Bed roughness estimation in gravel-bed rivers using UAV-SfM photogrammetry: flume and numerical application

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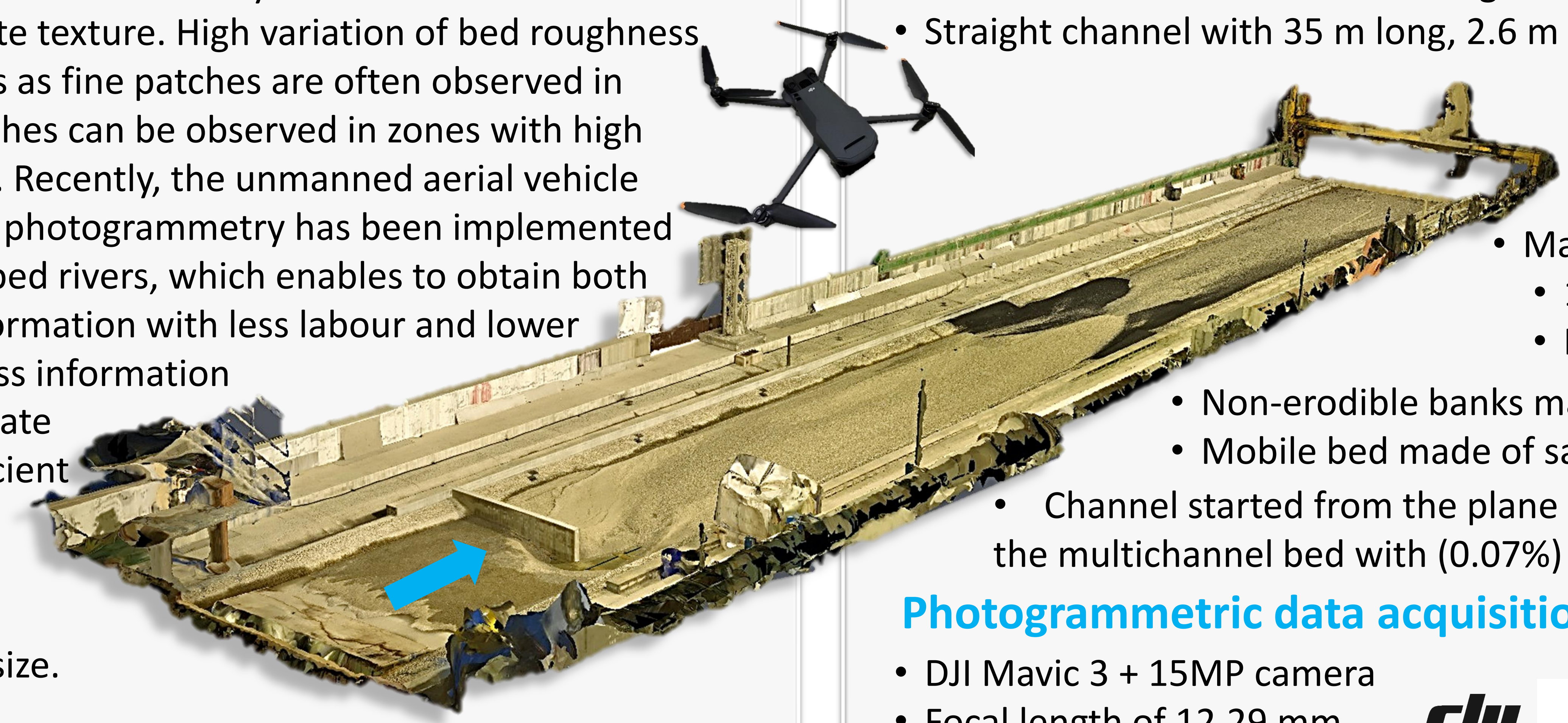
Introduction

In gravel-bed rivers, bed roughness is one of the key factors that influence flow resistance, shear stress and substrate texture. High variation of bed roughness can be observed in gravel-bed rivers as fine patches are often observed in pools and on bars while coarse patches can be observed in zones with high velocities such as the main channel. Recently, the unmanned aerial vehicle (UAV)-Structure from Motion (SfM) photogrammetry has been implemented for roughness estimation in gravel-bed rivers, which enables to obtain both spatial and temporal roughness information with less labour and lower material costs. This spatial roughness information combined with hydraulic data facilitate the calibration of the friction coefficient in hydrodynamic models, which is usually challenging for gravel-bed streams due to their high spatial heterogeneity of bed surface grain size.



