The Importance of Mixing Energy on Chemical Dispersant Application

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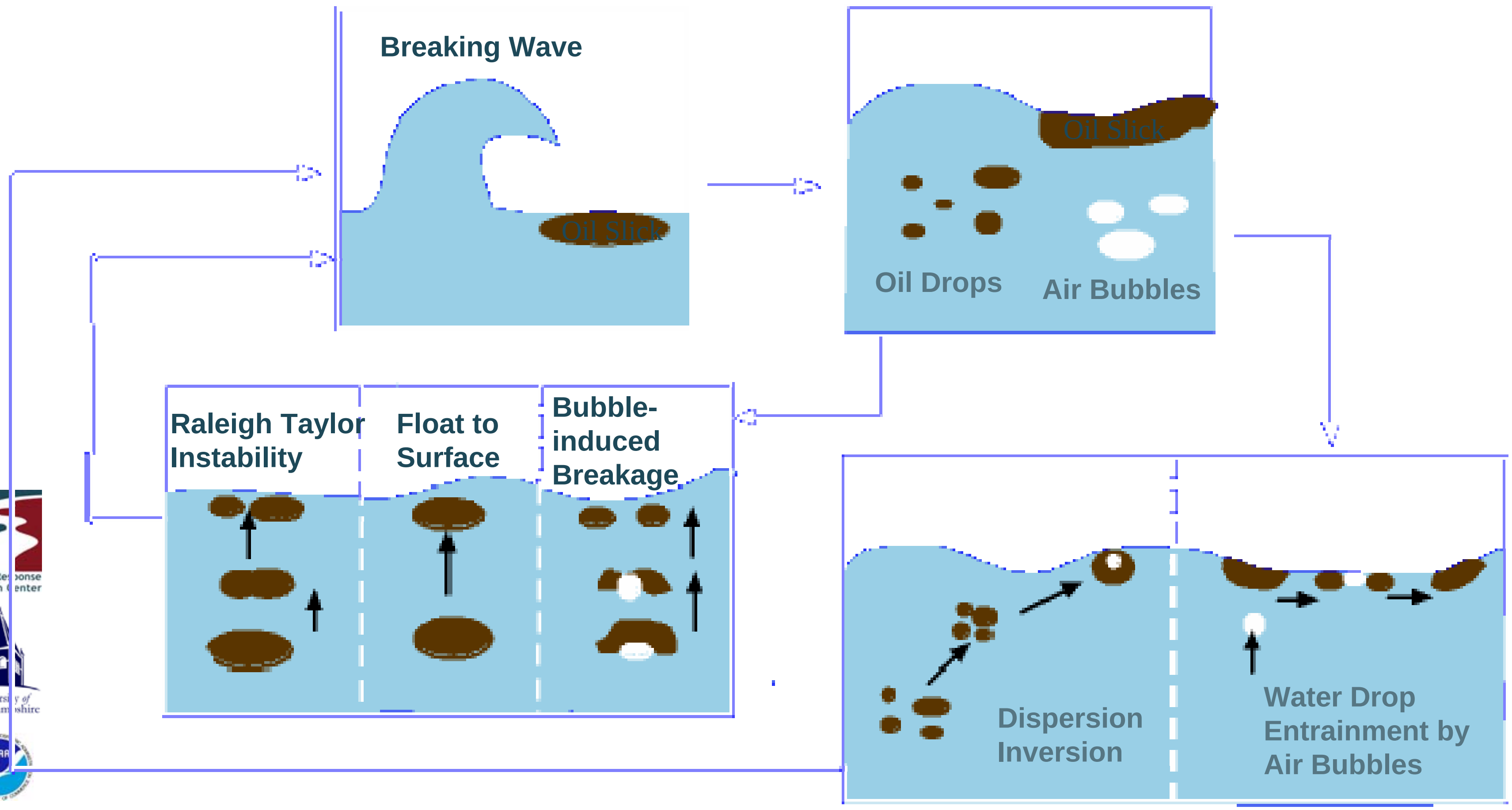
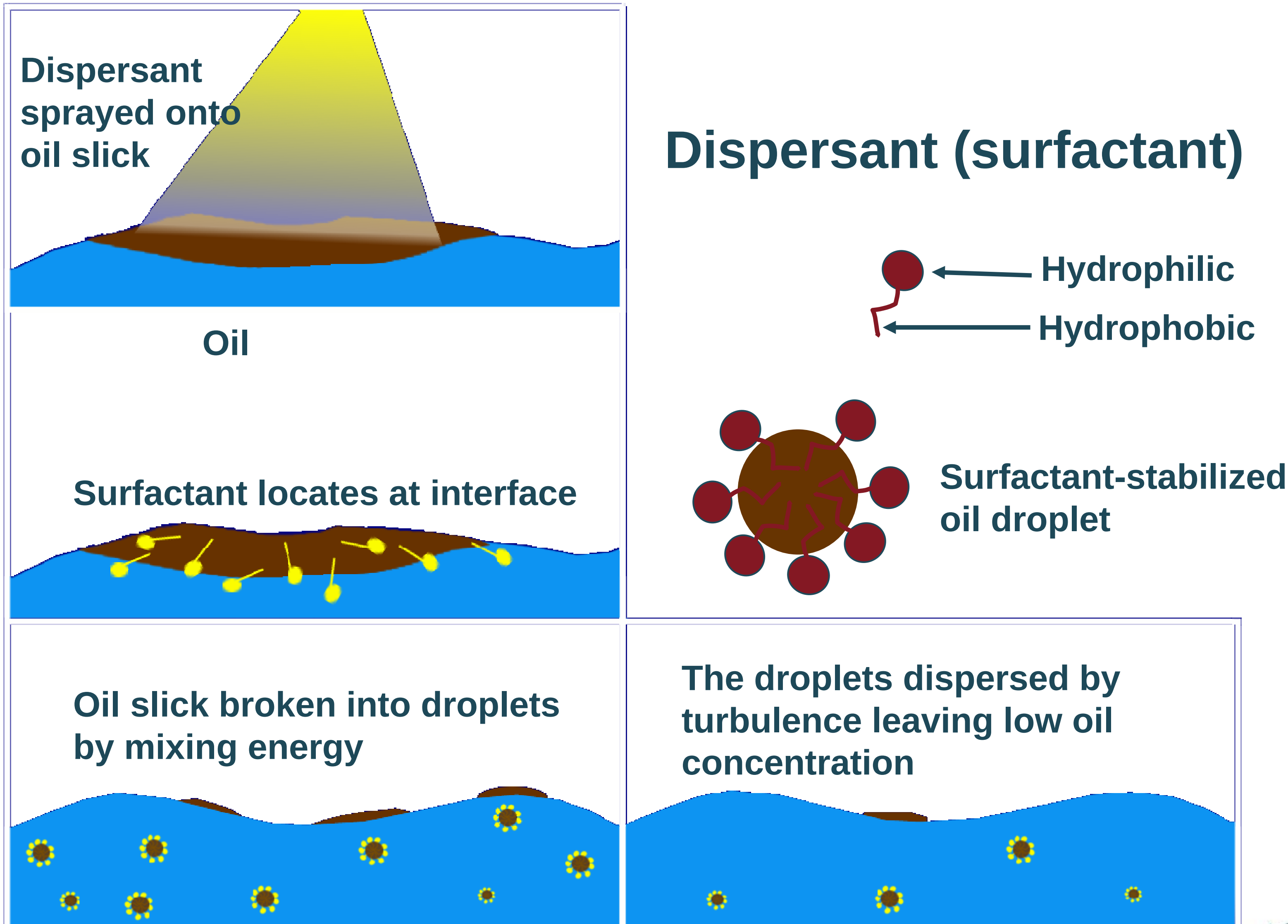
Dispersion Under Breaking-Wave Conditions*



