ADVANCED MODELLING & SIMULATION – AMS

TRANSAT-SPILL : A LAGRANGIAN INTEGRAL PLUME MODEL FOR SUBSEA OIL SPILL

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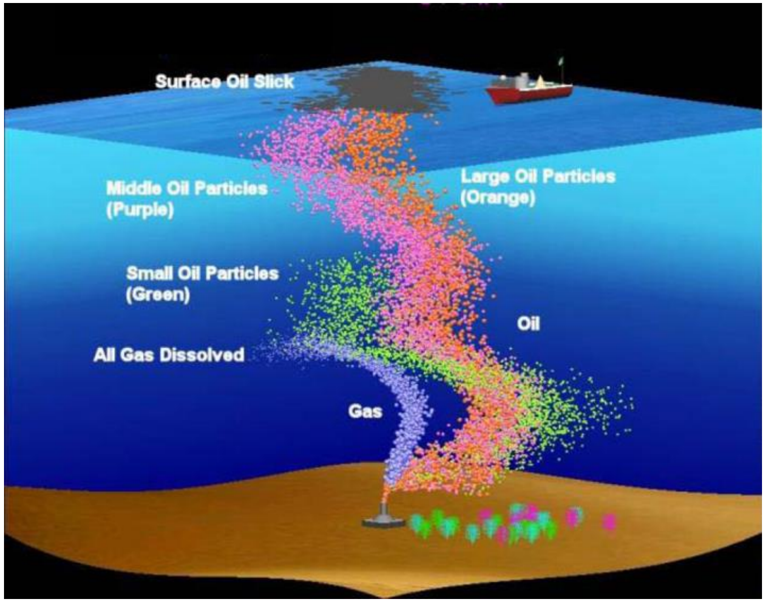
TRANSAT – SPILL (LAGRANGIAN INTEGRAL PLUME MODEL)

Context and solution

The subsea oil spill context:
The event of the Gulf of Mexico revealed a lack of understanding of flows subsequent to subsea hydrocarbon spills. Improving the realism and accuracy of predictions of these flows help define efficient mitigation operations to minimize environmental impact and costs.

Our solution:
The flows include multiphase flow jets, hydrate formation and dissolution, and transient interaction of plume constituents with the surrounding. 3D CFD is expensive, which appeals for the use of cost-effective, fast-response subsea plume models.



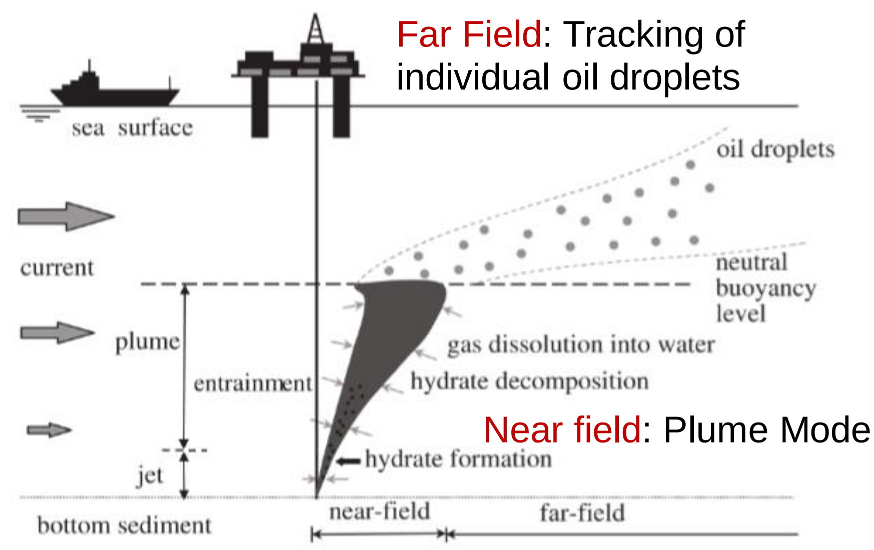
Yapa *et al.* (JHR, 2010)

TRANSAT – SPILL (LAGRANGIAN INTEGRAL PLUME MODEL)

Description

Description:
a Plume 1D model based on Yapa's approach to track oil and gas from a subsea spill, BUT linked to TransAT-3D above the neutrally buoyant layer to track gas bubbles and/or oil droplet trajectories in 3D, using sea-current data. Dispersion of the droplets by small-scale turbulence is modelled using a subgrid-scale model.

Credits:
TransAT-SPILL has been used for consultancy projects, including for BP, Shell, OMV Norge AS.



TRANSAT – SPILL (LAGRANGIAN INTEGRAL PLUME MODEL)

Salient features

- Mass balance of oil, gas, hydrates, water
- Momentum balance of oil/water mixture and gas
  - Slip between gas and mixture
  - Entrainment of water (shear, crossflow)
  - Buoyancy
- Energy balance of mixture (temperature)
- Salinity transport
- Gas dissolution
- Hydrate formation, dissolution
- Gas separation from oil/water plume
- Ambient sea characterization
  - Water density EOS(T, p, salinity)
  - Temperature variation with depth
  - Salinity variation with depth
  - Gas density EOS
  - Sea currents data

TRANSAT – SPILL (LAGRANGIAN INTEGRAL PLUME MODEL)

Input - output

TransAT-Spill requires the following input data:

Discharge conditions:	Environmental conditions:
• Outlet depth • Oil flow rate • Outlet diameter • Gas to oil ratio at standard conditions (GOR) • Outlet temperature	• Vertical sea temperature profile • Vertical Salinity profiles • Wind data (unsteady, spatial) • Ocean current data (unsteady, spatial)

TransAT-Spill produces the following outputs:

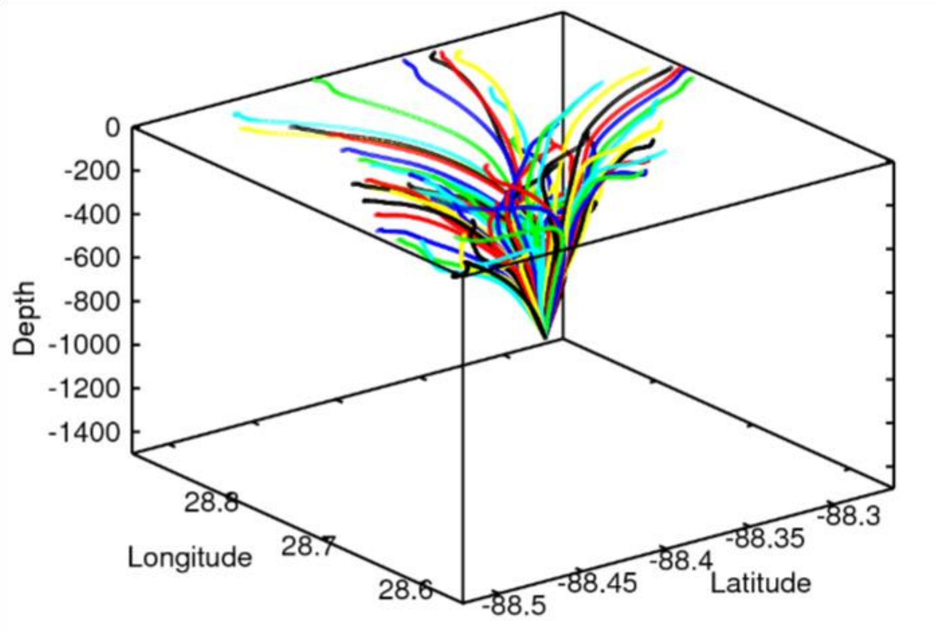
Plume Stage output	Far Field output

• Plume Trajectory
• Depth of trapping
• Rise time to depth of trapping
• Mixture properties along the plume trajectory
  ○ Temperature, density
  ○ Salinity
  ○ Velocities
  ○ Oil & gas concentration
	• 3D transient output in the ocean
	  ○ Oil concentration
	  ○ Gas concentration
	  ○ Density
	• 2D transient output at the ocean surface
	  ○ Gas flux on the surface
	  ○ Oil surface concentration

