NOAA/CRRC Oil Spill Modeling Workshop

- State of the art
- The future
- Research questions to be addressed

… in 10 minutes….

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State of the art

- Purposes of oil spill models: decision-support tools
  - Contingency planning
  - Spill response
  - Net environmental benefit analysis
  - Natural resource injury and damage assessment

- Aspects of applications
  - Physics – winds, waves, currents; ice, shorelines, sediments
  - Chemistry – evaporation, dispersion, dissolution, emulsification, degradation, photo-oxidation
  - Biology – behavior, exposure, effects; individuals, populations, ecosystems

State of the art

Scoring:

- 90% means we’re wonderfully happy with the state of the art
- 10% means we have a long way to go in this area

Relative State-of-the-Art versus Research Recommendations:

- Low score does not necessarily imply a high research priority
- Place our efforts
  - Where they will lead to the most improvement in decision support

    Or
  - Were we can fill gaps not being addressed elsewhere in the R&D world

State of the art

- Chemistry — Scores
  - Evaporation — 90%
  - Dispersion
  - Dissolution
  - Emulsification
  - Degradation
  - Photo-oxidation — 10%

Reference range

State of the art

Physics	Scores
Winds	60%
Currents	50
Waves	40
Ice	20
Sediments	30
Shorelines	40

State of the art

- Chemistry Scores
  - Evaporation 90%
  - Dispersion 50
  - Dissolution 70 given dispersion of a known mass, composition and droplet size distribution
  - 30 otherwise
  - Emulsification 70 with weathering data
  - 30 without
  - Degradation 70 dissolved, water column
  - 50 droplets, water column
  - 30 sediments
  - Photo-oxidation 50 with weathering data
  - 10 without

State of the art

■ Biology	Score
■ Behavior	80% sessile organisms
■	40 otherwise
■ Exposure	30% sessile
	(60% x 70% x 80%, currents x dissolution x behavior)
■	20% otherwise
■ Effects	70% acute, given an exposure
■	20% chronic

Physics: the future

- ……… is (almost) now!
- Currents, winds, waves
  - Nowcast-forecast: integrated global – local applications
    - As in weather models
    - Wave modeling
      - Probably the least standard component
      - Not included explicitly in most oil spill models
- Ice
  - Work on-going
  - Focus on small (m) and large (km) scales
  - Also a challenge to integrate the two
- Shorelines: needs work
- Sediments: needs work

The future: chemistry

- The Grail: to predict weathering process rates soley from oil composition
  - Emulsification remains the toughest nut
  - Role of photo-oxidation in both emulsification and degradation has not been quantified
- Characterization of degradation products and ”UCM”
  - Solubilities
  - Toxicities
  - Degradation rates
- Need to understand rheology of weathered oil, not just the viscosity

The future: biology

- The Grail: estimation of individual, population, and ecological effects within reasonable and quantifiable uncertainty limits
- Behavior modeling
  - Verisimilitude is very high (fantastic animation skills!!)
  - Causal linkages generally remain very weak
  - Limits reliability of exposure calculations
- Exposure, effects, individuals, populations, ecosystems
  - The fishy side is the easiest to work on (but still difficult)
  - The feathery, furry side is more difficult (establishing effects thresholds, for example)

Research questions: Coastal Oil Spills

- Wind, current, and coastal data
  - Spatial resolution
  - Topographical steering
  - Sea breeze-land breeze
  - Rivers and streams
- Shallow waters, coastlines, high turbidities
  - Oil-sediment interactions
    - Shorelines
    - Water column particles
    - Bottom sediments
  - Oil-ice-shoreline interactions

