Velocity pulsations in continuous turbidity currents: observations from the field, laboratory experiments and Direct Numerical Simulation

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SFU SIMON FRASER UNIVERSITY
THINKING OF THE WORLD

MAX-PLANCK-GESELLSCHAFT

Two-Phase Continuum Models for Geophysical Particle-Fluid Flows

Geoflo13: Lillooet Lake

Geoflo16: Lillooet Lake + Xiaolangdi Reservoir + DNS + lab + linear stability analysis

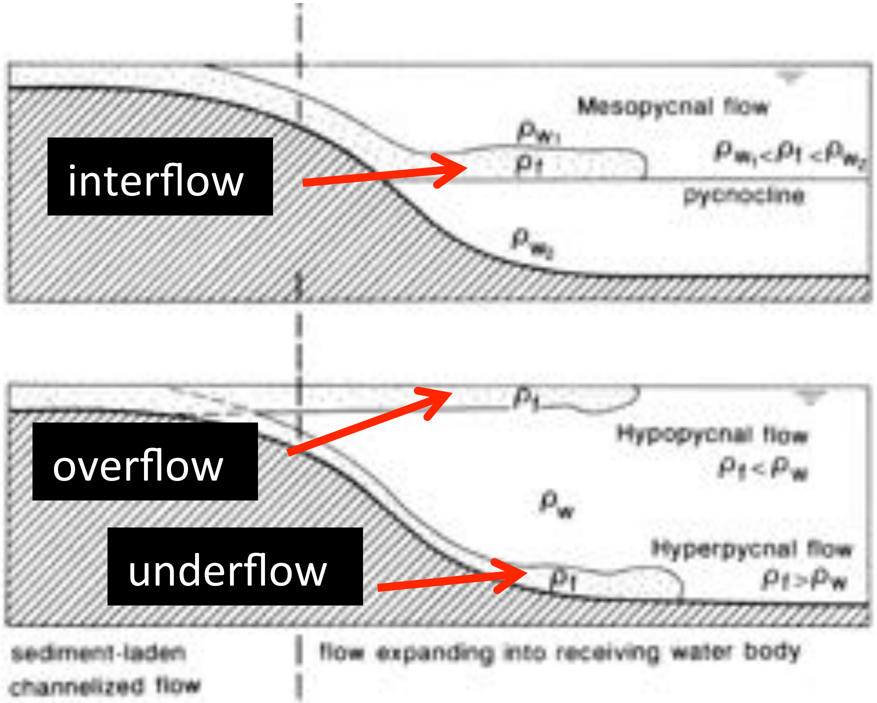
A global collaboration..

Turbidity currents

- Gravity current driven by a density difference caused by **suspended sediment**

Surge

Continuous



from Mulder & Alexander (2001)

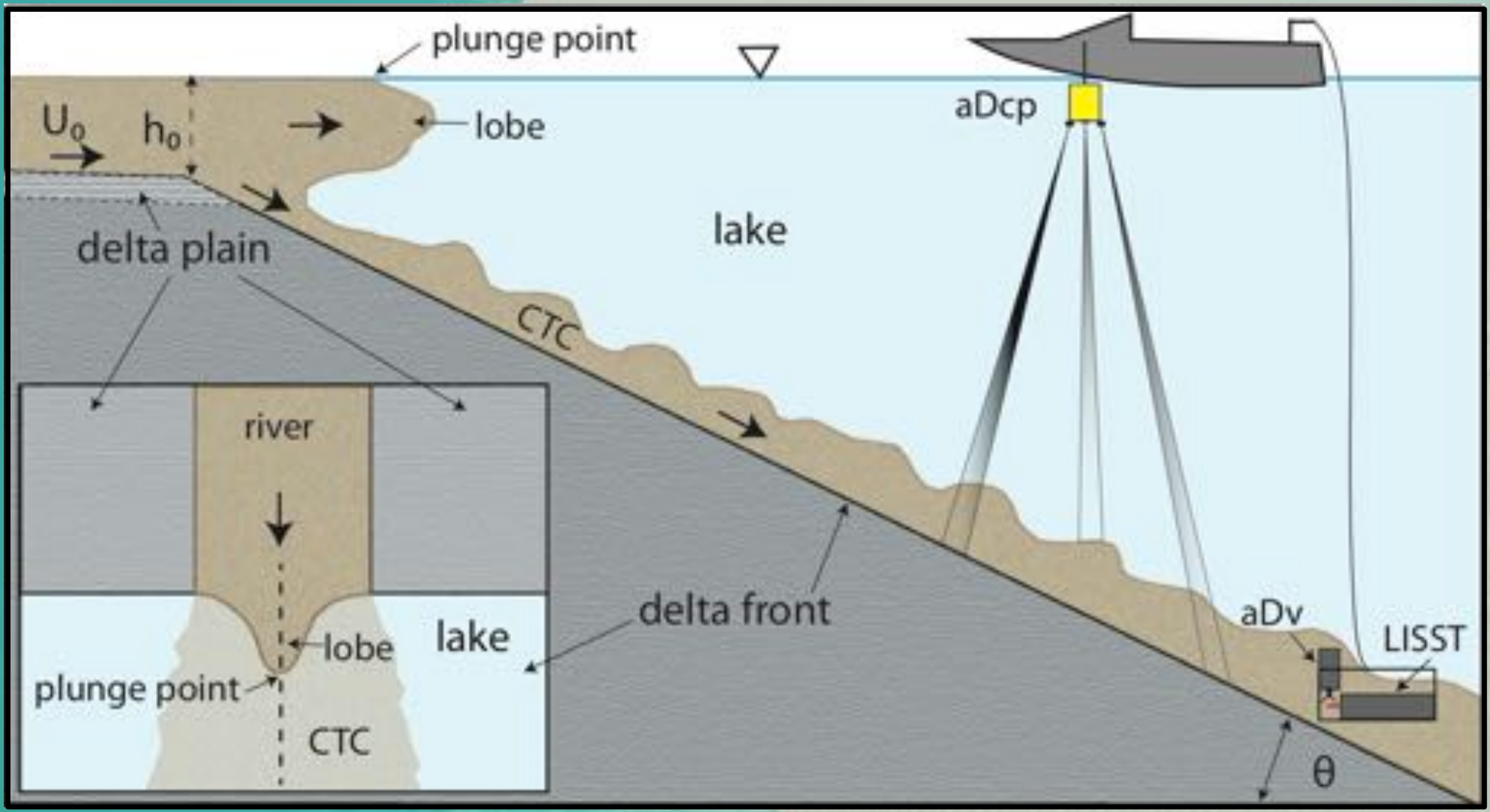
Research Objectives

- Primary objective: to examine the **cause(s) of pulsing** in continuous, natural turbidity currents in the field using laboratory experiments, numerical simulations and linear stability analysis of stratified shear flows

