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## Processing of hyperspectral aerial images to characterize the bathymetry of rivers

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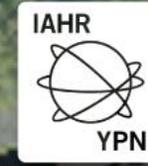
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# METHODS FOR ECOHYDRAULICS: REMOTE SENSING



International Association  
for Hydro-Environment  
Engineering and Research  
Hosted by  
Spain Water and IWHR, China



Poland  
Young  
Professionals  
Network



ECENet  
Early Careers on  
Ecohydraulics  
Network

Processing of hyperspectral aerial images to characterize the bathymetry of rivers

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WROCLAW UNIVERSITY  
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AND LIFE SCIENCES



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Environnement,  
Ville, Société

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Ain Aval & Affluents

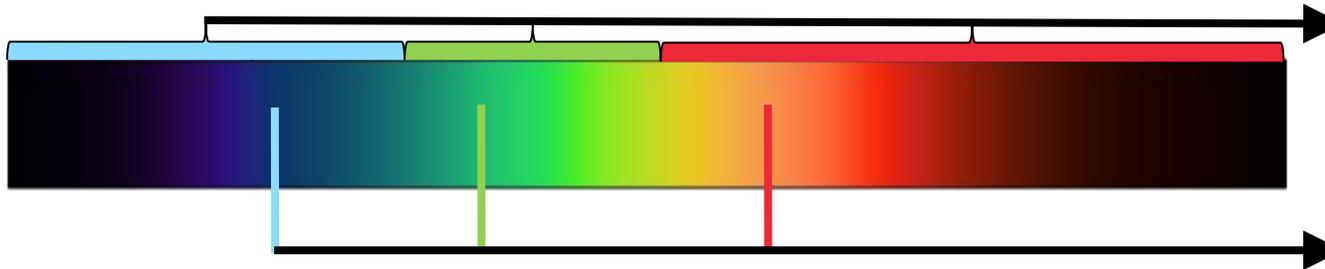


agence  
de l'eau  
RHÔNE MEDITERRANÉE  
CORSE

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# Context: What is hyperspectral imagery?

- Traditional colour images :
  - A small number of **broad spectral bands**
  - **Summarize the spectra** over a large spectral range to recreate what we can see



- Hyperspectral imaging :
  - A high number of **narrow spectral bands**
  - **Samples the spectra** with a precision similar to lab spectroscopy measurements

