Revisiting a 50-year-old conceptual model of plunging riverine inflows

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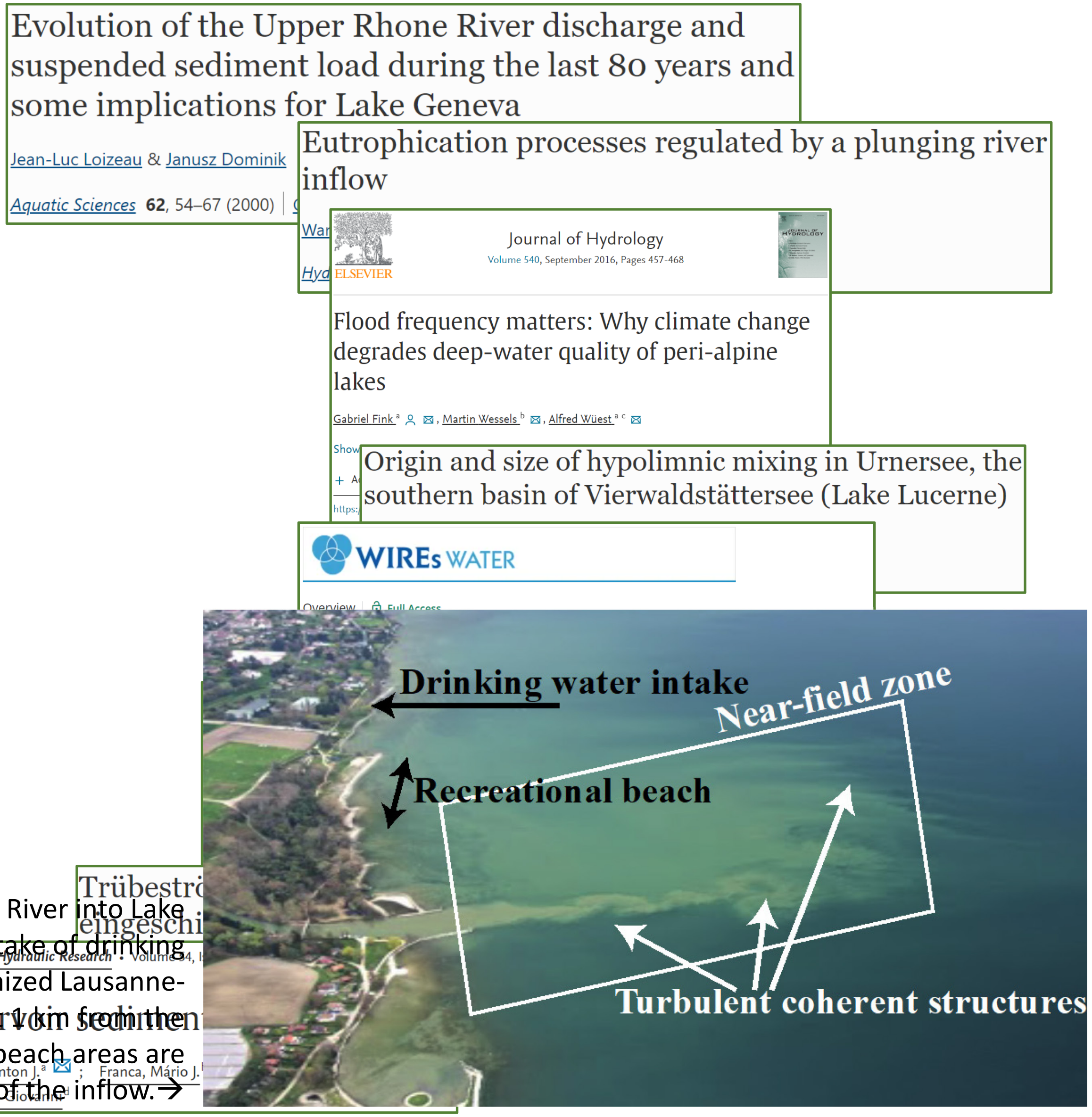
Motivation

River inflows are an important input of sediment, oxygen, contaminants, nutrients, heat, and momentum 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



Inflow of the Venoge River 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.

