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Processing of hyperspectral aerial images to characterize the bathymetry of rivers

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► To cite this version:

Julien Godfroy, Jérôme Lejot, Luca Demarchi, Kristell Michel, Hervé Piégay. Processing of hyperspectral aerial images to characterize the bathymetry of rivers. *Methods for Ecohydraulics: Remote Sensing*, IAHR, May 2022, Warsaw, Poland. 10.25171/InstGeoph_PAS_Publs-2022-0016 . hal-04081325

HAL Id: hal-04081325

<https://hal.science/hal-04081325v1>

Submitted on 25 Apr 2023

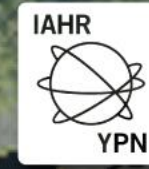
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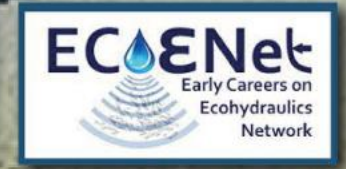
METHODS FOR ECOHYDRAULICS: REMOTE SENSING



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



Poland
Young
Professionals
Network



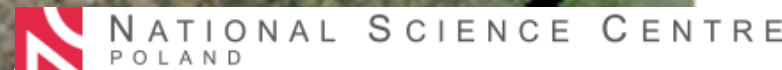
ECENet
Early Careers on
Ecohydraulics
Network

Processing of hyperspectral aerial images to characterize the bathymetry of rivers

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Environnement,
Ville, Société

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Ain Aval & Affluents

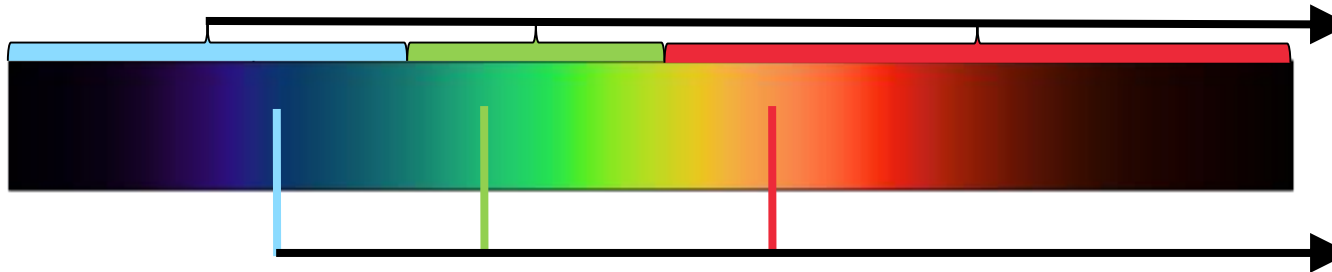


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Context: What is hyperspectral imagery?

