Combining hyperspectral and XRF analyses to reconstruct high-resolution past flood frequency from lake sediments

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33722.jpg

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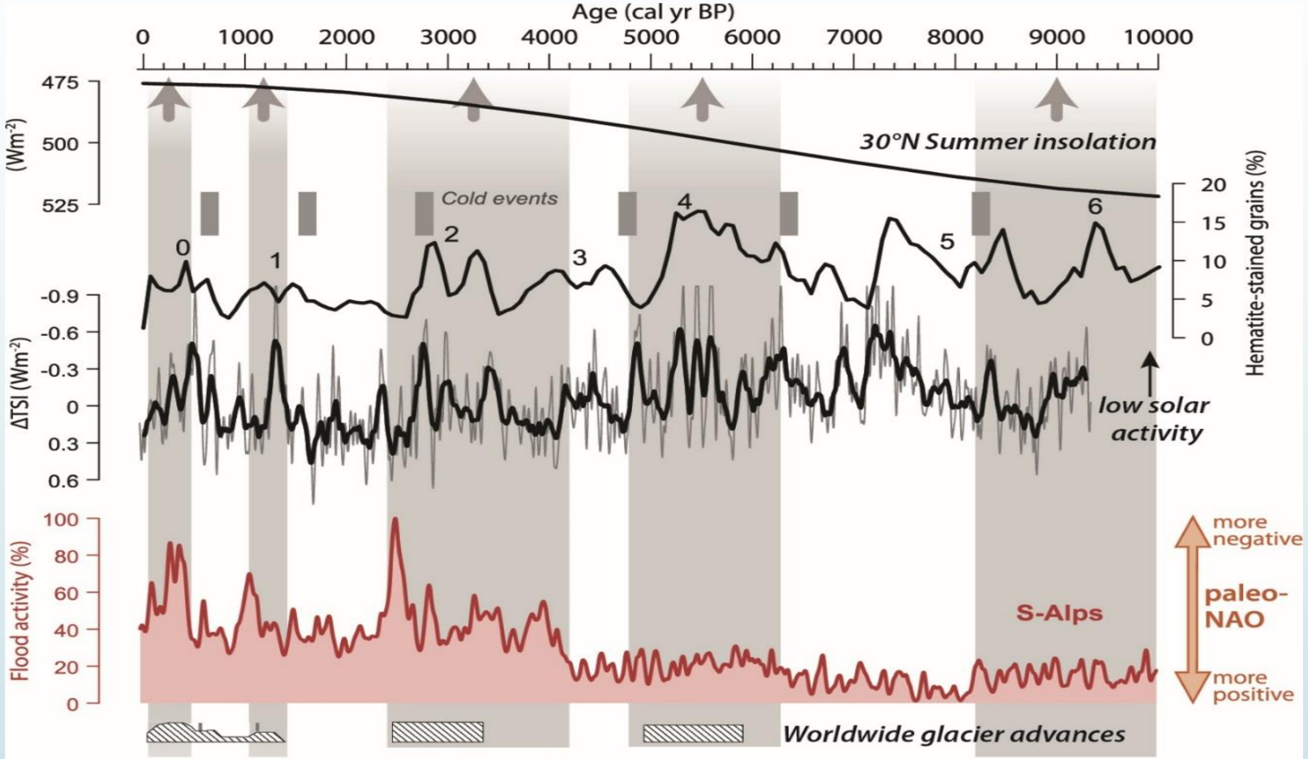
Introduction

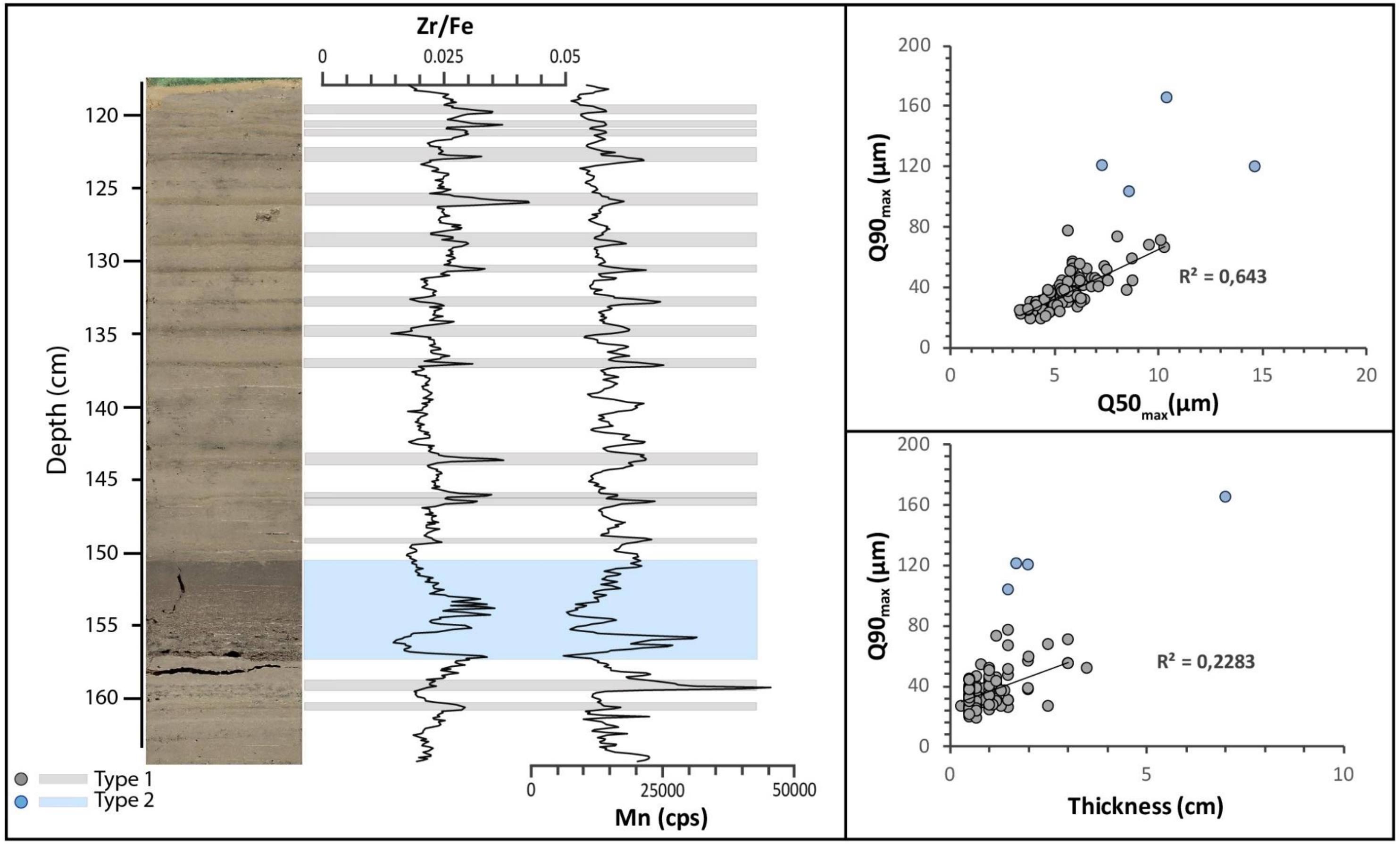
Flood studies



Wirth et al., 2013, QSR

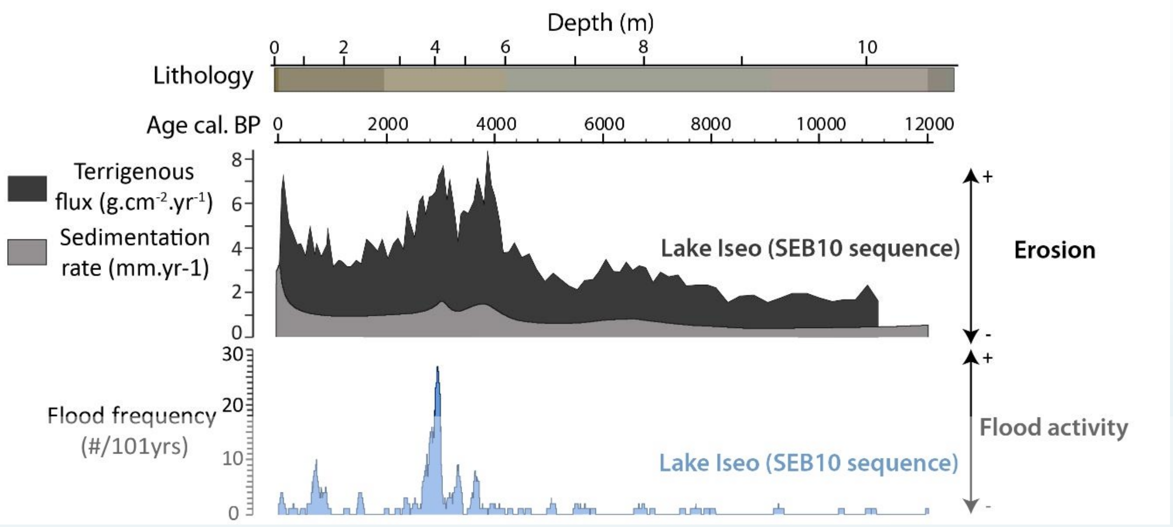
- Flood records from lake sediment could be a **proxy** of **paleo-hydrological variations**
- **Current increase** of the number of studies using flood frequency and magnitude
- Building a flood chronicle is **time consuming**, and currently made using **naked-eye observations**

Flood studies



- T1 deposits = • Turbidite-type • 148 deposits counted from naked-eye observations • mean thickness of 5.8 mm

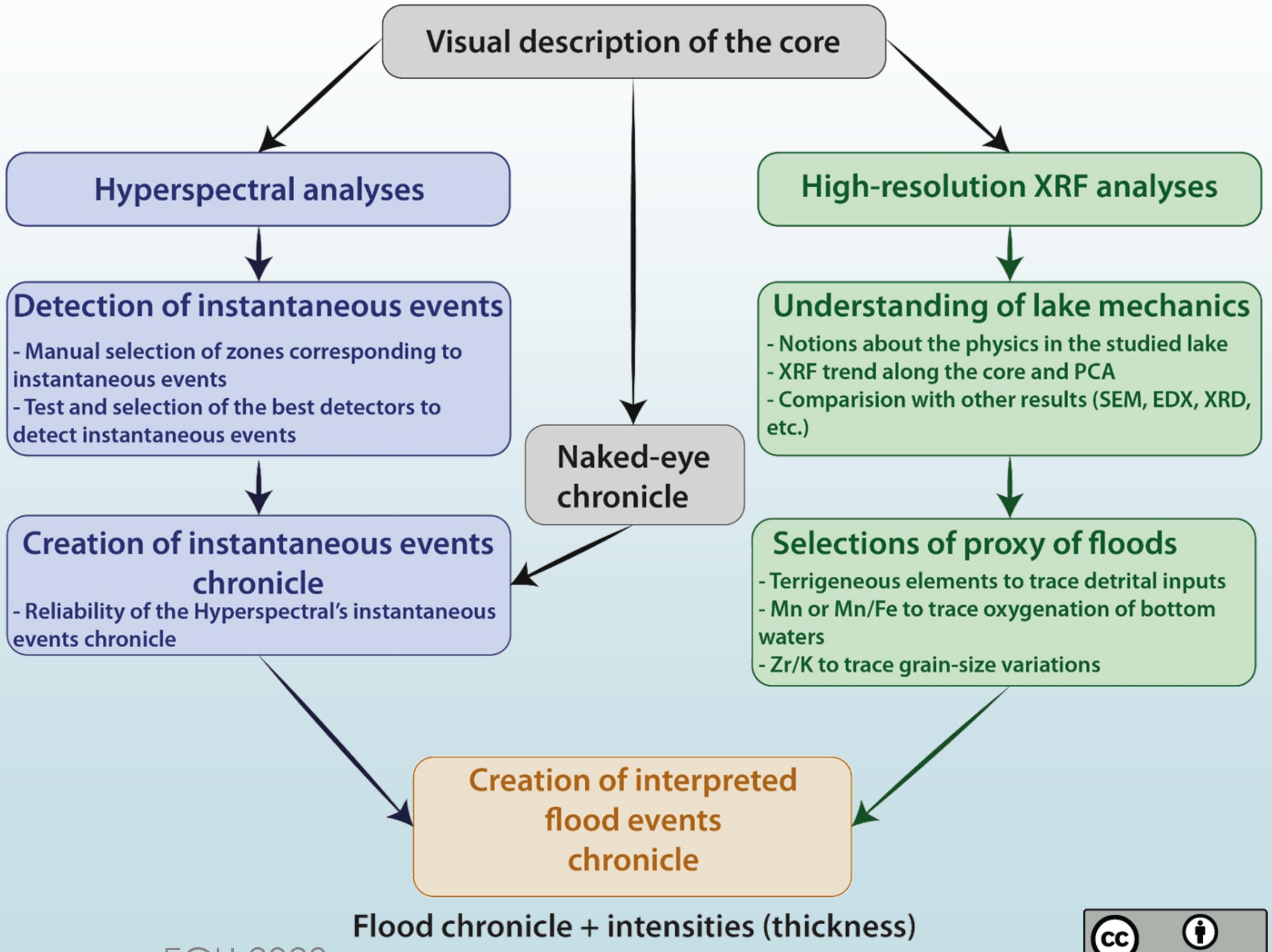
Limitations of the classical methods



1. Destructive analyses
2. Time consuming
3. Low resolution (from naked-eye observations, grain-size, or spectrocolorimetry analyses)
4. Linked to the observer
5. Incertainty on the origin of the deposits (no systematic linked between proxys and turbidites)
6. Hard to detect the upper limit of each instantaneous deposits