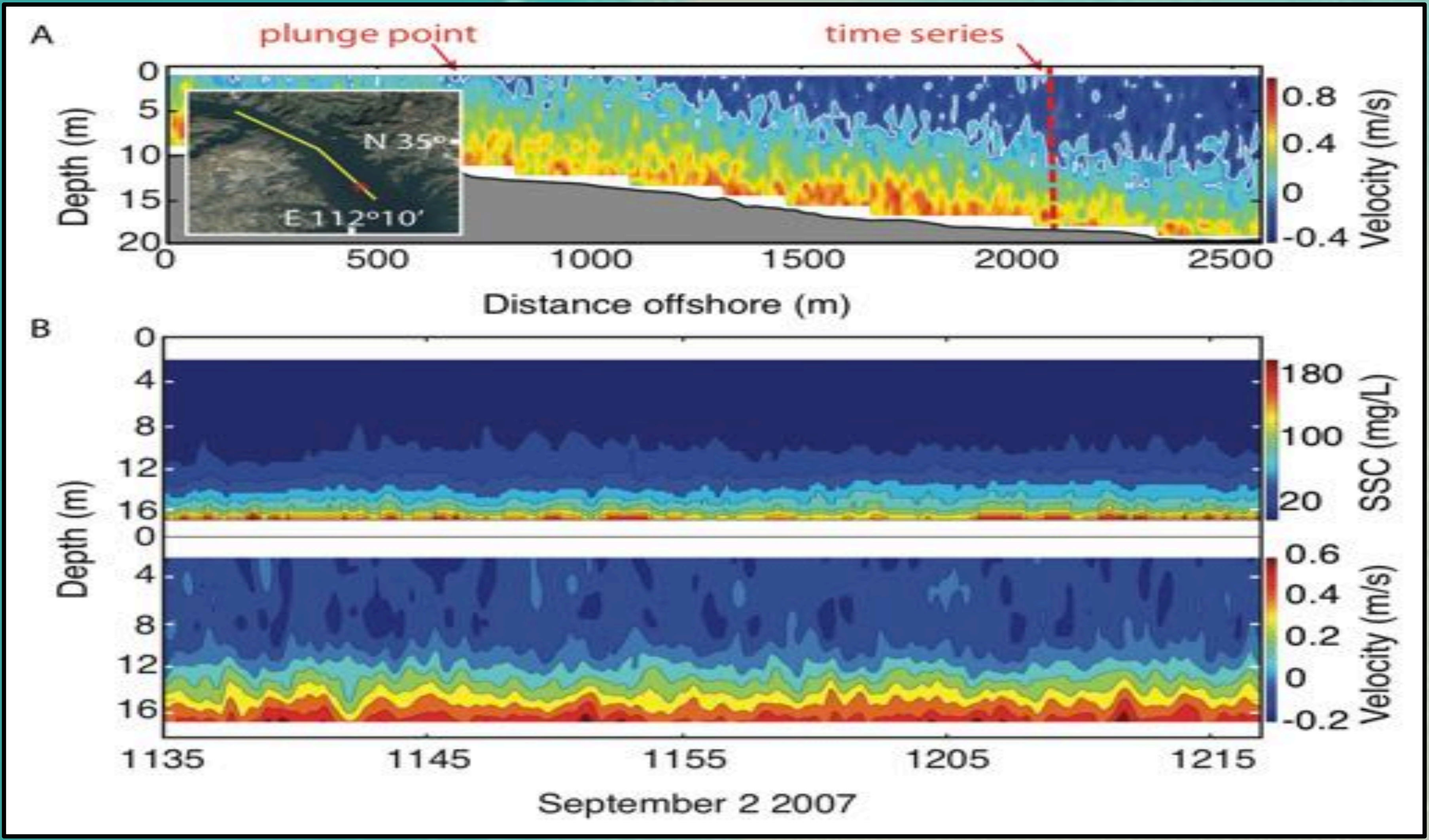
- Stratified shear layer instability: large-amplitude, wave-like structures such as **Kelvin–Helmholtz (*KH*)** (*Brown and Roshko*, 1974), **Holmboe (*H*)** (*Smyth and Winters*, 2003; *Smyth et al*., 2007) and **Taylor-Caulfield (*TC*)** (Taylor, 1931; Caulfield et al., 1995; Carpenter et al., 2013; Guha and Lawrence, 2014).

Field Methods

- Transects and time series: velocity, temperature, suspended sediment concentration and particle size in **Lillooet Lake** and **Xiaolangdi Reservoir**