- 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

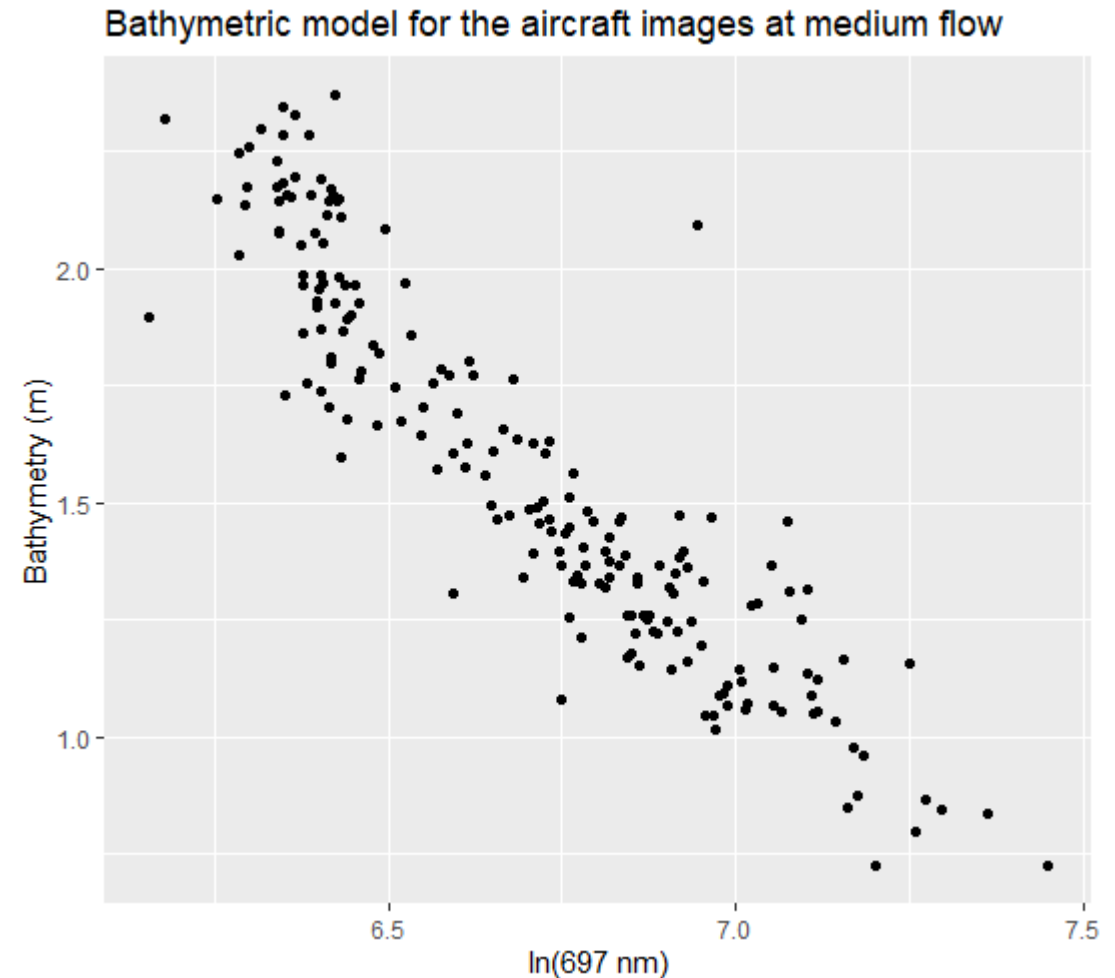


Context: How does it retrieve river bathymetry?

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

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

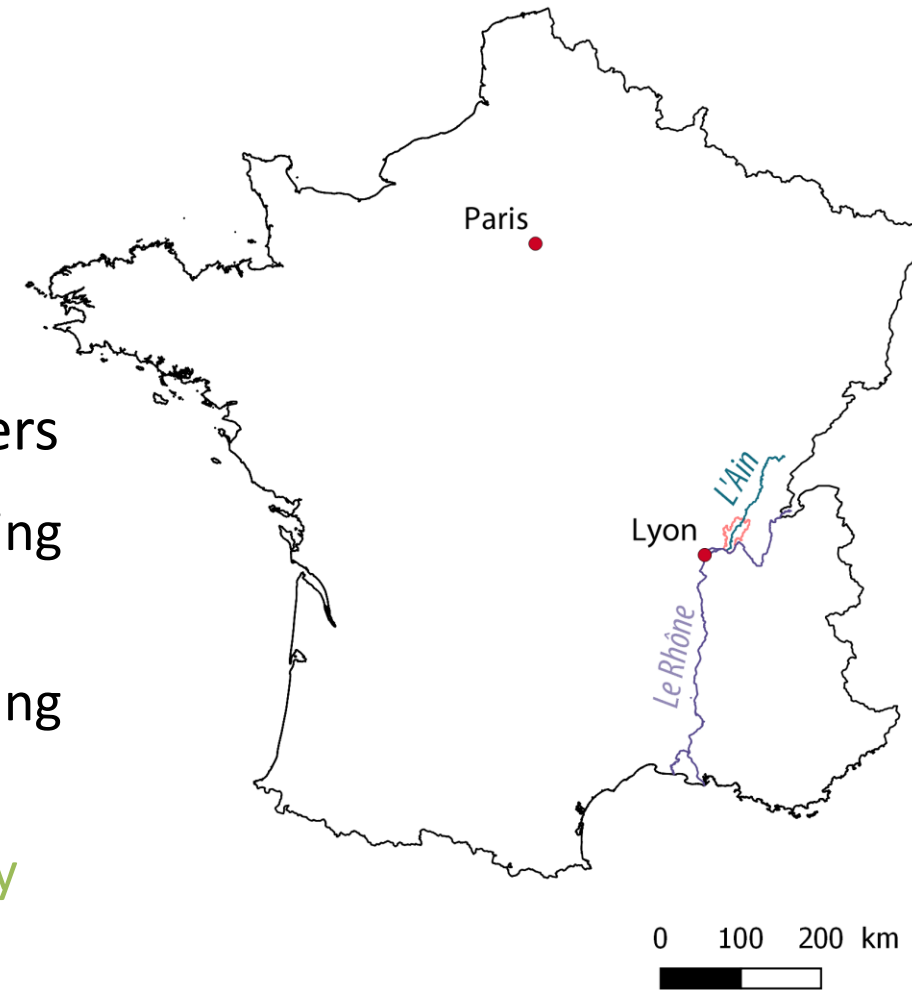
→ The goal is to identify the band combination that is the less sensitive to changes in c and the best correlated to d .



