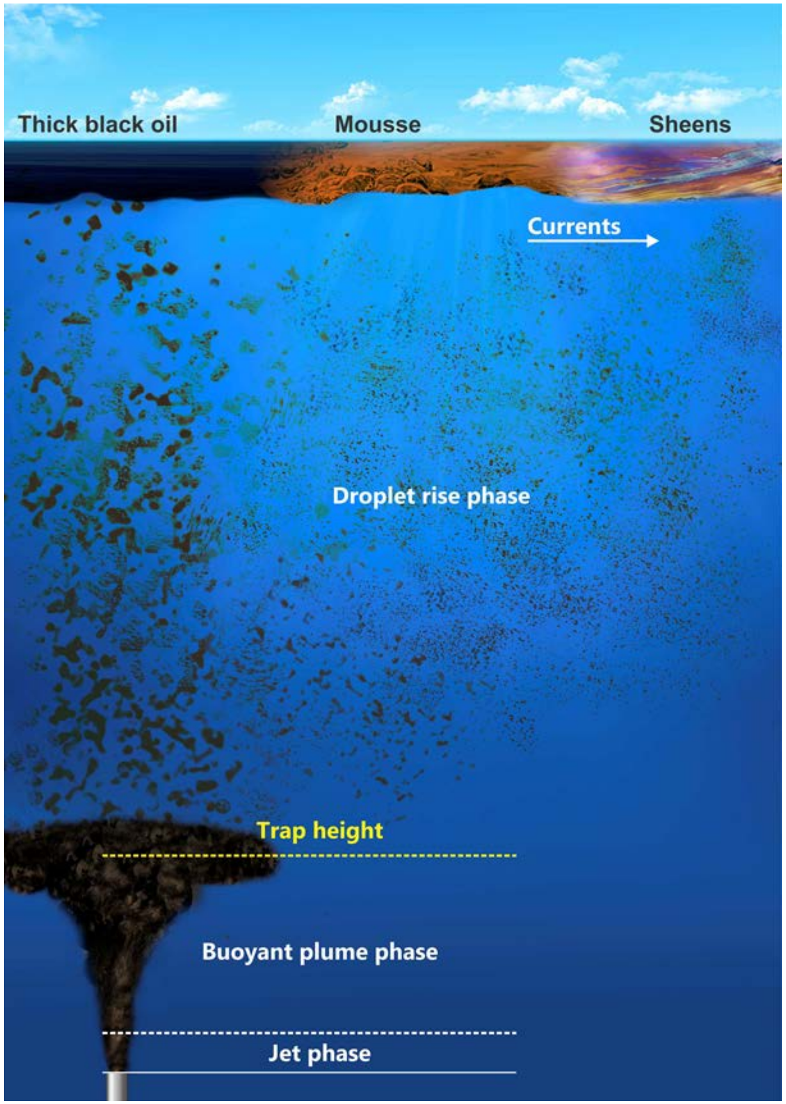
How Modeling is Used to Inform Response

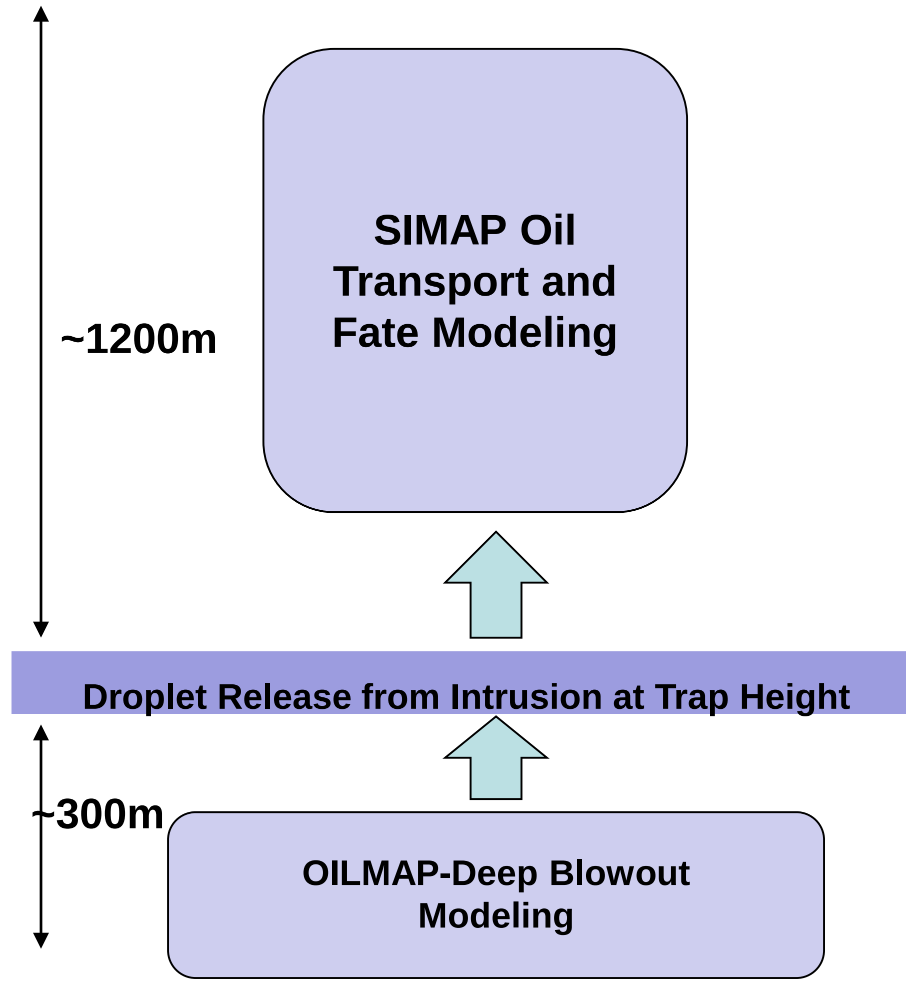
- Real-time spill forecasting with uncertainty analysis
  - Most important: Transport
    - Winds
    - Currents
- Model Development
- Studies Supporting Response Decision-Making
  - Oil spill risk assessments and contingency planning
  - Net Environmental Benefit Analysis (NEBA) and Comparative Risk Assessment (CRA)
    - Dispersant use
    - Tradeoff analysis

