Simulating oil films resulting from offshore produced water discharges

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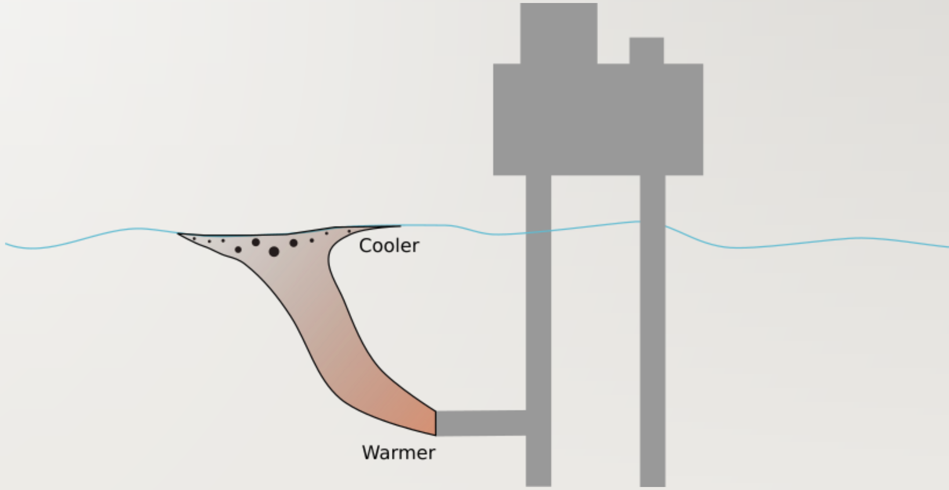
Why simulate this?

- Oil relase to the ocean is strongly regulated and it is of interest to know the source of each oil observation
- Simulating PW films at a platform with high accuracy would permit knowing when oil films originate from PW and when they do not
- Having a set up simulation allows testing future scenarios: higher rates, changes in oil concentration, or the effect of faulty oil-water separation

How does the oil get there? Produced water oil separation, discharge and transport

- Different separation techniques (hydrocyclone, gas separation, etc) are used offshore to reduce the amount of oil in PW
- After separation, small amounts of oil droplets, often called dispersed oil, remain in PW,
- Successful separation leaves droplets up to 10-25 μm in size (Judd et al., 2014)
- When PW is released to sea, droplets may rise to the sea surface with the buoyant PW plume to form a thin surface film
- Dissolved oil is also released with PW but does not contribute toward creating surface films



Observations

1. Aerial observation from plantform or field campaigns
2. Satellite observation

Field study Troll B platform, May 2001

- Sheen, metallic, and rainbow oil
- Implies thickness between 0.04 μm and 50 μm (BONN convention)
- Observations relevant to modelling
  1. Film forms right by the platform. Either:
     1. Droplets are quickly transported to the surface (more likely)
     2. Droplets surface further away but the tide has just turned (less likely)
  2. Droplets arrive in sufficient volume and density to the surface to create a continuous film

