Field characterization of the negatively buoyant inflow of the Rhône River into Lake Geneva

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Motivation

River inflows…

…are an important input of momentum, heat, oxygen, sediment, nutrients and contaminants for lakes and reservoirs

→influence on water quality, reservoir storage capacity & hazards

→hydrodynamic processes at the river-lake/reservoir interface control the fate of these components


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Eutrophication processes regulated by a plunging river inflow

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Loss of reservoir volume by sediment deposition and its impact on water availability in semiarid Brazil

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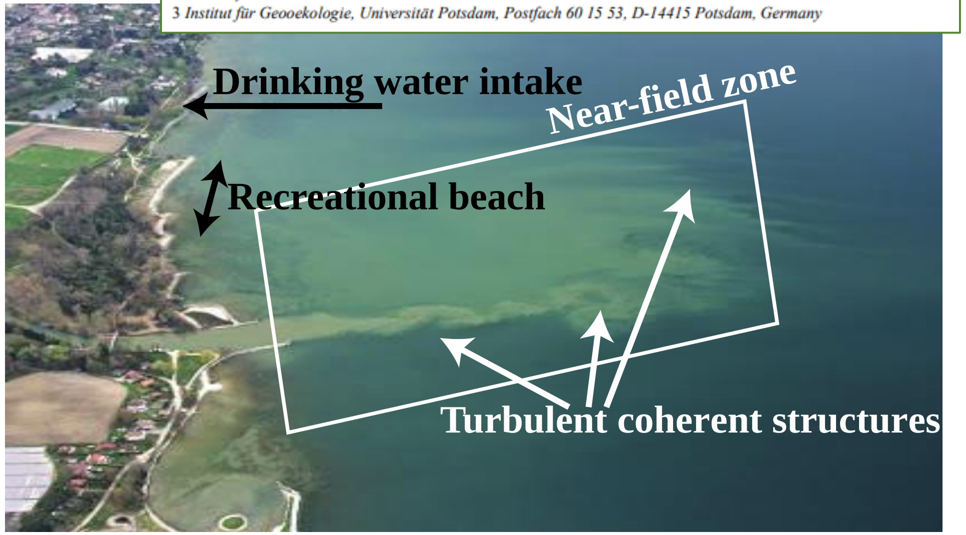
Inflow of the River Venoge into Lake Geneva (Switzerland). An intake of drinking water for the highly urbanized Lausanne-Geneva region is situated at 1 km from the inflow, and recreational beach areas are situated at both sides of the inflow.→



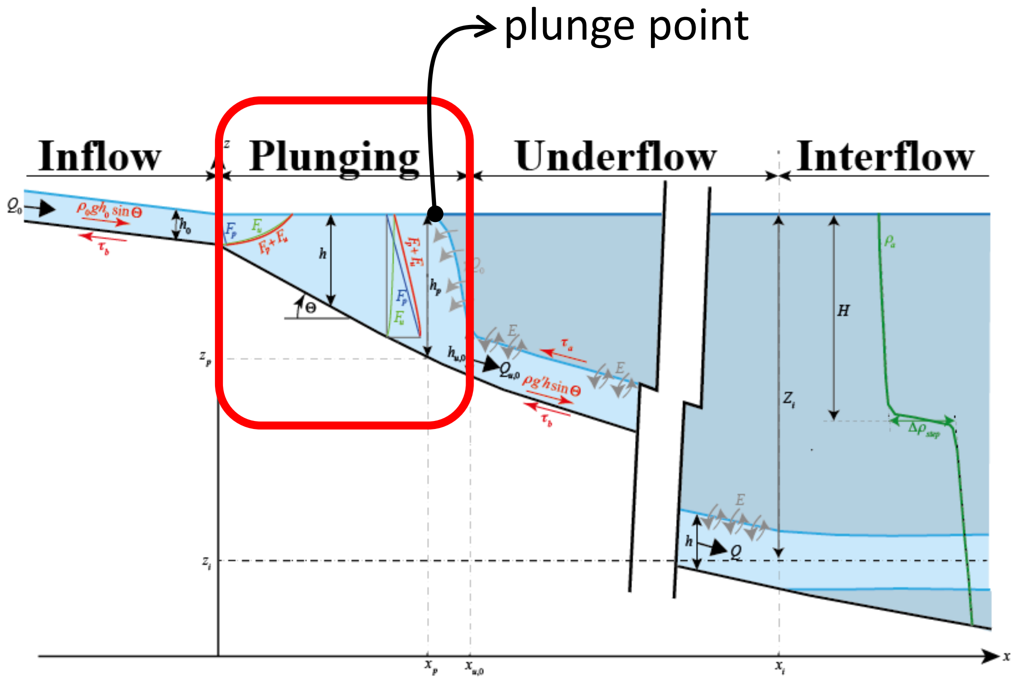
Motivation

River inflows…

…will plunge and form a gravity-driven density current near the bed (underflow) and/or intermediate current (interflow) when they are negatively buoyant w.r.t. lake surface water

