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Assessment of local bedload transport through dune-tracking: application to the Colorado River in the Grand Canyon, USA

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Le Coz, J., Perret, E., Camenen, B., Topping, D. J., Buscombe, D. D., Leary, K. C. P., Dramais, G., Grams, P.E. (2022).
Mapping 2-D bedload rates throughout a sandbed river reach from high-resolution acoustical surveys of migrating bedforms.
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https://doi.org/10.1029/2022WR032434

Bedload estimation through dune-tracking

- An indirect measurement based on repeated surveys of the bottom topography (Simons et al. 1965)
- Bedload discharge per unit width: $$q_b = (1-p)V_b H_b + q_{b,0}$$

Residual flux (neglegted)

porosity

Migration velocity

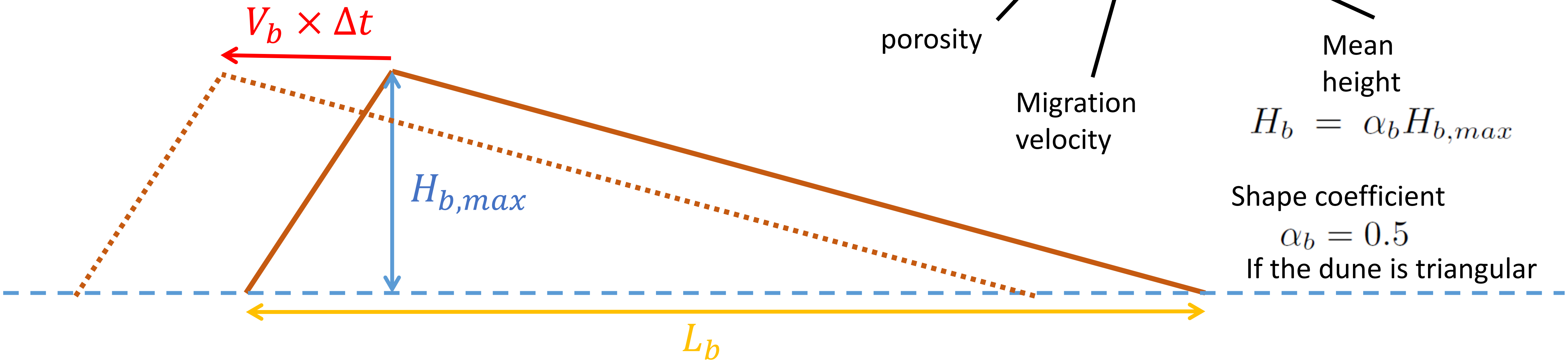
Mean height

$$H_b = \alpha_b H_{b,max}$$

Shape coefficient

$$\alpha_b = 0.5$$

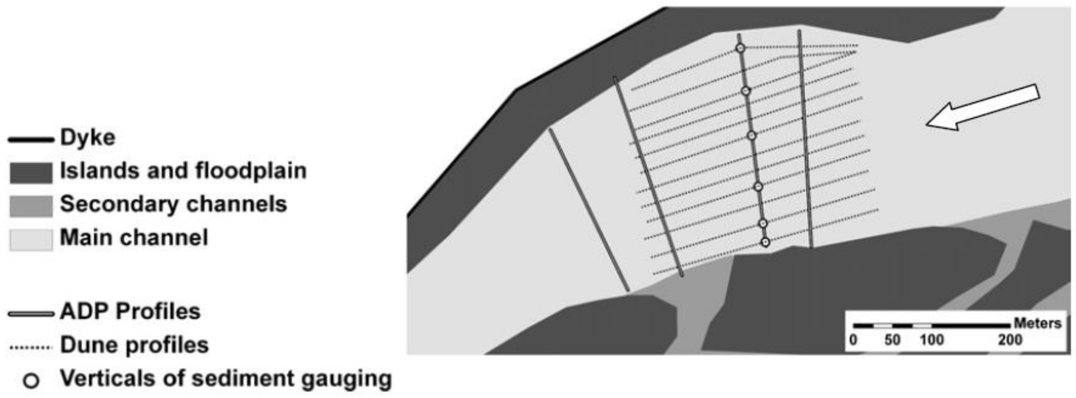
If the dune is triangular

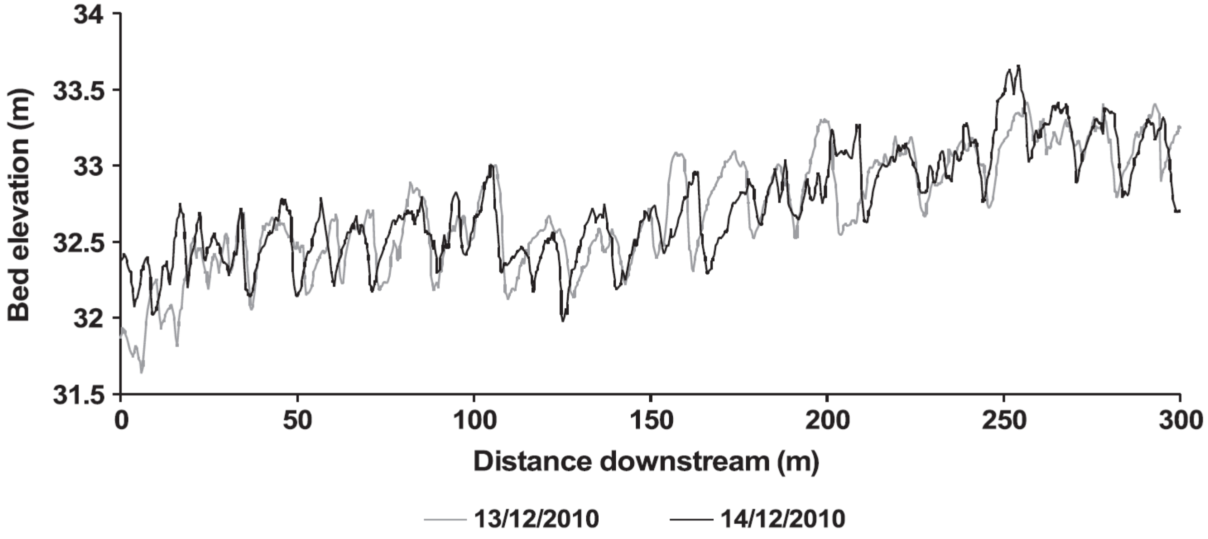


Bedload estimation through dune-tracking

- New high-resolution methods (ADCP, multibeam echo sounders, satellite imaging, laboratory experiments, etc.) provide DTMs with high spatial and temporal resolution.
- However, the quantification of bedload transport remains 1D (fixed direction).

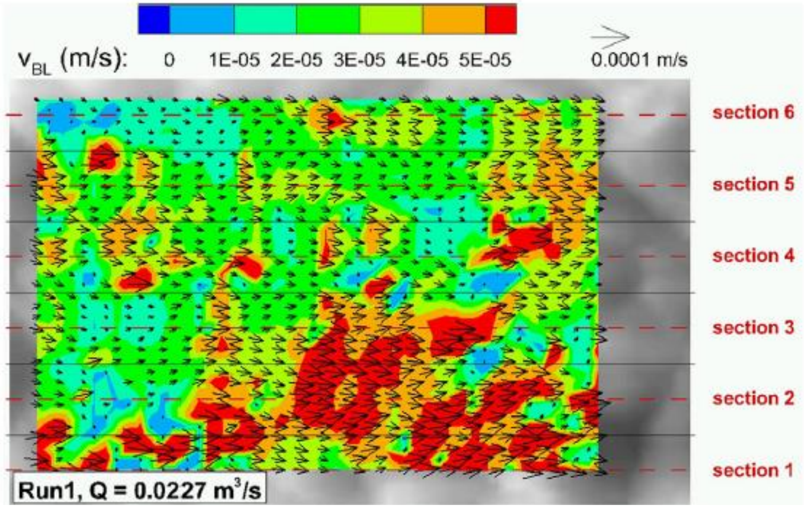
Hydroacoustic measurements on the Loire River at Bréhémont. Excerpt from Claude et al. (2012)



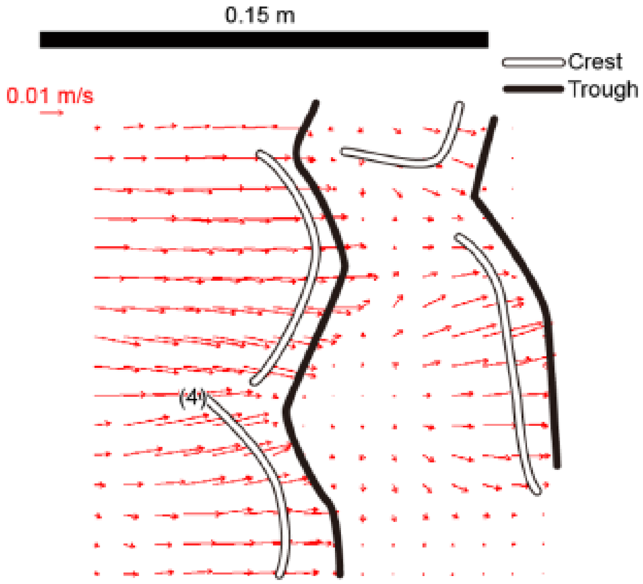


Towards 2D bedload transport measurements?