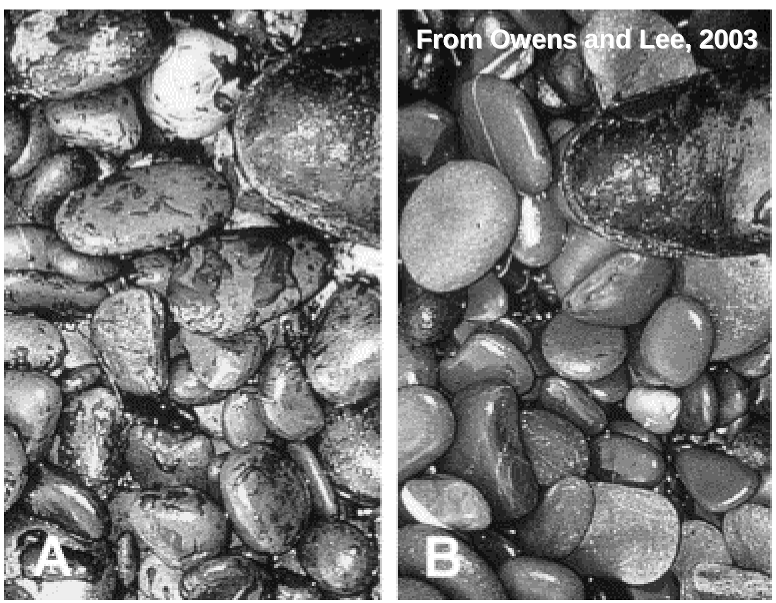
Oil ashore: we actually know a lot!

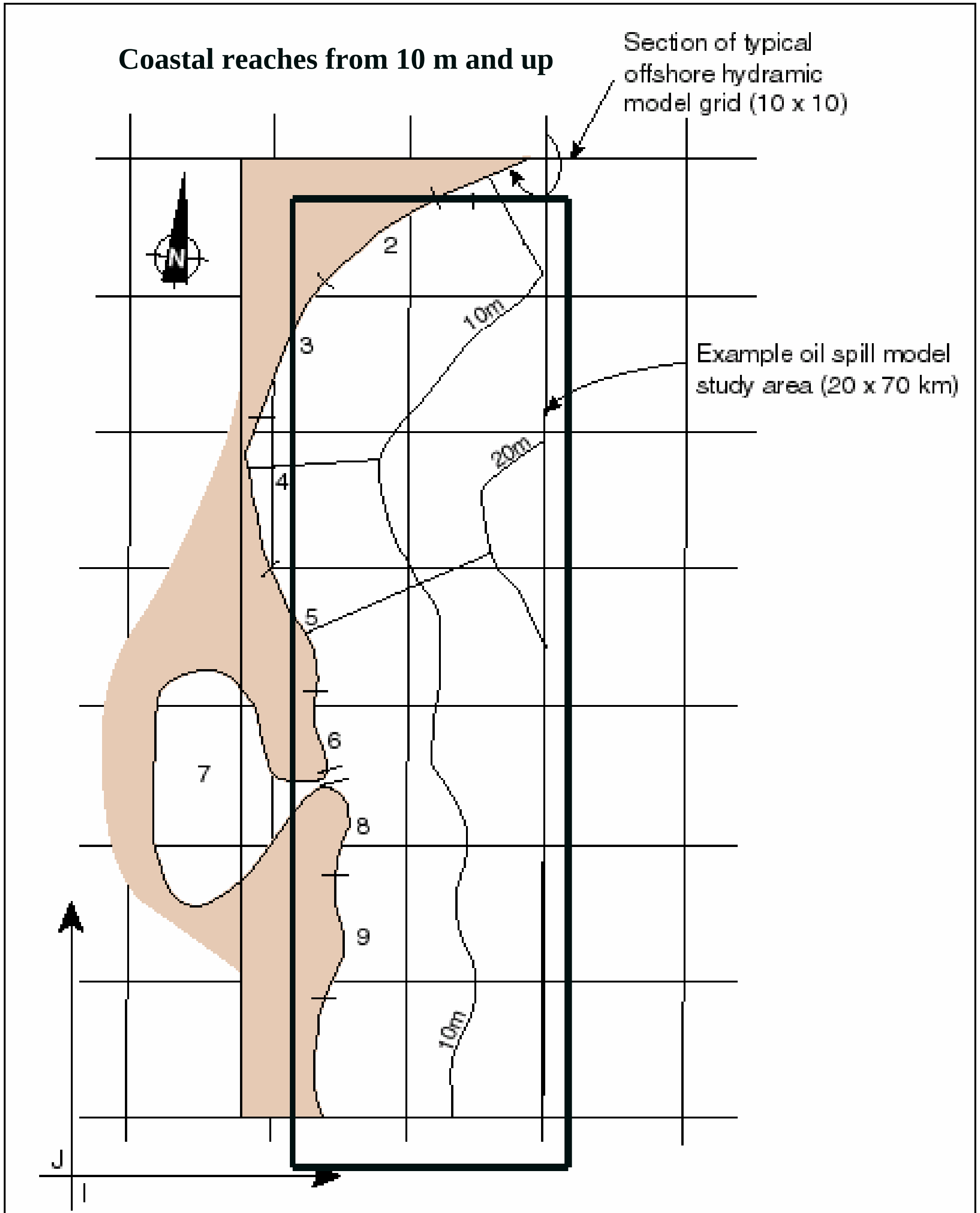
- Thousands of coastal spills
- Hundreds of papers
- Most oil spill models do not incorporate shoreline processes