Context: The Ain River as a study site

- The Ain River: a meandering gravel-bed river in France
 - Low Flow: $16 \text{ m}^3/\text{s}$
 - Mean Annual Flow: $120 \text{ m}^3/\text{s}$
- Accurate bathymetric information is crucial to stakeholders
 - Channel incision is propagating downstream following historical damming in the 20th 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 ³ /s	29/09/15	Ain River (20 km)
Rikola-2	UAV	6 cm	16 bands [500 – 845 nm]	27 m ³ /s	27/09/15	Local Reach (350 m)
Headwall Hyperspec	UAV	2.5 cm	480 bands [169 – 1200 nm]	100 m ³ /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)

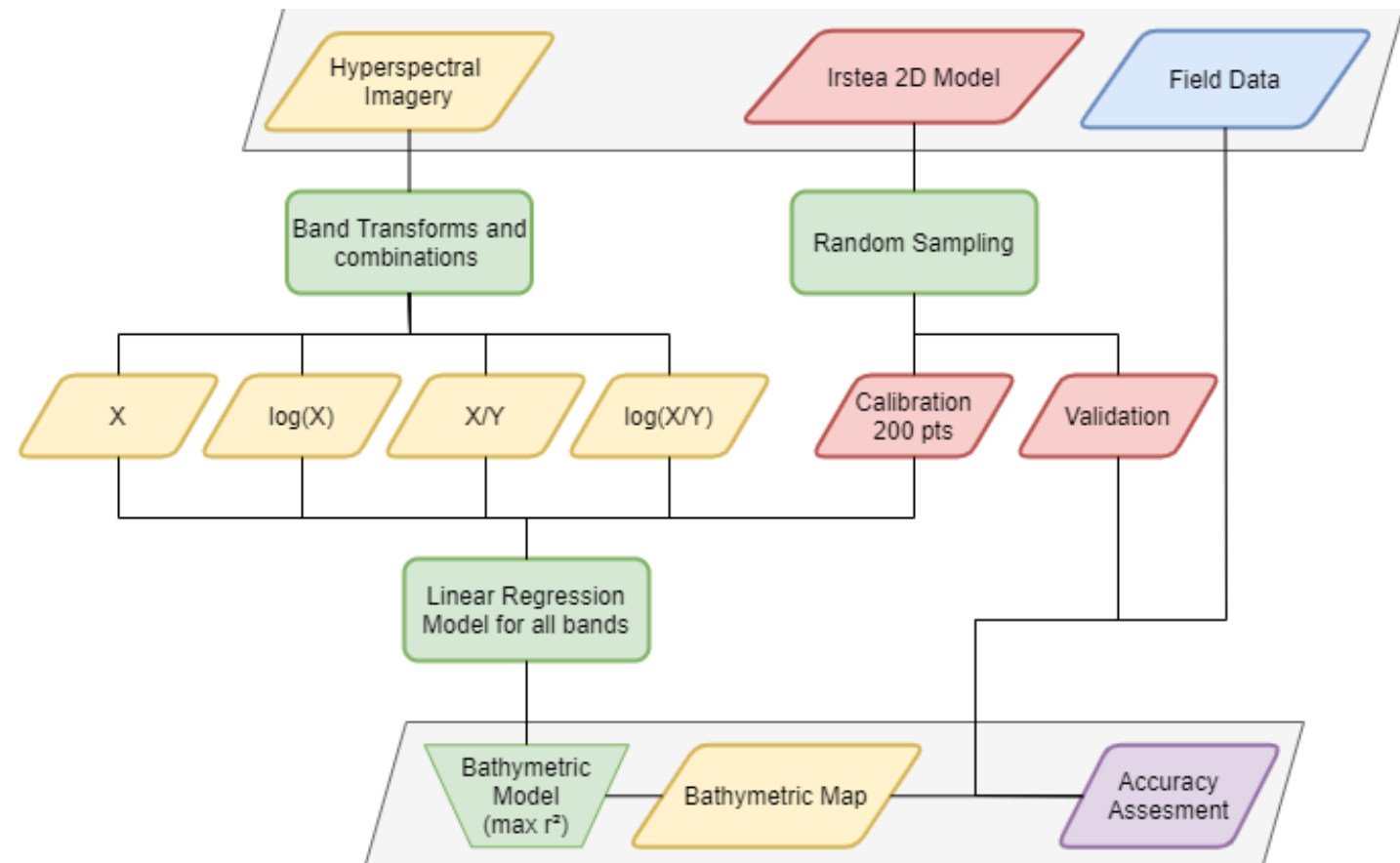
Methodology: correlating spectra to depth