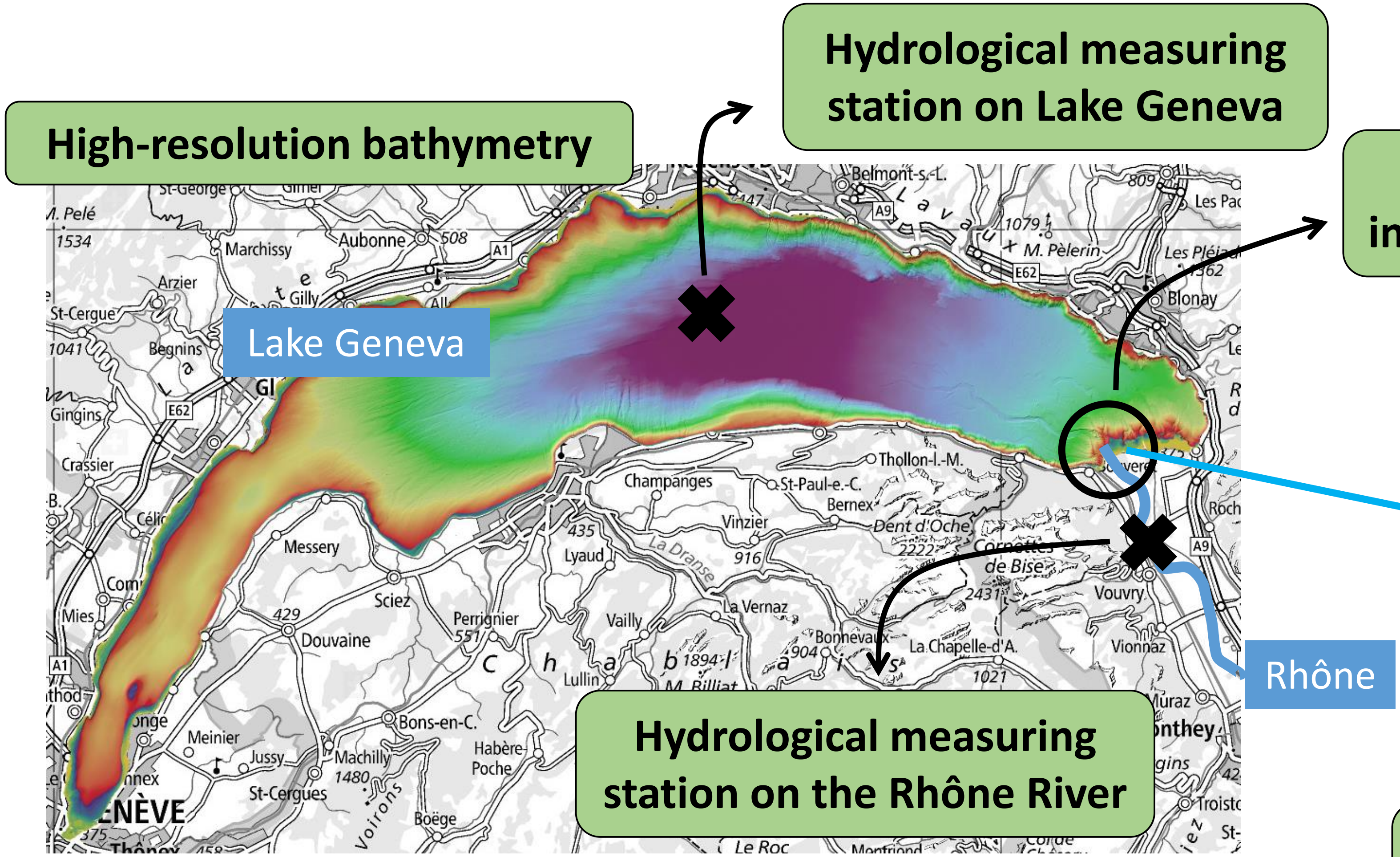
→plunging process provides upstream boundary conditions for density currents