Current knowledge

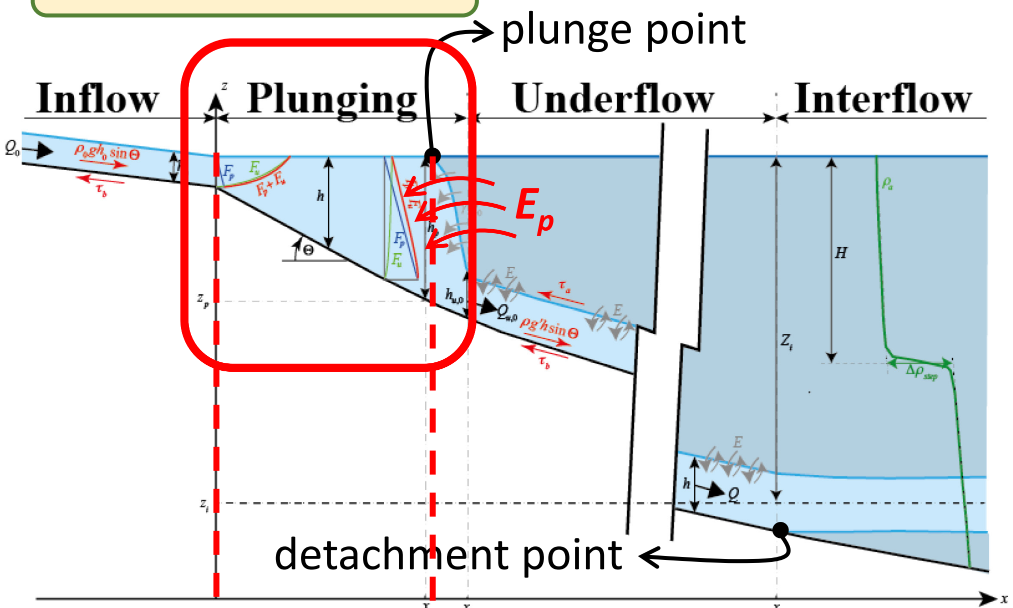
- Hyperpycnal river inflows will plunge and form an underflow and/or interflow

  → current knowledge mostly based on **laterally confined** lab experiments

  → plunging process provides upstream boundary conditions for underflows (entrainment of ambient water)

  → plunging process has crucial influence on pathway and final destination of sediment, nutrients and contaminants

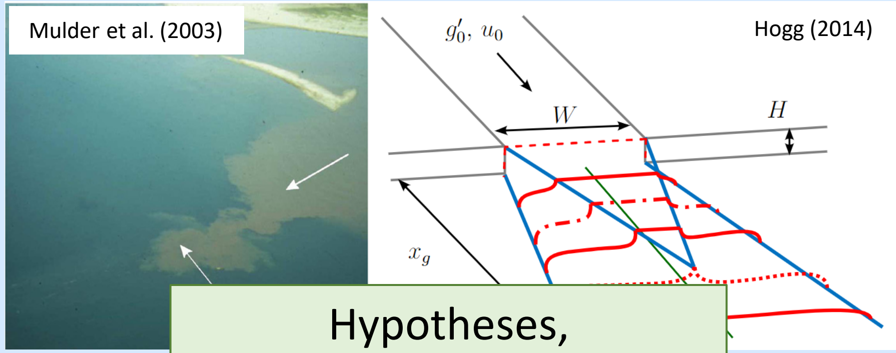
Classic (2-d) model:



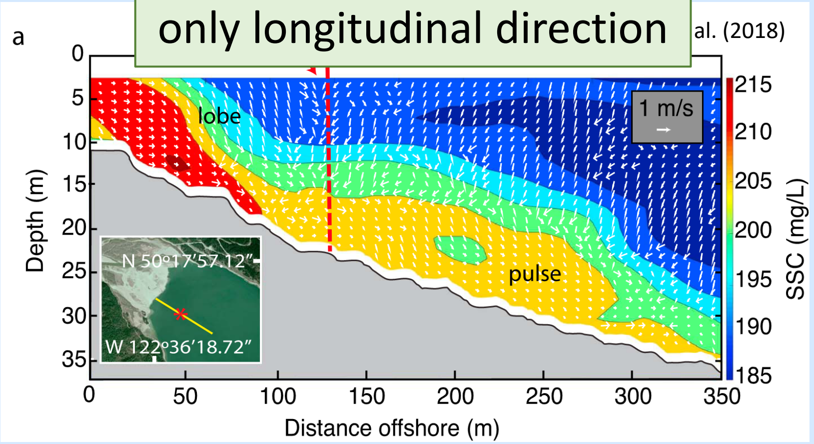
Confined Dranse de Bagnes torrent inflow into Lake Mauvoisin (Switzerland)

Current knowledge (3-d)