SERVER Oil Spill – IFO 180 - 02/2007
Norwegian Coast

Prestige Oil Spill, Spain

Cobbles before (A) and after (B) surf washing operations (scale provided by boot in upper right).





Generalized approach: representation of coastline by segments

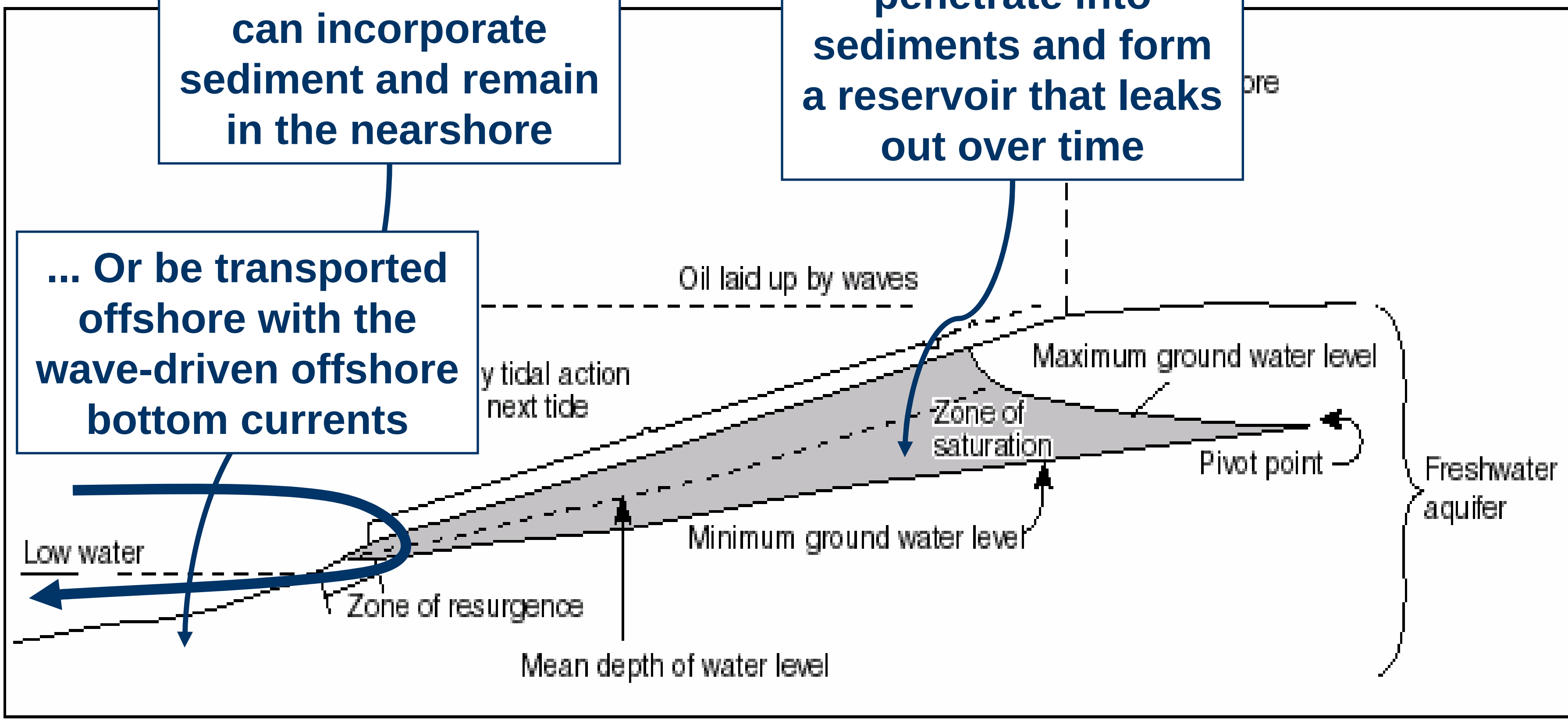
- morphology
- sediment type
- exposure

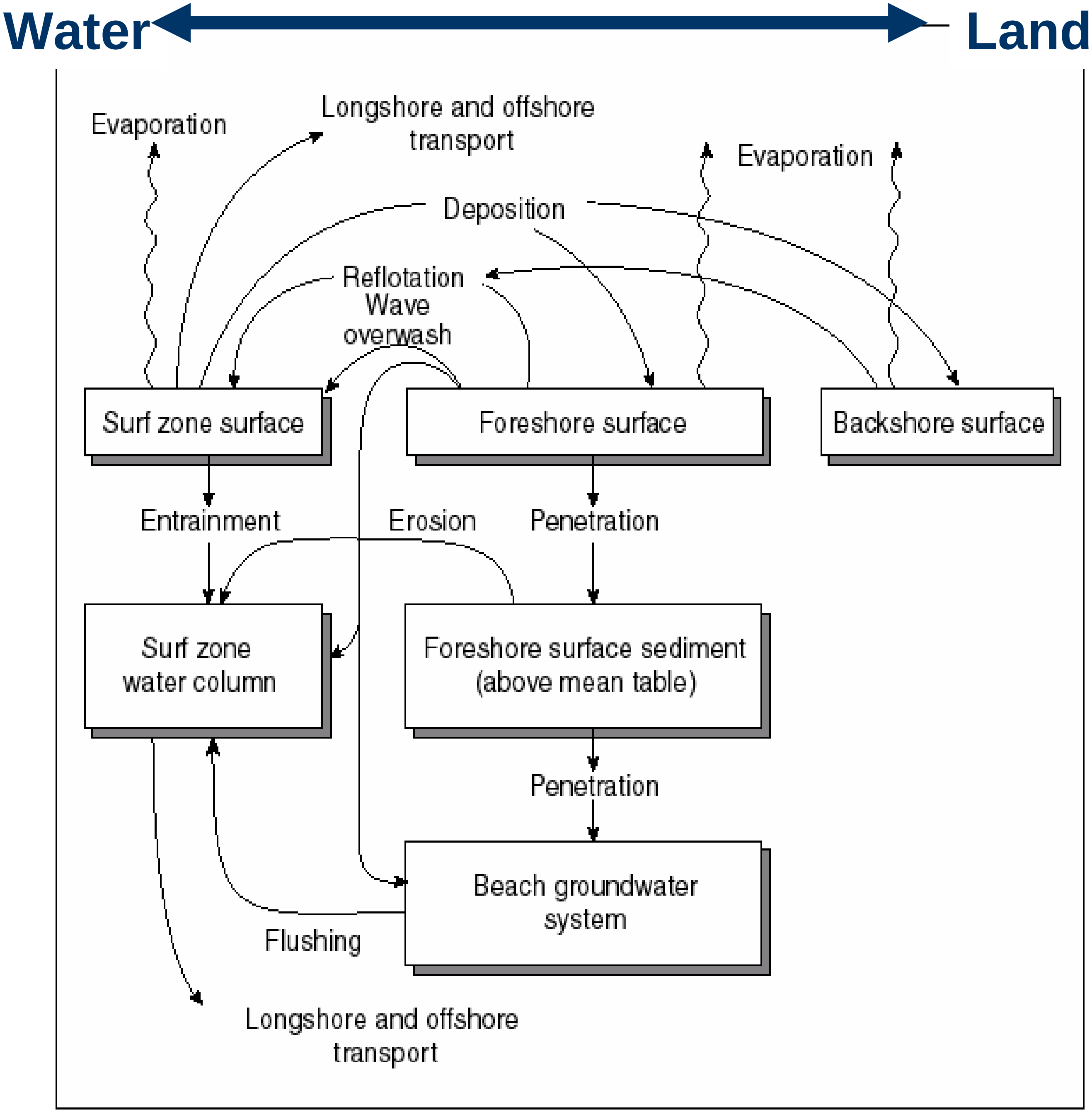
Cross-section of a reach with porous sediment: schematic of water (and oil) penetration

Oil on the foreshore can incorporate sediment and remain in the nearshore

Oil on the foreshore or backshore can penetrate into sediments and form a reservoir that leaks out over time

... Or be transported offshore with the wave-driven offshore bottom currents





Conceptual model of oil - shoreline interaction processes for each coastal segment

How many of all these details do we really NEED to include?