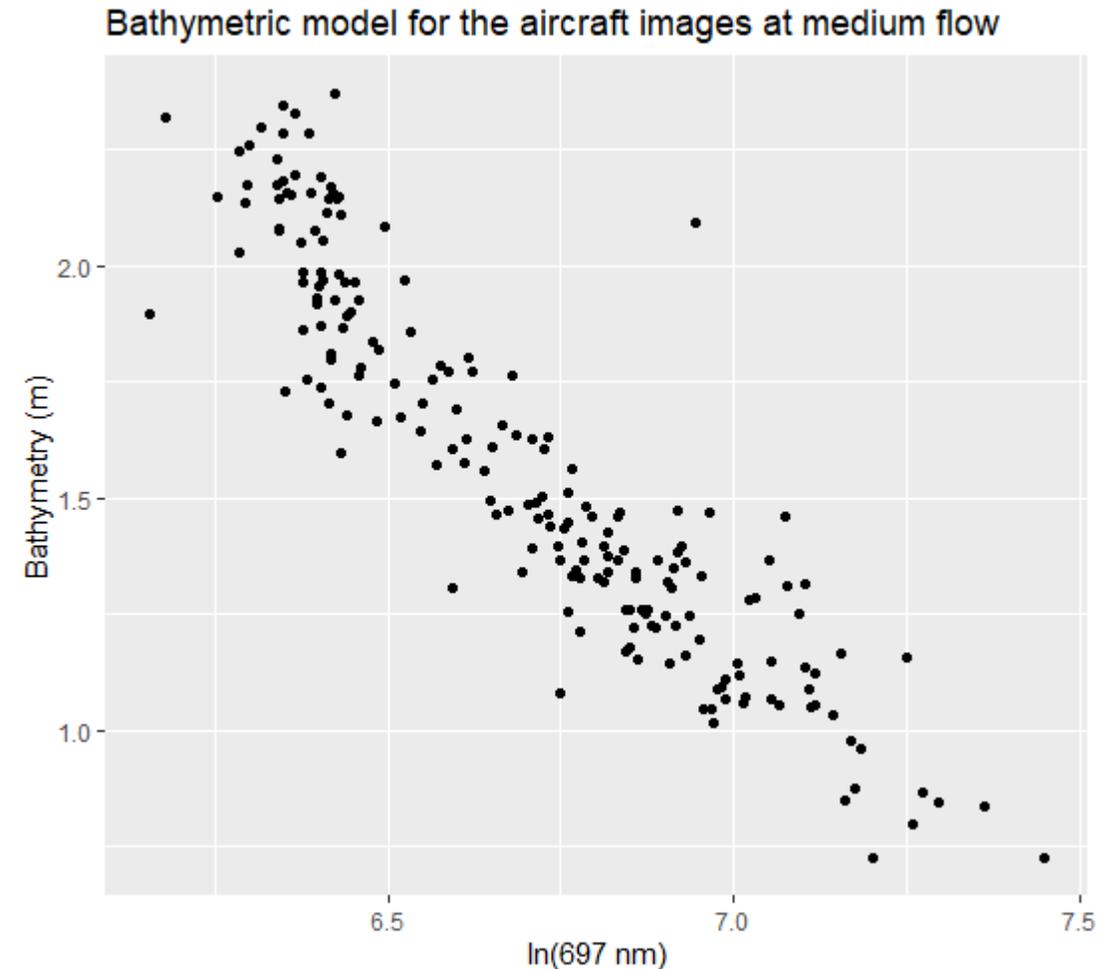


# Context: How does it retrieve river bathymetry?

- Optical model based on Beer-Lambert Law
  - The **intensity measured by the sensor** ( $I_{\text{sensor}}$ ) is a function of the **initial brightness** ( $I_{\text{sun}}$ ), **water depth** ( $d$ ) and of the **optical properties of the water column** ( $c$ ).

$$I_{\text{sensor}} = I_{\text{sun}} e^{-cd}$$

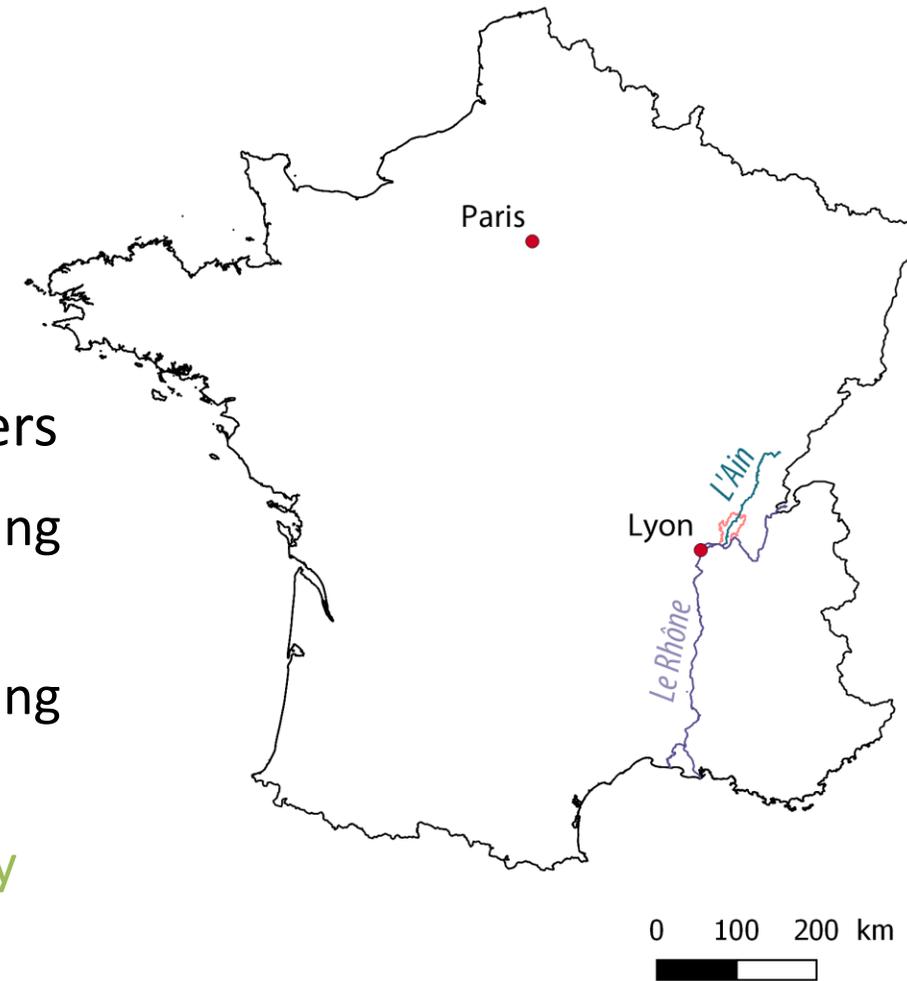
→ The goal is to identify the band combination that is the less sensitive to changes in  $c$  and the best correlated to  $d$ .



