State-of-the-Science for Dispersant Use in Arctic Waters

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Alaska Oil Spill Technology Symposium

Coastal Response Research Center (CRRC)

- Partnership between NOAA’s Office of Response and Restoration and the University of New Hampshire
- Since 2004
  - UNH co-director – Nancy Kinner
  - NOAA co-director – Ben Shorr

2013 SONS Senior Executive Seminar: Lesson Learned

2013 Late Summer Scenario

2014 Late Summer Scenario

If a decision is made t
dispersants in the Arc
communicating that c
stakeholders and the
require clear commun
science contributing to that decision.

Corrective Action

- Develop Summary of the State of Dispersant Science
  1) What we know
  2) What we don't know
  3) Key issues of which senior leadership should be aware
- Provide Recommendations on Outreach and Educational Materials
- Collaborate with ongoing efforts in Alaska

Focus of Science Discussions

- Effectiveness and Efficacy
- Physical Transport and Chemical Behavior
- Degradation and Fate
- Toxicity and Sublethal Impacts
- Public Health and Food Safety

Steps in Process

- CRRC prepared database of dispersant related references published after 2007
  - LUMCOM database covers prior to that
- Convene week-long workshop in Jan 2015
  - 1 day devoted to each topic

Steps in Process

- All subsequent work on state-of-science documents done with conference calls
- 40+ hours per group
- Sent out for public input
- Each group reviews public input and makes changes, as appropriate
- Final version of document on CRRC website
- NOAA ORR project leads will create a summary document for senior executives

Caveats

- Mostly focused on surface application
- Focus is U.S. Arctic waters
- Conditions considered:
  - Ice free water
  - Ice infested water
  - Full ice cover
- No operations evaluation
- Primarily Corexit 9500/9527 in U.S. and post-DWH research
- Literature through Dec 2015

Efficacy and Effectiveness

Doug Helton

NOAA ORR

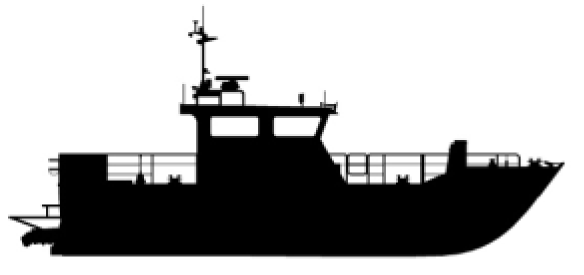
Why even consider dispersants?

- Conventional spill response equipment challenged by
  - Weather and Ice
  - Logistics and Infrastructure
  - Time and distance

- 150 knots
- Treats a huge area quickly
- Can be operated from long range

But…

- Works best on fresh oil
- Need good visibility
- Needs mixing energy
- Doesn’t remove oil from environment



- 2 knots
- Removes oil from environment

But…

- Requires large local logistics
- Needs calm seas
- Oil spreads very quickly

Efficacy & Effectiveness

- **Efficacy = how well dispersants work in ideal/controlled setting (e.g., laboratory trial)**

- **Effectiveness = how well dispersants work under "real-world" conditions**

Goals of Dispersant Application

- Reduce surface slicks
  - Break-up into small droplets that enter water column
    - Less contact for surface species (e.g., birds, marine mammals, turtles)
    - Speed dissolution
    - Speed biodegradation
    - Reduce oil toxicity by dilution
  - For subsea, disperse oil into droplets, so it does not reach surface

Knowns

- Factors that impact dispersant effectiveness:
  - Oil type
    - Oils have: different viscosities, weather differently
  - Emulsification
  - Mixing energy
  - Dispersant formulation
  - Dispersant : Oil Ratio (DOR)
  - Water’s salinity
  - Potential for dilution (small shallow water body vs. open ocean)
  - Temperature

Efficacy & Effectiveness

- **Knowns:**
  - If an oil remains fluid in cold waters in the Arctic, it will likely be dispersible if it is dispersible in temperate waters.
  - Subsea dispersant effectiveness in Arctic is likely equivalent to effectiveness in other subsea regions with the same conditions at depth.