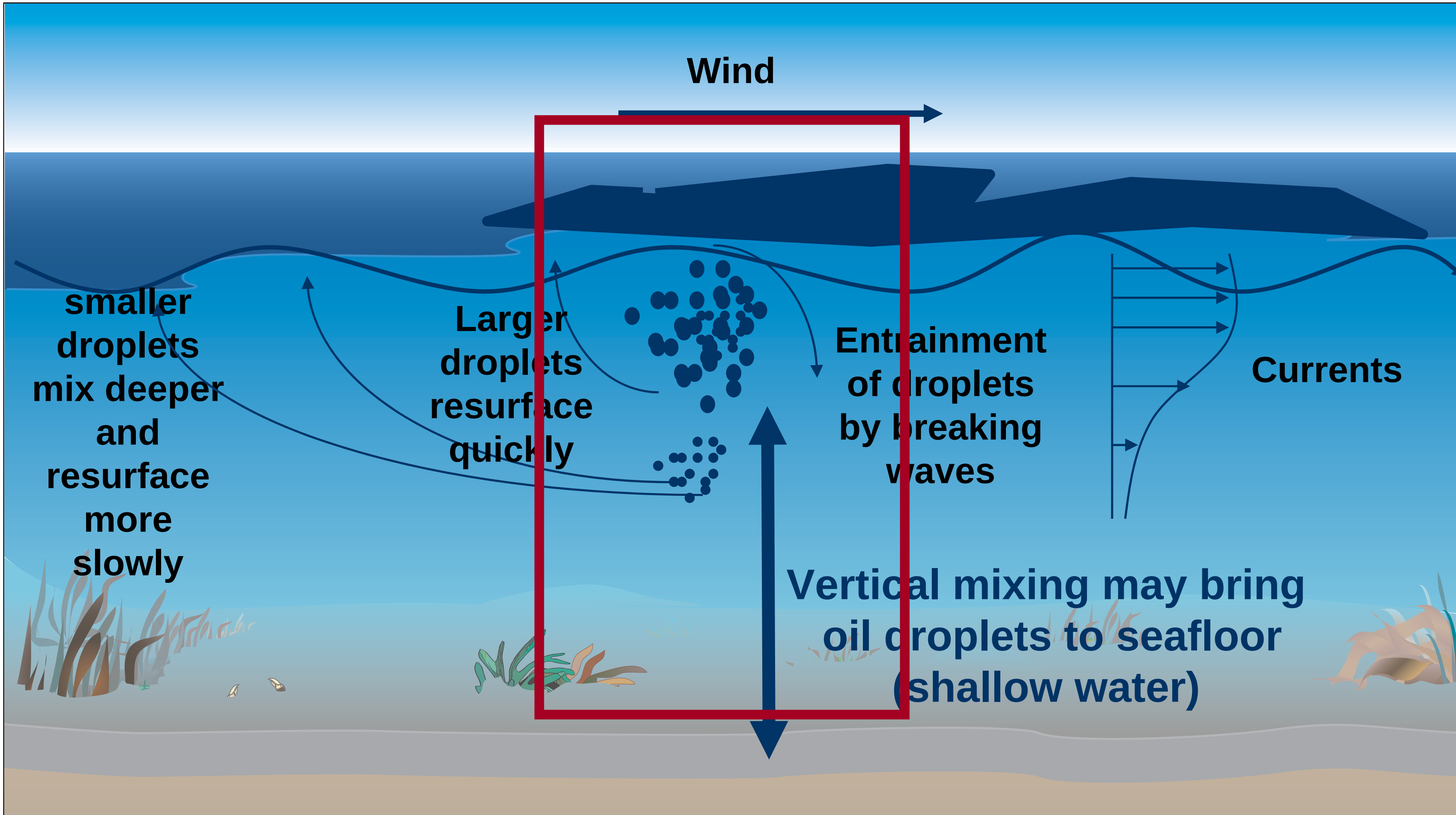
- What are the key questions we want the model to answer?
- Among others:
  - How long will a coastal area be impacted with no intervention?
  - What will be the natural removal rate?
  - What happens to oil washed off the beach?
  - What happens if we disperse the oil just before it comes ashore?
  - … or apply other mechanical or chemical treatments on shore?
  - Is this better or worse than dispersion offshore?