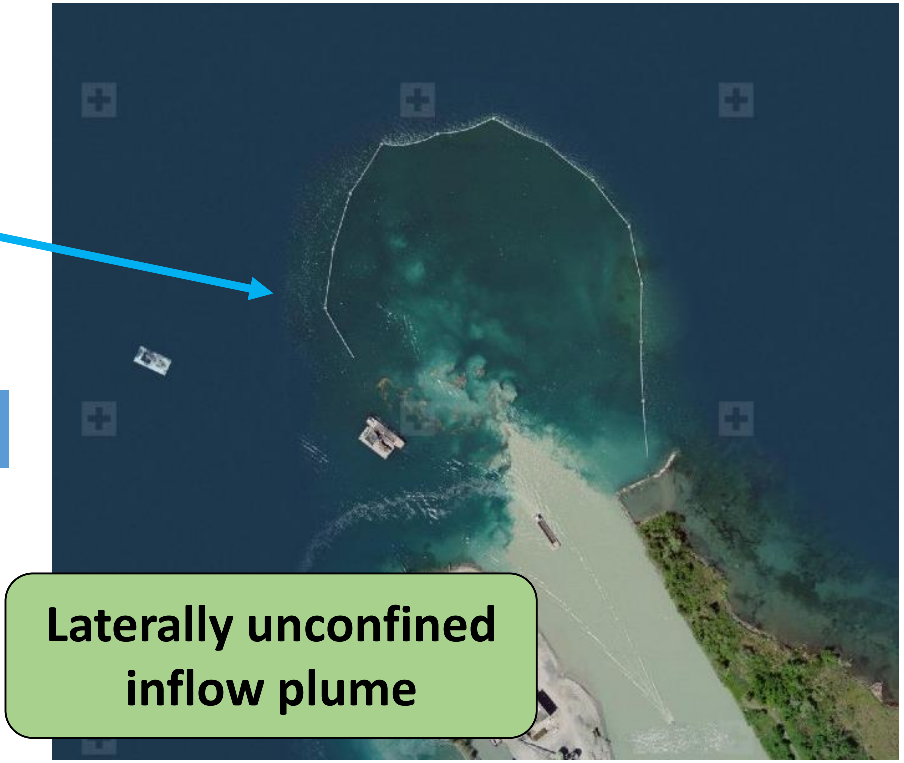
→important to identify and quantify the mixing processes involving entrainment of ambient water into the plunging flow



! hydrodynamics of plunging process still poorly understood, especially in laterally unconfined configurations

Study site: Rhône inflow into Lake Geneva



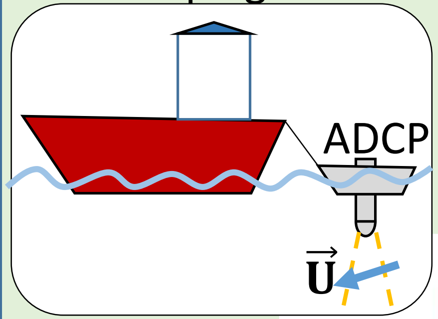


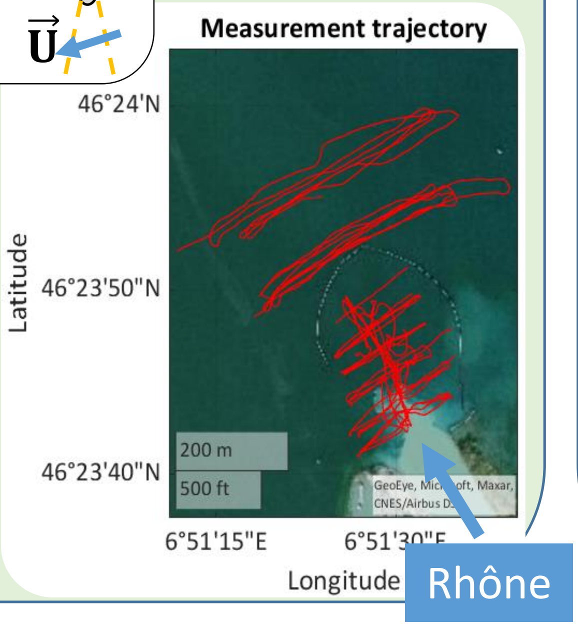
Virtually all boundary conditions are known!