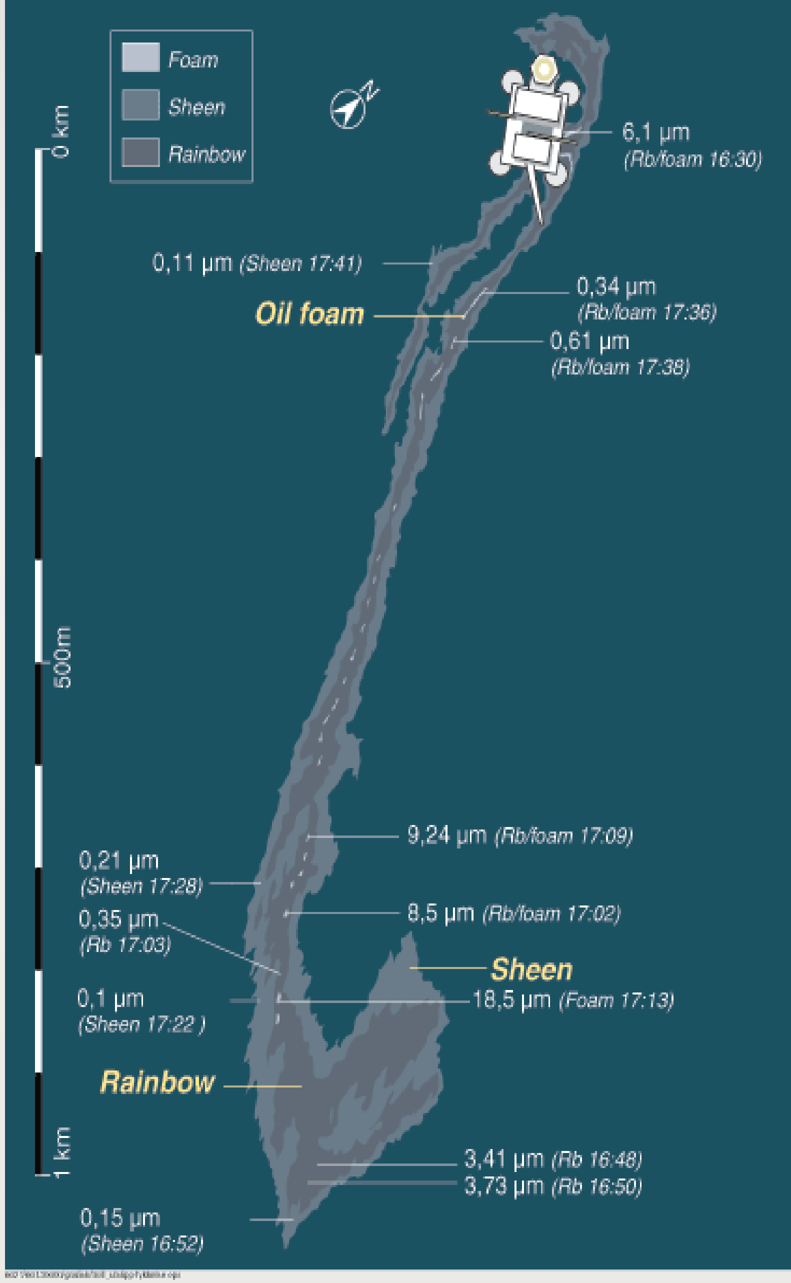
Field study Troll B platform, May 2001

Observed film estimates:

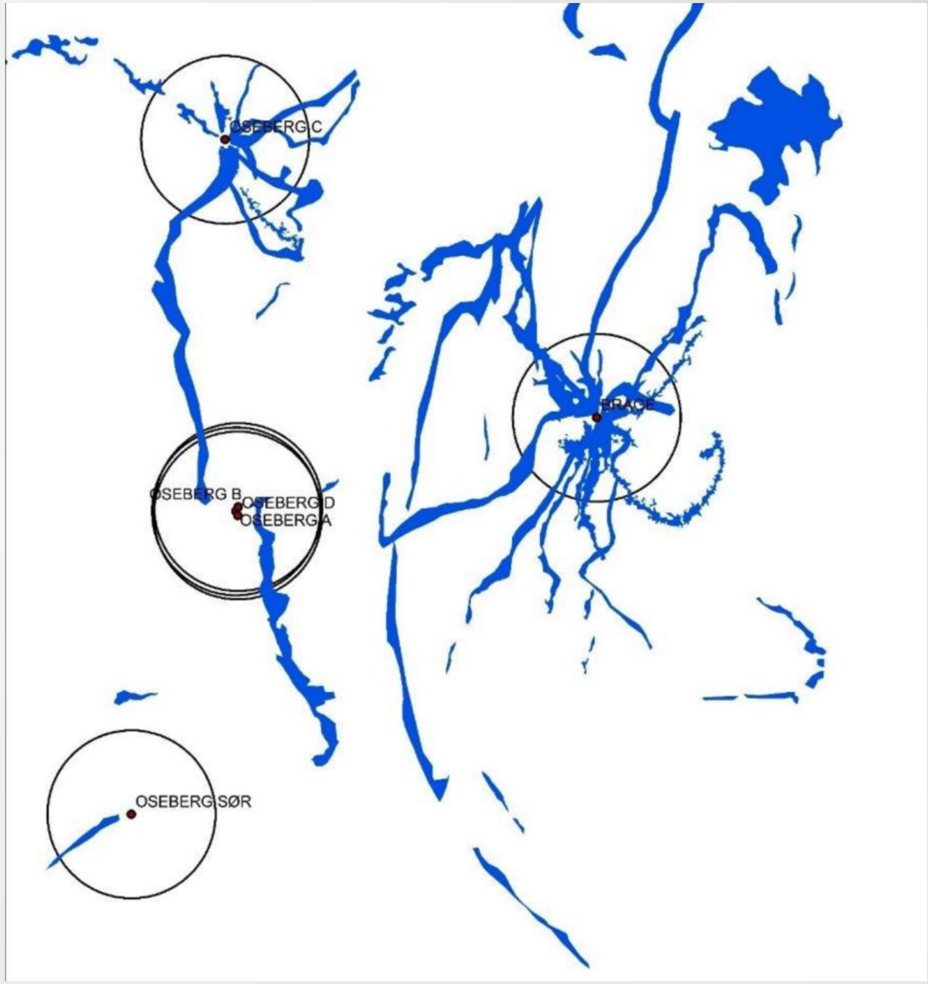
- Length: 1 km
- Area: 0.04 km^2
- Volume: 7 L to 106 L