# Context: The Ain River as a study site

- The Ain River: a meandering gravel-bed river in France
  - Low Flow: 16 m<sup>3</sup>/s
  - Mean Annual Flow: 120 m<sup>3</sup>/s
- Accurate bathymetric information is crucial to stakeholders
  - Channel incision is propagating downstream following historical damming in the 20<sup>th</sup> century
  - Restoration projects such as gravel injection are attempting to mitigate this

=> Our aim on the Ain River was to assess the accuracy of hyperspectral-based bathymetric models and the portability of local models to large reaches



# Context: Existing datasets on the Ain River

- Hyperspectral data over the same river for **different sensors, extents and discharges**

Sensor	Vector	Spatial Resolution	Spectral Resolution	Discharge	Date	Secteur
Specim AISA Fenix	Airplane	1 m	360 bands [380 – 2500 nm]	127 m <sup>3</sup> /s	29/09/15	Ain River (20 km)
Rikola-2	UAV	6 cm	16 bands [500 – 845 nm]	27 m <sup>3</sup> /s	27/09/15	Local Reach (350 m)
Headwall Hyperspec	UAV	2.5 cm	480 bands [169 – 1200 nm]	100 m <sup>3</sup> /s	18/11/21	Local Reach (120 m)

- A 2D numeric bathymetric model
  - Covers the study site with as a grid with 2 – 3 metres resolution (200k+ points)
  - Enables **adjusting depths according to a desired discharge**
- Field data acquired with a Differential GPS in 2013
  - Less coverage, but provides additional validation data (320 points)

