Investigation of the Fate of Dispersed Oil in Aquatic Systems

James Bonner
Michael Sterling
Cheryl Page
Chris Fuller

Texas A&M University
College Station, TX, USA

Early Oil Spill Research

- Emphasized fundamental “basic” science and hypothesis testing
- Advocated surface science principles “colloidal” applied to oil spill research
- His work led to other investigators winning Nobel Prize
- Advocated *in situ* oil spill monitoring to gain insight to behavior and understanding
- Advocated Intentional Release of Oil & Scaled experiments
- Could not get a U.S. permit, so conducted research in England

Ben Franklin -- 1st U. S. Oil Spill Researcher

Presentation Objectives

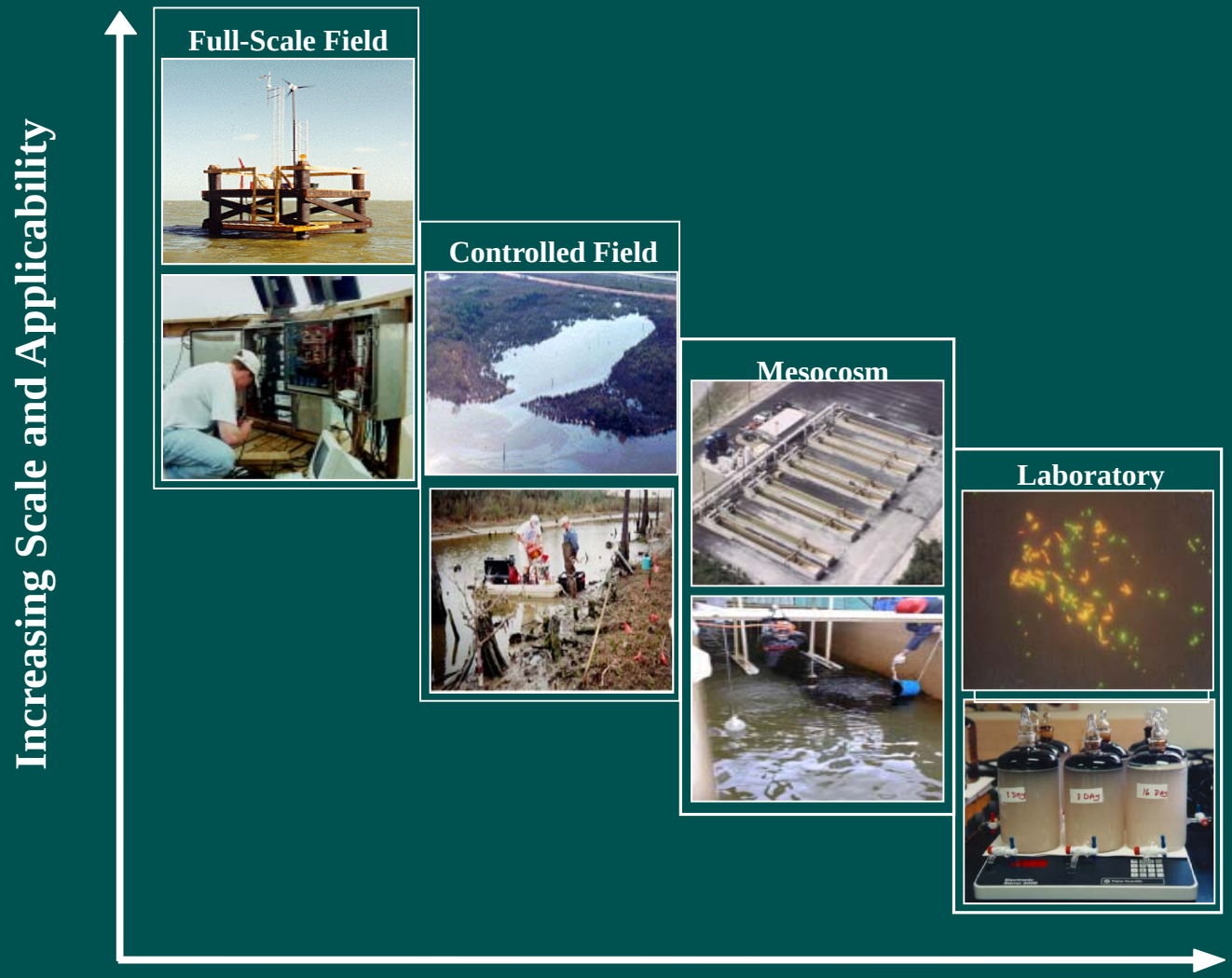
Discussion points & results involving:

- **experiments with crude oil dispersions at multiple scales including laboratory, mesocosm, controlled field and full field scale;**
- **‘scaling’ as a primary experimental design criterion;**
- **theoretical hypothesis testing involving mathematical modeling approaches;**
- **Understanding of key environmental processes is critical to the understanding, prediction, and management of dispersed oil fate in aqueous systems.**

PhD Pipeline Project
Historical Overview
(1993-current)

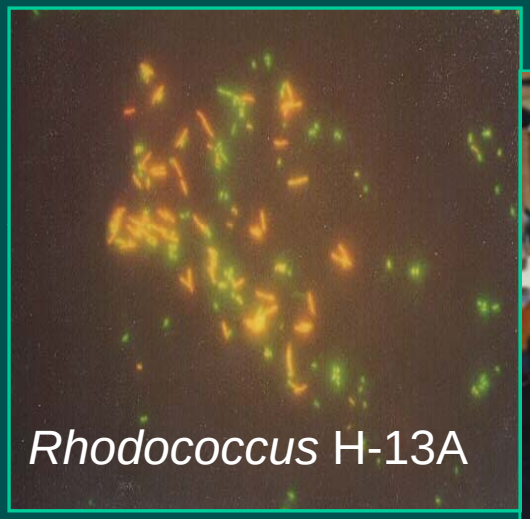
- Funded by Texas General Land Office (TGLO, API, MSRC, NSF, ONR, COE, TCEQ, NYSRF. ExxonMobil, ARO, DOD, DOE, CODAR, FI…….. Others
- Long-term collaboration for better understanding of oil spill remediation technology
- Multi-disciplinary research team

Comprehensive and Fully Integrated Research Program



Laboratory Studies

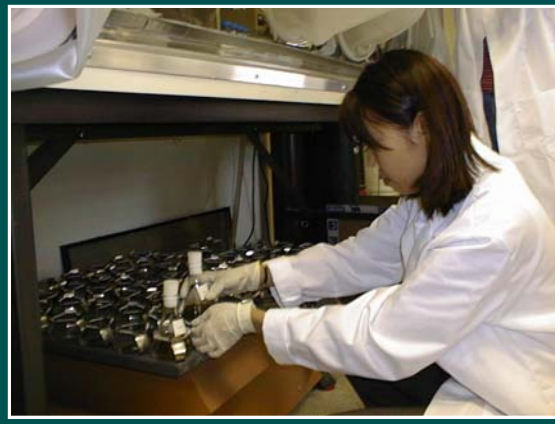
"Solubility" Aqueous phase



Rhodococcus H-13A

Biosurfactants

Biodegradation kinetics



Toxicity Analysis

Dispersed Oil & Naphthalene Toxicity

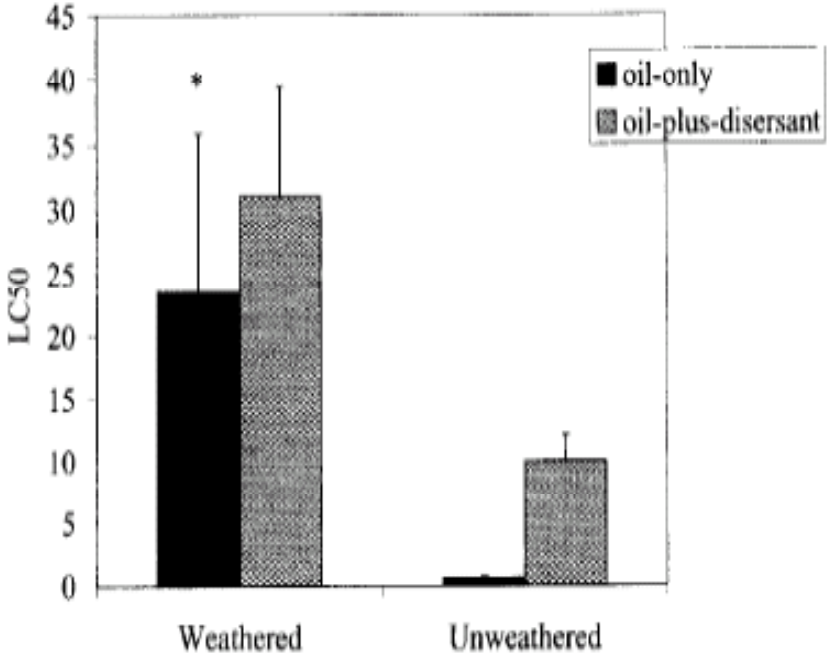


Fig. 2. *Mysidopsis beryllina* declining exposure toxicity results for fresh and weathered crude oil media. Median lethal concentration (LC50) represents the units of mg/L nonvolatile hydrocarbons. * = no-observed-adverse-effects concentration.