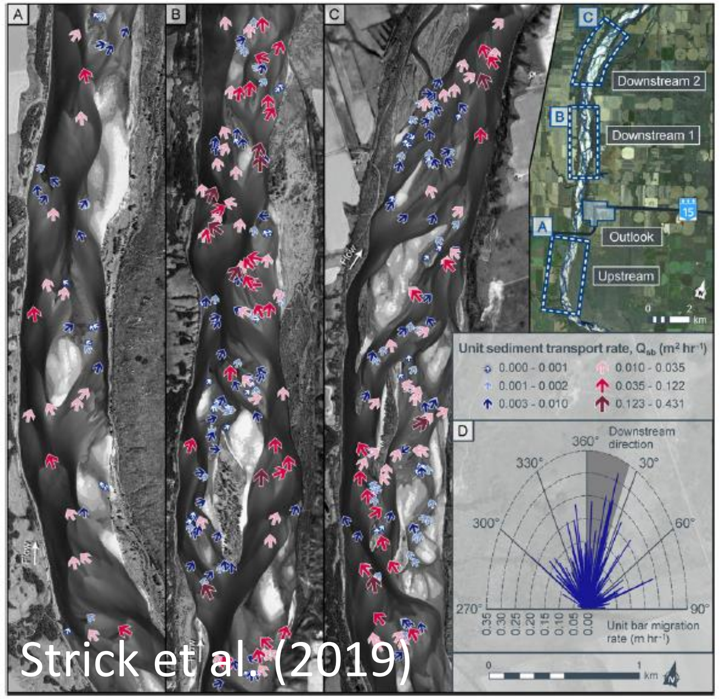
- Measurement of local 1D sediment transport by image velocimetry (LSPIV, Muste et al. 2016; Kim et al. 2016)
- Measurement of 2D bottom velocities by LSPIV (Tsubaki et al. 2018)
- Manual determination of 2D sediment transport on aerial images (Strick et al. 2019)



Muste et al. (2016)



Tsubaki et al. (2018)

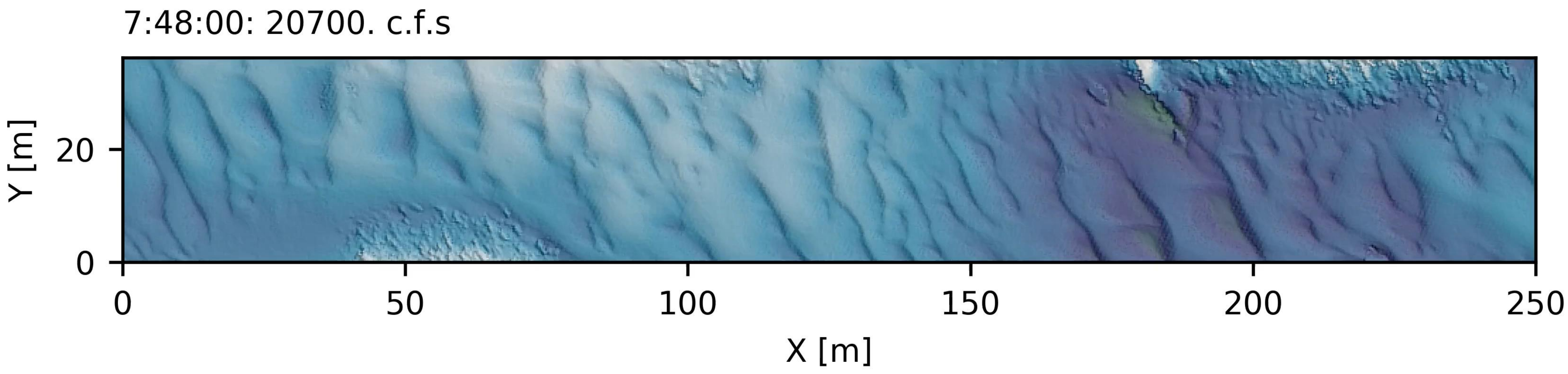


Strick et al. (2019)

Towards 2D bedload transport measurements?

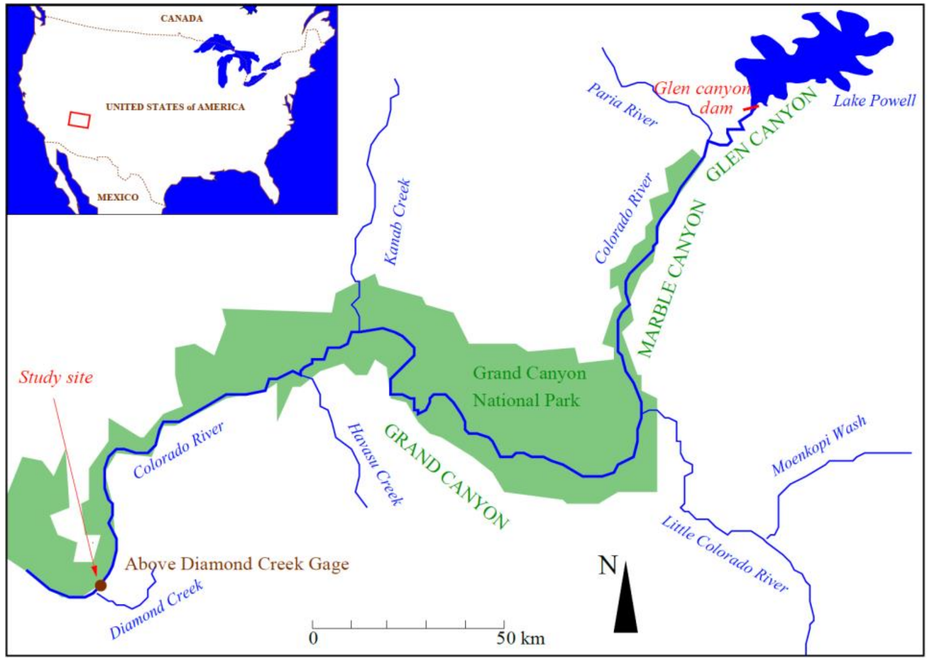
- What if we measured the dunes along the axis of their local movement?

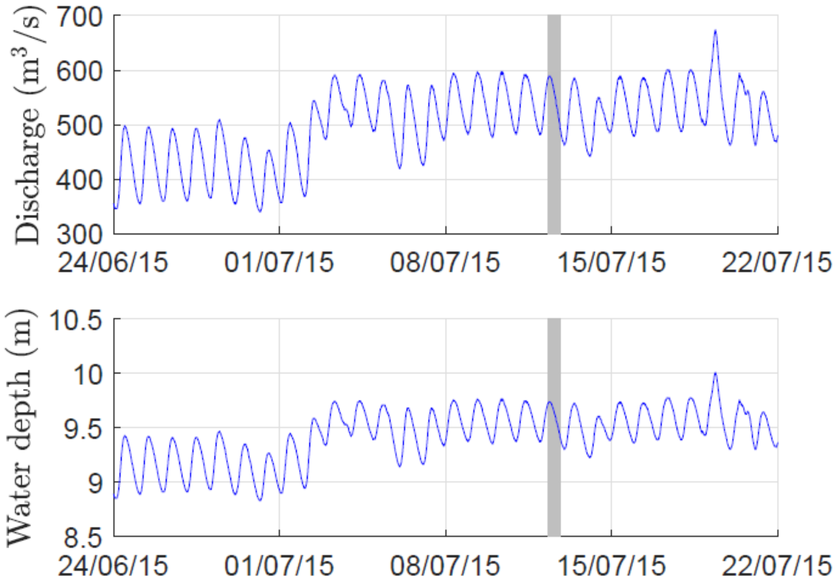
Colorado at Diamond Creek – Bathymetric survey of 12 July 2015 – USGS GCMRC data (Leary 2018)



