Marine snow, oil deposition on the seabed and the possibility of Marine Oil Snow Sedimentation and Flocculent Accumulation (MOSSFA)

Provided by Alun Lewis

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About

Alun Lewis is a research chemist who has worked with oil spills and dispersants since 1979. Initially this was at the BP Research Centre (until 1992), then briefly at the UK Government's WSL (Warren Spring Laboratory), then at SINTEF in Trondheim, Norway (1993 to 1997), AEA Technology (1997 to 1998). Since 1998, Alun has been an independent consultant. He has worked with many organizations, both commercial and government, throughout the world and has presented on numerous oil spill response / dispersant training courses over the years.

Review of marine snow papers, Brakstad, et al., 2018

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Review

A critical review of marine snow in the context of oil spills and oil spill dispersant treatment with focus on the Deepwater Horizon oil spill

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ABSTRACT

Natural marine snow (NMS) is defined as the "shower" of particle aggregates formed by processes that occur in the world's oceans, consisting of macroscopic aggregates of detritus, living organisms and inorganic matter. Recent studies from the Deepwater Horizon oil spill suggest that marine snow is also formed in association with oil spills and was an important factor for the transport of oil to the seabed. This review summarizes the research and literature on MS, mainly from the DWH oil spill, with a focus on the relation between the use of oil spill dispersants and the formation and fate of oil-related marine snow (ORMS). Studies are still required to determine ORMS processes at oil concentrations as relevant as possible for chemically dispersed oil.

Marine Snow, Marine Oil Snow and MOSSFA

- Marine snow (MS)
  - Marine snow is a naturally formed shower of organic material falling from upper waters to the deep ocean. As plants and animals near the surface of the ocean die and decay, they fall toward the sea floor. Marine snow also includes fecal matter, sand, soot, and other inorganic dust.
- Marine Oil Snow (MOS)
  - Marine oil snow is a special case of marine snow hypothesised to be associated with oil spills
- MOSSFA - Marine Oil Snow Sedimentation & Flocculent Accumulation
  - Recently hypothesized to explain the apparent deposition of large amounts of crude oil on seabed during the Macondo incident

How did the idea of oil containing snow arise?

- An Oil Budget was prepared by the Federal Interagency Solutions Group
  - 26%, or some percentage thereabouts, of the oil that had been released was described as being “residual” or “remaining”
  - This was interpreted by some to mean that oil was “missing” and needed to be found