Release data

- PW: 22.000 m^3/day
- Oil conc. 25 ppm
  - -> 30 L/hour



Oil films from PW are regularly observed around oil platforms with satellite monitoring



Satellite observations at the Brage/Oseberg fields. Indicative of signatures from PW releases (Norwegian Coast Guard, 2020)

From field to simulation

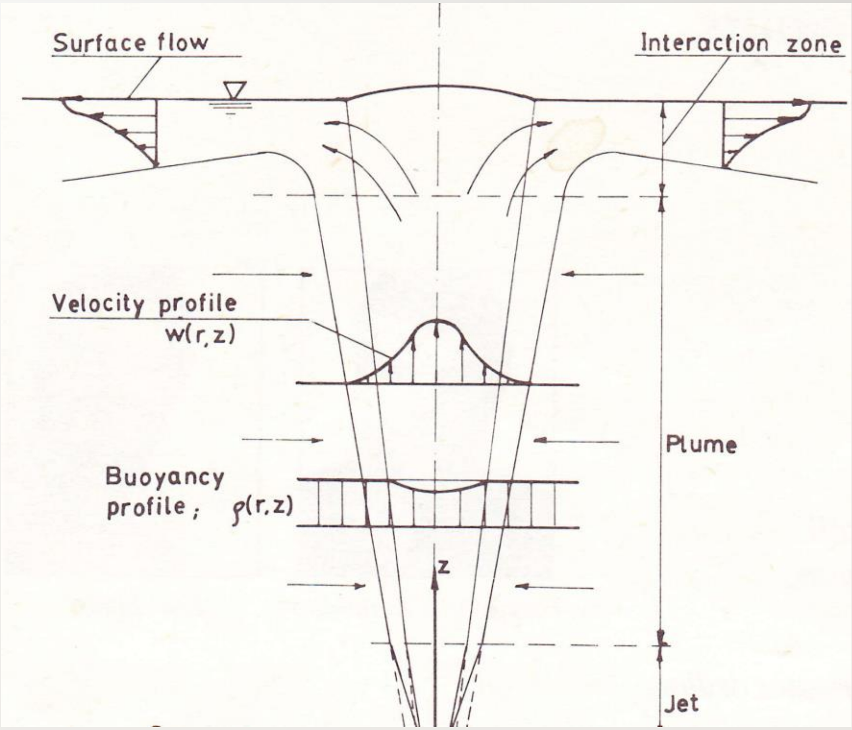
- We know that PW-associated oil films are regularly observed
- What is needed to simulate them?
- Key aspects:
  1. Plume mechanics: bouyant rise and surface spreading
  2. Oil droplet size distribution

Modelling of the mechanics of PW plume rise and spreading is important to understand film formation

PW with lower density than sea water will rise to the surface and spread radially after impinging on the sea surface.

This may transport small oil droplets close to the surface layer. Droplets thus deposited can form a surface film.