PÖYRY

TRANSAT-SPILL: MODEL TESTING

- One trajectory simulation per day
- 70 days after the spill simulated
- Rise time (and trajectories) depend on droplet size
- Typical rise time (300µ droplets): **40 hours**
- 1 deg = 144km



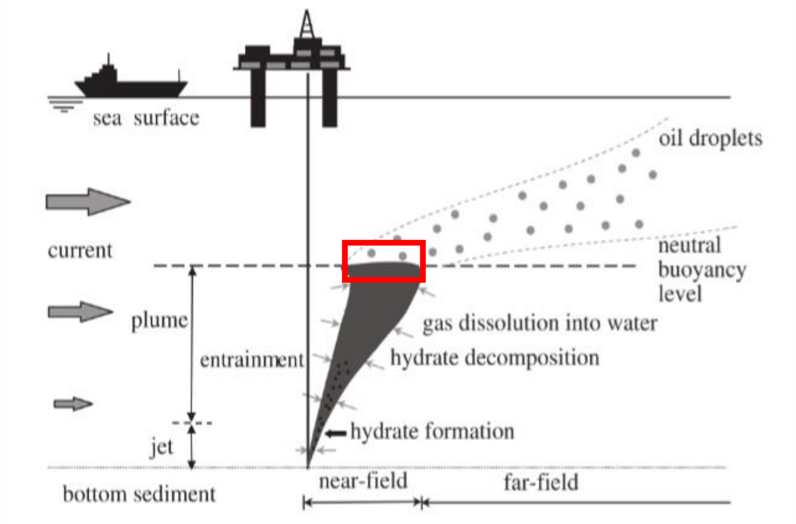
TRANSAT-SPILL: APPLICATION

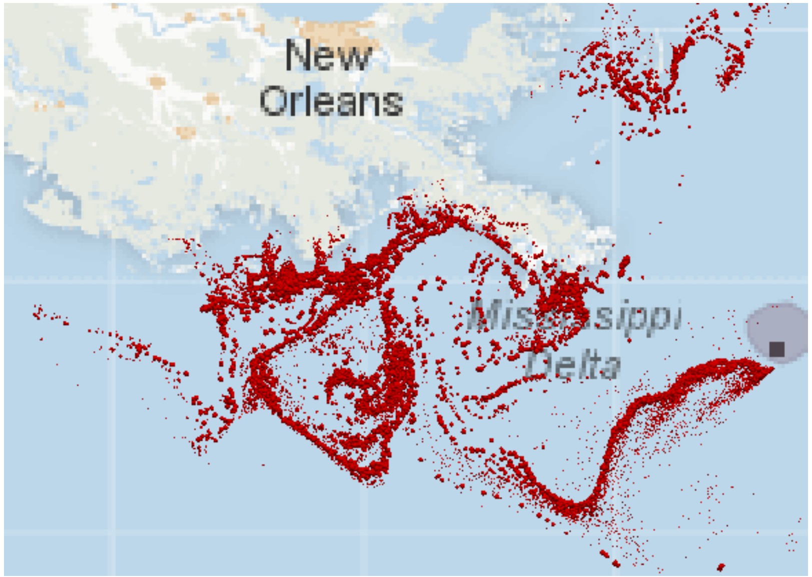
Example 1 (company xx):

The Macondo Well

PRODUCTION SIMULATIONS

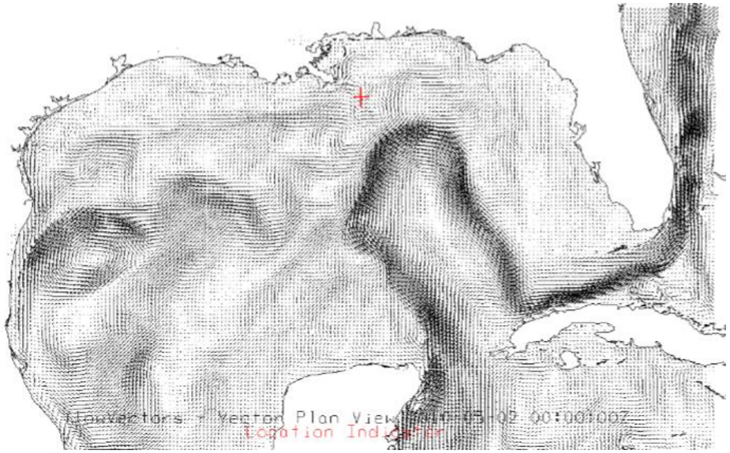
- Droplets are initialized at NBL (end of the plume regime). Plume displacement and diameter are insignificant compared to surface dispersion → set plume as point source
- Far field calculation not sensitive to elevation of NBL
- Size range is obtained from Exp.
- Droplets:
    1. rise due to buoyancy
    2. convected by sea currents
    3. effect of wind is considered
- Turbulent dispersion is modelled
- No weathering of the oil



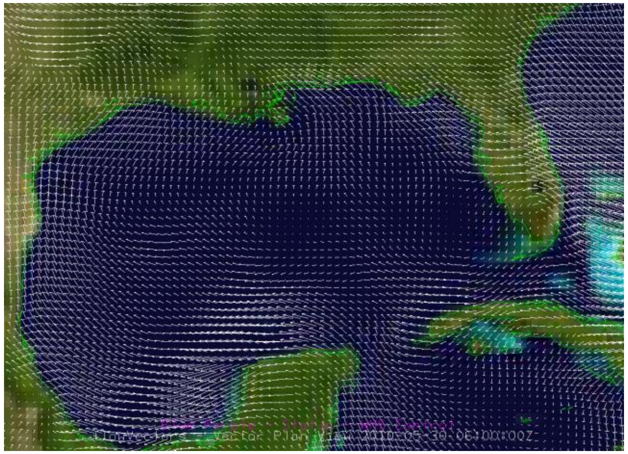


SEA CURRENT DATA (IASNFS) AND WIND DATA (CCMP)