Efficacy & Effectiveness

- Uncertainties:
  - The environment, oil and water systems are very complex, so applying general rules about dispersibility to the Arctic must be done carefully.
    - Ice is a big complicating factor
  - Dispersibility of higher viscosity oils

Mixing Energy

- **Knowns:**
  - Ice-free waters: mixing energy impacts equivalent to those in temperate waters
  - Ice-infested waters: ice dampens surface waves energy, slowing dispersion kinetics
  - Propeller wash from ships, including ice breakers, can enable dispersion of oil + dispersant

Mixing Energy

- **Uncertainties:**
  - Limited studies of surface mixing energy for some ice conditions (e.g., frazil ice)
  - Effectiveness of oil dispersion not fully characterized with highly ice-infested waters
  - Effects/interactions of shearing, dampening and reduction of evaporative weathering on oil dispersion not well understood

Limitations to the Understanding of Dispersant Effectiveness

- **Uncertainties:**
  - Poorly studied topics:
    - Effects of low salinity and hyper-saline water
    - Behavior of oils with viscosities >2000 cP
    - Dispersants other than Corexit
    - Impacts of gas at high subsea pressure

Detection & Monitoring of Effectiveness

- No standard dispersant effectiveness monitoring protocols for ice-infested waters
- Existing quantitative assessment techniques for measuring overall effectiveness have lots of uncertainty

Overall Conclusions on State of Science of Efficacy & Effectiveness of Dispersant Use in Arctic Waters

- Oils that are dispersible in temperate waters are likely dispersible in the Arctic if they remain fluid in cold waters.
- Subsea efficacy & effectiveness should be similar in the Arctic to elsewhere if conditions are the same at depth.
- Ice in Arctic waters changes the conditions for oil dispersant interactions in ways we do not fully understand.

Physical Transport & Chemical Behavior

Scott Pegau

OSRI

Physical Transport & Chemical Behavior

- Open water transport and behavior very similar to other regions
    - Cold conditions on weathering
- Impact of Sea Ice and ice coverage
- Freshwater inputs

Physical Transport & Chemical Behavior

- Sea Ice Impacts
  - Brine exuded from ice during ice formation is transported to bottom waters
  - Ice formation, transport and melting may create additional types of mixing vs. open water
  - Breaking waves and wind mixing are reduced in ice covered waters

Physical Transport & Chemical Behavior

- **Knowns: Droplet size/formation**
  - Key point: dispersants do not change oil or its constituents chemically
  - Dispersants help reduce droplet size = stay in water column longer
- **Uncertainties: Droplet size/formation**
  - No models of near surface droplet size distribution for naturally vs. chemically dispersed oil in ice infested waters
  - Turbulence regimes under ice are not well understood - droplet rise

Physical Transport & Chemical Behavior

- **Knowns: Transport**
    - Capacity of ice to pool non-dispersed oil increases with under-ice roughness
- **Uncertainties:**
    - Pooling capacity and transport under ice difficult to predict
    - Transport of surface oil in water with intermediate ice coverage is uncertain
    - Difficult to predict transport and mixing in frazil, grease and slush ice

Physical Transport & Chemical Behavior

- <u>**Knowns: Oil in Ice**</u>
  - **Experimental field releases have increased understanding of behavior of oil-in-ice**
  - **Spreading (movement of oil within ice field) is constrained by ice**
  - **Oil in pack ice will move with the ice unless pack ice is at low concentrations**
    - **Then may move independently of ice**
  - **Secondary release of oil entrapped in ice occurs at site where ice melts**

Physical Transport & Chemical Behavior

- Uncertainties: Oil in Ice
  - Uncertain how oil is transported when 3/10ths to 8/10ths ice cover
  - Uncertain if oil dispersant mixtures trapped in ice will be dispersed when ice is melted