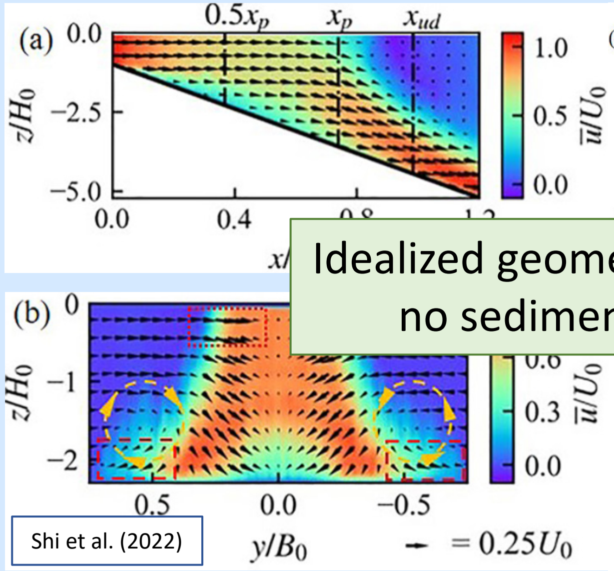
Field

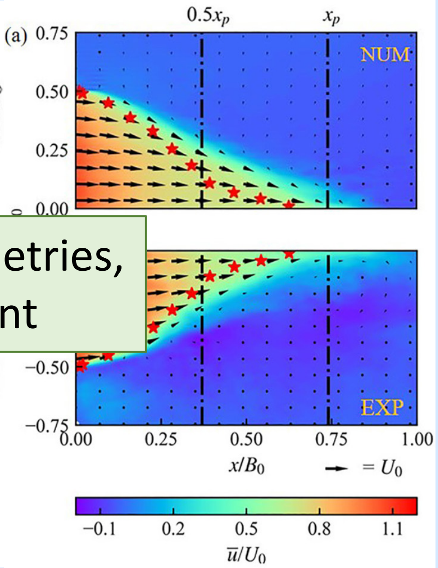


Hypotheses,
only longitudinal direction



Laboratory/Numerical





Idealized geometries,
no sediment

! no direct field measurements

Science questions

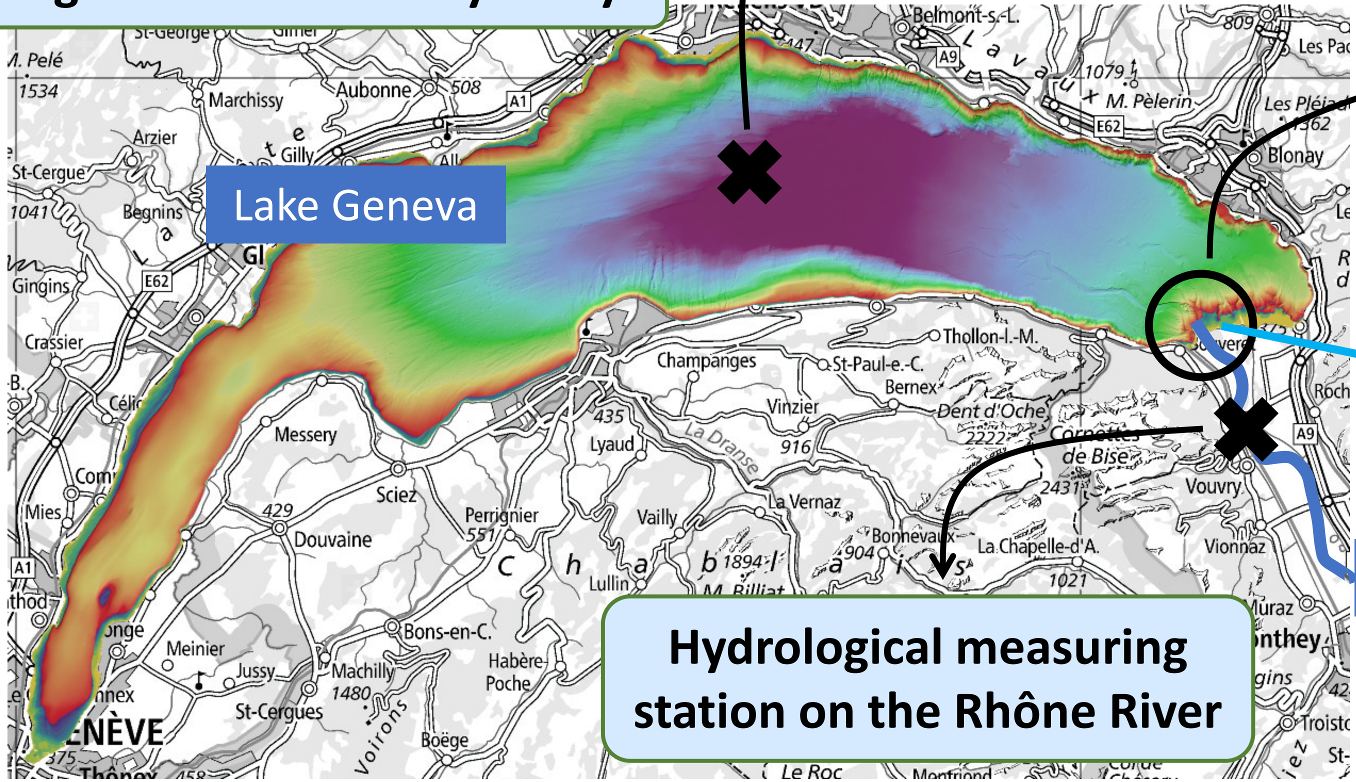
- Can the dominant **three-dimensional** hydrodynamic processes related to unconfined plunging be resolved for the first time using transect **field** measurements and remote imagery?
- What is the three-dimensional **flow structure** of an unconfined plunging plume and, in particular, **where is the plunge** located?
- How can existing **conceptual models** of plunging plumes be extended for **unconfined configurations**?