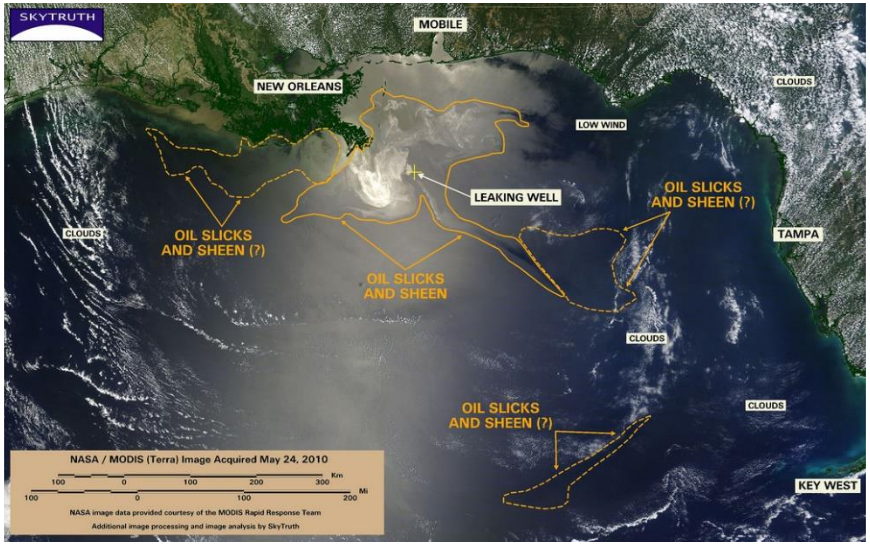
- Simulation (Nowcast) of currents in the Gulf of Mexico every 6 H
- Spatial resolution: 1/24 deg (~6 km) and 23 depth levels
- Large dataset is coupled with the model (15GB)
- **Implemented tool to extract real-time data at different locations.**

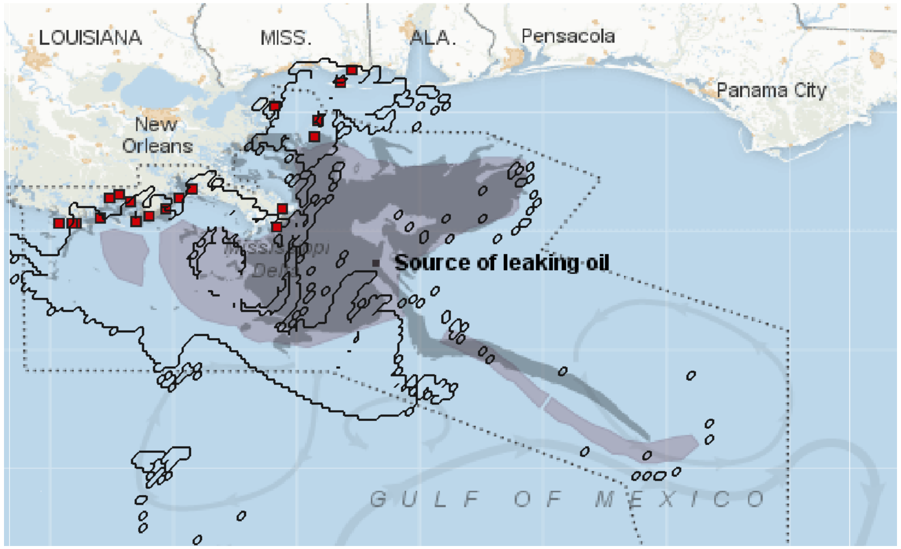


- Cross calibrated remote sensing data (wind data CCMP)
- Spatial Resolution 1/4 degrees
- Updated every 6 hours
- 2% of wind velocity is added to the sea current velocity at the surface



SATELLITE IMAGE EXAMPLE (MAY 24)





Source: skytruth.org

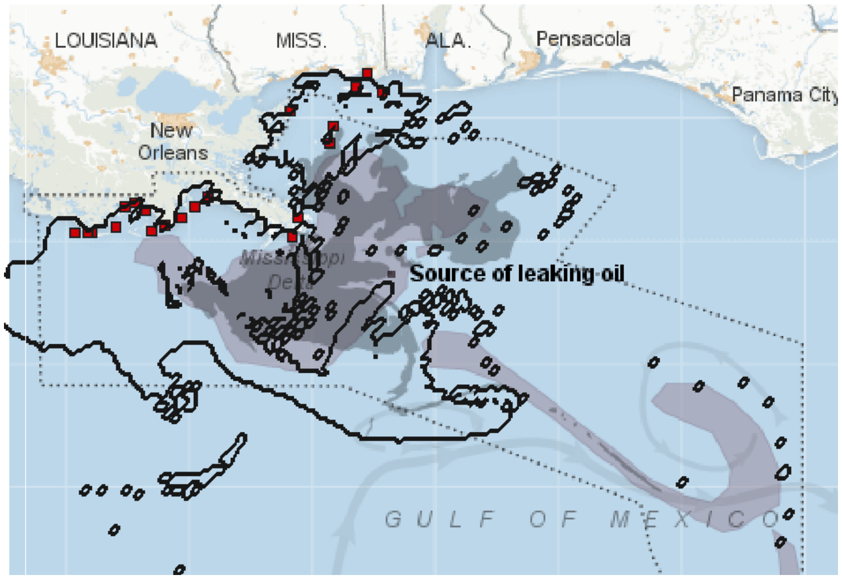
Satellite images were difficult to interpret: what was observed was not necessarily at the surface skin, but probably underneath it, as was proven by our simulations.

- Particle Envelope/ Surface Slick boundary (this work)
- Oil observed on the beach
- Slick observations from satellite
- Forecasts during spill by NOAA (re-initialized from satellite images)