Physical Transport & Chemical Behavior

- **Knowns: Oil Weathering**
  - Bulk properties of oil frozen into first year ice are much the same as when oil first encapsulated
  - Field trials show weathering in Arctic is slow; dispersant window as long as 7 days
- **Uncertainties:**
  - Limited field data - causes uncertainties
  - Variation with ice concentration and type
  - Degree of water-in-oil emulsification, volatilization, dissolution

Physical Transport & Chemical Behavior

- **Knowns: Oil Weathering**
  - **State-of-the-art models use coupled ice-ocean models**
- **Uncertainties/Issues: Mathematical Modeling**
  - **Limited empirical data to develop improved predictive models of dispersed oil droplet sizes, dissolution, OMA formation, water-in-oil emulsification for oil spills in ice**
  - **Modeling movement of oil through brine channels**
  - **Modeling of oil movement under ice**
  - **Modeling with higher concentrations of ice**

Physical Transport & Chemical Behavior

- **Knowns: Subsea Release**
  - **In shallow waters, force of rising gas from blowout could break ice**
- **Uncertainties: Subsea Release**
  - **Effect of gas bubbles from subsea spill and hydrate formation on oil droplet size formation**
  - **In shallow release, uncertain if oil-water plume will melt ice**

Degradation & Fate

Nancy Kinner

CRRC

Fate of Dispersants Alone

- **Knowns:**
  - Dispersant components have different half lives in the environment
    - Affected by environmental conditions
  - Anionic surfactants (e.g., DOSS) biodegrade under aerobic conditions and more slowly anaerobically
    - Most studies are surfactants alone, not dispersant mixtures

Fate of Dispersants Alone

- **Knowns (continued):**
  - DOSS is most studied anionic surfactant and is a constituent of the dispersant Corexit
    - In DWH, found in water column up to 4 months after last use
    - In sediments, still present in DWH-oiled sediments (not in natural seep sediments)

Fate of Dispersants Alone

- **Uncertainties:**
  - Because dispersants vary in composition, degradation and fate are not well known
  - Do other sources of surfactants (non-oil spill related) exist in the Arctic?
  - Effect of sunlight, low temperatures, and natural organic matter on dispersant decay/degradation not well understood

Marine Snow

- **Knowns:**
  - Normal aggregation of marine bacteria, phytoplankton, zooplankton that naturally accumulates particles and sinks to bottom
  - During Deepwater Horizon, oil caused microbes and phytoplankton to produce more exopolymer
  - More exopolymer production = more marine snow

Marine Snow

- **Knowns (continued):**
  - Oil becomes incorporated in marine snow
    - Marine Oil Snow Sedimentation and Flocculant Accumulation (MOSSFA)
  - Found evidence after DWH of major MOSSFA layer on bottom
    - Now buried by subsequent sediment accretion in Gulf of Mexico (GOM)
  - Sediment cores from IXTOC well blowout spill in GOM (1979) show MOSSFA event

Marine Snow

- **Uncertainties:**
  - **How does dispersant use affect marine snow formation in Arctic?**

Biodegradation of Oil

- **Knowns:**
  - Hydrocarbon-degrading (HD) microbes are ubiquitous
    - McFarlin et al. (2014) Arctic near-shore waters crude oil biodegradation at -1°C
    - Microbial community structure may differ geographically
    - HD microbes found in Arctic waters
  - Microbes degrade dissolved oil constituents and also at oil-water interface

Biodegradation of Oil

- **Uncertainties:**
  - **What actually happens in the field?**
    - **Few studies**
    - **Most based on lab not field**

Oil Biodegradation Pathways

- **Knowns:**
    - Oil constituents degrade at different rates
        - Arctic biodegradation pathways follow typical pattern observed in temperate waters
        - Complex microbial consortia degrade different oils (and their constituents) with complementary metabolic pathways
            - Live vs. dead oils
            - Light vs. heavy oils
    - Lab studies show no change in biodegradation sequence with dispersants present

Oil Biodegradation Pathways

- **Uncertainties:**
  - Is biodegradation sequence in anaerobic marine environment consistent?