Study site

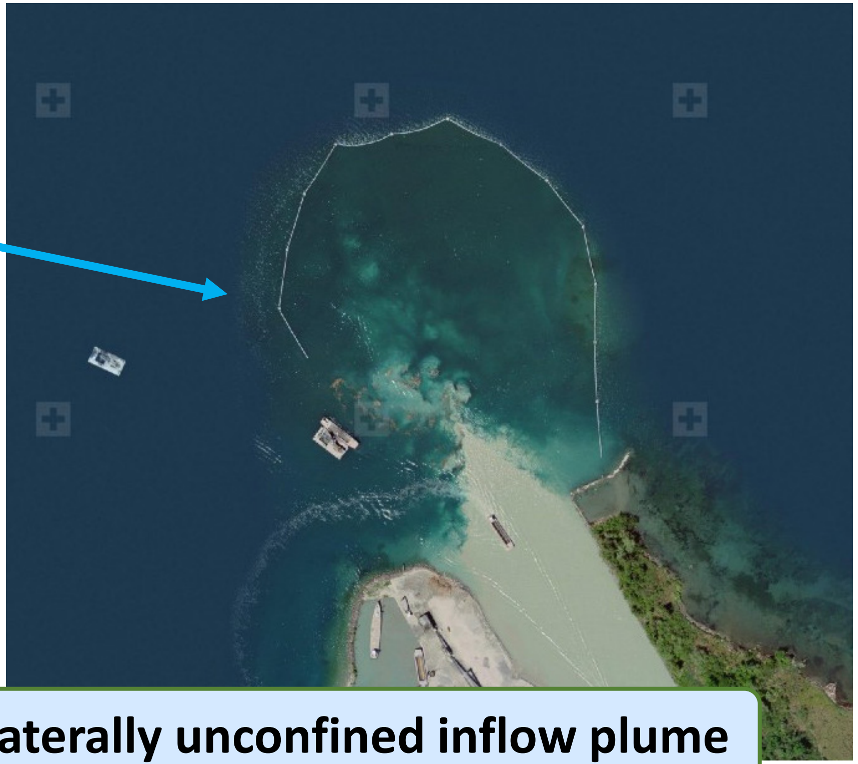
High-resolution bathymetry

Hydrological measuring station on Lake Geneva

Wide range of inflow conditions



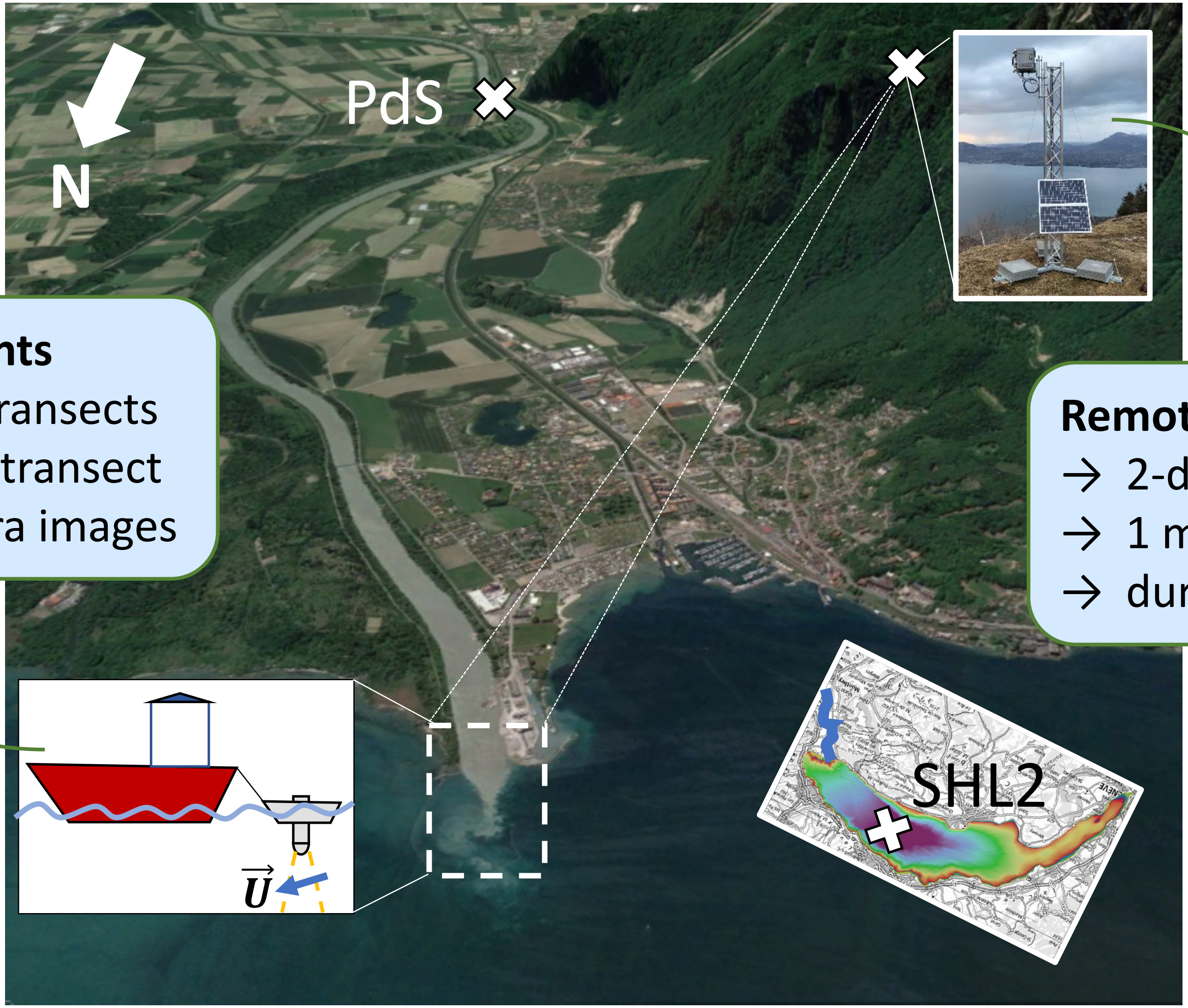
Hydrological measuring station on the Rhône River