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

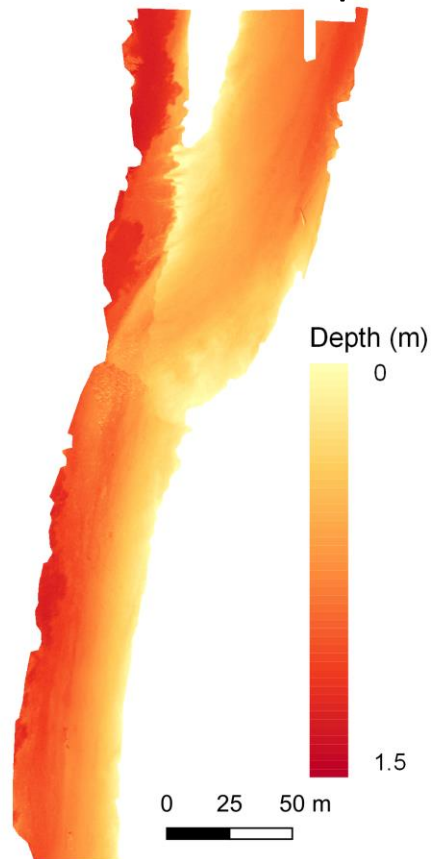
> Models are calibrated on short reaches and assessed for the full extent of the data which is higher for the airplane campaign



