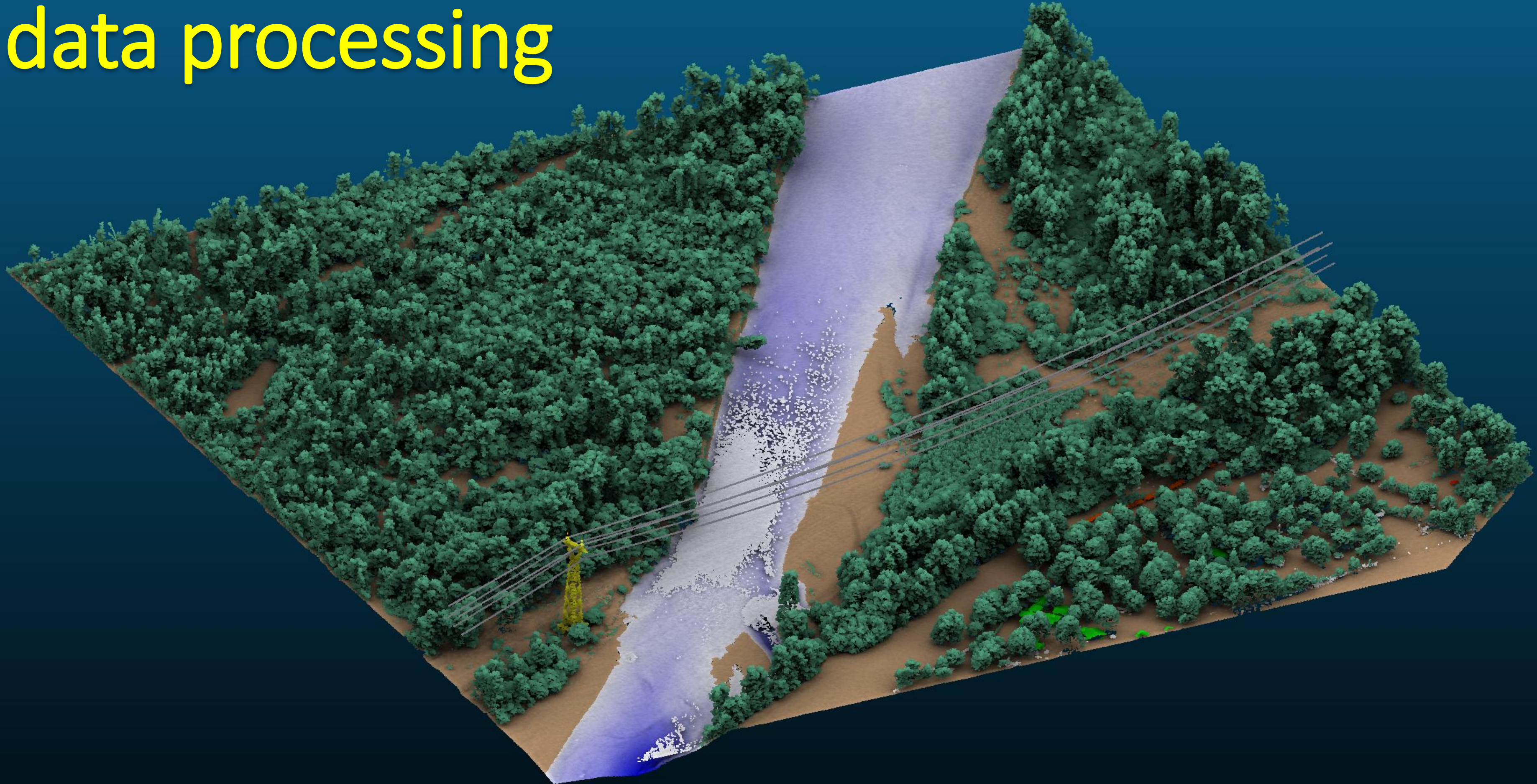
High Resolution Topography & Lidar in environmental sciences: instruments & data processing



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https://geosciences.univ-rennes1.fr/interlocuteurs/dimitri-lague
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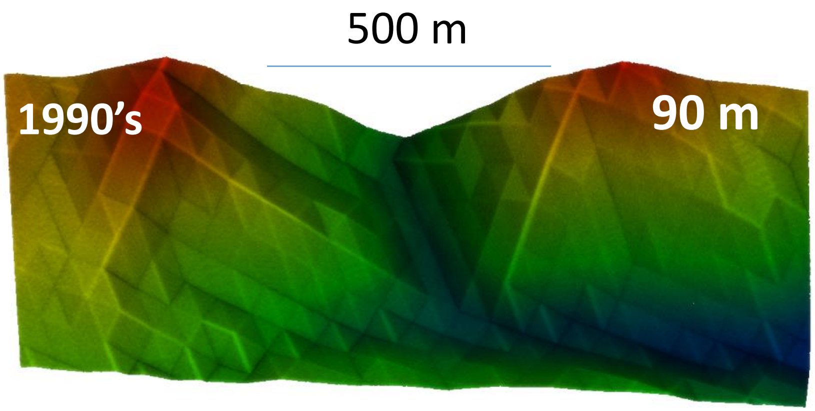
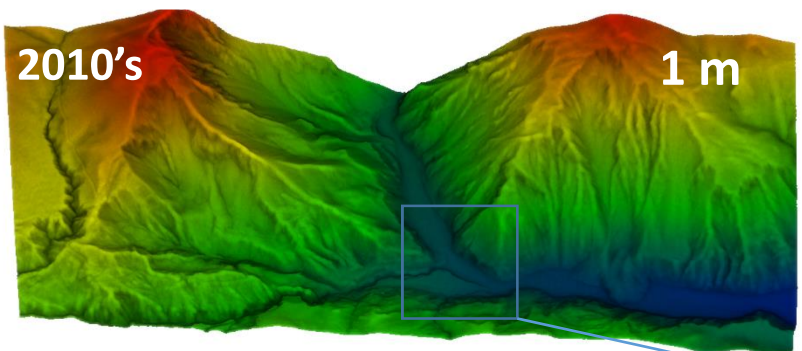
Topographic data evolution over 30 years