- What's the minimum model we can build that will give us some reasonable answers?

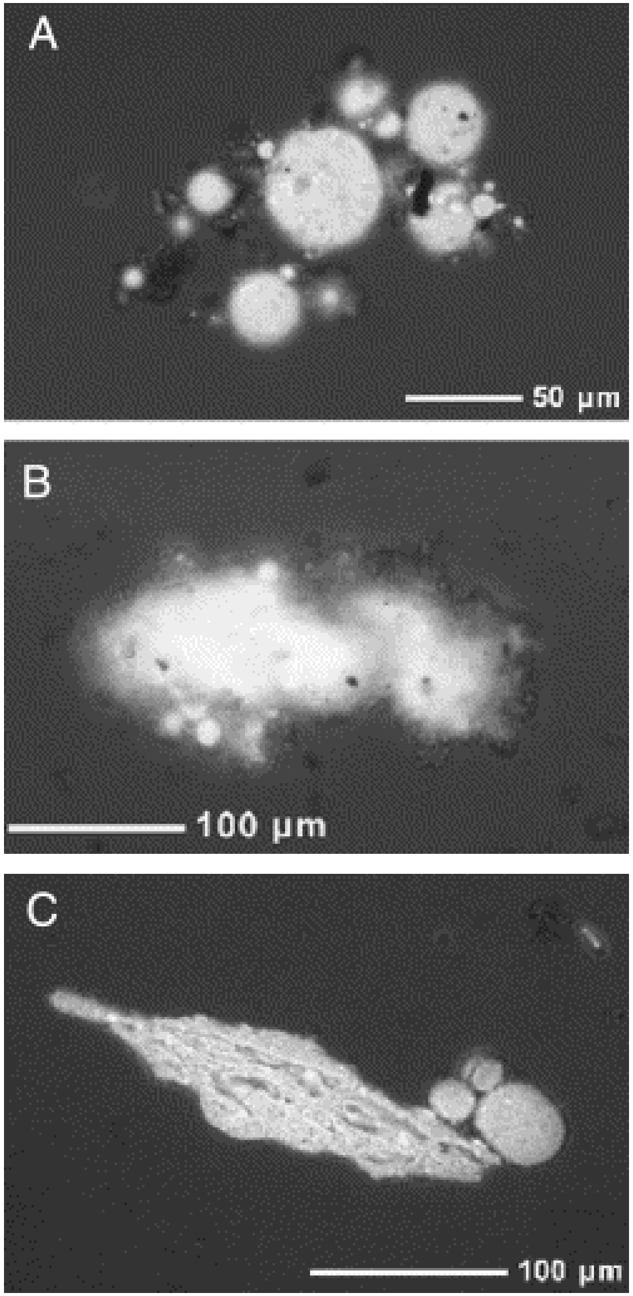
Suggested minimum data needs for modeling oil-shoreline interactions

1. "Maximum holding capacity" (e.g. mass or thickness/unit area) as function of sediment type, oil type, and weathered state.
2. Natural removal rates (surface oil versus oil within sediments) as functions of the above parameters, plus degradation, wave and tidal exposure, placement on the beach.
3. Partitioning among surface, water column, and sediment compartments for oil washed off a beach.
4. Changes in these parameters for alternative response options in the coastal zone.