Methods

vessel-mounted ADCP

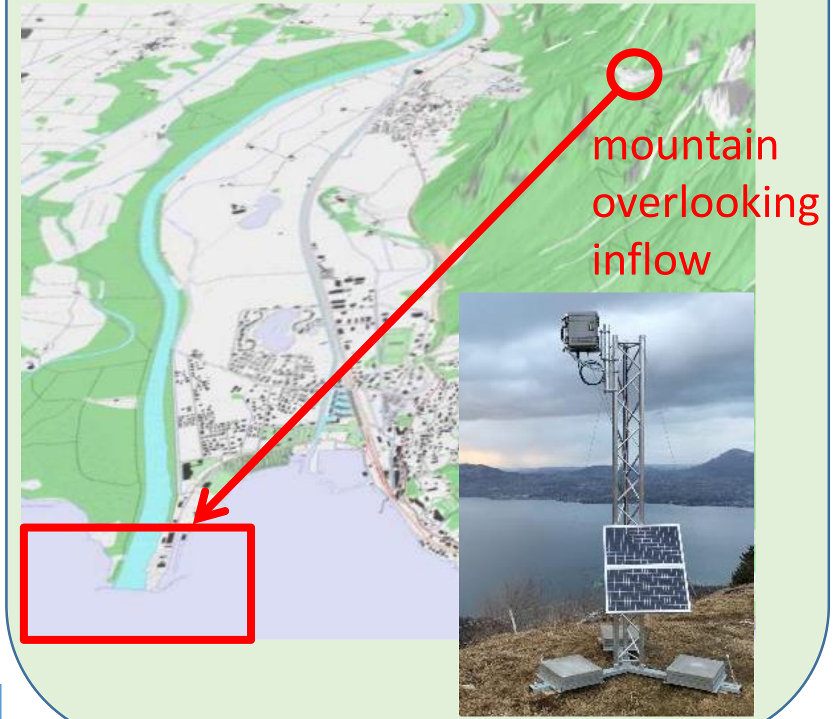
→three-dimensional velocity field along transversal and longitudinal transects
→multiple repetitions to catch low magnitude, secondary currents
→4 campaigns for various inflow cond.





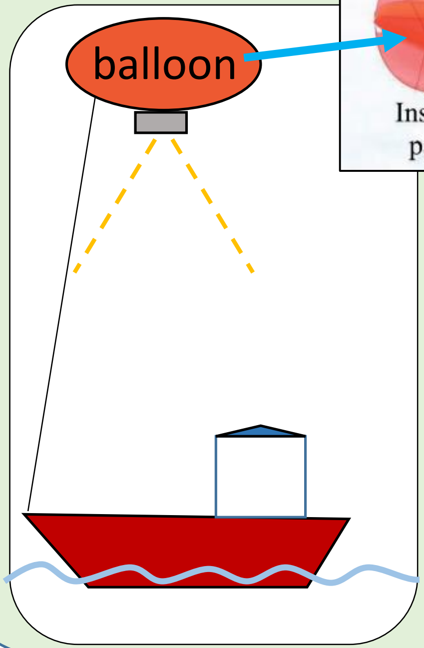
static remote sensing camera system

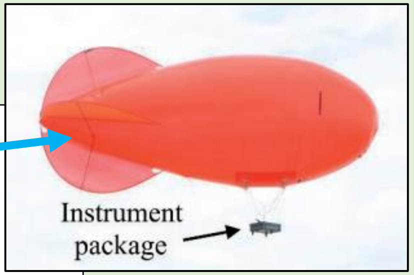
→two-dimensional surface patterns
→large scale processes
→1-10 minute resolution
→ongoing since June 2019, also during some ADCP campaigns



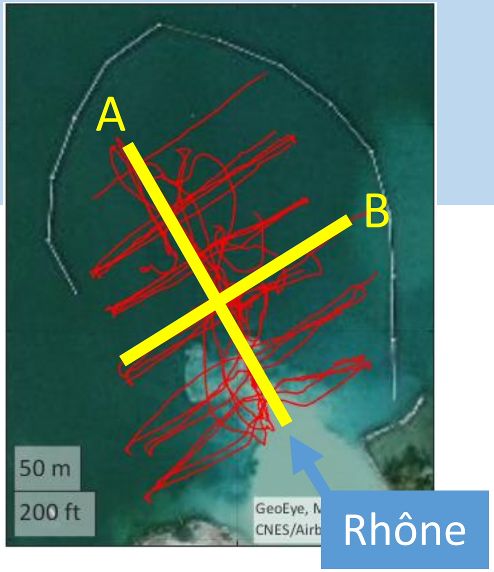
mobile balloon-mounted camera system

→two-dimensional surface patterns
→medium to small scale processes
→1 second resolution
→during 1 ADCP campaign and 2 extra runs





