

## 1 Abstract

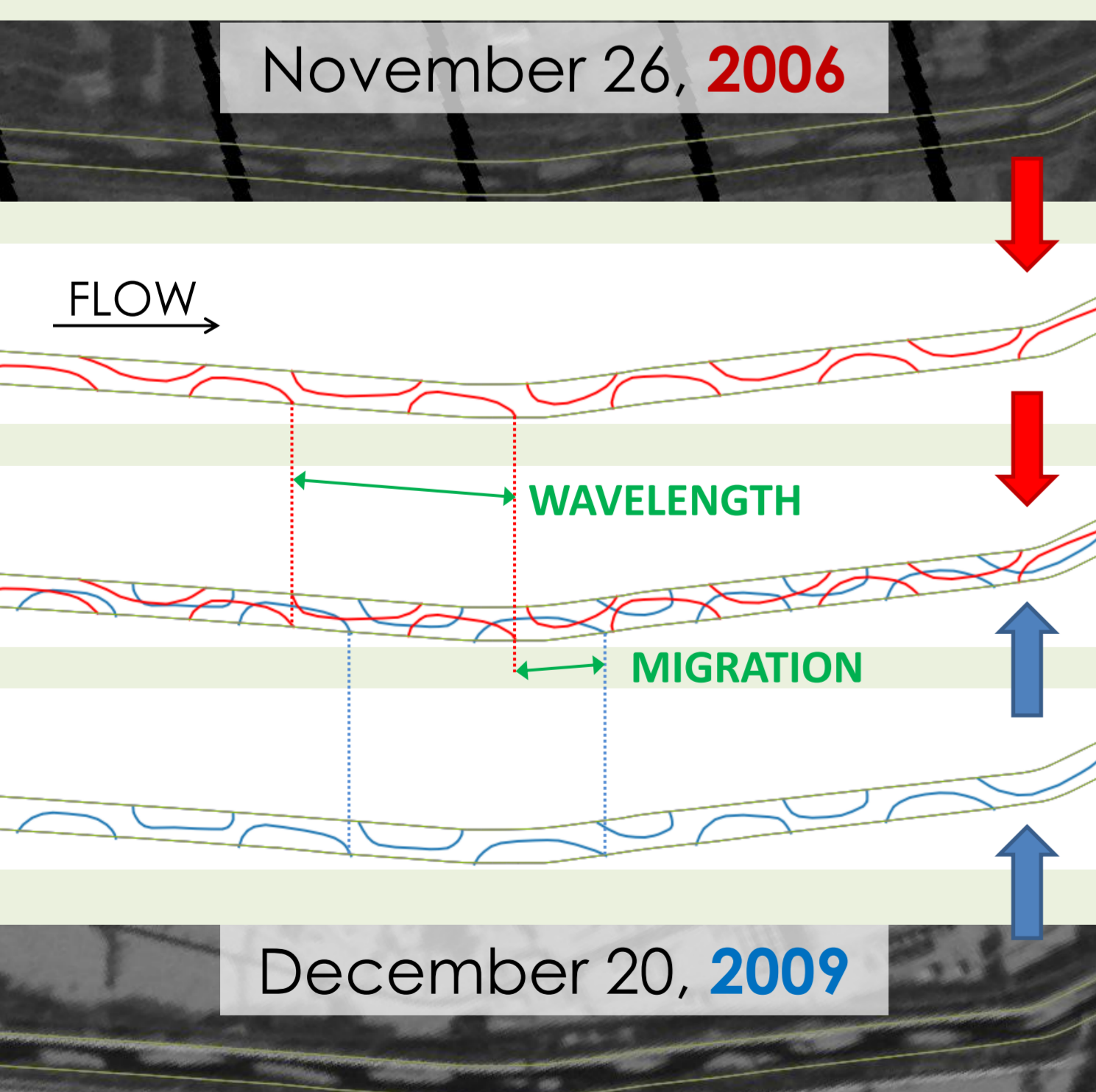
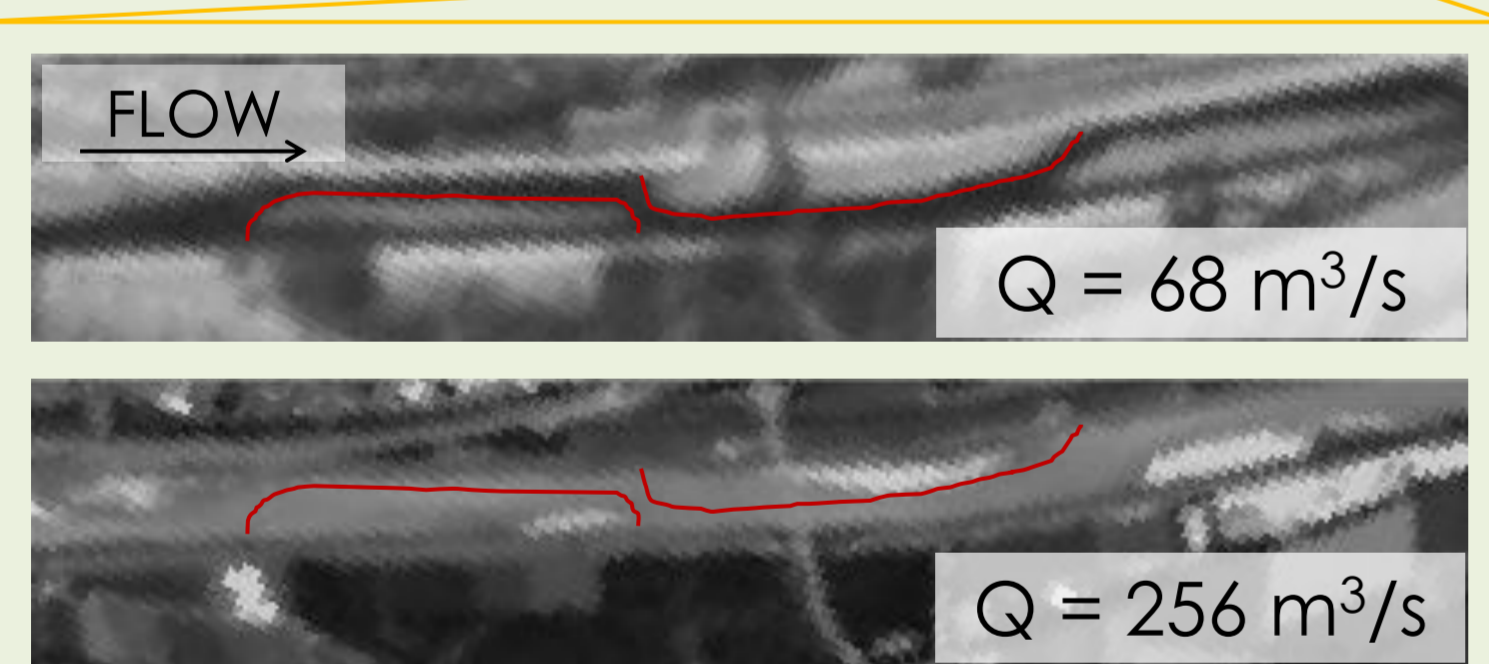
**CONTEXT:** The **formation and dynamics of alternate bars in straight channels** has been studied since the late '60s through analytical theories, mobile-bed flume experiments with fixed banks, and, more recently, with morphodynamical numerical models. **Field observations** at the time and spatial scales and resolution required to investigate alternate bars long term dynamics are only recently becoming feasible, and they **remain still rare**. Many studies report on short term analysis focusing on relatively short reaches, where only a few bars are present. In **this work** we describe the multi decadal (**30 years**) morphodynamics of alternate bars in a 40-km reach (**400 times the channel width**) of the **Alpine Rhine** river, between Switzerland, Liechtenstein and Austria. Alternate bars - presently more than 40 bar wavelengths - are present here since the 19<sup>th</sup> century, providing an almost unique opportunity to extract a consistent set of bar properties, e.g. bar length, migration, from freely available Landsat images since 1984. Information on bar amplitude have also been obtained from regularly surveyed cross sections.