***Environmental Toxicology and Chemistry,* 23(12), 2941-2949, 2004.**

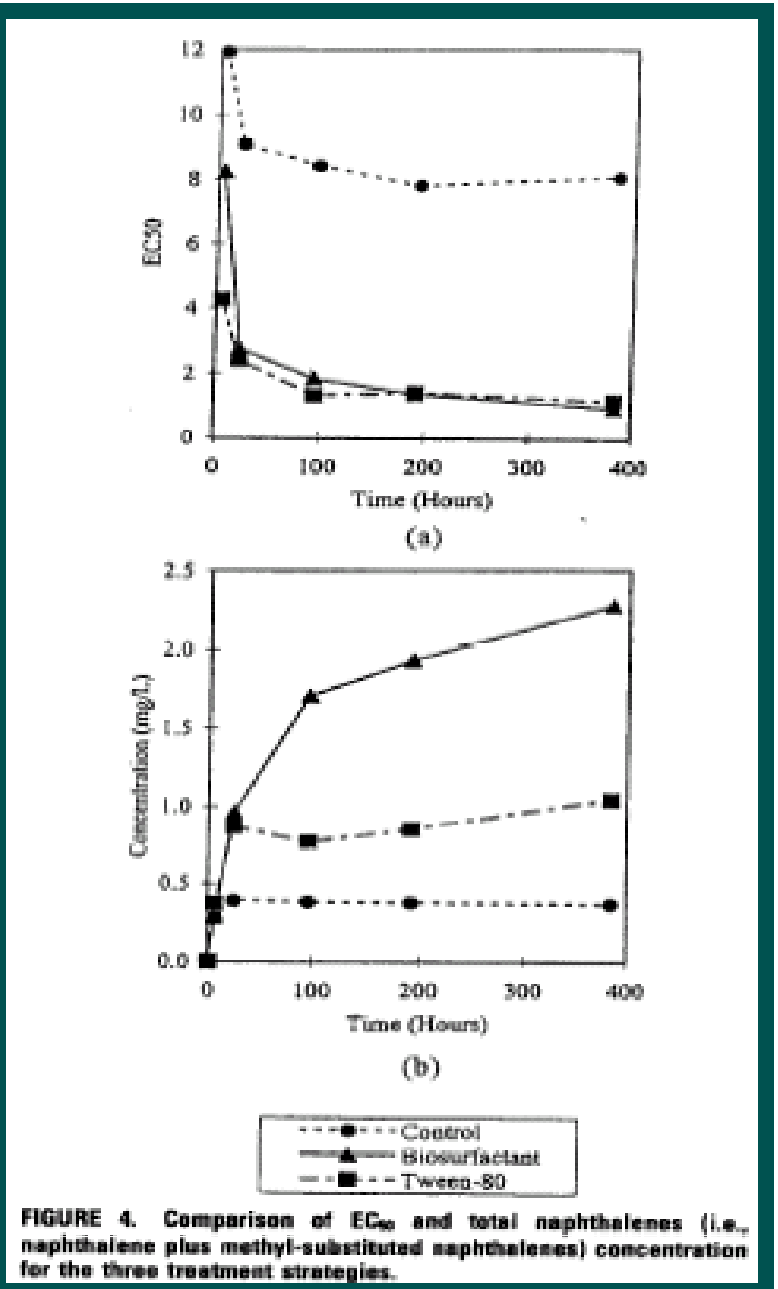


FIGURE 4. Comparison of EC_{50} and total naphthalenes (i.e., naphthalene plus methyl-substituted naphthalenes) concentration for the three treatment strategies.

***Environmental Science & Technology* 31(2), 556-561, 1997**

Biosurfactant-Enhanced Aqueous Concentration of Methyl-Substituted Naphthalene

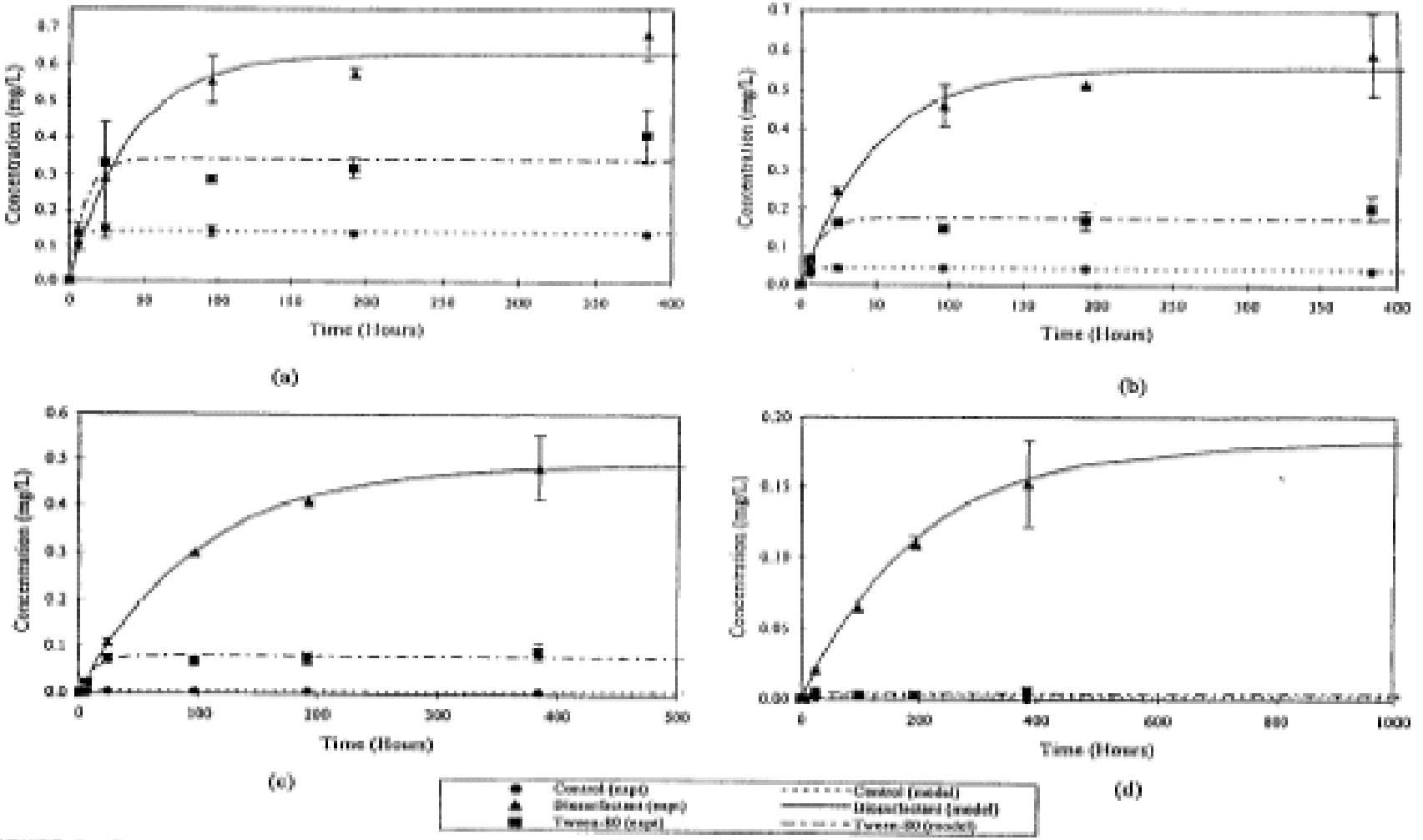


FIGURE 2. Aqueous-plus-micellar phase concentration of (a) C1-naphthalenes, (b) C2-naphthalenes, (c) C3-naphthalenes, and (d) C4-naphthalenes over time, in the absence and presence of surfactants.