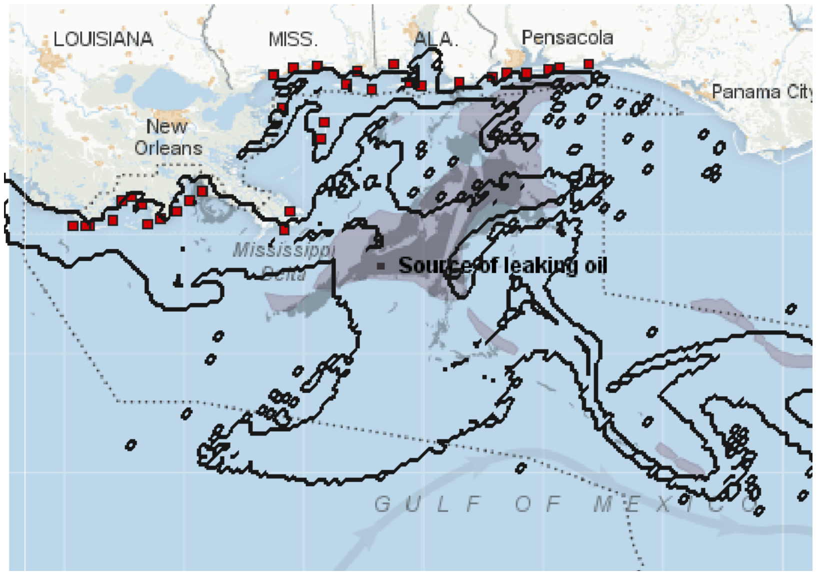
Source: nytimes.com

BEACHING OF OIL

The dates for beaching were found to coincide with predictions



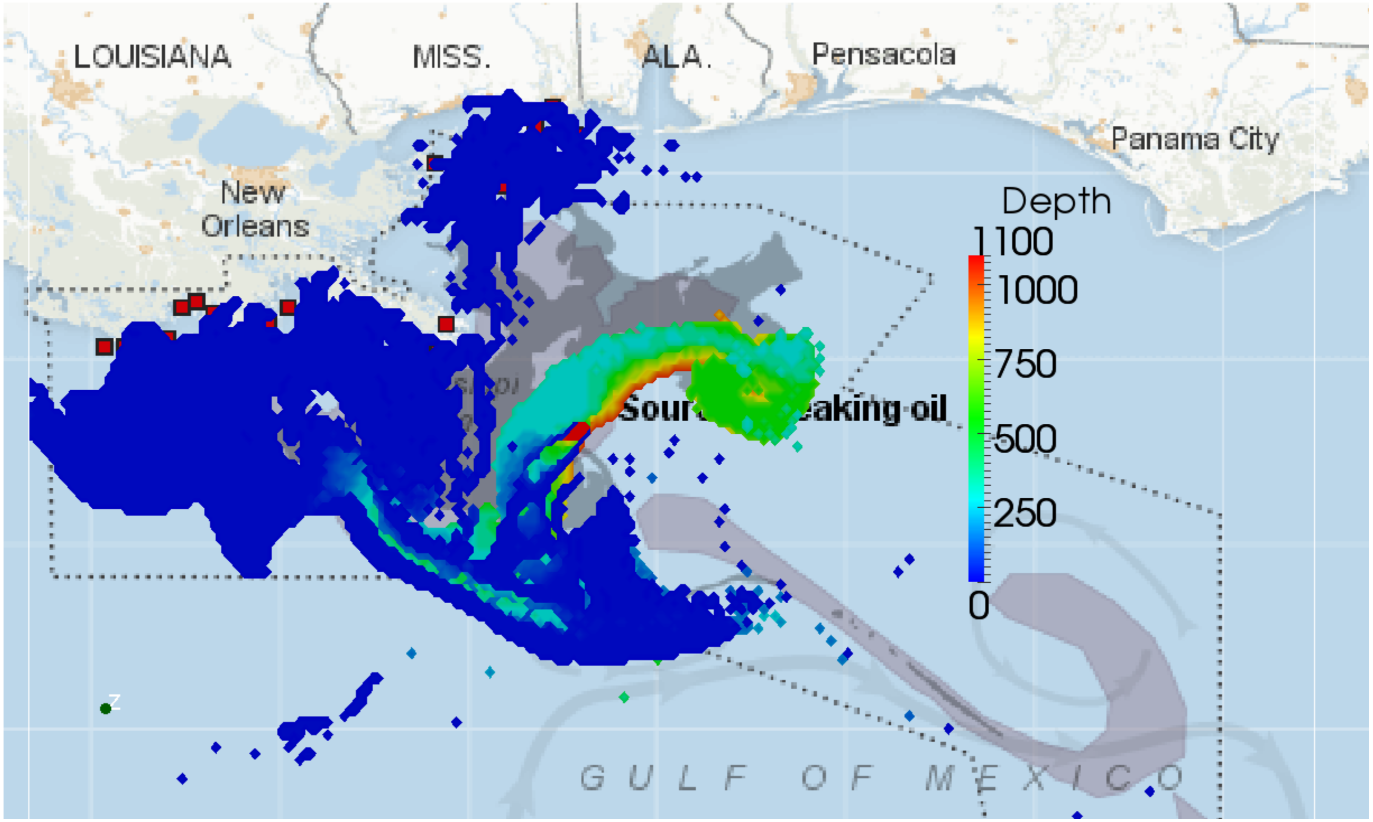
5-27-2010



6-6-2010

■ Oil observed on the beach

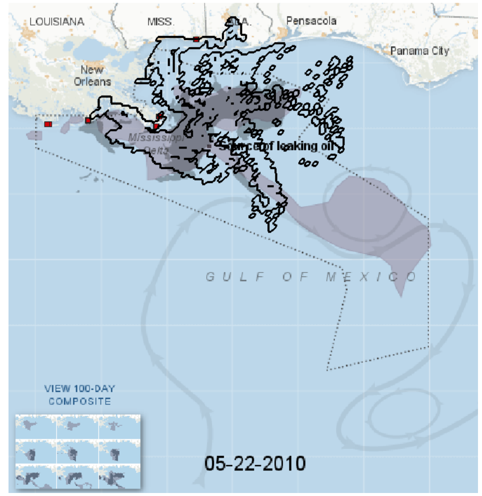
SUBSURFACE OIL

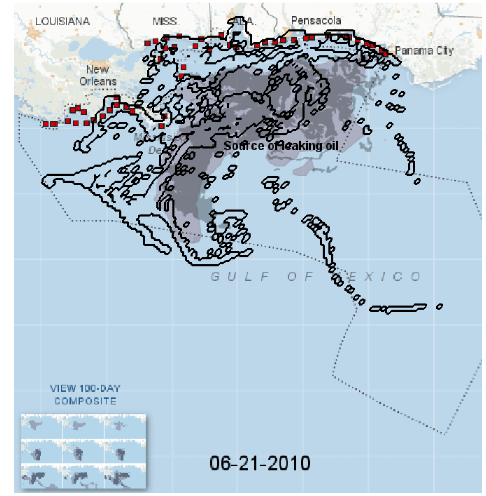


27th May

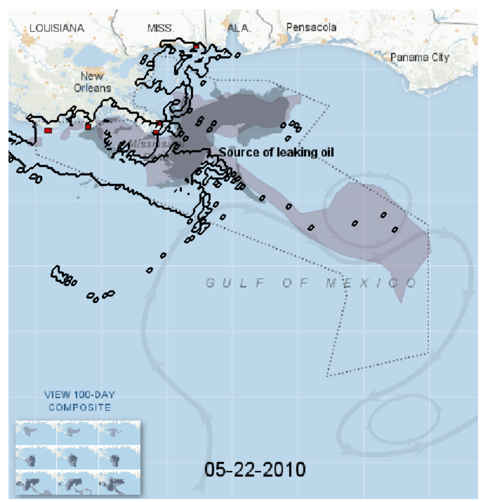
COMPARISON OF CURRENT MODELS

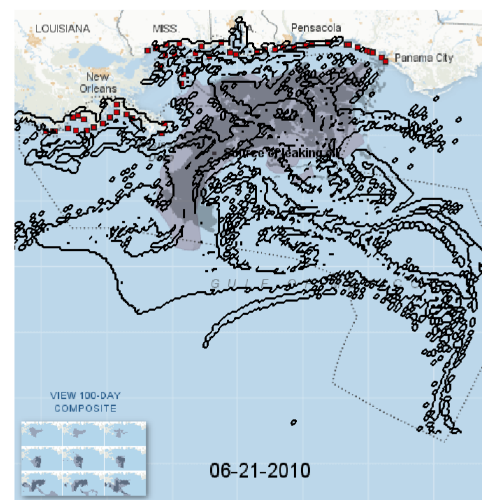
HYCOM





IASNFS





Example 2 (Company yyy):

