



The North Sea Blowout: A gas bubble megaplume with spiral vortex motion and why it might, or might not, contribute much to the atmospheric methane

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In the Central North Sea, during drilling operations, a gas blowout accident happened in 1990. Thereafter, natural gas has leaked prodigiously from a 60 m diameter and 20 m deep crater located at 95 m depth into the water column and to the sea surface. A series of field studies was carried out at this site since 2005 evidencing ongoing intense seepage activity. Three gas bubble megaplumes and dozens of minor to major bubble seeps were observed in the crater during a manned submersible dive, ROV mapped hundreds. Analysis of gas bubbles captured at 118 m water depth revealed concentrations between 88-90% Vol CH₄ with $\delta^{13}\text{C-CH}_4$ values around -74‰ VPDB, consistent with a biogenic origin.

Blowout site flux estimates derived from ROV video show the site's emissions are the strongest and most intense marine methane seepage quantified to date with seabed emissions of ~32.6 kt/y. Based on previous research suggesting greater flux correlates with greater transport efficiency, the direct bubble-mediated atmospheric flux to the atmosphere was estimated at a surprisingly low 0.7kt/y. This is orders of magnitude smaller compared to the seabed flux, thus the bulk methane dissolves before reaching the atmosphere, suggesting enhanced bubble dissolution rates for megaplumes.

Analysis of more than 120 water samples from near the blowout plume showed dissolved methane concentration distributions consistent with enhanced bubble dissolution at depth. CH₄ concentrations ranged from 0.2 $\mu\text{mol/L}$ at 20 m depth to a peak in the crater of an extraordinary 400 $\mu\text{mol/L}$.

To evaluate further the controlling factors on the rising bubble plume, multibeam water column data were analyzed. The bubble plume spatial distribution revealed a horizontal intrusion of gas bubbles just below the thermocline. This pronounced pattern was traced 200 m horizontally with a downflow plume orientation suggesting trapping of methane-enriched fluids at depth.

A numerical bubble propagation model was used to simulate the extraordinarily intense Blowout site plume. Simulations that used normal bubble dissolution rates were unable to explain the observed trapping of almost all methane at depth, even when neglecting the observed very strong upwelling flows at the site. Incorporating a hypothesized enhanced bubble gas exchange rate allowed reproduction of observations.

Video and multibeam water column analyses revealed significant turbulence in and around the bubble plume on decimeter and meter scale. Moreover 3D water column assessments by multibeam reveal that the gas ebullitions merge into a 20 m wide spiral vortex extending throughout the water column. Spiral vortex formation never has been reported for gas seepage and may be an important process enhancing plume methane dissolution. Numerical simulations incorporating vortical bubble trapping (slow rise) and enhanced bubble gas exchange were able to reproduce observations. Thus, megaplume processes could explain the surprising low surface methane observations, with important implications for understanding the fate of methane from intense seepage and for blowout response.