### AIMS:

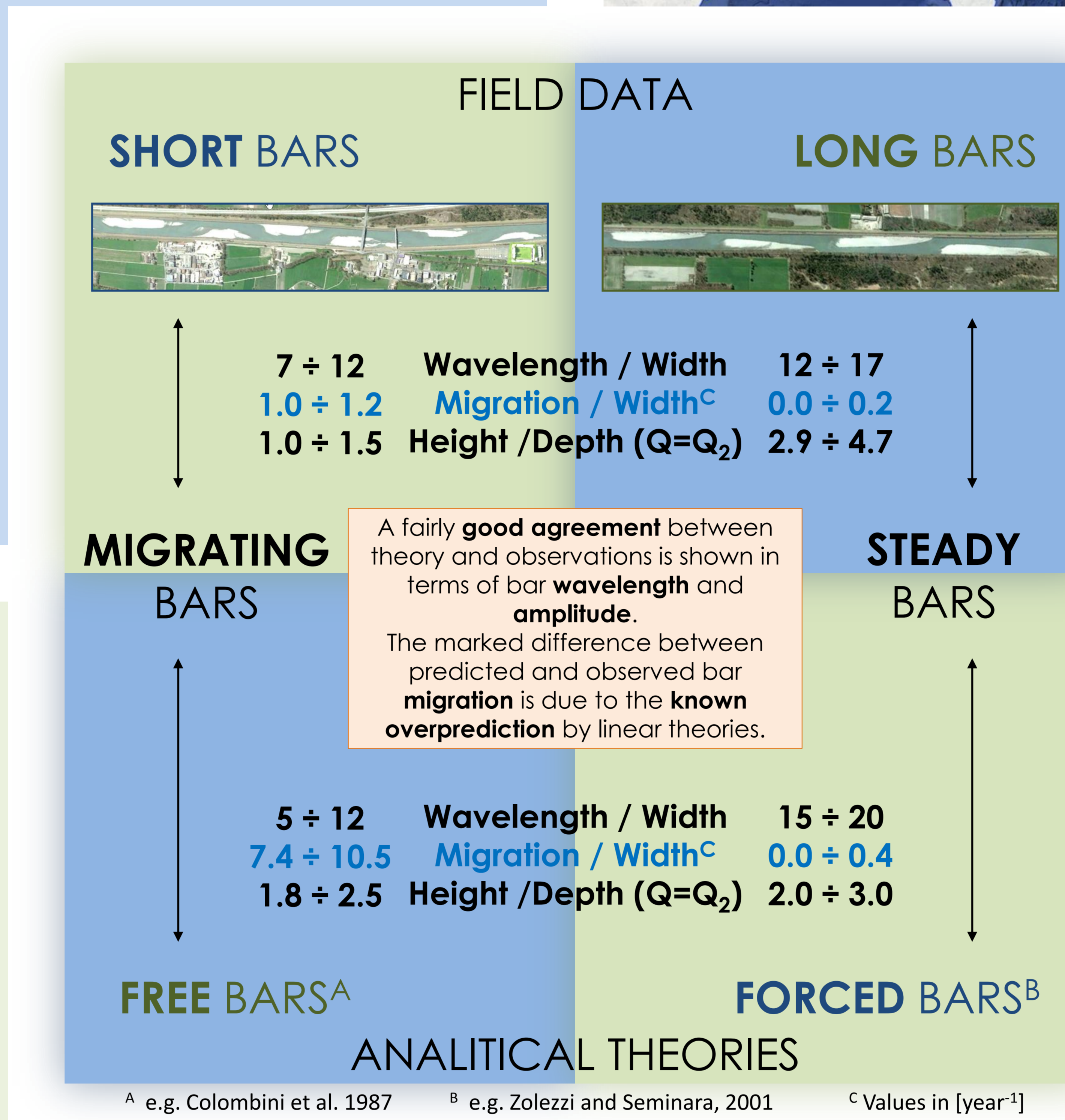
- Describe** the long term evolution of alternate bars in a real river :
  - Time scale: **multi-decadal**;
  - Space scale: **tens of wavelengths**.
in terms of:
  - ✓ Bar **wavelength (L)**;
  - ✓ Bar **migration**;
  - ✓ Bar **height**.
- Assess** the potential of **analytical bar theories** (free - forced bars in straight reaches, e.g. Colombini et al., 1987; Zolezzi and Seminara, 2001) to replicate observed bar dynamics and to support interpretation of field observations.