Factors Affecting Biodegradation

- **Knowns:**
  - Nutrients and trace metal availability important in oil biodegradation rates
    - Lab studies suggest oil biodegradation can become nutrient limited
    - At low oil concentration (dispersed oil), there should be sufficient micronutrients

Factors Affecting Biodegradation

- **Knowns:**
  - Cold-water adapted microbes in deep water exhibit higher degradation rates of oil at lower temperatures than at high temperatures
    - Psychrophilic unique enzyme
  - Bioavailability, solubility and physical properties affect observed biodegradation rates

Factors Affecting Biodegradation

- **Uncertainties:**
  - Importance of psychrophiles and psychrotrophs in Arctic oil biodegradation
  - Biodegradation rates in ice uncertain
  - Effect of oil mineral aggregates on biodegradation in Arctic

Effect of Chemical Dispersants on Oil Biodegradation

- Lots of papers published on this topic, some not scientifically sound and some not representative of environmental conditions
  - Examples:
    - Nominal initial oil concentration (not actually measured)
    - Dispersant concentrations very high >1,000 ppm

Effect of Chemical Dispersants on Oil Biodegradation

- **<u>Knowns:</u>**
  - **10 µm oil droplets degrade faster than 30 µm oil droplets (Brakstad et al., 2015)**
  - **Dispersants increase oil-water interfacial area, thus increasing biodegradation of oil droplets vs. slick**
  - **Chemical dispersion most frequently increased oil biodegradation rates vs. physically dispersed oil**

Effect of Chemical Dispersants on Oil Biodegradation

- Caveats to Chemically Dispersed Oil Biodegradation Findings:
  - Often studies used proxy for biodegradation (e.g., increase bacterial numbers)
  - Need multiple lines of evidence (e.g., oil decreases, TEA decreases)
  - Publication bias against negative results
  - Oil spill comparison is usually chemically dispersed vs. oil slick; usually not physically dispersed in environment

Effect of Chemical Dispersants on Oil Biodegradation

- Caveats to Chemically Dispersed Oil Biodegradation Findings (continued):
  - Magnitude of effect varies
  - Lots of factors vary (e.g., temperature, concentration of oil, dispersant vs. particulate, DOR, dispersant type and concentration, oxygen, nutrients)

Effect of Chemical Dispersants on Oil Biodegradation

- **Uncertainties:**
  - Impacts of droplet size; only 10 µm vs. 30 µm studied
  - Impact of dispersants/dispersion on microbial activity
    - Degrading short-term vs. long-term release and adaptation
  - Lack of realistic field conditions
    - DWH oil concentrations in water typically < 10 ppm

Effect of Chemical Dispersants on Oil Biodegradation

- **Uncertainties (continued):**
  - Order of biodegradation of dispersant components vs. oil constituents
    - Preferential biodegradation?

Eco-Toxicity and Sublethal Impacts

Sarah Allan

NOAA ORR

Toxicity

- Coming soon… the final version of this document is not yet available

Toxicity

- Focuses on toxicity of oil and chemically dispersed oil
  - Not dispersants alone
  - Modern dispersant formulations

- Includes species that could be exposed to an oil spill in the Arctic marine environment
  - Species with exclusively Arctic distributions
  - Species with Arctic and sub-Arctic distributions

Toxicity

- Exposure and exposure pathways (General):
  - Pathway from source -> biological receptor
  - Inhalation, aspiration, ingestion and external contact (adsorption, absorption)

  - Adverse effects are a function of:
    - Exposure pathway
    - Degree of exposure (concentration, duration)
    - Inherent toxicity of the stressor
    - Sensitivity of the organism

Toxicity

- Exposure (Knowns):
  - Oil is a complex mixture
    - Different constituents have different toxicity and mechanisms of action

  - Dispersants change how oil partitions in water
    - Dissolved phase exposure concentration
    - Size distribution of particulate oil

  - Dispersants have lower toxicity compared to oil
    - Different mechanism of action