Model System



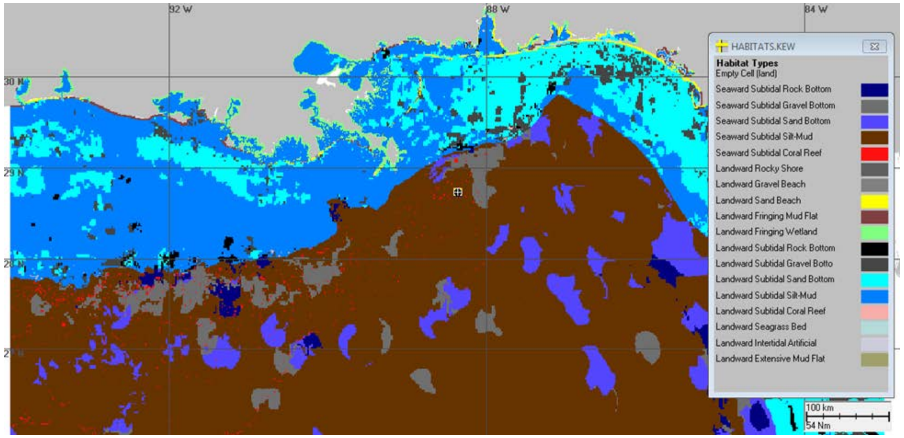
Modeling of the Near-field Blowout and Far-field Phases of an Oil and Gas Blowout



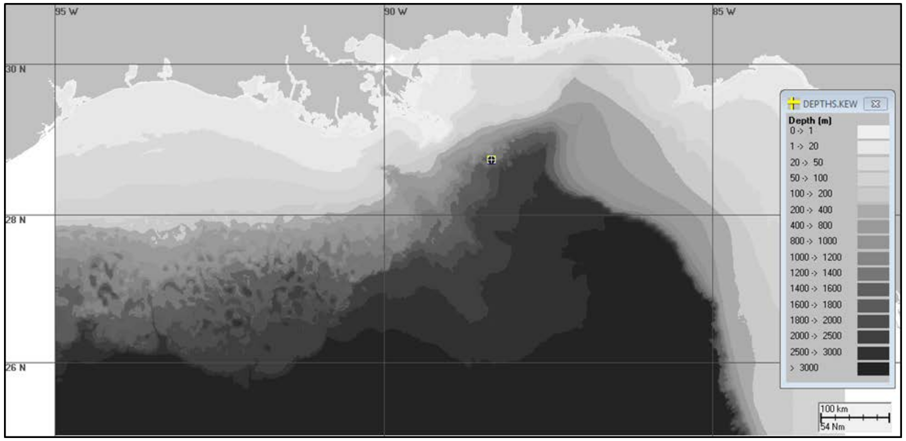


Physical Fate and Exposure Modeling SIMAP: Approach & Discretization

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



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



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17 Volatile Components of Oil Modeled Separately