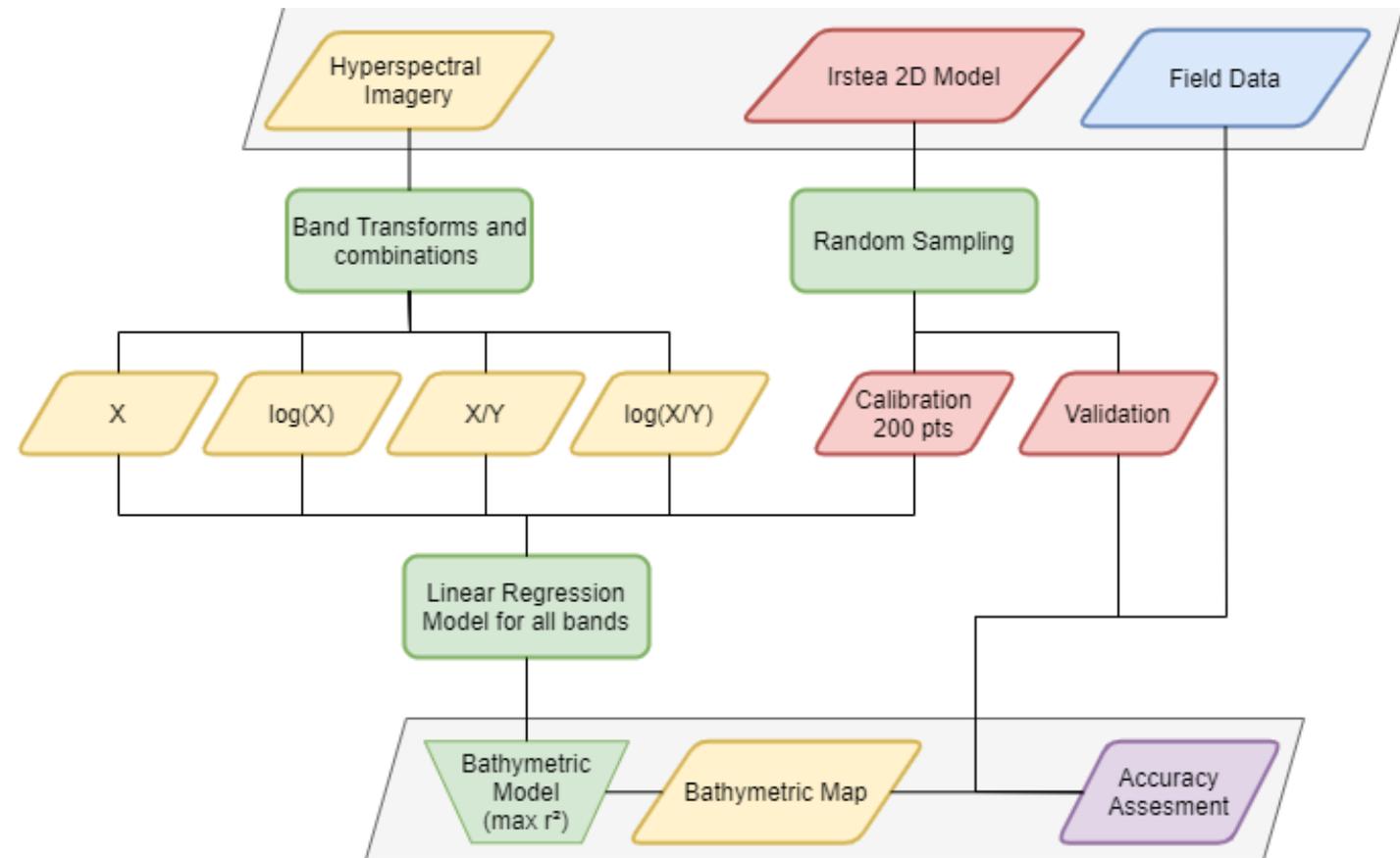
# Methodology: correlating spectra to depth

1°) Increasing the dimensionality of the data

2°) Testing the linear relationship to depth for all bands and band combinations

3°) Assessing the accuracy of a given model

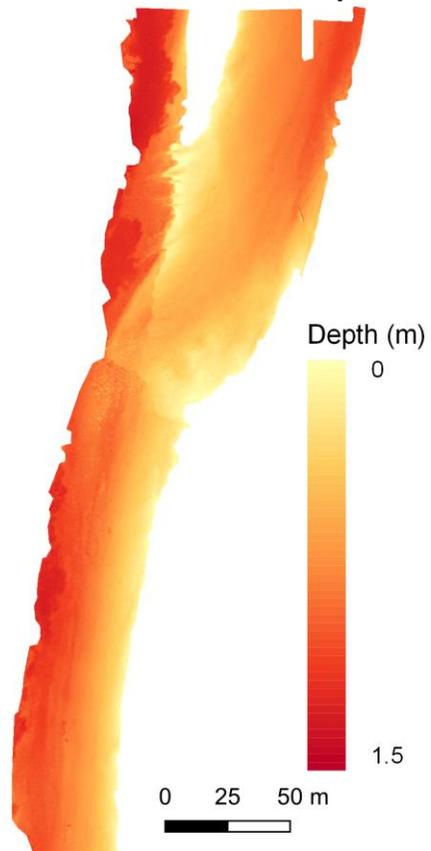
> Models are calibrated on short reaches and assessed for the full extent of the data which is higher for the airplane campaign