* Shaw, 2003

Dispersants



Operational Practice and Sea Trial Observations

- Dispersants are ineffective under calm sea state conditions
- Under high sea-state conditions, dispersant use may not be necessary due to natural dispersion rates

Why Mixing is Important?

- **Oil and dispersant have to be in good contact**
  - Mixing provides more contact efficiency

- **Oil slick has to be broken into small droplets**
  - Mixing provides energy needed to overcome interfacial tensions

- **Oil droplets have to be dispersed to overcome re-coalescence and buoyancy**
  - Mixing provides turbulence that facilitates vertical and horizontal transport of oil droplets

Dispersant Effectiveness Testing

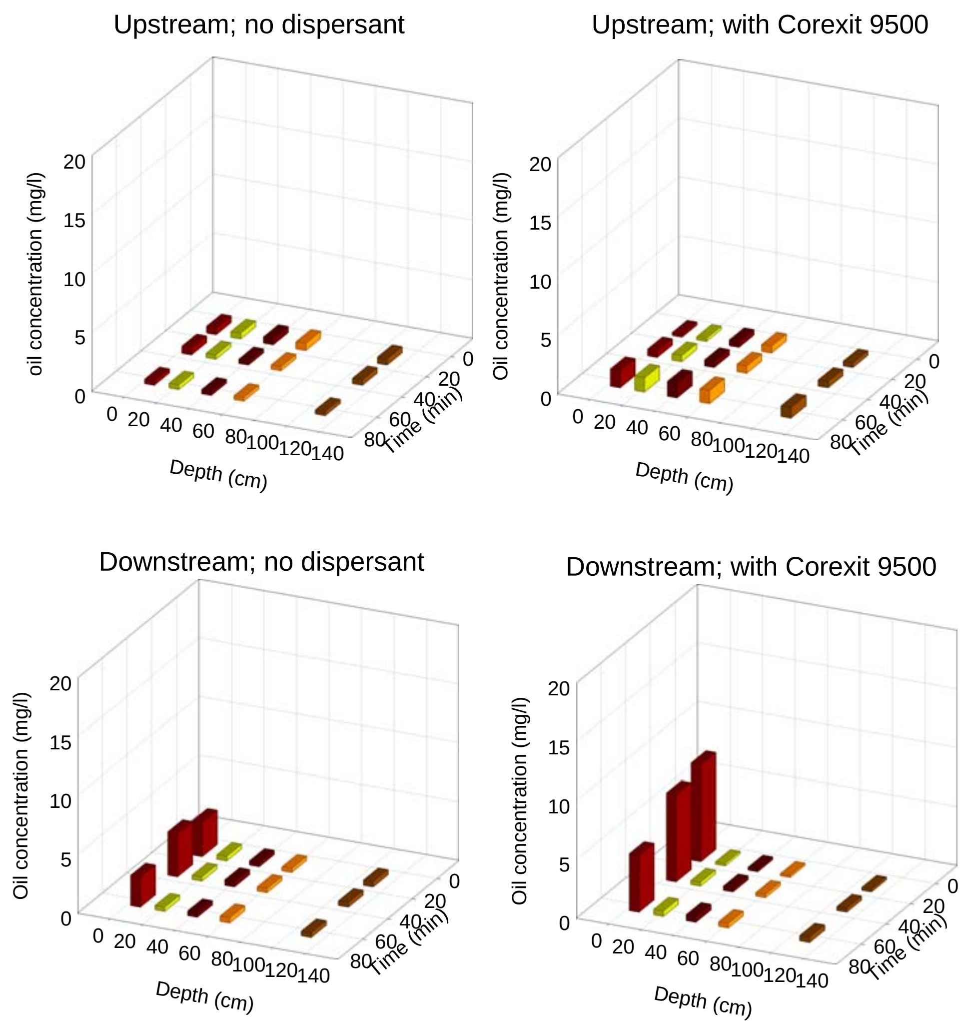
- **Laboratory flask testing**
  - Swirling Flask Test (SFT)
  - Baffled Flask Test (BFT)
  - Warren Spring Laboratory (WSL) Test
  - Institut Francais du Petrole (IFP) Test
  - Mackay Nadeau Mackay (MNS) Test
- **Wave tank testing**
- **Field sea testing**