Toxicity

- Exposure (Uncertainties):
  - Oil constituent and degradation products that are not analyzed for
  - Dispersant effect on dissolution rates and uptake
  - Role of oil droplets

Toxicity

- Exposure in Arctic Conditions (Knowns):
  - Sea ice creates different exposure pathways
    - Under-ice biological communities, food webs
    - Marine species tend to aggregate at interfaces where oil can collect
  - High spatial/temporal variability in physical and biological parameters in the Arctic
  - Arctic food chains are shorter and lipid-rich
  - Temperature impacts uptake and metabolism

Toxicity

- Exposure in Arctic Conditions (Uncertainties):
  - Effect of Arctic food chains on trophic transfer
  - Consequences of tight benthic-pelagic coupling
  - Effects of changing climate on exposure pathways
  - Effects of low temperatures on chemical processes and biological effects

Toxicity

- **Toxicity of DDO to Birds (Knowns):**
  - **Undispersed oil impacts birds at the sea surface**
  - **Dispersants and DDO can disrupt feather structure**
  - **High bird densities in the Arctic increase risks from oil spills**
  - **Dispersants, oil and dispersed oil are toxic to bird eggs**

Toxicity

- Toxicity of DDO to Birds (Uncertainties):
  - Effect of environmentally relevant concentrations of dispersed oil on bird feathers
  - Sublethal and indirect impacts of DDO on birds

Toxicity

- **Toxicity of DDO to Marine Mammals (Knowns):**
  - **Undispersed oil can impact MMs at the sea surface**
  - **Dispersants and DDO can disrupt fur structure**
  - **Polar bear natural history predisposes them to oil exposure**
  - **Inhalation of VOCs and aspiration of oil and DDO cause toxic effects (esp. for cetaceans)**
  - **Chronic/sublethal impacts on MMs include:**
    - **Endocrine and reproductive impacts**
    - **Lung disease**
    - **Carcinogenic potential**

Toxicity

- Toxicity of DDO to Marine Mammals (Uncertainties):
  - Toxicokinetics
  - Dispersant effect on exposure at air-water interface
  - Effects on baleen
  - Significance of ingestion exposure pathway
  - Impacts on Arctic MMs

Toxicity

- Toxicity of DDO to Fish and Lower Trophic Levels (Knowns):
  - No evidence of systematic difference between Arctic and non-Arctic species
  - Dispersants increase oil exposure but do not change toxicity
  - Early life stages of fish are very sensitive to oil
    - Latent effects on survival
  - Life stage is determinant in toxic effects
  - Photoenhanced toxicity is significant

Toxicity

- Toxicity of DDO to Fish and Lower Trophic Levels (Uncertainties):
  - Sensitivities of other species and life stages
  - Magnitude of photo-toxic effect
  - Effect of low temperatures on exposure/toxicity
    - Possible delayed response in Arctic species
  - Ecological physiology of Arctic fish
  - Susceptibility of species in Arctic habitats
  - Population-level impacts

Final Comments

Still to Come on Documents

- Public Health and Food Safety
  - Finish Draft for Public Release
  - Receive Public Input
  - Panel Reviews Input
  - Panel Finishes Document
- Discussion on how to communicate state-of-science

Final Comments on Project

- Time marches on
  - This took a long time
    - It is hard to wade through these topics with a diverse group of experts
  - Dispersant literature since Dec 31, 2015

Final Comments on Project

- **Agreement possible** on the knowns vs. uncertainties among diverse group of scientists
    - **TAKES LOTS OF DISCUSSION!!!!**

Huge Thanks to the Panelists

Their volunteer efforts, patience and commitment has been amazing!!!!!