Laterally unconfined inflow plume

Virtually all boundary conditions are known!

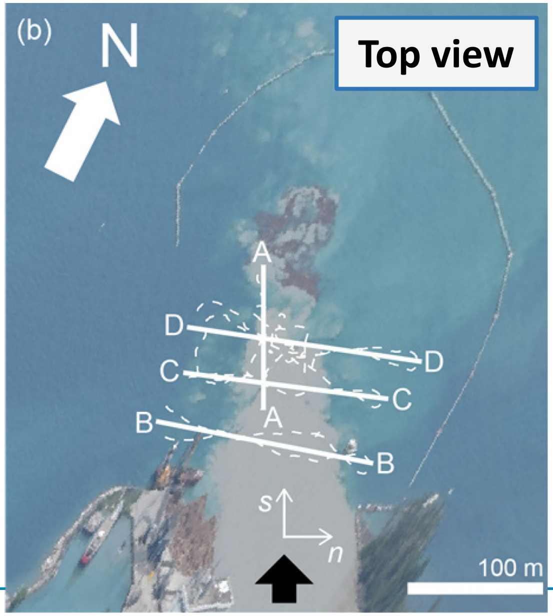
Methods

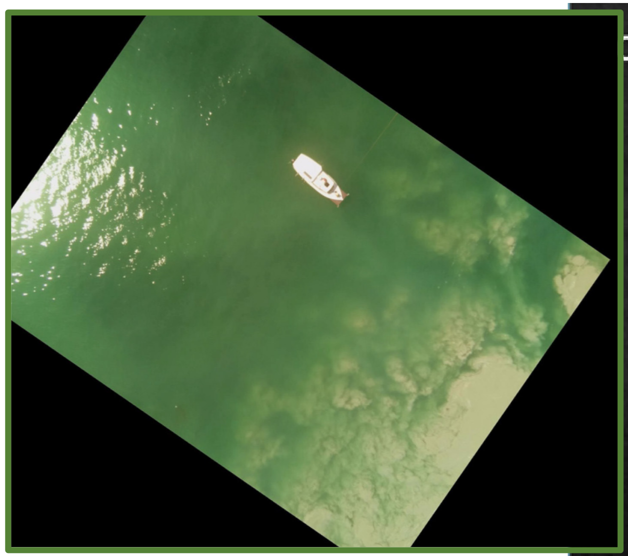


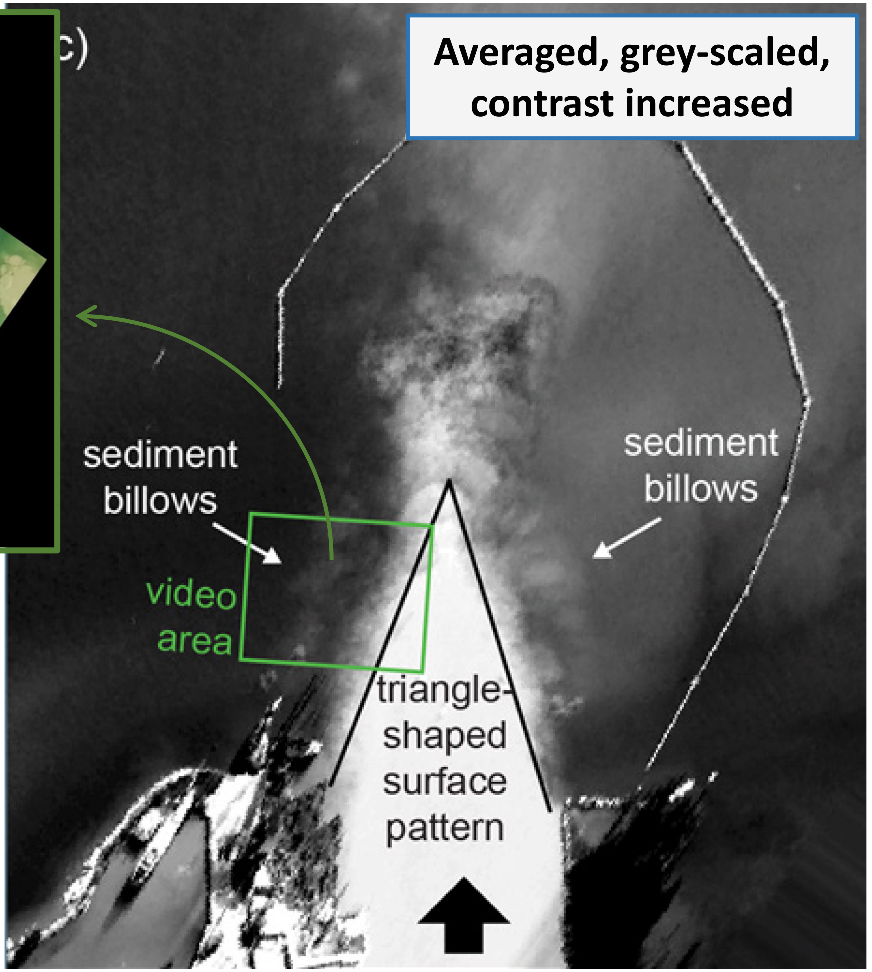
Gridded ADCP measurements
→ 3-d velocity field along transects
→ multiple repetitions per transect
→ guided by remote camera images