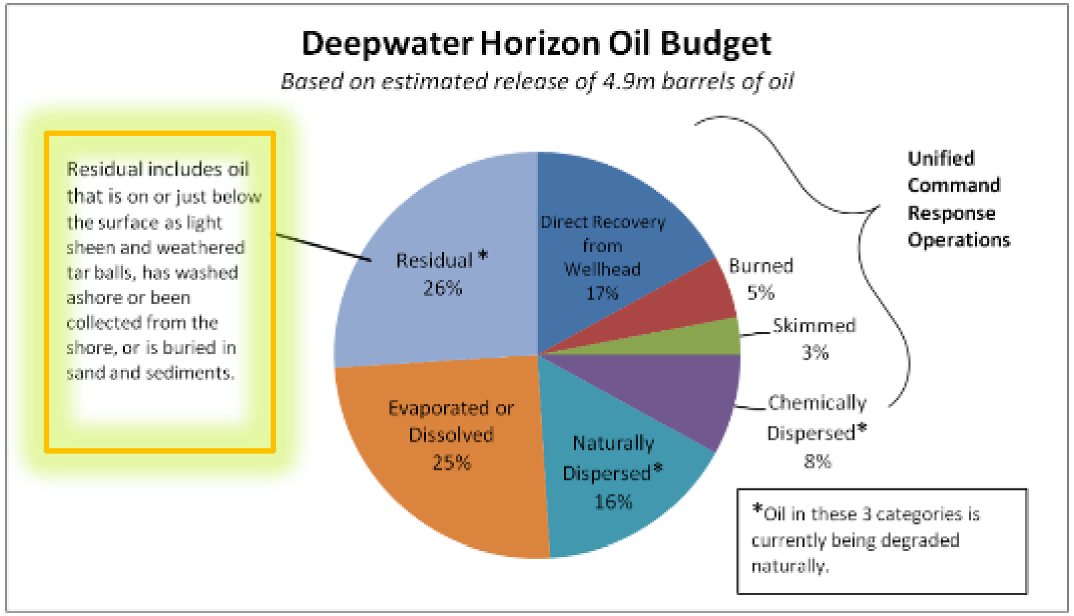
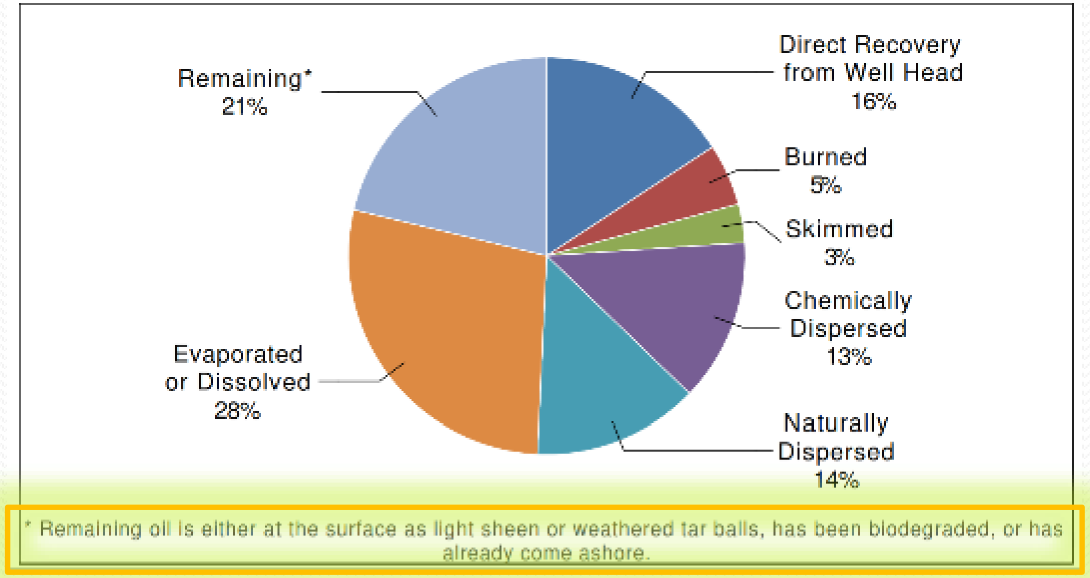


Figure 1: Oil Budget - Shows current best estimates of what happened to the oil.