Environmental Science & Technology **31(2), 556-561, 1997**

CDO Properties and Aggregation

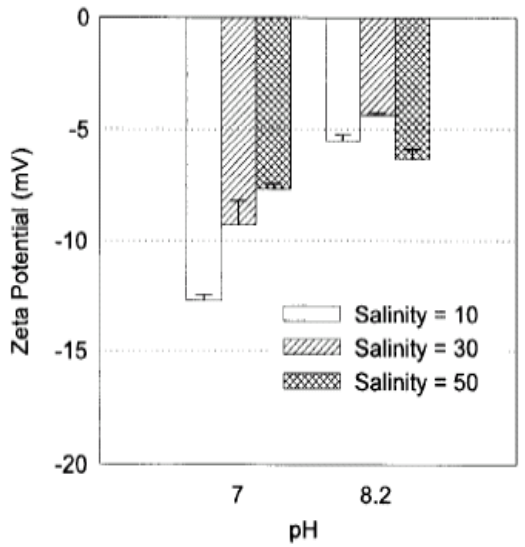


Fig. 1. Measured ζ-potential values of chemically dispersed crude oil droplets at selected pH values.

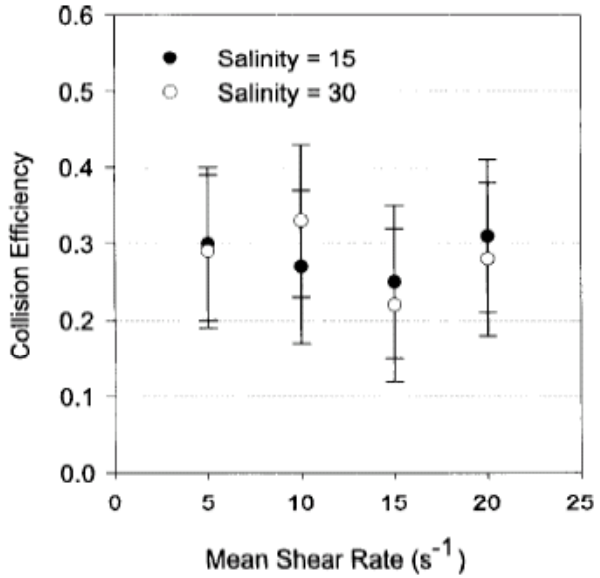


Fig. 2. Effect of shear rate on collision efficiency.

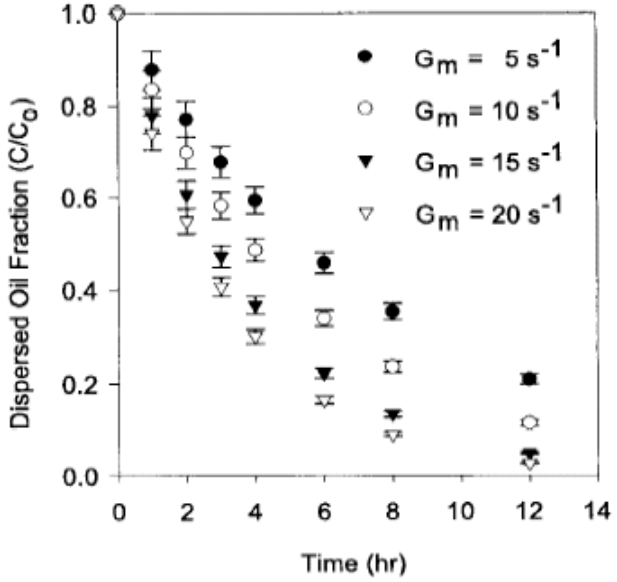
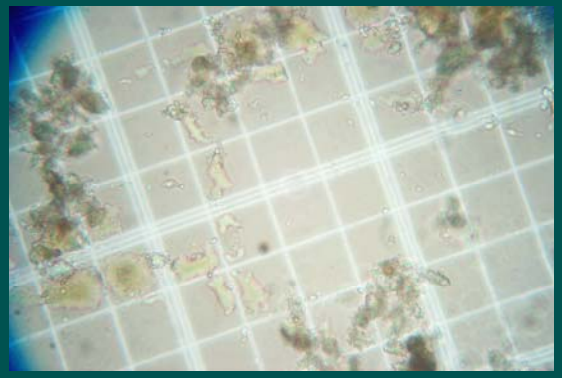
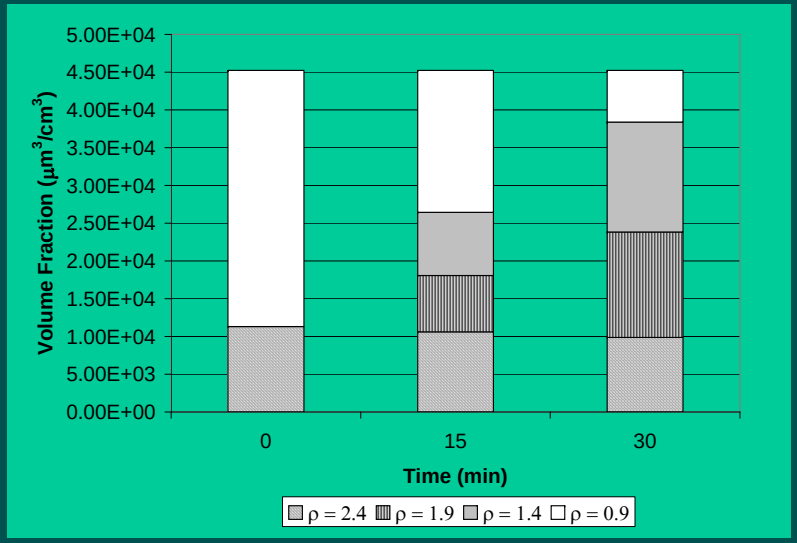


Fig. 3. Effect of shear rate (G_m) on dispersed oil concentration.

CDO Dynamic Size Distribution



Clay-Oil Aggregate Formation over Time
(initial clay-oil ratio 1:3 Gm = 20s-1)