### LANDSAT images:

- Pixel resolution :** 30x30 m → 15x15 m
- Covered period:** 1984-to date
- Available images:** 78 (> 2.5 per year)
- Discharge range:** 64 ÷ 540 [m<sup>3</sup>/s]

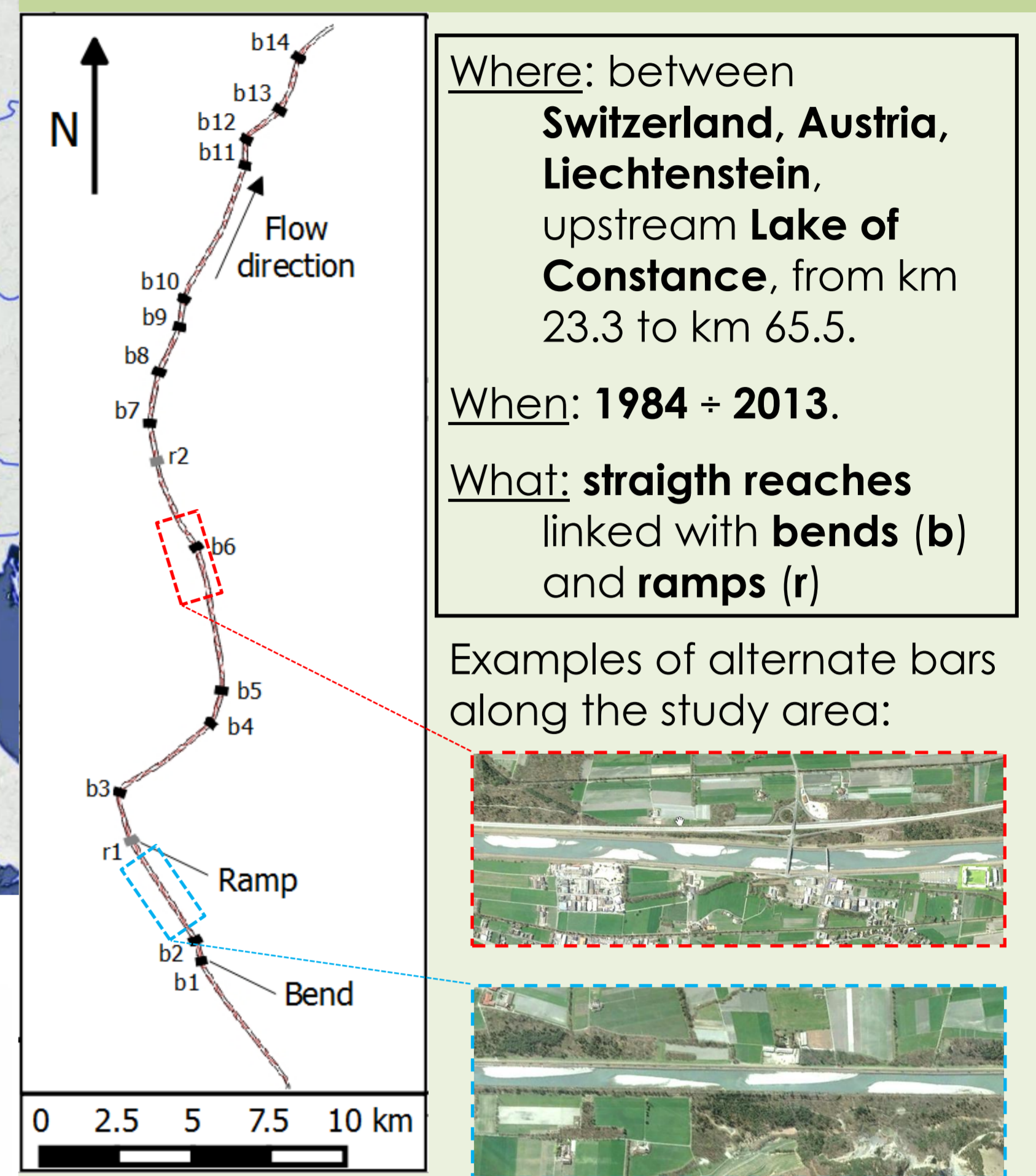


## 3 Remote sensing analysis



- 1.a) Original LANDSAT image
- 2.a) Data conversion to shp
- 3.) Data elaboration
- 2.b) Data conversion to shp
- 1.b) Original LANDSAT image