Site and data

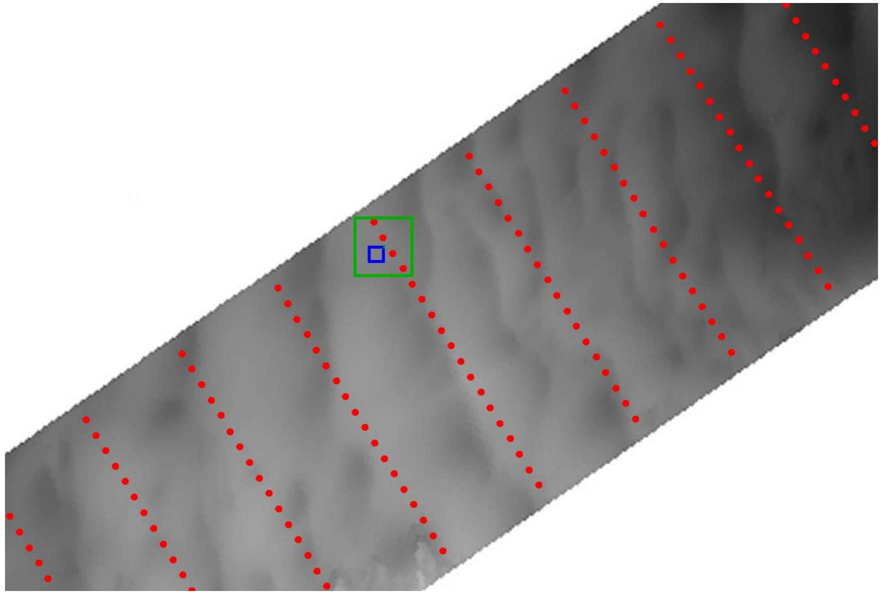
- Survey (echo sounder) of the section every 6-10 minutes for 12 hours
- DTM interpolated to 25 cm, vertical standard deviation u_z ≈1.2 cm

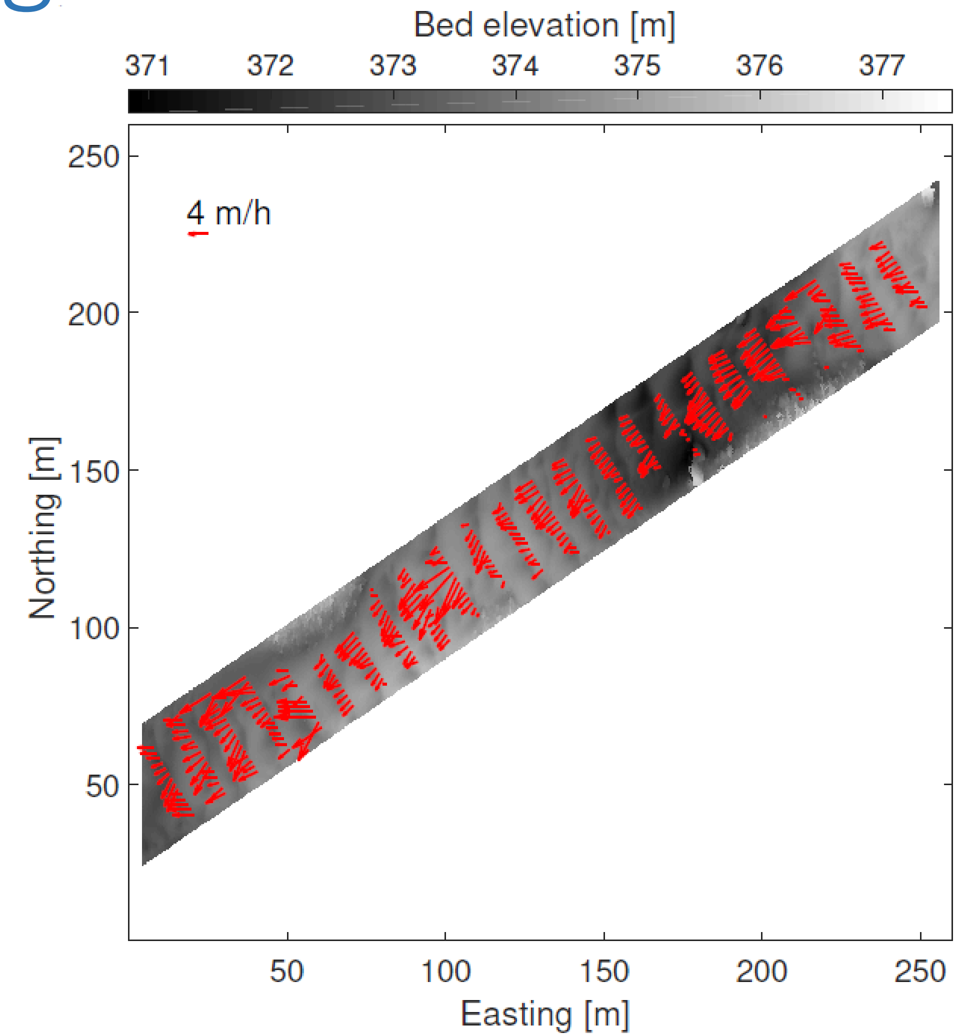




LSPIV measurement of migration velocities

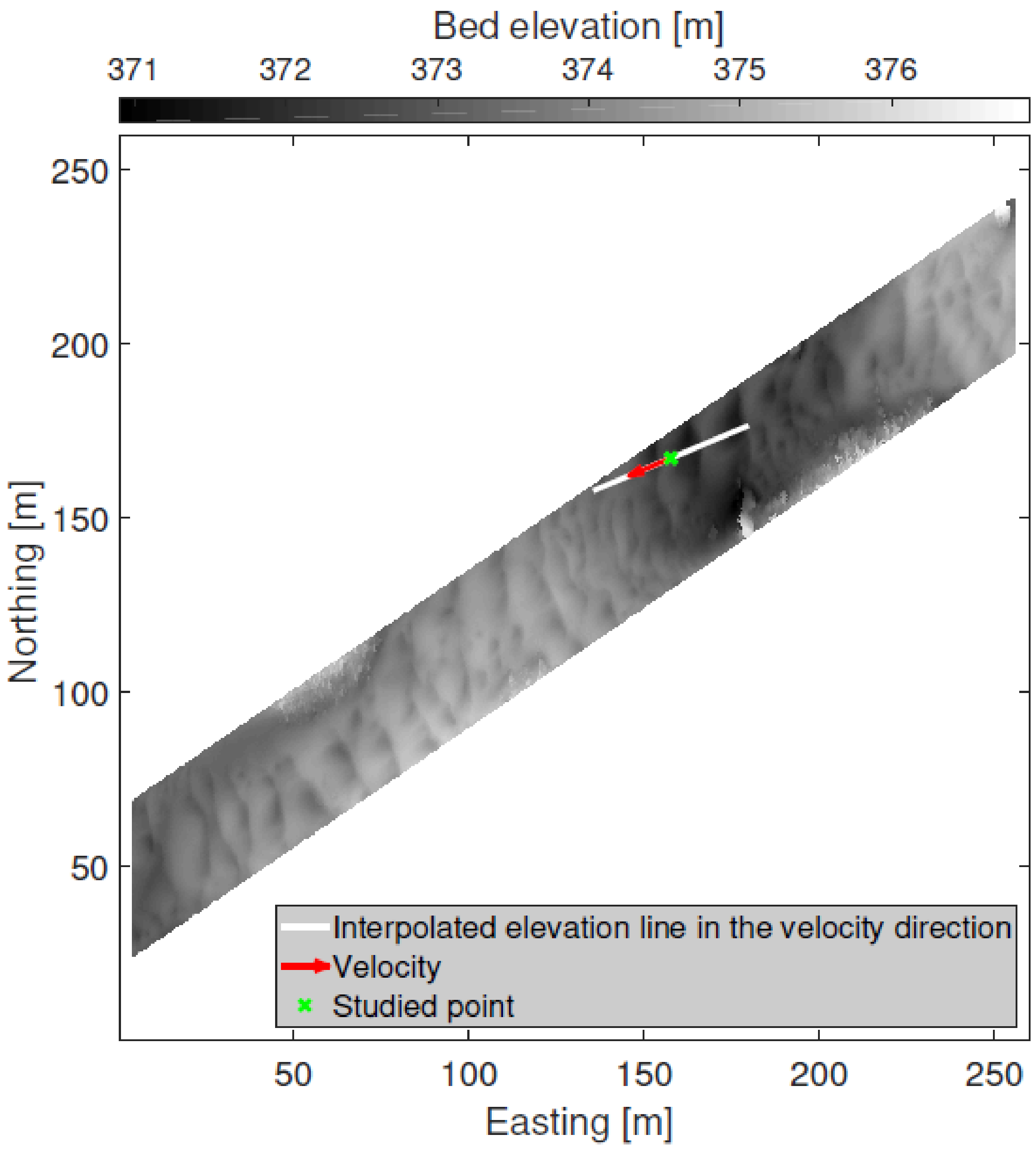
- Fudaa-LSPIV software (EDF/INRAE, open-source)
- The correlation must be performed on sufficiently large areas (IA=6 m) to detect the movement of the main dunes and not more local bed deformations.