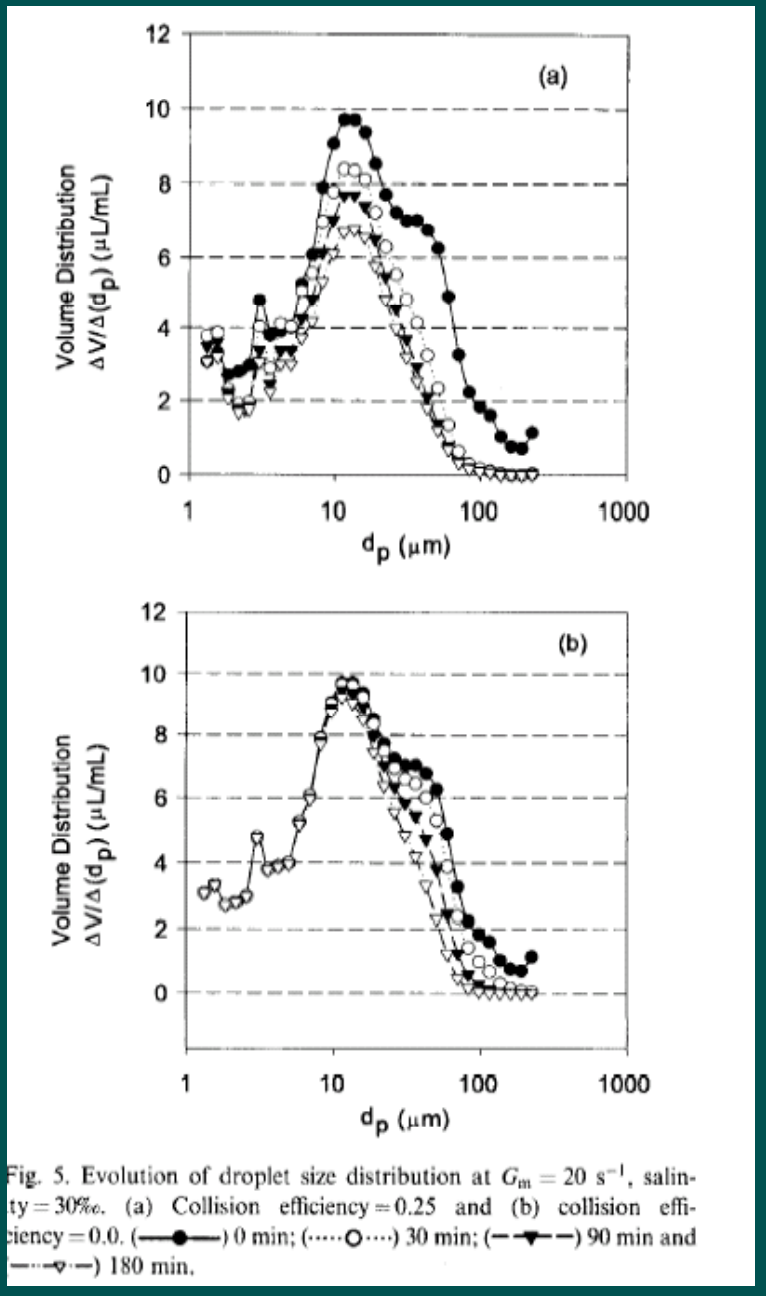
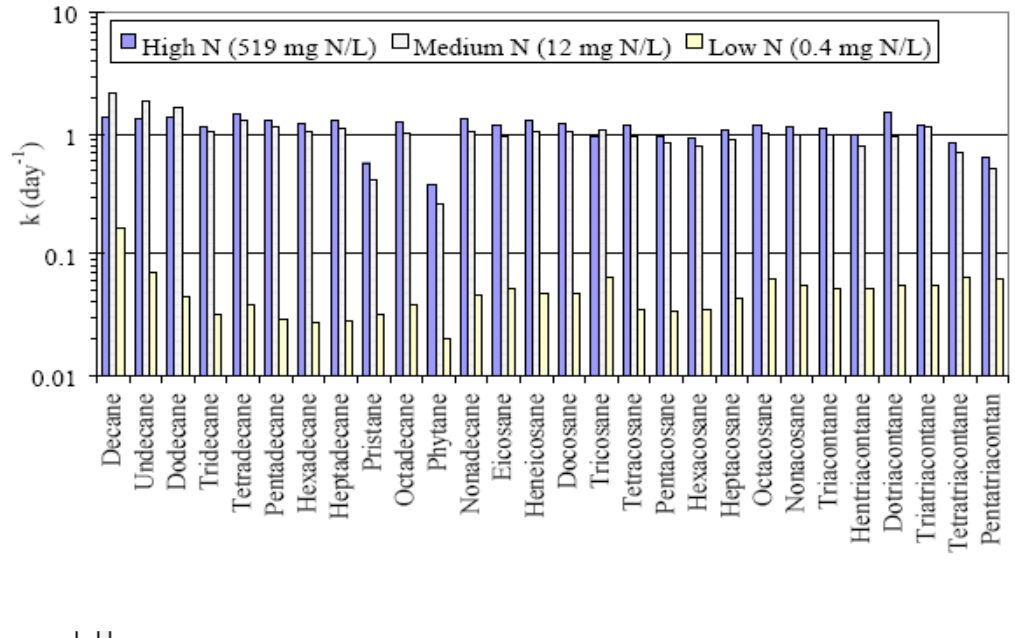
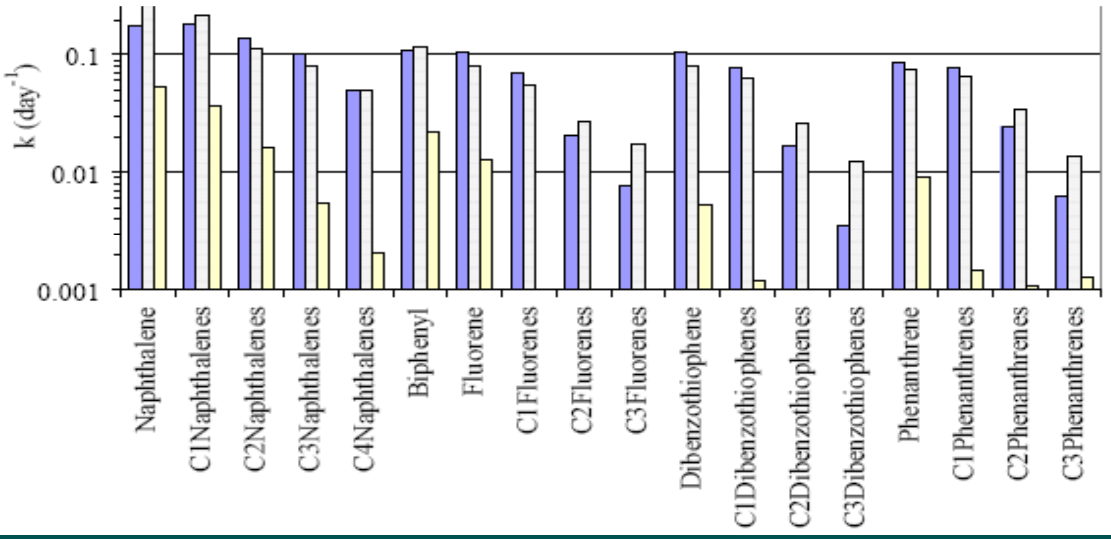


Fig. 5. Evolution of droplet size distribution at $G_m = 20\ s^{-1}$, salinity = 30‰. (a) Collision efficiency = 0.25 and (b) collision efficiency = 0.0. (—●—) 0 min; (·····○·····) 30 min; (— ▼ —) 90 min and (—·▽·—) 180 min.