Evidence of the Importance of Mixing Energy Level in Lab Testing

- Laboratory testing use the same
  - Oil type and weathering state
  - Temperature and salinity
  - Dispersant type and DOR

- Produce different percentage results
  - Different tests employ different levels of agitation
  - Same tests at different rpm
  - Different tests employ same levels of agitation

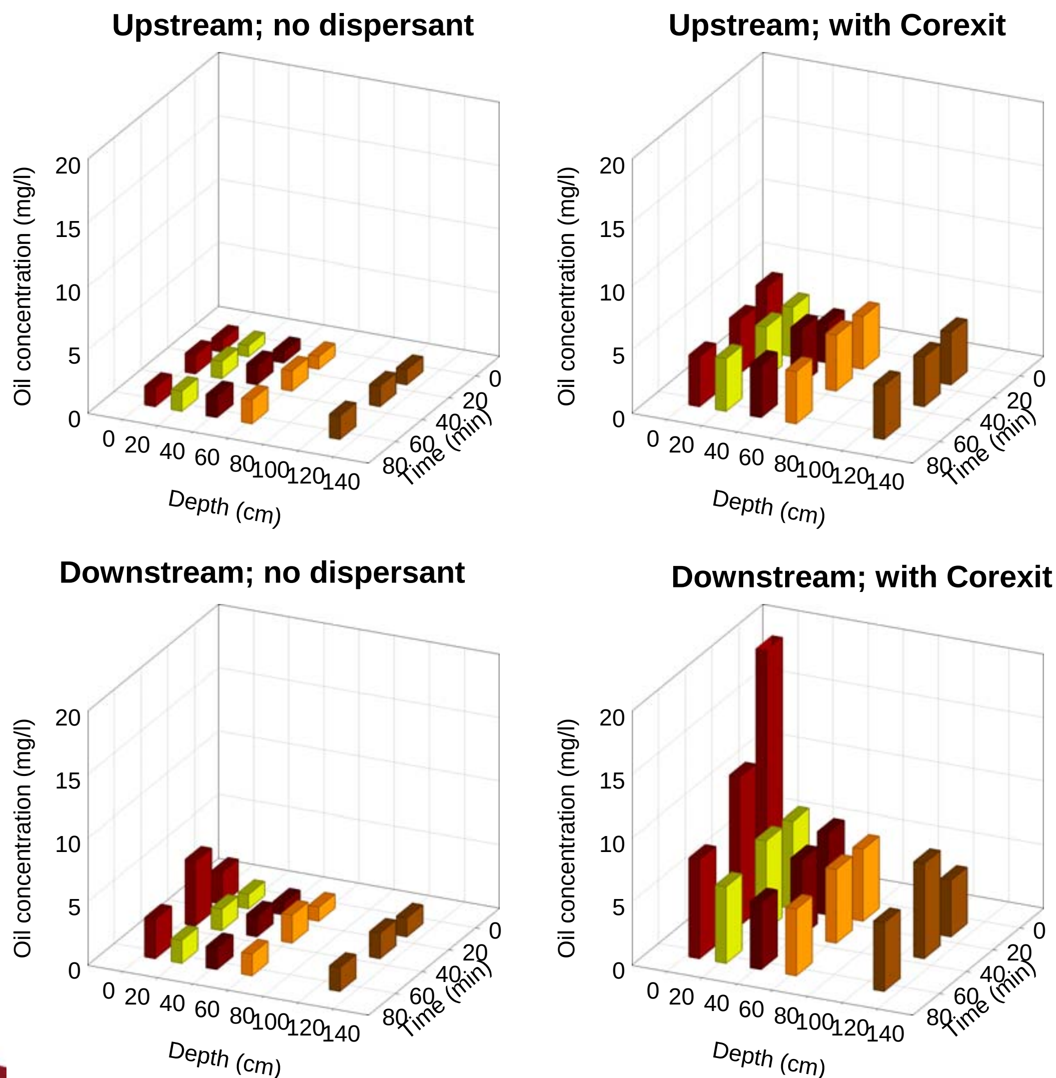
Importance of Mixing in Wave Tank: Case of Poor Mixing



16 m wave tank under regular non-breaking wave condition with poor mixing

* Li et al, 2008, MPB.

