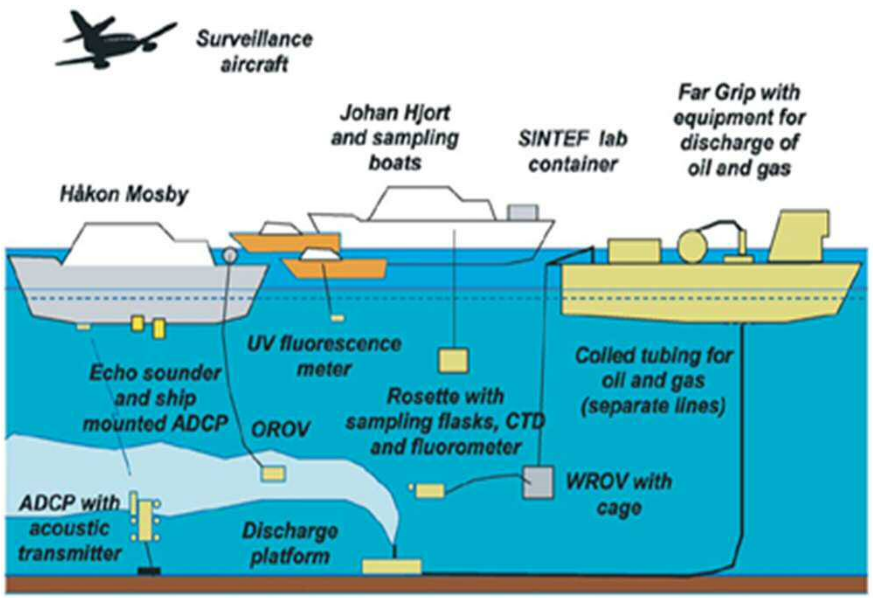
# Deep water plume models - What's special about deep water

Øistein Johansen

Senior scientist

SINTEF Marine Environmental Technology

# Deep water blowouts - knowledge basis



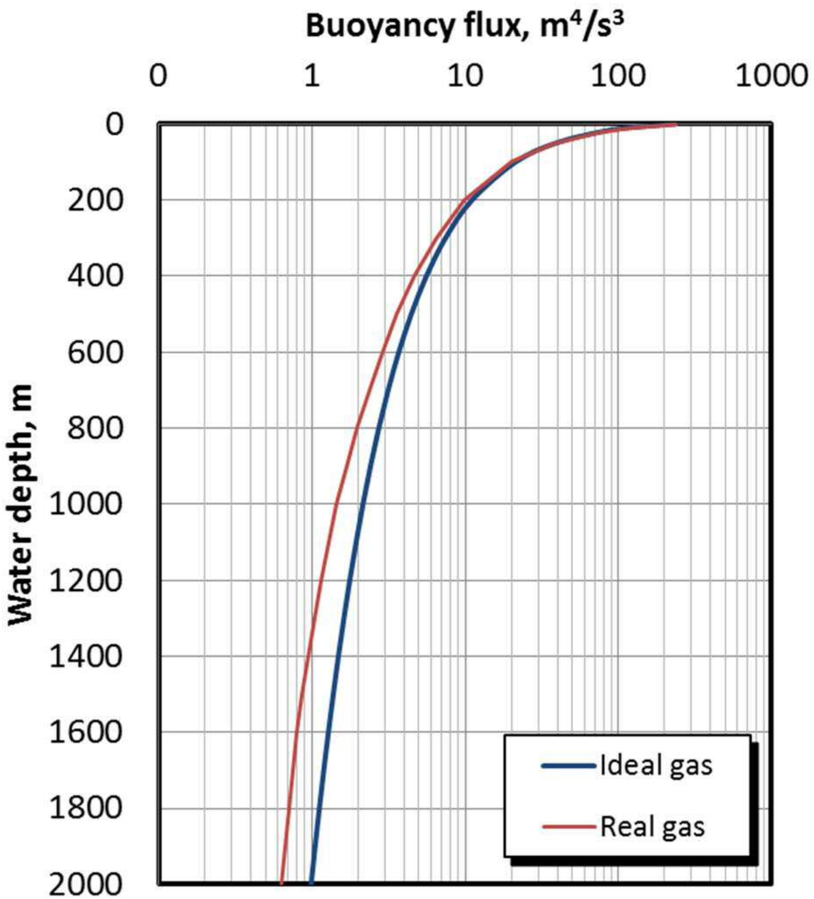

- Present knowledge based on
  - General work on specific deep water processes
  - Learnings from the DeepSpill experiment,
  - Observations from the Gulf of Mexico accident