A Later Version of the Chart



Other representations of the uncertainties

Earlier Version

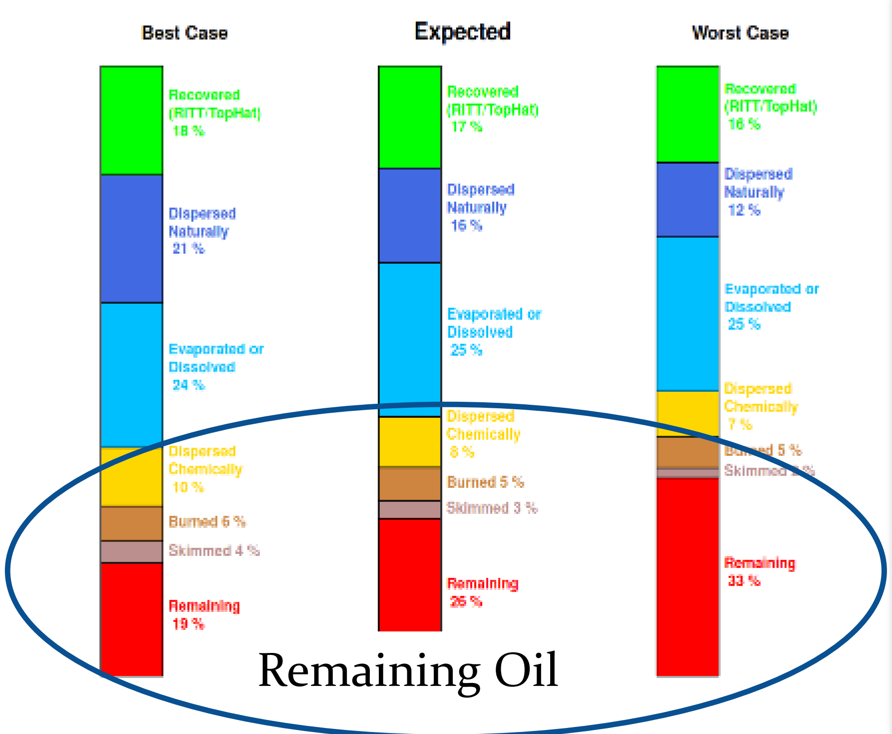
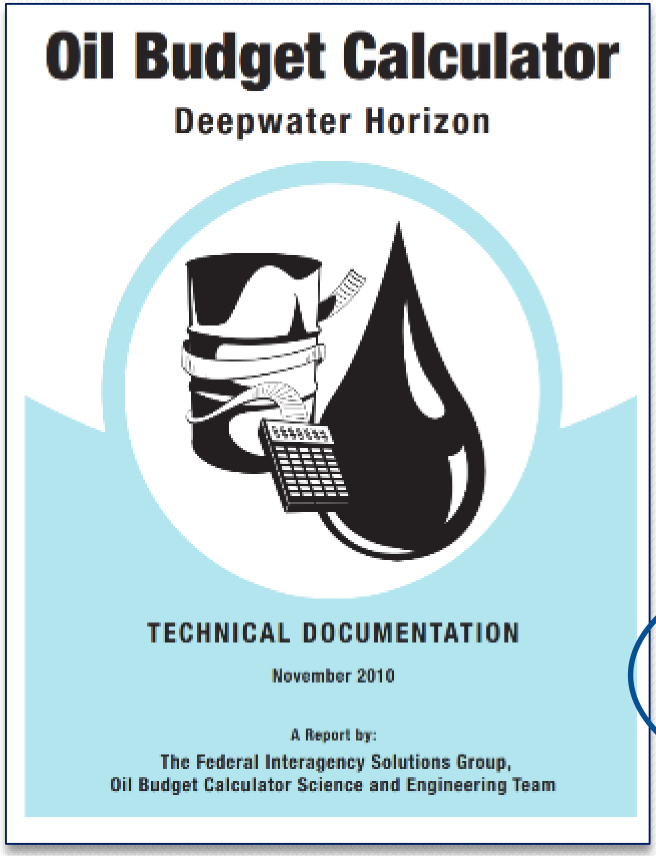


Figure 6: **Where the Oil Went:** Expected volume percentages and best and worst case scenarios from uncertainty analysis for day 102 (July 30th, 2010). The height of each bar is 100 % (of the total volume of oil discharged in each of the three cases, which is listed in the first row of Table 3).



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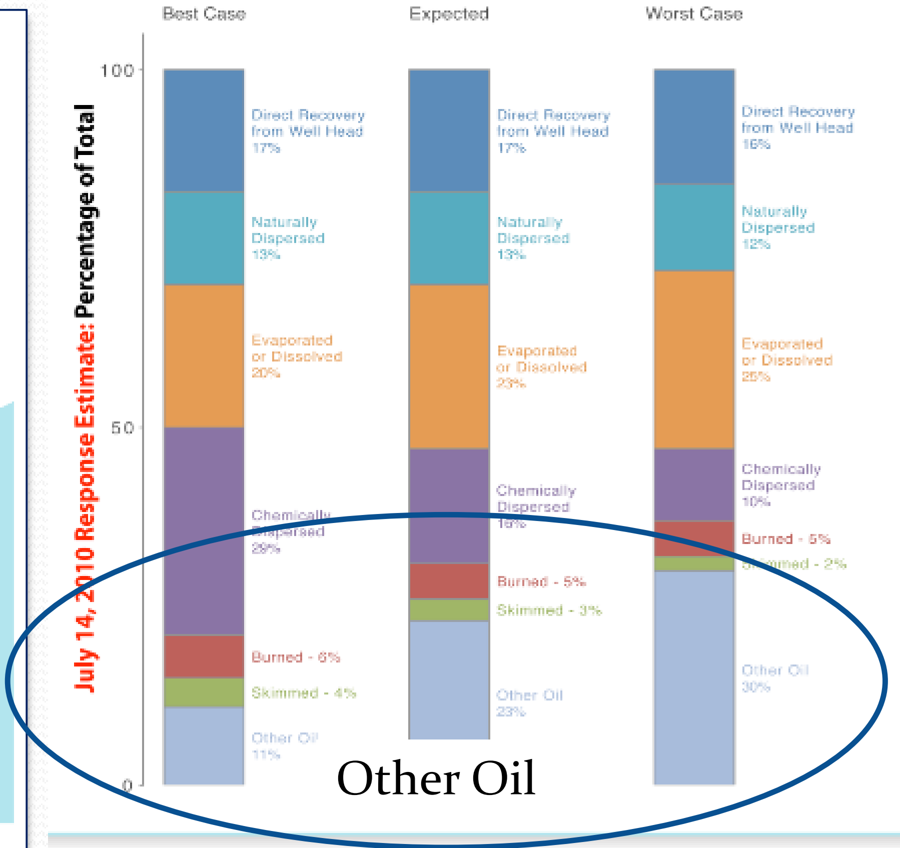