Wave Tank: Case of Strong Mixing



16m Wave tank under plunging breaking wave condition with strong mixing (breaking waves)

* Li et al, 2008, MPB

The Missing Link: Mixing Energy Levels for Different Systems?

- Critical for its potential to relate lab testing results to the field efficacy
- Energy dissipation rate - the energy losing rate per unit mass of seawater at different system - may serve as the link
  - Agitation intensity of flask testing
  - Wave breaking intensity in the wave tank
  - Wave conditions in the field at sea

How to Evaluate Dispersant Effectiveness?

- **Laboratory testing**
  - Complete mass balance, the percentage of the added oil in dispersed water column is reported as “effectiveness”
- **Sea Trial**
  - Given the complexity, not readily measurable
- **Wave tank**
  - Quantify the amount of oil that has been dispersed into the water column
  - Quantify the amount of oil remaining on the water surface

Evaluate Dispersant Effectiveness

- National Research Council (NRC) Committee on Understanding Oil Spill Dispersants: Efficacy and Effects (2005) identified two factors to be addressed in oil dispersant effectiveness studies:
  - Energy Dissipation Rate
  - Particle Size Distribution

- A wave tank has been constructed in BIO to address a variety of relevant issues:
  - Hydrodynamic Characterization
  - Dispersant Effectiveness
  - Particle Size Distribution
  - Monitoring *in-situ* dispersed oil

Evaluate DE through Particle Size Distribution (PSD)?

- Lewis et al, 1985. "The Significance of dispersed oil droplet size in determining dispersant effectiveness under various conditions" (IOSC)
- Lunel, 1993, 1995. "Understanding the mechanism of dispersion through oil droplet size distribution measurement at sea" (AMOP, ASTM)
- PSD can be measured readily in different systems:
  - Laboratory: epi-fluorence microscopy
  - Wave tank: particle counter
  - Field: particle counter

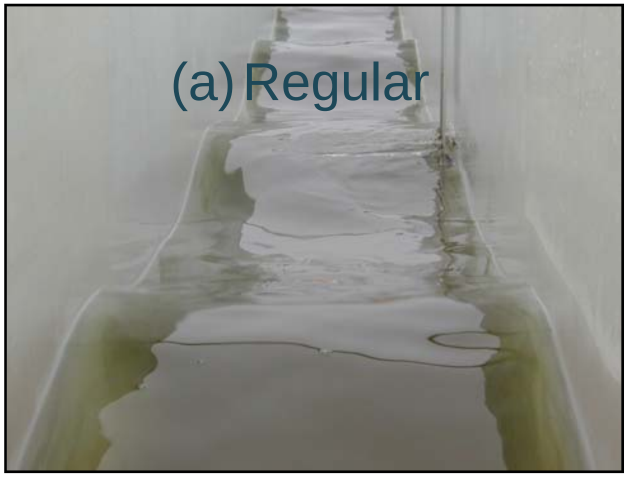
Revisiting Theory – Size Matters!

- **Oil and dispersant have to be in good contact.**
  - Mixing provides more contact efficiency
- **Oil slick has to be broken into small droplets**
  - Mixing provides energy needed to overcome interfacial tensions
  - *Smaller droplets with the more vigorous mixing*
- **Oil droplets have to be dispersed to overcome recoalescence and buoyancy**
  - Mixing provides turbulence that facilitates vertical and horizontal transport of oil droplets
  - *Smaller droplets are transported more effectively*