Water column transport processes for oil droplets



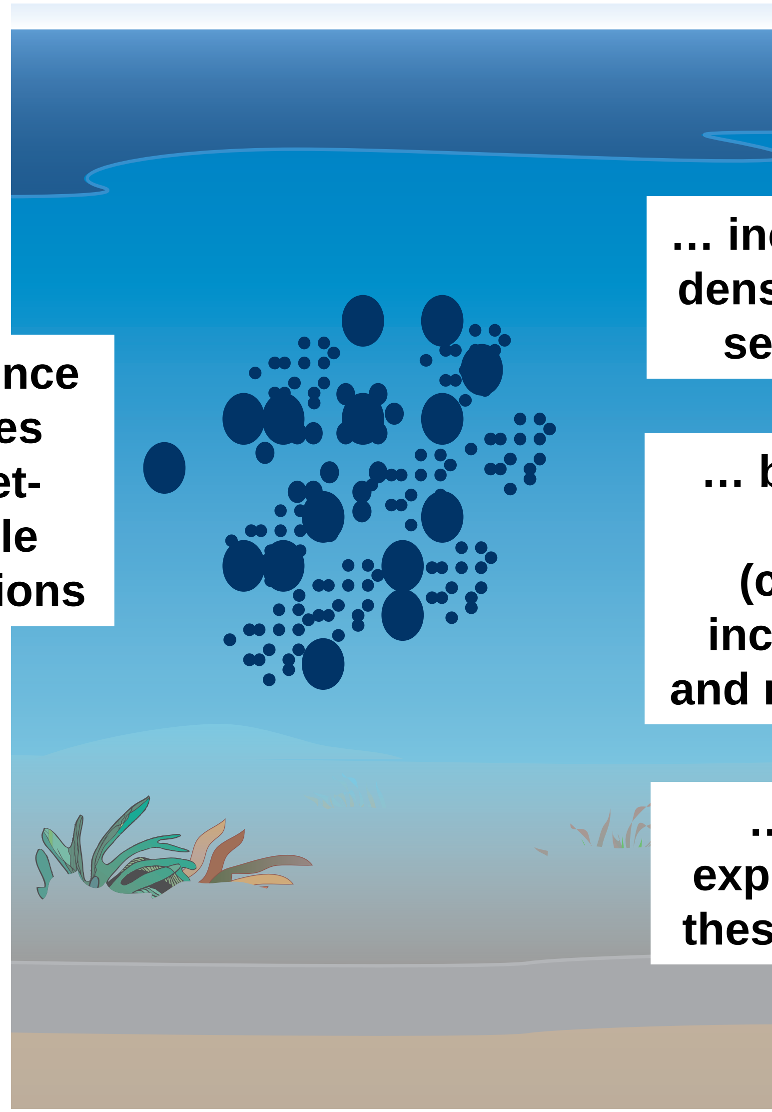
Interactions among droplets and suspended particulate matter in near-coastal waters



Interaction with fine clay particles contributes to sinking, and increased degradation rates

From Owens and Lee, 2003

Interactions among droplets and suspended particulate matter in near-coastal waters



Turbulence induces droplet-particle interactions

… increases density and settling

… but droplet-droplet interactions (coalescence) will increase droplet size and may induce rising…

… so we want the experiments to give us these interaction terms.

Turbulent dispersion equation for an experimental setup

$$\frac{\delta C}{\delta t} = \vec{\nabla} \bullet D \vec{\nabla} C - Loss_{sed} - Loss_{srf} - Loss_{walls} + Q$$

We're interested in these terms.

$\frac{\delta C}{\delta t}$ = local rate of change of hydrocarbon concentration

$\vec{\nabla}$ = gradient operator= < δ /δx , δ /δy , δ /δz >

D = turbulent dispersion coefficient (isotropic ?)

Losses are to sediments, re-surfacing, walls of experimental apparatus

Q represents sources of C, such as dispersion from surface slicks

Loss to sediments: fractional partitioning of oil droplets to sediments (each collision or inter-action)

$$F_{sorp} = \mathrm{K_p}\, C_{spm}\, F_{oil}$$

F_{sorp} / F_{oil} ~ probability of a sorptive interaction given a collision

- F_{sorp} = fraction sorbed to particulate matter (water column, nepheloid layer, or bottom sediments
- K_p = sorption partition coefficient, **need K_p!**
- C_{spm} = concentration of suspended particulate matter,
- F_{oil} = fraction of oil which does not sorb to particles on interaction

Turbulent dispersion equation for the experimental setup

$$\frac{\delta C}{\delta t} = \vec{\nabla} \bullet D \vec{\nabla} C - Loss_{sed} - Loss_{srf} - Loss_{walls} + Q$$

