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Methane ebullition and fate in the Rhone River delta: Hydroacoustic evaluation of ebullition

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Motivation

- Inland water bodies have been neglected as sources of methane[1]
- River deltas in large lakes can be CH_4 ebullition hot spots[2]
- Ebullition is the most efficient CH_4 pathway to the atmoshpere from shallow waters[1,3]
- Ebullition's spatiotemporal variability makes quantification quite difficult[1]

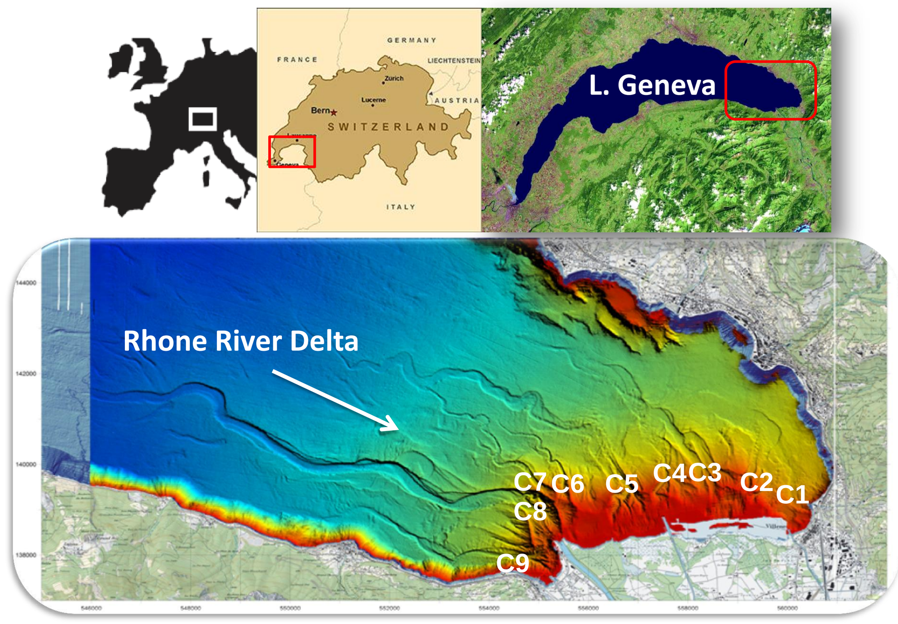

Figure 1. Results shown below are from surveys of the Rhone River Delta in Lake Geneva (Switzerland), which has 9 subaquatic canyons. Multibeam data from Sastre et al. 2010[5]

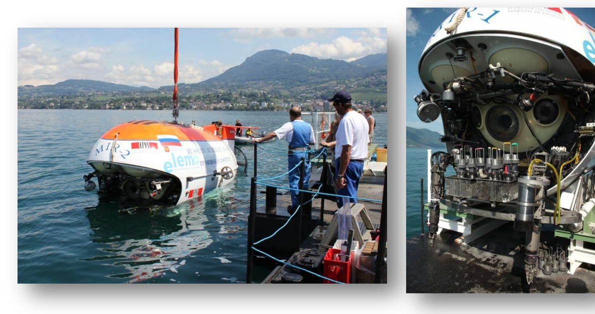

Figure 2. MIR submersible with cores and core heads in front

- Within the framework of the Elemo project (elemo.ch), ebullition was investigated in the Rhone River delta of Lake Geneva (Fig. 1). The EPFL-hosted project included the use of the Russian MIR submersibles (Fig. 2) for various projects during summer 2011.

Echosounder calibration

- A 120 kHz echsounder (Kongsberg Simrad EK60) was calibrated for bubble size at 10 m depth in a natural lake
- Bubbles of known volume or measurable size were created *in situ* (Fig. 3) and related to the backscattering cross-section (σ_{bs}) seen by the echosounder (Fig. 4)
- Our calibration agreed with a lab calibration performed with another 120 kHz echosounder[4]

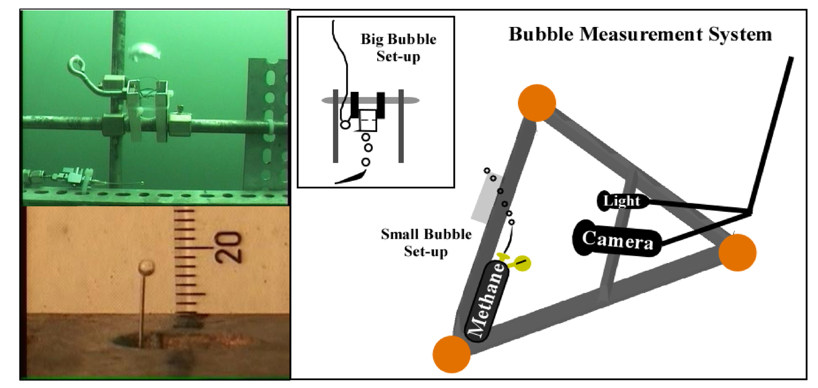

Figure 3. Bubble measurement system for making and recording bubbles for the calibration