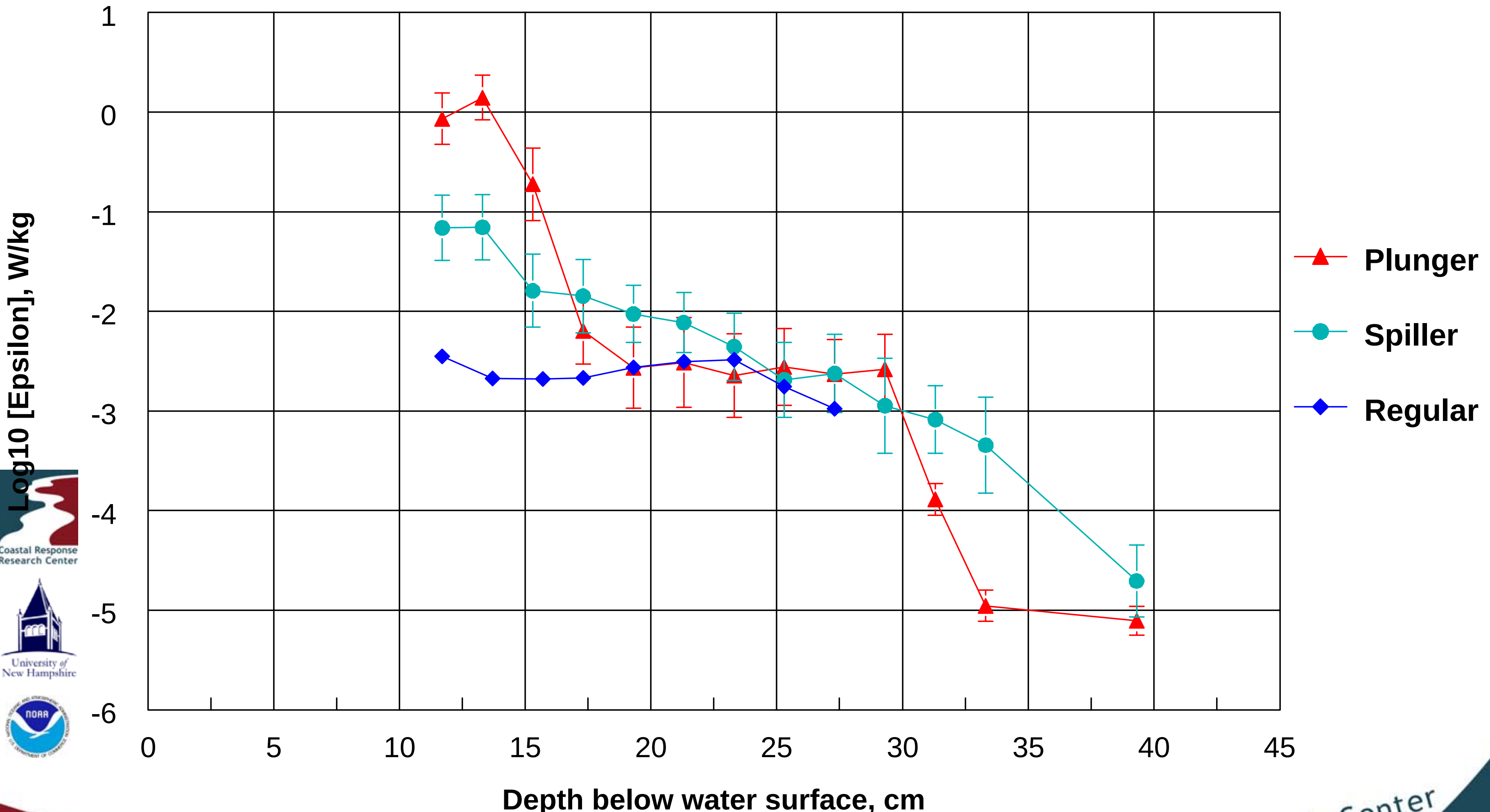
Chemical Dispersant Effectiveness as a Function of Energy Dissipation Rate and Particle Size Distribution *

* Co-funded by CRRC/UNH, EPA, DFO

Different Wave Conditions



Energy Dissipation Rate for Spilling, Plunging, and Regular Waves as a Function of Depth Below Water Surface



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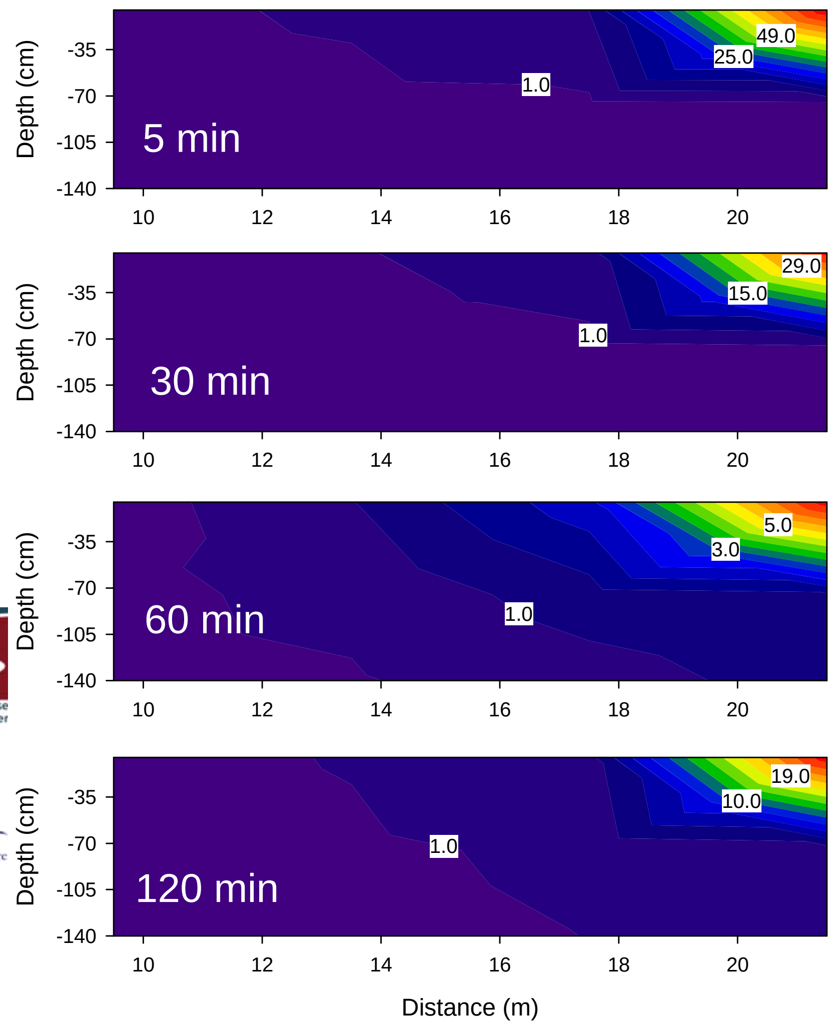
Factorial Experimental Design