Proposed methodology

- Based on two complementary sensors:
  - Visible and Near Infrared hyperspectral sensor: molecular composition
  - X-Ray fluorescence spectroscopy: elementary composition
- Validation with naked-eye observations

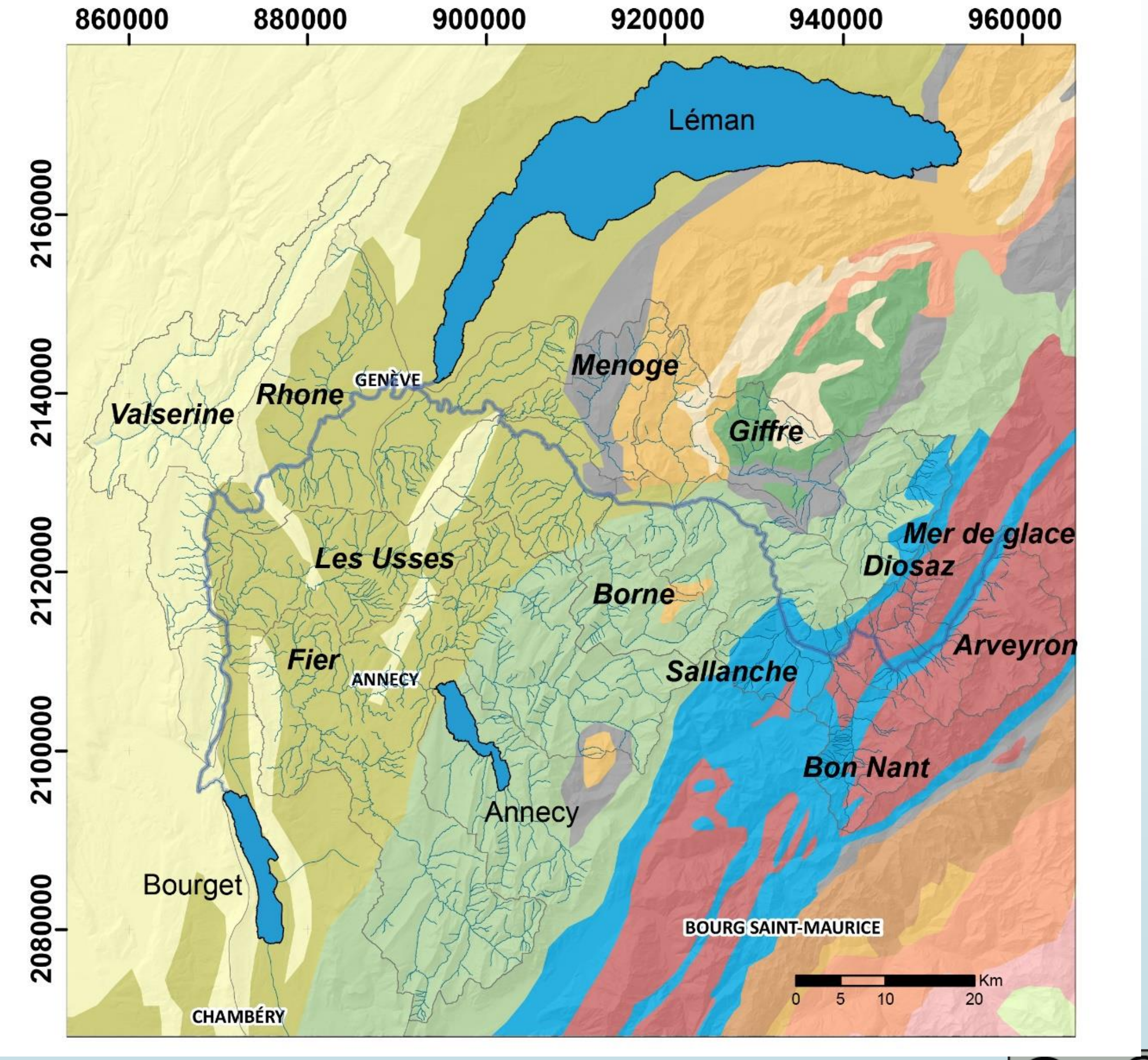


Study site

- **Lake Le Bourget** (*LDB*)
  - Northern French Alps
  - Lenght = 18 km
  - Surface area = 44.5 km²
  - Altitude = 231 m a.s.l
  - Main tributary = Rhône

Geology

- Zone de schistes lustrés piémontais
- "Nappe de la Brèche" et "Piémontais externe"
- Nappes de Flyschs à helminthoïdes
- Domaine externe (à soubassement houiller)
- Domaine interne (à socle cristallins)
- Zone subbriançonaise et préalpes médiane "plastiques"
- Zone valaisane
- Zone ultra-dauphinoise et ultra-helvétique
- Zone dauphinoise
- Massifs cristallins externes
- Massifs subalpins domaine vocontien au Crétacé
- Zone molassique péri-alpine
- Chainons jurassiens



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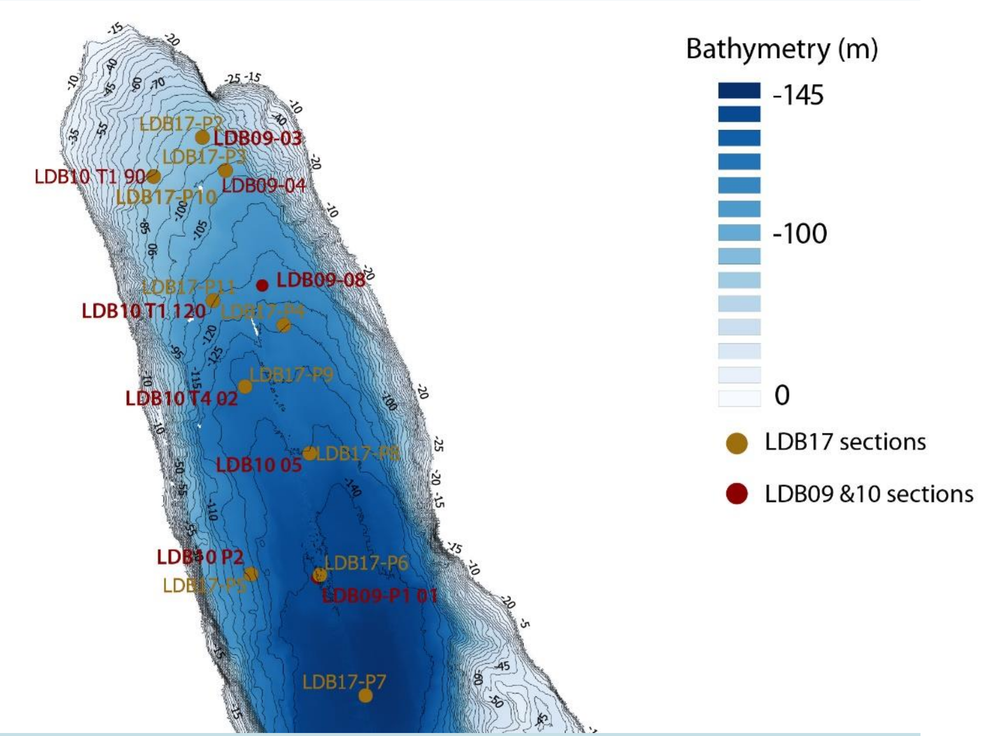
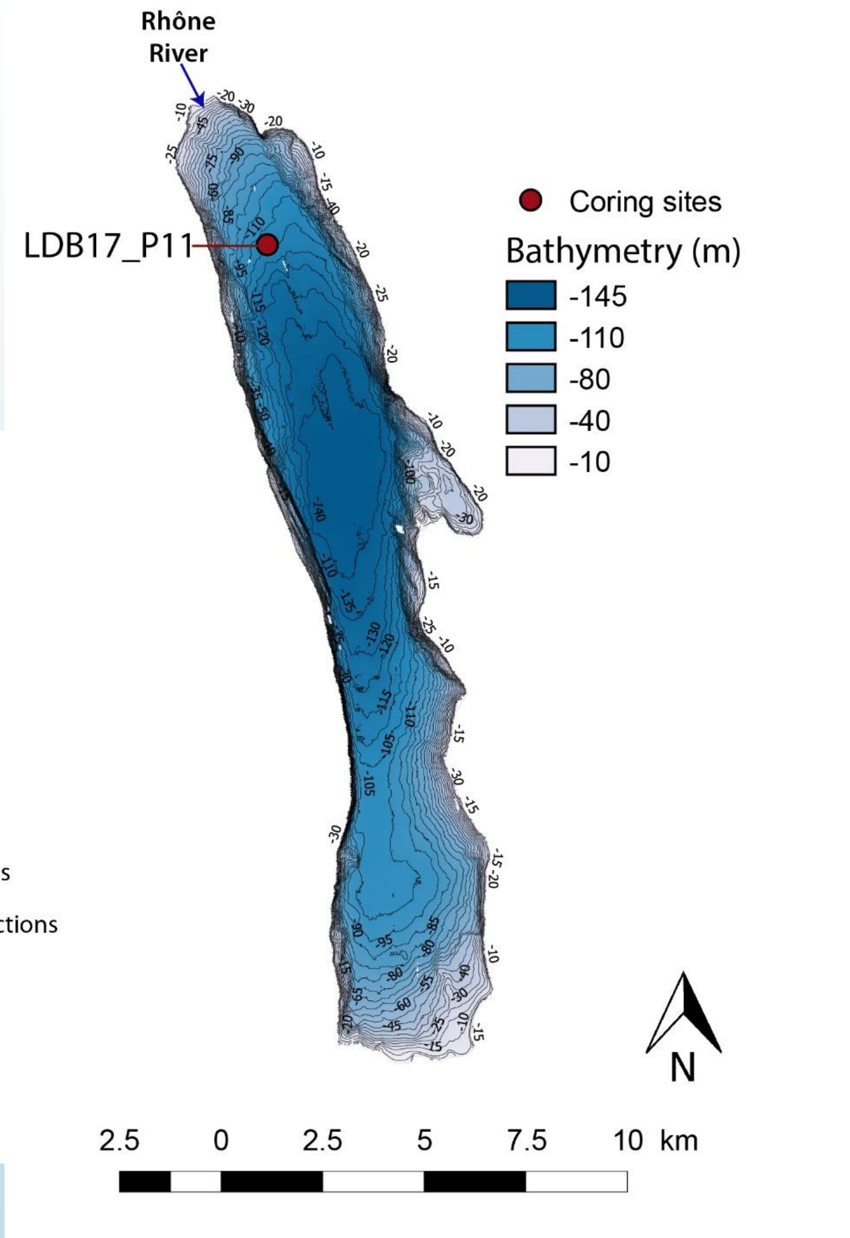
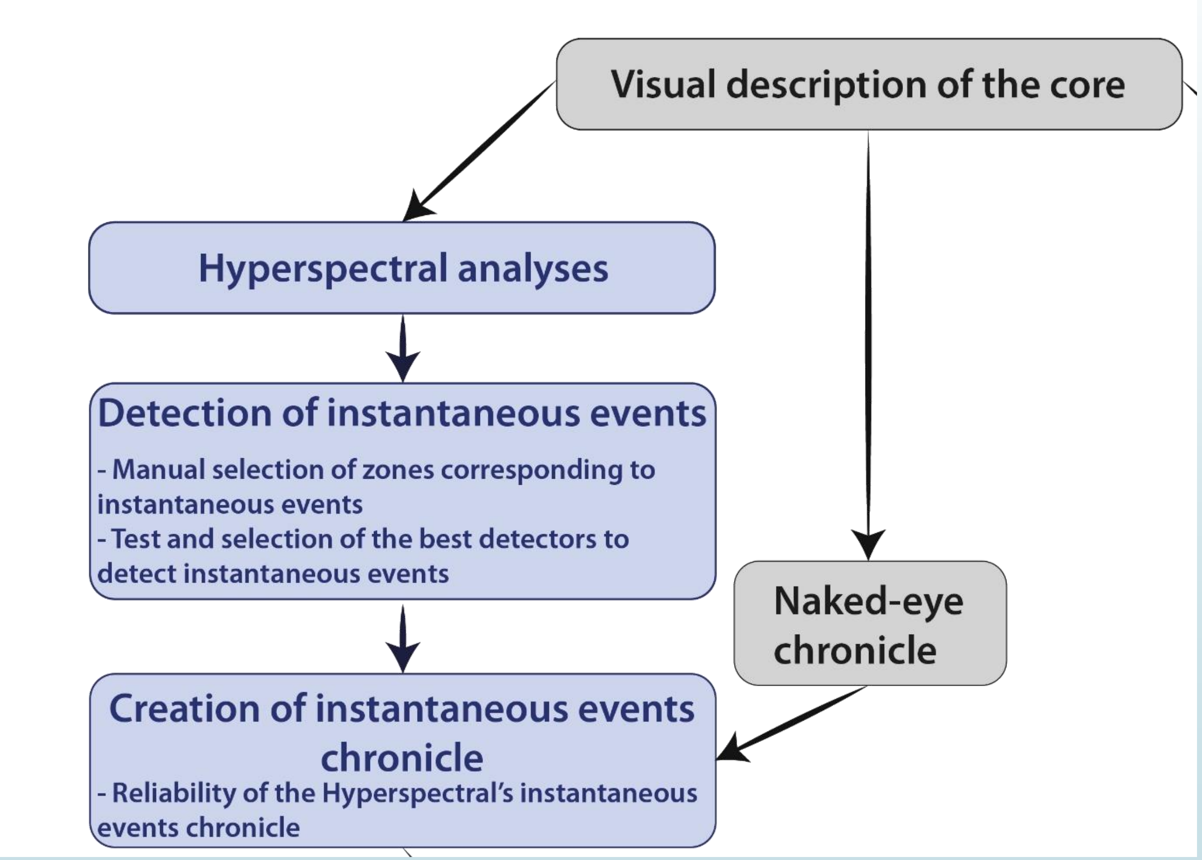