# Major terms

- Buoyancy flux
  - increasing with gas flow rate and decreasing with depth due to compression
- Entrainment
  - Ambient water is entrained into the plume. The entrainment rate increases with increasing plume rise velocity and plume radius
- Separation height
  - increasing with buoyancy flux and decreasing with strength of cross flow
- Depth of trapping
  - Increasing with buoyancy flux and decreasing with the density gradient

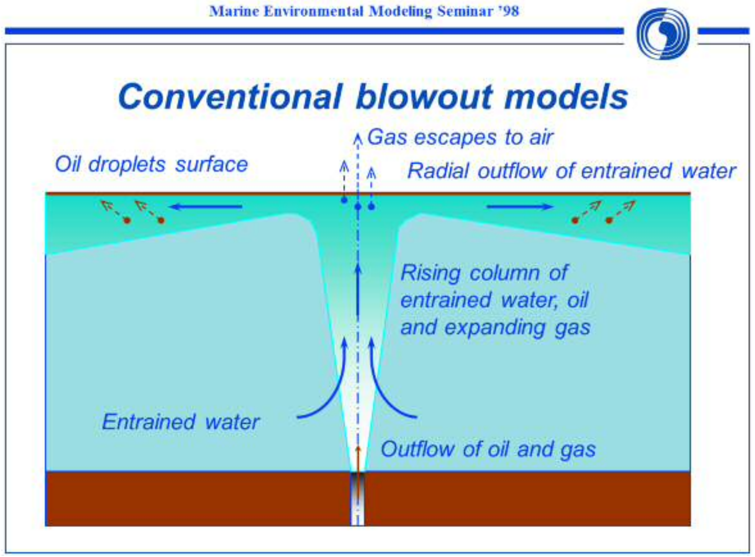
# Buoyancy flux for an oil and gas blowout

## Oil rate 300 $m^3/h$, GOR 300:1



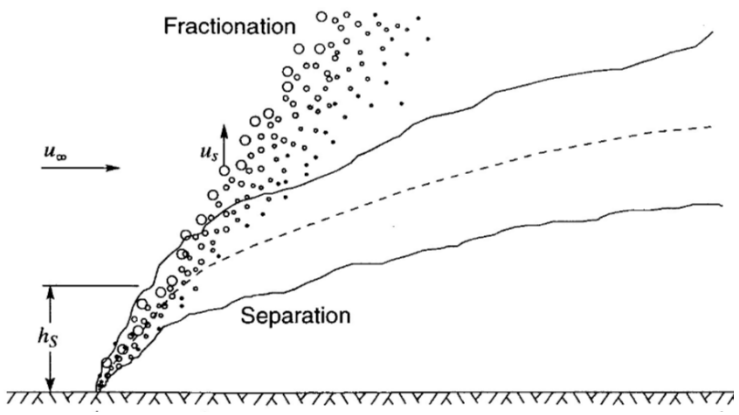

- The gas generates a buoyancy flux that drives the vertical rise of the plume
  - The buoyancy flux $B_H$ at a depth H depends on the gas volume flow $V_Z$ at that depth: $B_H = V_H\, g'$, where g' is the reduced gravity, practically equal to g = 9.8 $m/s^2$ for gas.
  - For ideal gas and constant temperature: $V_H = V_0\, 10/(H + 10)$

# Blowouts in moderate to shallow waters




- When gas is leaking together with oil from a subsea blowout, gas bubbles will generate a buoyant plume that will entrain ambient water and lift it towards the sea surface.
- In moderate and shallow waters, surfacing of entrained water will cause a strong outward surface flow.
- The rising plume will carry oil droplets towards the surface. When the droplets settle to the surface in the outward flow, a thin slick will be formed, with thickness in the order of one tenth of a millimeter.