C-C-C-C-C-C

Aliphatics:

- Alkanes – C12-C23 – volatile, negligible solubility
- Alkanes ≤ C12 & Cyclics – volatile & soluble

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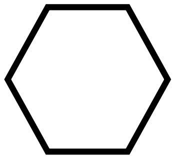
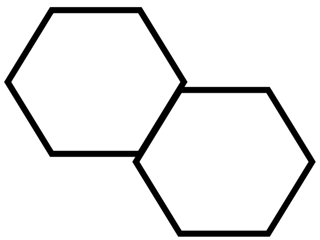


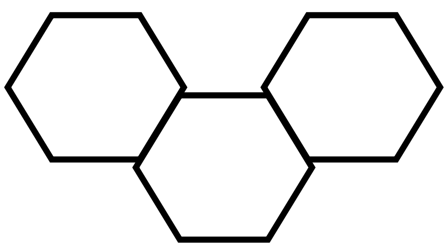
Monoaromatic Hydrocarbons (MAHs)

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

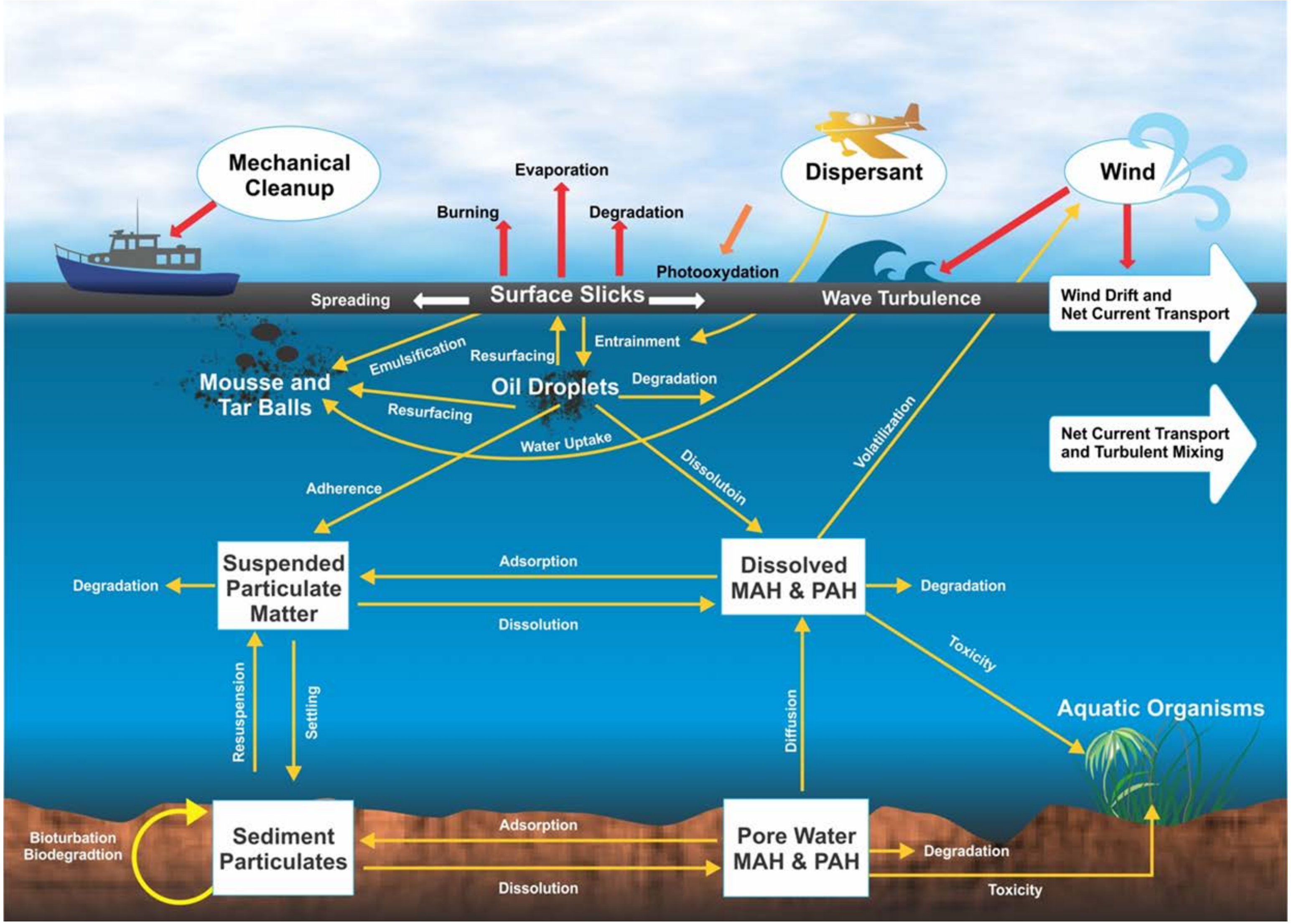


Polynuclear Aromatic Hydrocarbons (PAHs)