Hyperspectral methodology

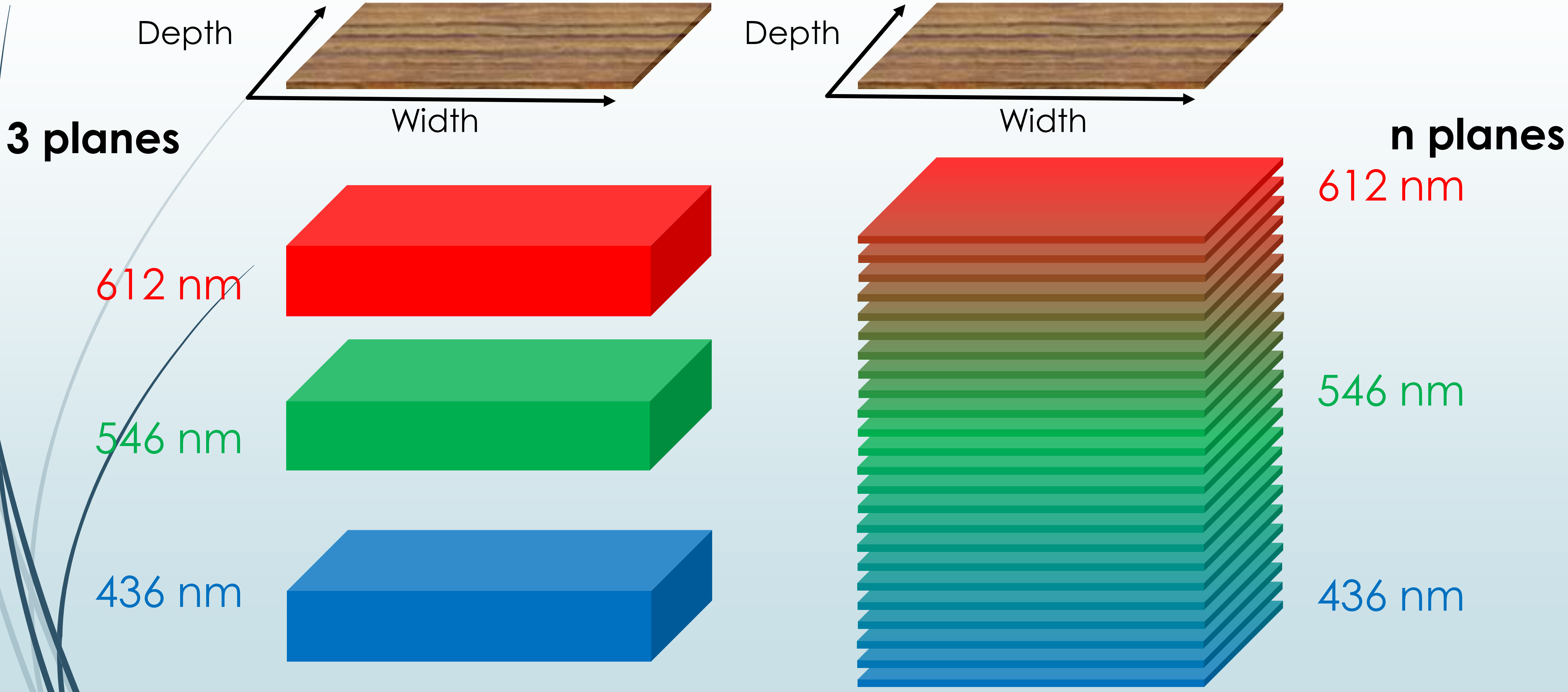


Classical RGB imaging

3 planes

CIE, 1999. IEC 61966-2-1:1999: Multimedia systems and equipment - Colour measurement and management – Part 2-1 : Colour management - Default RGB colour space - sRGB.

Hyperspectral imaging

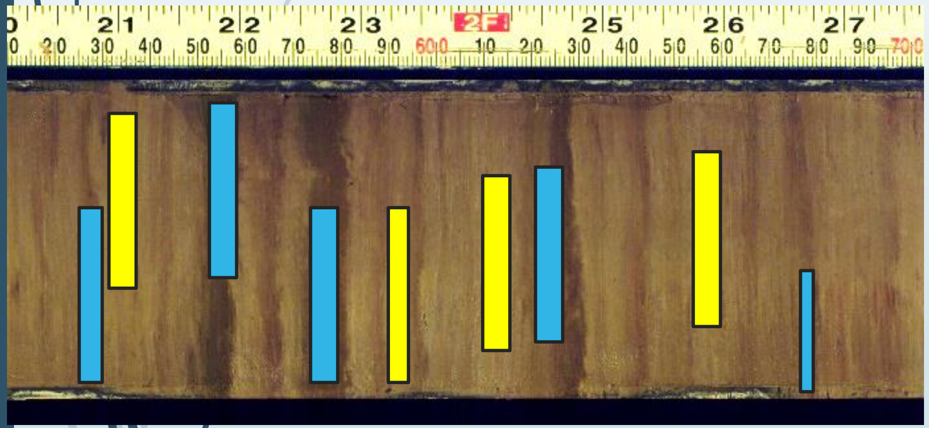


Hyperspectral sensor properties

- 2 hyperspectral sensors:
  - Visible and Near-Infrared (VNIR)
    - Spectral range: 400-1000 nm (resolution 12 nm)
    - Spatial resolution: 60 µm
    - Some chemical information registered: colorful oxydes, pigments
  - Short Wave-Infrared (SWIR)
    - Spectral range: 1000-2500 nm (resolution 6 nm)
    - Spatial resolution: 200 µm
    - Some chemical information registered: organic matter, hydrocarbons, mineral compounds, moisture

Machine learning for events classification

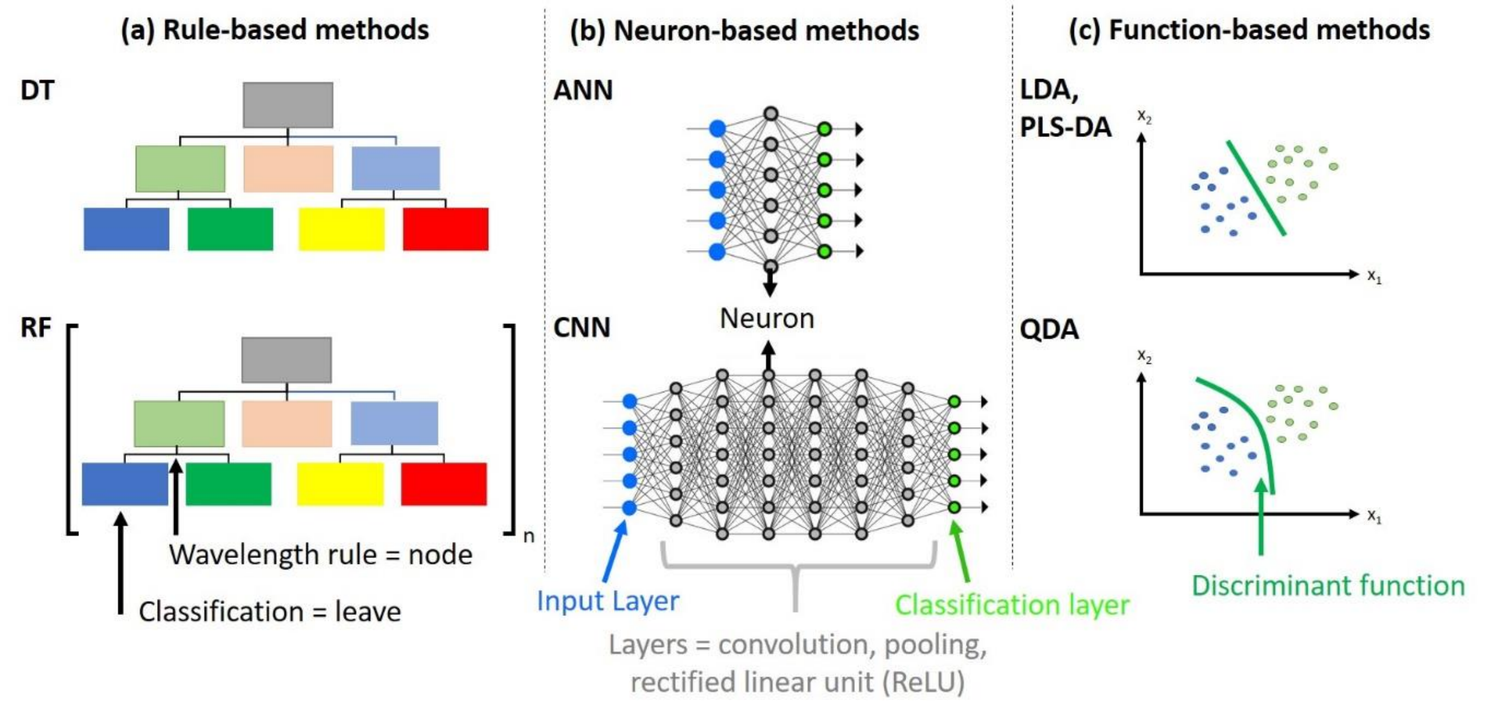
1. Events labelling
   - Continuous sedimentation
   - Instantaneous events



Jacq, K. et al. Supervised classification modeling for the automatic and high-resolution detection of instantaneous deposits on several sediment cores with hyperspectral imaging (work in progress)

Machine learning for events classification

1. Events labelling
2. Machine learning model estimation



Decision tree (DT)
Random forest (RF)

Artificial Neural Network (ANN)
Convolutional Neural Network (CNN)

Linear Discriminant Analysis (LDA)
Quadratic Discriminant Analysis (QDA)
Partial Least Squares Discriminant Analysis (PLS-DA)

