Integrated Modeling: A New Approach to Improved Spill Response Modeling

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I. Trajectory models

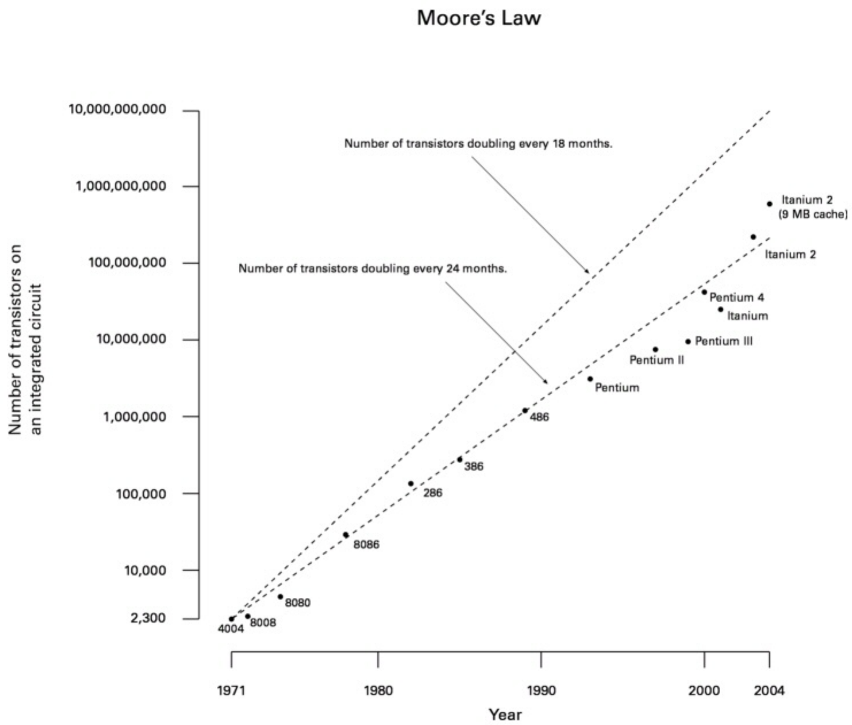
II. Coagulation models

Overall Themes

- Not one size fits all—scale dominates the choice of ‘best’ model

- Tension between development and practicality

- Moore’s law extended



Not one size fits all—scale dominates

0-12 hours post-spill

- Oil Slick Location
  - Spreading
  - Drifting
- Oil Slick Mass Loss and Compositional Changes
  - Evaporation
  - Dispersion
  - Emulsification
- Toxicity
  - acute oiling

See Mackay *et al.*, 1983

Not one size fits all—scale dominates

12 hours – few days post-spill

- Oil Slick Location
  - Drifting
  - Interaction with shoreline
- Oil Slick Mass Loss and Compositional Changes
  - Dispersion
  - Emulsification/vertical mixing
  - Dissolution
- Toxicity
  - acute toxicity of mixture

Not one size fits all—scale dominates

Days to months to years post-spill

- Oil Slick Location
  - Remobilization from oiled shoreline

- Oil Slick Mass Loss and Compositional Changes
  - Reaction/Biolysis
  - Coagulation/Sinking
  - Tar Ball Formation

- Toxicity
  - chronic toxicity of weathered mixtures
  - altered bioavailability
  - altered habitats, trophic structure, *etc.*

Part I. Trajectory Models

On-Site Hydrodynamically-Integrated Trajectory (O-SHIT) models

- Operational criteria
  - Always up
  - Always fast
  - Data lean
  - Conservative
  - Easily understood output

Part I. Trajectory Models

- Examples
  - General NOAA Oil Modeling Environment (GNOME; NOAA Hazmat)
  - DISPRO
  - SIMAP
  - MEDSLICK (European Commission V Framework Program Energy, Environment and Sustainable Development)

Part I. Trajectory Models

- Strengths
  - Operational
  - Fast
  - Minimal data requirements

- Weaknesses
  - Often 1 D in the vertical
  - Often no chemical weathering
  - Averaged hydrodynamics
  - Often poorly documented in accessible peer-reviewed literature

Part I. Trajectory Models

- An inherent characteristic (limitation?)

The operational requirements of reliability and constant availability work against rapid assimilation of ‘new’ information.

The criticism that these models are ‘out of date’ or ‘too simple’ must be tempered against their operational requirements.

However, shortening the ‘product development cycle’, especially to take advantage of faster/cheaper hardware, is possible.