The presence of gas bubbles in PW will strengthen plume buoyancy

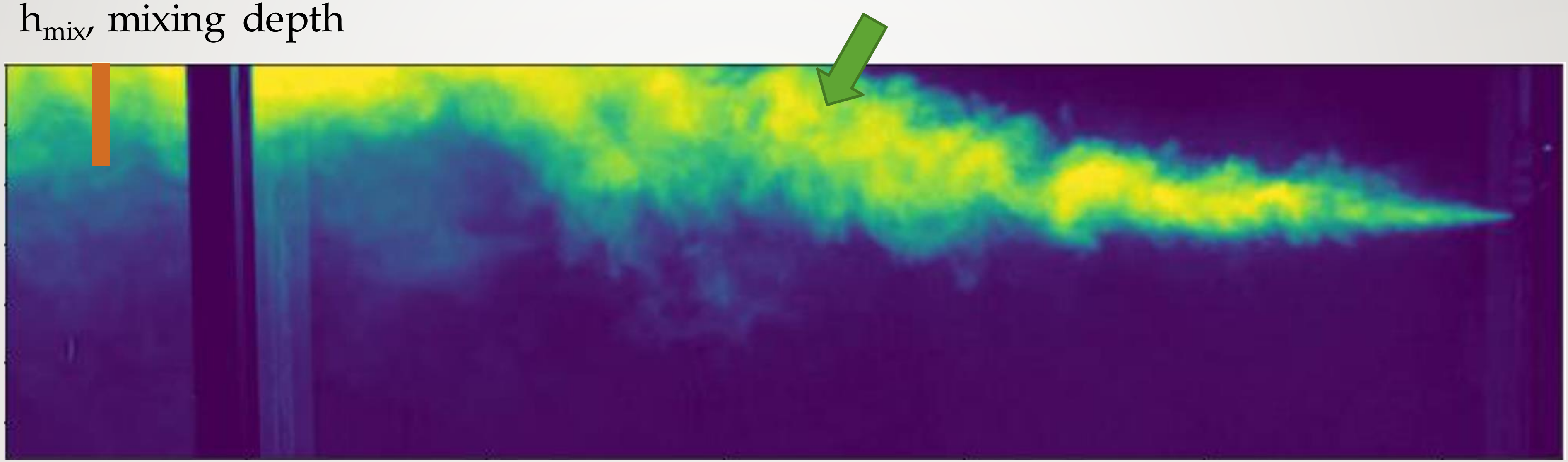


Fanneløp and Sjøen, 1980

Mechanics of PW plumes can be studied with down-scaled laboratory experiments

Potential for tracking individual oil droplets in plume

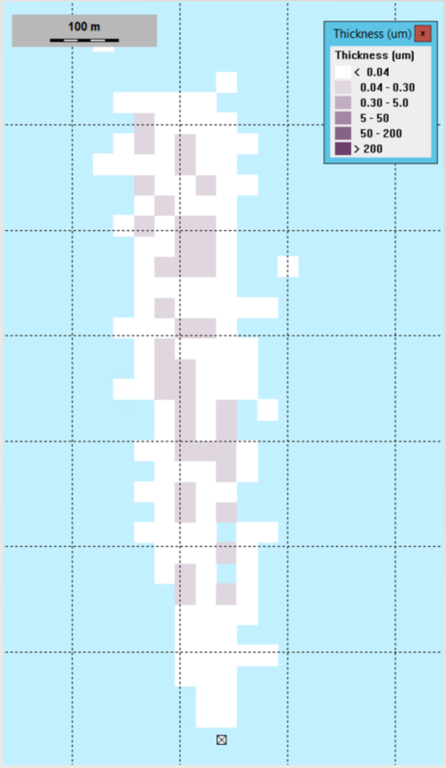
h_{mix}, mixing depth



Experimental PW release into SINTEF meso-scale flume containing seawater.
Release data: T: 58 °C, salinity 35 psu, release angle 45°
(Wiken, 2021, Master Thesis)

Simulating PW-related oil films with OSCAR

- OSCAR is a general purpose 3D oil spill model, developed for nearly 30 years (Reed et al., 1995, Reed et al. 2000, Pan et al. 2020)
- Integrated with the Plume3D integral plume model, with surface interaction terms from Fanneløp and Sjøen (1980)
- Relevant input data:
  - Ocean currents for vertical transport
  - Wind speed for transport and upper ocean turbulent mixing
  - PW release data: rate, oil concentration, temperature, salinity
  - Oil droplet size distribution