CDO Biodegradation Rates

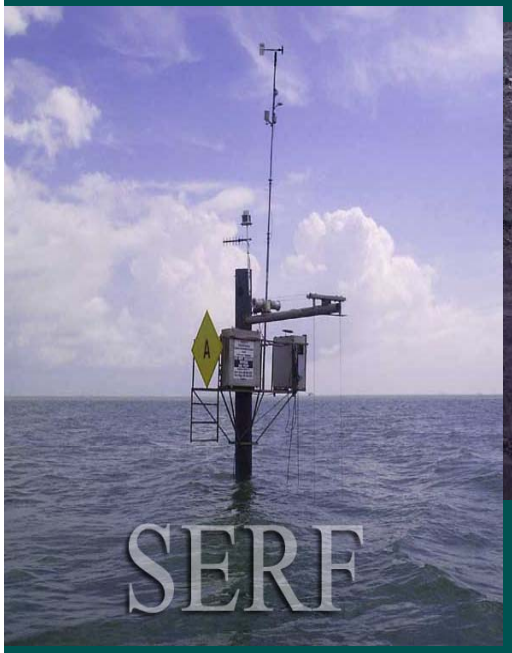


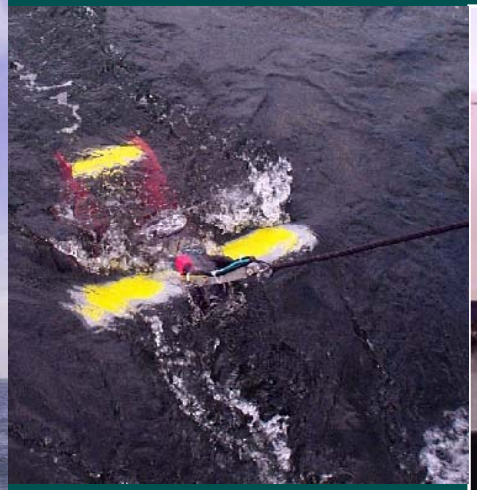
At these Rates in 3 Days 95% Reduction

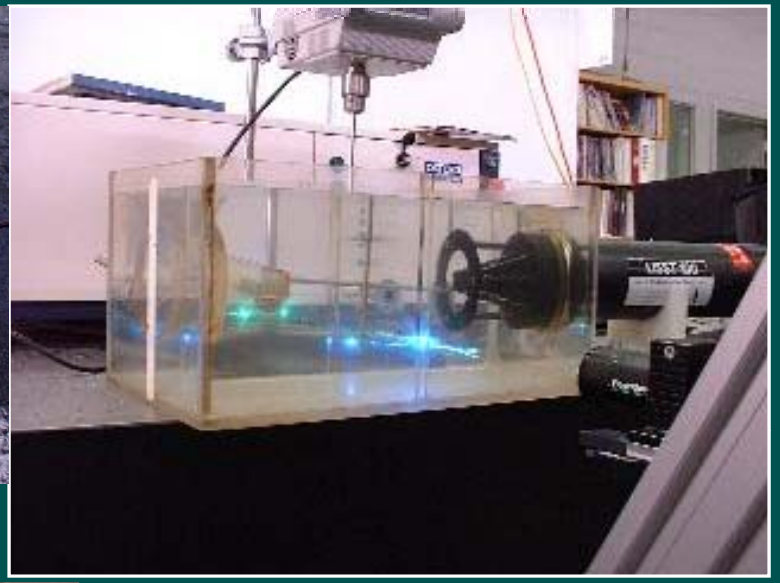


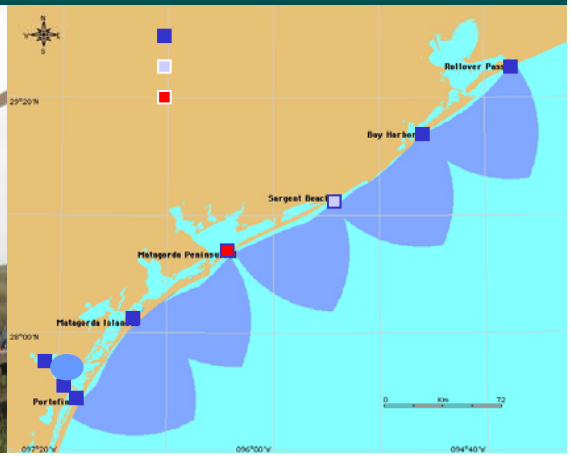
At these Rates in 30 Days 95% Reduction

Real-time *In situ* Sensor Development

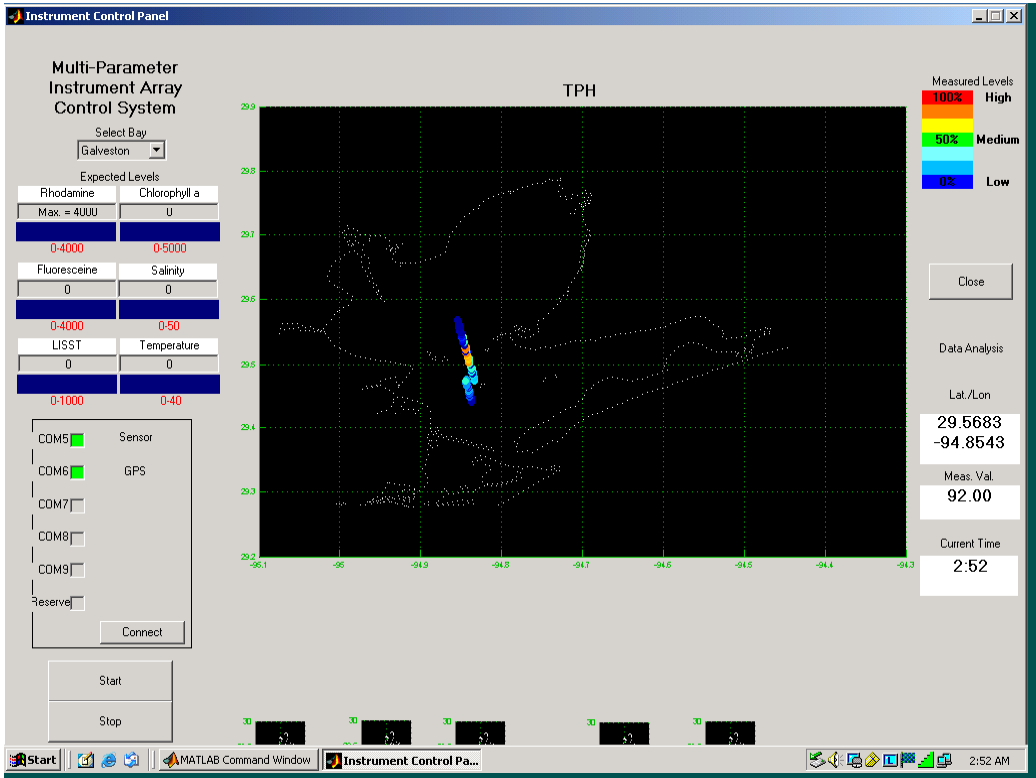


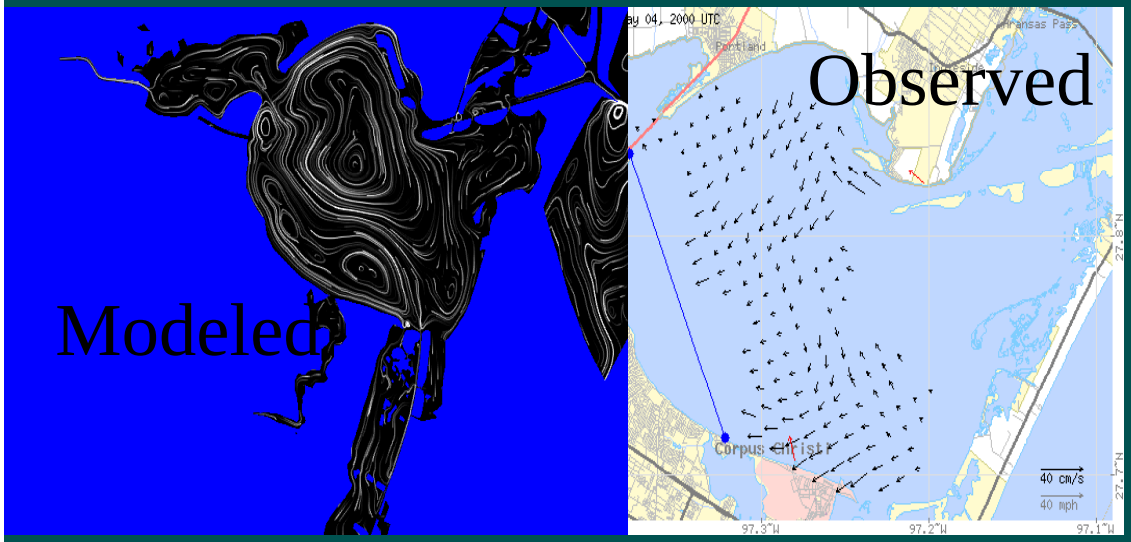


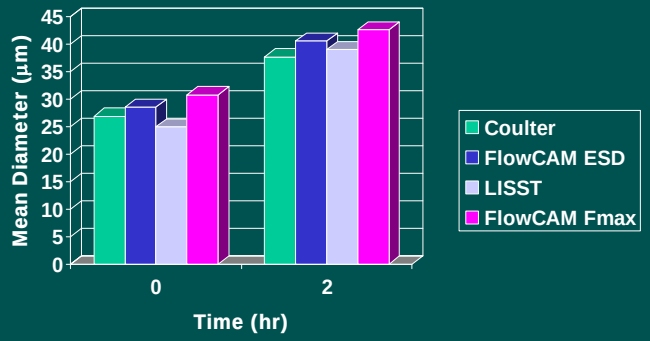




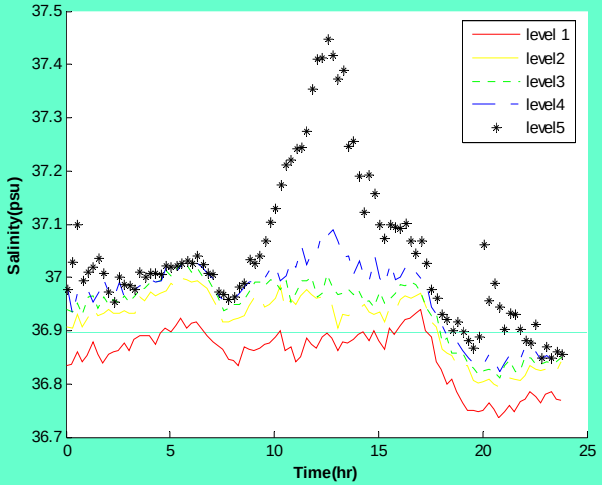
Sensor Results

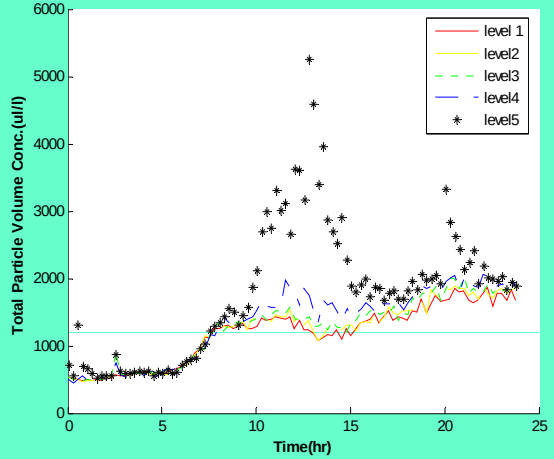


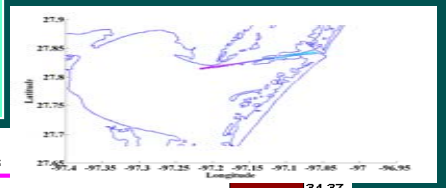


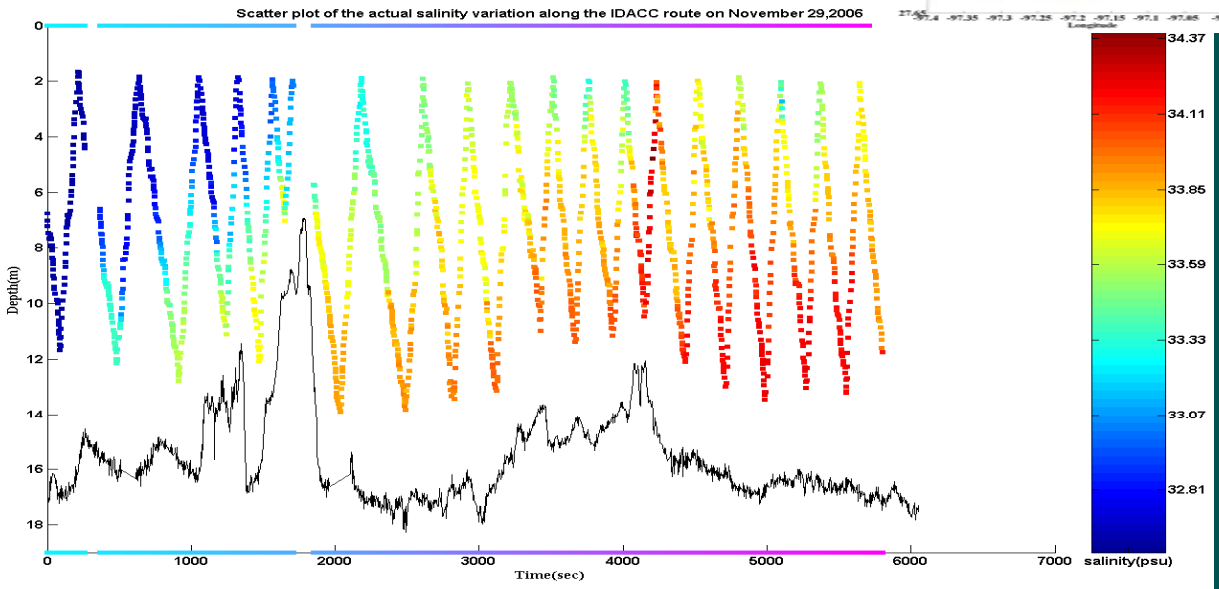


Robotic *In Situ* Sensors Results



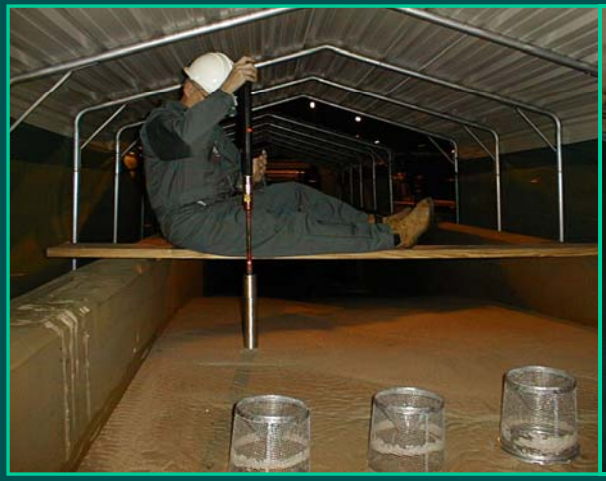






Meso-scale (SERF)

(**S**horeline
Environmental
Research
Facility)



Wave Tank Scaling

- Testbed = Corpus Christi Bay ---- $Fr_{testbed}$
- Model system = SERF wave tank -Fr_{model}
- Scaling factor
  - *Fr=[inertial force]/[gravity force]$^{0.5}$ = V/(g* L)$^{0.5}$*
    where g gravity, L is the wave length, V is the velocity or wave celerity
- Wave length for linear waves
- Wave velocity
- Shear rate
- Power Dissipation

$$L = \frac{gT^2}{2\pi}$$

$$V = \frac{L}{T} = \frac{gT^2}{2\pi T} = \frac{gT}{2\pi}$$

$$G_m = \left(P/V\mu\right)^{0.5}$$

$$P = [\tau o] = G_m^2 V\mu, = E_{area} C_g, = E_{area} C_g (1m_{crestwidth}), \left[\frac{kgm^2}{s^3}\right]$$

SERF: Dispersant Study (toxicity effects)