Determination of dune geometry

- Along the local movement:
  - At each node of the LSPIV calculation grid
  - At each time step (each pair of DTMs)
  - Extraction of the interpolated bathymetric transect

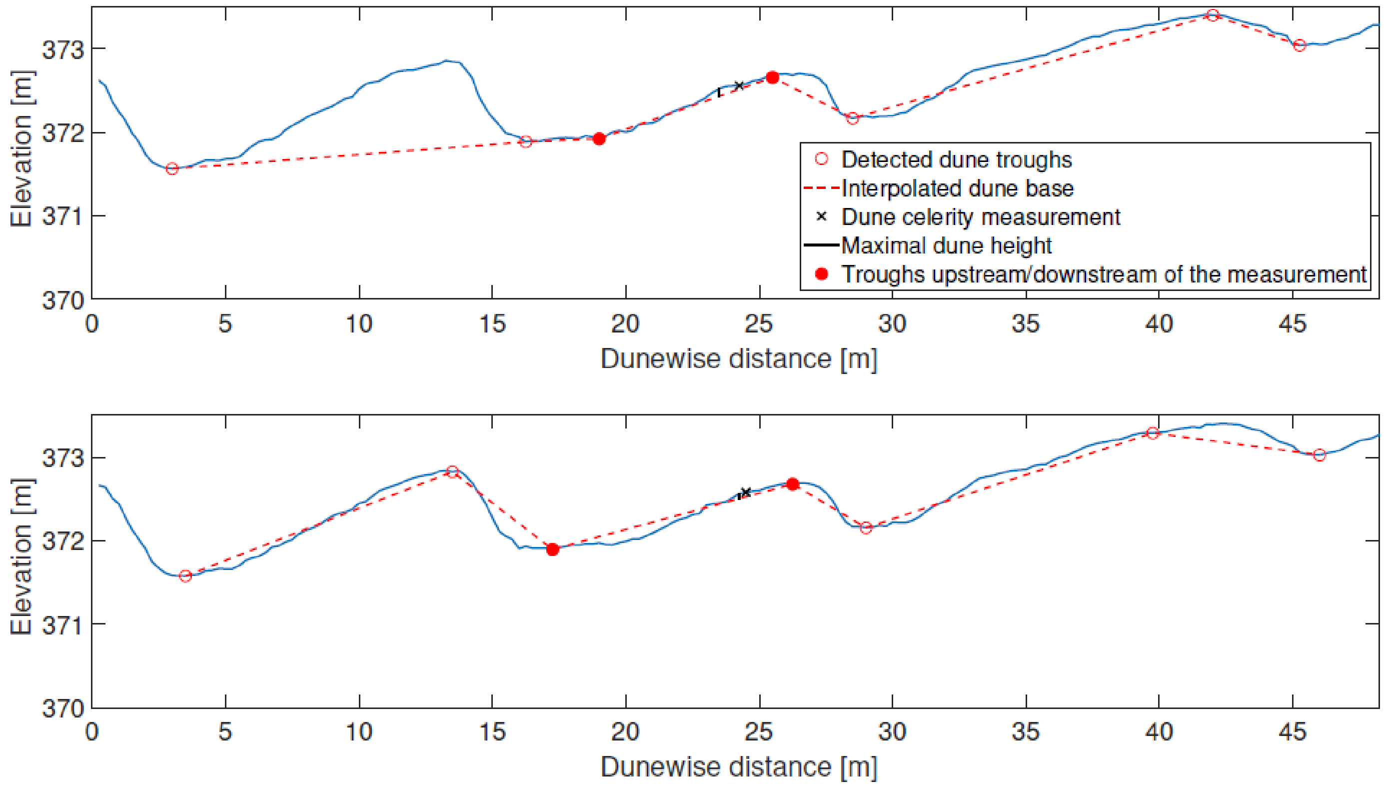


Determination of dune geometry

- Detection of troughs surrounding the LSPIV velocity measurement
- Matlab function *envelope(x,np,"peak")* to detect peaks separated by at least *np* samples
- Calculations at different *np* values and automatic selection

Example:

np = 10 (2.5 m) : too short!

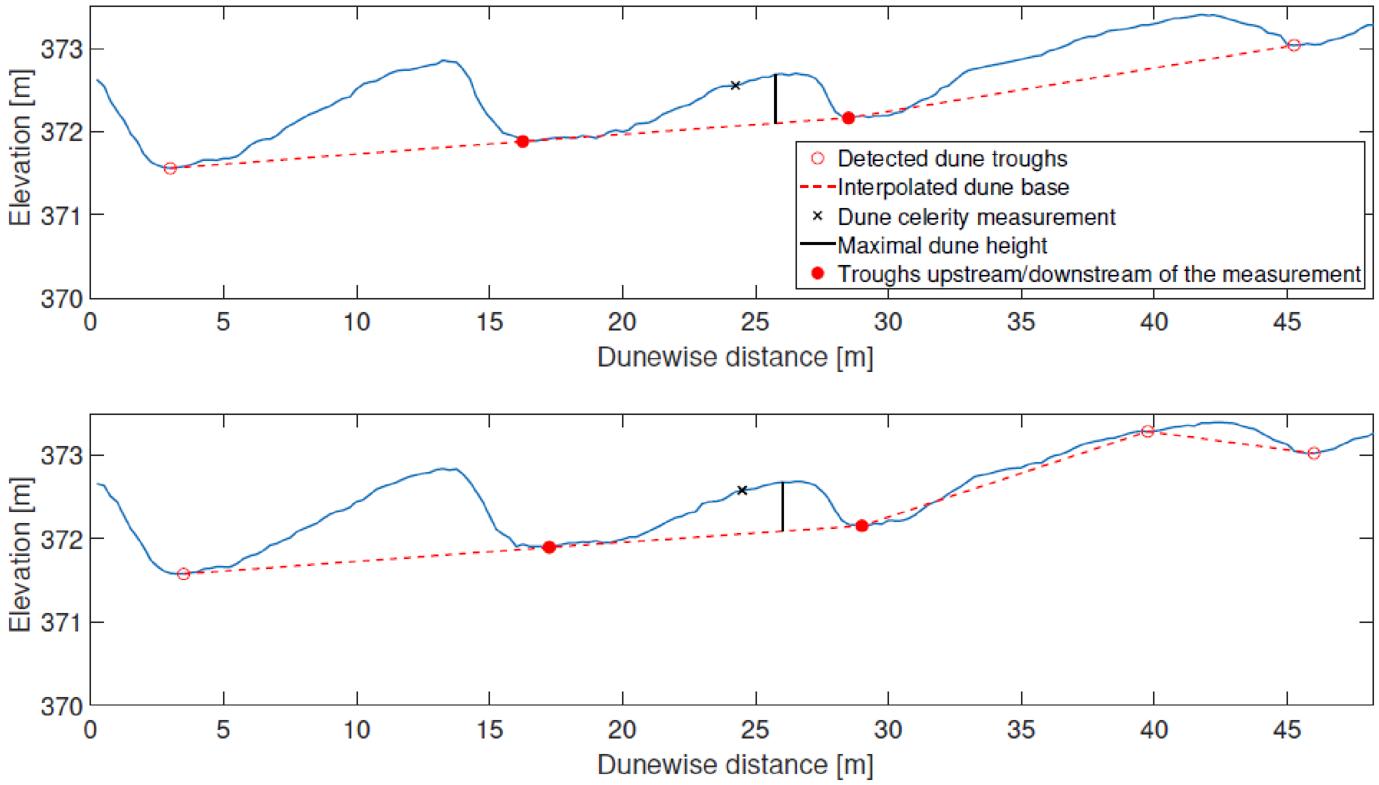


Determination of dune geometry

- Detection of troughs surrounding the LSPIV velocity measurement
- Matlab function *envelope(x,np,"peak")* to detect peaks separated by at least *np* samples
- Calculations at different *np* values and automatic selection