Factors that affect surface oil formation

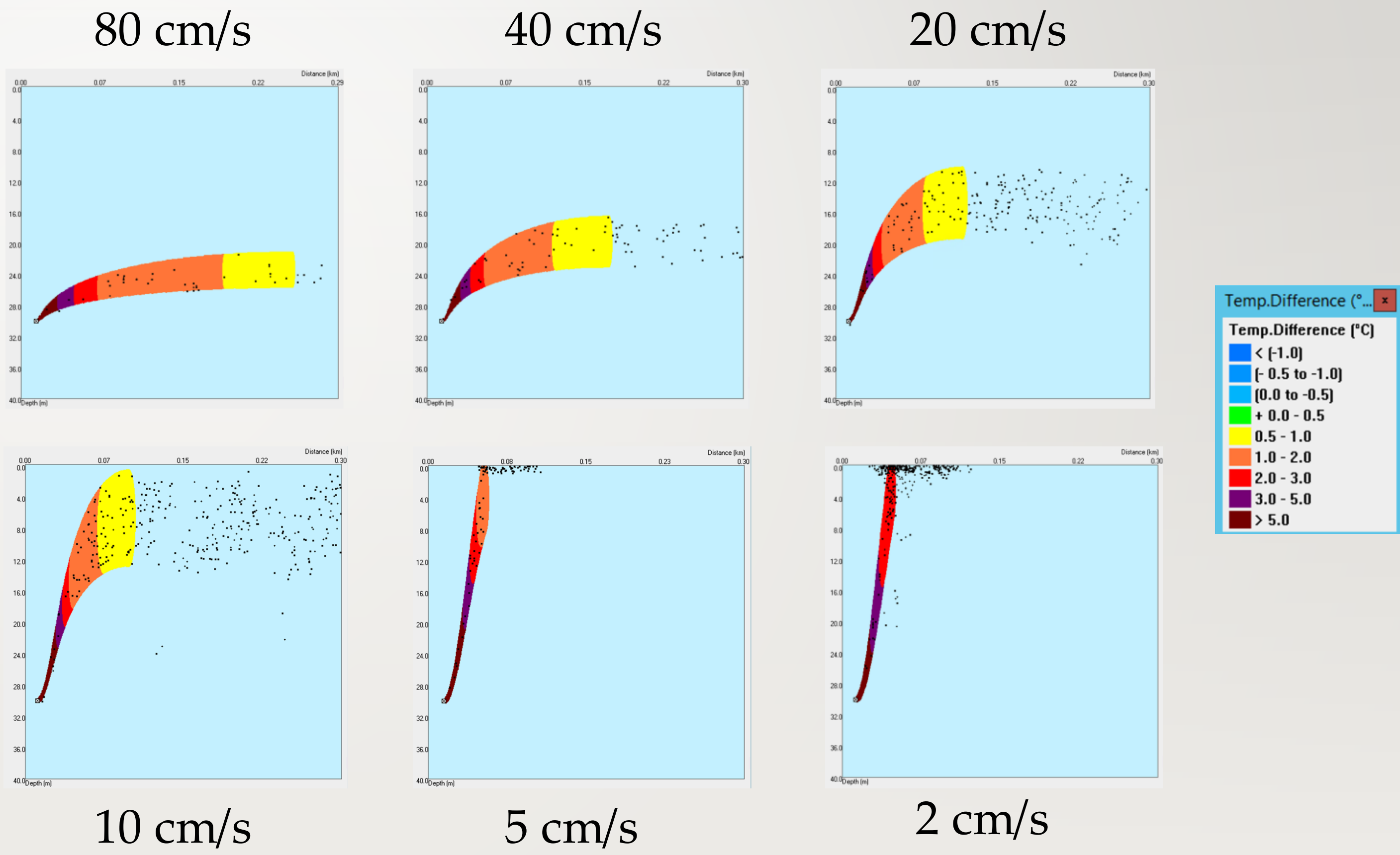
- Volume of oil droplets in PW – need a certain amount of oil mass to reach the surface per unit time
- Oil droplet size – bigger droplets are more likely to reach the surface
- PW salinity and temperature – PW must be positively buoyant to reach the sea surface
- Ocean currents – strong currents will dilute the PW plume and restrict plume surfacing
- Ocean waves – mixing the upper water layer breaks up thin oil films and can prevent their formation