## 2 Study site: Alpine Rhine

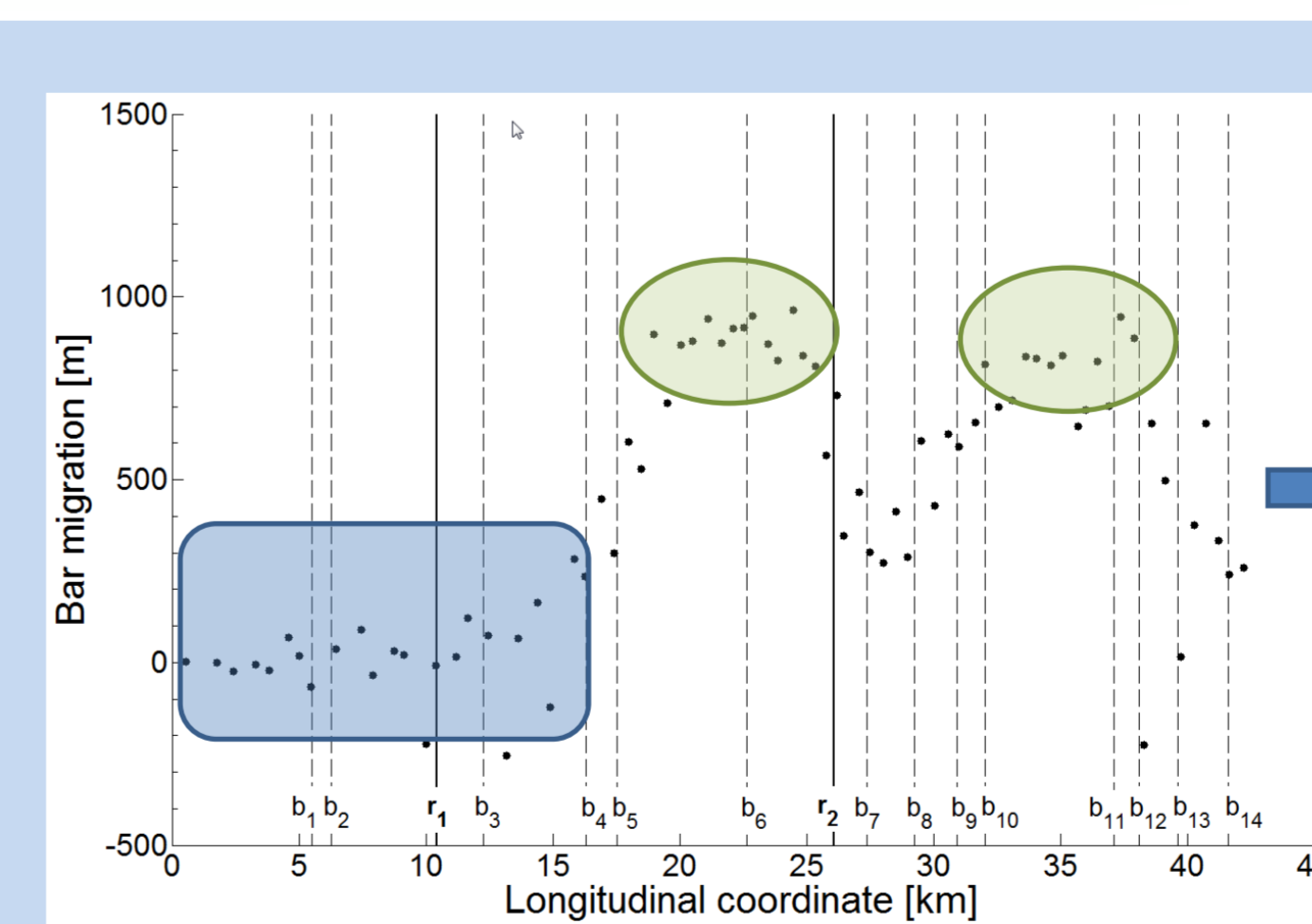