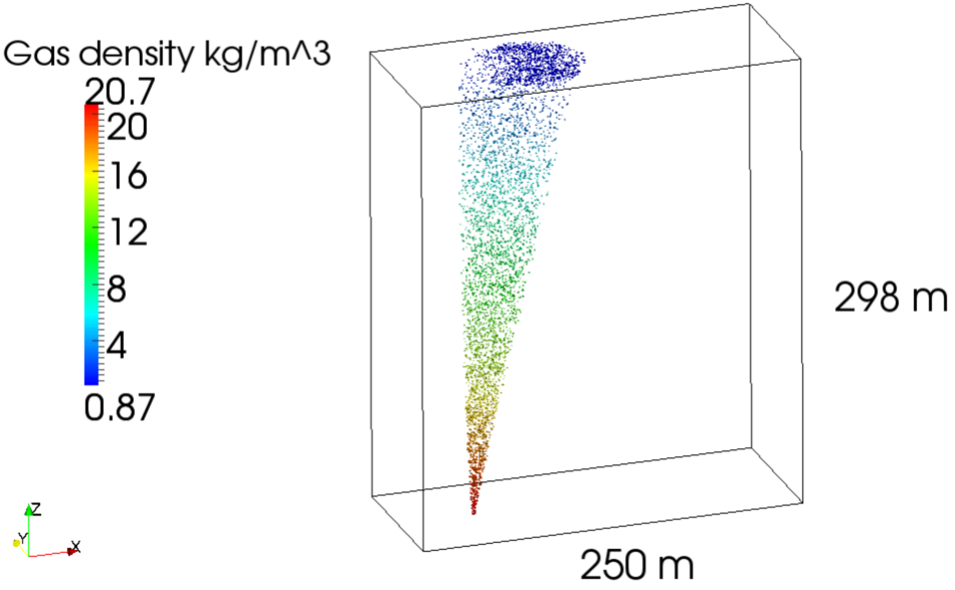
The ONXY well case (North Sea). Hypothetical Accident

ONXY SUBSEA OIL WELL

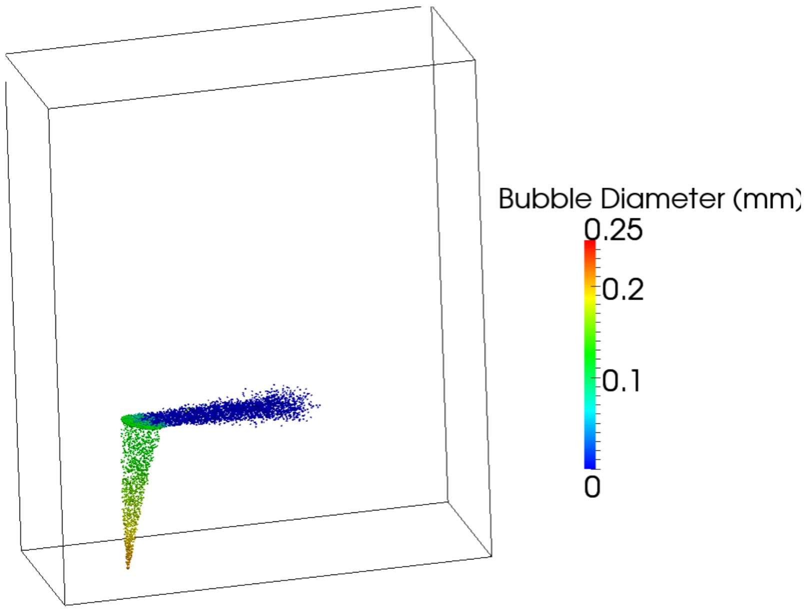
- **Input parameters**
  - Discharge rates (gas & oil)
  - Discharge Depth
  - Outlet Diameter
  - Discharge temperature
  - Salinity & temperature profiles
- **Dissolution model (Gas in seawater)**
  - For the reference case the dissolution model is disabled, … worst case scenario.
  - The rate of mass transfer mainly depends on the interfacial area density and therefore the bubble diameter at the spill outlet.
  - The bubble diameter is estimated using a correlation and depends on the turbulence at the spill outlet (difficult to estimate). Variations in bubble size estimates have a big impact on the plume trajectory, since gas buoyancy drives the plume to the surface.

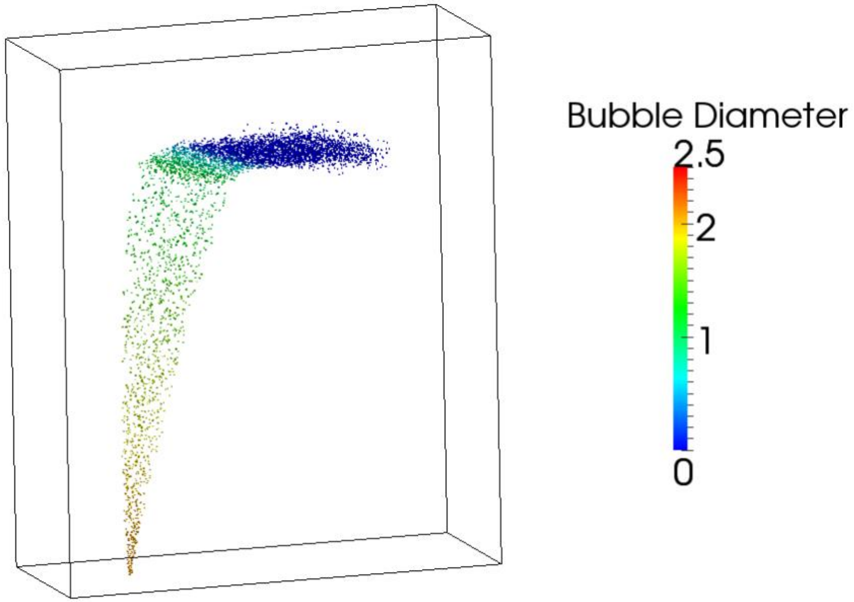
RESULTS: OVERVIEW REFERENCE CASE

- The plume reaches the surface during the plume stage. Far field modeling is not needed.
- Rise Time: 143 s. Plume radius at the surface: 35.4 m
- Horizontal plume center displacement at the surface: 35.6 m



RESULTS: WITH DISSOLUTION MODEL





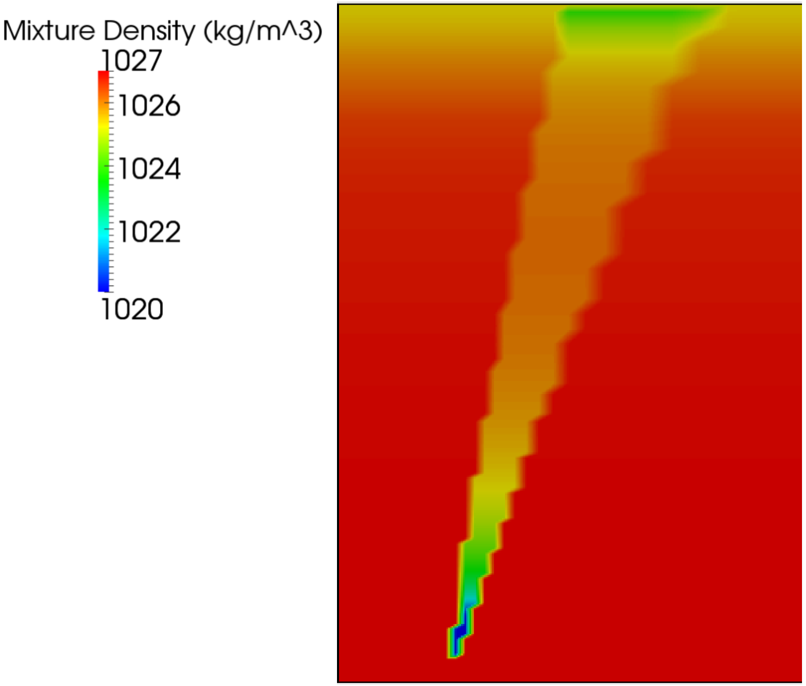
- The plume termination height is very sensitive to the initial bubble diameter
- A more conservative estimate of the bubble size was used because there is much uncertainty in estimating the bubble size.
- With this bubble diameter the plume terminates at 223m above the spill as compared to 87m when the initial bubble diameter is only 0.2mm.