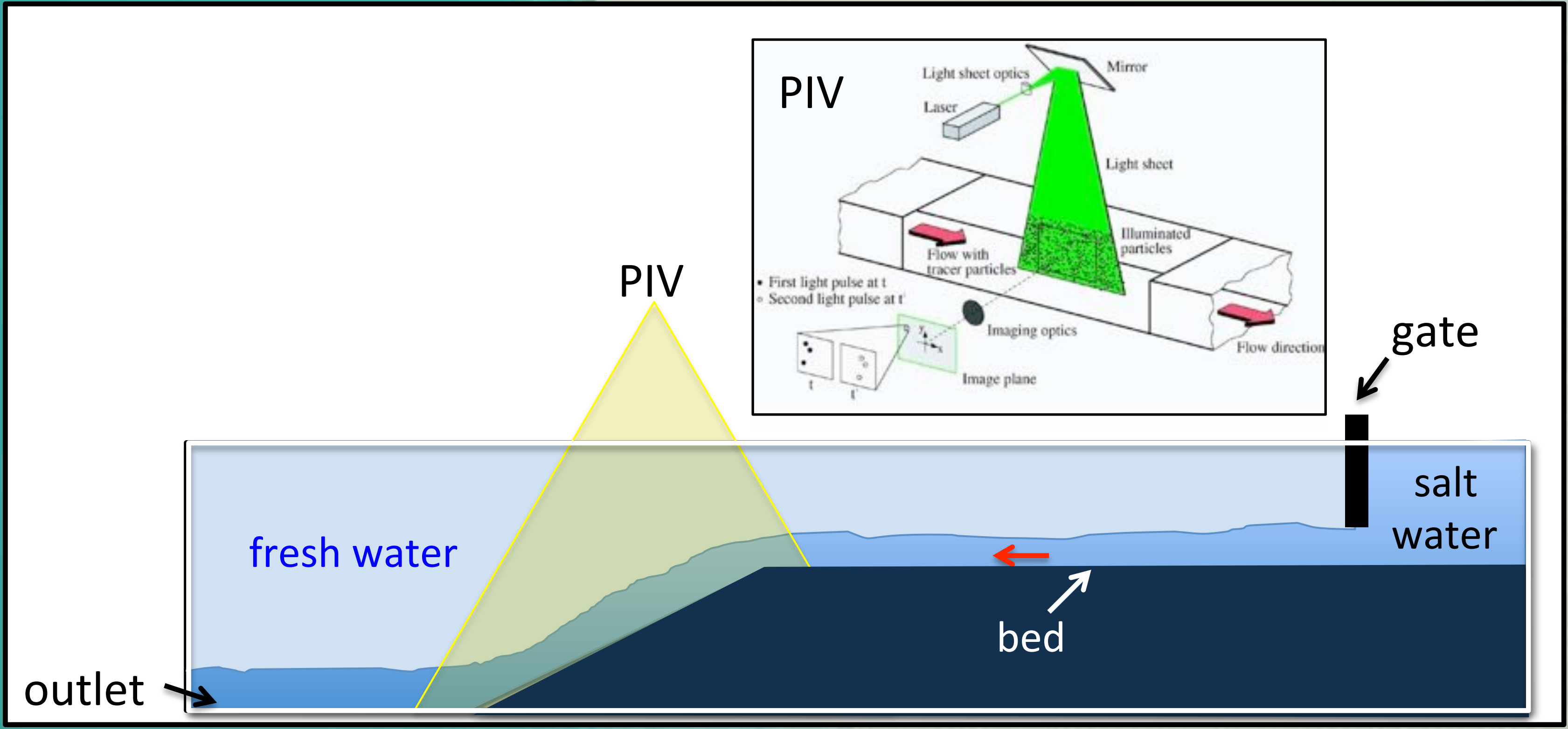


Field Results



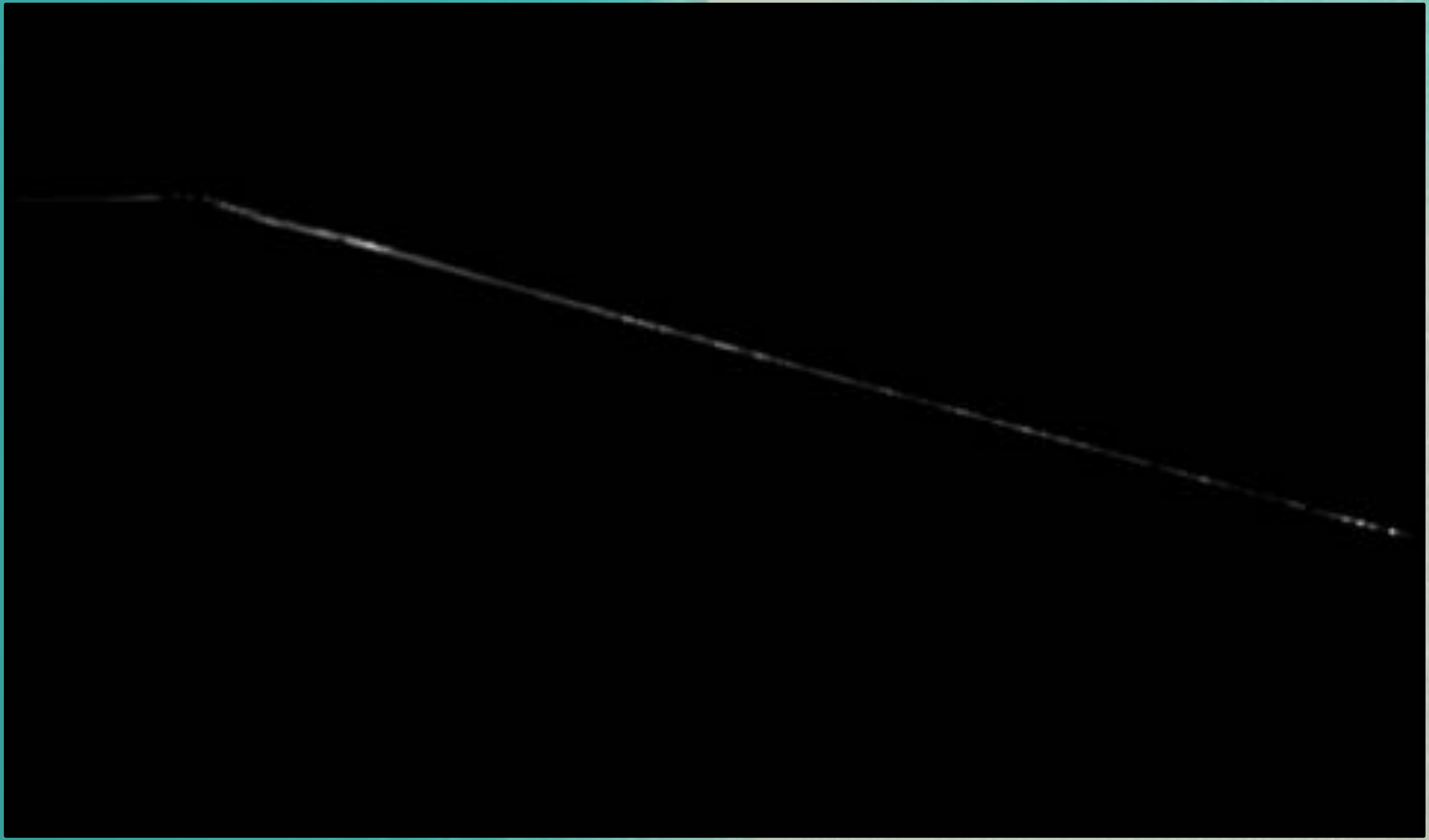
Laboratory Methods

- Saline **gravity current** experiments: 6 m long open glass-wall tank with an internal channel
- Velocity: Particle Imaging Velocimetry (PIV)



Based on Negretti et al. (submitted to JFM)

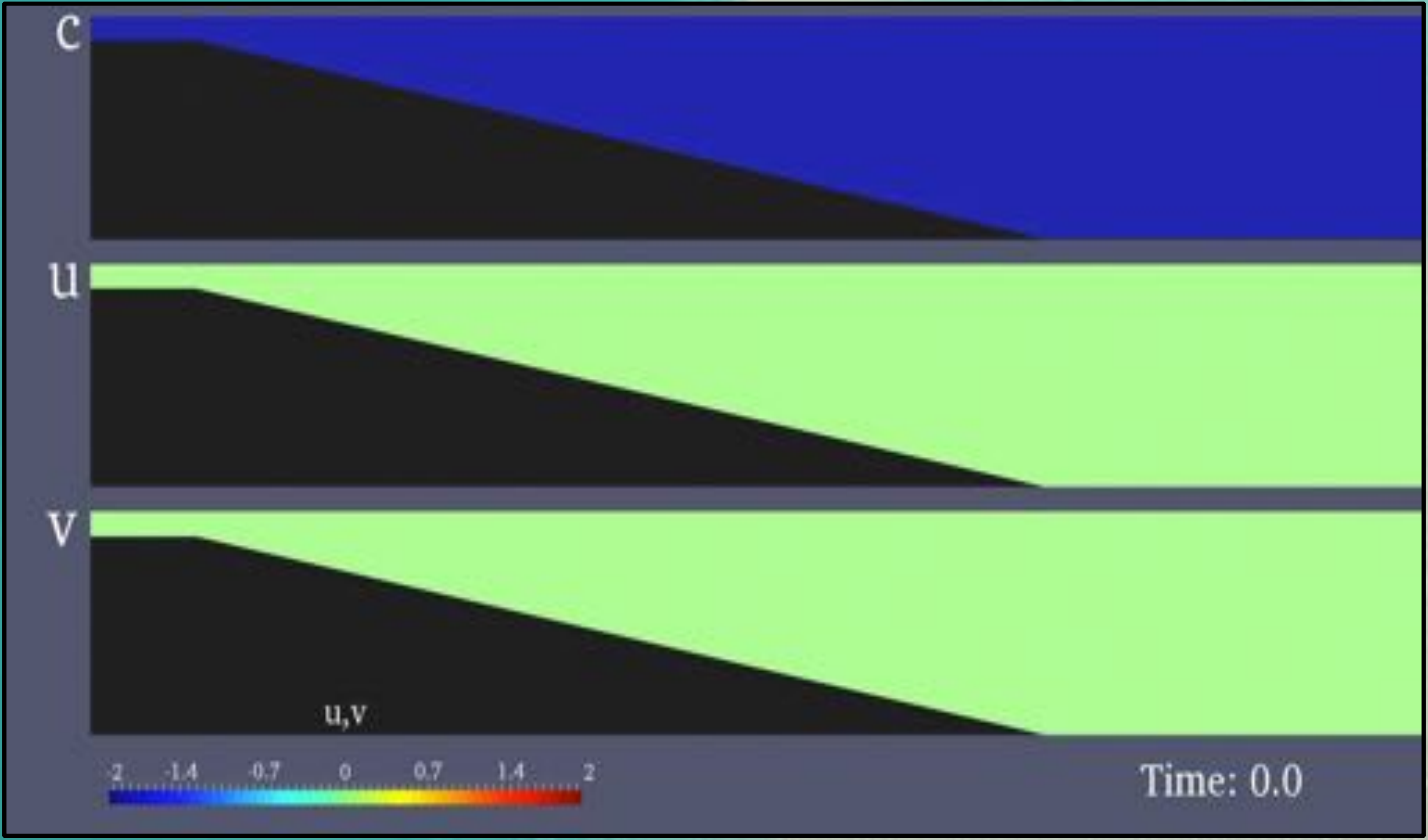
Laboratory Results



DNS Methods

- Software **TURBINS** (e.g., Nasr-Azadani and Meiburg, 2014): direct numerical simulations (DNS) of continuous two-dimensional gravity and turbidity currents
- **Simulations**: combination of straight and segmented bed slopes; gravity and turbidity currents with settling velocities consistent with sand (150µm) and silt-clay (30µm)
- This study: **gravity currents** - similar to silt-clay turbidity currents and saline gravity currents