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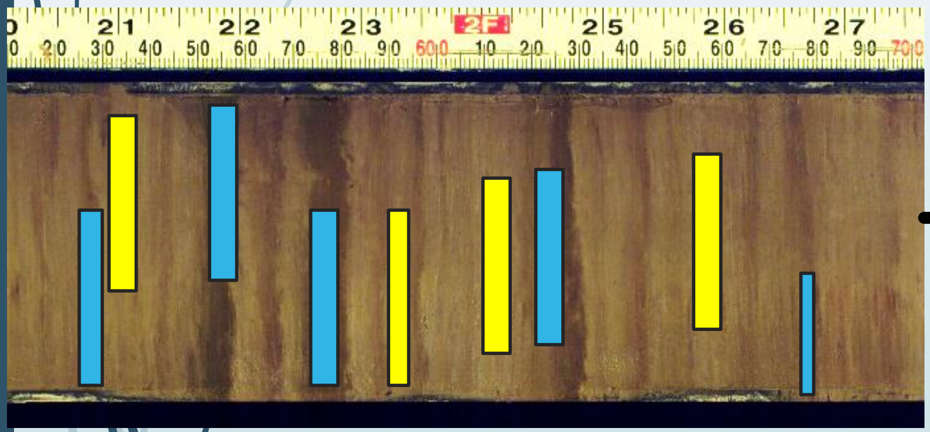
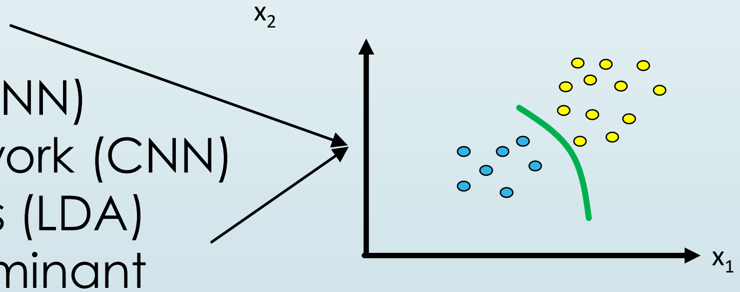


Machine learning algorithms:

- Decision tree (DT)
- Random forest (RF)
- Artificial Neural Network (ANN)
- Convolutional Neural Network (CNN)
- Linear Discriminant Analysis (LDA)
- Partial Least Squares Discriminant Analysis (PLS-DA)



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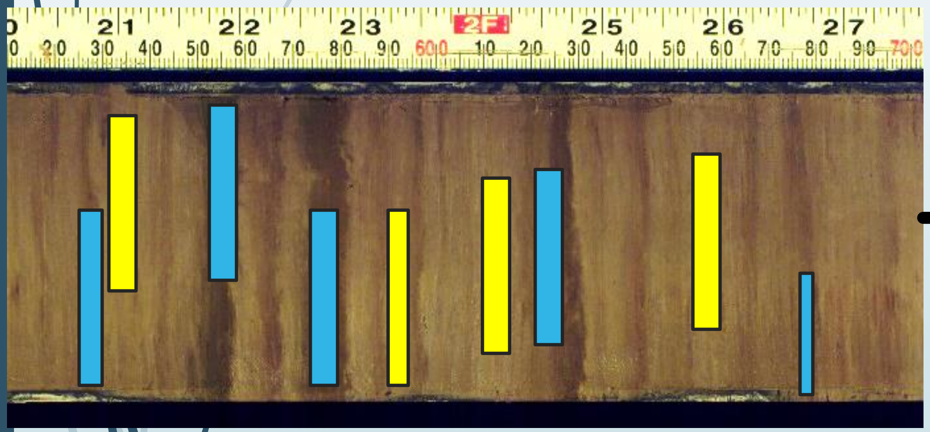
Machine learning for events classification

1. Events labelling
2. Machine learning model estimation
3. Model use on all the pixel of the hyperspectral image



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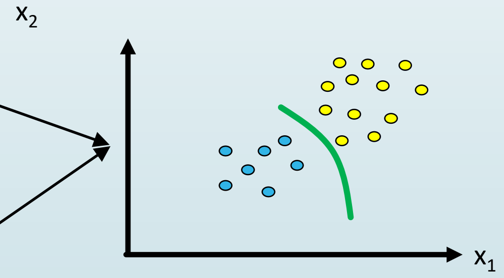

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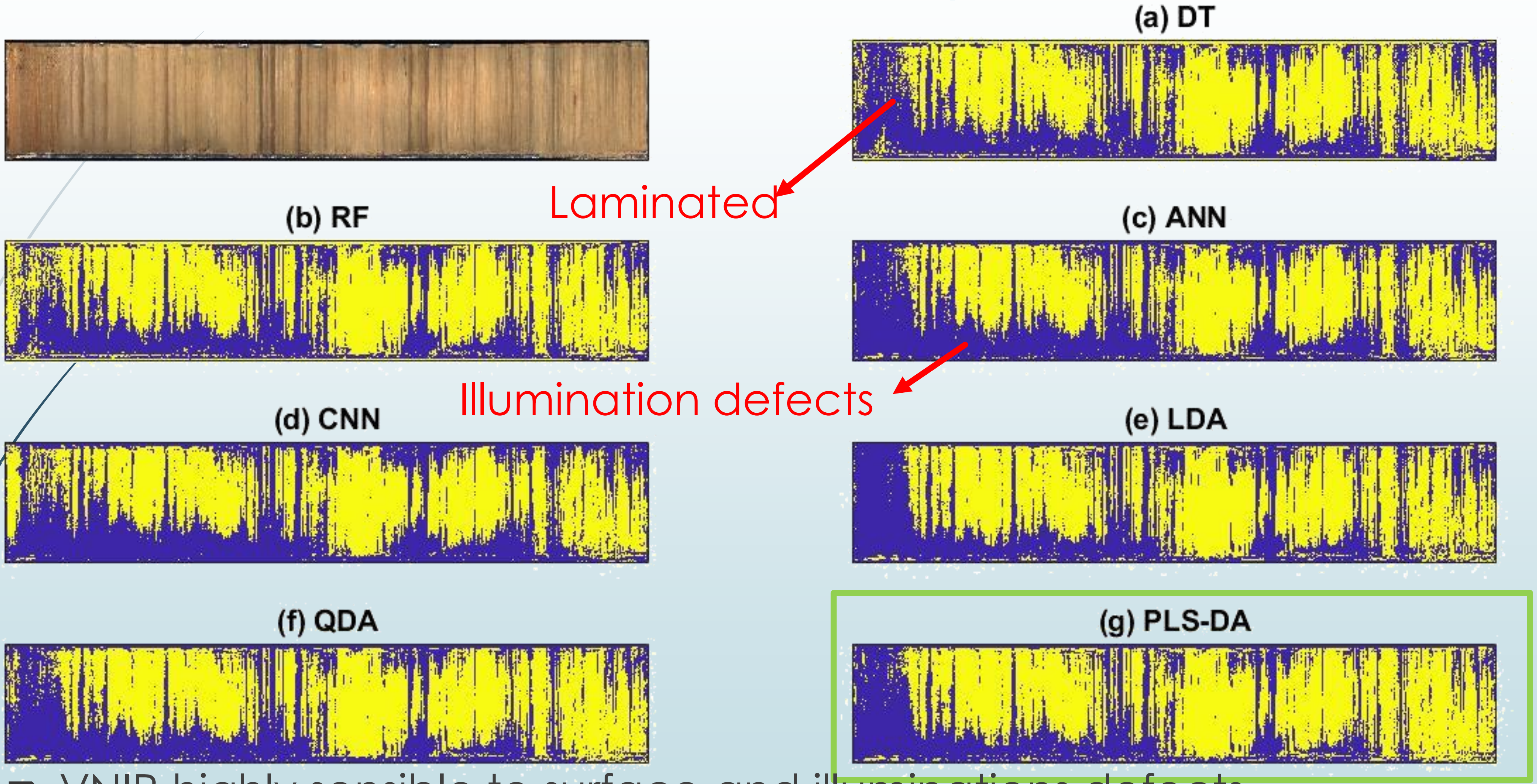
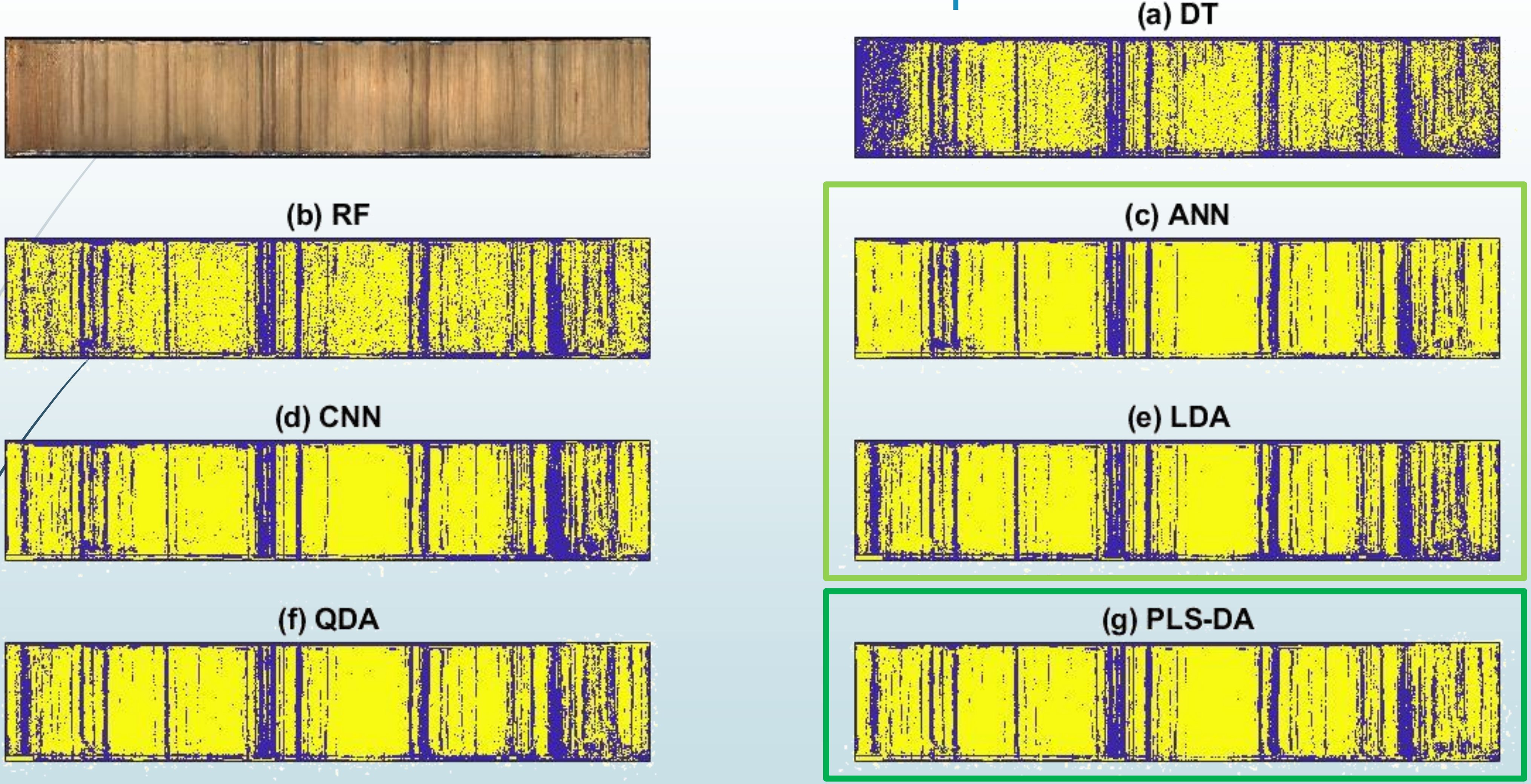
VNIR classification maps