Example 2 (Company yyy):

The DRAUGEN well case (North Sea). Hypothetical Accident

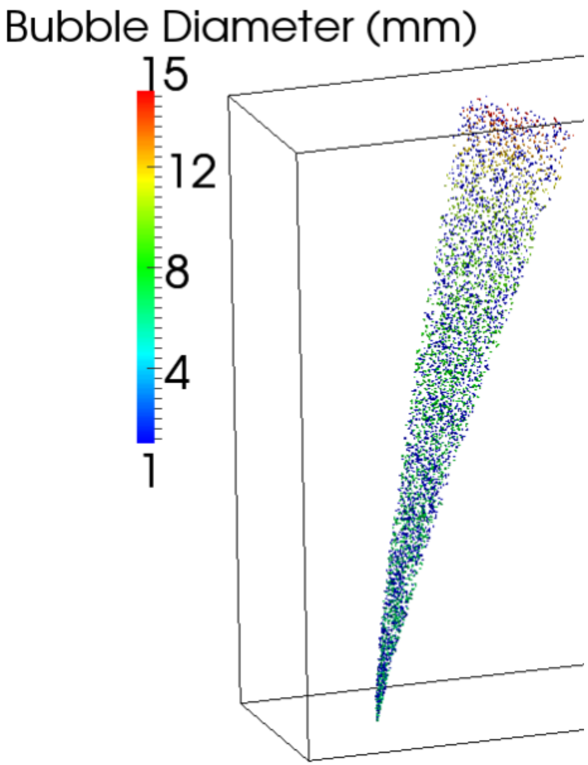
DAUGEN SUBSEA OIL WELL

- The plume reaches the surface during the plume stage.
- Far field modeling is not needed.
- Rise Time: -- s
- Plume radius at the surface: -- m
- Horizontal plume center displacement at the surface: -- m



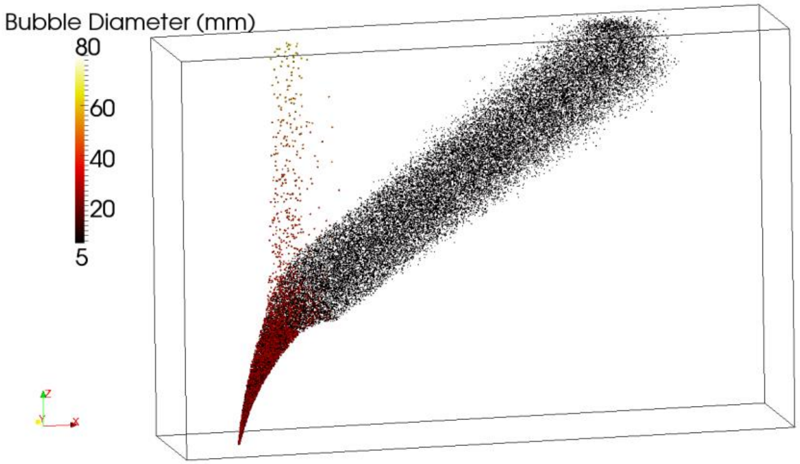
BUBBLE SIZE

- The bubbles are larger due to the lower velocities at the spill outlet.
- The Weber number of the oil droplets is significantly higher compared to the gas bubbles. This is mainly due to the higher density of the oil droplets. Therefore the oil droplets are smaller than the gas bubbles.
- The diameter of the oil droplets stays constant around 1mm (blue particles in the image)
- The gas bubbles expand due to the change in ambient pressure (shown in red an green)



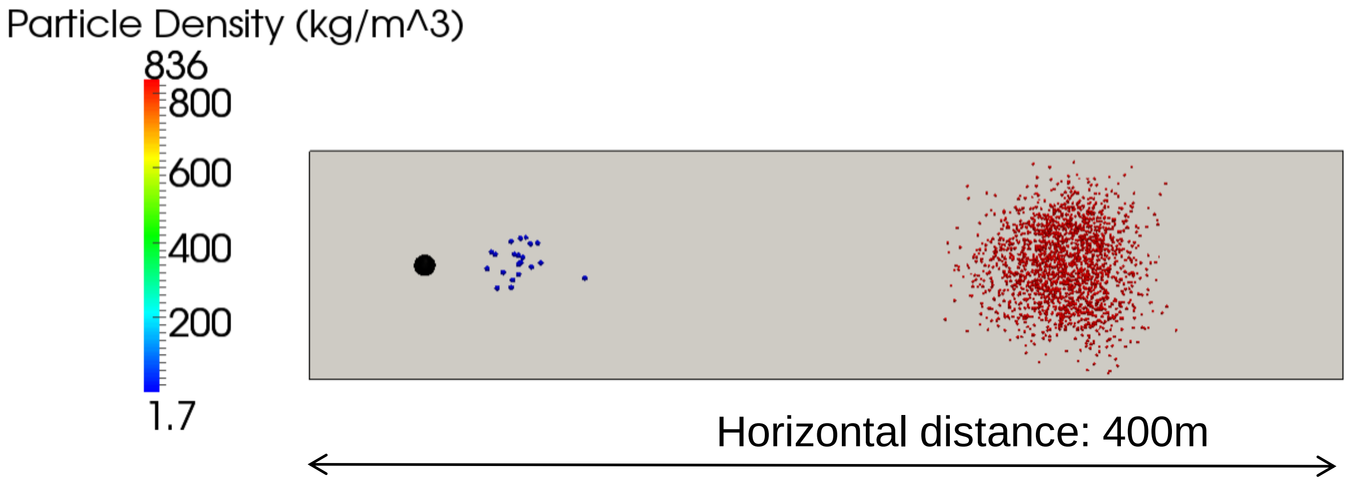
RESULTS: OVERVIEW 25% FLOW RATE

- Plume stage stops at -- m above spill
- Rise Time to end of plume stage: -- s
- Plume radius at the end of plume stage: -- m
- Horizontal plume center displacement at the end of the plume stage: -- m
- As soon as the plume stage ends the gas (shown in red yellow) separates and rises to the surface
- The oil (black) rises slower and reaches the surface further downstream