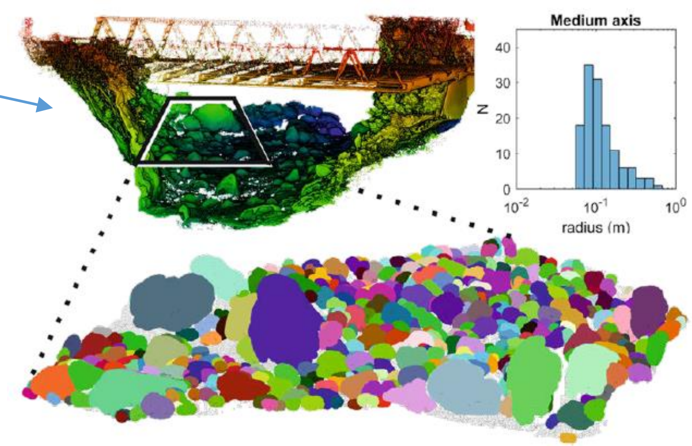


SRTM data, 90 m resolution, worldwide cover, *z precision ~ 5 m*

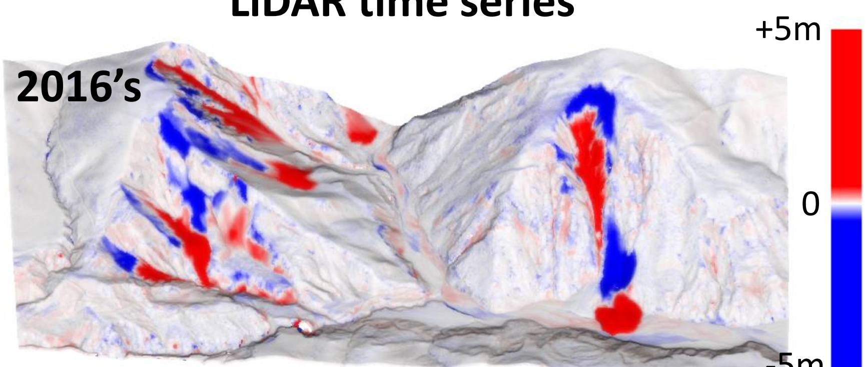


Airborne lidar, 1 m resolution, *z* ***precision 10 cm***

Terrestrial lidar, 1 cm resolution, Z precision 1 mm



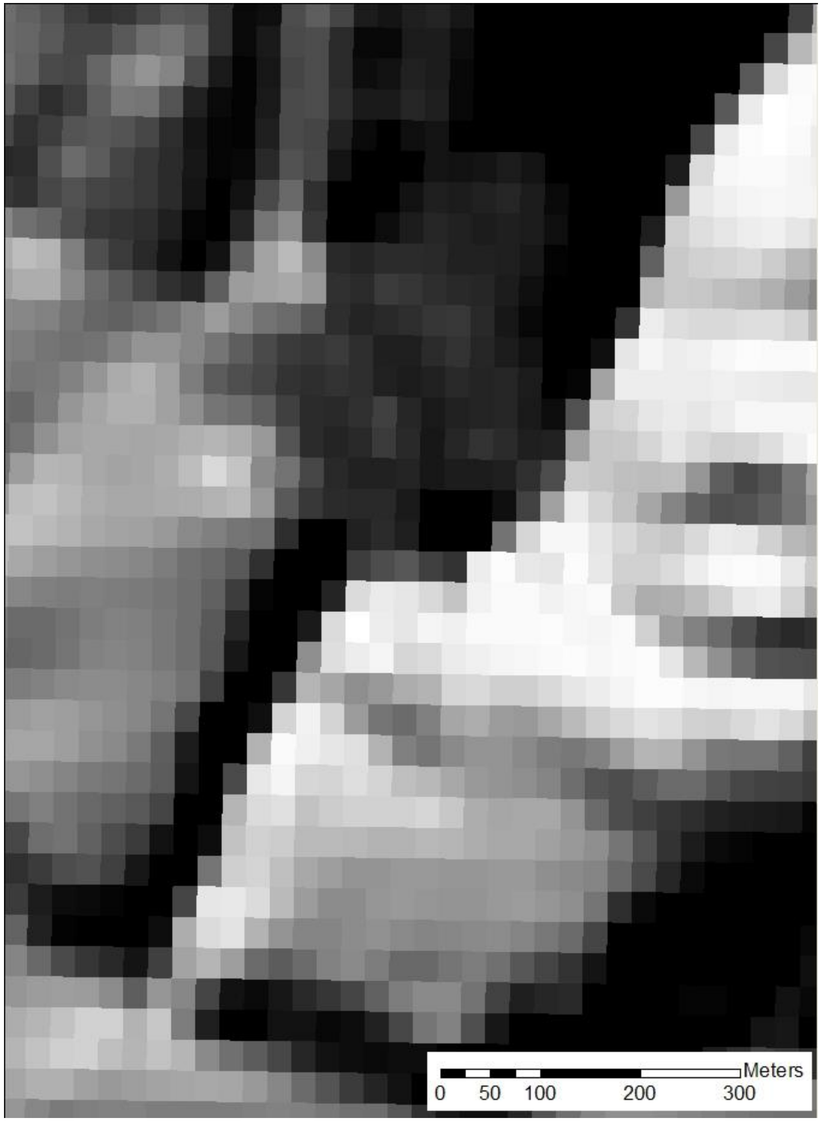
LiDAR time series



Landslides, Kaikoura eq, 2016

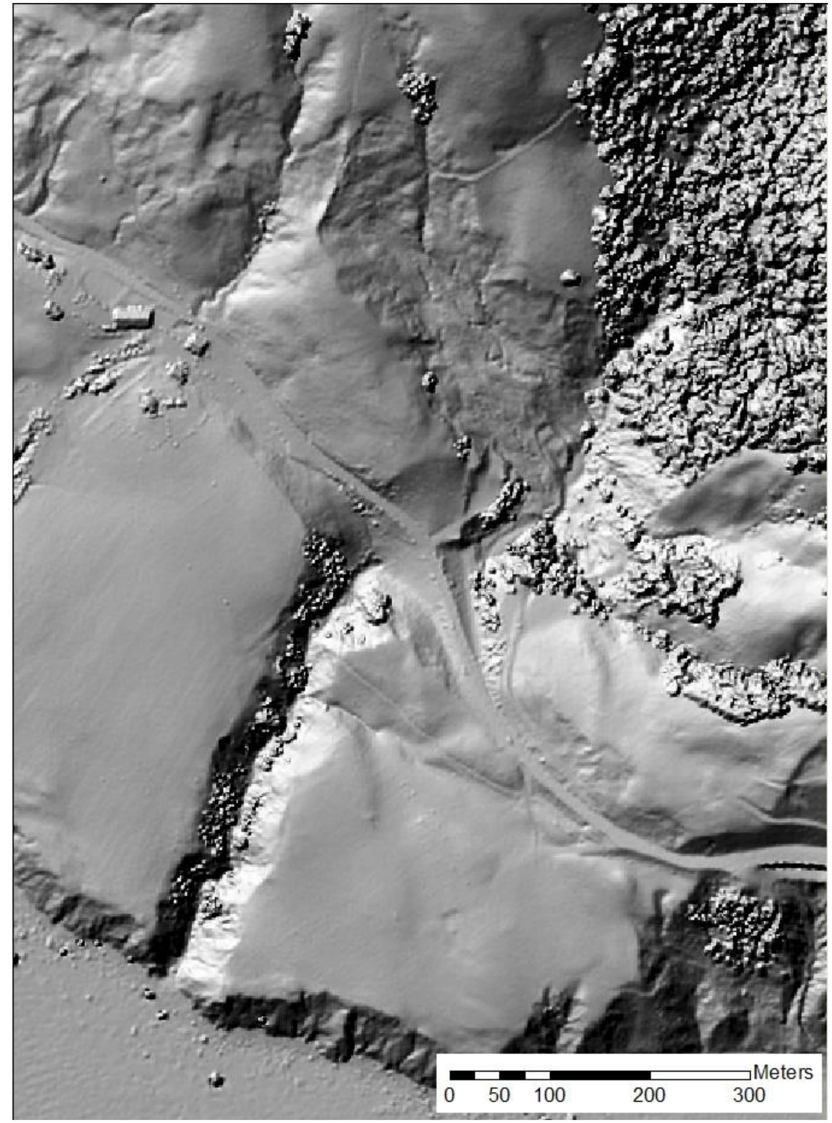
« Standard » topographic data

30 m DEM



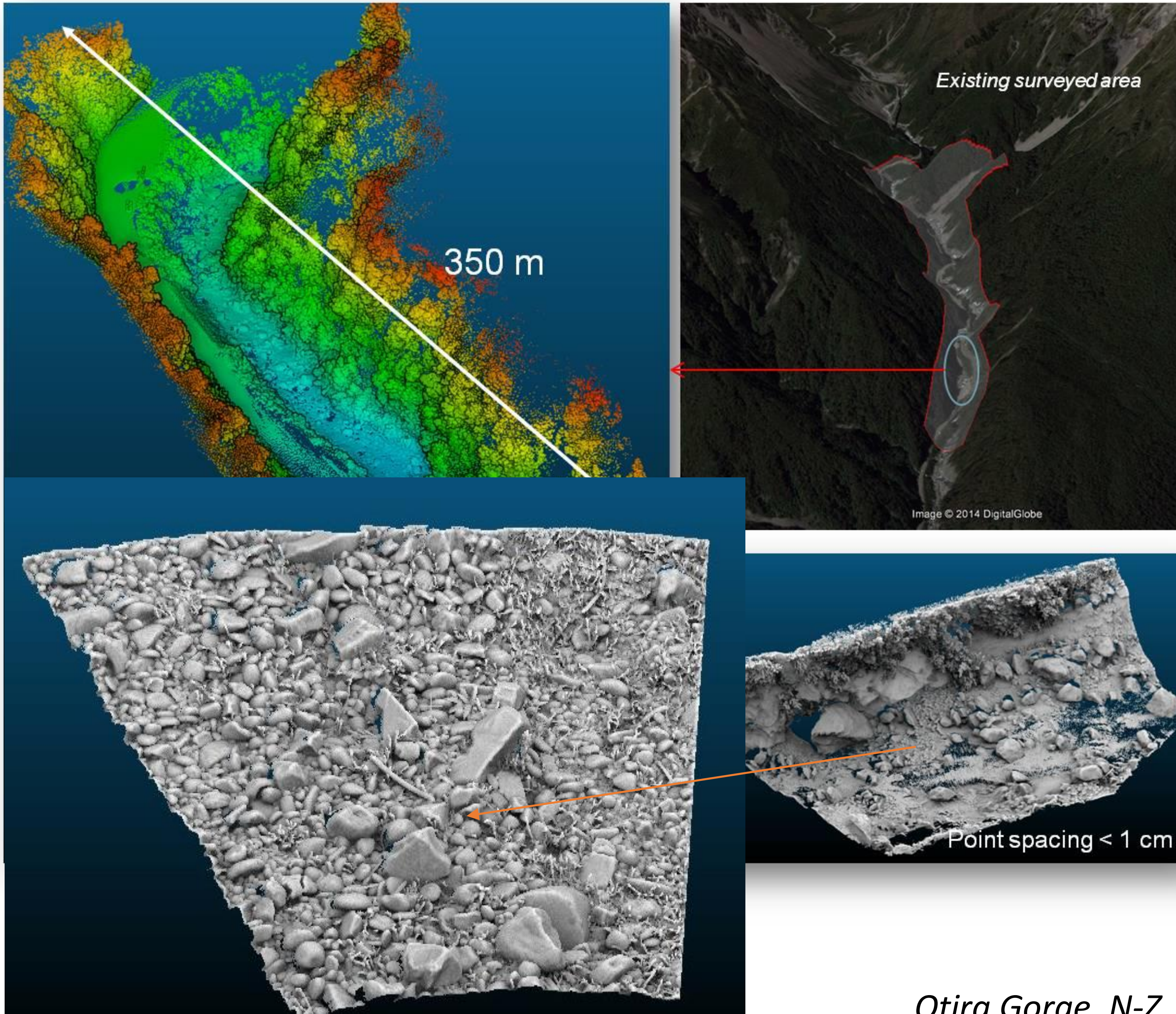
High Resolution Topography

1 m DEM
(airborne LiDAR)



C. Crosby, Opentopography presentation

Very high resolution topography, Terrestrial Lidar, spatial resolution < 1 cm



Otira Gorge, N-Z, D. Lague

Plan

1. **Data acquisition methods**
    1. Light Detection and Ranging: terrestrial, mobile & airborne
    2. A few words on image based reconstruction (Structure From Motion)

2. **Some processing techniques**
    1. Classification
    2. Raster product creation (DEM, DSM) (via Cloudcompare)
    3. Change detection/deformation measurement

       Practical with Cloudcompare on change detection

3. **Applications in Earth Sciences & Environment**

A few websites

- Opentopography : http://www.opentopography.org
  - US lidar data for the academic research community. Easy to download
    - Used during the practical
    - References to a variety of tools