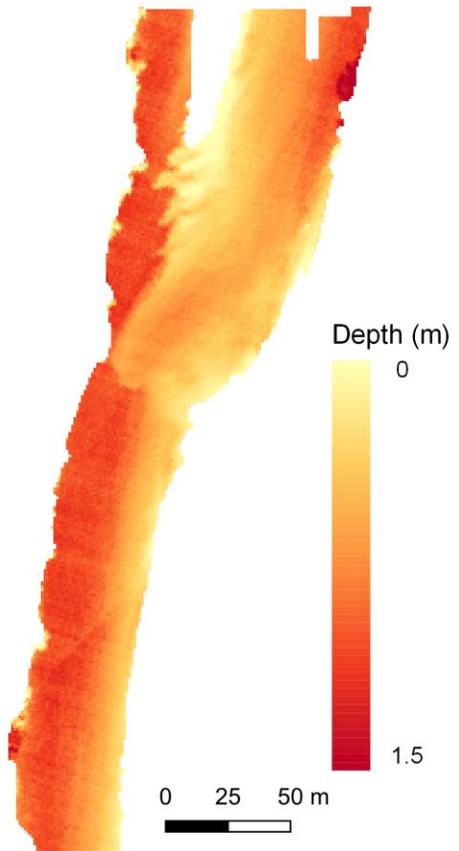
# Application: Mapping over large extents

## Bathymetric restitution at two reach scales

Water depth in 2015 for 27 m<sup>3</sup>/s



UAV Campaign  
Initial Discharge: 27 m<sup>3</sup>/s

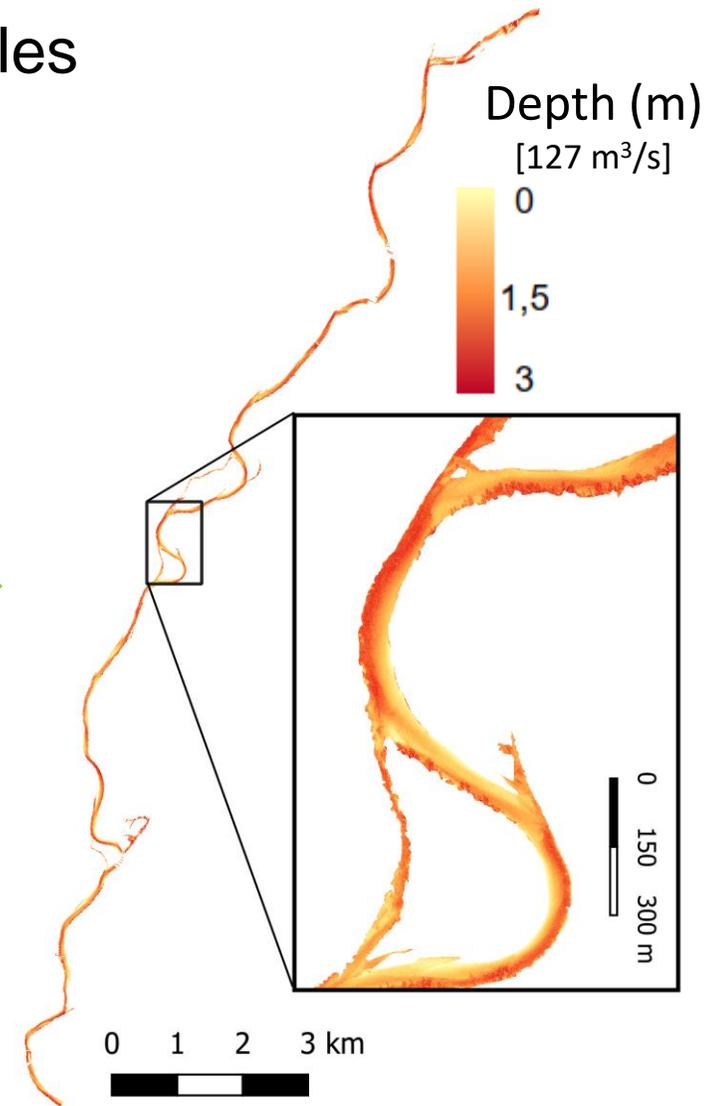


Airplane Campaign  
Initial Discharge: 127 m<sup>3</sup>/s

Accuracy: 10 – 15 cm  
Depths up to 2.5 m (127 m<sup>3</sup>/s)  
Single bands and ratios