Example:

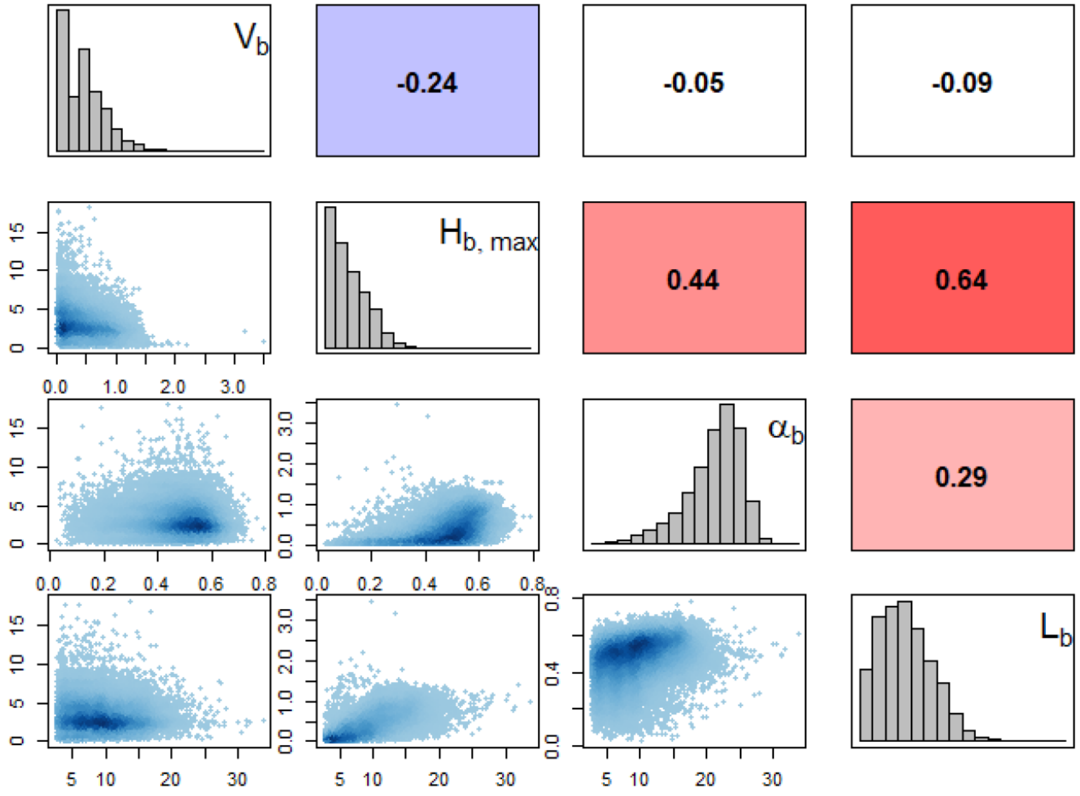
np = 20 (5 m) : *OK!*



Dune characteristics: observations

- Dune length and height are the most correlated parameters
- On average (weighted by local transport), the dunes appear slightly convex ($\alpha_b = 0.63$)

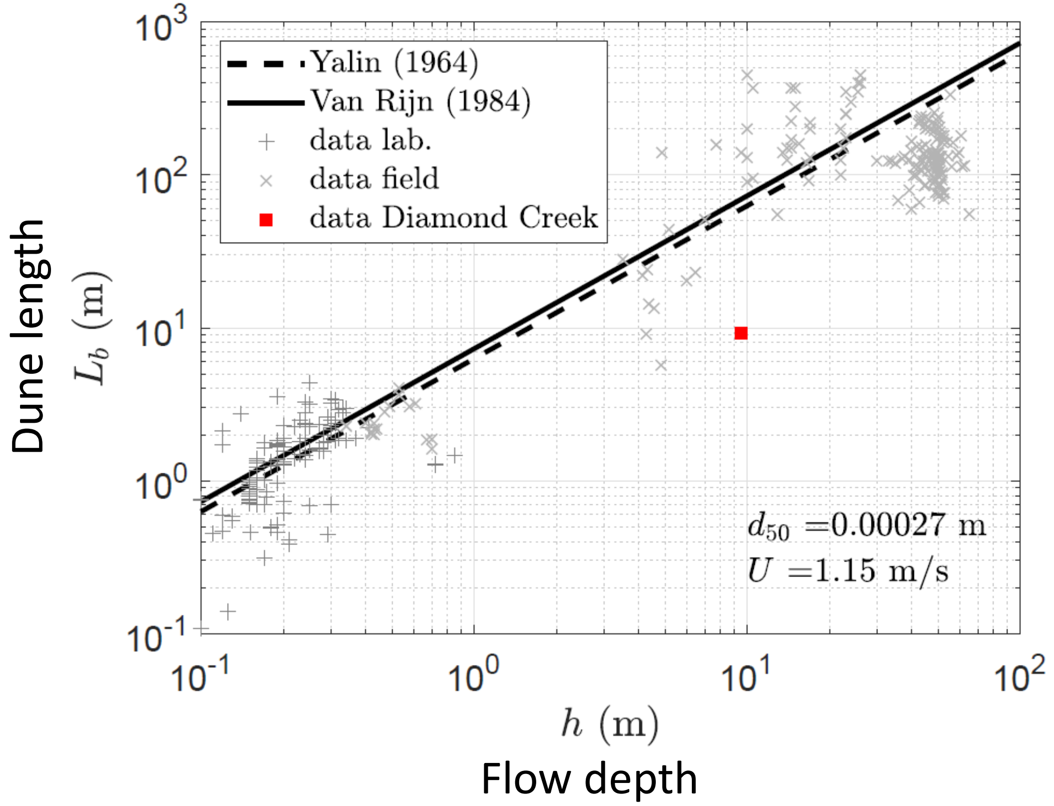
Variables	Units	Simple average (mean±std)	Bedload-based average (mean±std)
L_b	[m]	9.2 ± 0.31	
$H_{b,max}$	[m]	0.42 ± 0.032	0.30 ± 0.041
α_b	[-]	0.47 ± 0.0077	0.63 ± 0.041
H_b	[m]	0.21 ± 0.018	0.19 ± 0.019
V_b	[m/h]	2.2 ± 0.51	
q_b	[m^3/s/m]	$7.7 \times 10^{-5} \pm 2.0 \times 10^{-5}$	