# Separation of bubbles and droplets




Separation and fractionation (from Socolofsky and Adams 2002)

- When multi-phase plumes are bent over in cross-flow, gas bubbles and oil droplets may escape from the plume due to their individual buoyancy
- Separation is a self-reinforcing process as the deflecting effect of the cross current will increase when the buoyancy in the plume is reduced.
- This process may thus deprive the plume of all buoyancy at an early stage. As a result, plume rise will terminate, while the dispersed phase will rise to the sea surface.

# Blowouts in deep waters


*Picture of plume of oil and gas from the DeepSpill experiment.*

- In deep water, the gas in the blowout will be strongly compressed: at 1000 m depth the gas volume will be at least 100 times smaller relative to the gas volume at atmospheric pressure.
- Non-ideal gas behavior and gas dissolved in the oil may reduce the gas volume further
- This will cause a significant reduction in buoyancy, and the plume will be much weaker than in moderate water depths.

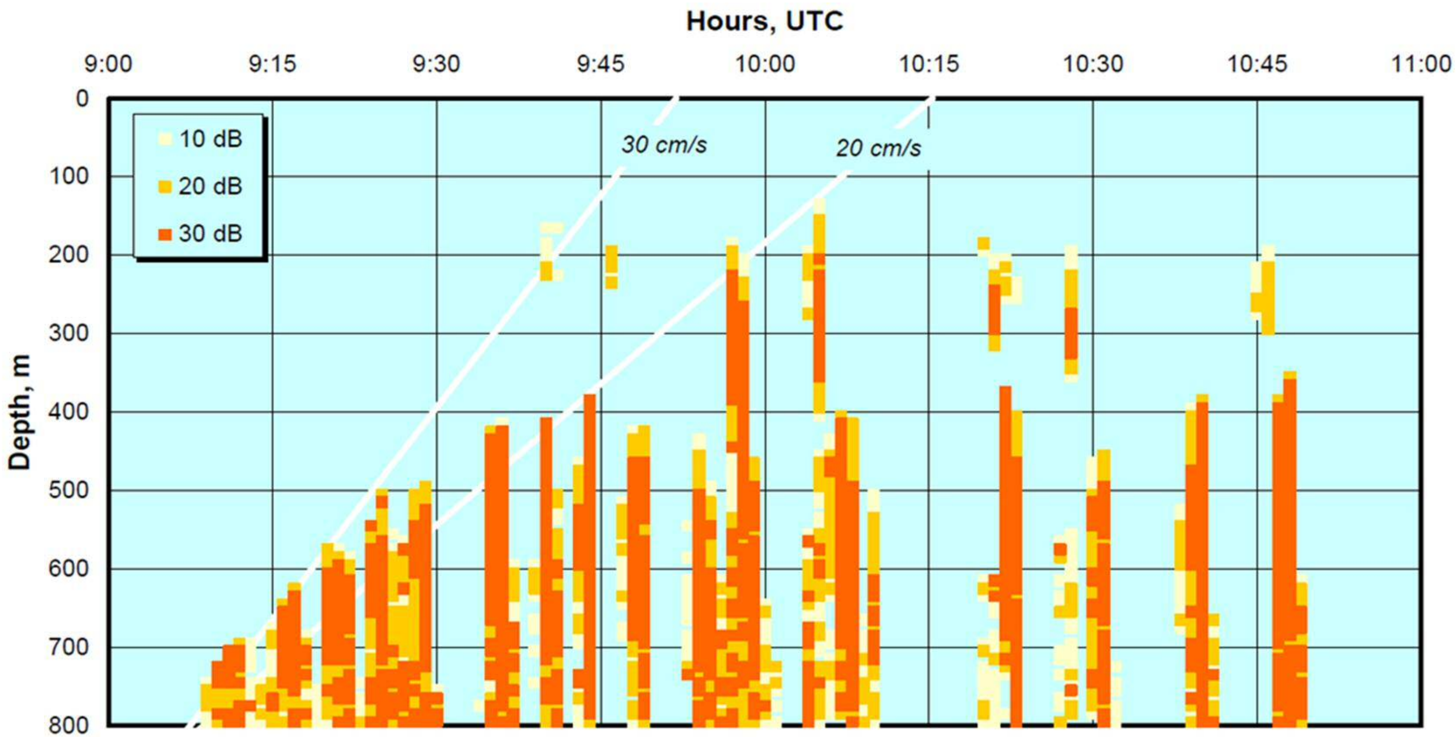
# Surfacing of oil

*Picture of crude oil slick from the DeepSpill experiment. Patches of emulsion appear brownish in color*