From a small reach  
to a 20 km reach

Accuracy : 15 – 20 cm  
Depths up to 2.5 m (127 m<sup>3</sup>/s)  
Only band ratios



# Application: Change monitoring

Bathymetric changes between 2015 and 2021 for a short reach of the Ain River

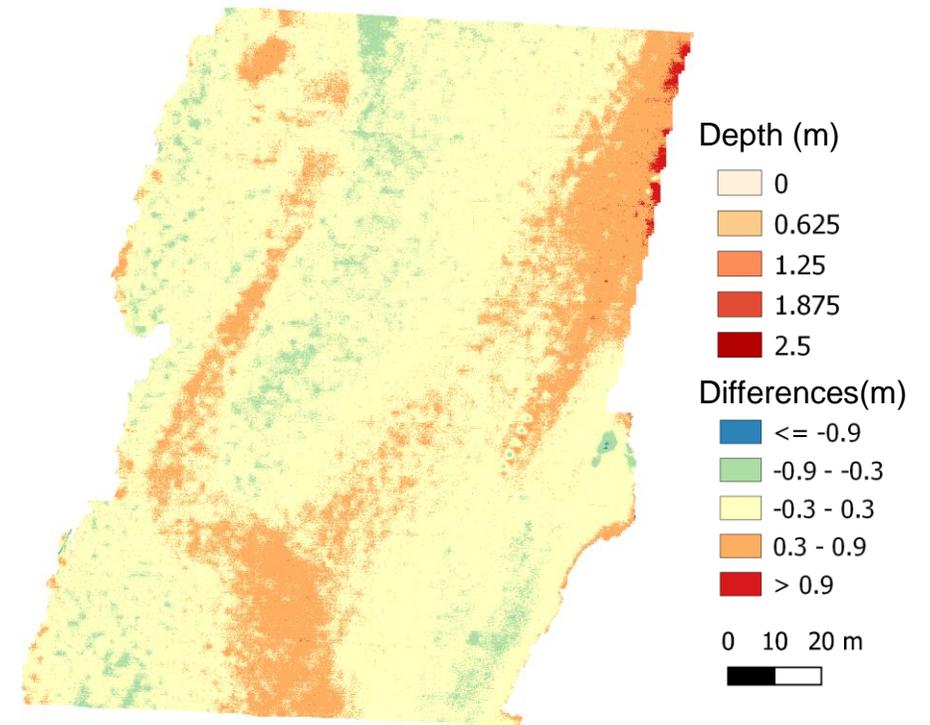
Airplane Campaign (2015)  
Resolution: 1 m



UAV Campaign (2021)  
Resolution: 2.5 cm



Difference (2021-2015)  
Resolution: 2.5 cm



# Limitations: clusters of errors

- Sources of errors :