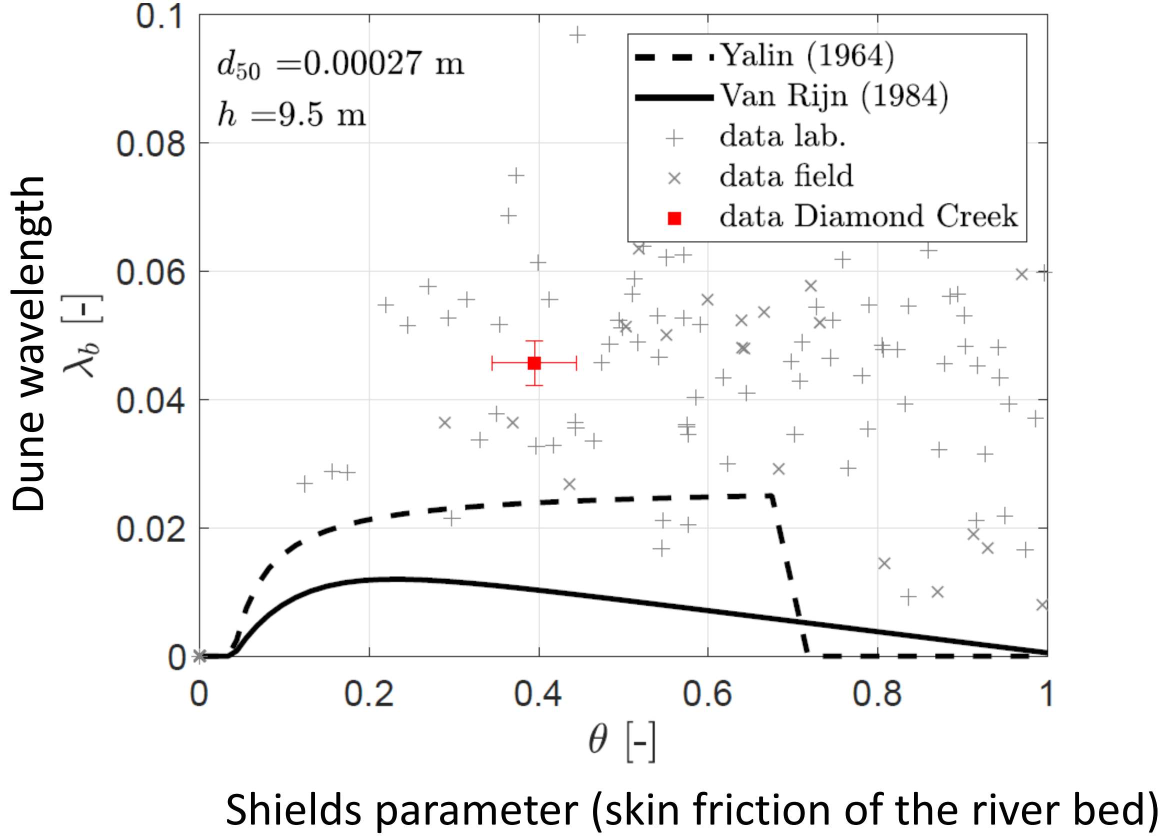


Dune characteristics: models

- Conventional dune models predict longer and less steep dunes than our measurements.