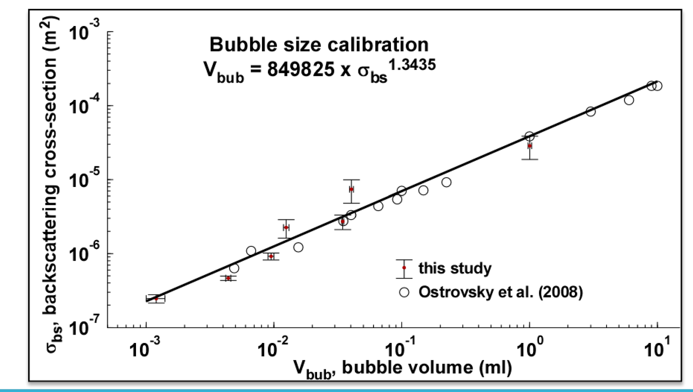

Figure 4. Echosounder calibration results for bubbles size from this study and a similar one

Hydroacoustic analysis of ebullition flux

I. Use rise velocity (V_z) to distinguish between fish (~0 m/s) and bubbles (15-50 m/s, Fig. 5)

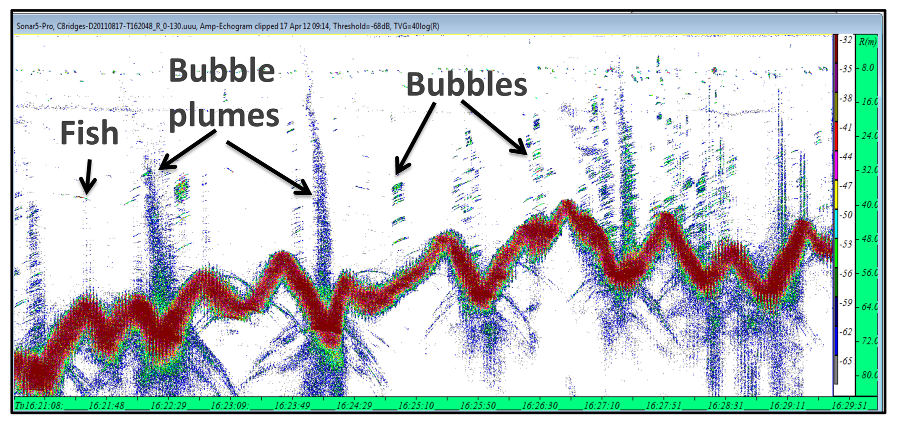

Figure 5. Example echogram from Rhone delta showing bubbles, bubble plumes, and fish

II. With the best bubble echoes, find the bubble size distribution (TS, Fig. 6)

$$TS\ [dB] = 10*\log(\sigma_{bs})\ [m^2]$$

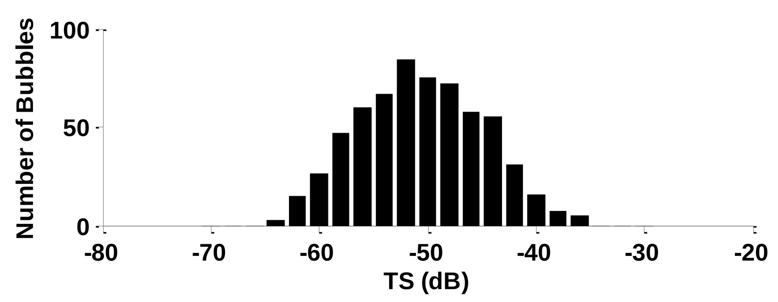

Figure 6. Bubble size distribution expressed as TS (target strength) distribution

III. Scale the acoustic energy in water (sv) by TS (Fig. 7) to get bubble density (N)

$$N\ [\#/m^3] = sv/TS\ [m^{-1}/m^2]$$

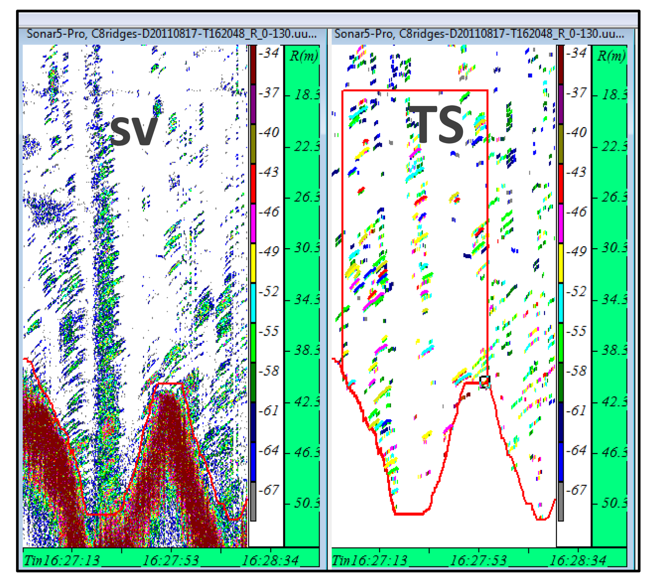

Figure 7. The full acoustic energy (sv) in the left echogram has many reliable bubble echoes in the right echogram for the TS distribution