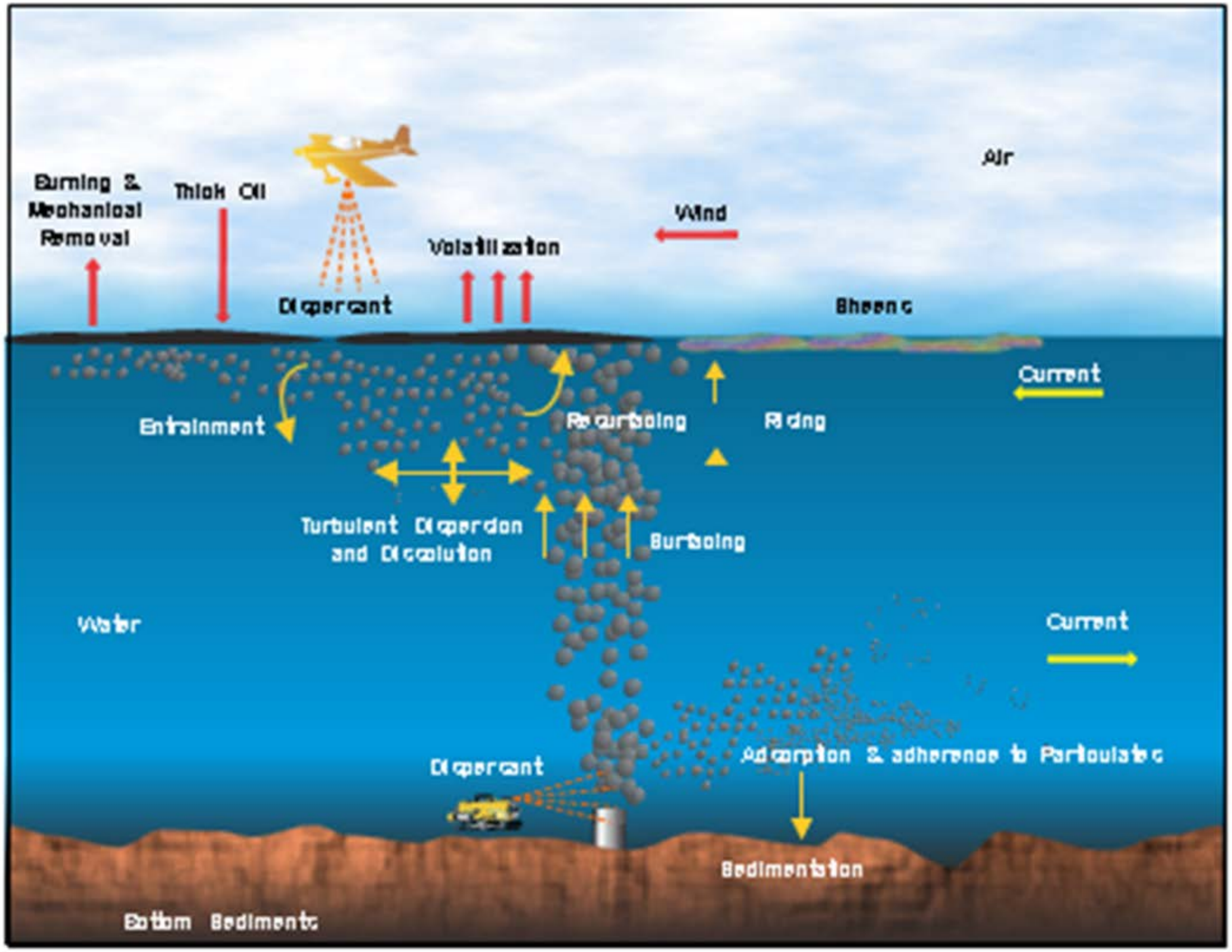
- Naphthalenes (2-ring PAHs)
  - soluble, less volatile, more toxic
  - with more alkyl chains, less soluble but more toxic
- 3 ring PAHs – semi-soluble, most toxic fractions
  - Phenanthrenes
  - Fluorenes
  - Dibenzothiophenes
- 4-ring PAHs – fluoranthenes, pyrenes, chrysenes
- larger PAHs insoluble