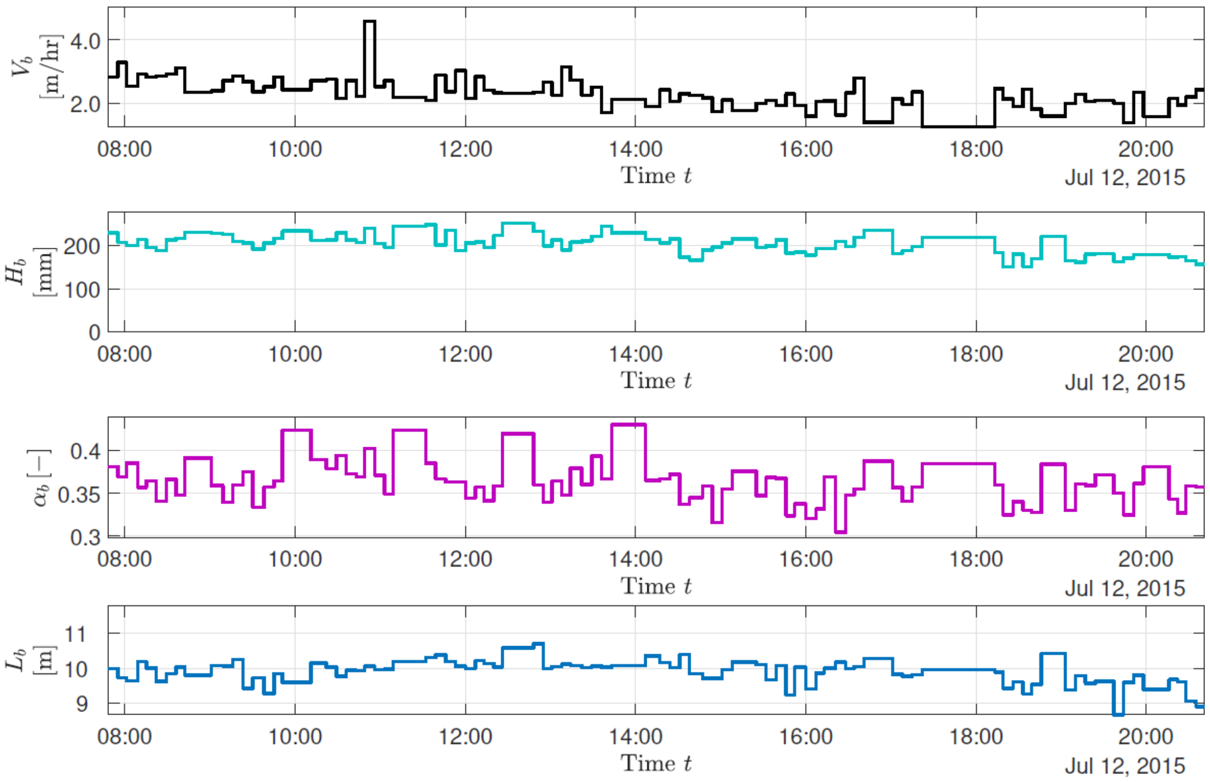
$$\lambda_b = H_{b,max}/L_b$$

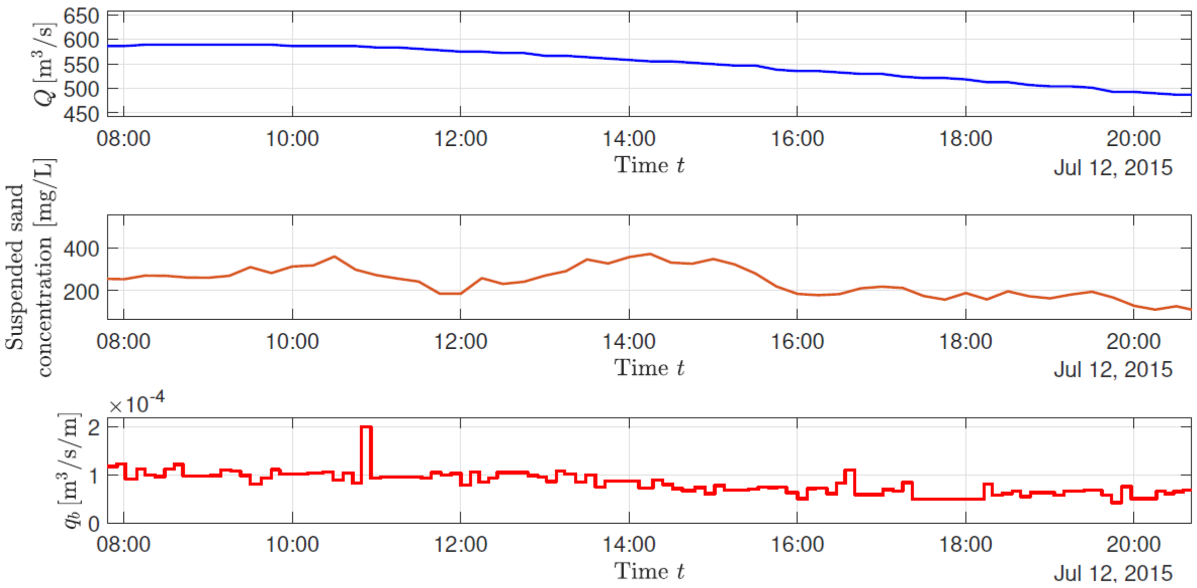




Temporal dynamics of bedload

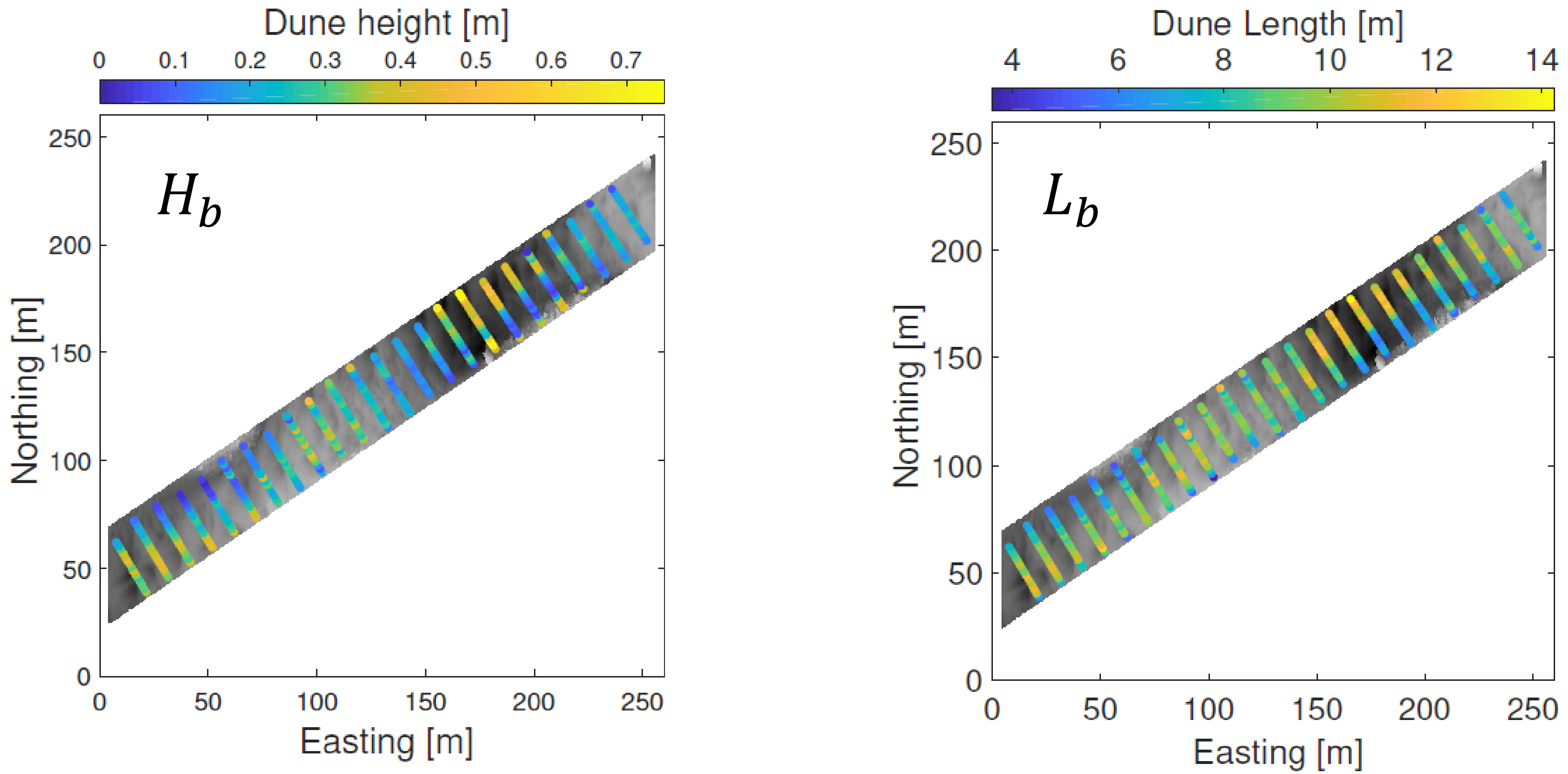
- Reaction of all parameters to the decrease in discharge during the surveyed period of time





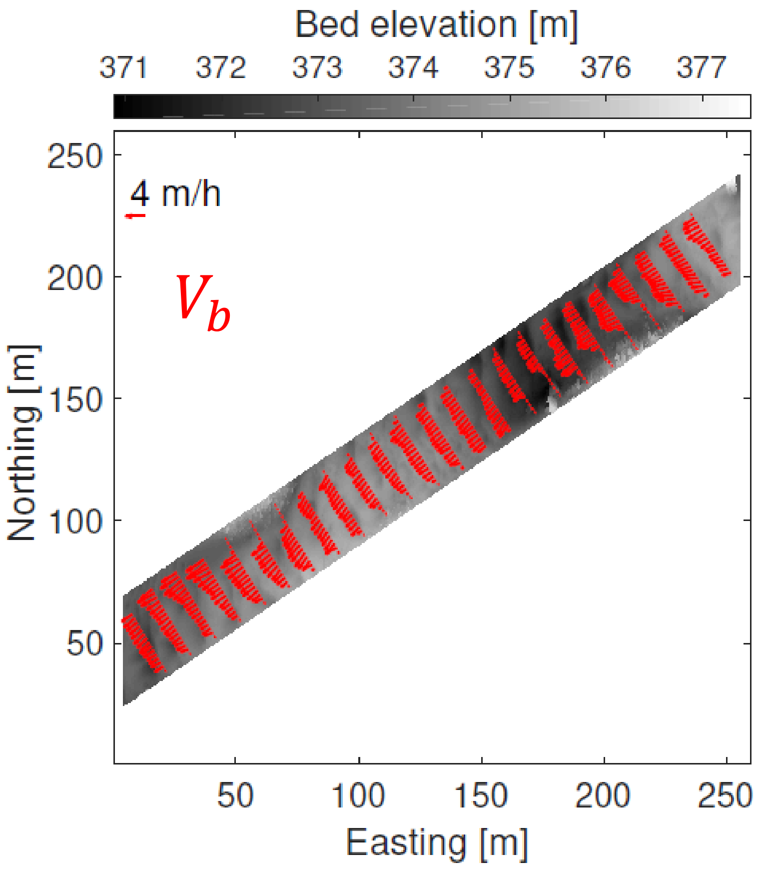
Spatial distribution: dune geometry

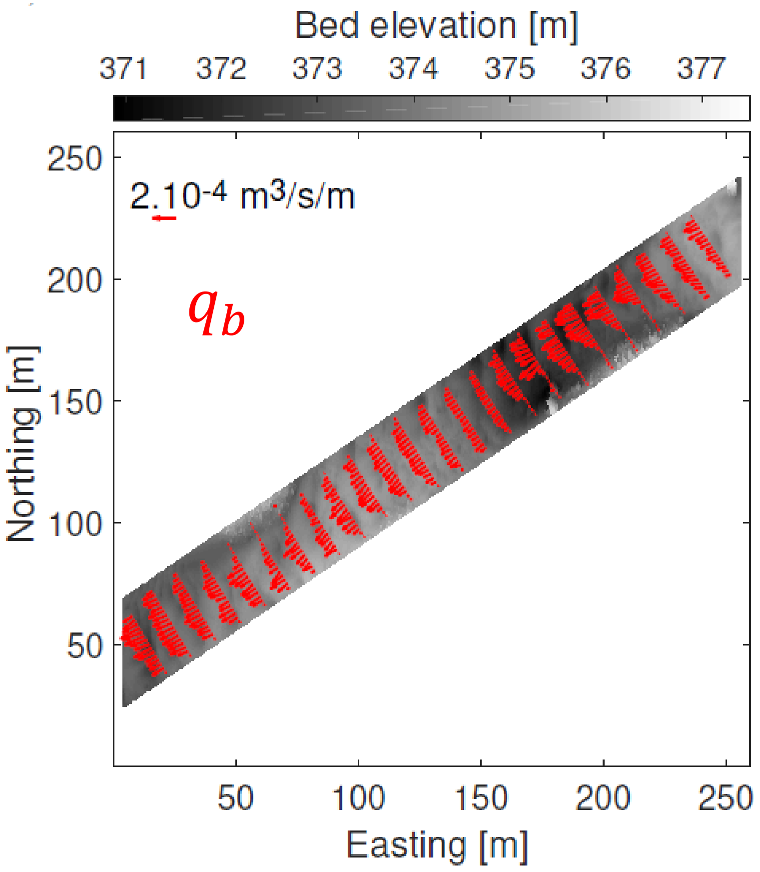
- The largest dunes are located where sediment transport is most concentrated (on average over time).



Spatial distribution: dune migration and bedload

- Hence, bedload varies slightly more locally than migration velocity.