Part I. Trajectory Models

- Three operational strategies
  - Use current surface winds and tabulated local currents and tides to predict surface flows at the time of the spill
  - Prior to event, model the most-likely currents by running climatologies run through 3-D models
  - Integration of real-time data

Part I. Trajectory Models

Climatology-driven scenario runs

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Current data assimilation modelling for oil spill contingency planning

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Part I. Trajectory Models

Copeland and Thiam-Yew (2006)

- Brunei shelf sea (375 x 100 km)
- 3 ADCP current profilers and met. towers deployed for 1 year
- 209 ‘typical flow fields’ identified were used as the ‘library’ of hydrodynamic conditions encountered (5.4 days on a 1.7 GHz P4!)
- Year-long simulations of a variety of spills run to generate probability of land-fall

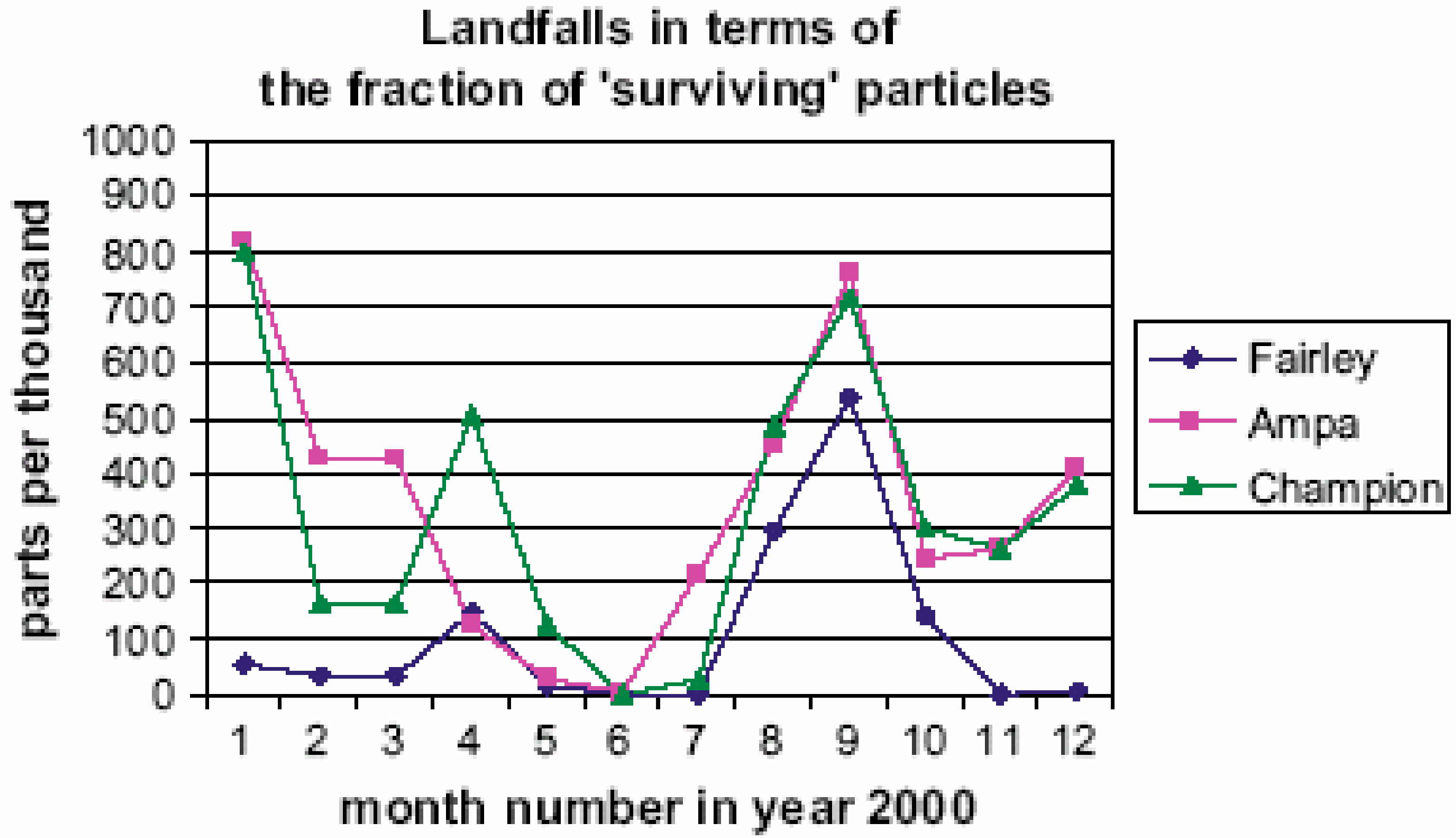


Fig. 7. Landfall occurrences in parts per thousand of total number of 'surviving' particles.