- Cloudcompare : http://www.cloudcompare.org
  - Open source software for visualisation, processing and change detection. Huge user community, leading open source software for 3D point clouds (academy and private sector)
  - **Most of the figures and movies in this course have been generated with cloudcompare**

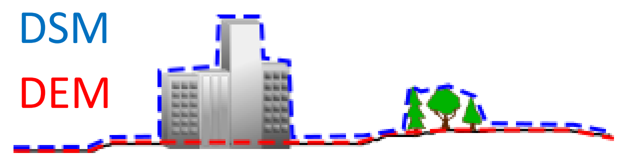
- Data vizualisation with potree directly in a website
  - US data: https://usgs.entwine.io/
  - Data example :

  ot-process2.sdsc.edu/potree/index.html?r=%22https://ot-process2.sdsc.edu/sampleUT/pc1569530546678%22

- NEON website (US) with a focus on application of lidar on ecological studies:
  - Learning hub as everal interesting ressources and videos, and R tutorials:
  - www.neonscience.org/resources/learning-hub/tutorials/introduction-light-detection-and-ranging-lidar-explore-point

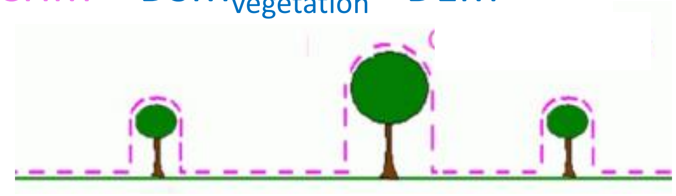
Definitions

	GROUND	Above GROUND features (trees, houses, powerlines…
Digital **S**urface **M**odel	X	X
Digital **E**levation **M**odel*	X	



CHM : **C**anopy **H**eight **M**odel = vegetation height

$CHM = DSM_{vegetation} - DEM$

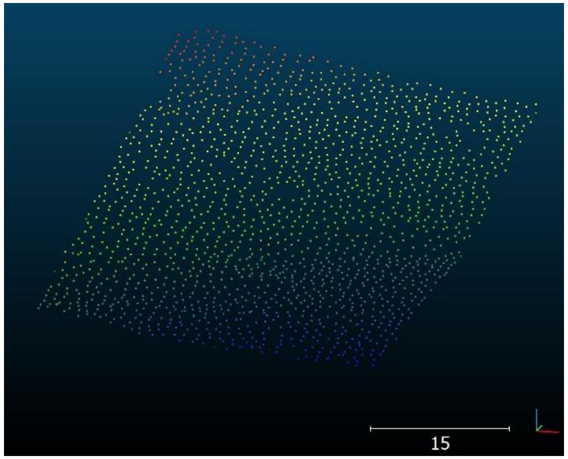


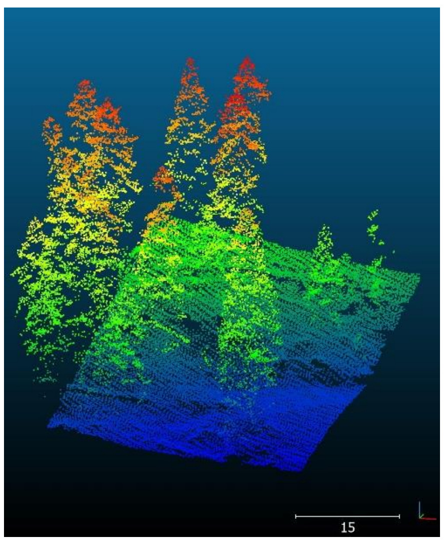
*: also called ***D**igital **T**errain **M**odel*

Format of topographic data

3D point cloud

x,y,z + attributs

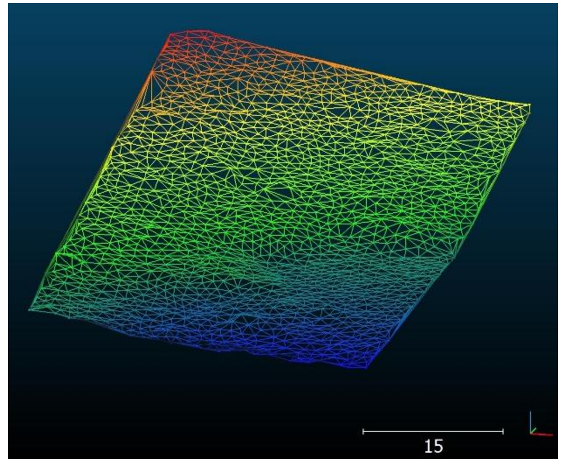


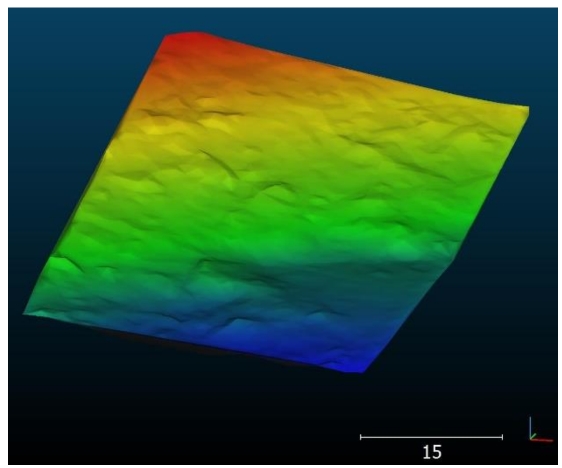


Raw data format
Generally unorganized
Fully 3D : several points on the same vertical