Objective

1. To estimate the bed roughness using data from UAV-SfM photogrammetry
2. To understand the spatio-temporal variation of bed roughness along a flume run
3. To improve the friction coefficient calibration of a 2D hydrodynamic model

Experimental set-up

- Model with a scale factor of 35 in geometry to study bar dynamics
- Straight channel with 35 m long, 2.6 m wide and a slope of 0.17%
- Constant discharge of 34.5 l/s → mobilisation of only two classes of sand
- Manual sand feed from upstream
  - 1.07 l/h for 840 h (T1)
  - Increase to 2 l/h until 1200 h (T2)
- Non-erodible banks made of gravels
- Mobile bed made of sand mixture
- Channel started from the plane bed (T0) and ended up with the multichannel bed with (0.07%) separated by bars

Photogrammetric data acquisition

- DJI Mavic 3 + 15MP camera
- Focal length of 12.29 mm
- 4 m over the flume
- Three UAV surveys at T0 (0 h), T1 (840 h), and T2 (1200 h), respectively
- Agisoft Metashape to obtain a 2D orthomosaic and a dense point cloud

Table 1. Grain-size of the flume bed

Grain size (mm)			
%	Prototype	Model	Scale
32	12	0.6	18.47
36	28	1.4	20.24
32	55	2.3	23.56

Roughness metric estimation

Roughness height *rh* (Vazquez-Tarrio et al., 2017):

- Difference in height between the point and the best-fitting plane of a neighbourhood of points in the point cloud (estimated in CloudCompare).
- high value of *rh* refers to great difference in altitude → a rough bed surface and vice versa.

Entropy (Wong et al., 2024):

- Transformation of a raw grey scale orthomosaic into a textural image where the value of each pixel corresponds to an entropy estimated with the cooccurrence matrix below (estimated using scikit-image Entropy in Python):

$$Entropy = -\sum_{i=0}^{255} p_i \log_2(p_i)$$

- High value of entropy signifies a great variation in the local gray level distribution → a rough bed surface and vice versa.