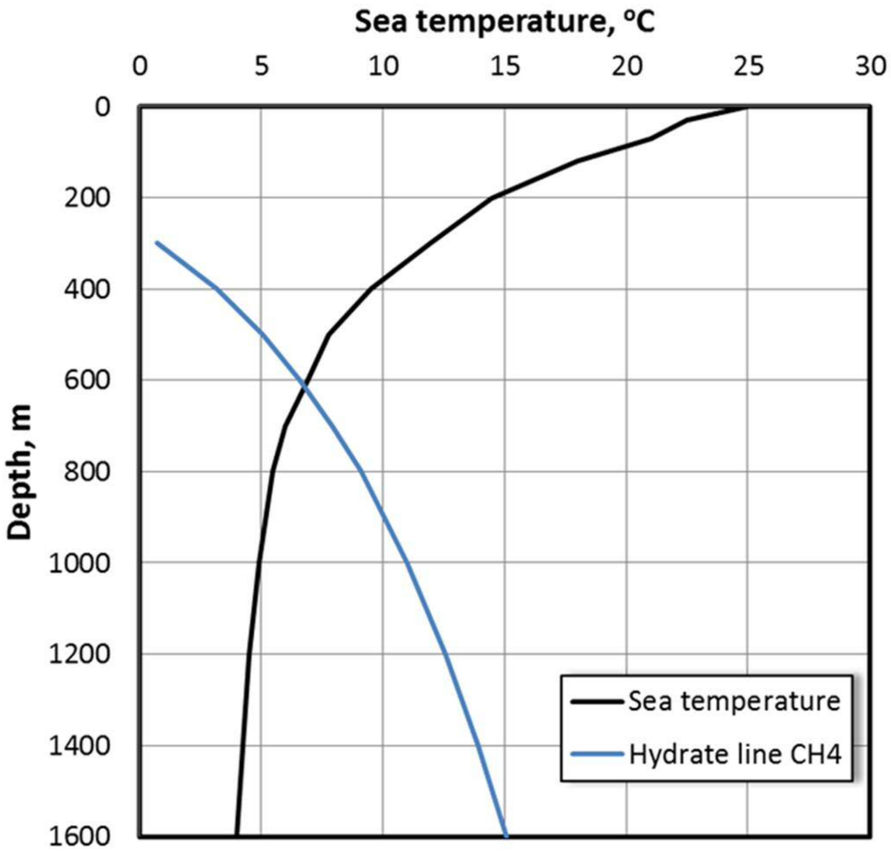
- Trapping of the plume will also imply that the outward surface flow will vanish:
  - The formation of the surface slick will then to as large extent depend on the size distribution of the oil droplets: Small droplets will have significantly larger rise times than large droplets, and hit the surface more distant from the source.
  - For this reason, thicker patches of oil may be found on the surface, in some cases thick enough to emulsify.

# Dissolution of gas from rising bubbles

- The long rise time will give time for dissolution of gas bubbles in ambient water
- Gas bubbles may dissolve completely before reaching the surface as shown by echo-sounder data from the DeepSpill experiment