Results: ADCP measurements

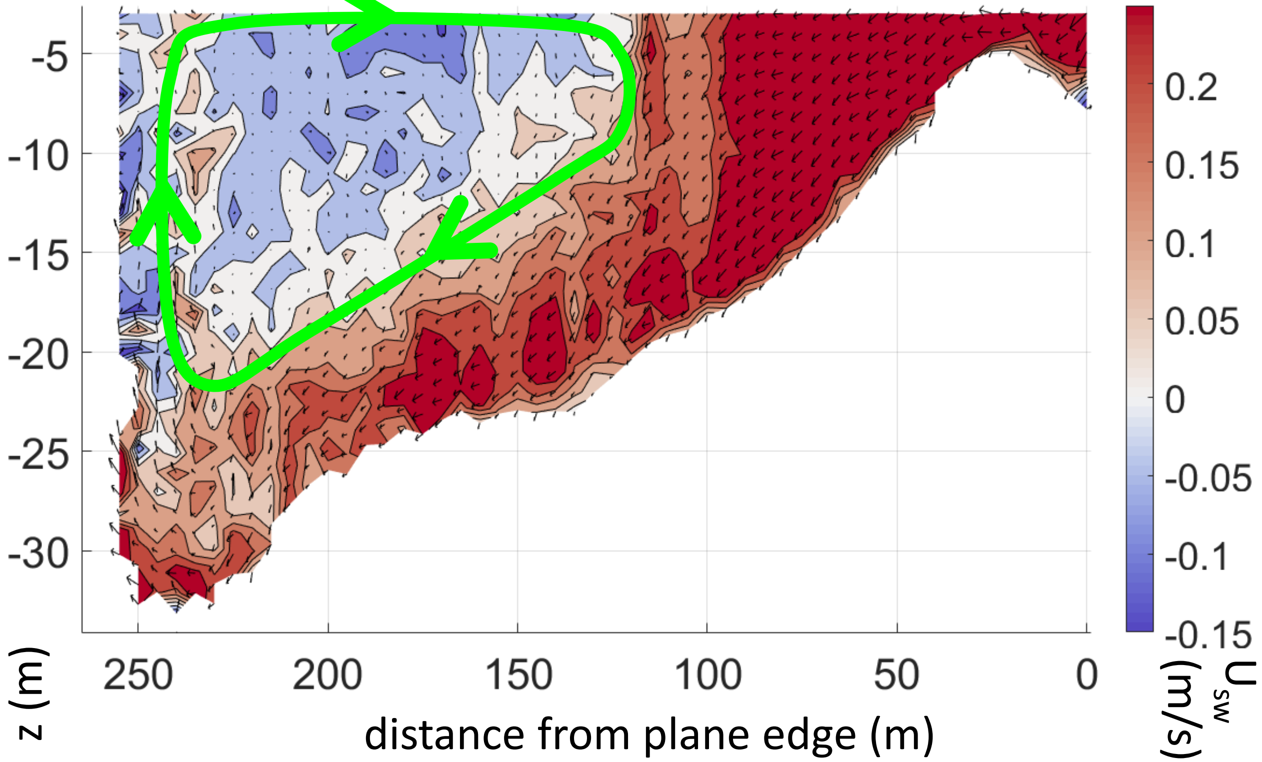


Results for 1 ADCP campaign → here $Fr_d = U_0/\sqrt{g'h_0}$ = 2.7 at inflow

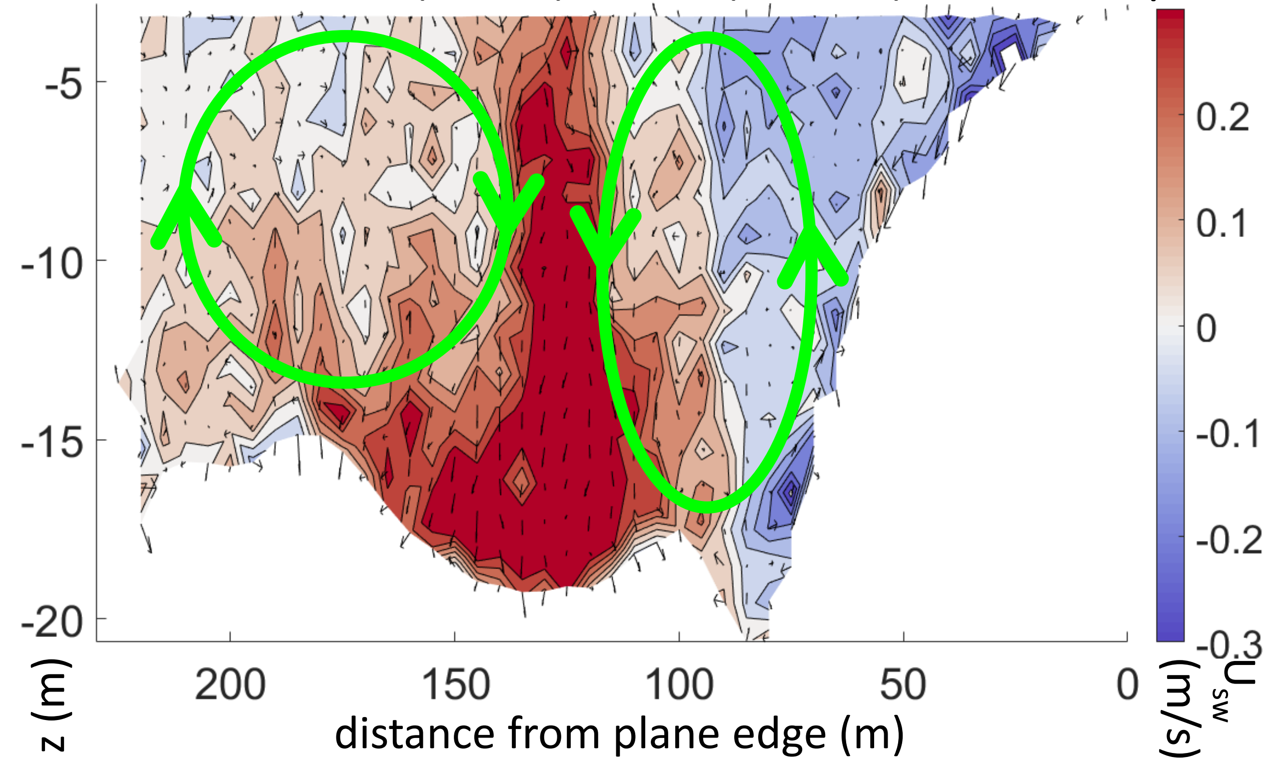
→plunge point around d = 120 m and underflow formation further downstream
→strong backflow towards plunge point
→upwards velocities around d = 240 m