Remote camera imagery
→ 2-d surface patterns
→ 1 min, 1 m resolution
→ during ADCP measurements

Results

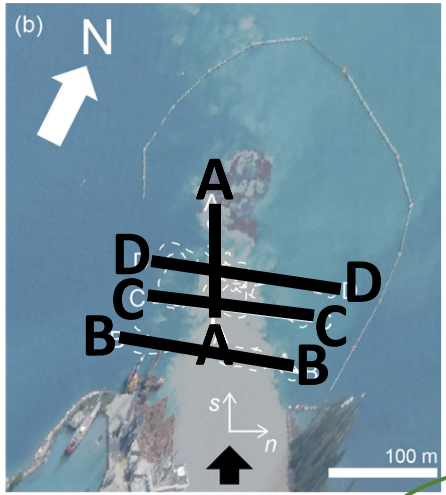


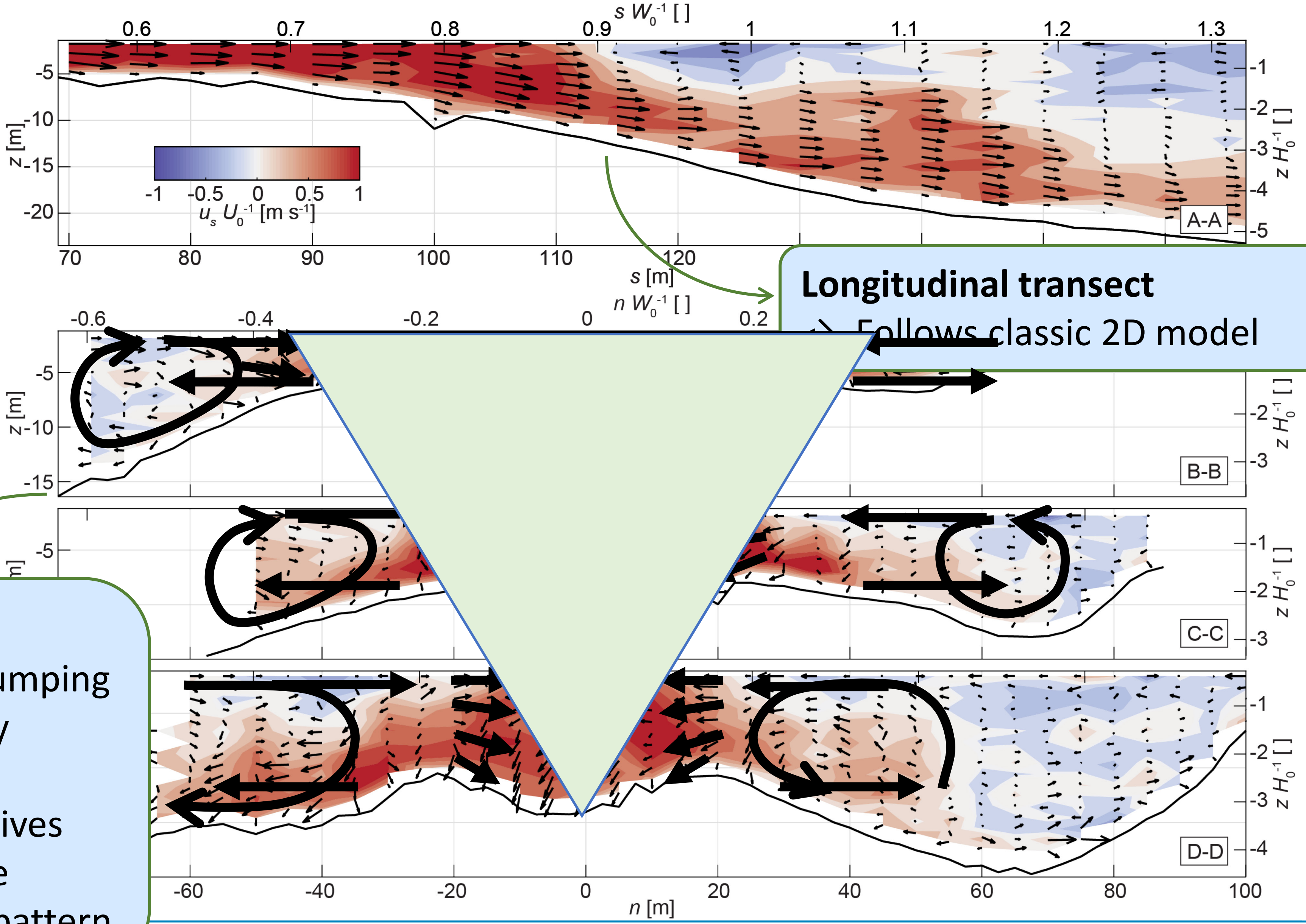




Secondary currents transporting sediment-rich water to the surface?