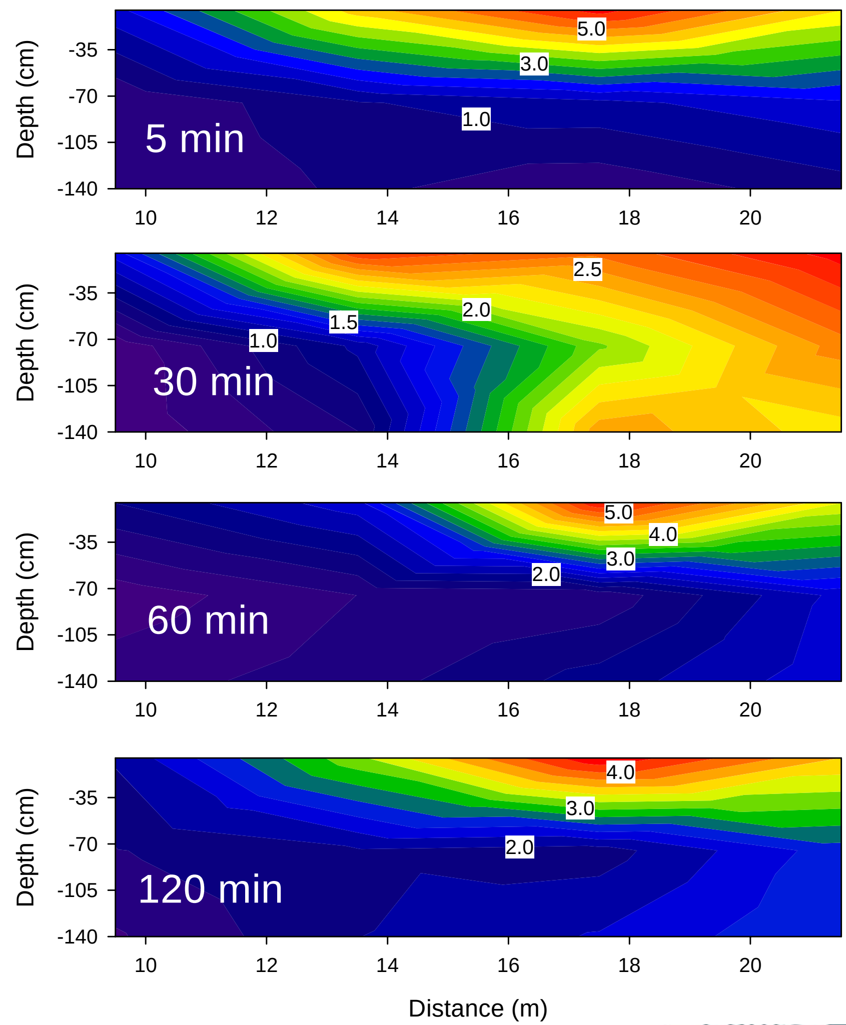
- Factors:
  - Dispersants: Water (control), Corexit, SPC
  - Waves: regular non-breaking wave, spilling breaker, plunging breaker
  - Oil types: MESA, ANS
- Effectiveness indicators:
  - Oil concentration
  - Droplet size distribution
- Analytical methods
  - Ultraviolet Spetrophotometry
  - Ultraviolet Fluoremetry
  - Laser In-Situ Scattering and Transiometry
  - Epifuorescent microscopy