Measure these quantities

...and eliminate this one

$\frac{\delta C}{\delta t}$ = local rate of change of hydrocarbon concentration

$\vec{\nabla}$ = gradient operator= < δ /δx , δ /δy , δ /δz >

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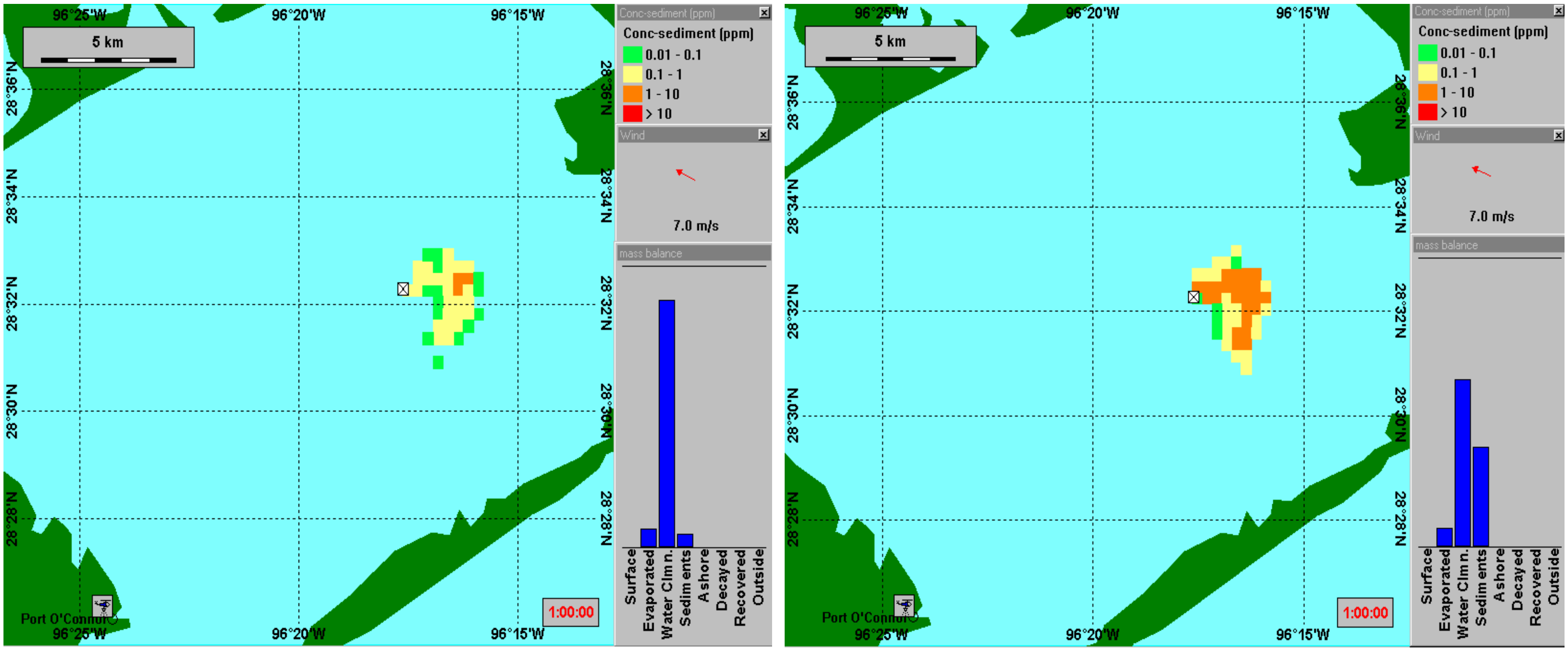
Modelling interactions of oil droplets with bottom sediments



Model sensitivity to sediment sorption coefficient in shallow water. Sorption parameter (K_p) increased by 10x in right hand picture.

(Modelling study for ExxonMobil; Reed, Johansen, Konkel et al, 2003; Env'l Modelling and Software)

Interactions of oil with water column and bottom sediments

- What determines the probability that an oil droplet that encounters bottom sediments will adhere?
  - Oil type
  - Weathered stage
  - Sediment characteristics
  - Application of dispersants
  - Turbulence level
  - ...other factors?
  - Effects of dispersant application?

Need K_p for this experimental space

- What are <u>effective</u> oil droplet – suspended particulate matter (SPM) interaction rates in the water column?
  - Turbulence
  - Droplet and SPM density (numbers per liter)
  - Oil and SPM characteristics

...and for this one