1. Pool areas (< 5% of the river reach)

> Poor accuracy in the data for calibration and validation

2. Glint and turbulence at the water surface

3. Vegetation shadowing

4. Changes in riverbed or water column properties

> Sensitivity is dependant on wavelength combination

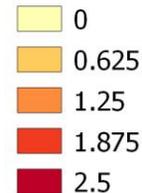


### Bathy

#### 1. Bathy - Mean Flow (m)



#### 3. Bathy - Low Flow (m)

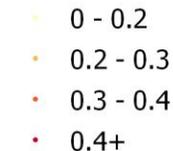


### Errors

#### 2. Error - Mean Flow (m)

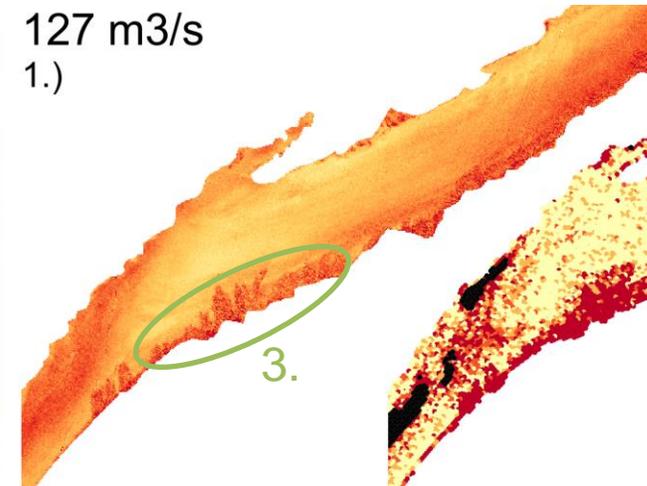


#### 4. Error - Low Flow (m)



127 m<sup>3</sup>/s

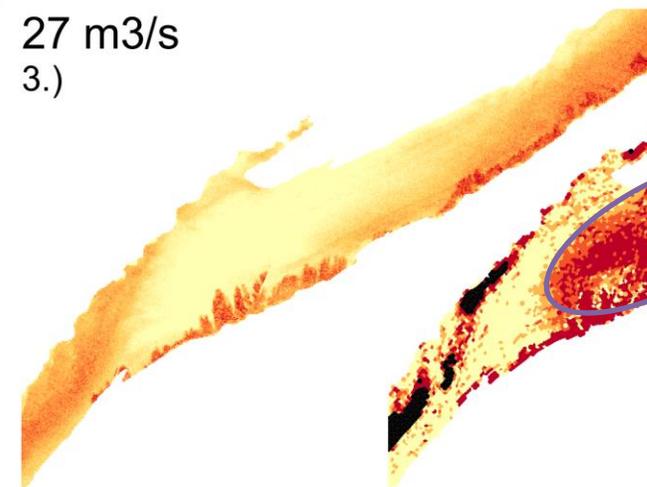
1.)



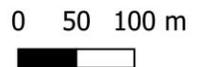
2.)

27 m<sup>3</sup>/s

3.)



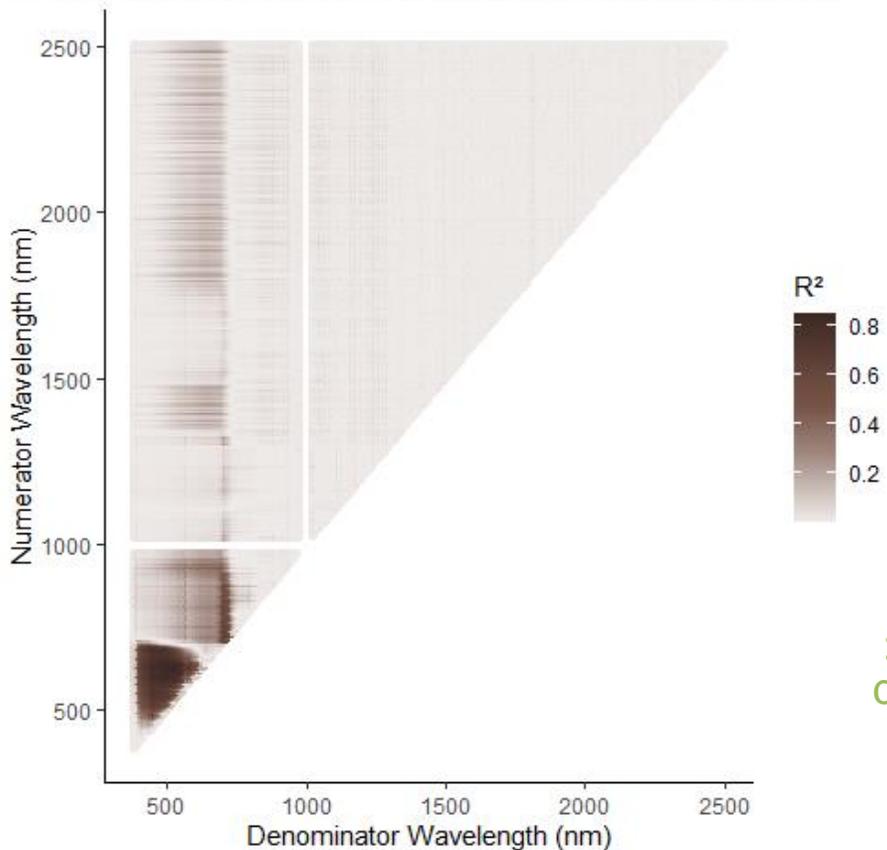
4.)