DNS Results



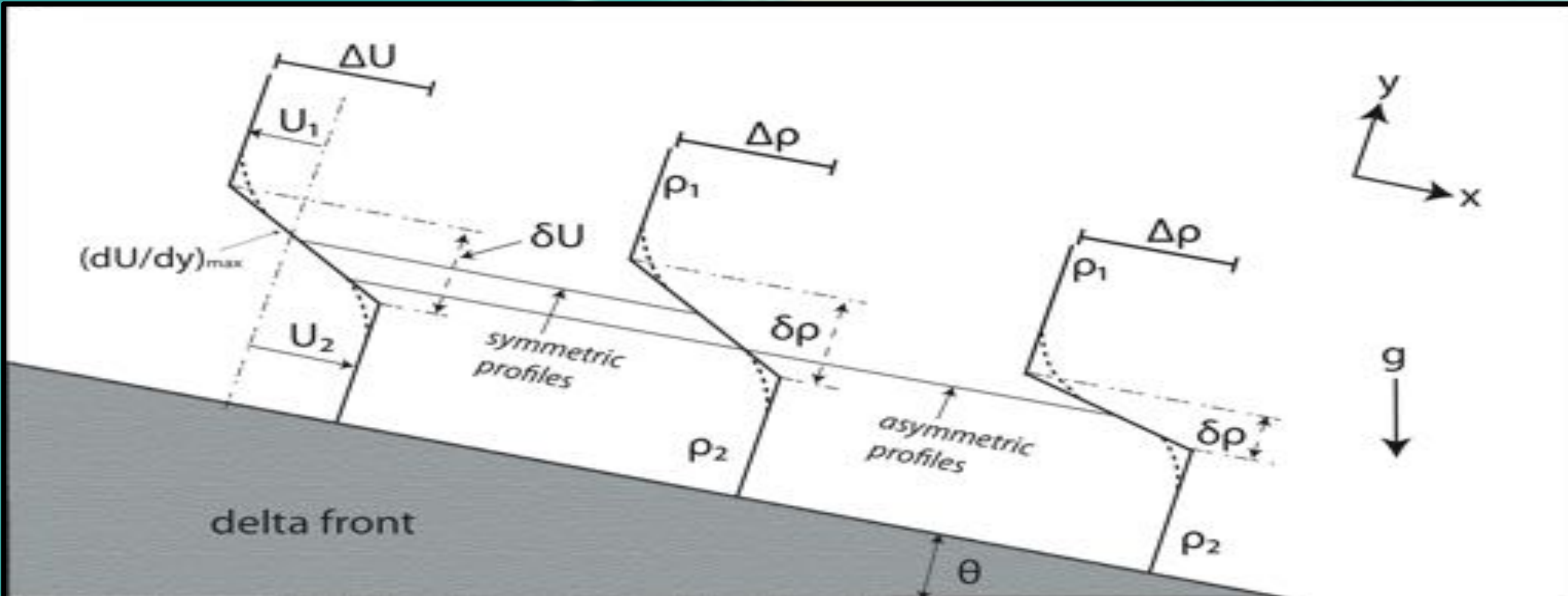
Linear Stability Analysis

- Linear stability analysis: evolution of stratified shear layers is based on the **Taylor-Goldstein (TG)** equation (e.g., Lawrence et al., 2013):

$$w'' + \left[\frac{N^2}{(U-c)^2} - \frac{U''}{U-c} - k^2 \right] w = 0$$

- Analytical solutions: possible assuming **piecewise** velocity and density profiles
- Velocity and density profiles: expressed non-dimensionally by the **bulk Richardson Number (J)**, **wave number (α)**, and the **scale ratio (R)** of shear layer thickness to density layer thickness

Linear Stability Analysis



$J_L = g' h / \Delta U^2$ where: $g' = g \Delta\rho / \rho_2$ $h = \Delta U / (dU/dy)_{\max}$

$\alpha = kh$ where: $k = 2\pi / \lambda$

$R = \delta U / \delta\rho$

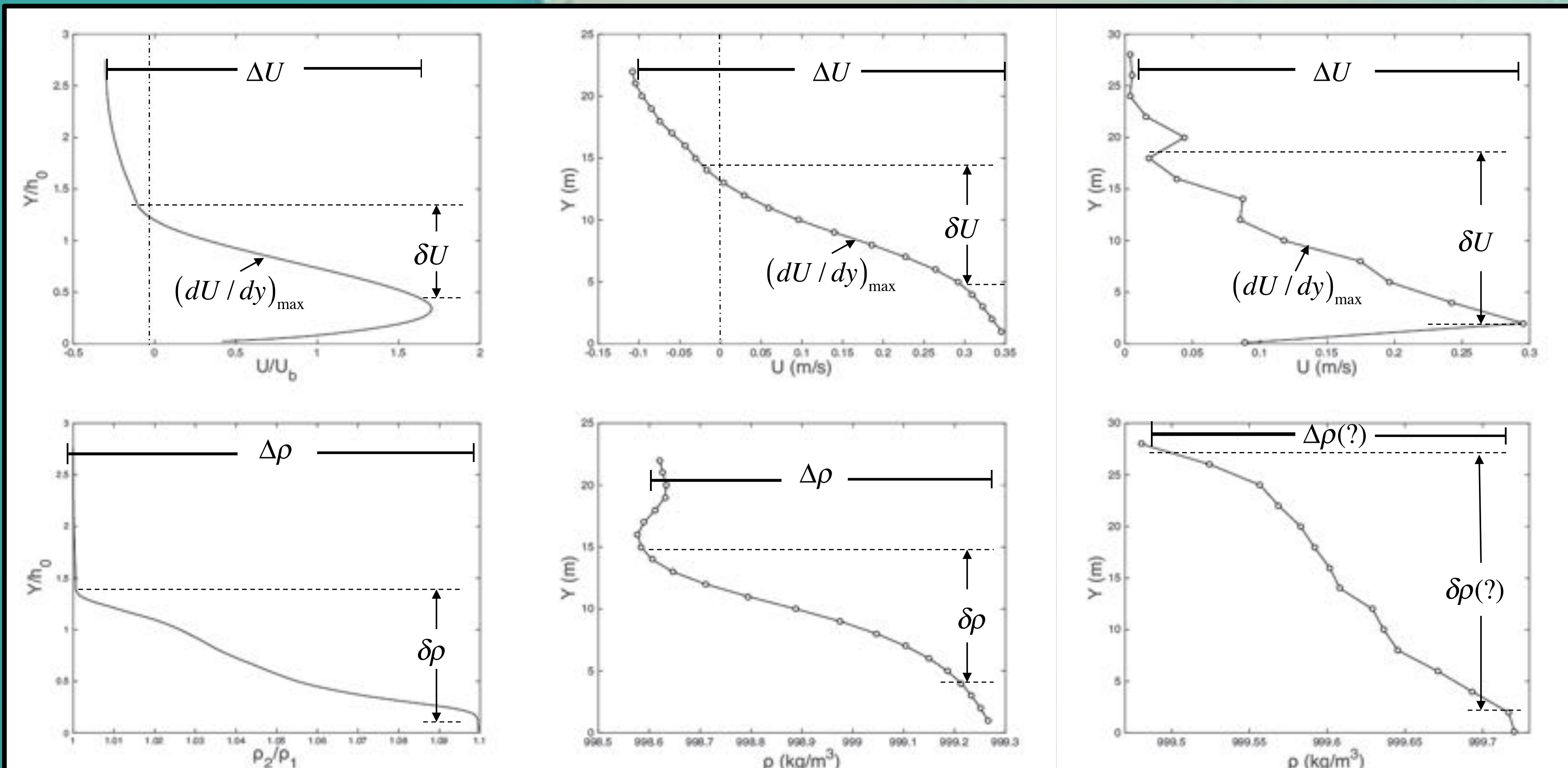
Based on: Lawrence et al. (1991, 2013), Negretti et al. (2008), Khavasi et al. (2013)