SIMAP Oil Fate Processes in Open Water



Important Processes for Oil Fate



SIMAP Model Validation

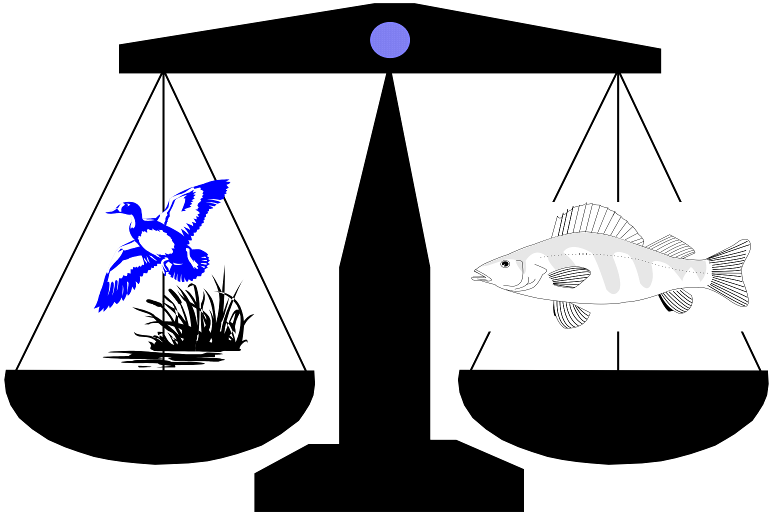
- Developed over 3 decades, several peer reviews, validation studies
- Derived from CERCLA Type A model (French et al. 1996); also referred to in OPA 90 NRDA regulations
- *Exxon Valdez* Oil Spill (French McCay 2004)
- *North Cape* Oil Spill (French McCay 2003)
- 20 spills (French McCay and Rowe, 2004)
- Test spills designed to verify algorithms (French and Rines 1997; French et al. 1997; Payne et al. 2007; French McCay et al. 2007)
- Deepwater Horizon (DWH) oil spill in support of the Natural Resource Damage Assessment (NRDA) – NOAA (Spaulding et al. 2015; French McCay et al. 2015, 2016) and as part of validation study for BOEM risk assessment project (French McCay et al., 2018a,b,c)

Potential Impacts and Tradeoffs of Effective Dispersant Use on Oil Spills

Application of dispersants

- Reduces impacts from surface floating oil
  - on birds and other wildlife
  - on shorelines

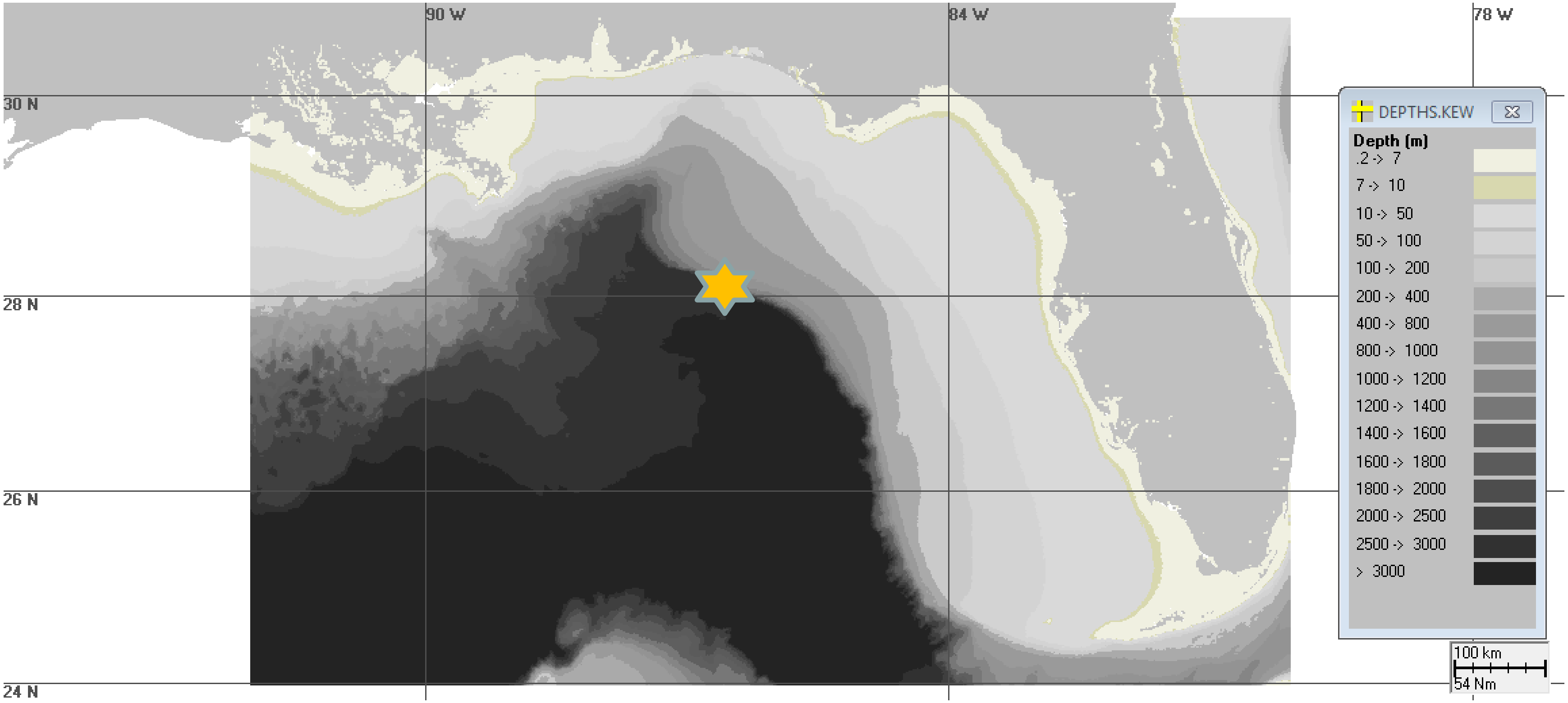
- However, dispersant use is a trade-off with increased risks to fish and invertebrates in the water column.