Results



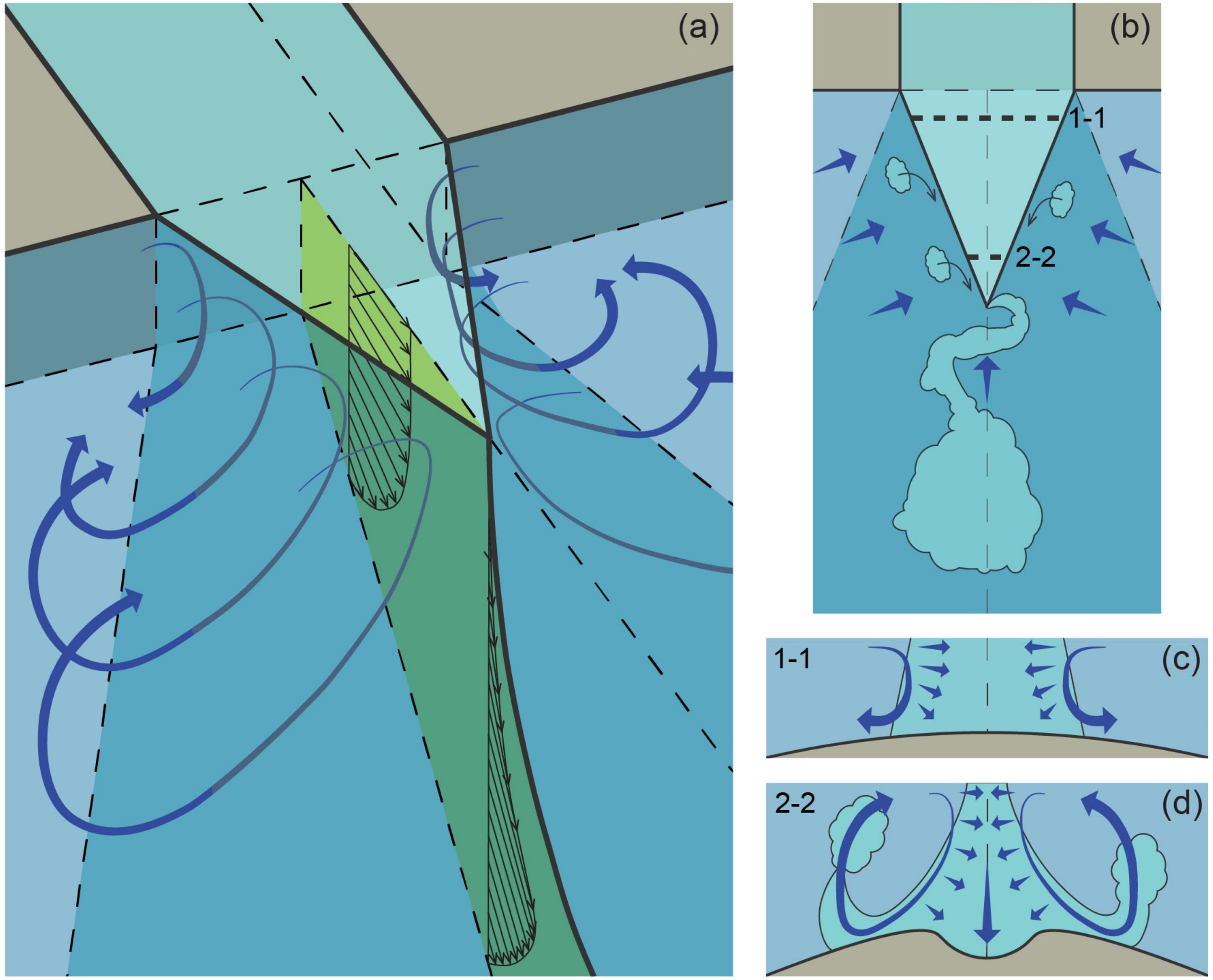


Longitudinal transect
→ Follows classic 2D model

Transverse transects
→ $\Delta\rho$ drives lateral slumping
→ LS drives secondary currents
→ Vert. divergence drives lateral convergence
→ Triangular surface pattern