3D Mesh or Triangular Irregular Network

Points are connected to form surfaces

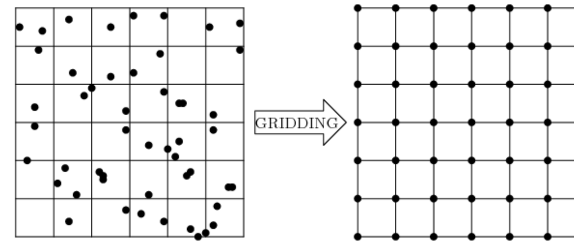


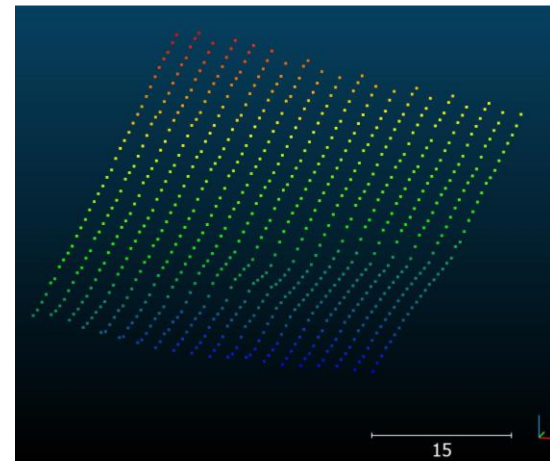


Rarely used in topographic data processing
May require interpolation

2D Raster

Regular grid of elevation





Spatial resolution set by pixel size
Frequently used in 2D GIS processing

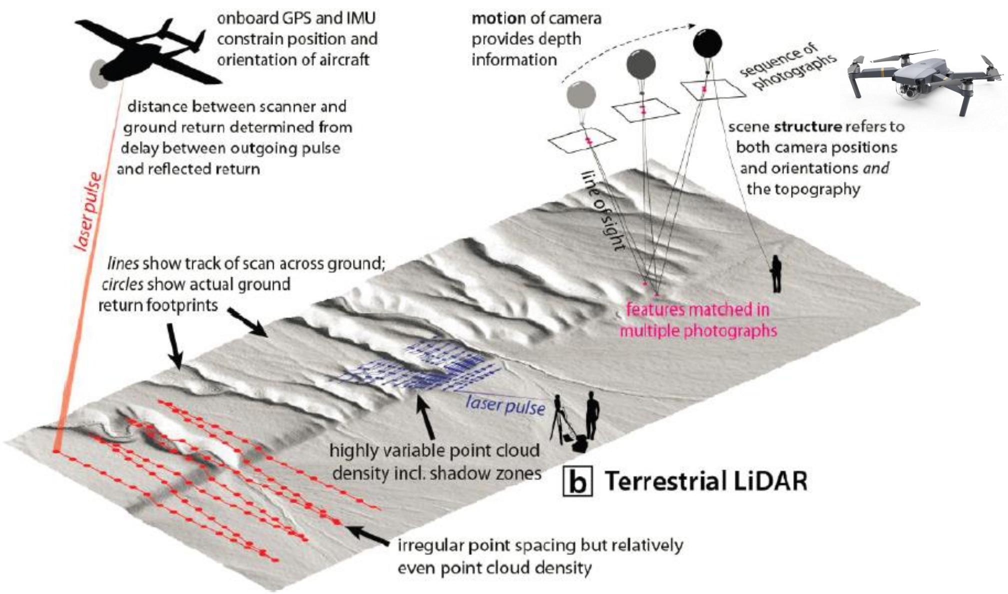
Compact and easy to process

But :
Potential loss of resolution
May require interpolation
Cannot describe vertical surfaces or overhangs

High Resolution Topographic data sources

Spatial Resolution= 20 cm
Z Accuracy= 5-10 cm
Vegetation penetration

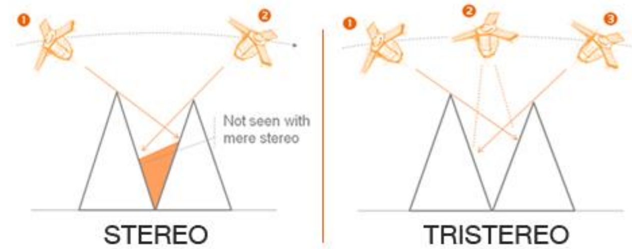
Spatial Resolution= 1-20 cm
Z Accuracy= 2-20 cm
No vegetation penetration



Johnson et al., Geosphere (2014)

Spatial Resolution= 0.5-10 cm
Z Accuracy= 0.5-1 cm
Vegetation penetration

Satellite Stereo Imagery



Spatial Resolution= 1-2 m
Z Accuracy= 50 cm
No vegetation penetration

LiDAR: Light Detection And Ranging

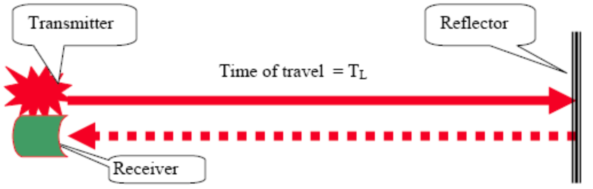
RAW DATA = 3D point clouds

Lidar measurement principle

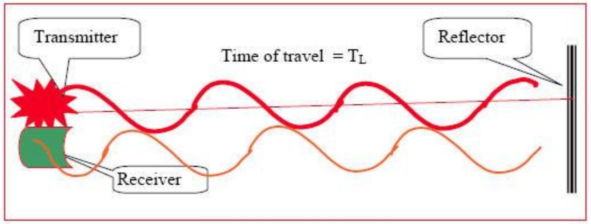
***Li**ght **D**etection **A**nd **R**anging*

How distance is measured

- **Time of Flight** :
  - Long range Terrestrial lidar (> 500 m)
  - Airborne lidar
  - Satellite lidar



- **Phase difference** of a modulated signal
  - Short range Terrestrial LiDAR (< 300 m)
  - Very fast (2 Million pts/sec)
  - Extremely precise at short distances (< 1 mm)

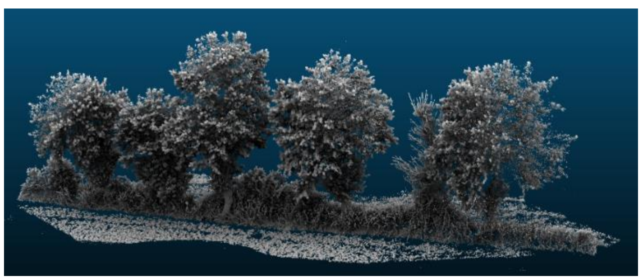


Lidar platforms

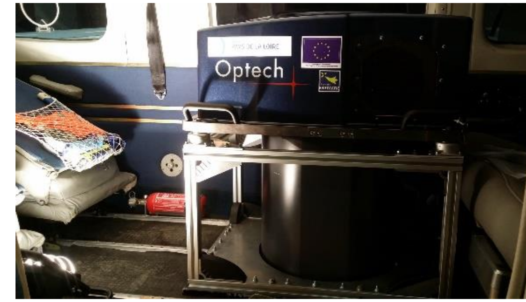
Terrestrial Laser Scanning (TLS)