Comparative Risk Assessment (CRA): Oil Fate and Exposure from a Deep Sea Blowout, With and Without Subsea Dispersant Injection Treatment

Oil Release Rate	45,000 bbl/day
Release Duration	21 days
Release Depth	1400 m
Crude oil density	API = 34.2

- Currents – Naval Research Lab HYCOM
- Winds – NOAA NCEP CFSR hourly

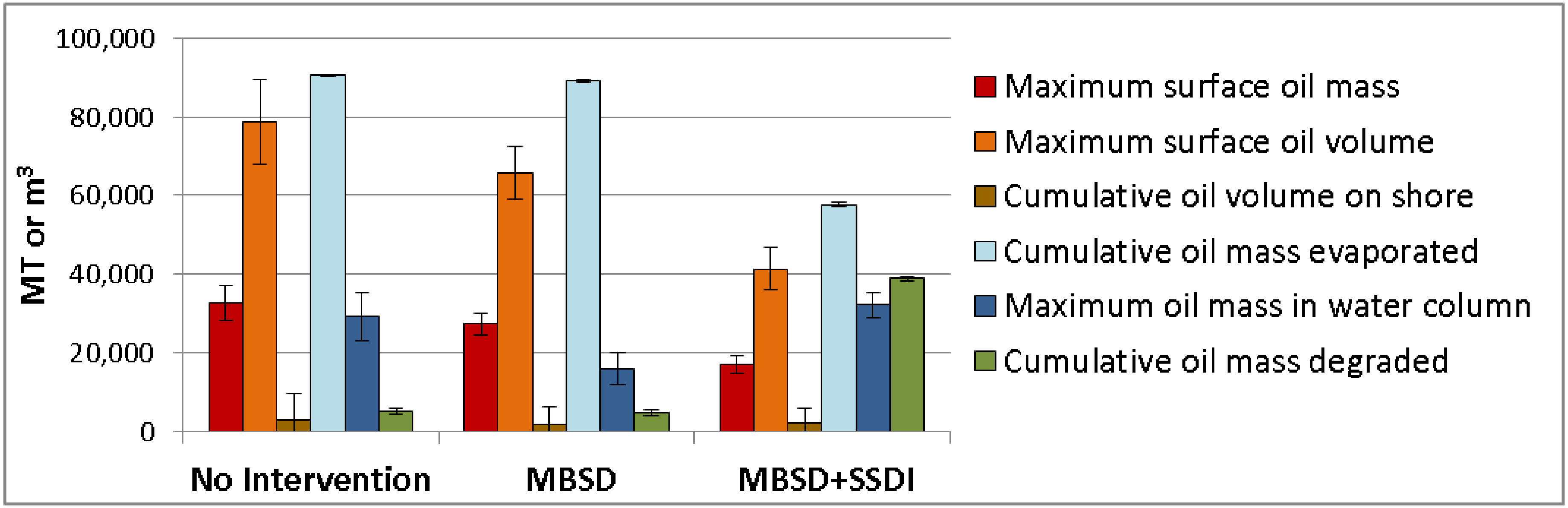


Results of CRA Study

Summary of Exposure Metrics for 100 Model Runs, Randomizing Start Date and Time

MBSD = Mechanical + Burning + Surface Dispersant
SSDI = Subsea Dispersant Injection