Physical Dispersion

Water-MESA-Regular



Water-MESA-Plunging



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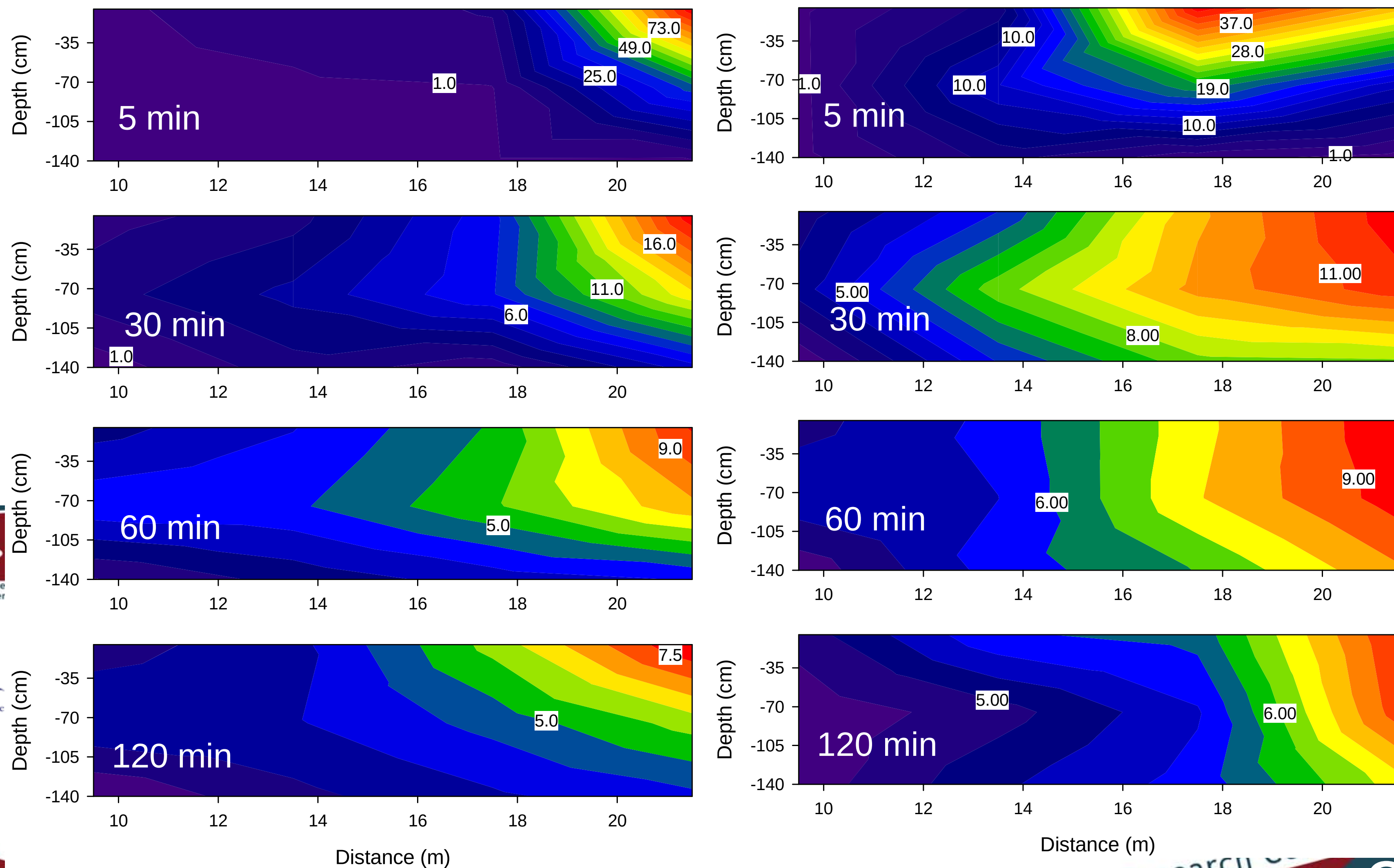
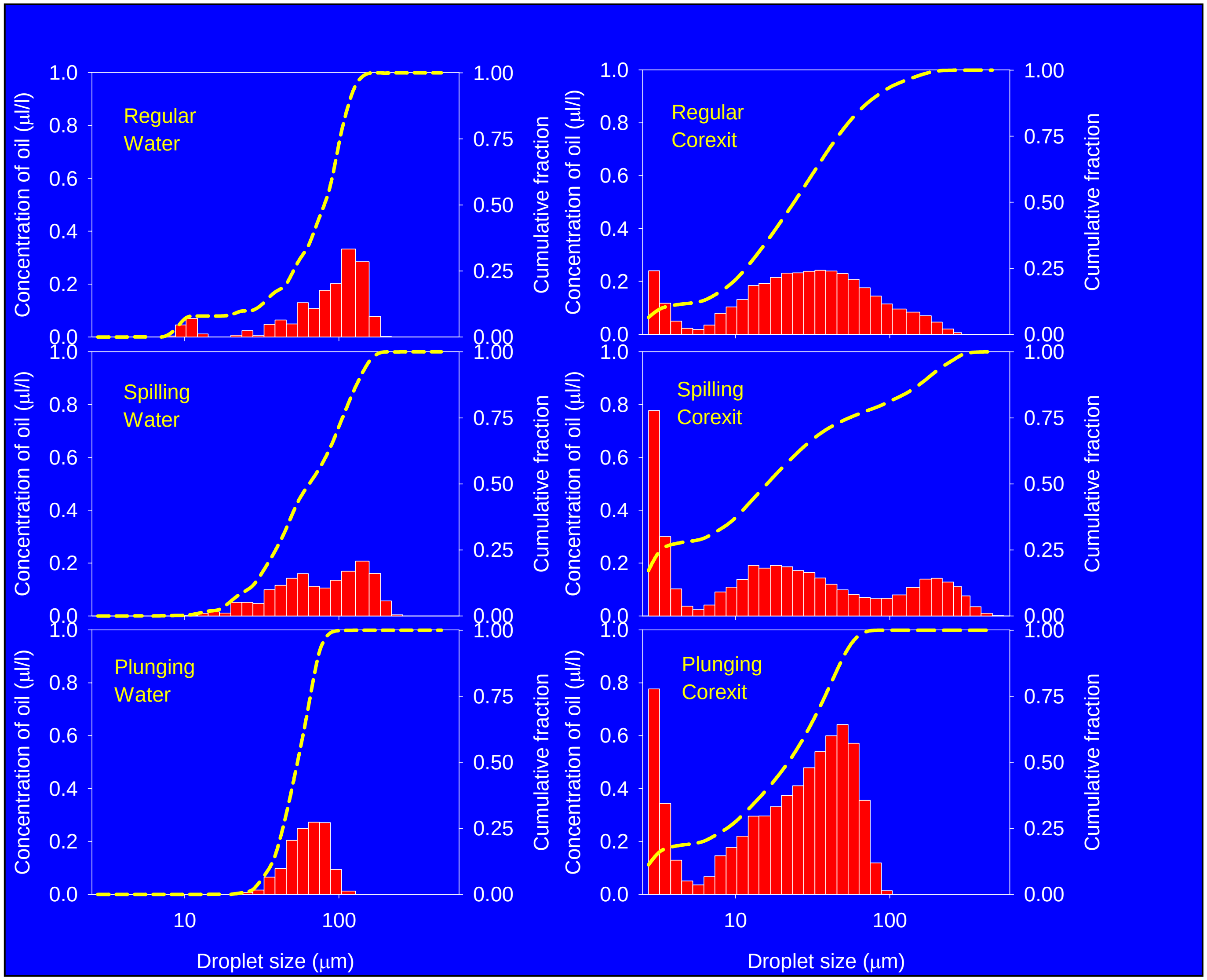
Chemical Dispersion