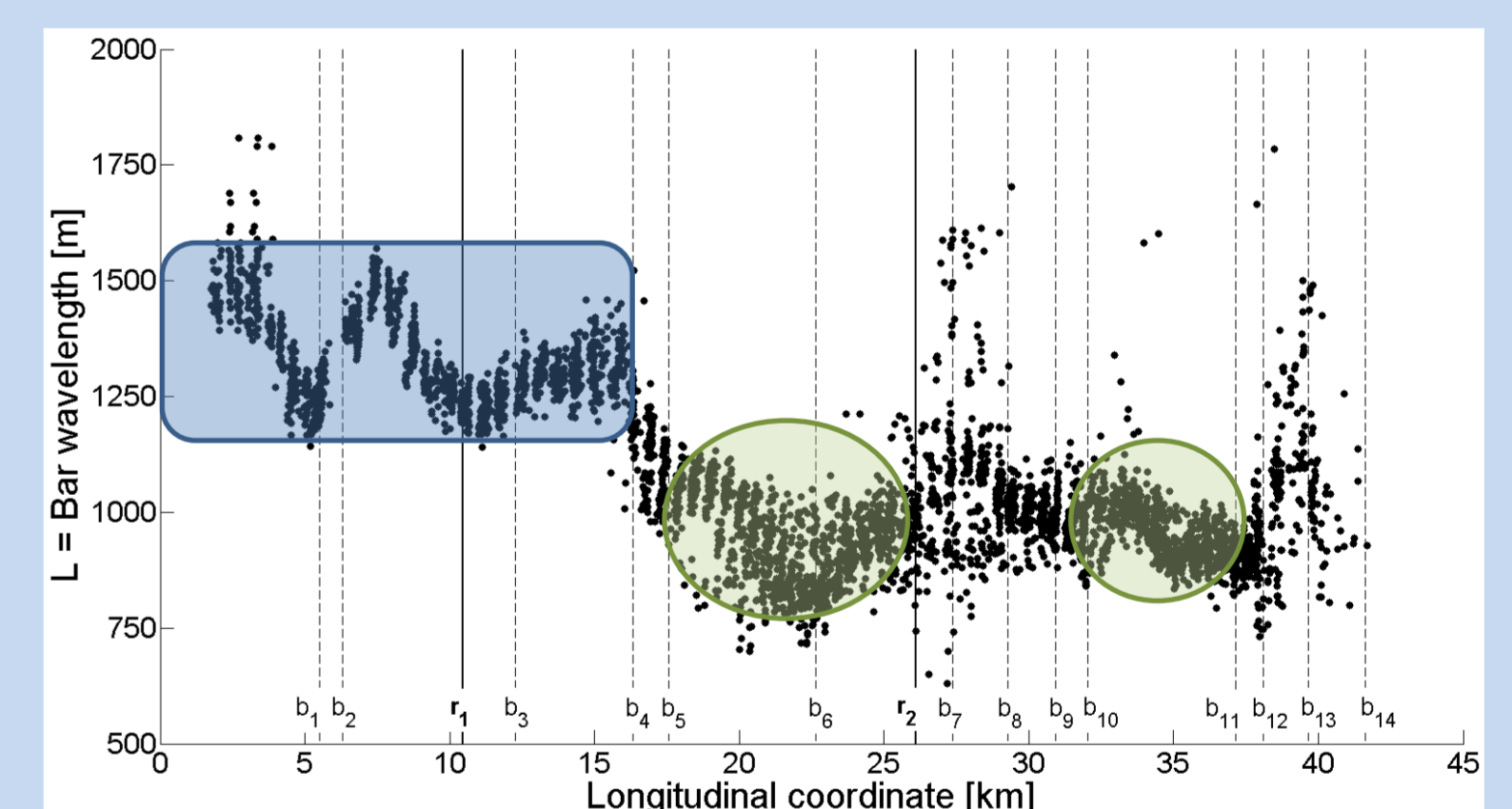