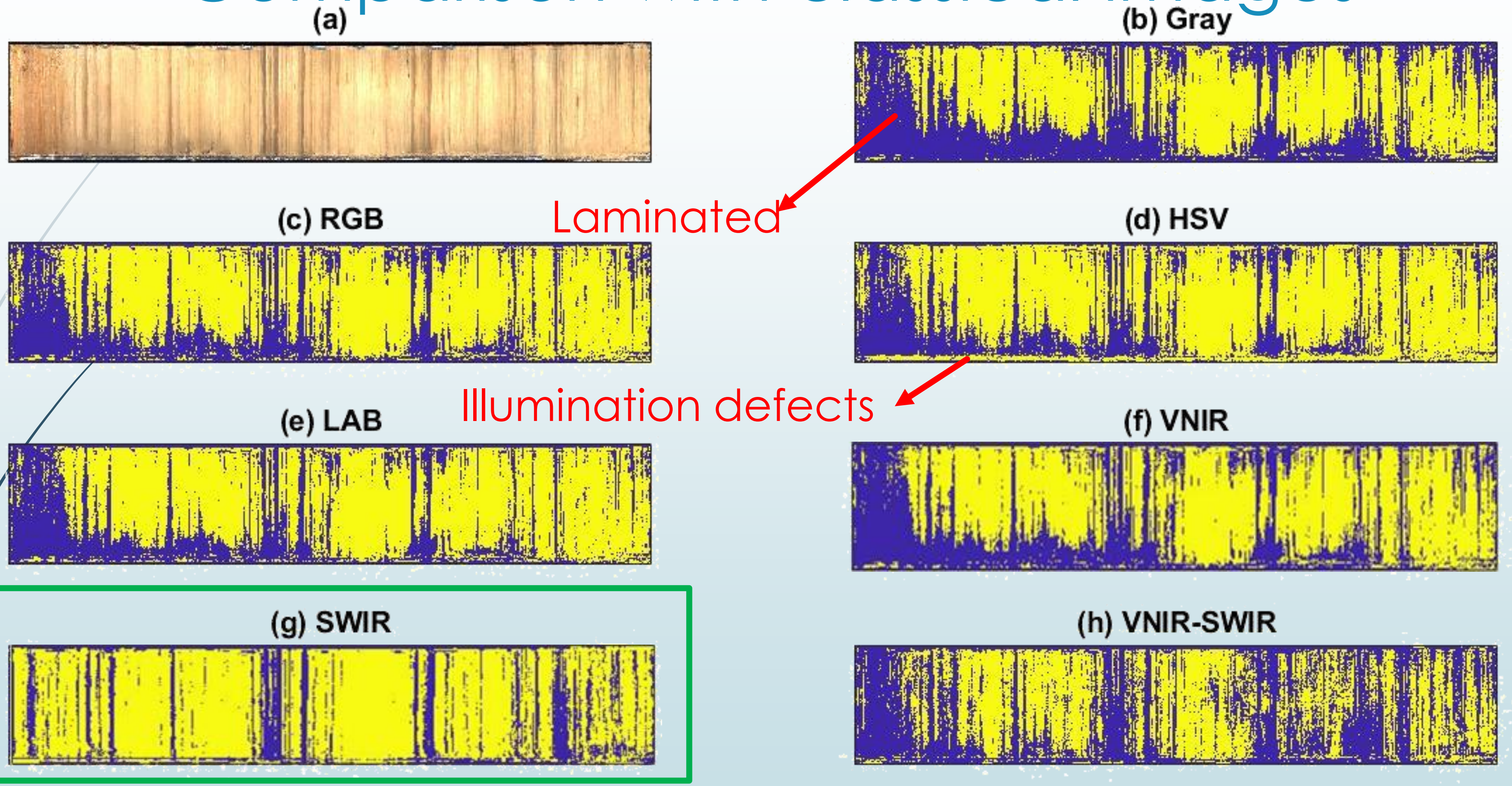
- VNIR highly sensible to surface and illuminations defects
- Misclassication with non-learning deposits (laminae)

SWIR classification maps



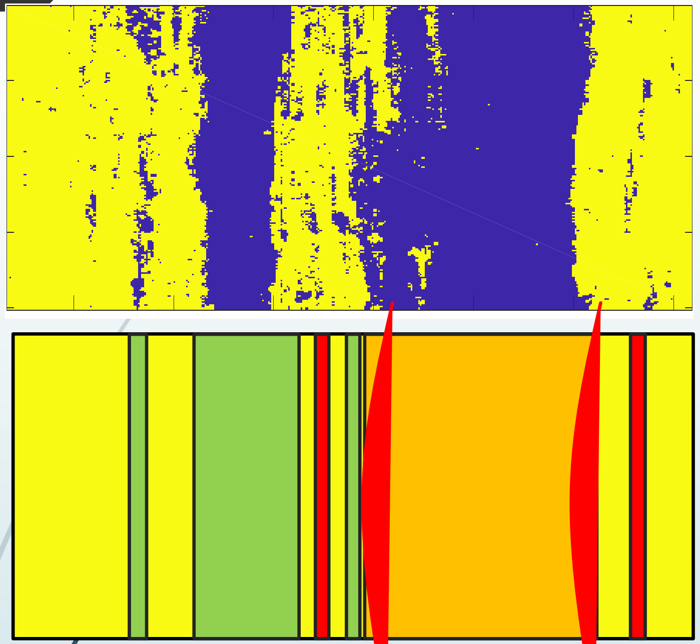
- SWIR not sensitive to the previous defects

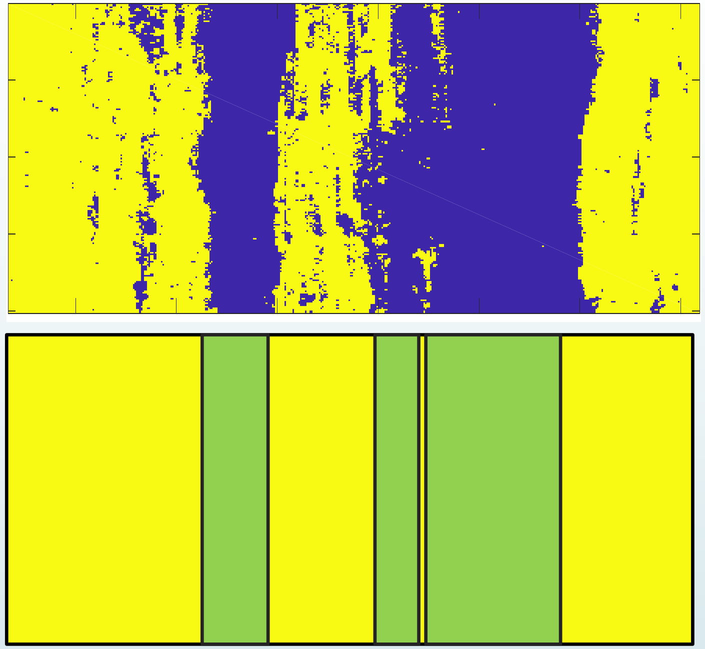
Comparison with classical images

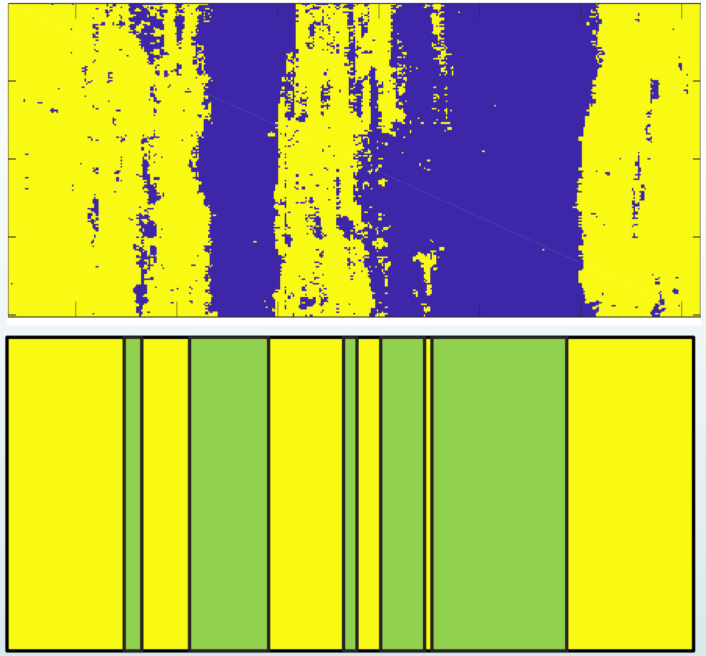


➨ **Optimal model : SWIR + PLS-DA**

Estimation of the HSI chronicle (thresholds)







Thin (<50%):

- ✓ Thin deposits
- × Artifacts / misclassifications
- × Wrong limits :
  - × Combination of close deposits
  - × Due to the curvature of the deposit

Large (>50%):

- ✓ Artifacts / misclassifications
- × Thin deposits
- ~ Wrong limits due to the curvature of the deposit

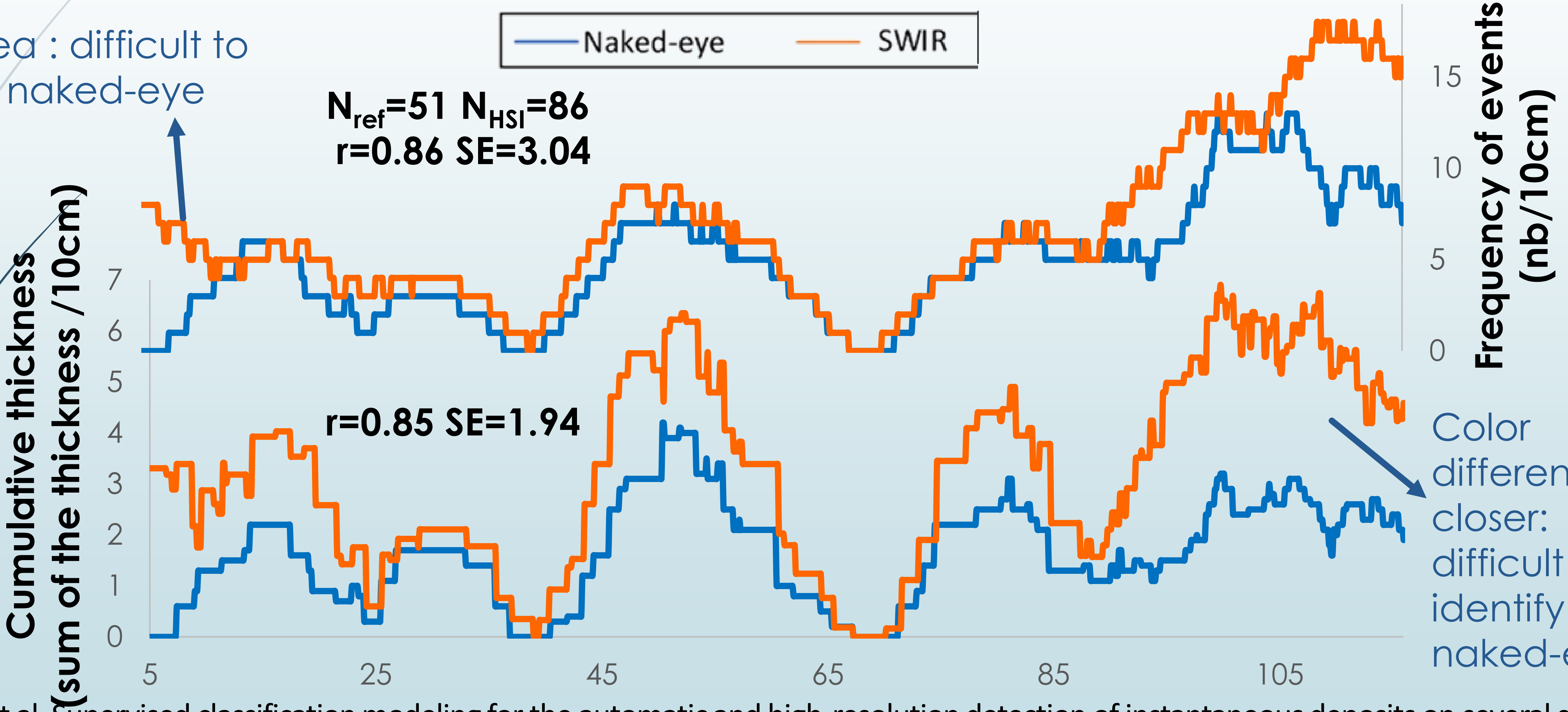
1) Average (50%),
2) Large (>50%) for large ones:

- ✓ Thin deposits
- ✓ Artifacts / misclassifications
- ~ Wrong limits due to the curvature of the deposit

Comparison of the chronicles

- **Flood** naked-eye vs HSI **instantaneous event** chronicles

Lamina area : difficult to studied by naked-eye



Color differences closer: difficult to identify by naked-eye

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Complementary information

- Matlab codes will be available soon
- Spectral preprocessing need to be used to reduce noise and highlight discriminant information
- Conclusions on the use of the methodology on several cores:
  - SWIR sensor has higher discriminant capacities, but not enough to characterize instantaneous event types
  - VNIR sensor sensible to surface defects and illumination
  - Models are site-specific