Part I. Trajectory Models: Integration of real time data

- Motivation: More accurate trajectories based on ‘now-casting’ with near-real time observations
  - Meteorology
  - Drifter deployments
  - Current profilers
    - Deployed in response to spill
    - Long-term deployments in critical areas

- Challenges: getting the real time stuff to talk to the models during a spill (hurricanes, etc.)

Tracking and Predicting the Atmospheric Dispersion of Hazardous Material Releases: Implications for Homeland Security

Committee on the Atmospheric Dispersion of Hazardous Material Releases, National Research Council

ISBN: 0-309-08926-3, 114 pages (2003)

Findings from NRC 2003

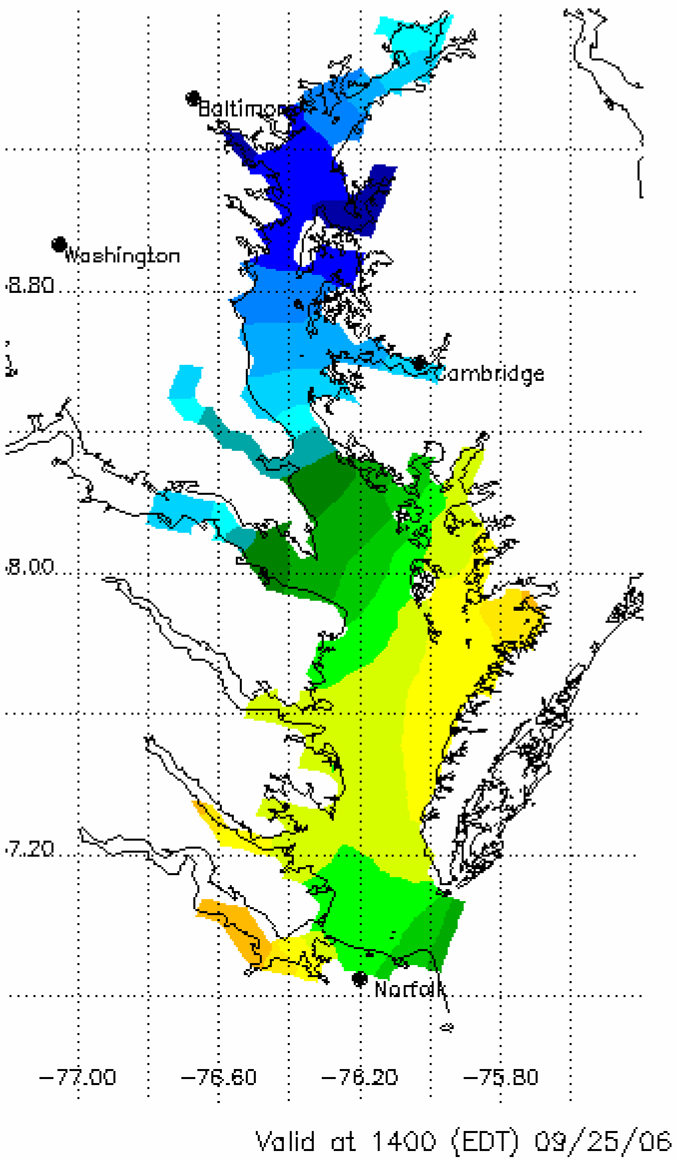
- … (I)t often is difficult to obtain the data from multiple observational arrays, especially in real time.

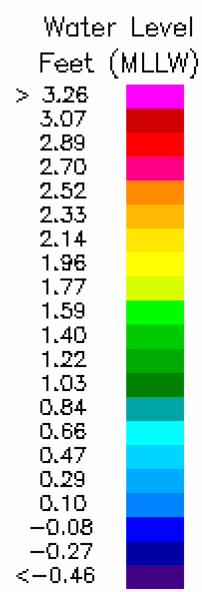
- A comprehensive survey of the capabilities and limitations of existing observational networks should be conducted, followed by action to improve these networks and access to them, especially around more vulnerable areas.

- Mobile observational platforms can provide valuable information and fulfill multiple needs in the first minutes to hours after a hazardous release.