Velocity and Density Profiles

DNS

Lillooet Lake 08-22-2001

Lillooet Lake 08-13-2008



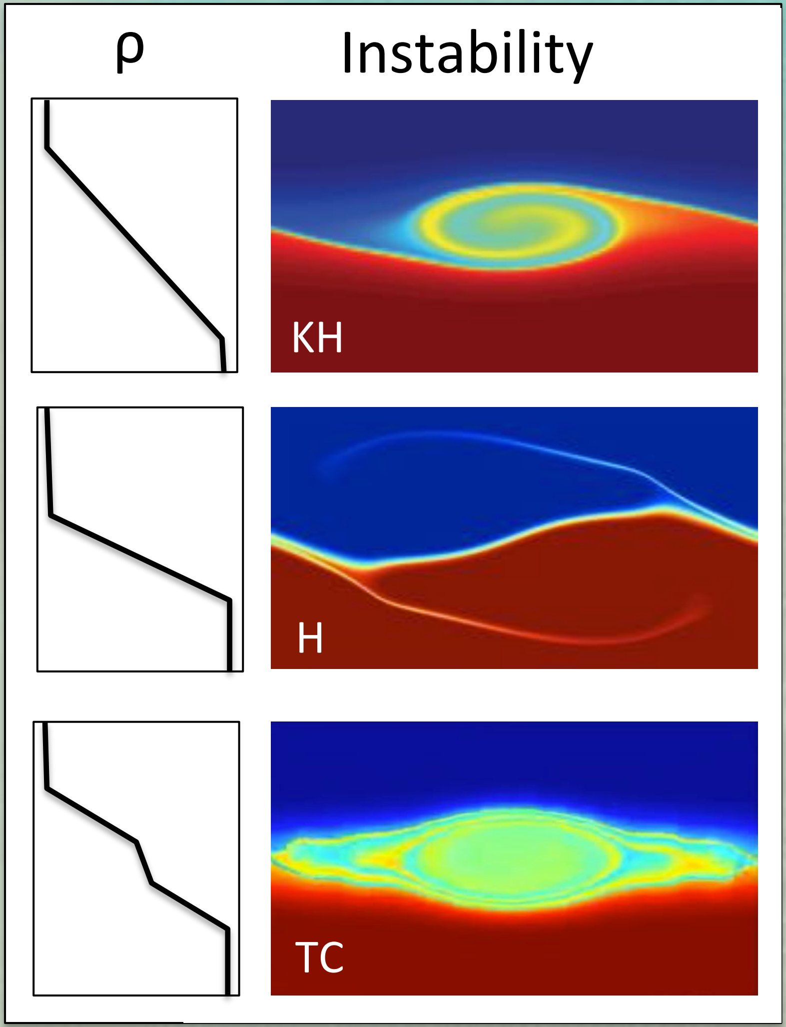
R = 0.8

R = 1

R = 0.6(?)

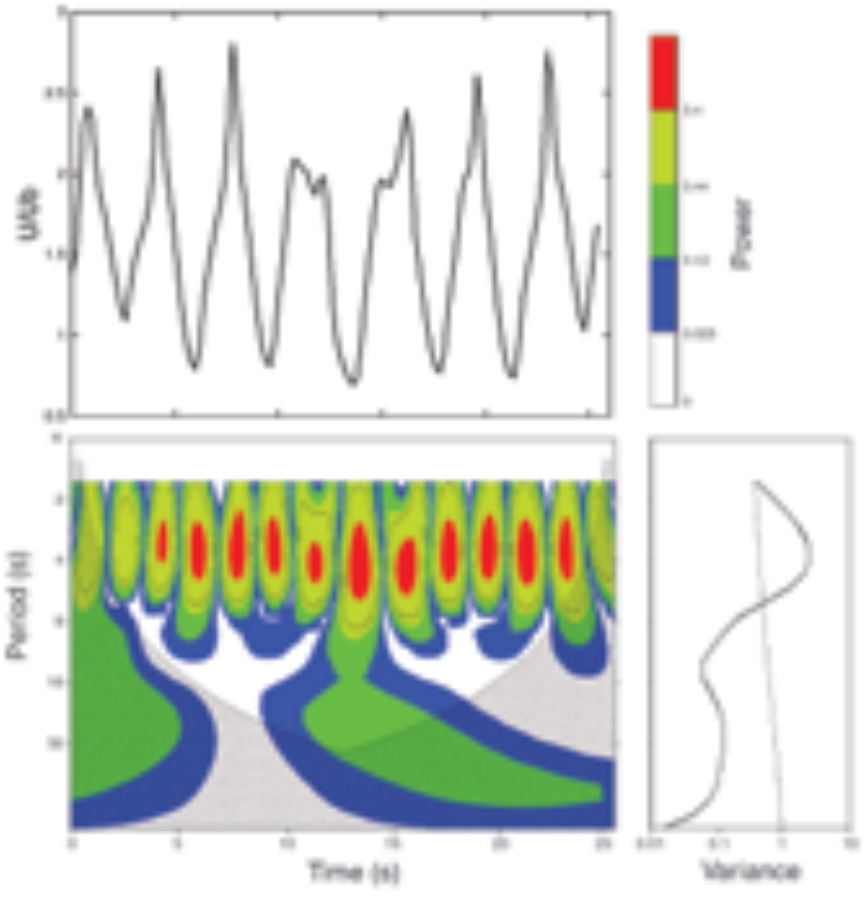
Stratified Shear Layer Instabilities

- **Kelvin-Helmholtz**
  - Two vorticity waves
  - Overturning billows
- **Holmboe**
  - Vorticity and gravity waves
  - Positive and negative cusps
- **Taylor-Caulfield**
  - Two gravity waves
  - Intermediate density layer