25% FLOW RATE: SURFACE EXPRESSION

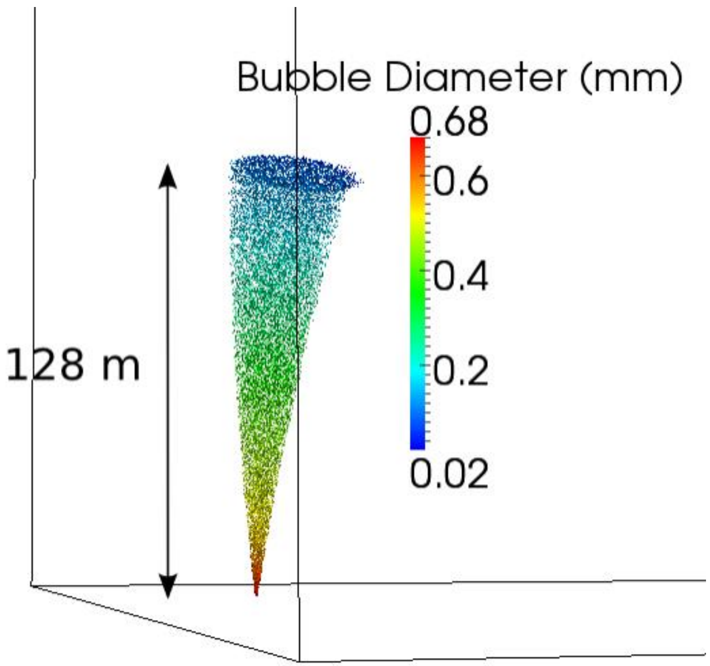
- Birds eye view onto the sea surface
- The black dot indicates the spill source
- Gas is shown in blue and oil in red
- The snapshot shows the situation when the oil reaches the surface



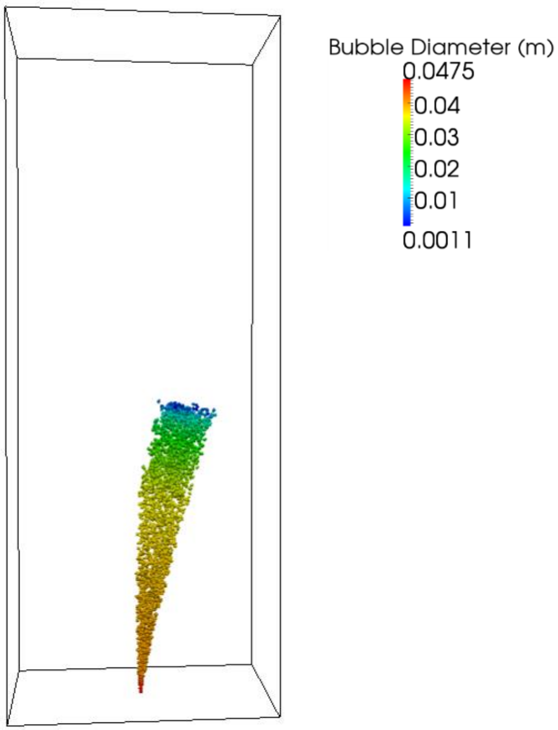
Example 3 (Company zzz):

The BENIN well case. Hypothetical Accident

SIMULATION 1: GAS ONLY, WITH DISSOLUTION & CURRENTS



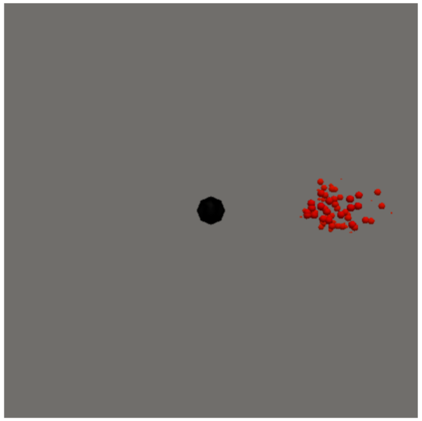
- **Initial bubble D: correlation** (0.68mm)
- Plume height: 128m
- Rise time to end of plume stage: 150s
- Plume radius at end of plume stage: 19m
- Horizontal plume center displacement at end of plume stage: 10m

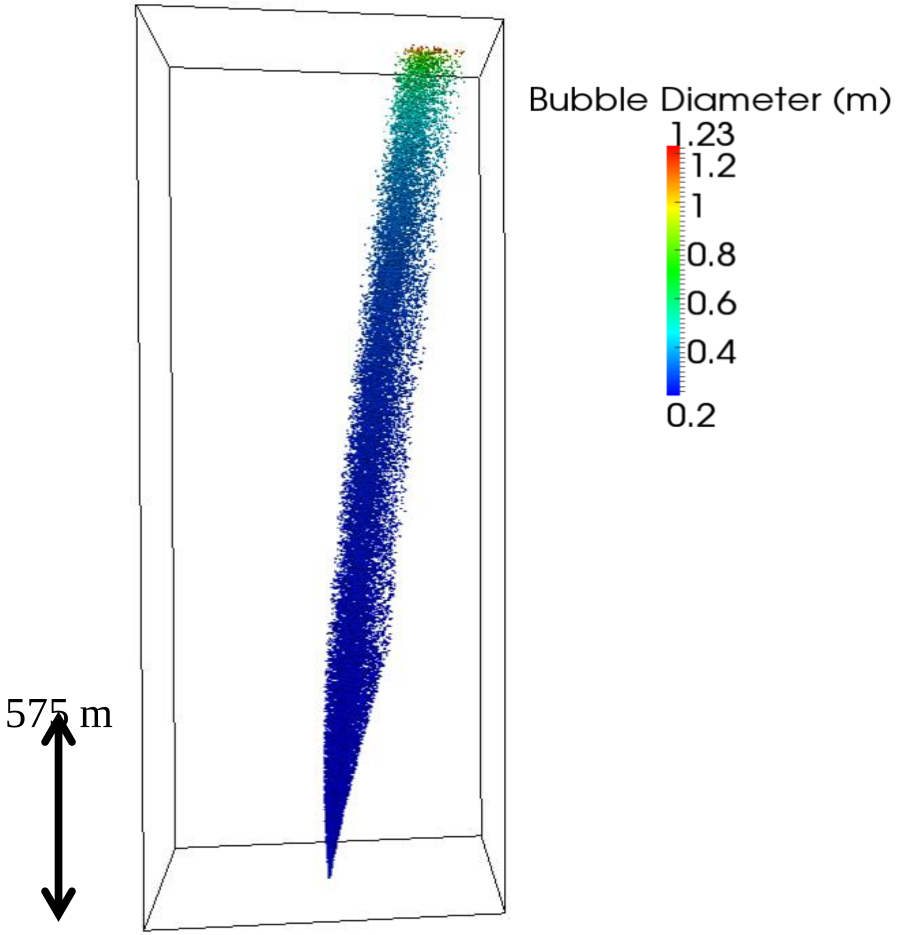


- **Initial bubble D: 10% of outlet D** (4.76cm)
- Plume height: 847m
- Rise time to end of plume stage: 21min 12s
- Plume radius at end of plume stage: 108m
- Horizontal plume center displacement at end of plume stage: 100m

SIMULATION 3: GAS ONLY, WITH DISSOLUTION & CURRENTS

- **Initial bubble diameter: 50% of outlet diameter** (23.8 cm)
- Plume height: 785 m
- Rise time to end of plume stage: 20'.15''
- Plume radius at end of plume stage: 101m
- Horizontal plume center displacement at end of plume stage: 95 m
- Rise time to surface: 4
- **Surface expression**