Figure 13: Response estimates expressed as percentages of the cumulative volume of oil discharged through July 14, 2010, in the best, expected, and worst cases. These estimates served solely as a guide for the national response to the Deepwater Horizon MC252 Gulf Incident.

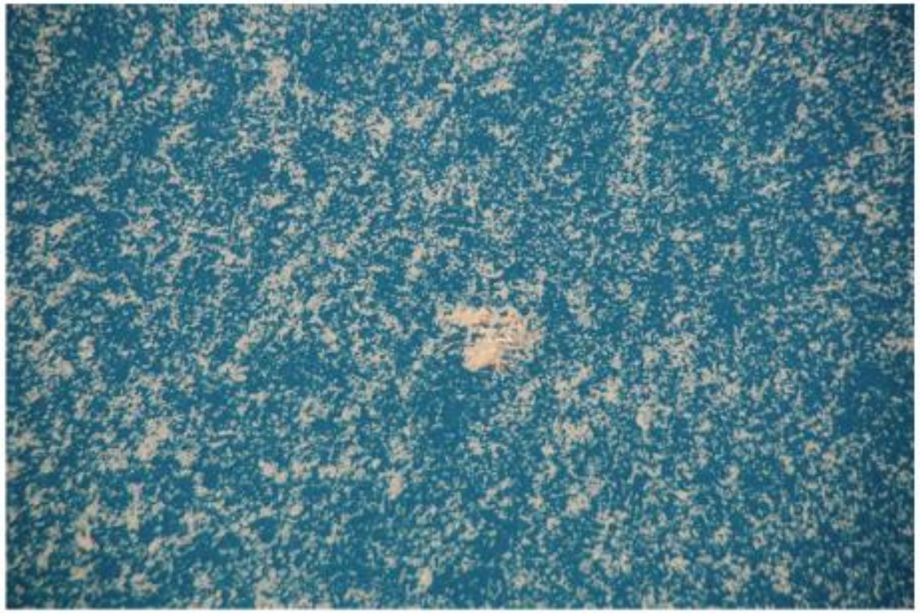
Early hints of hypothetical oil-related marine snow

In May 2010, mucus-like, non-persistent particles ("sea snot") were observed on the surface in the vicinity of DWH incident