# Hydrate formation



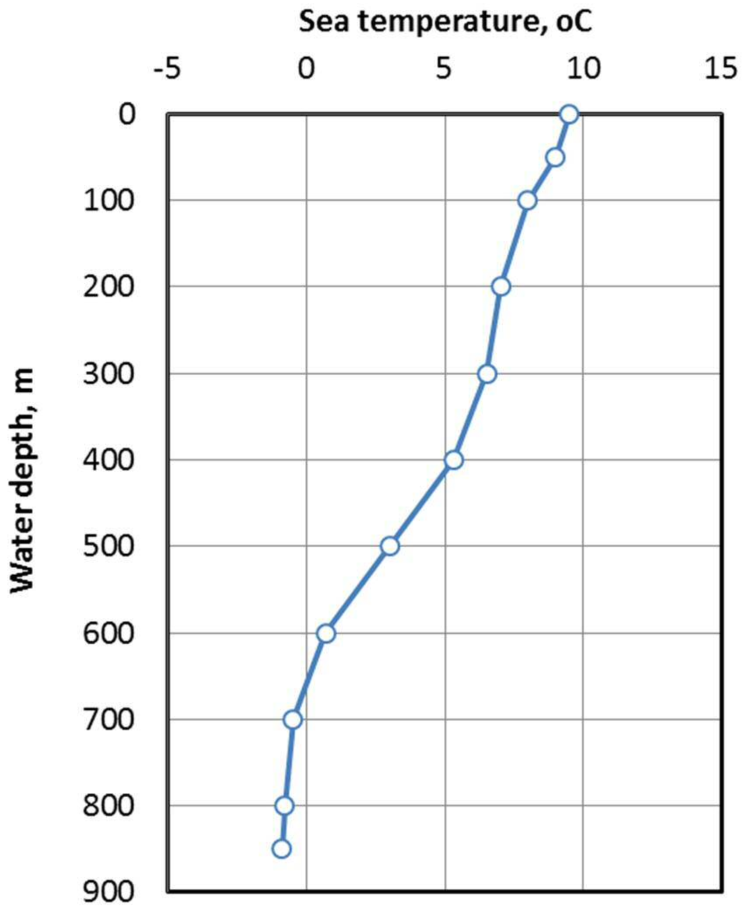

- According to the hydrate equilibrium line for methane in sea water, hydrate may form below 600 m depth in the Gulf of Mexico
- However, the hydrate line is a necessary – but not sufficient condition for hydrate growth
  - Nucleation requires a certain super-cooling
  - Persistent growth requires gas saturated ambient water
- Present understanding
  - A thin hydrate shell may form on the surface of the bubbles, causing reduced dissolution loss by stabilizing the bubbles