→transect through plume tip
→high velocity core in streamwise dir.
→two counter-rotating secondary currents
→lateral collapsing of plume

A. Velocities in "streamwise" direction (colors and vectors)



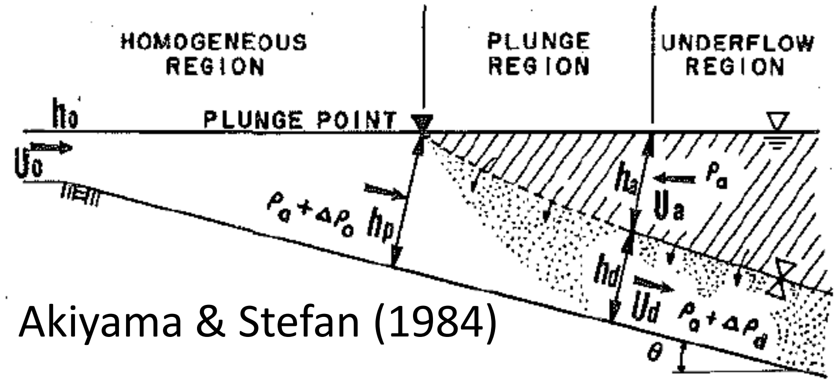
B. Velocities across (colors) and in (vectors) transverse plane