Crab cages on the beach

Oyster deployment in tanks

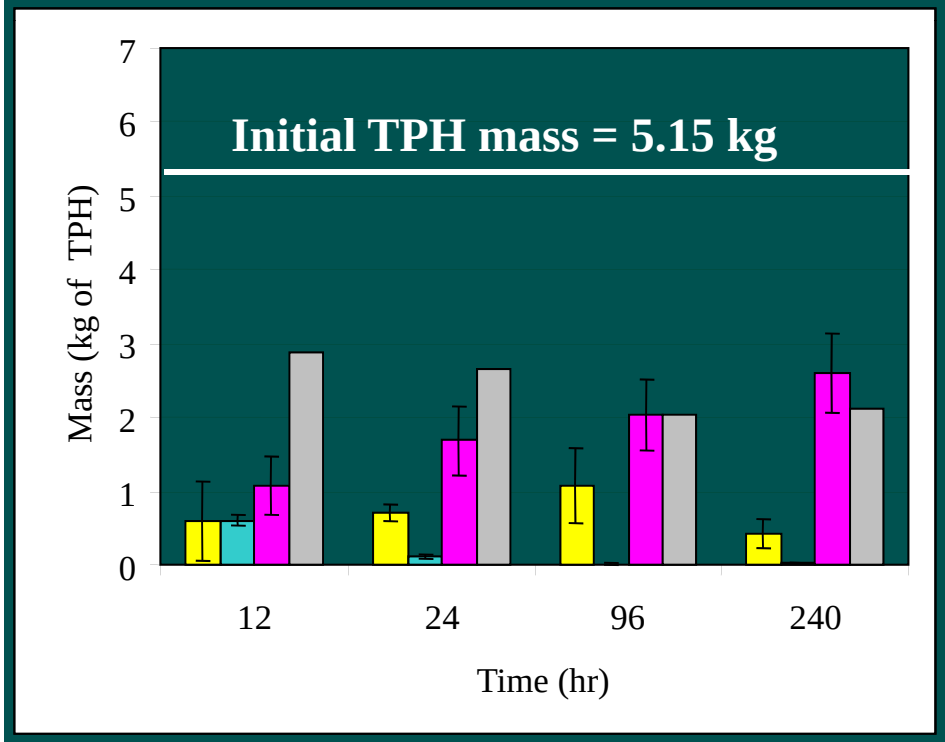
Chamber for Sheepshead Minnow study

Oiled snails on the beach

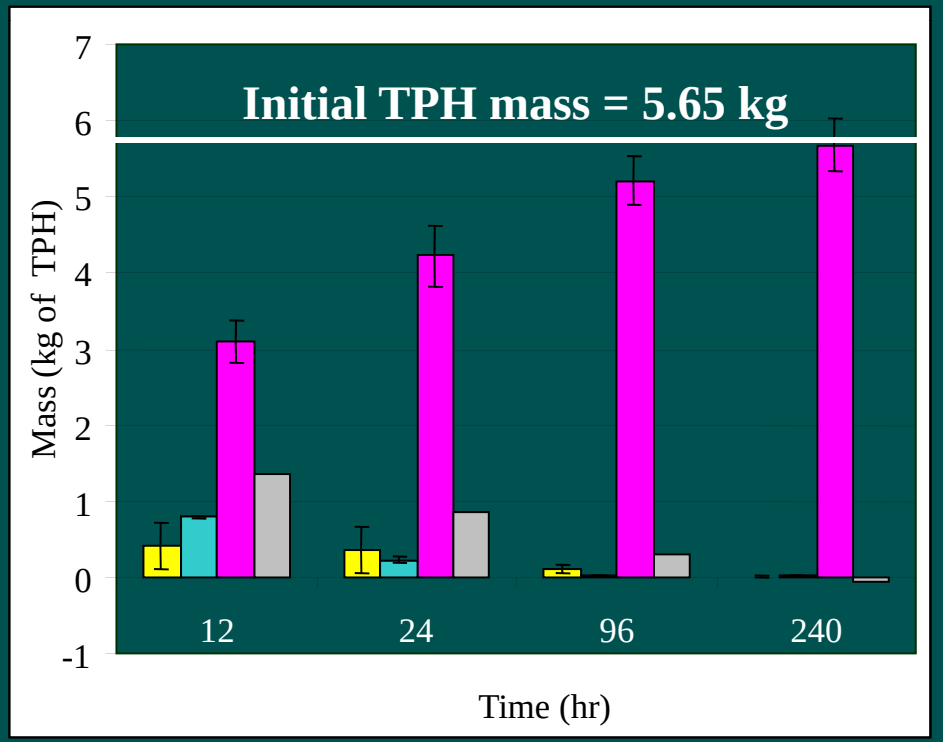
SERF: Dispersant Study (oil mass balance)

***Water Research* 34(9): 2507-2516, 2000**

Oiled Control



CDO



sediment water cumulative effluent Free-phase oil

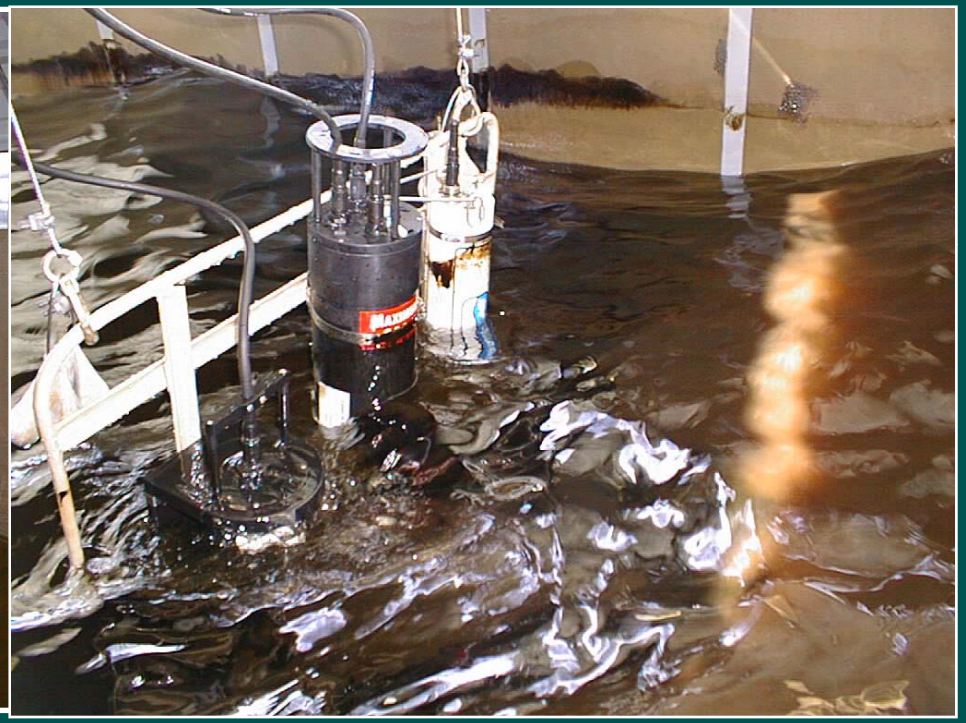
SERF: Dispersant Effectiveness Experiments

Dispersant Application

(calibrated delivery rate)

SERF: Dispersant Effectiveness Experiments

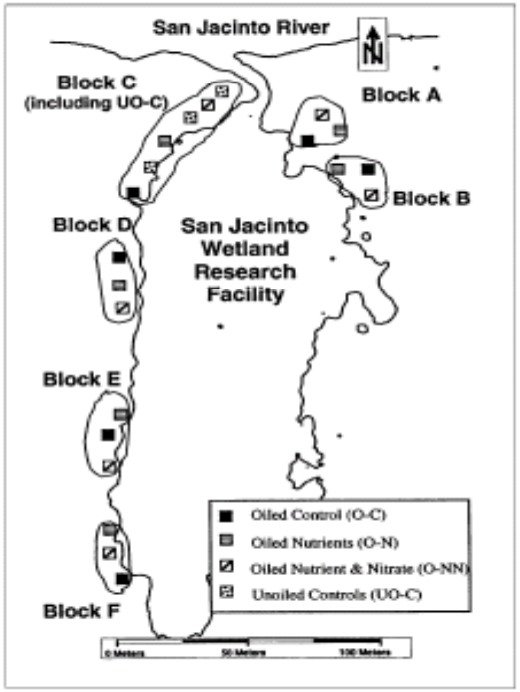
Wave Dissipator



In-Situ sensors

Controlled-Field Studies San Jacinto Wetland Research Facility, (SJWRF)

- Controlled application of oil: to evaluate the behavior and effects of chemically-dispersed oil (CDO) in a wetland setting
- Monitored sediment petroleum chemistry; toxicity; microbial numbers; nutrients…….