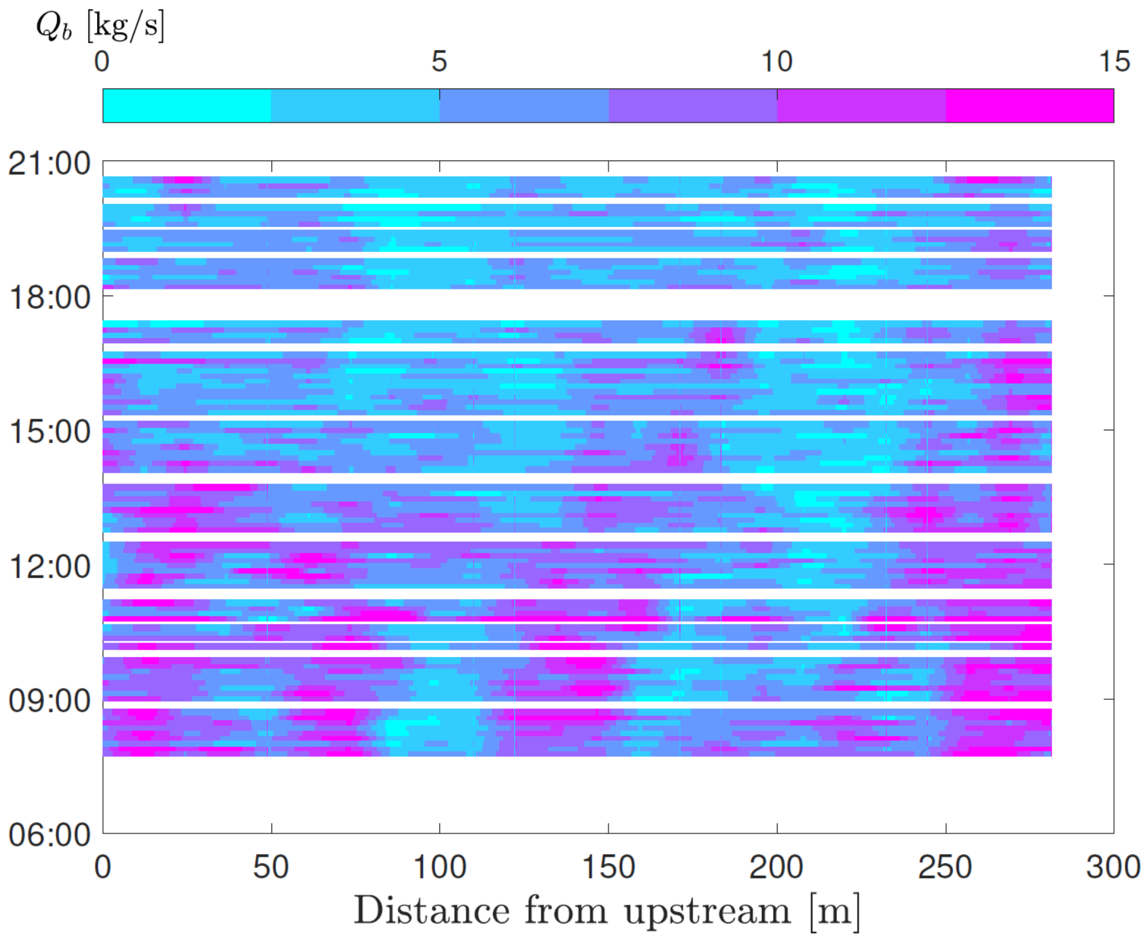




Sediment transport is generally aligned with the channel axis, with local variations due to the alluvial fans formed by the canyon walls.

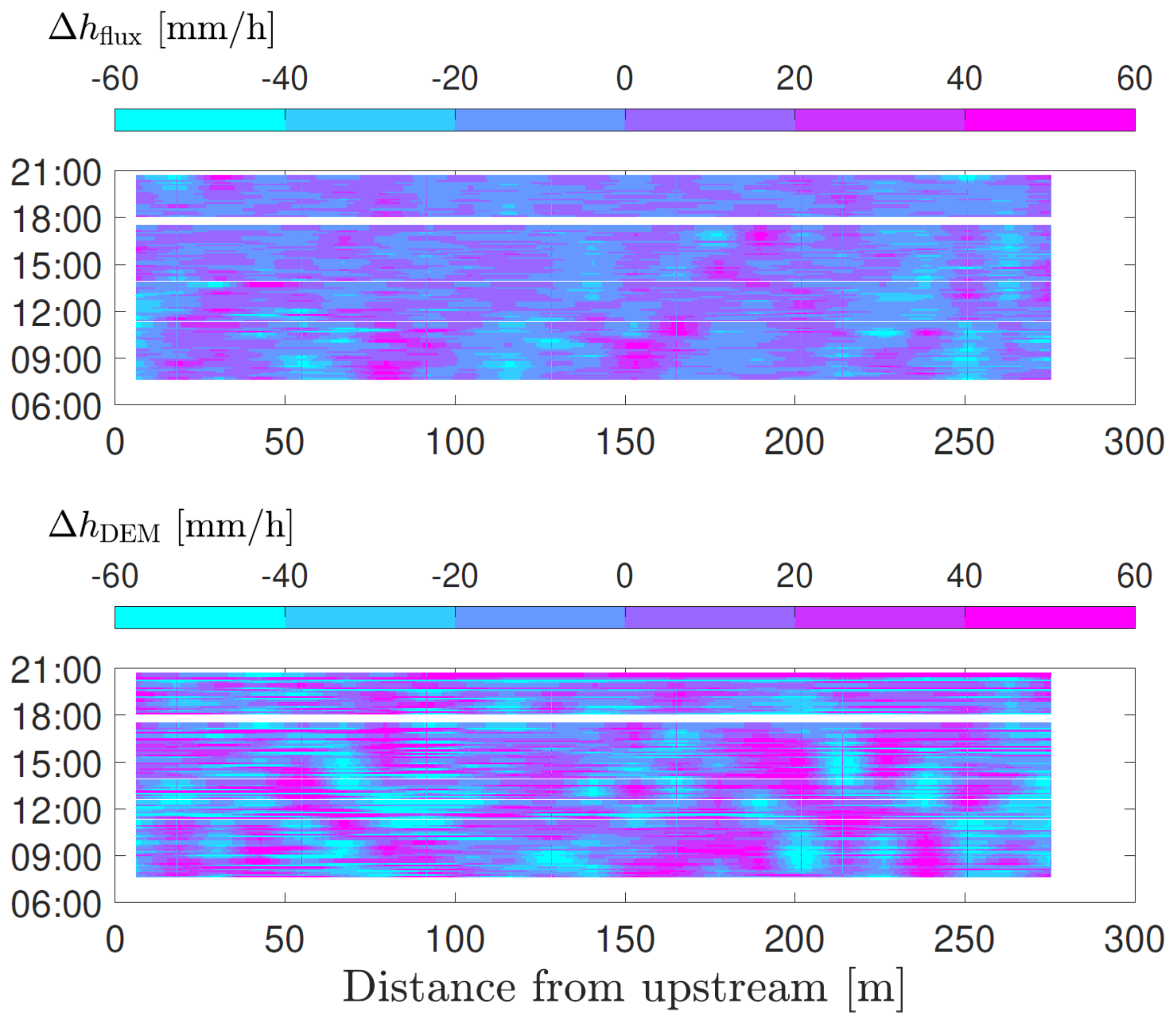
Dynamics of the total sediment flux

- The total sediment flux across each transect of the LSPIV grid is calculated by integrating local bedload transport.
- Downstream migration of areas of more or less intense bedload transport.
- Overall decrease in bedload transport over time (decreasing discharge).
- Estimated average bedload transport:
  - Our measurements: $5.7 - 9.7 \times 10^{-5}$ m²/s
  - Measurements by Ashley et al. 2020: $3 - 5 \times 10^{-5}$ m²/s
  - MPM 1948 equation: 3.0×10^{-5} m²/s
  - Van Rijn 1984 equation: 5.3×10^{-5} m²/s



Bed evolution

- Using mass balance (Exner equation), the local change in the depth can be calculated from the calculated fluxes: Δh_{flux}
- The change in depth obtained by DEM difference (Δh_{DEM}) shows similar patterns but is slightly more pronounced.



Conclusions and perspectives

- The proposed method combines LSPIV velocity measurement and local dune analysis to establish the spatio-temporal distribution of bedload transport.
- In the Colorado case study, the method yields total fluxes similar to other methods but with different dune characteristics.
- The approach is sufficiently robust and automated to be applied to other repeated, high-resolution bathymetric surveys.

Acknowledgements

- Contributors:
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  - Glen Canyon Dam Adaptive Management Program
  - Grand Canyon Monitoring and Research Center
  - INRAE and CNR

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