Results: ADCP measurements

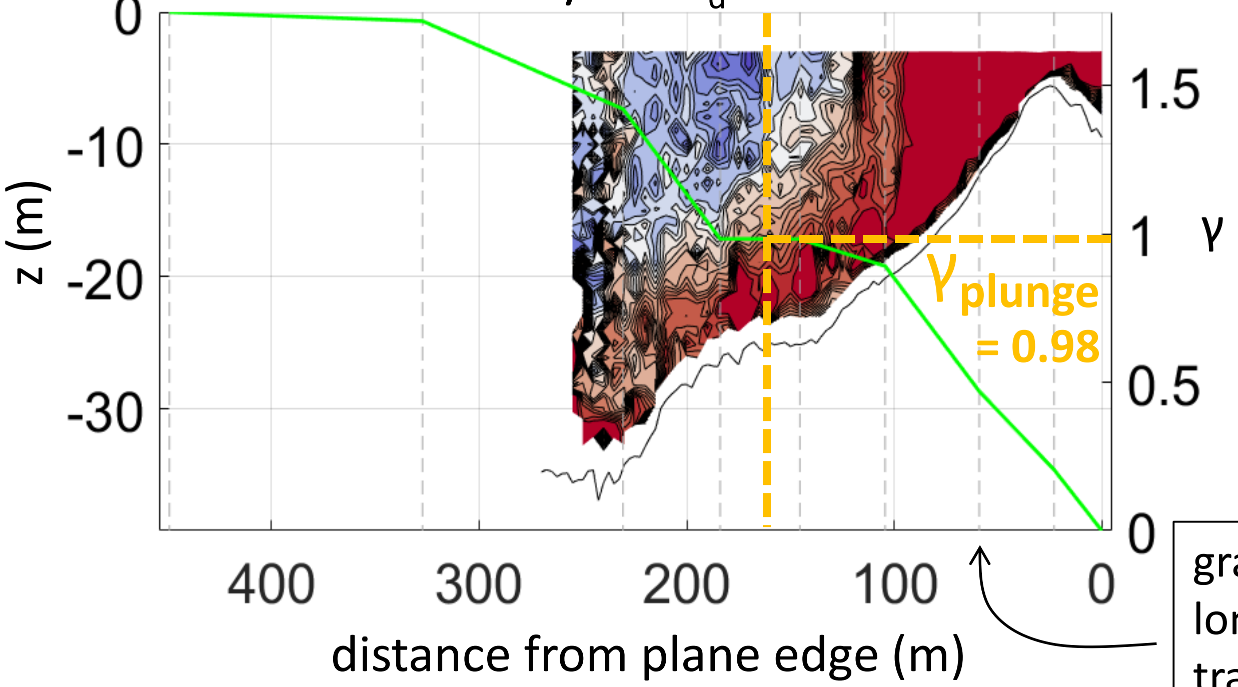
Quantifying mixing through the plunging mixing coefficient γ:

- Akiyama & Stefan (1984) for 2D case: $u_d = \frac{(1+\gamma)q_0}{h_d}$
- In 3D: $\gamma = \frac{Q_d}{Q_0} - 1$ → integrate streamwise velocities over high velocity core to find Q_d in every transversal transect, Q_0 is (known) discharge at inflow



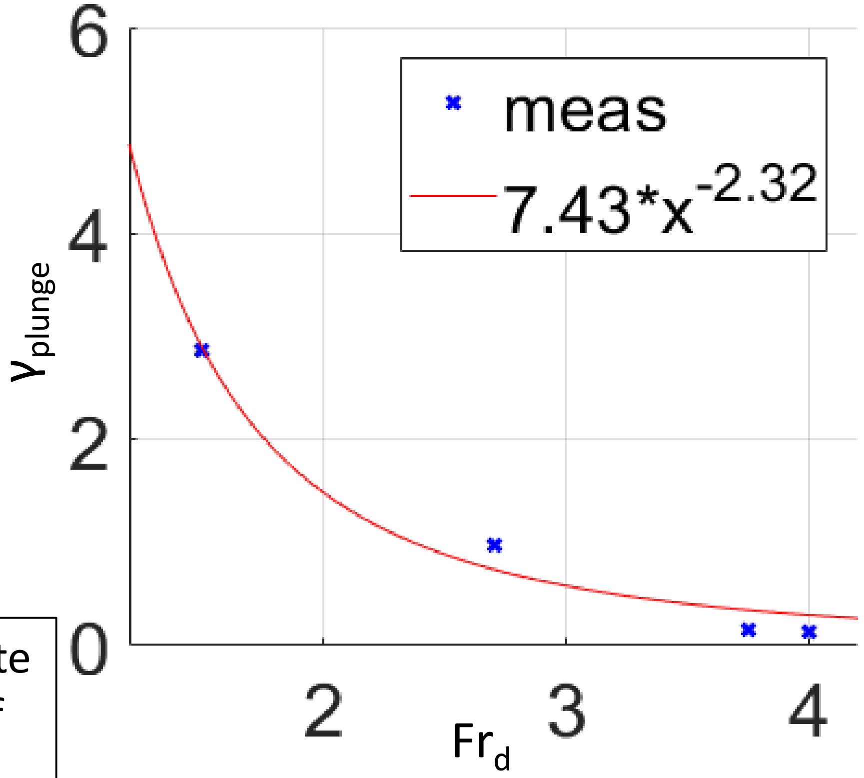
Akiyama & Stefan (1984)