Simulation examples

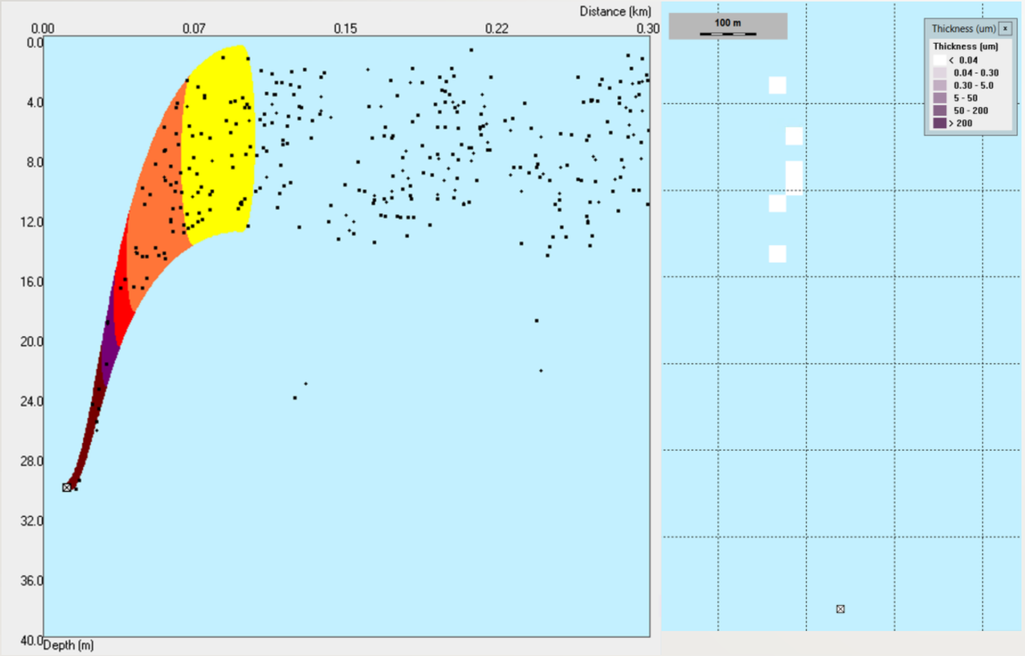
1. Effect of ocean currents
2. Effect of droplet size distribution

Strong currents prevent PW plume surfacing: side view

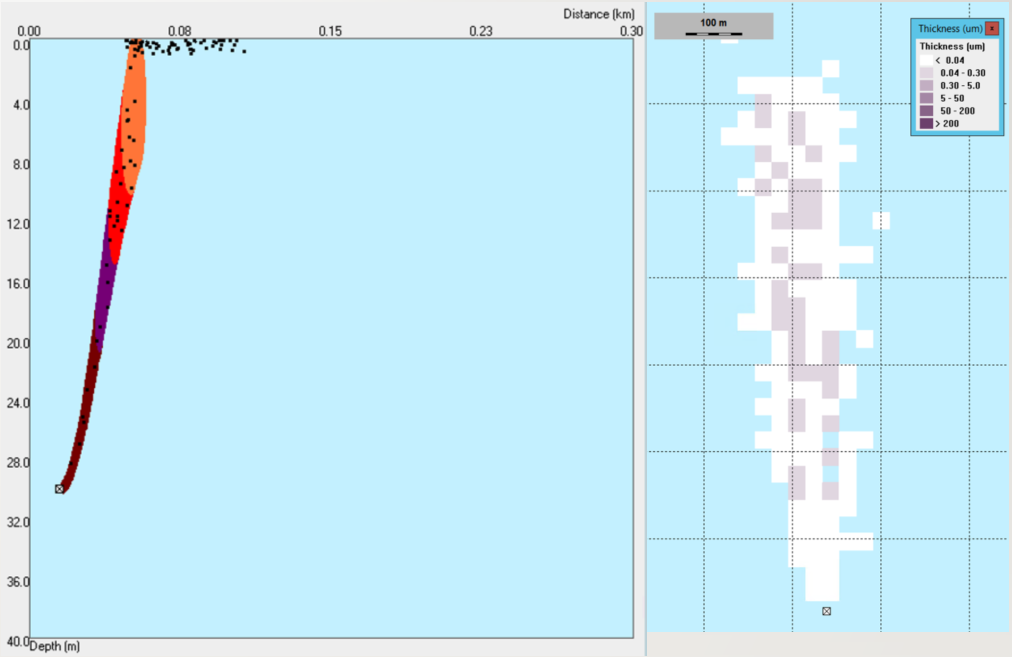
- Release data in OSCAR:
  - Rate: 20.000 m^3/day
  - Oil concentration: 25 ppm
    - 10 ppm liquid; 15 ppm dissolved
  - Release depth: 30 m
  - Temperature: 65
  - Salinity 48 psu
  - Current speed: variable
  - Median droplet size: 50 µm
- Figure scles:
  - Horizontal: 300 m
  - Vertical: 40 m