Findings from NRC 2003

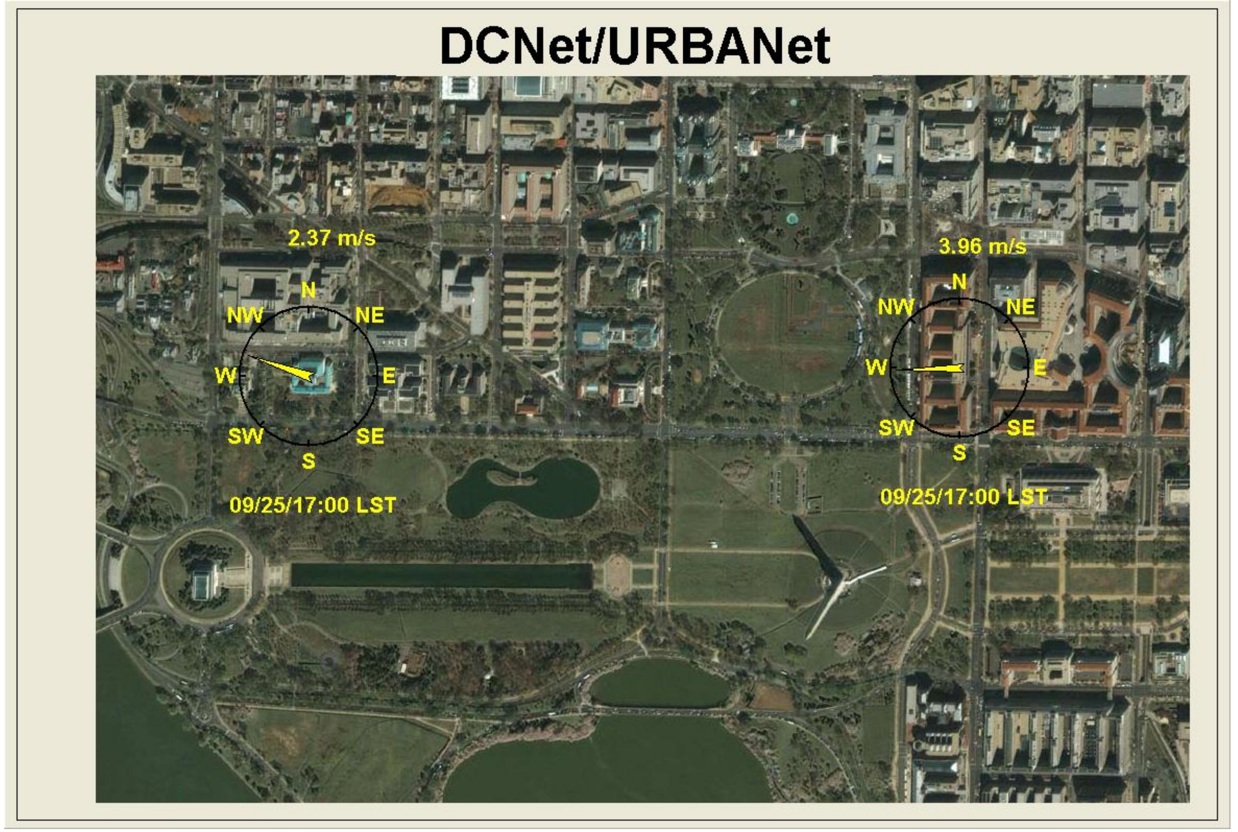
"…(U)tilize … instrumentation for other applications (e.g., to enhance air pollution monitoring, optimize agricultural practices, aid in severe storm forecasting and highway network safety), thus sharing the costs and ensuring that the array will be continuously used, maintained, evaluated, and quality controlled." (NRC 2003)





Chesapeake Bay Operational Forecast System (CBOFS)