NATIONAL GEOGRAPHIC Daily News

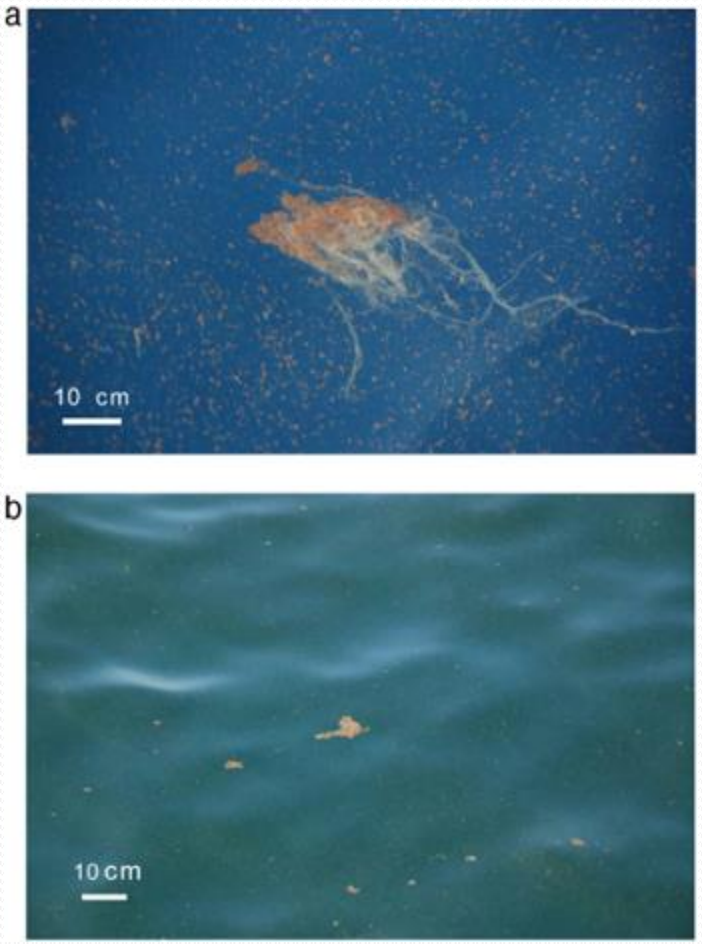
"Sea Snot" Explosion Caused by Gulf Oil Spill?

Marine "snowstorm" possibly crippled base of Gulf of Mexico food chain.



"Sea snot"—sticky clumps of phytoplankton—permeates an undersea patch of the Gulf of Mexico in May. *Image courtesy Arne Diercks*

by Christine Dell'Amore
National Geographic News
Published September 23, 2010



Speculation

- One month later, the “sea snot” had gone from the sea surface and it was speculated that oil had been sunk by a marine snow “blizzard”

  – On August 19th, Christine Dell'Amore of the National Geographic News reported preliminary results of a University of South Florida (USF) 10-day research cruise that **had detected oil in sediment samples taken from the seabed** by using UV light. “*The early results are reminders that the oil hasn't been fully dispersed or degraded away*” said cruise member David Hollander, a USF chemical oceanographer.

  http://news.nationalgeographic.com/news/2010/08/100818-gulf-oil-spill-seafloor-toxic-science-environment

  – The RV *Oceanus* conducted a research cruise starting on August 21st and collected sediment cores. On September 10th, it was reported that ***“Samantha Joye describes seeing layers of oily material — in some places more than 2 inches thick — covering the bottom of the seafloor.”***

  http://www.npr.org/templates/story/story.php?storyId=129782098

Conditions that occurred during the Macondo spill

- Oil on sea surface
  - Floating oil and dispersed oil in upper 10 meters of water at 2 to 3 ppm oil concentration

- Oil dispersed subsea
  - Dispersed oil detected in water column at a maximum of 1 ppm at 1 km from wellhead, with the concentration rapidly dropping with increasing distance from wellhead
  - Beyond 20 km from wellhead oil in water concentration was below 100 ppb
  - Background was 1 ppb

Processes that occurred at during the Macondo spill

- Oil on sea surface
  - "Classic" weathering:
    - Loss of volatile oil components by evaporation
    - Some natural dispersion
    - Water-in-oil emulsification to form characteristic red-orange coloured mousse
- Oil dispersed subsea
  - "Subsea" weathering
    - Loss by dissolution of soluble oil components (similar to those which evaporate at surface)
    - Rapid and extensive biodegradation of oil dispersed in the water column
    - Most alkanes, cycloalkanes and aromatics lost to leave a recalcitrant, i.e., long lived, residue
    - Continuous oil release for 87 days led to low concentrations of recalcitrant residues being deposited on seabed sediment under the track of the dispersed oil plume