Strong currents prevent PW plume surfacing: top and side view

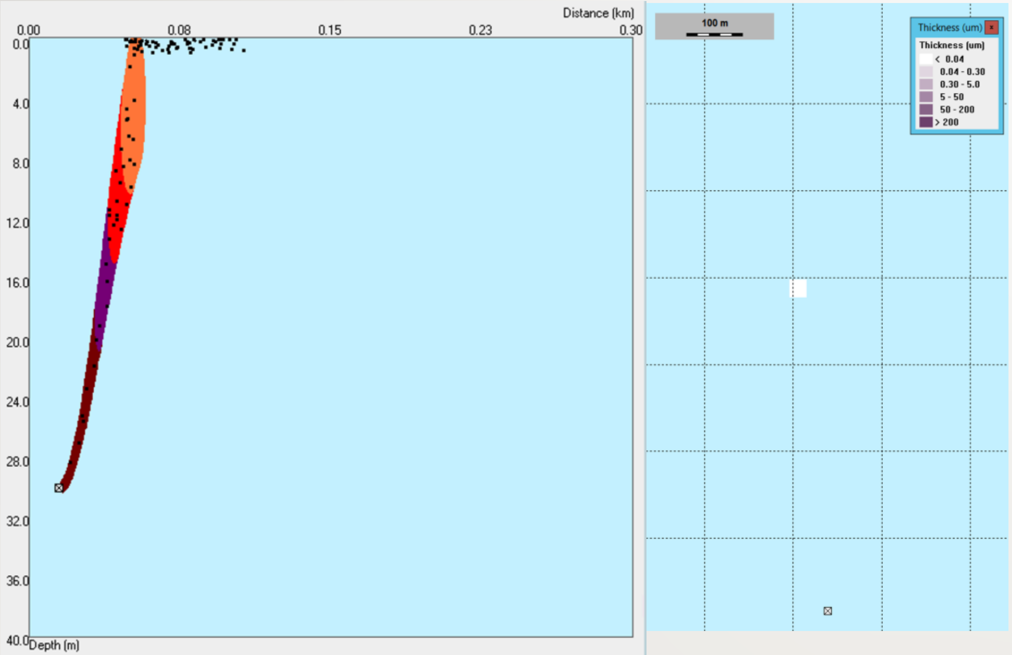


10 cm/s current speed

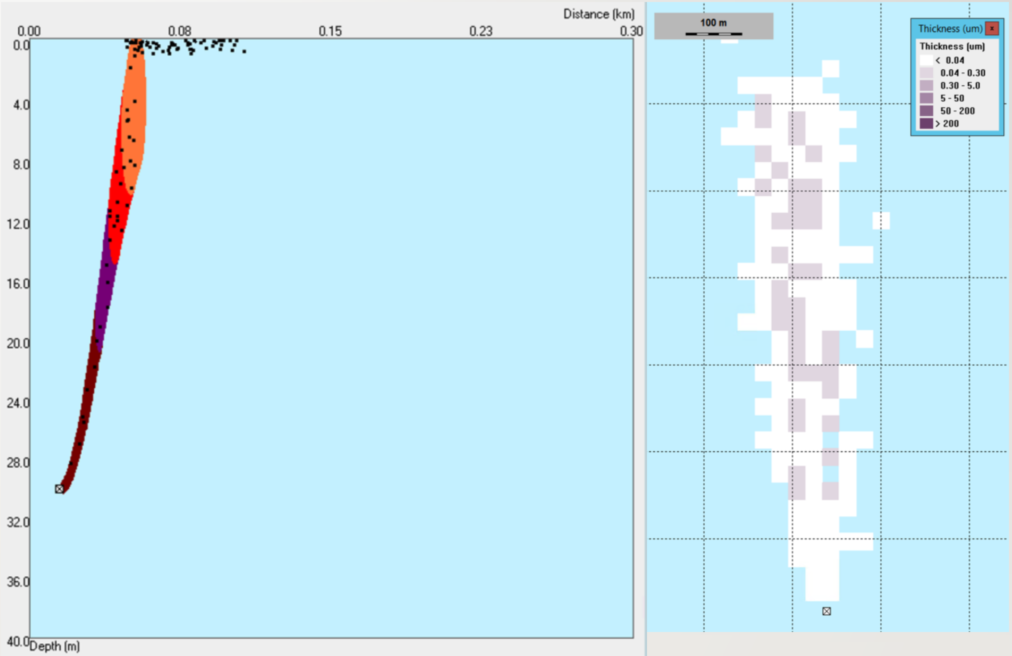


5 cm/s current speed

Droplet size strongly influences film formation



Median droplet size: 10 µm
Max droplet size: 20 µm



Median droplet size: 50 µm
Max droplet size: 100 µm

Small oil droplets do normally not reach the surface

- Hydrocyclone separation should leave droplets no larger than 20 μm (Judd, 2014)
- Small droplets rise too slowly to surface near platforms from even just 5 cm depth:
  - 5 μm: 0.1 mm/min
  - 10 μm: 0.4 mm/min
  - 20 μm: 1.6 mm/min
- Near-surface ocean turbulence normally effectively disperses droplets of this size
- What explains the presence of PW-associated oil films under normal operational conditions?

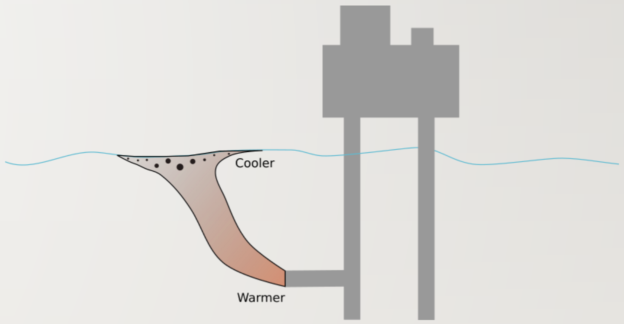
Hypotheses to explain how PW-associated oil sheen is formed under normal operational conditions

Platform/equipment:

1. Sheen is caused by another oil-source than PW such as hydraulic oil or fuel
2. Separation equipment is not working optimally but thus goes undetected