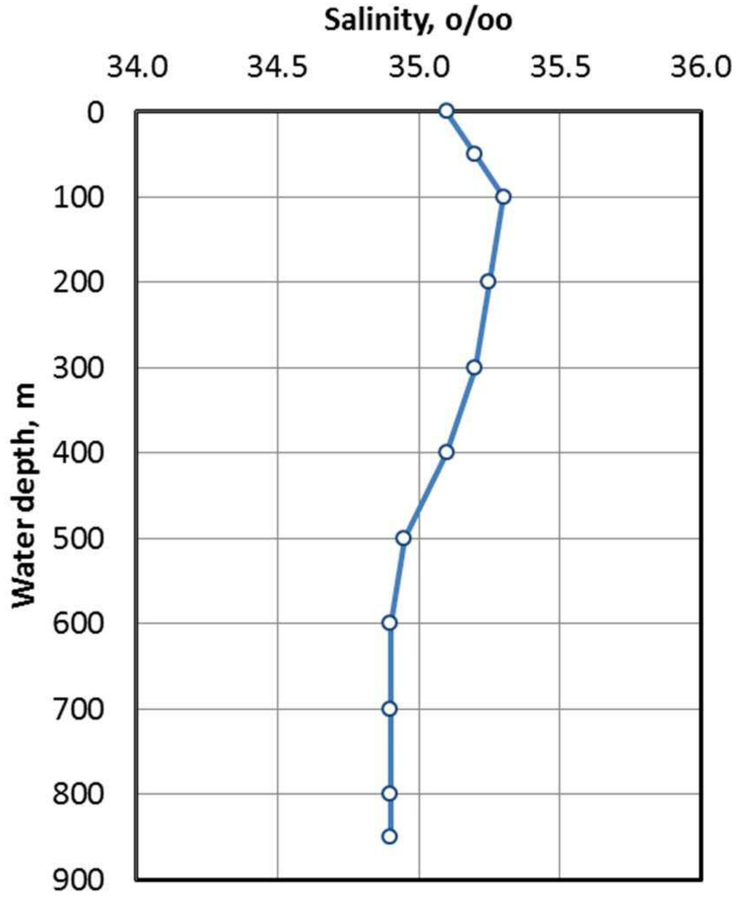
# Example calculation

- Oil and gas blowout in deep water in the Norwegian Sea
  - Oil rate 300 $m^3/h$
  - Gas to oil ratio (GOR) 300:1
  - Water depth 840 m
  - Measured temperature and salinity profiles (summer)
  - Cross currents from 10 to 30 cm/s

# Ambient data

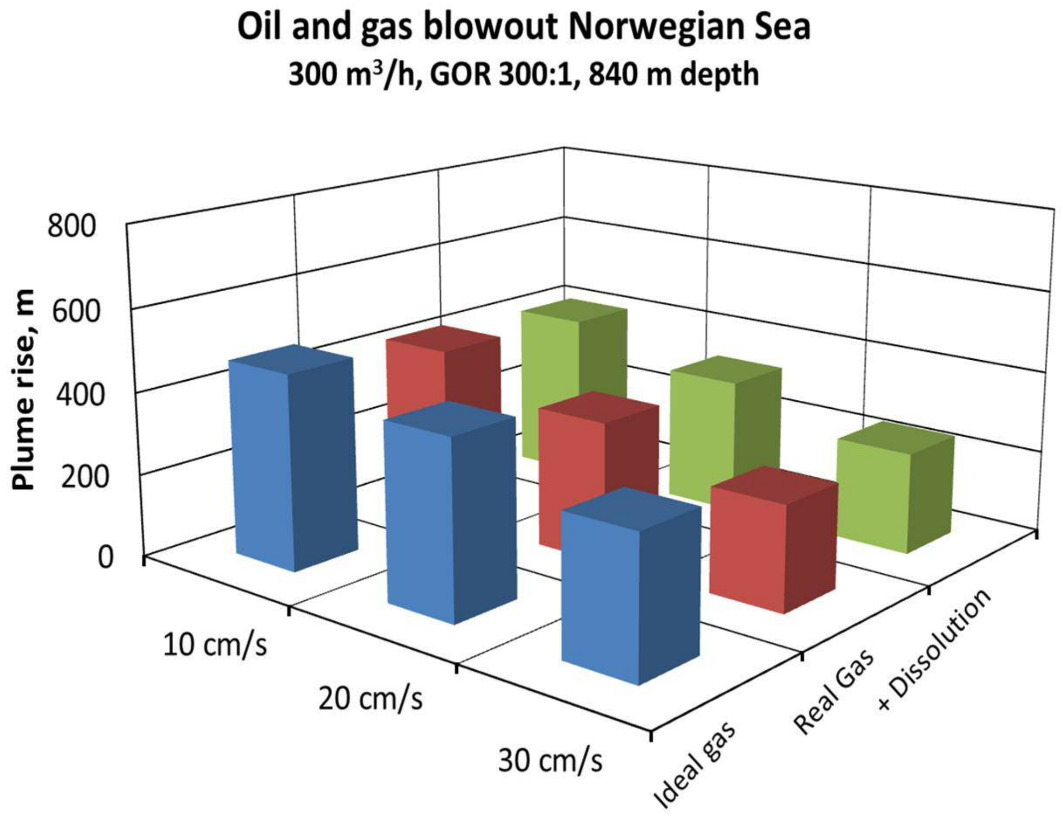
- Sea temperature and salinity profiles - Norwegian Sea