IV. Calculate volumetric bubble density (N_b) using TS converted to volume (TS_{vol}) via Fig. 4

$$N_b\ [ml/m^3] = N\ [\#/m^3] * TS_{vol}\ [ml]$$

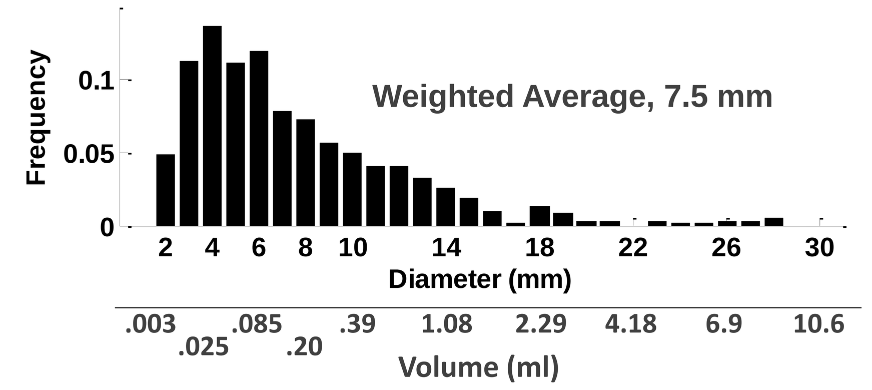

Figure 8. Bubble size distribution expressed as bubble diameter and volume.

V. Use bubble rise velocity (V_z) and fraction of CH_4 in bubble (F) to find CH_4 bubble flux (J)

$$J\ [mg\ m^{-2}\ d^{-1}] = N_b\ [ml/m^3] * V_z\ [m/s] * F\ (\%)$$

Avg. Rise Velocity (V_z)	0.24 m/s
Avg. CH_4 Fraction (F)	84%

Table 1. Sediment Ebullition Flux in Rhone delta

Rhone Delta Region (Fig. 9)	Ebullition Flux, J ($mg\ m^{-2}\ d^{-1}$)
Delta	400
Northeast	300
Southwest	230
Average	310

Spatial heterogeneity of ebullition

- Ebullition was more prominent directly in front of the river inflow than to the NE and SW (Fig. 9a)
- Concentration of bubbles to north could be due to the Coriolis force acting on Lake Geneva (Fig. 9a)
- Bathymetric highs produced more ebullition, particularly at deeper depths (>50 m, Fig. 9b)
- Deeper than 100 m ebullition focused on canyon levees/shoulders