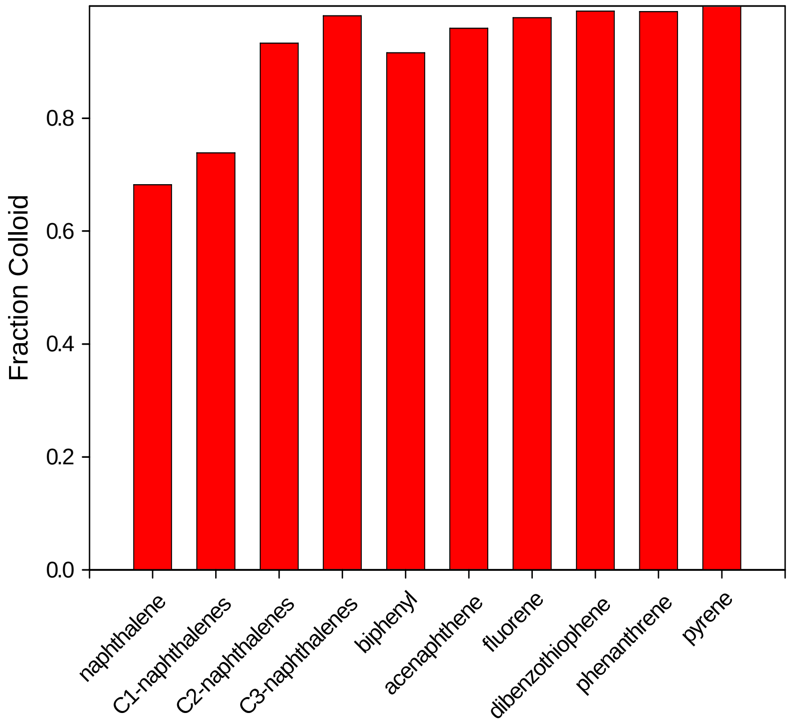
- "It is necessary to learn how to more effectively assimilate into models an appropriate range of meteorological data … from observing systems…, especially as the quality and availability of these data increase." (NRC, 2003)



NOAA Air Resources Laboratory

Part II. Modeling Colloidal Oil

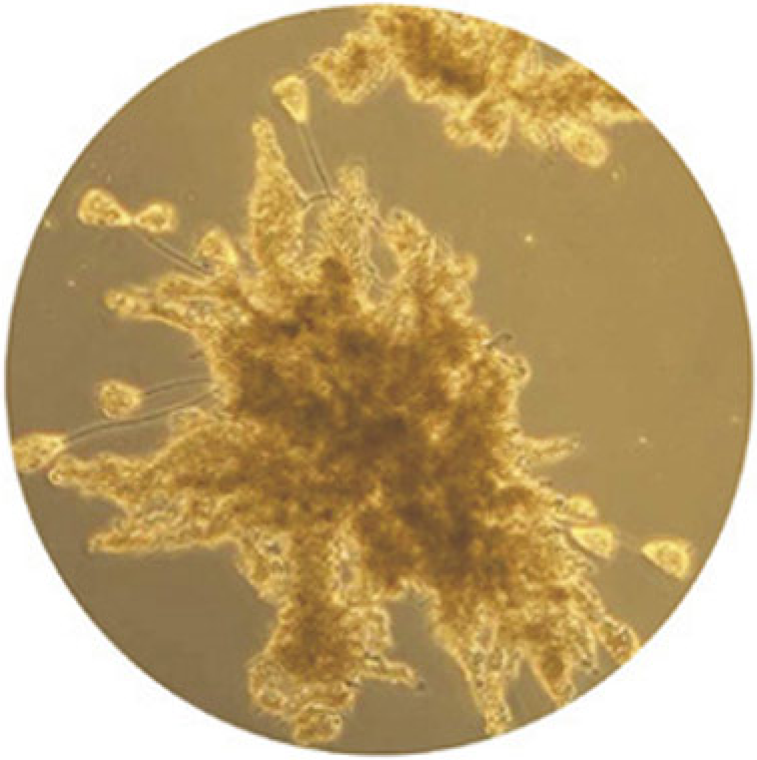
- Motivation
  - Entrainment of oil below surface
  - Colloidal-sized droplets buffer dissolved hydrocarbon concentrations
  - Coagulation with aquatic particles drives oil settling and controls water column residence times
  - Size and surface properties influence bioavailability and reactivity