Fixed position

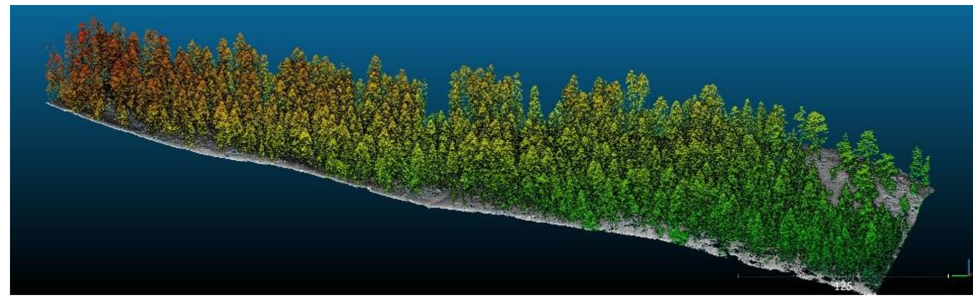
(Leica Scanstation 2, OSUR/Univ Rennes 1)



Airborne Laser Scanning (ALS)



Lidar Optech Titan Univ Nantes + Rennes, Avion Fit-Conseil



Mobile Laser Scanning (MLS)

Autonomous vehicles

UAV

***2021**: Dji L1 (12000 €), using a LiVOX LiDAR (900$)*

+ satellite (e.g., Icesat) etc…

Example of Terrestrial Laser Scanner

e.g., Faro X330 (2014)

- **Infrared laser (1550 nm) for eye safety**
  - **Laser spot size ~ 2-3 mm**

- **Phase difference calculation :**
  - range **300 m**
  - range noise **< 2 mm (1std) at 50 m**
  - **3D accuracy ~ 1-2 mm**

- **Field of view : vertical 300°, horizontal 360 °**

- **Up to 1 Million pts/sec**

- **Coaxial camera, low resolution GNSS, compass**

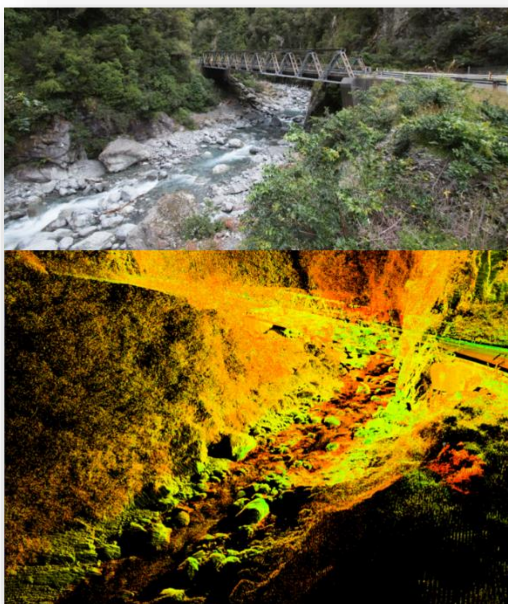
- **high accuracy inclination sensor**

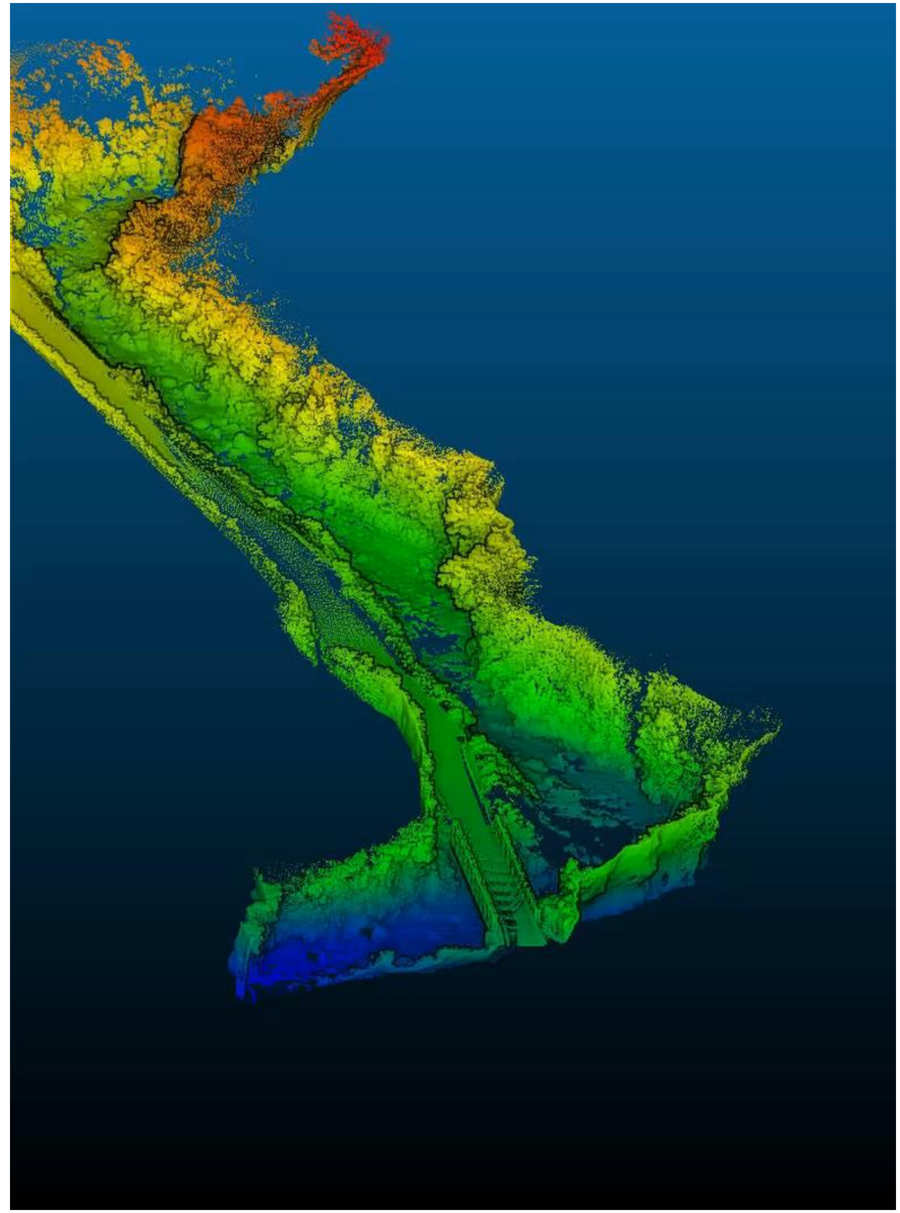
- **Raw data= point clouds with X,Y,Z, backscattered intensity, RGB information**