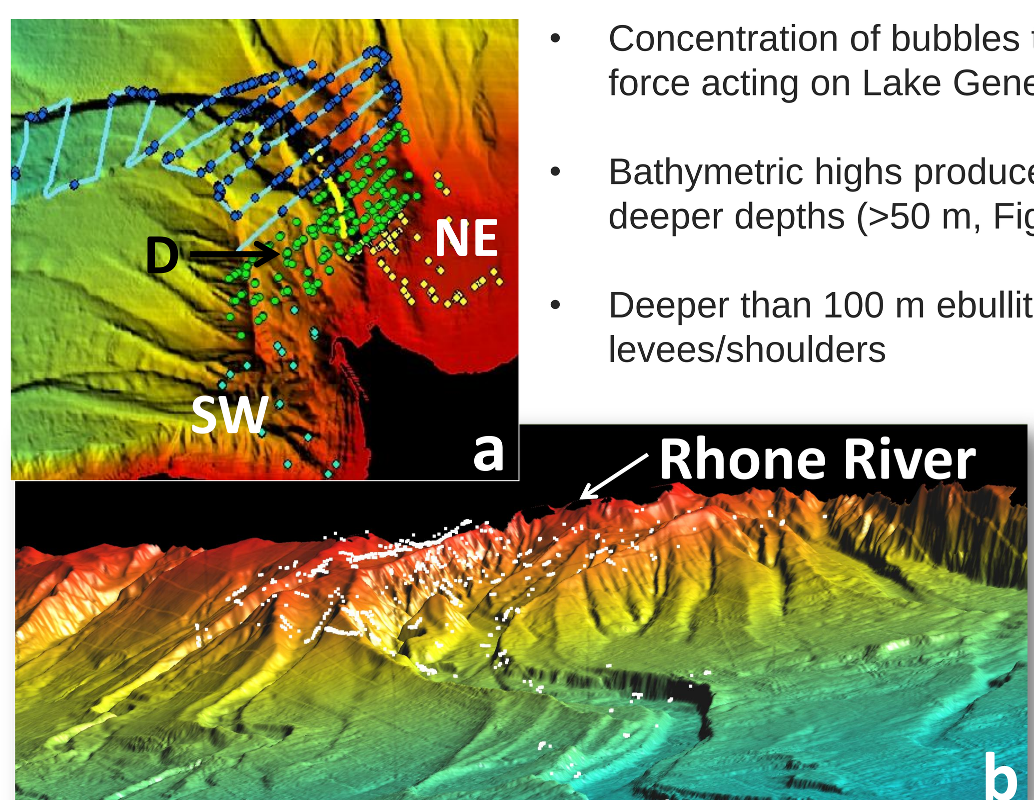

Figure 9. (a) Locations of bubbles found in proximal delta (D), northeast (NE) and southwest (SW) of Rhone inflow. **(b)** 3D view of active canyon (C8) with bubble locations shown in above where they were observed

Fate of CH_4 bubbles

- A bubble of average size (7.5 mm) will release 50% of its CH_4 to the atmosphere if released from 20 m, but only 10% from 60 m and 0 from 100 m (Fig. 10)
- From the average depth of the delta region (30 m) and using the average estimated flux (Table 1), the 1.7 km[2] delta emits ~0.2 t CH_4 per day in summer
- Therefore, the Rhone River delta emits up to 70 t CH_4 per year, a small but non-negligible amount

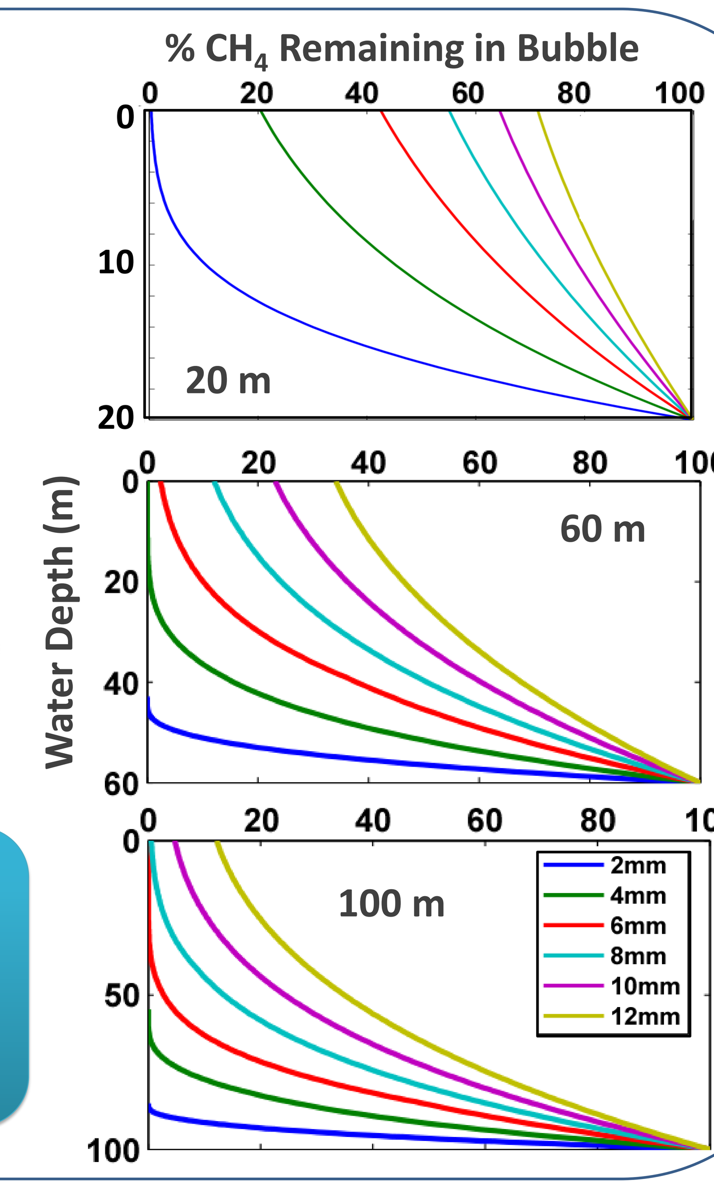

Figure 10. Amount of CH_4 released to atmosphere depends on initial bubble size (colored lines show diameter), release depth, gas concentrations in bubble and in ambient water

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