Mean (Coefficient of Variation = SD/Mean)
Due to Environmental Conditions



Conclusions of CRA Study

The Model-Predictions Show

- **Mechanical and *in situ* burning only removed a small fraction of the oil that would otherwise have been floating or evaporate.**
- **SSDI has the potential to substantially**
  - **Reduce the amount of oil and mousse on the water surface and on the shoreline**
  - **Increase dissolution rate of soluble & semi-soluble hydrocarbons (BTEX, PAHs and soluble alkanes) and so their degradation rate**
  - **Increase weathering rate of rising oil such that floating oil contains much less soluble & semi-soluble aromatics (BTEX, PAHs)**
  - **Decrease VOC emissions to and concentrations in the atmosphere and human and wildlife exposure**
  - **Reduce the concentrations of PAHs in surface waters**
  - **Increase the concentrations of PAHs in deep water; however, densities of biota are << than near surface**

Risk Assessment for BOEM – Implications of Response Alternatives for Deepwater Blowouts

Spill Scenario

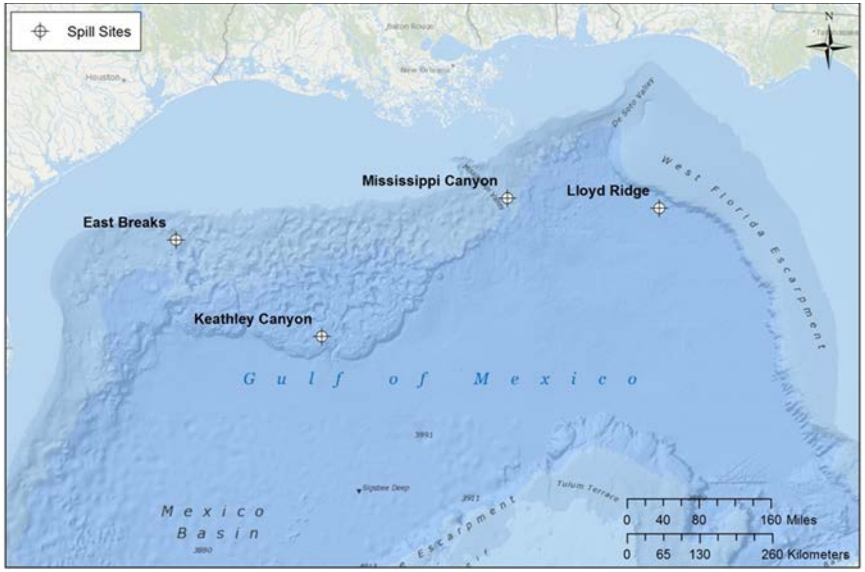
- 45,000 bbl/day over 30 days decreasing by 113.1 bbl/day
- Total Release = 1,300,802 bbl
- Simulation Length = 75 days

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

Results

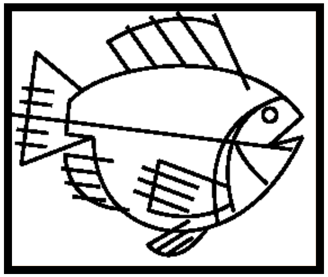
- Surface area swept by floating oil decreased by use of dispersants
- Increased potential exposure in deep water



Physical Parameters	Mars TLP 2004	Ship Shoal Block 269
Oil Type	Medium	Light
Pour Point (°C)	-28°	-42°
API Gravity	26.8	38.7
Density at 25°C (g/cm^3)	0.8817	0.8236
Viscosity (cP) @ 25°C	24	4

Oil Spill Risks: Surface Spills

- Used oil fate and biological exposure modeling (SIMAP) to quantify exposure areas/volumes
- Evaluated a Range of Oil Types, Spill Volumes, Environmental Conditions, Timing of & Fraction Dispersed
- Results: Area and Volume Indices
  - Surface area swept by floating oil > threshold for potential effects
  - Water volume adversely affected by dispersed oil and dissolved hydrocarbons