Corexit-MESA-Regular

Corexit-MESA-Plunging



Droplet Size Distribution

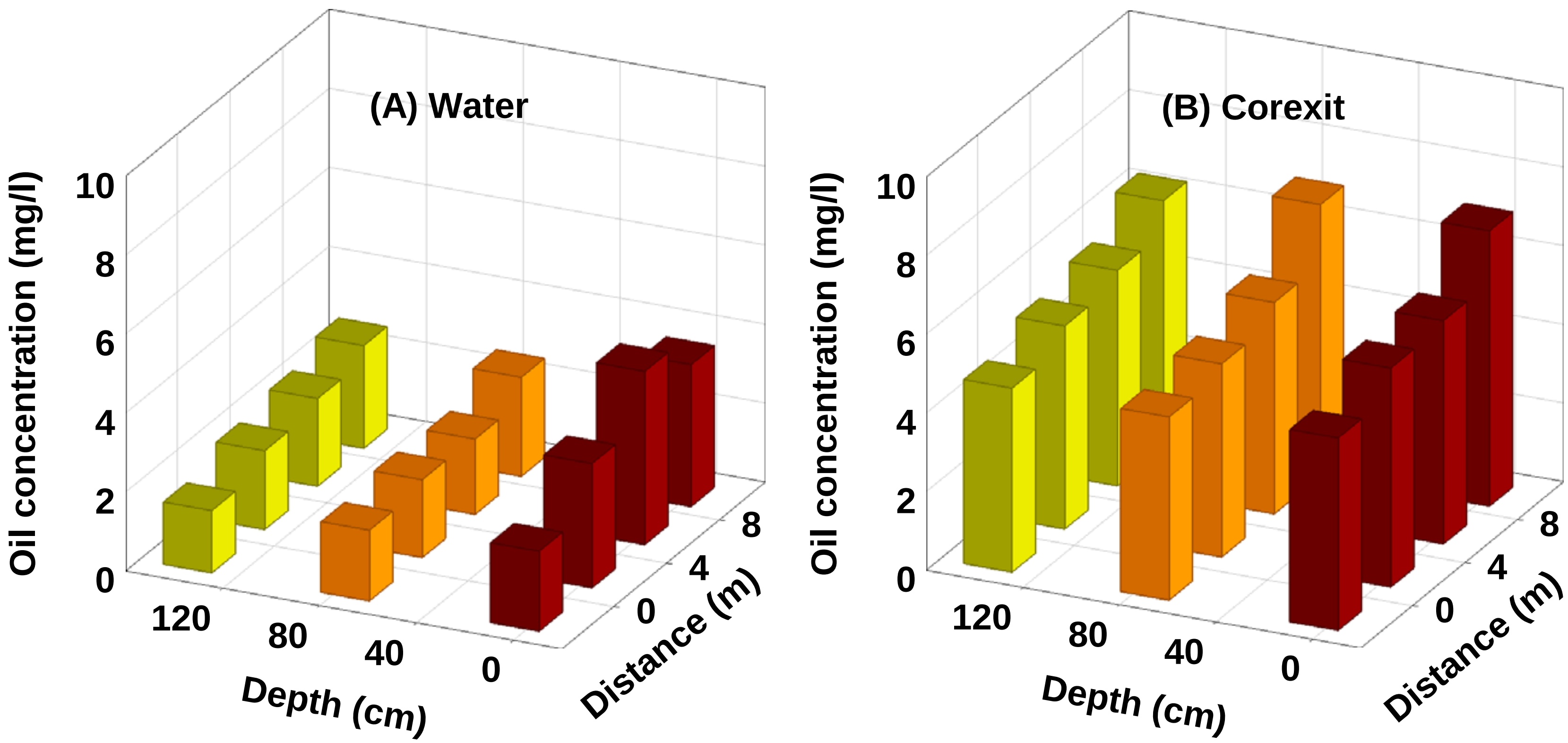


Droplet Size Distribution

- **In the absence of dispersant - dispersed oil droplet size distribution fits log-normal distribution; mass median diameters of the dispersed oil were similar**

- **In the presence of chemical dispersant - oil droplet size distribution fits multi-modal log-normal distribution:**
  - **Increase of dispersed oil droplets with log-normal distribution mode between 10 and 100 µm,**
  - **Larger number of small dispersed oil droplets with a log-normal distribution mode <2.5 µm.**
  - **The dispersed oil droplets covered a broader range of size distribution (GSD >3.0)**

Oil Concentration Under Plunging Breaking Waves



Conclusions

- Dispersant reduced oil droplet size and increased dispersed oil concentration
- Breaking waves decreased oil droplet size
- The effect of mixing energy dissipation rate on reducing oil drop size has been verified in the laboratory baffled flask test (BFT)
- Plunging and spilling breaking waves increased oil concentration compared to non-breaking wave
- The combination of *in-situ* particle counter with *in-situ* UV Fluorometry is potentially effective tool to monitor dispersed oil distribution

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