3. Separation by gas flotation leads to coalesence of droplets and bubbles, decreasing density and increasing rise velocity in surviving droplets

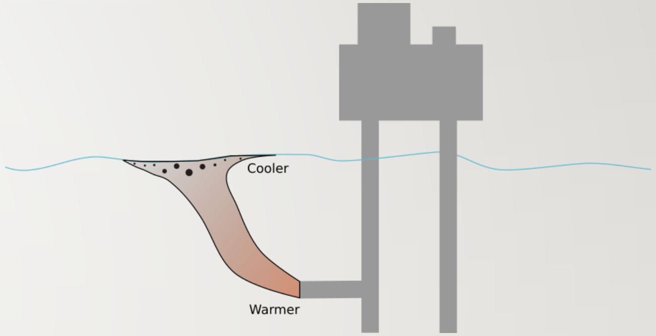
Model:

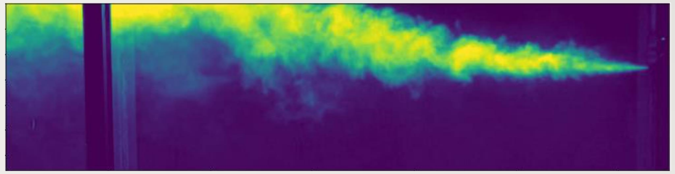
1. Droplets are deposited by the rising plume closer to the sea surface than predicted by OSCAR. 1 cm rise distance vs 5 cm rise distance makes a big difference for a 20 μm droplet.
2. Near-surface turbulent mixing is not well described in low-wave, low-wind conditions



Future work: Ideas to increase knowledge for improved modelling of PW-associated oil films

- For plume physics and droplet size distribution, establish offshore platform monitoring:
  - Measure standard PW-parameters (rate, temperature, salinity, oil concentration)
  - Measure oil droplet size distribution in PW
  - Add fluourescent tracer to PW and probe plume with flourometer
  - Measure ambient data: wind speed, current direction, wave height, surface turbulent energy
- Lab studies and modelling:
  - Study down-scaled model of offshore PW release in the lab
  - Measure plume droplet deposit depth and plume-surface interaction
  - Improve models for turbulent mixing in low-wind, low-wave conditions





Thank you