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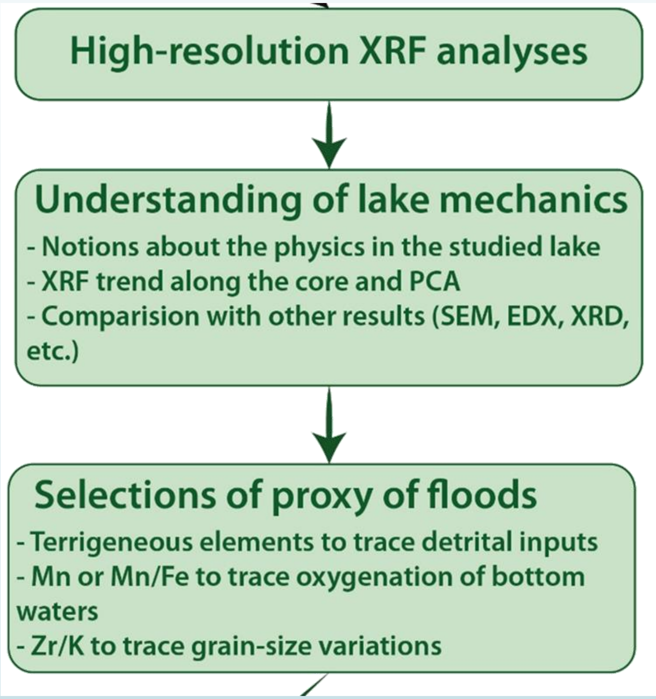
X-Ray fluorescence methodology

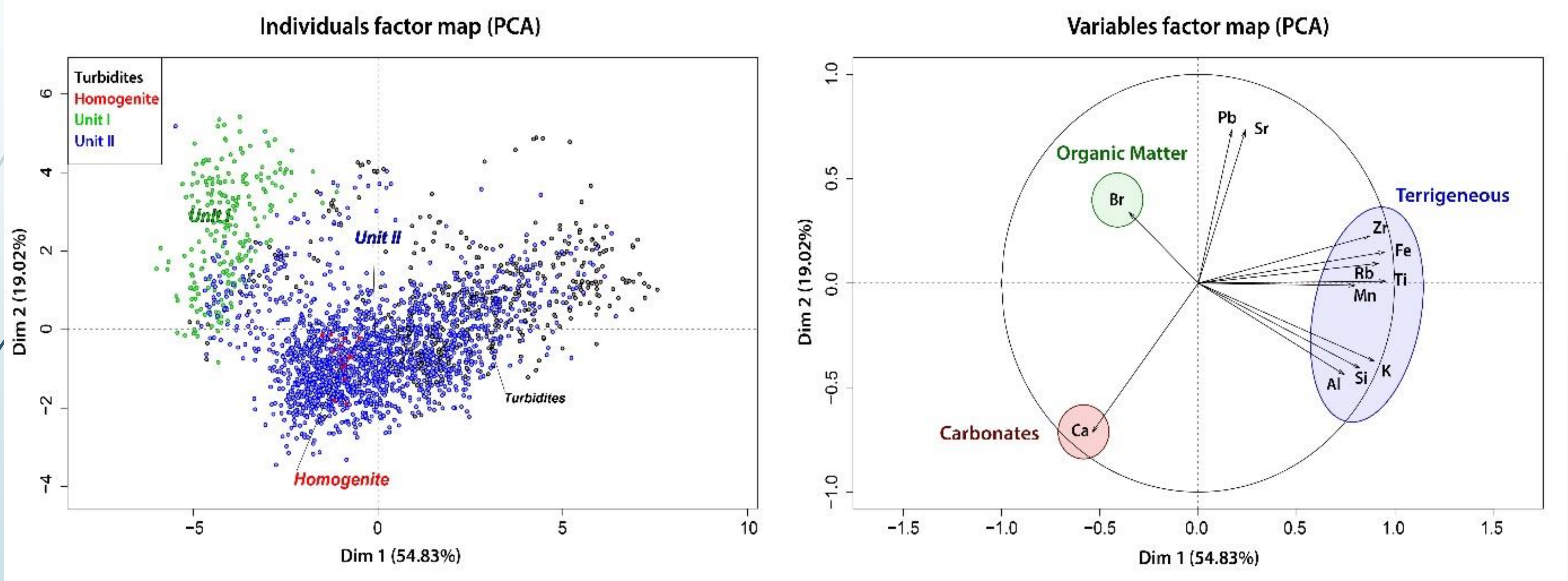


X-Ray fluorescence properties

- Avaatech core scanner
  - Spatial resolution: 500 µm
  - Two runs:
    - 10 kV and 0.25 mA for 20 s to detect lightweight elements
    - 30 kV and 0.4 mA for 20 s
  - Registration of the chemical éléments

Selection of flood proxies

- From XRF and SEM+EDX



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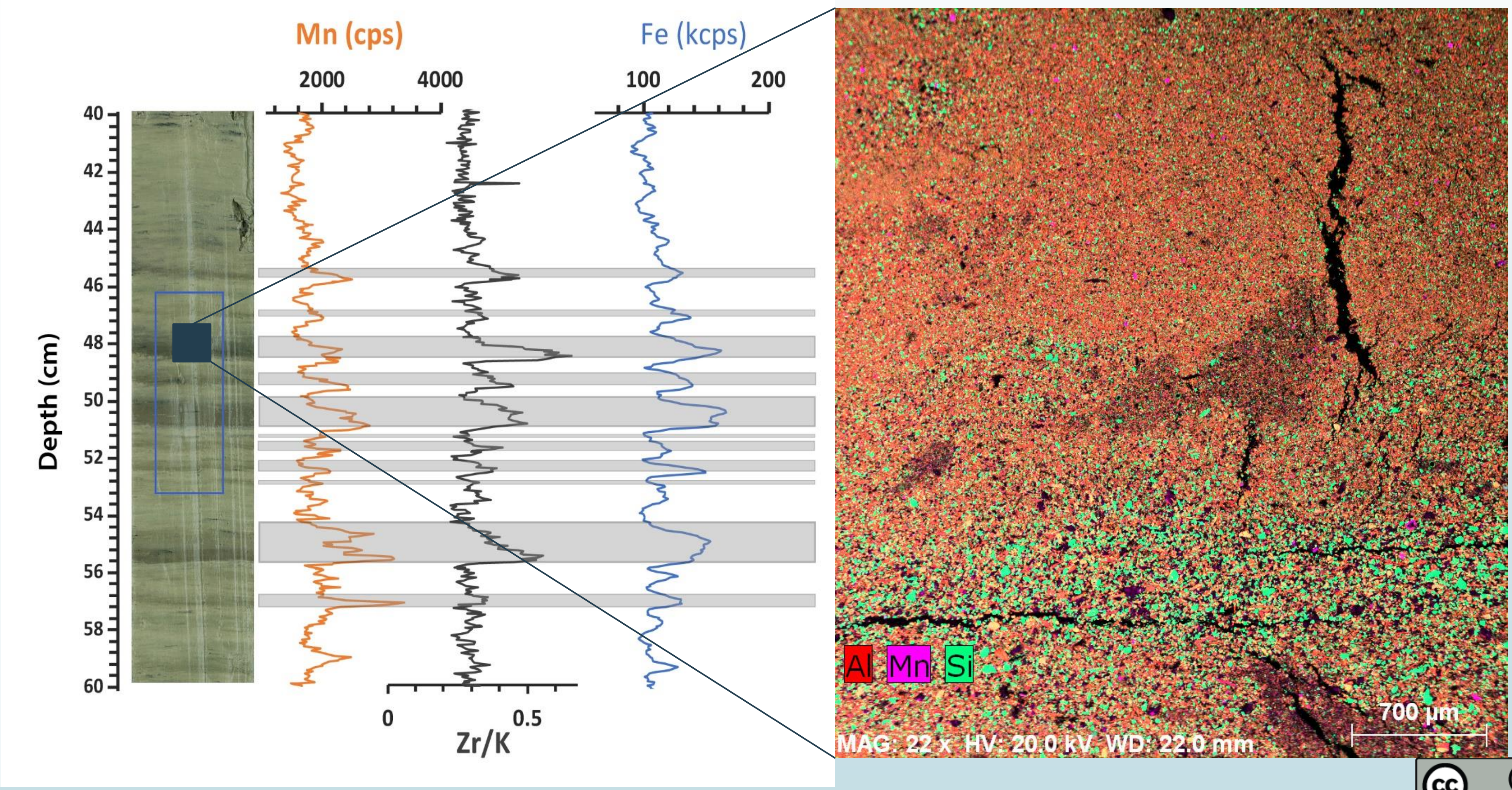
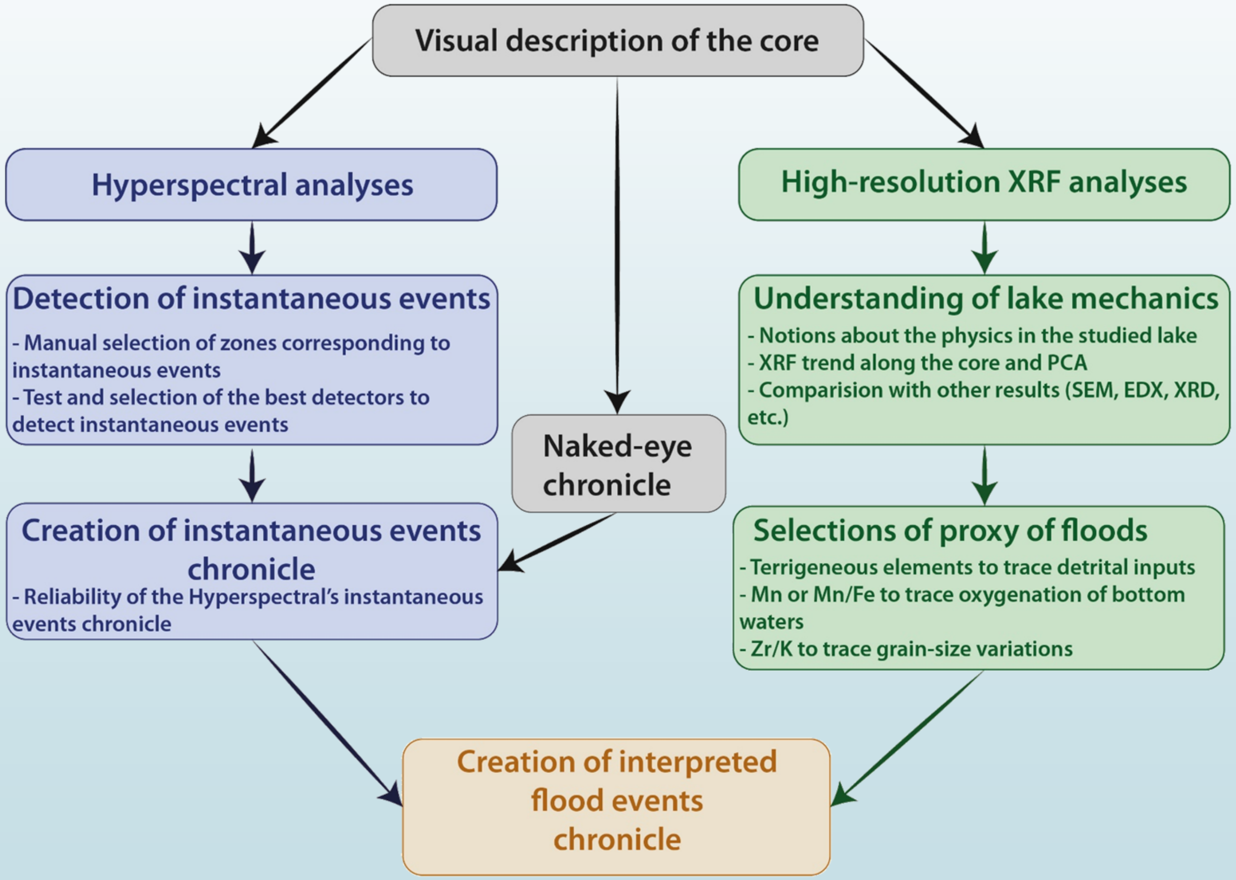