Sterling *et al.* (2003) Environ. Sci. Technol. 37,4429-4434

Physical characteristics of flocs

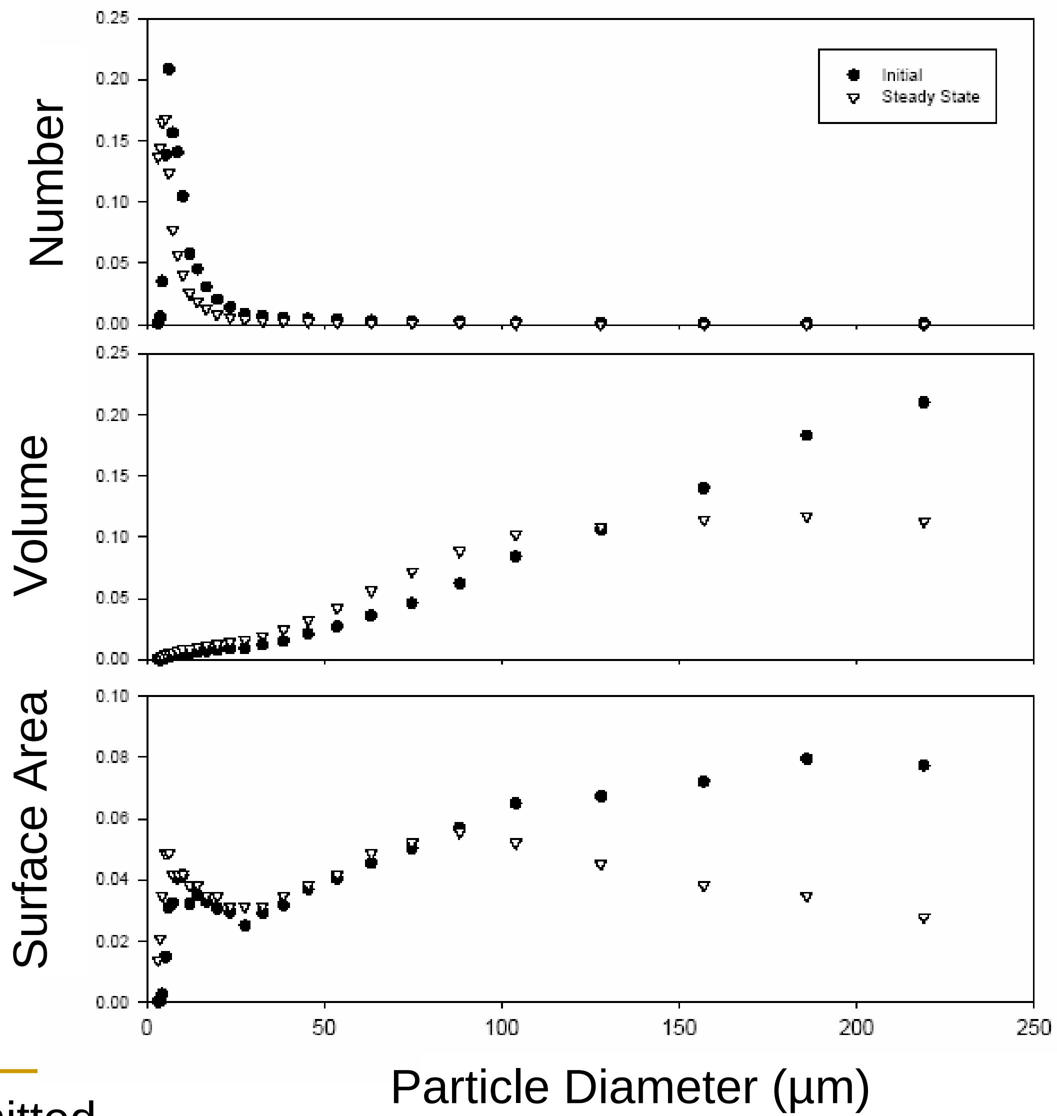
- Lower settling velocity
- Lower bulk density
- Higher contact area (porosity)