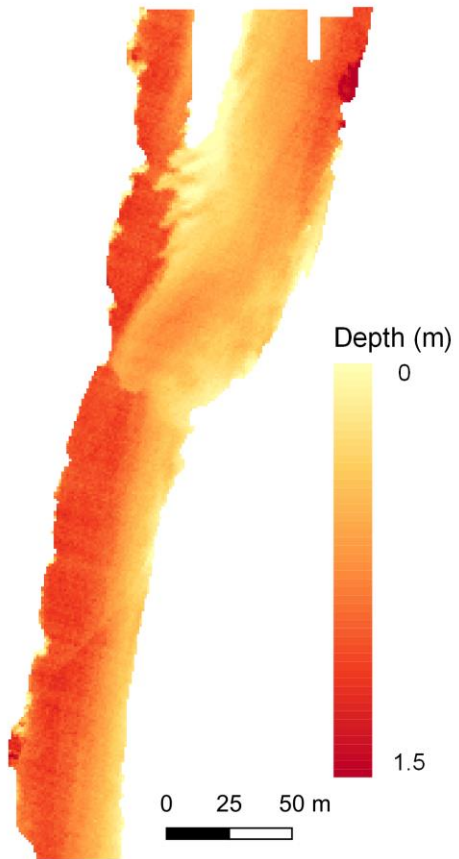
Application: Mapping over large extents

Bathymetric restitution at two reach scales

Water depth in 2015 for 27 m³/s



UAV Campaign
Initial Discharge: 27 m³/s

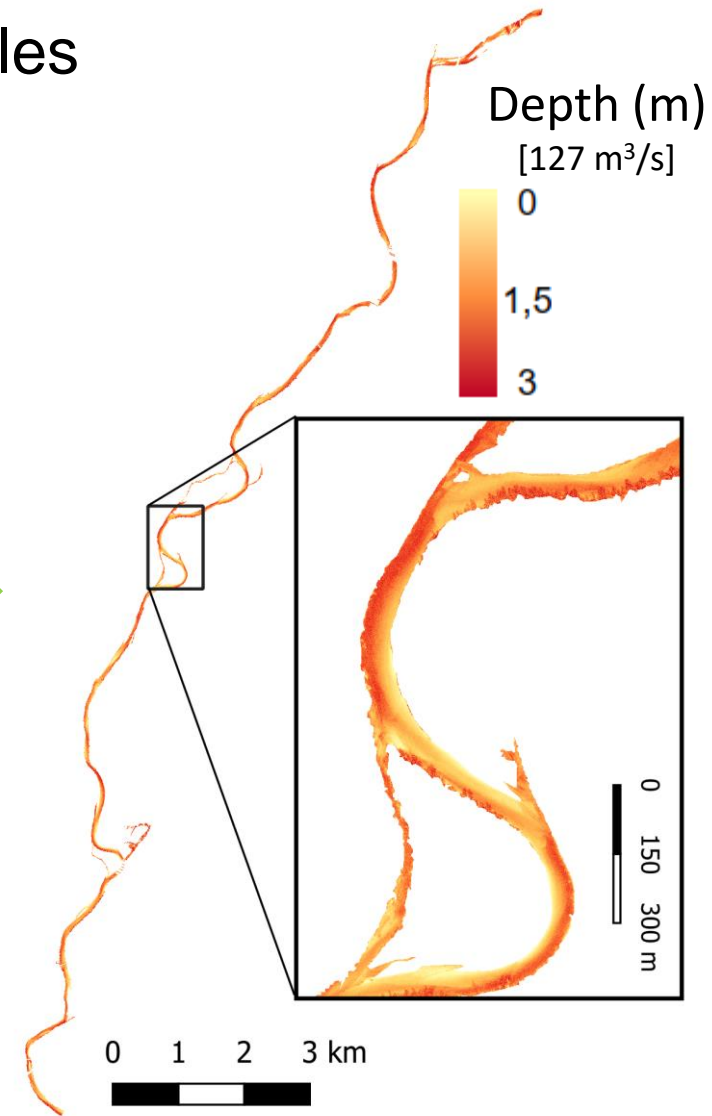


Airplane Campaign
Initial Discharge: 127 m³/s

Accuracy: 10 – 15 cm
Depths up to 2.5 m (127 m³/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 m³/s)
Only band ratios