Selection of flood proxies

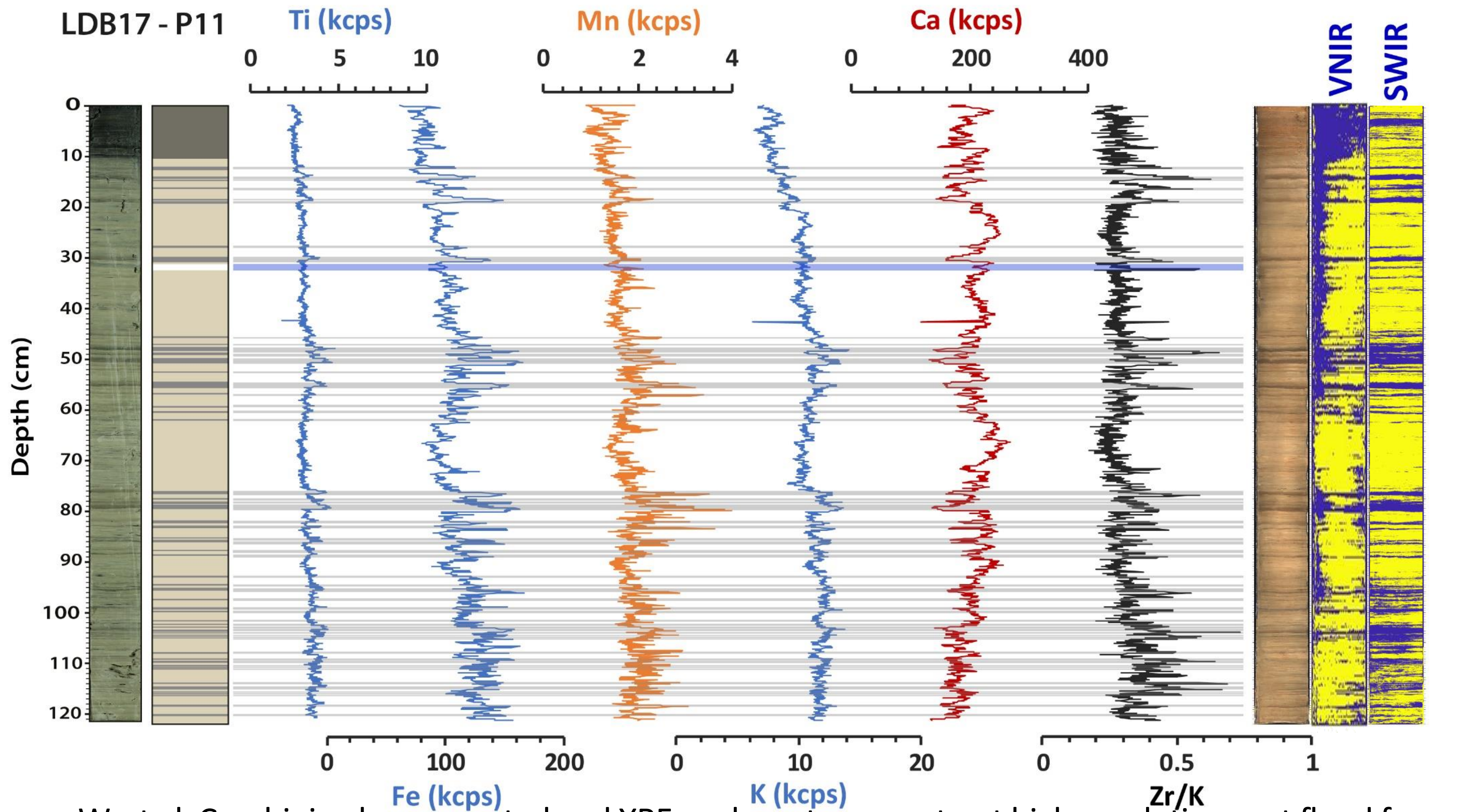
- Mn : proxy of oxygenation of the water at the sediment interface
- Ti : proxy of terrigenous input of the river
- Mn+Ti : flood origin bringing terrigenous particles and well oxygenated water to the water's-sediment interface

Combining hyperspectral and XRF analyses



Flood chronicle + intensities (thickness)

Proxies comparison



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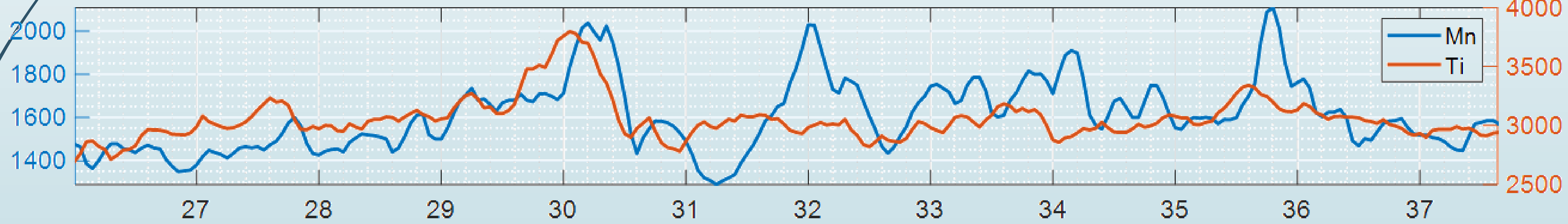
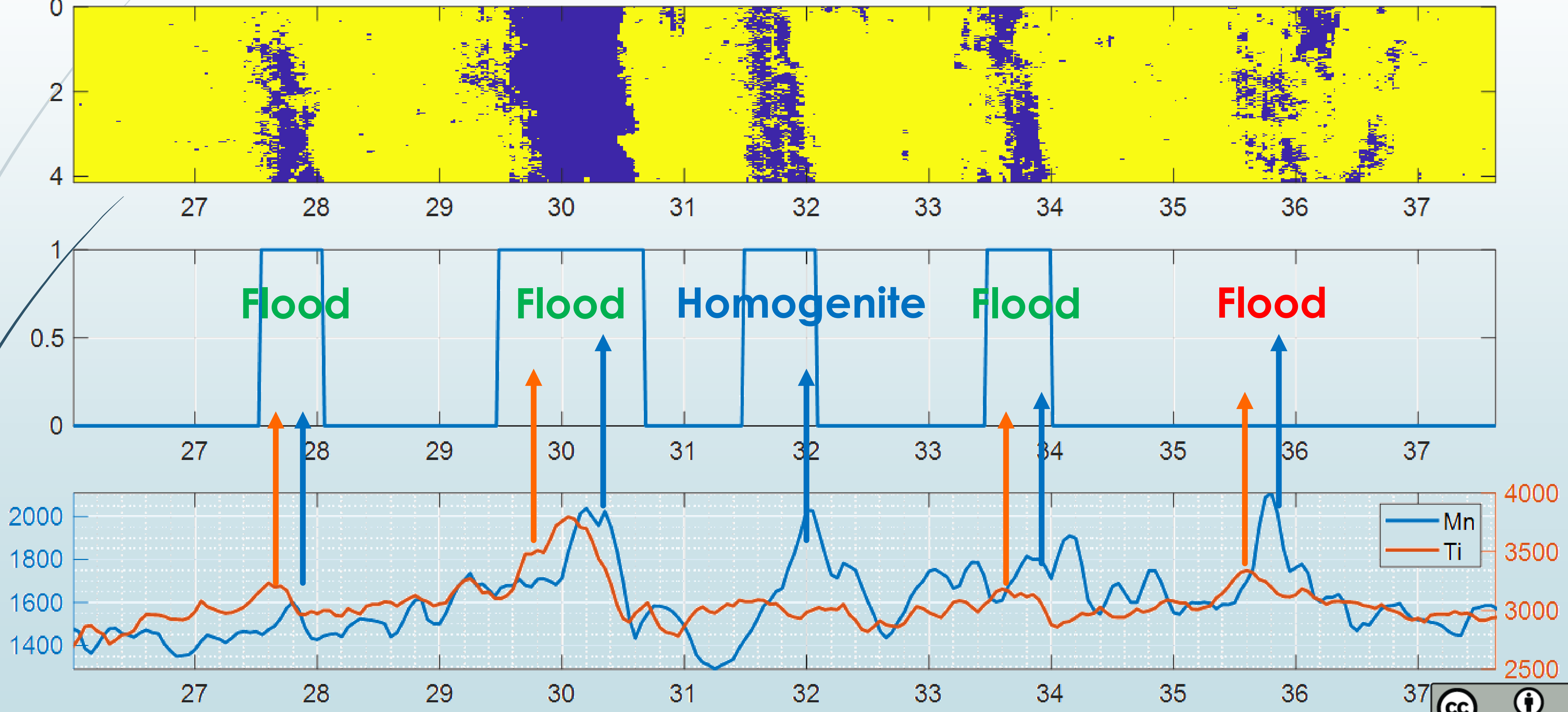
XRF use alone ?

- Ti signal too noisy
- For both proxies, there are many peaks independent of flood signatures
- Only the combination of the two sensors can characterize the flood layers



Event characterization

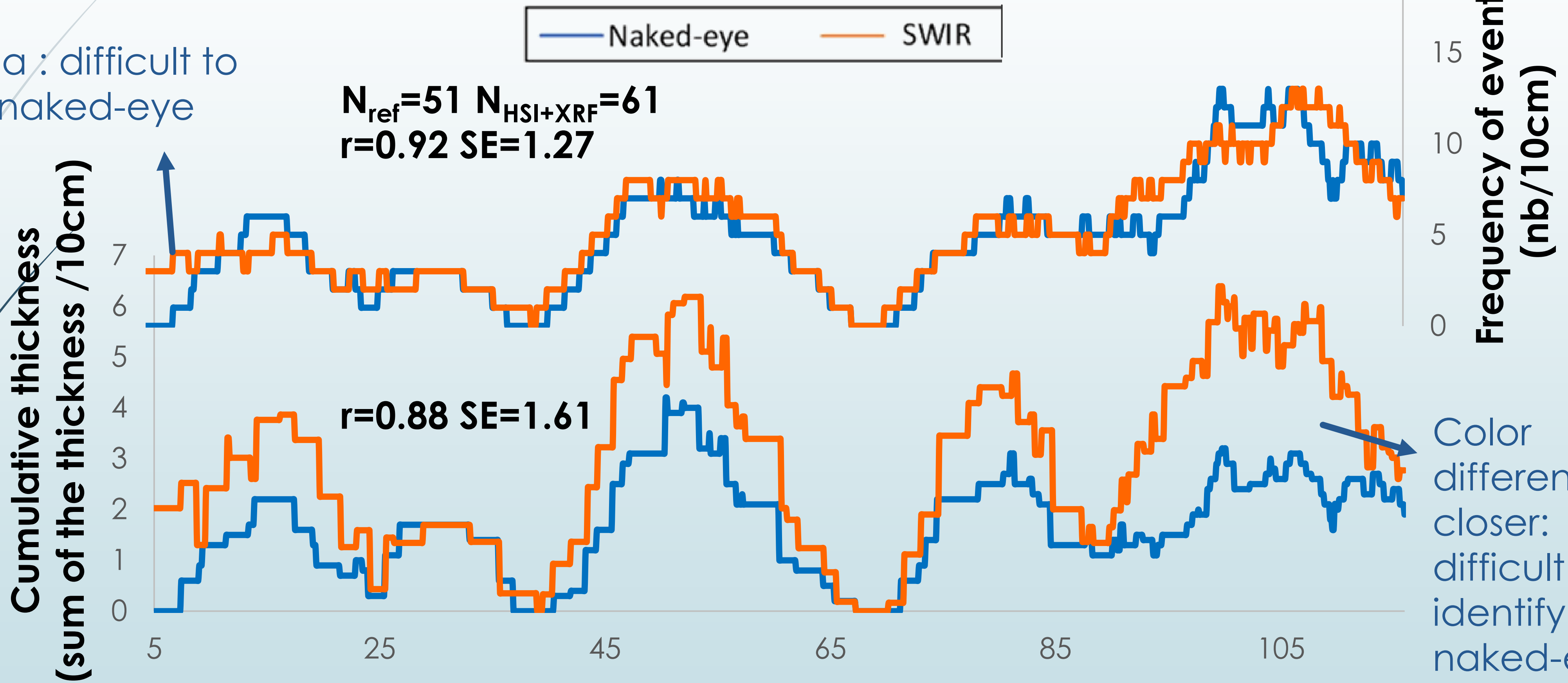
- Combination of HSI instantaneous events + XRF proxies