# Limitations: sensitivity to the calibration data

## Reach 1 : site of the initial calibration

R<sup>2</sup> values for Numerator/Denominator as a predictor of bathymetry



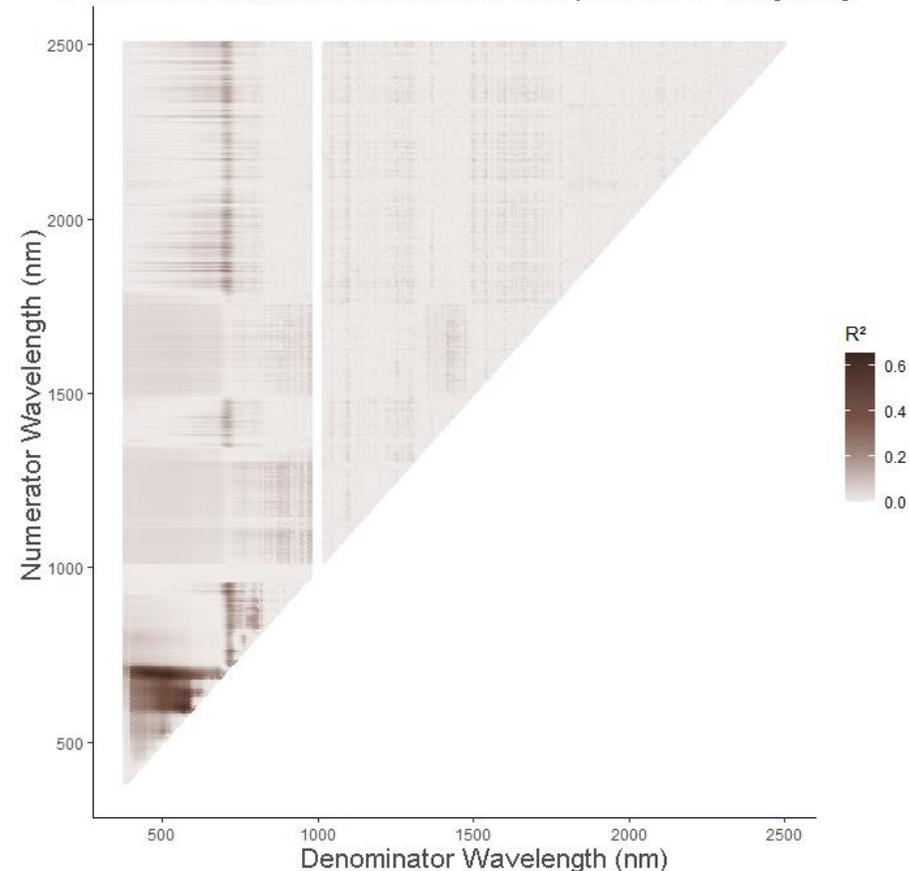
Squared-Root  
is reduced

Range of optimal  
wavelengths is  
reduced

> The best  $r^2$  model will highly depend on calibration data and might not be the one with the most portability

## Reach 2 : site from the map of errors

R<sup>2</sup> values for Numerator/Denominator as a predictor of bathymetry



# Conclusion

- Hyperspectral remote-sensing is promising for bathymetric retrieval
  - It can provide **accurate bathymetric maps** for a given discharge
  - Attempts at **large scale mapping** and **change detection** were successful
  - Campaigns acquired under mean annual flow conditions (**less than ideal conditions** for optical models) were successful
- Specific reproducibility issues must be assessed
  - Acquiring data for a **wider range of depths, turbidity conditions and lithology** to better understand limitations
  - **How to choose the best model** for the river rather than for the calibration data

A wide river flows through a landscape with a rocky bank in the foreground. The background is filled with a dense forest of trees, many of which have turned yellow and orange, indicating autumn. The sky is a clear, pale blue. The water in the river is calm, reflecting the trees and the sky. The text "Thank you for your attention!" is overlaid in the center of the image in a bright yellow font.

Thank you for your attention!