Thank You for Listening

Questions???

www.crrc.unh.edu

Organizing Committee

- Lt CDR Stacey Crecy, USCG
- Mark Everett, USCG District 17
- Doug Helton and Gary Shigenaka, NOAA ORR
- Leslie Holland-Bartels, USGS
- Phil Johnson, US DOI-Alaska
- Lee Majors, Alaska Clean Seas
- Kristin Ryan, Alaska DEC
- Greg Wilson and Vanessa Principe, USEPA
- Susan Saupe, Cook Inlet RCAC
- Mark Swanson, PWSRCAC

State of Science for Dispersant Use In Arctic Waters workshop

January 5 – 9, 2015

NOAA, Seattle, WA

BREAKOUT GROUPS

Monday January 5	*Tuesday January 6*	*Wednesday January 7*	*Thursday January 8*	*Friday January 9*
Group 1: Efficacy and effectiveness	**Group 2: Physical transport and chemical behavior**	**Group 3: Degradation and fate**	**Group 4: Toxicity and sub-lethal impacts**	**Group 5: Public health and food security**
Catherine Berg	Chris Barker	Robyn Conmy	Sarah Allen	Jim Berner
Robyn Conmy	Edwin Barth	Merv Fingas	Mace Barron	Sandrine Deglin
Ben Fieldhouse (WebEx)	CJ Beegle-Krause	Terry Hazen (WebEx)	Adriana Bejarano	Bob Dickey (WebEx)
Merv Fingas	Robyn Conmy	Robert Jones	Jewel Bennett	Jim Fall (WebEx)
Ken Lee (WebEx)	Tom Coolbaugh	Samantha Joye	Debbie French McCay (WebEx)	John French
Tim Nedwed	Merv Fingas	Ken Lee (WebEx)	Michel Gielazyn	Craig Gerlach
Chris Reddy	Ali Khelifa (WebEx)	Marybeth Leigh	Peter Hodson (WebEx)	Julia Gohlke (WebEx)
Ken Trudel (WebEx)	Ken Lee (WebEx)	Karl Linden	Sharon Hook (WebEx)	Susan Klasing
Tim Steffek	Jim Payne	Kelly McFarlin	Russell Hopcroft	Richard Kwok (WebEx)
	Scott Pegau (WebEx)	Scott Miles	John Incardona	Ken Lindemann (WebEx)
	Chris Reddy	Roger Prince	Angela Matz	
		Mathijs Smit	Teri Rowles	
		Mark Sprenger	Mathijs Smit	
			Mark Sprenger	
			Robert Suydam (WebEx)	
			Ron Tjeerdema (WebEx)	
			Dana Wetzel	
			John Wise	
			Jack Word	
			Mike Ziccardi	

Panel Experts Efficacy and Effectiveness

- Catherine Berg, NOAA
- Robyn Conmy, USEPA
- Ben Fieldhouse, Environment Canada
- Merv Fingas, Spill Science
- Tim Nedwed, ExxonMobil
- Christopher Reddy, Woods Hole Oceanographic Institution
- Ken Trudel, SL Ross Environmental Research Ltd
- Timothy Steffek, US Bureau of Safety & Environmental Enforcement

Panel Experts: Physical Transport and Chemical Behavior

- **Christopher Barker, NOAA**
- **CJ Beegle-Krause, SINTEF**
- **Robyn Conmy, US EPA**
- **Thomas Coolbaugh, ExxonMobil**
- **Merv Fingas, Spill Science**
- **Ali Khelifa, Environment Canada**
- **James R. Payne, Payne Environmental Consultants, Inc.**
- **W. Scott Pegau, Alaska Oil Spill Recovery Institute**

Panel Experts: Degradation and Fate

- Robyn Conmy, US EPA
- Thomas Coolbaugh, ExxonMobil
- Merv Fingas, Spill Science
- Terry Hazen, University of Tennessee and Oak Ridge National Laboratory
- Robert Jones, NOAA
- Samantha (Mandy) Joye, University of Georgia Athens
- Mary Beth Leigh, University of Alaska Fairbanks
- Karl Linden, University of Colorado Boulder
- Kelly McFarlin, University of Alaska Fairbanks
- Scott Miles, Louisiana State University
- Mathijs Smit, Shell Global Solutions International BV
- Mark D. Sprenger, US EPA