Variation of bed roughness during a 1200 h run

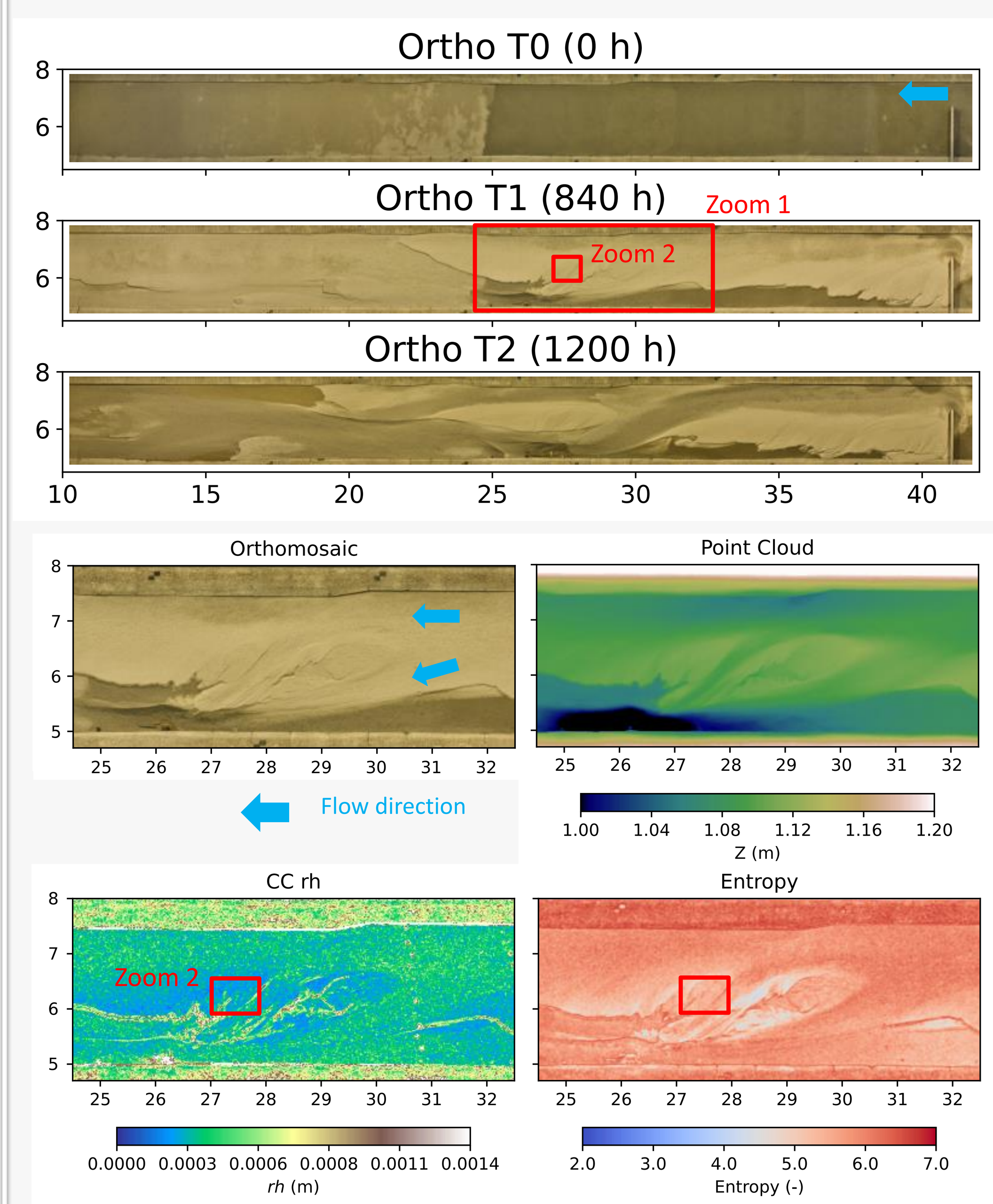


Figure 1. Map of *rh* and