Mixing coefficient superposed onto streamwise velocity for Fr_d = 2.7

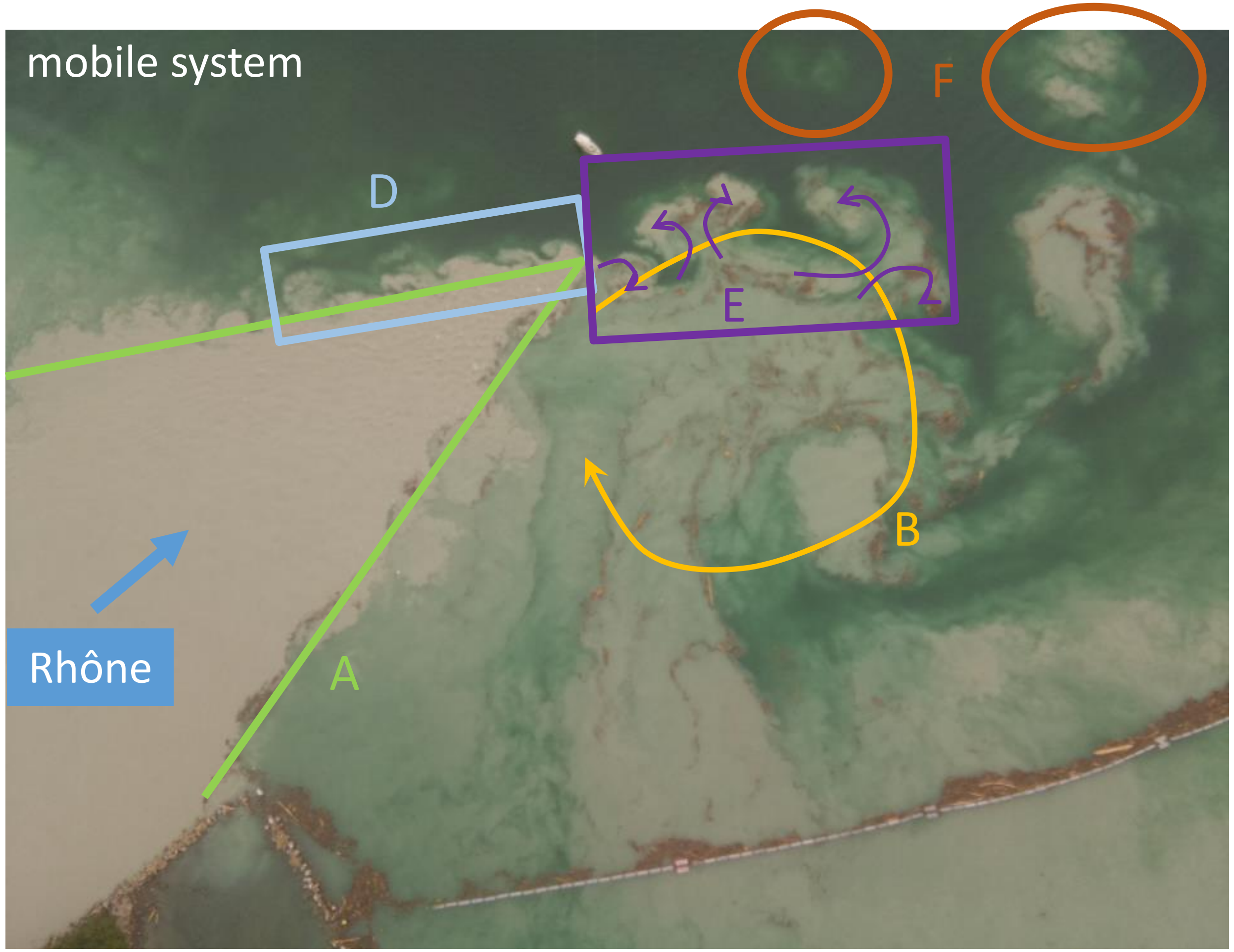


for all 4 campaigns

gray, dotted lines indicate longitudinal positions of transversal transects



Results: camera systems



Process description: A. persistent triangular plume shape; B. large scale circulation; C. surface leaking; D. Kelvin-Helmholtz instability; E. vortex shedding and dipole formation; F. boiling up of sediment rich water downstream of plume

→ open question: how do these processes depend on inflow conditions?

Conclusions

- Boat-towed ADCP measurements enable the investigation of the underwater 3D velocity field of a plunging flow
  - → can be used for quantifying the amount of mixing taking place
  - → relation to inflow densimetric Froude number was found: higher Fr_d leads to less mixing
- Static and mobile camera systems allow for the description of flow patterns visible at the surface
  - → next step: quantify these processes and link to inflow conditions (dependence on Fr_d?)
- The combination of the above three measurement techniques provides a detailed insight into the hydrodynamic processes of a plunging flow from large to small scales