http://www.water-technology.net/contractor_images/cu_water/flocke.jpg

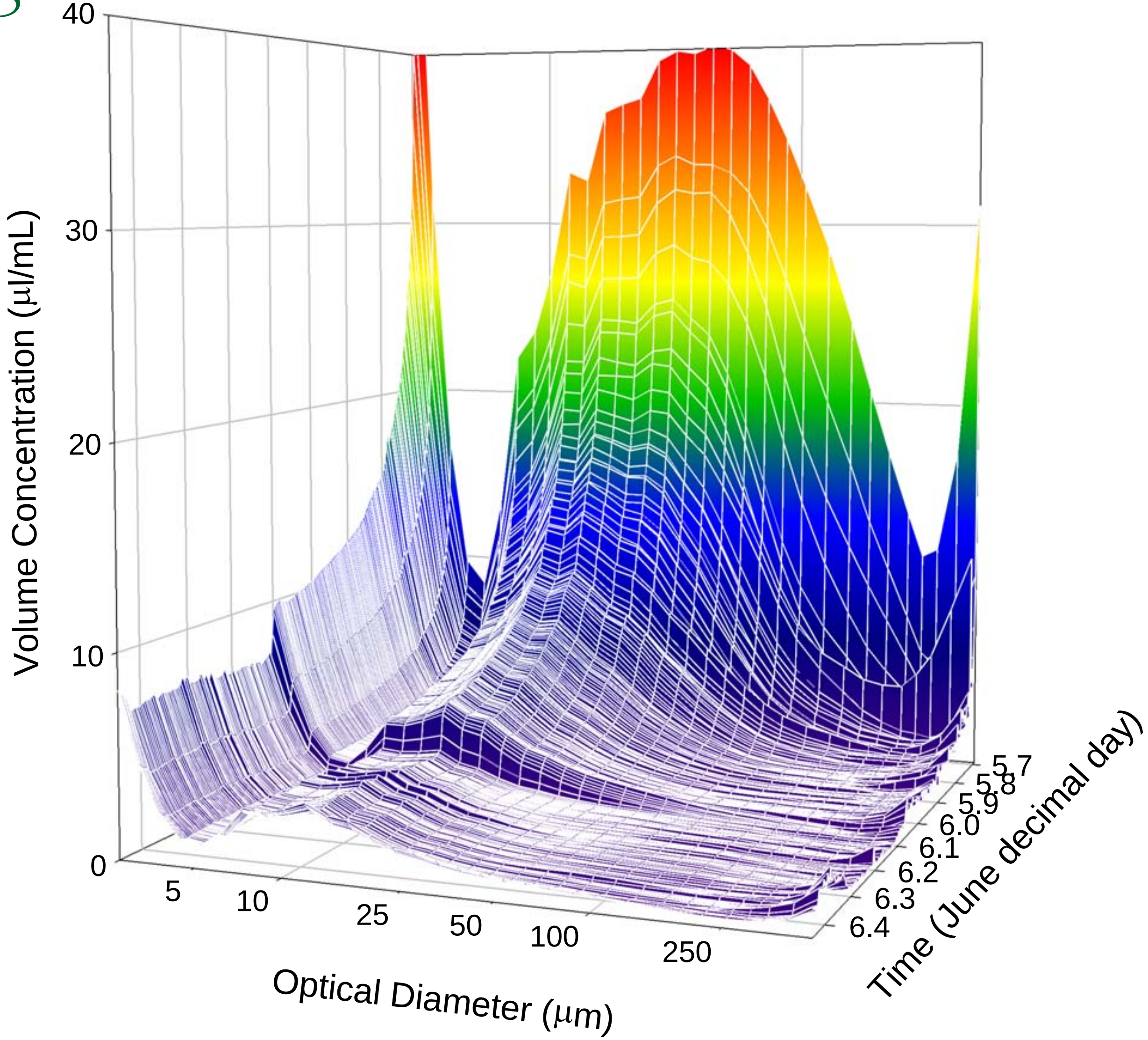
Part II. Modeling Colloidal Oil

Laser In-Situ Scattering Transmissometry (LISST)



Schneider and Baker, submitted

Changes in particle size distribution during settling: mesocosm measurements



Part II. Modeling Colloidal Oil

- Coagulation Kinetics

$$\frac{dn}{dt} = -\alpha\beta n^2$$

$$\beta_{Brownian\_motion} = \frac{2}{3}\frac{kT}{\mu}\frac{(D_i + D_j)^2}{D_i D_j}$$