entropy in Zoom 1 at T1

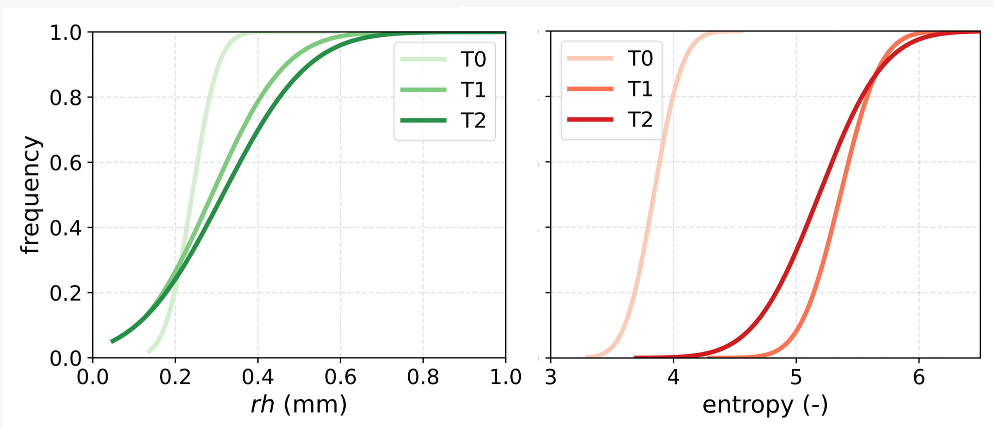
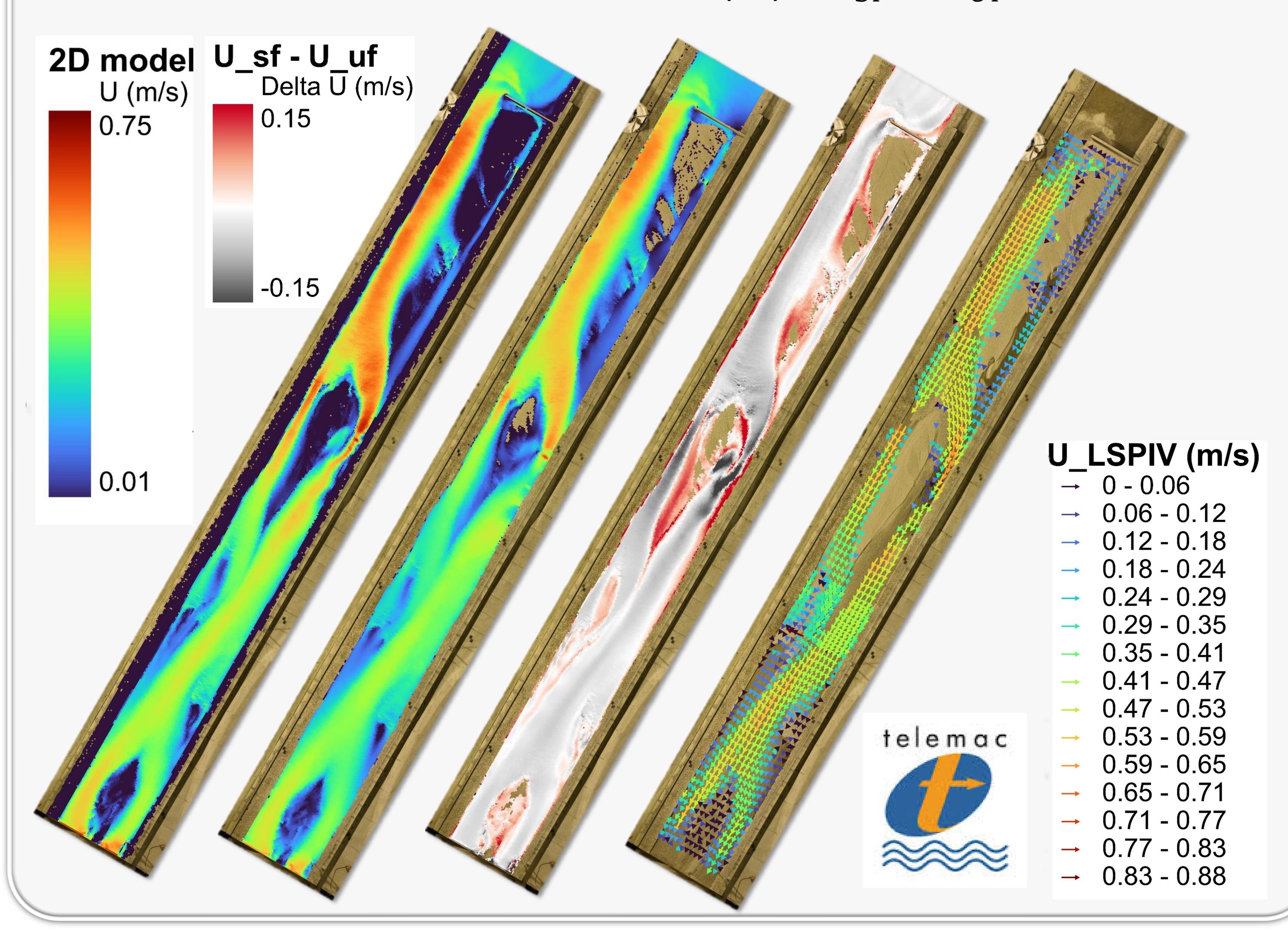