Alternate bar reach	UP-STREAM	CENTRAL	DOWN-STREAM
Length [km]	10.7	20.0	11.1
Width [m]	85	95	105
Slope [%]	2.9	2.0	1.3
d <sub>50</sub> [mm]	50 ÷ 60	30 ÷ 50	20 ÷ 30
Q <sub>FW</sub> [m <sup>3</sup> /s]	380	270	230
Q <sub>FT</sub> [m <sup>3</sup> /s]	830	630	510

FW, FT: Fully Wet, Fully Transporting cross sections

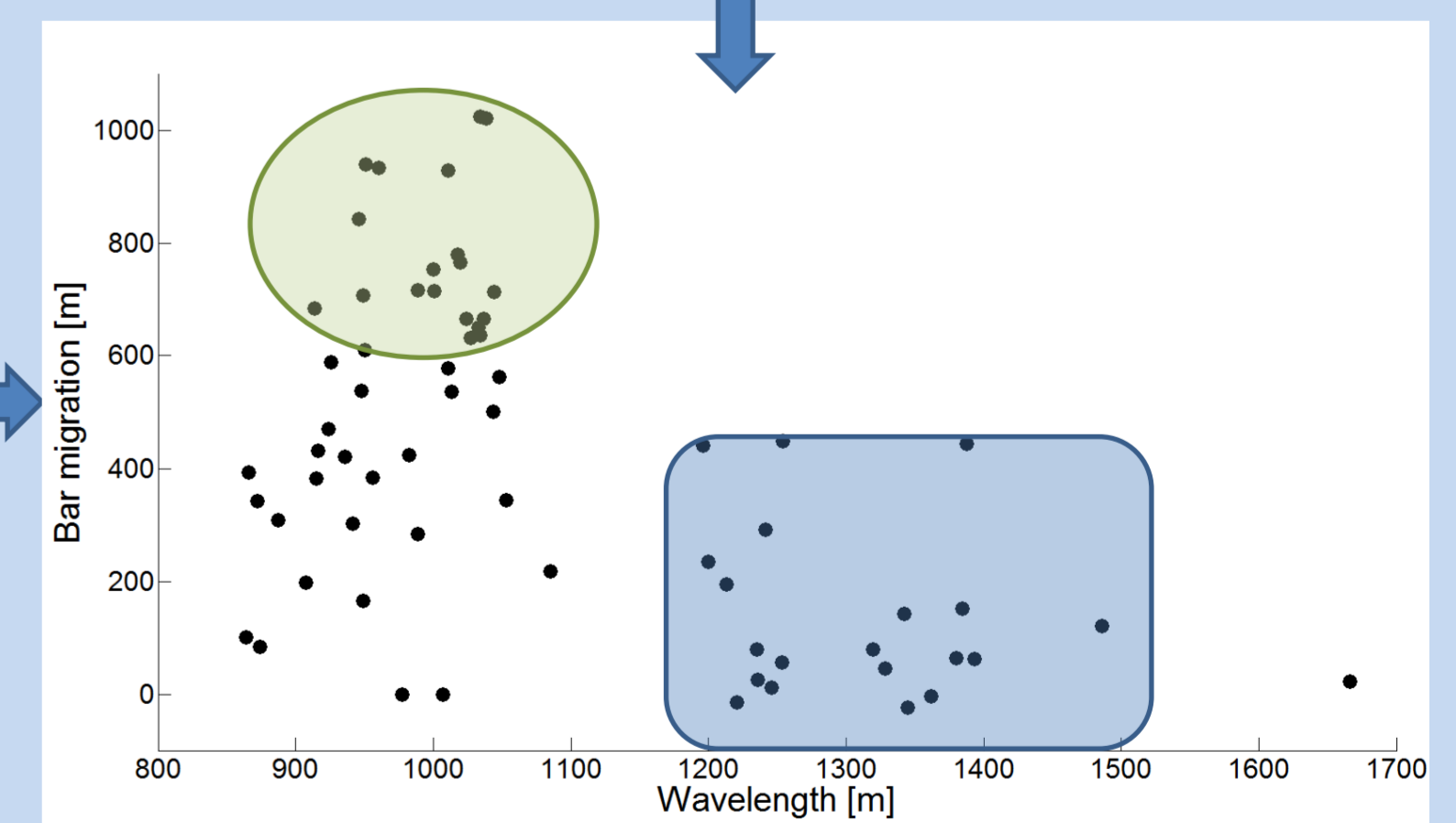
### A) Bar wavelength (period 1984-2013)

Longer bars (L ~ 1150 ÷ 1600) up to bend<sub>4</sub>, then bars tend to be shorter (L ~ 700 ÷ 1000); role of bends and ramps in the change of bar wavelength.



### B) Bar migration (period 2001-2010)

No migration up to bend 3 (b<sub>3</sub>), then migration increases up to the maximum in the straight regions bend 5 (b<sub>5</sub>) + ramp 2 (r<sub>2</sub>) and bend 10 (b<sub>10</sub>) + bend 11 (b<sub>11</sub>)



### C) Wavelength-migration (averaged)

84% of the short bars migrated > 200 m  
81% of the long bars migrated < 200 m

## 4 Results

### KEY FINDINGS

- ✓ both steady and migrating alternate bars occur in straight reaches of the Alpine Rhine river study site;
- ✓ migrating bars are consistently shorter than steady bars;
- ✓ comparison with analytical theories suggests a dominantly "free" origin of the migrating bars and a dominantly "forced" nature of the steady bars.

### REFERENCES

- Colombini, M., Seminara, G. and Tubino, M. 1987. Finite-amplitude alternate bars. *Journal of Fluid Mechanics* 181: 213-232;
- Zolezzi, G. and Seminara, G. 2001. Downstream and upstream influence in river meandering. Part 1. General theory and application of overdeepening. *Journal of Fluid Mechanics* 438: 183-211.