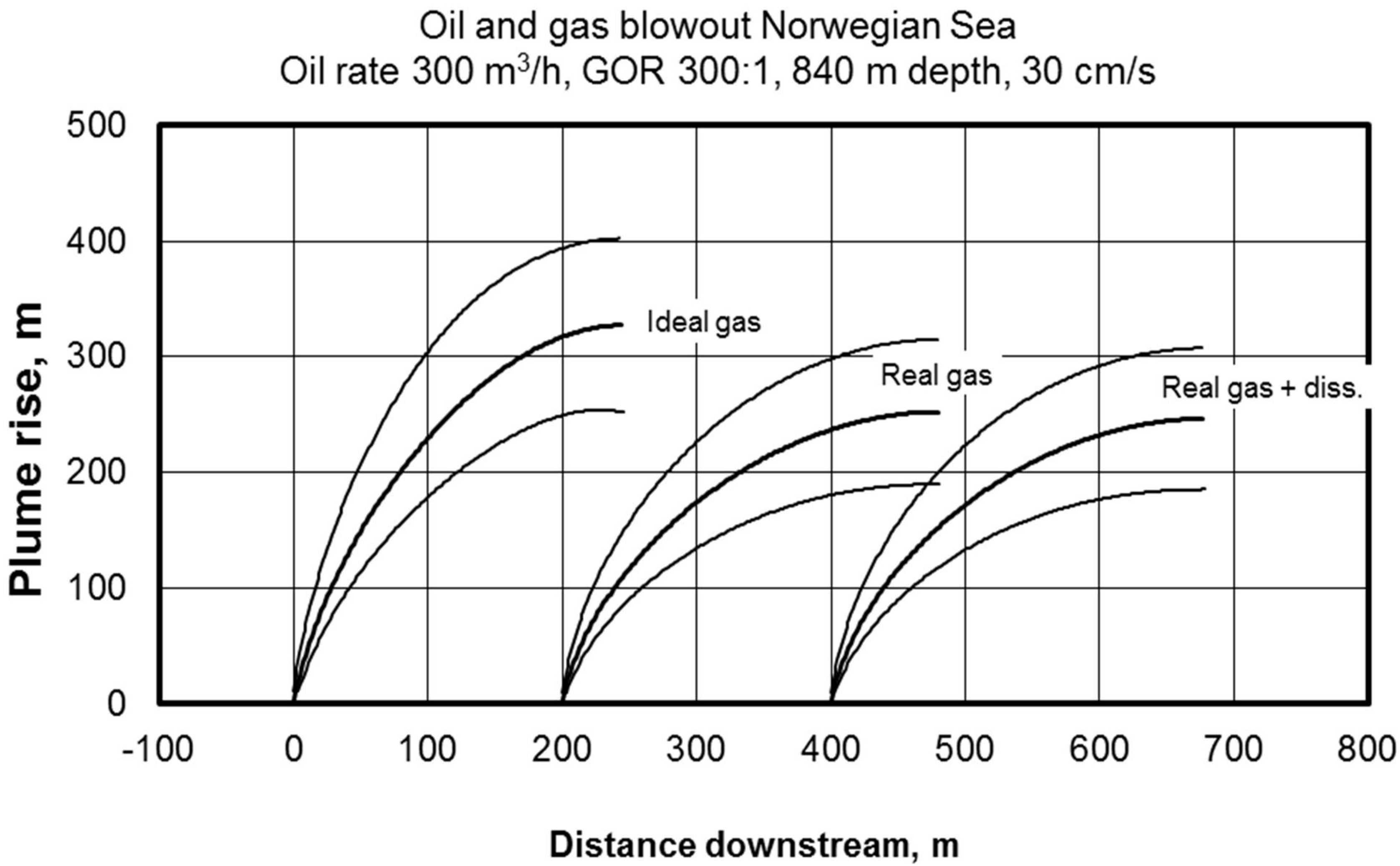



# Deep Blow simulations

- Computed plume rise – different assumptions



# Computed plume trajectories



# Conclusions

- The depth is main factor that causes differences between deep water blowouts and blowouts in moderate to shallow water
  - Large depth implies stronger compression of the gas and a corresponding reduction in buoyancy flux, making the plume more sensitive to cross currents and stratification
  - The plume may for loose all buoyancy and be trapped at intermediate depths before reaching the surface
  - Oil droplets and gas bubbles will then continue towards the surface
  - The gas bubbles may dissolve before reaching the surface, but the surfacing oil droplets will form an oil slick
  - The appearance and thickness of surface slick will depend strongly on droplet size (small droplets will form a thin slick)