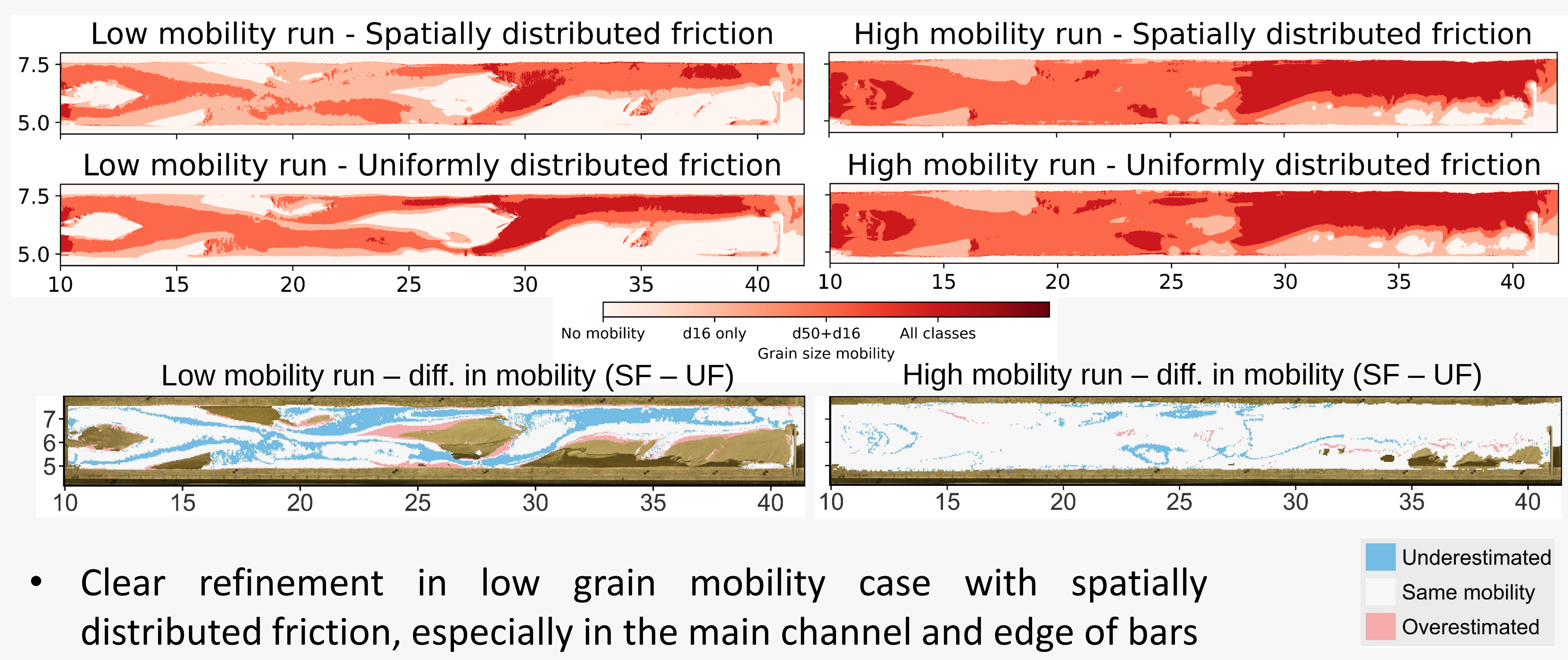
Figure 2. Cumulative frequency distrbution of *rh* and entropy in Zoom 2 at T0, T1 and T2

- General bed coarsening from T0 to T1 after the sediment deficit
- Upstream coarsening over time due to the forcing of the deflector
- Clear spatial bed roughness signature in related to geomorphic units
- Upper end of rh cumulative distribution is more sensitive to the roughness changes while median of entropy is more sensitive to the roughness changes

Effects of spatial roughness on flow velocity in 2D model



Effects of spatial roughness on grain mobility in 2D model



- Clear refinement in low grain mobility case with spatially distributed friction, especially in the main channel and edge of bars
- Less sensitive to friction coefficient in high grain mobility case

Perspectives & Conclusion

- *rh* and entropy can directly correlate to the surface GSD for the surface grain size sorting investigation, a surface GSD sampling in the bed would be required to verify this correlation.
- The applicability of this method can be tested in flumes with different GSD (gravel to fine sediment)
- Spatially distributed friction refined both flow velocities and grain mobility in 2D model especially in low mobility case

References

Vázquez-Tarrío, D., Borgniet, L., Liébault, F. & Recking, A. (2017) Using UAS optical imagery and SfM photogrammetry to characterize the surface grain size of gravel bars in a braided river (Vénéon River, French Alps). Geomorphology, 285, 94–105.

Wong, T., Khanal, S., Zhao, K. & Lyon, S.W. (2024) Grain size estimation in fluvial gravel bars using uncrewed aerial vehicles: A comparison between methods based on imagery and topography. *Earth Surface Processes and Landforms*, 49(1), 374–392.