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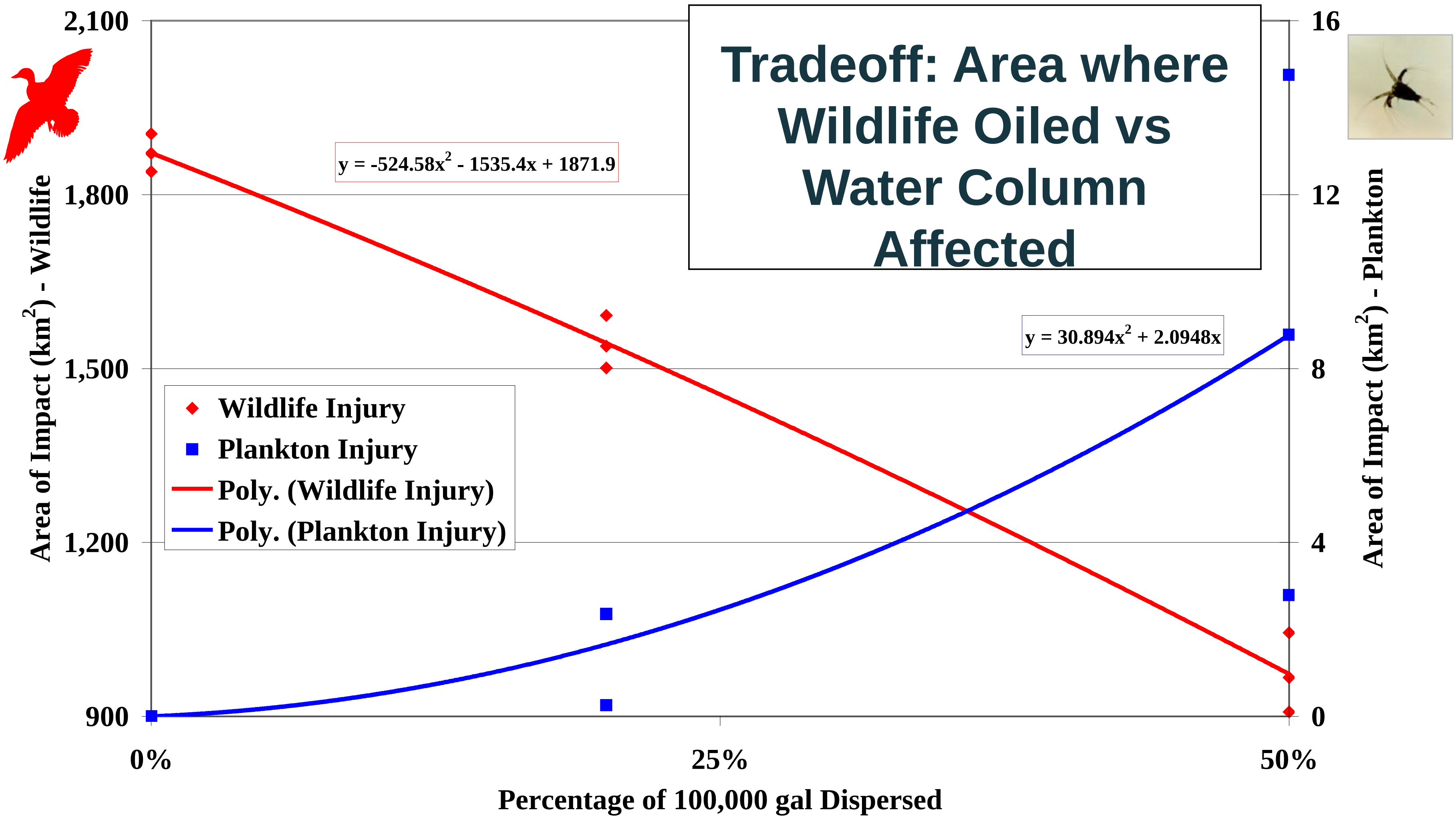
Injury Trade-Offs: Effect of Dispersant Applied after 12 hrs of Weathering
ANS Crude (Mid-Heavy), 5 kt Wind, 25°C, LC50 = 5 pppb



Wildlife Area >100 X Water Column (Mixed Layer)

Communication is Important!

- How can industry/academia/business partnerships contribute to improved response to future spills?
  - Ask the responders, who need to make timely decisions: What do you think are the research needs?
  - Cooperative research projects between academic researchers and practitioners
  - Improved communications, e.g., workshops

Over-arching Questions

- What is the state of the art for oil spill modeling
  - for informing response decision-making?
  - For risk assessments?
- What research is needed to improve the model algorithms?
- What are the most important inputs for oil spill modeling with respect to informing response decisions? What inputs generate the most uncertainty?
- How well can these important/uncertain inputs be measured/quantified in the time frame needed for response decision-making?
- What research is needed to improve the model algorithms for informing understanding oil transport, fate, exposure and impacts? [Needed for risk assessments, on a longer time scale than the response needs.]