- **Field instrument, fully autonomous ~ 40 k€ HT**

Field data acquisition

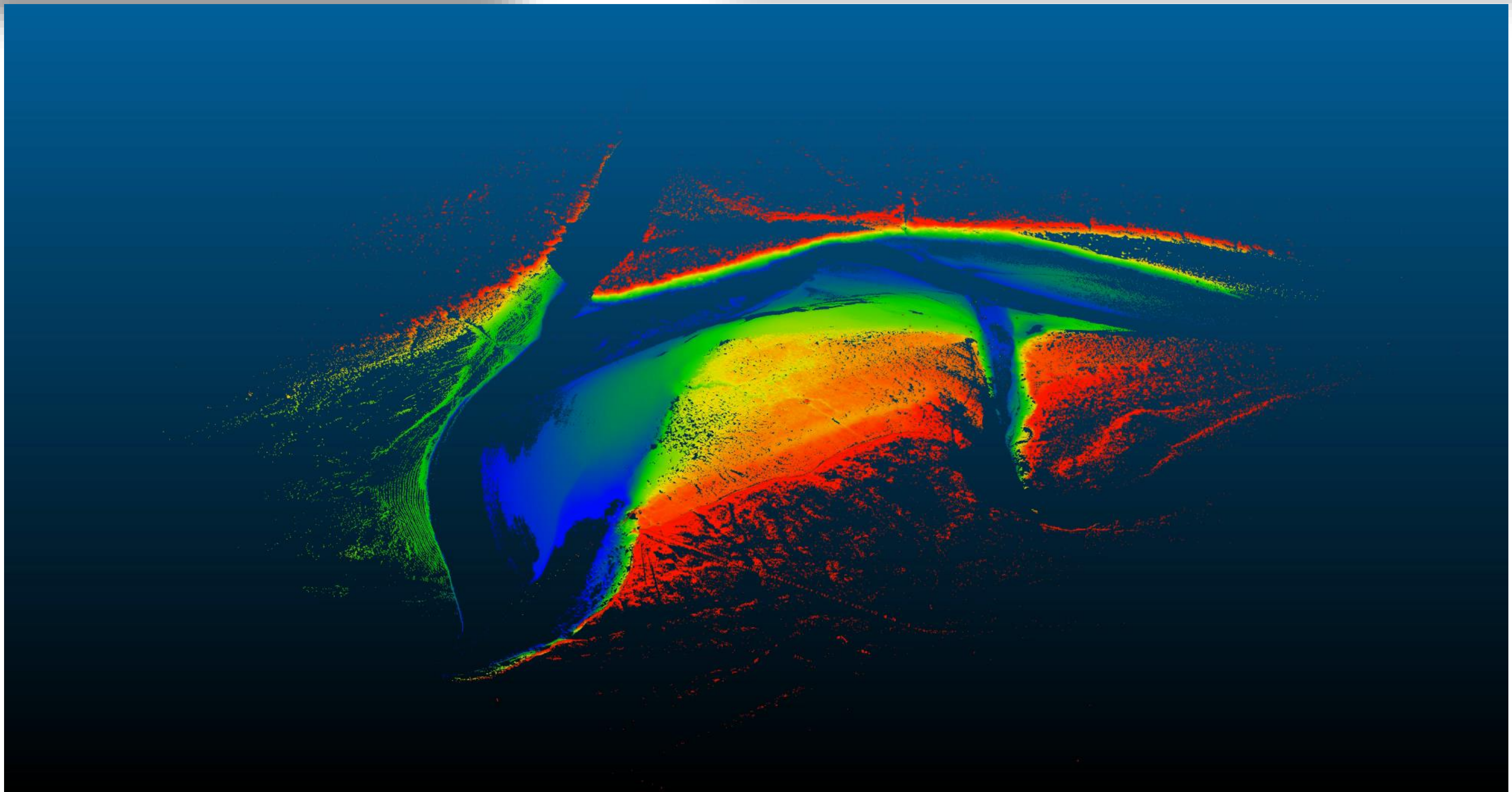
New-Zealand, mountain rivers



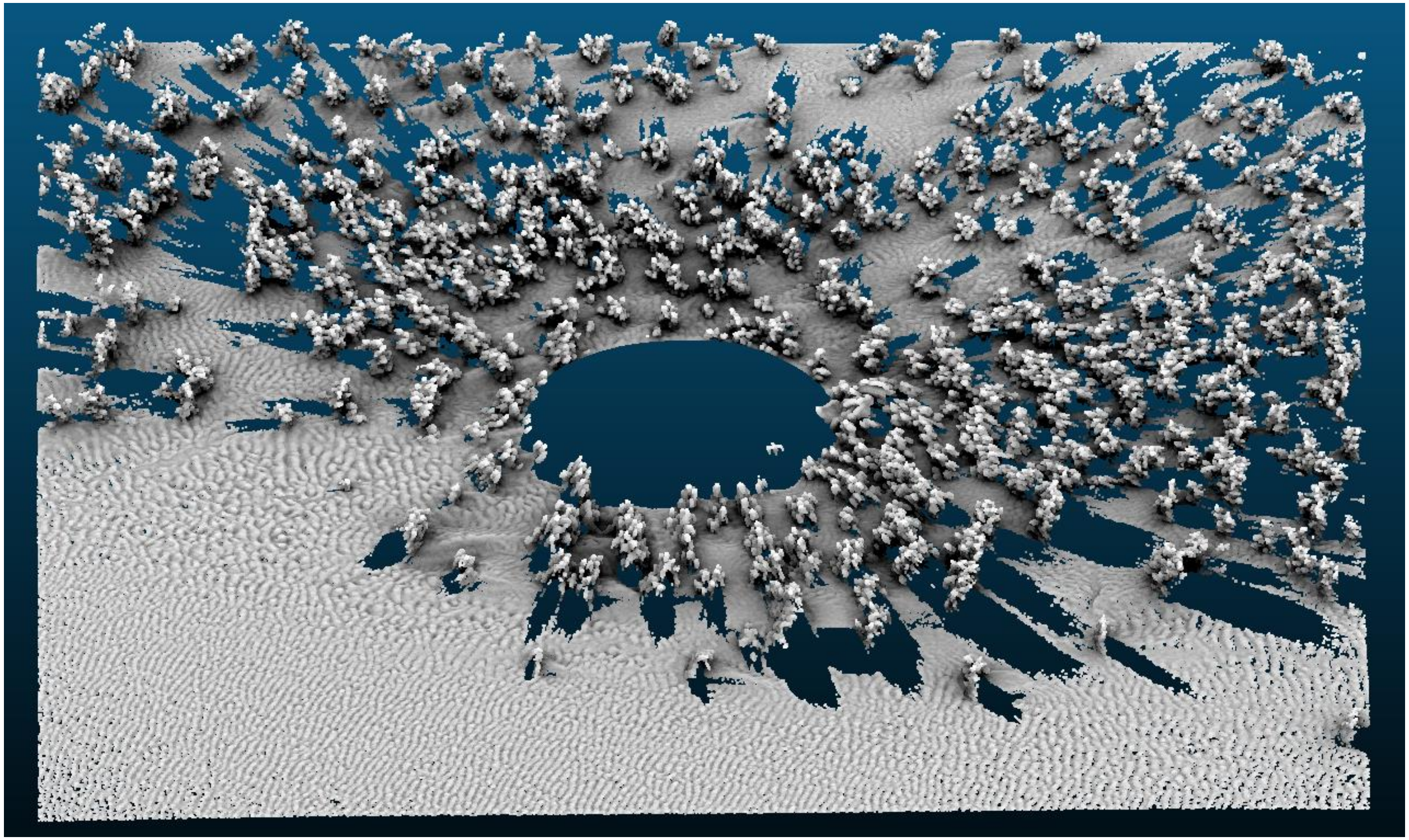


Field data acquisition

Mont Saint Michel Estuary, Brittany



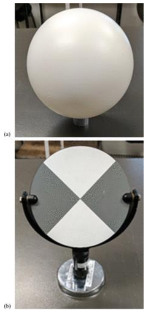
Typical point cloud data acquired at a single station



- Vegetation may generate « shadows »
- The instrument needs to be set up in other positions to limit shadow areas

Registration of survey stations

- *Use of specific targets set up during the survey to compute geometrical transformation between successive stations*