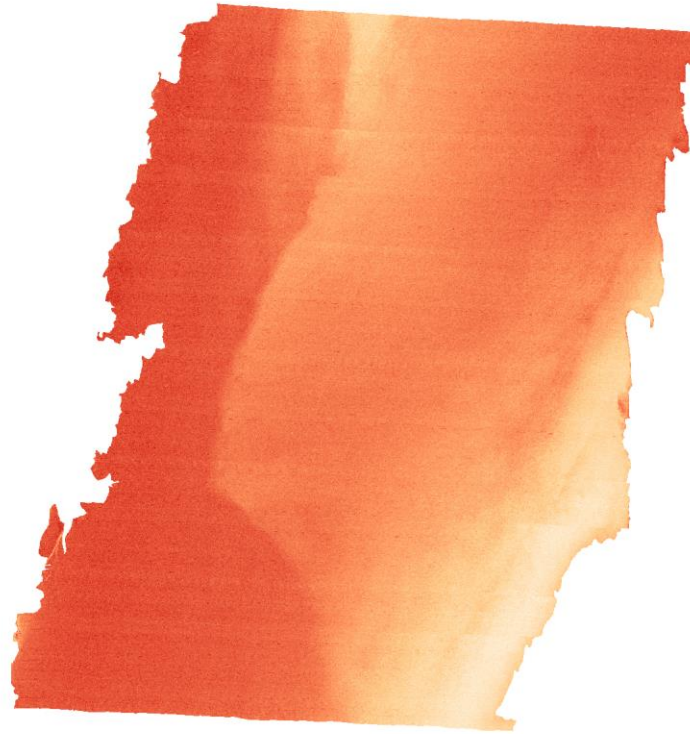
Application: Change monitoring

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

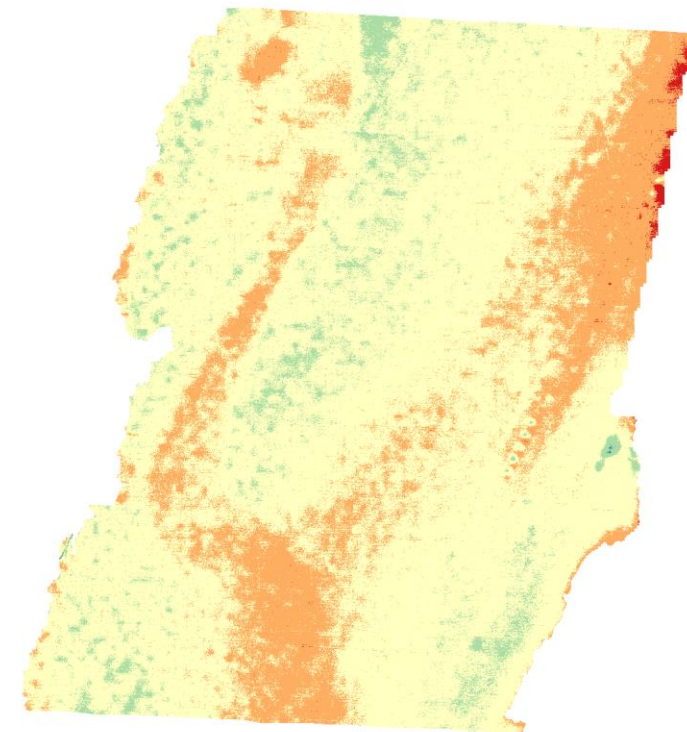
Airplane Campaign (2015)
Resolution: 1 m



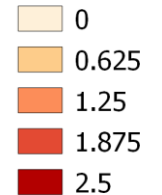
UAV Campaign (2021)
Resolution: 2.5 cm



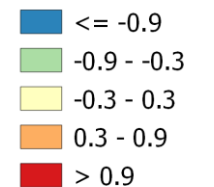
Difference (2021-2015)
Resolution: 2.5 cm



Depth (m)



Differences(m)



0 10 20 m



Limitations: clusters of errors

- Sources of errors :

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

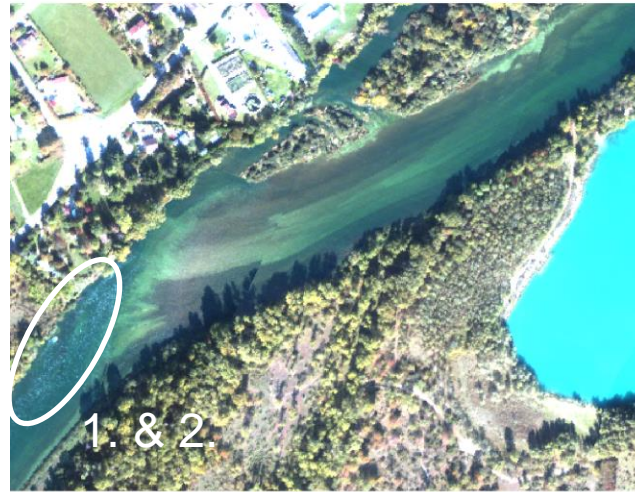
> Poor accuracy in the data for calibration and validation