Studies

- GoMRI funded many studies including a variety of marine snow projects, such as:
  1. Attempting to simulate, via laboratory experiments, what may have occurred in the deep sea during the Macondo release
  2. Estimating the amount of crude oil deposited by using analytical chemistry of oil-derived material located in or on seabed sediments

Example: Passow, et al., 2012 / Ziervogel, et al., 2012

- Studies described in these papers used laboratory incubations in rotating glass bottles (roller bottles) in an attempt to simulate conditions that occurred during the DWH incident
  - 12 ml of crude oil were added to 1 litre of seawater in a 1150 ml volume bottle to produce a 1% w/w of (10,000 ppm) oil in water and the bottles were rotated at 3.5 rpm for 21 days at 25°C
  - Research conclusions could be viewed as speculative / tentative, for example -
    - *"The formation and sinking of oil-derived marine snow in surface as well as subsurface waters is <u>a possible pathway</u> that determines the distribution and cycling of oil within the ecosystem. Sinking oil-derived aggregates would contain fossil carbon within mucus and bacteria biomass and presumably also unassimilated hydrocarbons."*

Laboratory conditions are not representative of real world

Estimations of the amount of deposited oil

- Modern analytical chemistry techniques are capable of detecting and quantifying extremely low levels of chemical compounds
  - Including those chemical compounds in the recalcitrant residue from oil found on the surface of seabed sediments
- Many thousands of samples were analysed and the analytical chemistry results made openly available
- Some researchers used the concentrations of bio-markers such as hopane or high molecular weight alkanes (waxes) to estimate quantity of original crude oil from which residue was produced

Fallout of submerged oil: Valentine, et al., 2014

- Used concentrations of hopane in seabed sediment samples
  - Hopane is present at 69 ppm in ‘fresh’ Macondo crude oil and 1 gm hopane relates to 15 Kg of ‘fresh’ Macondo crude
- Total amount of ‘fresh’ Macondo crude oil released estimated at ~5.0 million barrels with ~2 million barrels being dispersed oil in the subsea plume
- Hopane concentration was used to estimate an amount of oil that could have been deposited in sediments over a wide area, e.g., 3,200 km^2 of seabed
- ~12% (a range 4% to 31%) of the total of Macondo release, 240,000 barrels (with a range of 80,000 to 620,000 bbl) – however-

“Because hopane is used as a proxy for oil, the estimate does not account for biodegradation or dissolution of other petroleum hydrocarbons”

What was deposited on the sea floor?

- The residue that remained in samples >1.6 km from the wellhead after severe biodegradation consisted mainly of compounds that were too insoluble and too resistant to biodegradation to be further depleted, i.e., they were poorly bioavailable.
- Most of the potentially acutely toxic PAH compounds had dissolved andbeen biodegraded, resulting in predominance of the highest molecular weight PAHs, such as C1 to C4-fluoranthenes/pyrenes, C1 to C4-naphthobenzothiophenes and C1 to C4-chrysenes present in the residue (Stout and Payne, 2016a).
- Physically, the residue would be semi-solid, much like asphalt, i.e., not bioavailable

MOSSFA

- Basis of argument for MOSSFA hypotheses
  - ‘Fresh’ Macondo crude oil has a density of 0.833 gm/ml at 5°C and could not sink in seawater with a density of 1.025 gm/ml, therefore “something” must have caused the ‘fresh’ crude oil to sink
  - The aggregation of Marine Snow with oil residues, and possibly other suspended particles, created **marine oil snow** that sank to the seabed, carrying the oil with it

An alternative explanation

- 'Fresh' Macondo crude oil can have neutral buoyancy if dispersed as very small oil droplets, i.e., it will not rise rapidly to the surface
  - Oil dispersion likely occurred naturally by the turbulence of gas flow and was enhanced by the use of SSDI
- Very small droplets of dispersed 'fresh' *Macondo* crude oil rapidly lost some components by dissolution and was rapidly and extensively biodegraded
  - The rapid biodegradation of the dispersed oil by marine microorganisms produced large amounts of 'floc' (bacterial biomass) that is evidence of extensive biodegradation
- 'Fresh' crude oil was converted into a much smaller quantity of recalcitrant residues
- This denser residue diffusely deposited on the seabed under the path of the subsea plume

Thanks for listening.