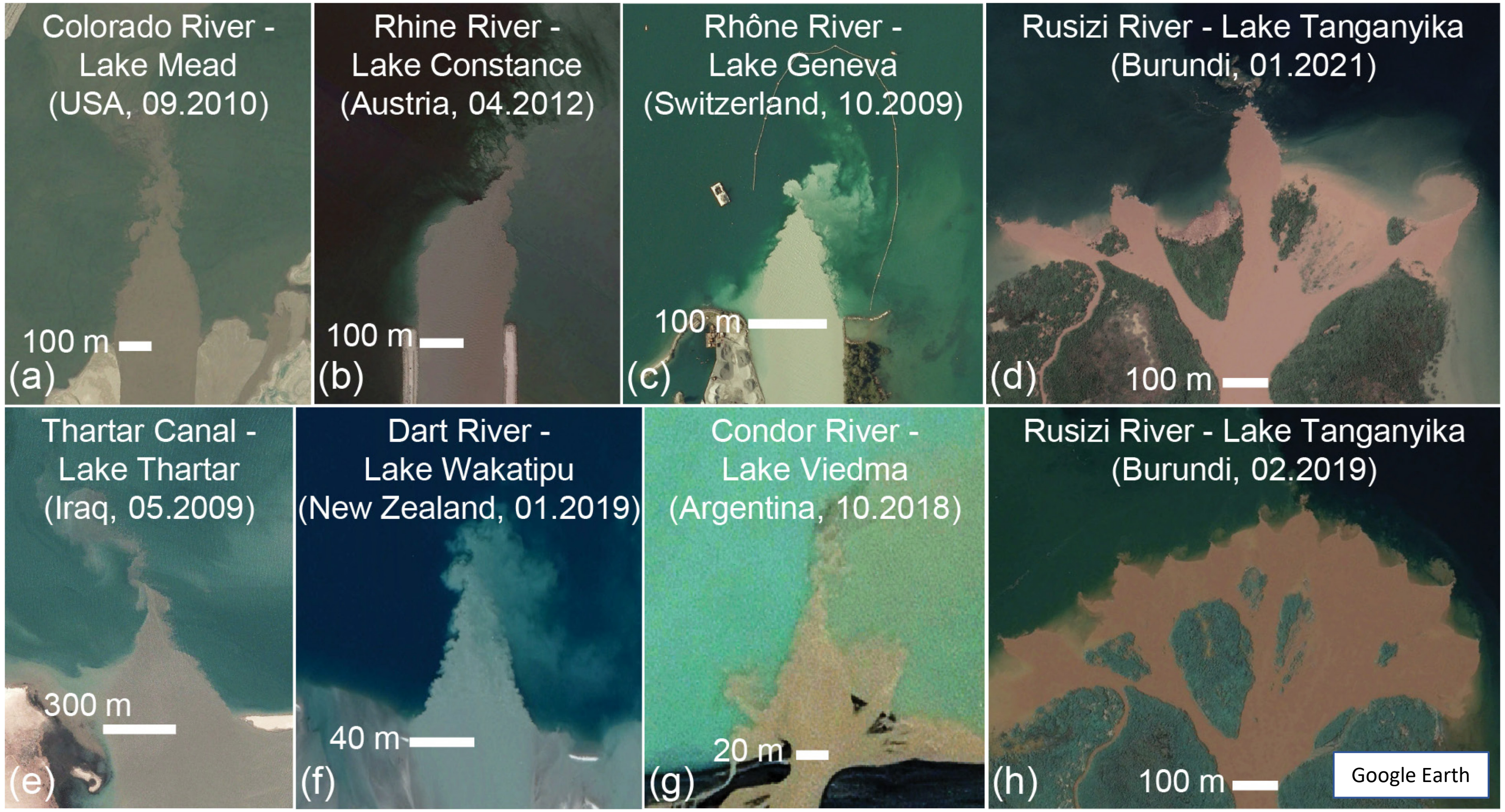
Away from the river mouth

Conceptualization



- ✓ Longitudinal velocity field
- ✓ Return current
- ✓ Lateral slumping
- ✓ Secondary currents with sediment transport
- ✓ Lateral flow convergence
- ✓ Triangular surface pattern

Applicability



Triangular surface pattern is not an exception → conceptual model widely applicable

Conclusions

- Transect **field** measurements and remote imagery allowed for resolving the dominant **three-dimensional** hydrodynamic processes related to unconfined plunging for the first time
- The three-dimensional **flow structure** of an unconfined plunging plume was elucidated
- The existing **conceptual models** of plunging plumes were extended for **unconfined configurations**