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

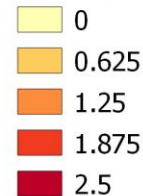


Bathy

1. Bathy - Mean Flow (m)



3. Bathy - Low Flow (m)

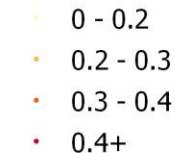


Errors

2. Error - Mean Flow (m)

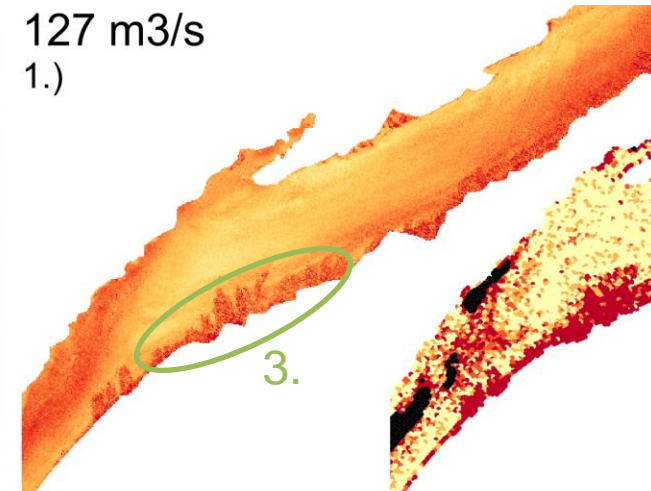


4. Error - Low Flow (m)



127 m³/s

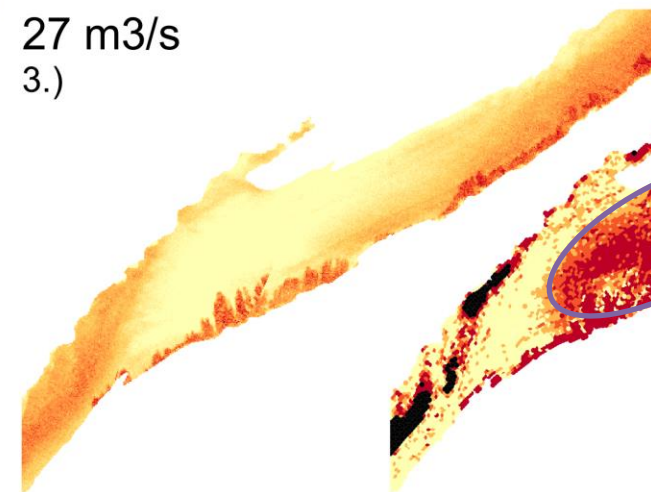
1.)



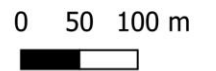
2.)

27 m³/s

3.)



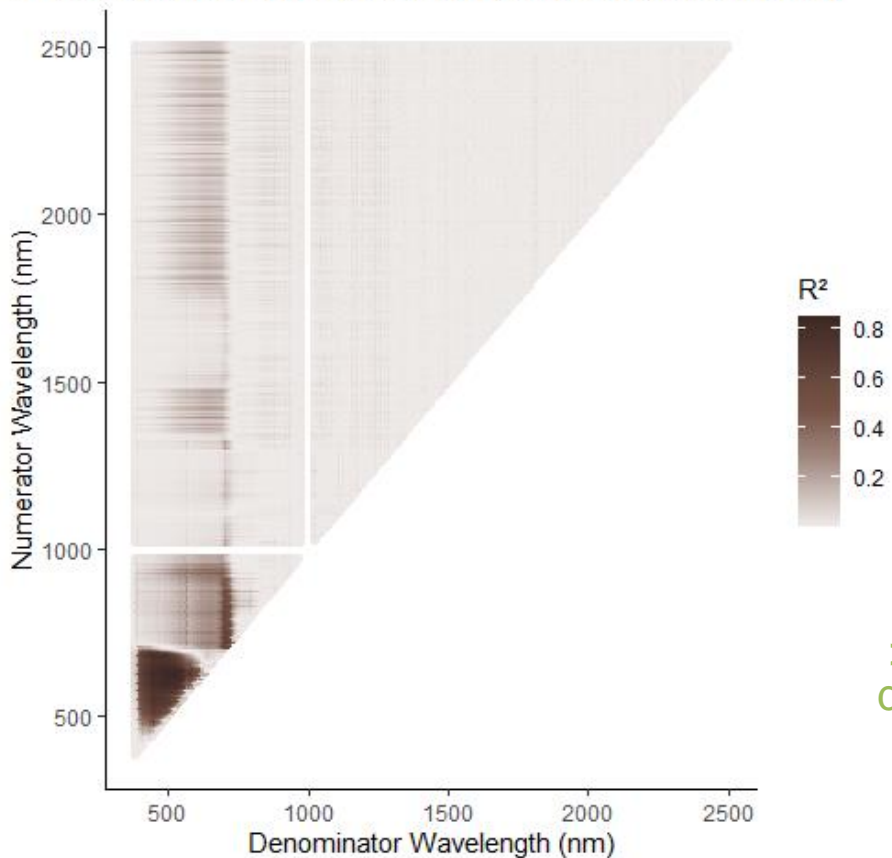
4.)