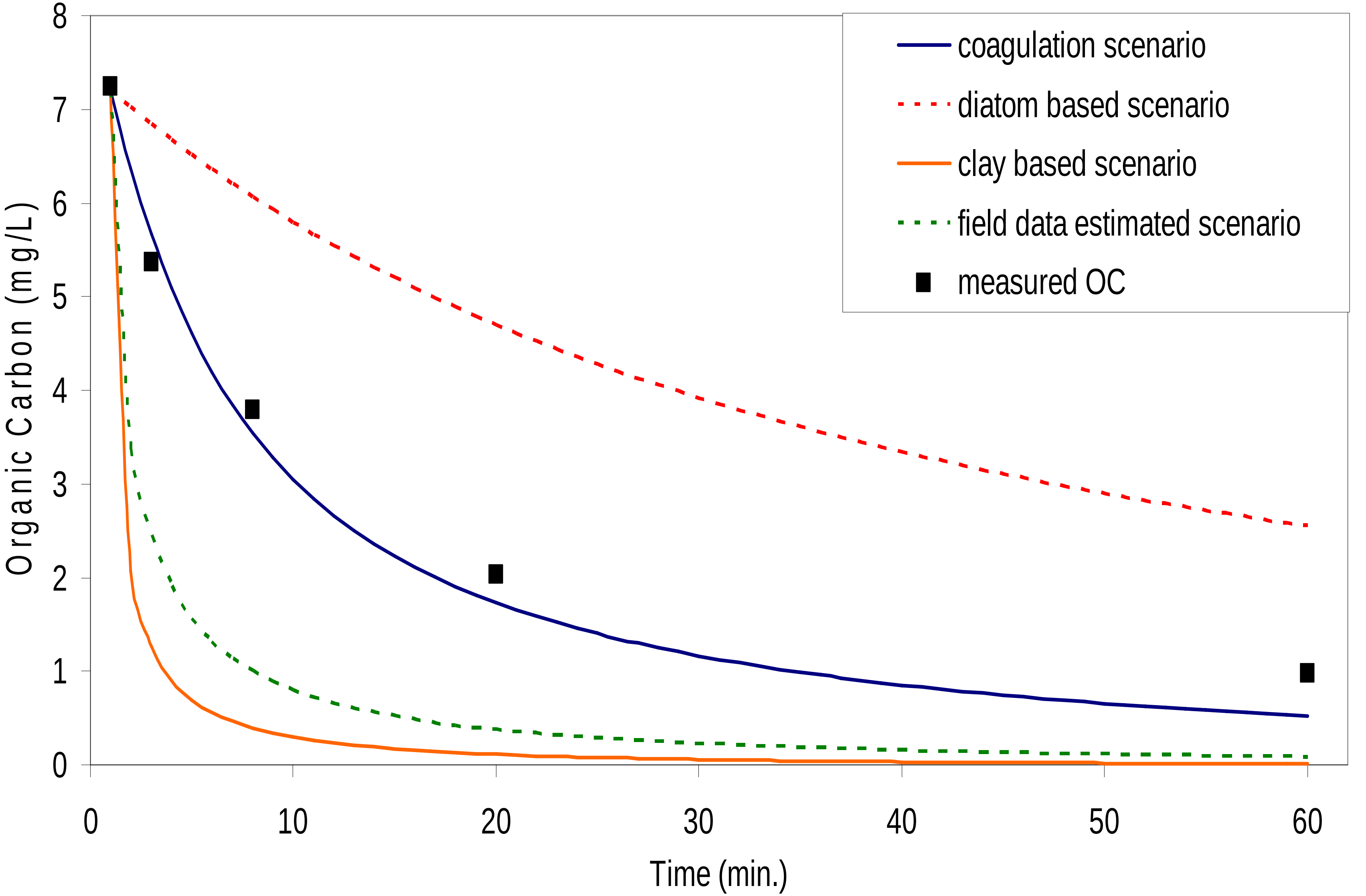
$$\beta_{different\_velocity;i\_and\_j} = \pi(D_i + D_j)^2 \left| w_{s,i} - w_{s,j} \right|$$

$$\beta_{shear\_stress;i\_and\_j} = \frac{4}{3}\left(\frac{\varepsilon}{\nu}\right)^{0.5}(D_i + D_j)^3$$

Part II. Modeling Colloidal Oil

- Chang and Baker estuarine coagulation model
  - 1000 particle sizes between 2 and 1000 µm
  - Two fundamental particles
    - Diatoms
    - Clay
  - Size-specific porosity, bulk density, organic carbon content, and settling velocity calculated dynamically at each time step

Mesocosm settling experiment: Model calibration



Part II. Modeling Colloidal Oil

- See also

  - Sterling, M.C., Bonner, J.S., Ernest, A.N.S., Page, C.A., Autenrieth, R.L., (2004) Characterizing aquatic sediment–oil aggregates using in situ instruments. Mar. Pollut. Bull. 48, 533–542.
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  - Hill, P. S., A. Khelifa and K. Lee (2002). "Time scale for oil droplet stabilization by mineral particles in turbulent suspensions." Spill Science & Technology Bulletin 8(1): 73-81.
  - Khelifa, A., P. Stoffyn-Egli, P. S. Hill and K. Lee (2002). "Characteristics of oil droplets stabilized by mineral particles: Effects of oil type and temperature." Spill Science & Technology Bulletin 8(1): 19-30.
  - Khelifa, A., P. Stoffyn-Egli, P. S. Hill and K. Lee (2005). "Effects of salinity and clay type on oil-mineral aggregation." Marine Environmental Research 59(3): 235-254.

Final Thoughts

- ***0-12 hours post-spill***
  - ***Early weathering (volatilization/evaporation)***
  - ***Subsurface transport ($\rho_{oil} > \rho_{seawater}$)***
  - ***Real-time data***

- ***12 hours – few days post-spill***
  - ***Conversion to small droplets***
  - ***Coagulation***
  - ***Acute toxicity to sensitive targets***

- ***Days to months to years post-spill***
  - ***Bioavailability!***