Comparison of chronicles

- **Flood** naked-eye vs HSI+XRF **flood event** chronicles

Lamina area : difficult to studied by naked-eye



Color differences closer: difficult to identify by naked-eye

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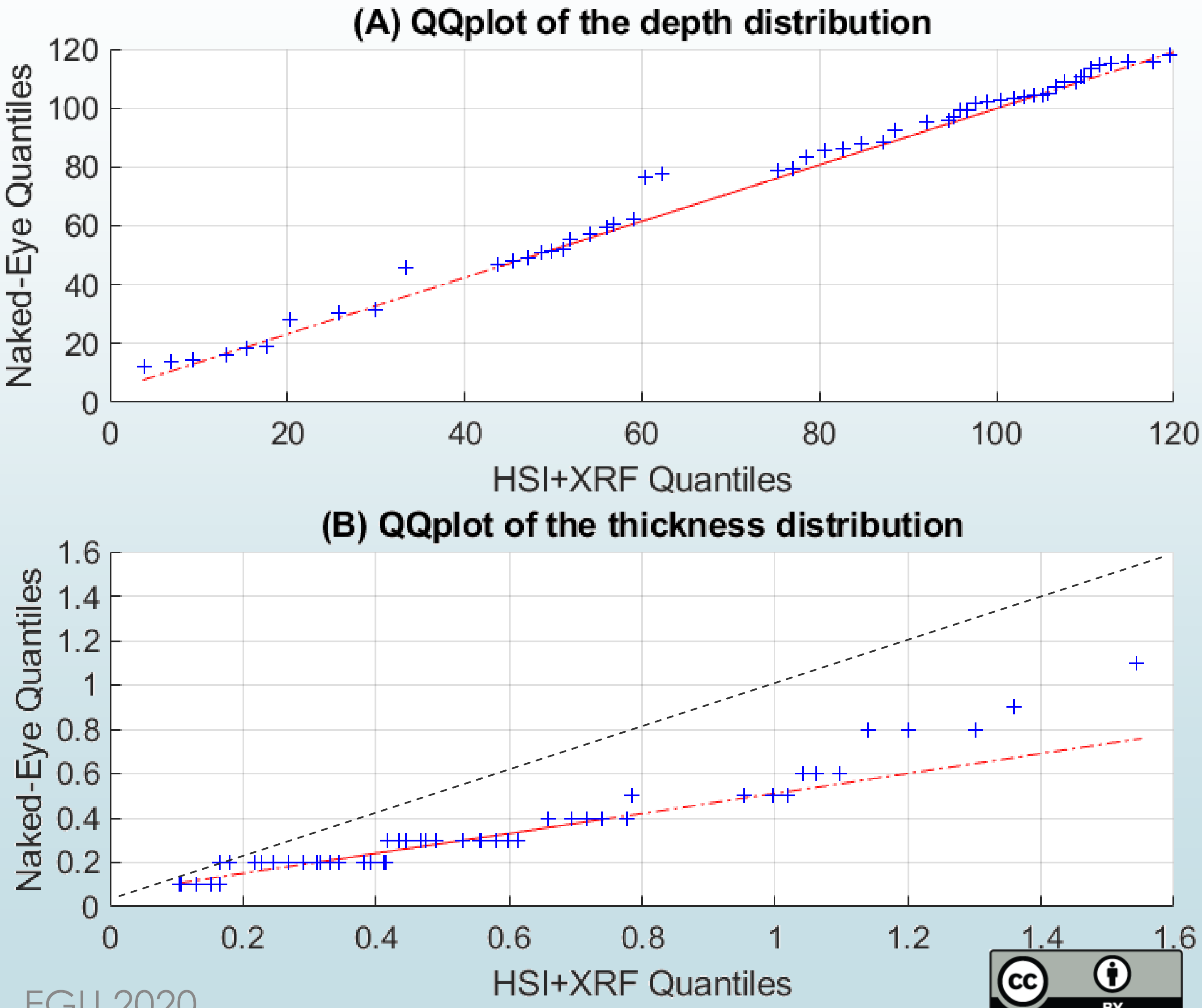
Distribution analysis

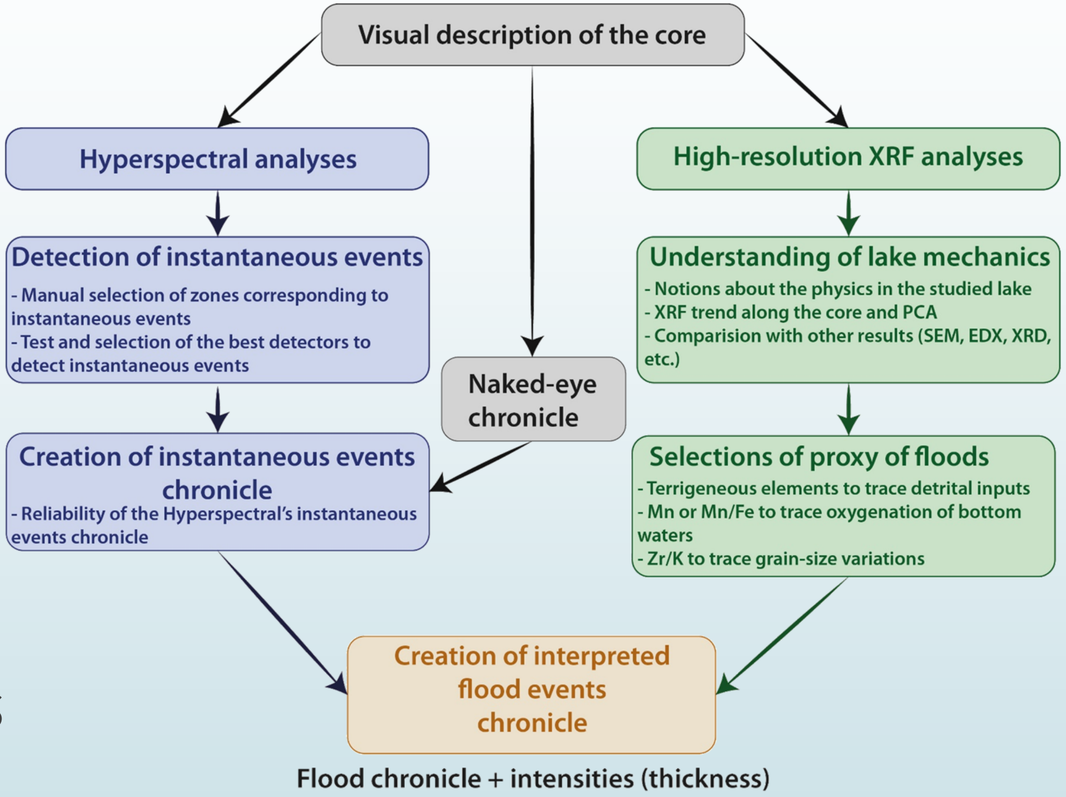
- Agreement between both depth distribution

- Linear trend between the thickness distribution, but with higher values estimated by HSI+XRF
  - curvature of the deposits => bias on the layer limits
  - eye resolution => highest HSI sensibility



Conclusion

- HSI + machine learning algorithm allows to estimate instantaneous layers
- + XRF proxies => flood can be characterized
- Instantaneous and flood chronicles can be estimated at a 200 µm resolution



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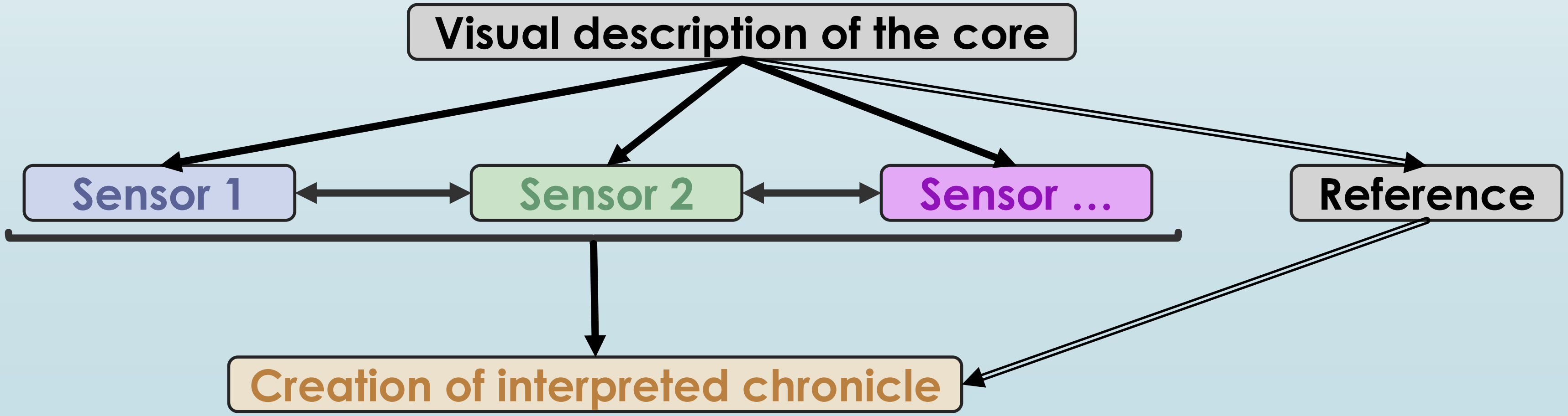
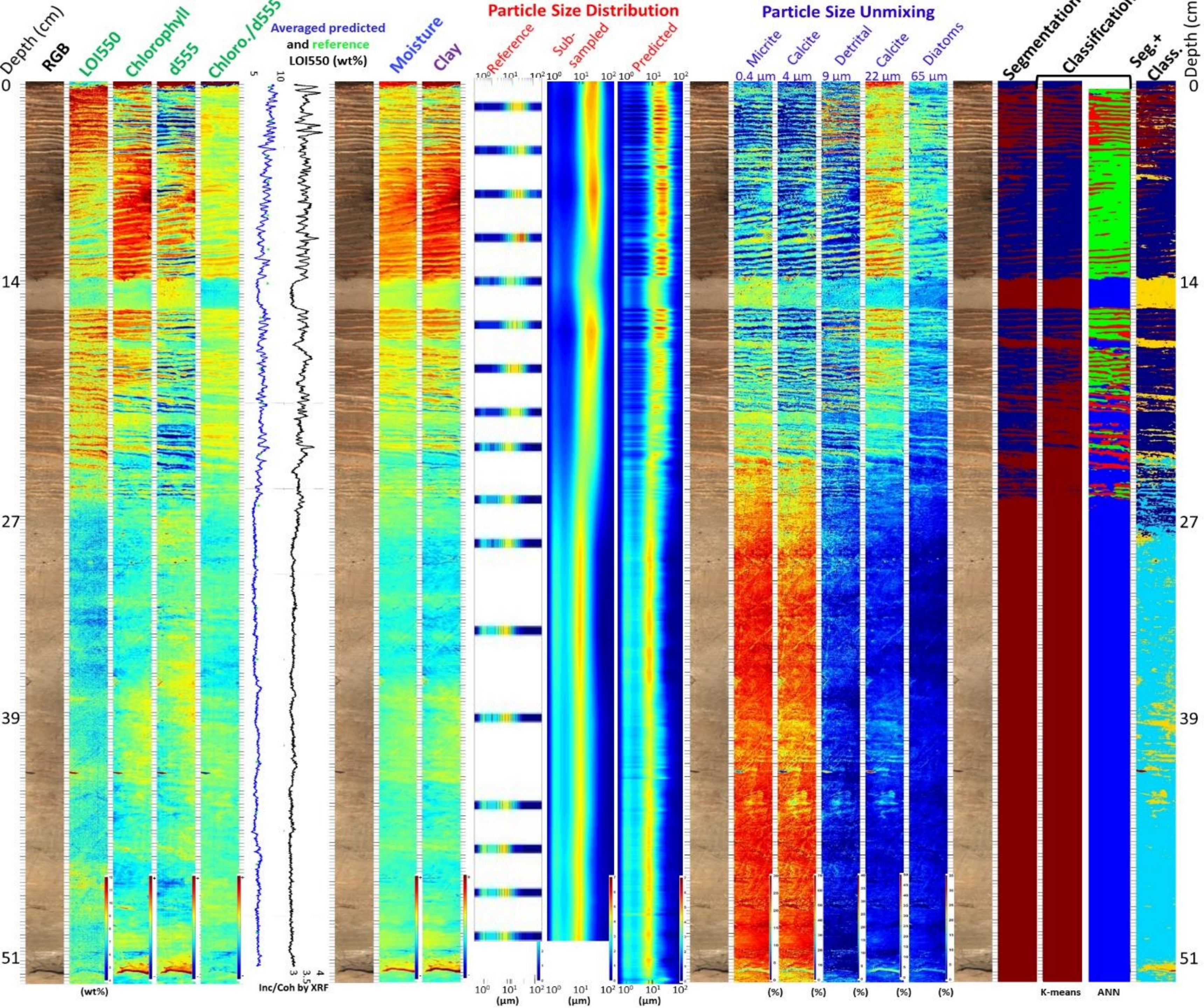
Perspectives

- Discrimination of several sedimentary processes (instantaneous event types, or lamination)
- Combining some complementary sensors
- Transfer to other samples





Hyperspectral imaging an efficient tool for multi-proxy estimations and sediment lithology descriptions to reconstruct paleoenvironment and paleoclimate at high-resolution