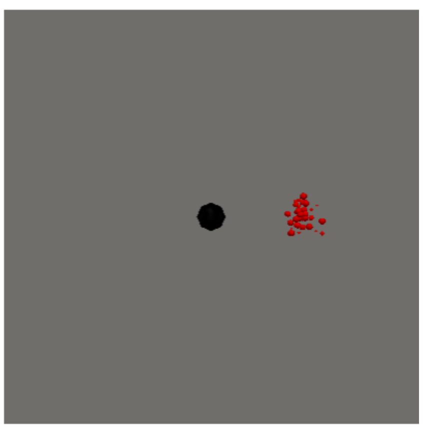


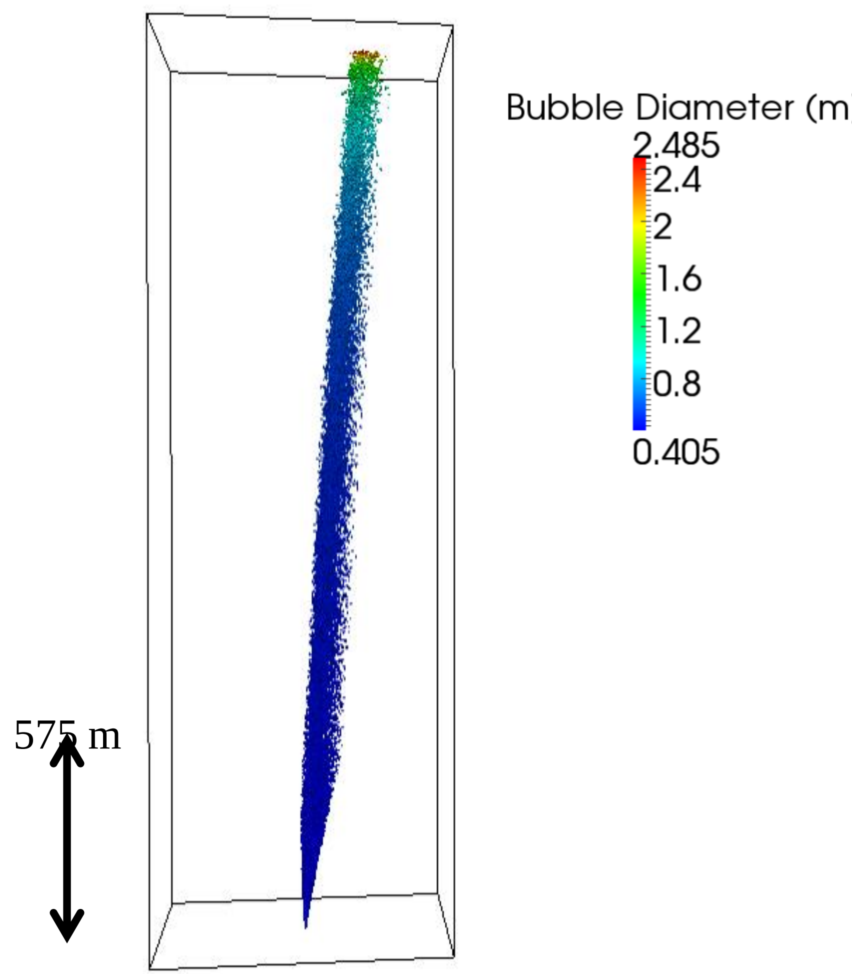
SIMULATION 4: GAS ONLY, WITH DISSOLUTION & CURRENTS

- **Initial bubble diameter: 100% of outlet diameter** (47.6cm)

- Plume height: 575m
- Rise time to end of plume stage: 15’.3’’
- Plume radius at end of plume stage: 75m
- Horizontal plume center displacement at end of plume stage: 70m
- Rise time to surface: 30min

- **Surface expression**



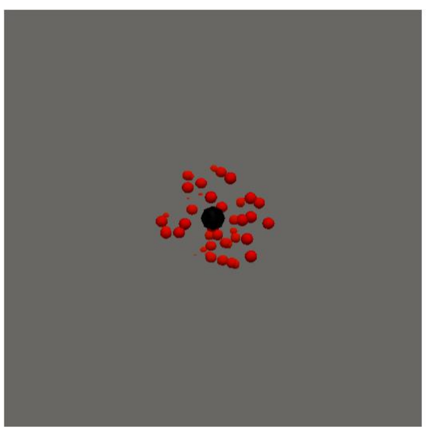


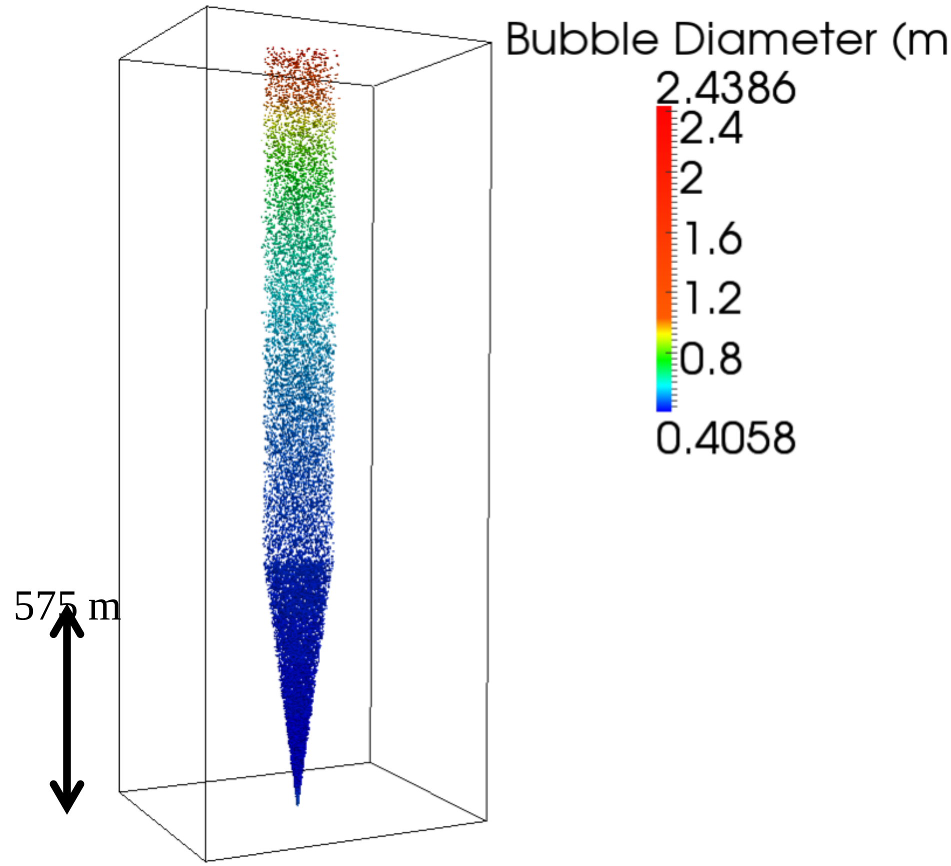
SIMULATION 5: GAS ONLY, WITH DISSOLUTION, W/O CURRENTS

- **Initial bubble diameter: 100% of outlet diameter** (47.6 cm)

- Plume height: 909 m
- Rise time to end of plume stage: 23’ 3’’
- Plume radius at end of plume stage: 129 m
- Horizontal plume center displacement at end of plume stage: 0
- Rise time to surface: 40 min

- **Surface expression**





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