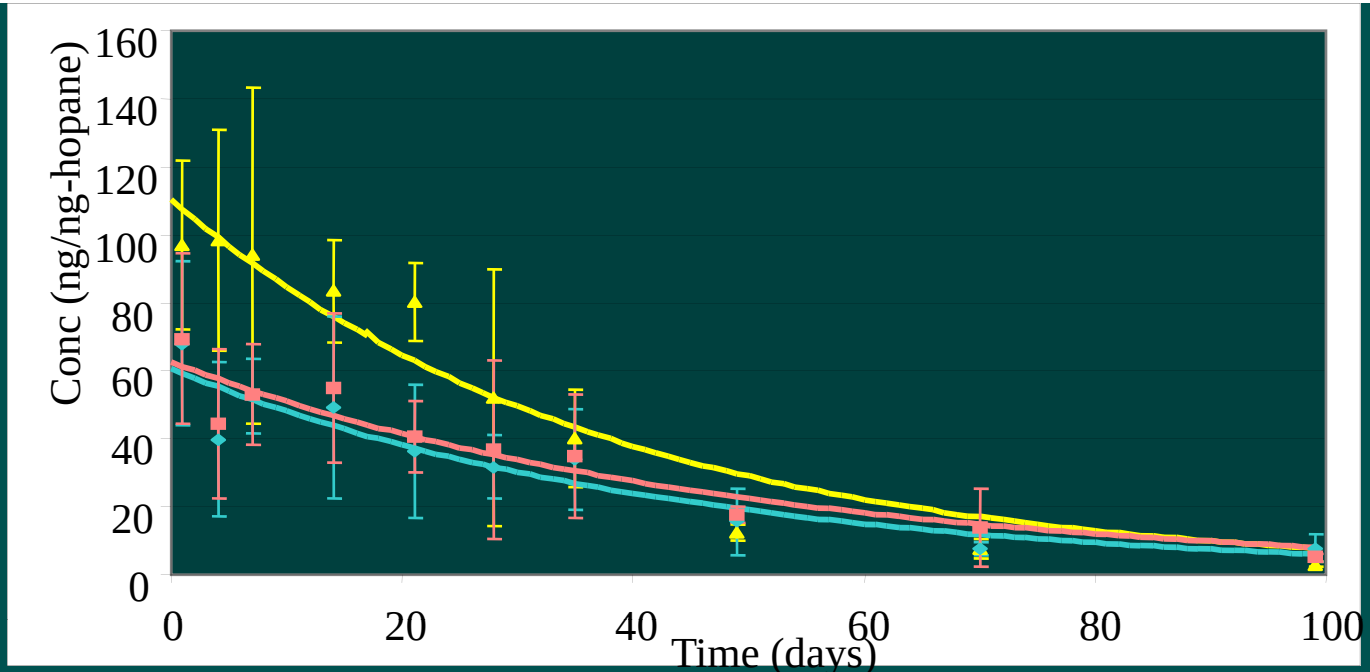
Controlled Application of Oil

Soil sample processing

Soil sampling

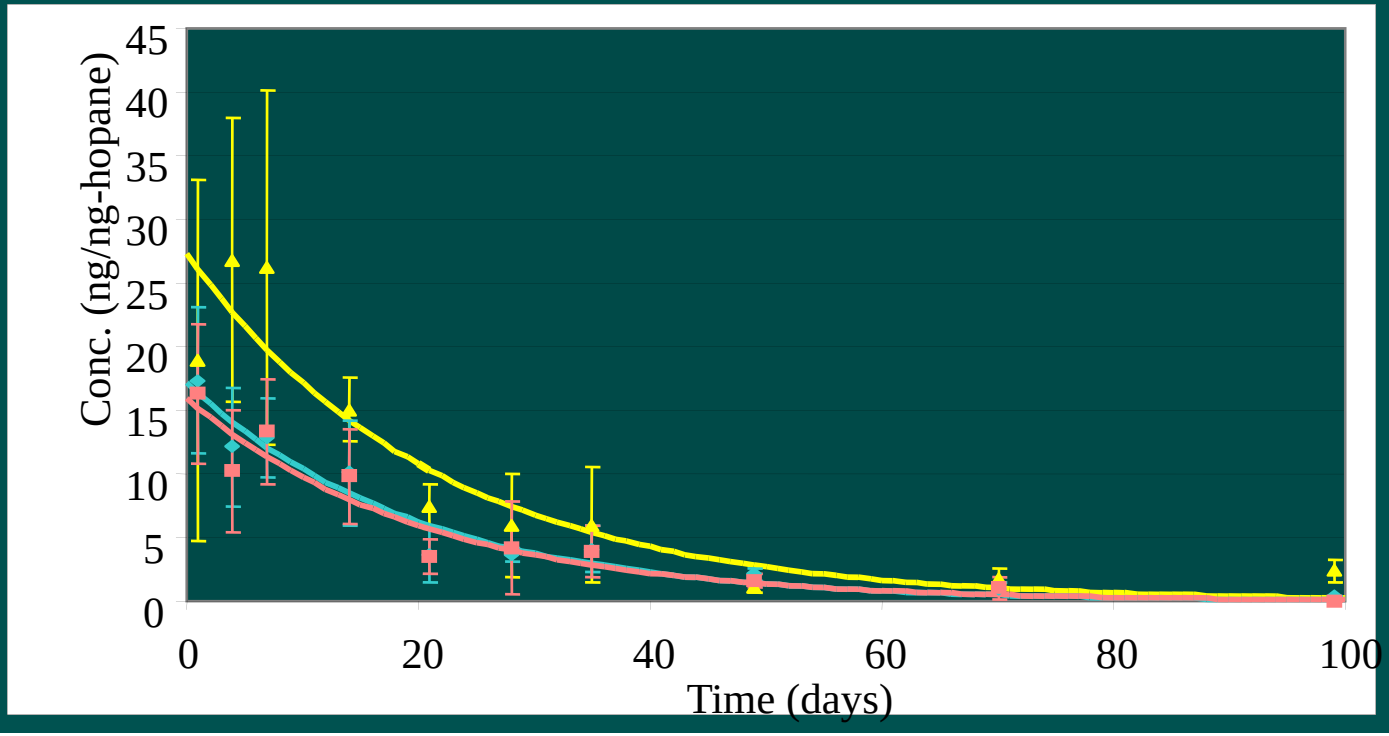
Dispersed Oil in Wetlands

(Total Target Saturates)



Control
Control
High-CDO
High-CDO
Low-CDO
Low-CDO

(Total Target Aromatics)

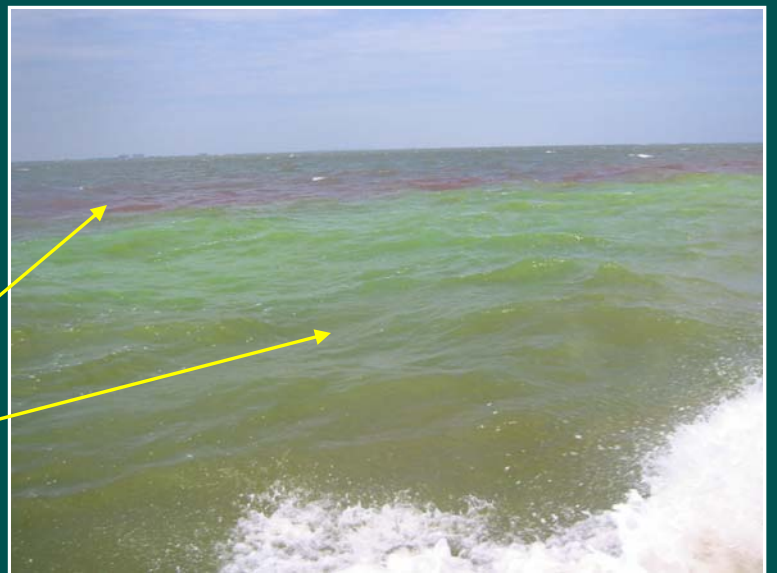


Full-Field Studies:
Texas Coastal Waters

Fluorescein dye

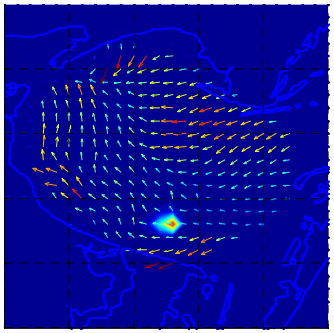
AT 502

Rhodamine dye

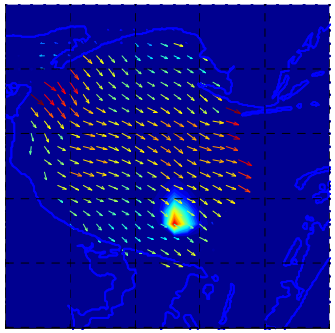


Both dyes apparent

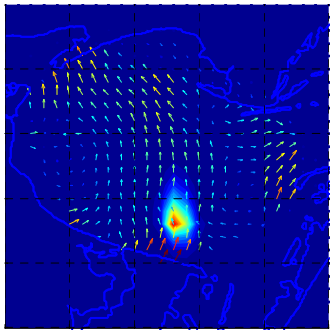
Model Simulation
Results with Passive Tracer (over



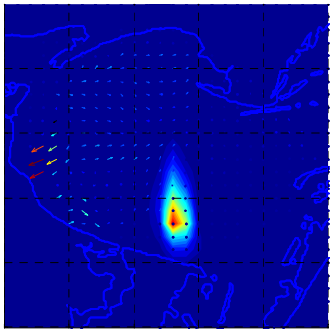
t = 12 hrs



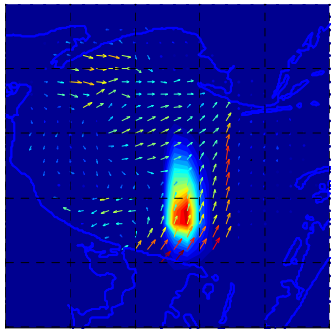
t = 24 hrs



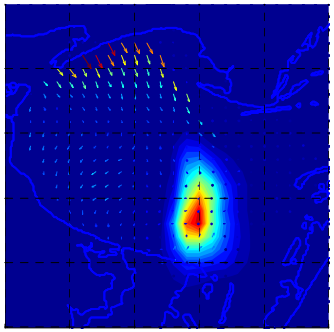
t = 36 hrs



t = 48 hrs



t = 60 hrs



t = 84 hrs

Color scale: from blue to red (0 to 150 cm/s)

Conclusions

- Chemically-dispersed oil
  - Behaves like particle ‘colloid’ (10-100um)
  - Biodegrades
  - Aggregates w/ ambient particles
  - Aggregates w/ oil particles
  - Accumulates Less on surfaces ‘beaches, shorelines, & wetlands
  - Is transported like other environmental particles