Limitations: sensitivity to the calibration data

Reach 1 : site of the initial calibration

R² values for Numerator/Denominator as a predictor of bathymetry



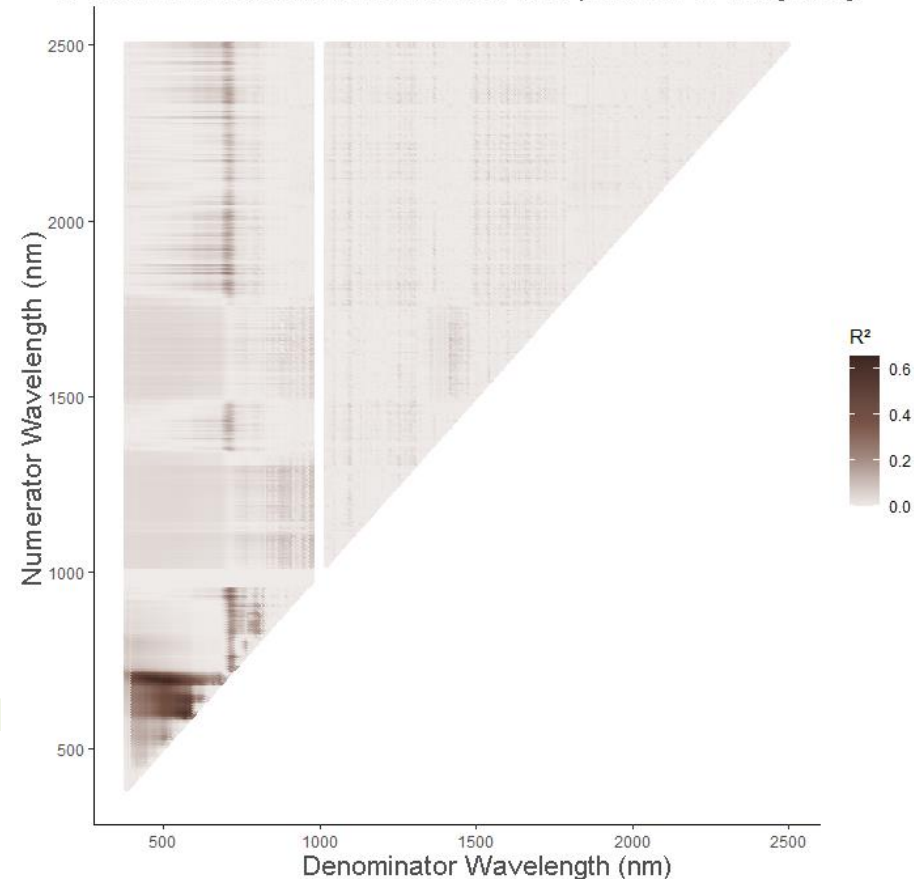
Squared-Root
is reduced

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

R² 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



Thank you for your attention!