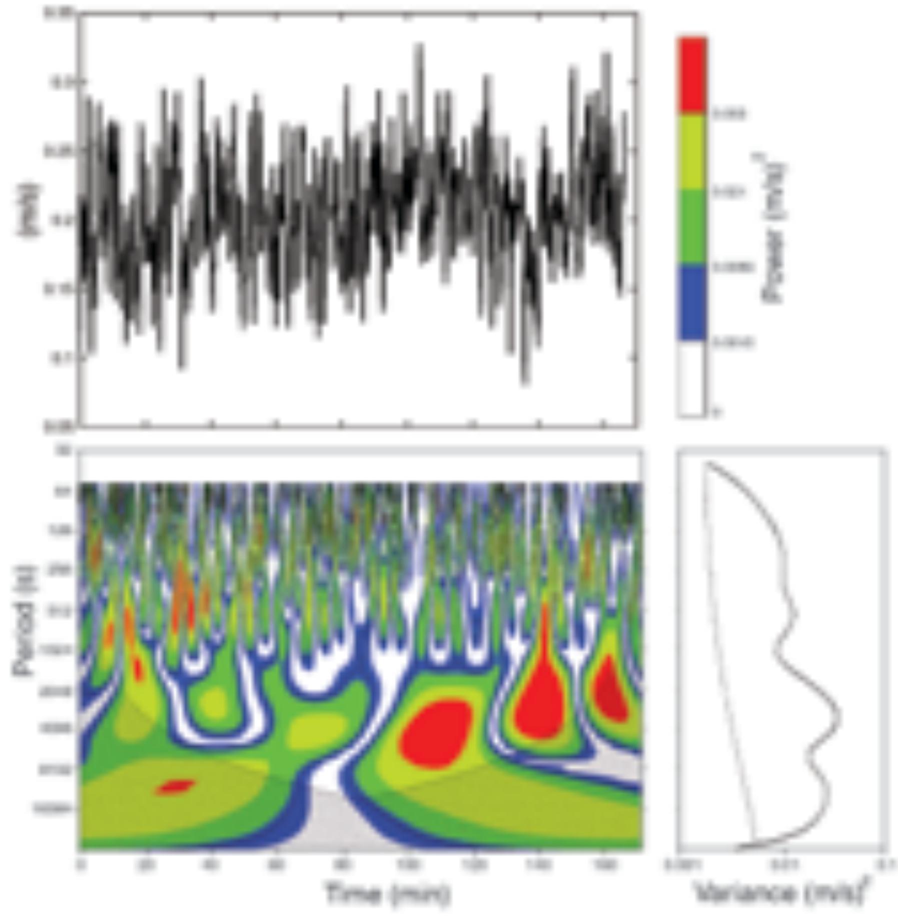


Wavelet Analysis

DNS

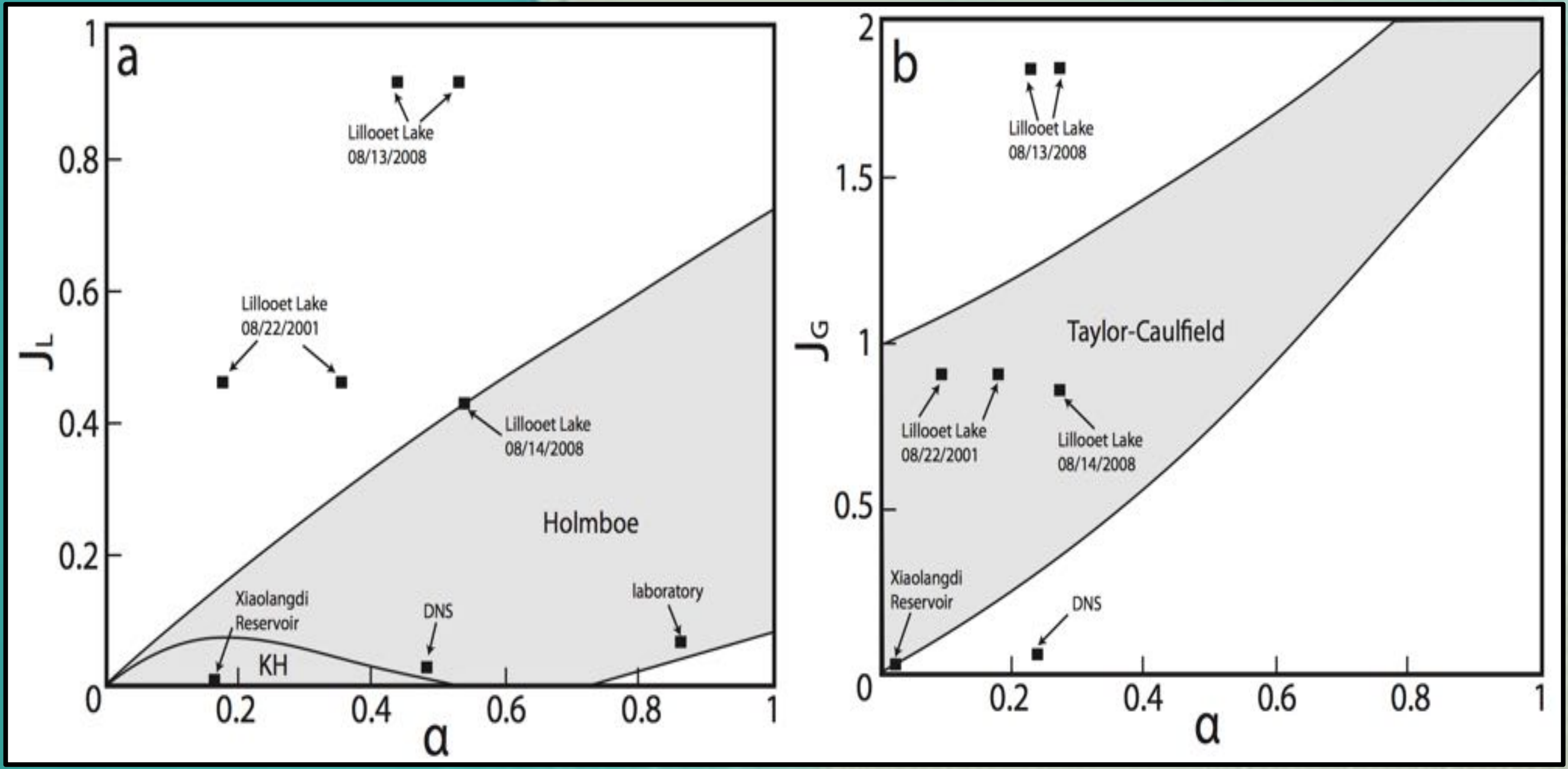


Xiaolangdi Reservoir



Stability diagrams

Horizontal flow: θ = 0

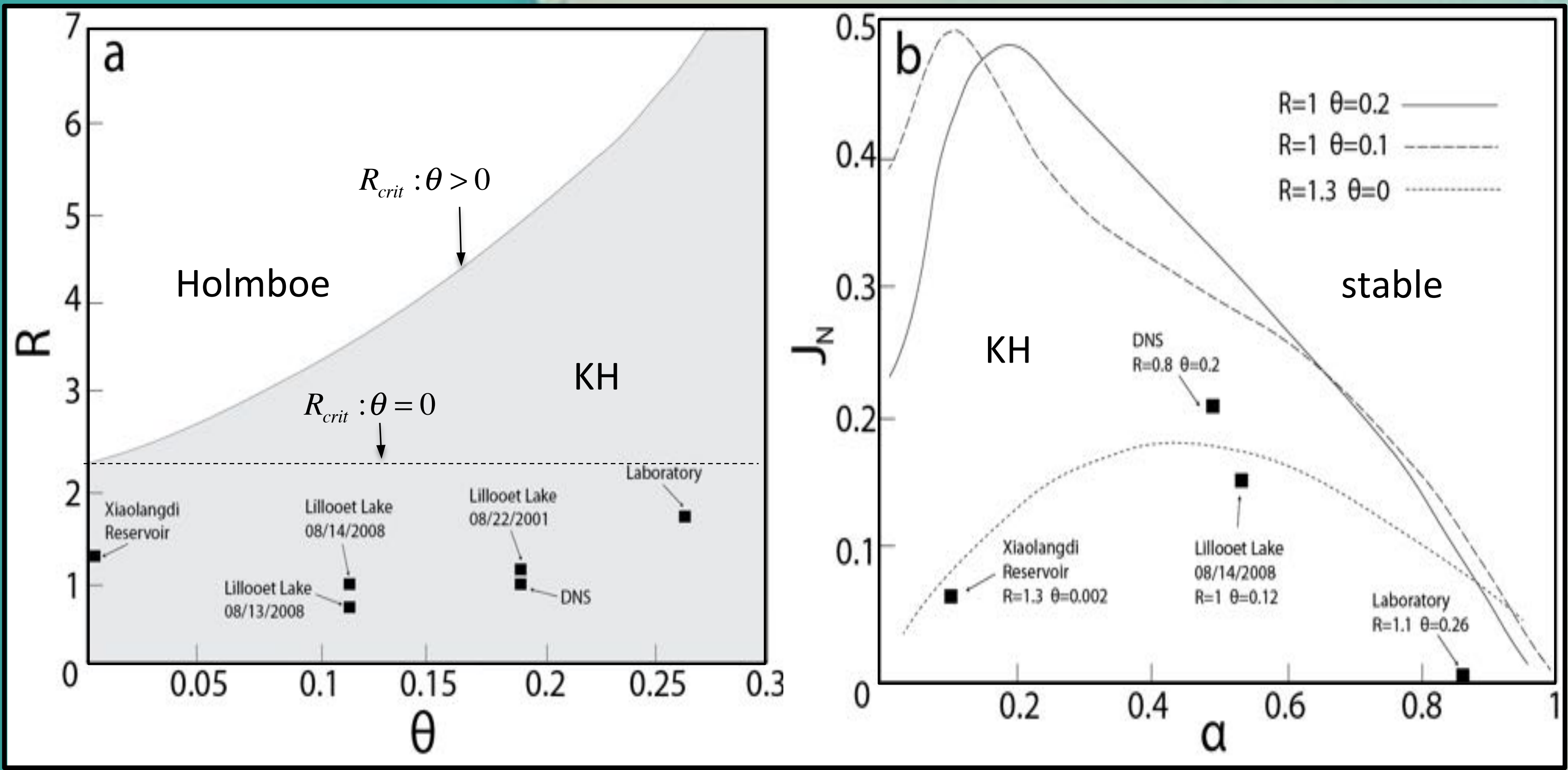


Based on: Lawrence et al. (1991, 2013)

Based on: Guha and Lawrence (2014)

Stability diagrams

Inclined flow: θ > 0



Based on: Khavasi et al. (2013)

Based on: Negretti et al. (2008)

Conclusions

- **Causes of velocity pulsing**
  - Laboratory and DNS currents: KH instability
  - Stability analysis for horizontal flow: KH, H and TC instabilities
  - Stability analysis for inclined flow: primarily KH instability, H and TC instabilities at large values of bulk Richardson number?
- **Continuous turbidity currents**
  - Caulfield et al. (1995): “all three instabilities *(KH, H, TC)* can be observed simultaneously at markedly different wavelengths and phase speeds for extended periods of time, even though linear theory may predict significantly different growth rates”

Danke!