- *« Registration » of all stations in a single, **local coordinate system** is performed by a dedicated software*



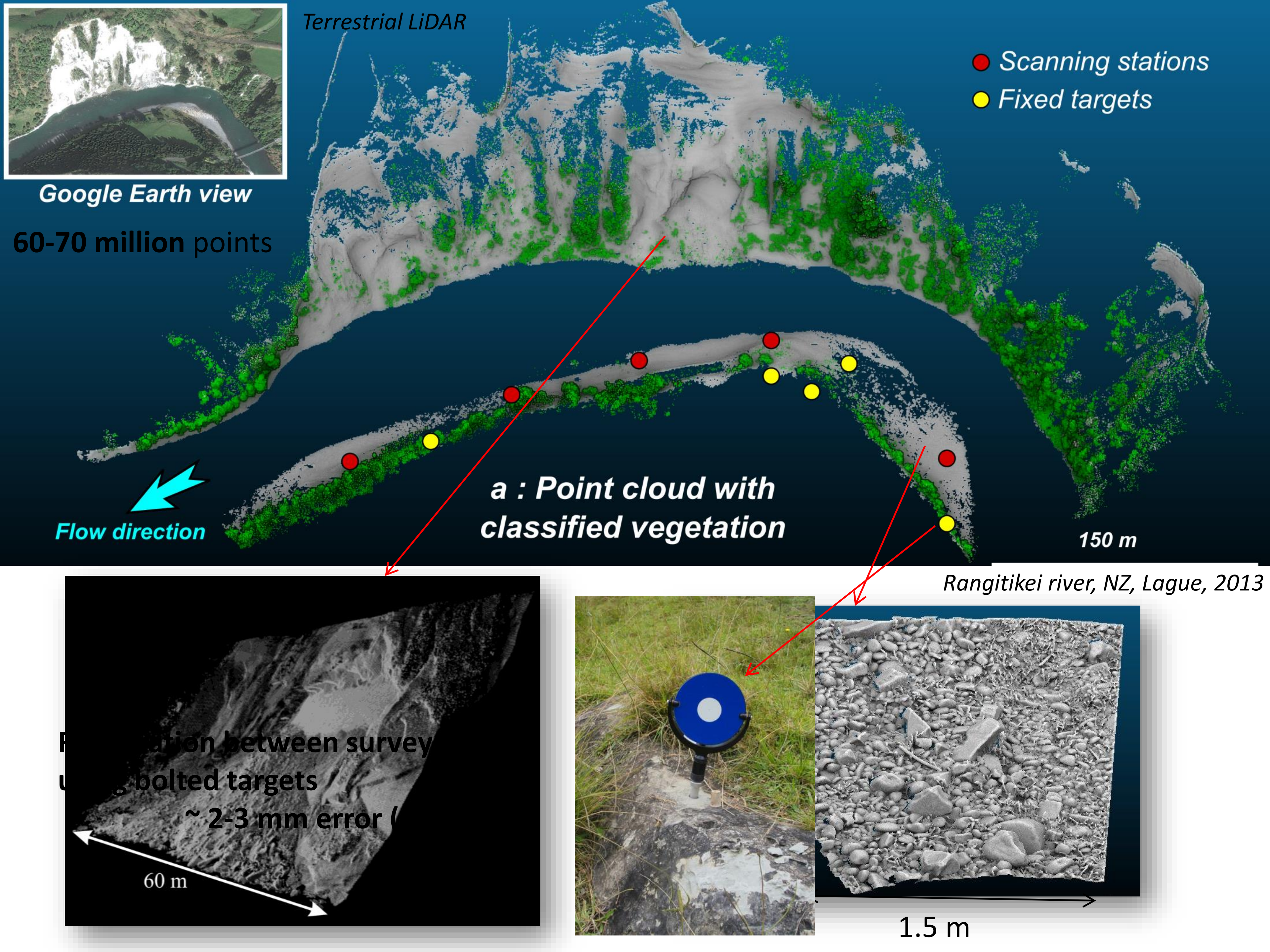
Coordinate systems: local to global

- **Global Coordinate System** : targets used during the registration process are surveyed with GNSS
  - Accuracy of the registration to the GCS is a function of the GNSS accuracy
  - Coordinates of the lidar survey are transformed in a the GCS
  - Data can be used with auxiliary geospatial data: orthoimagery, satellite imagery…

1- 2 cm
registration error

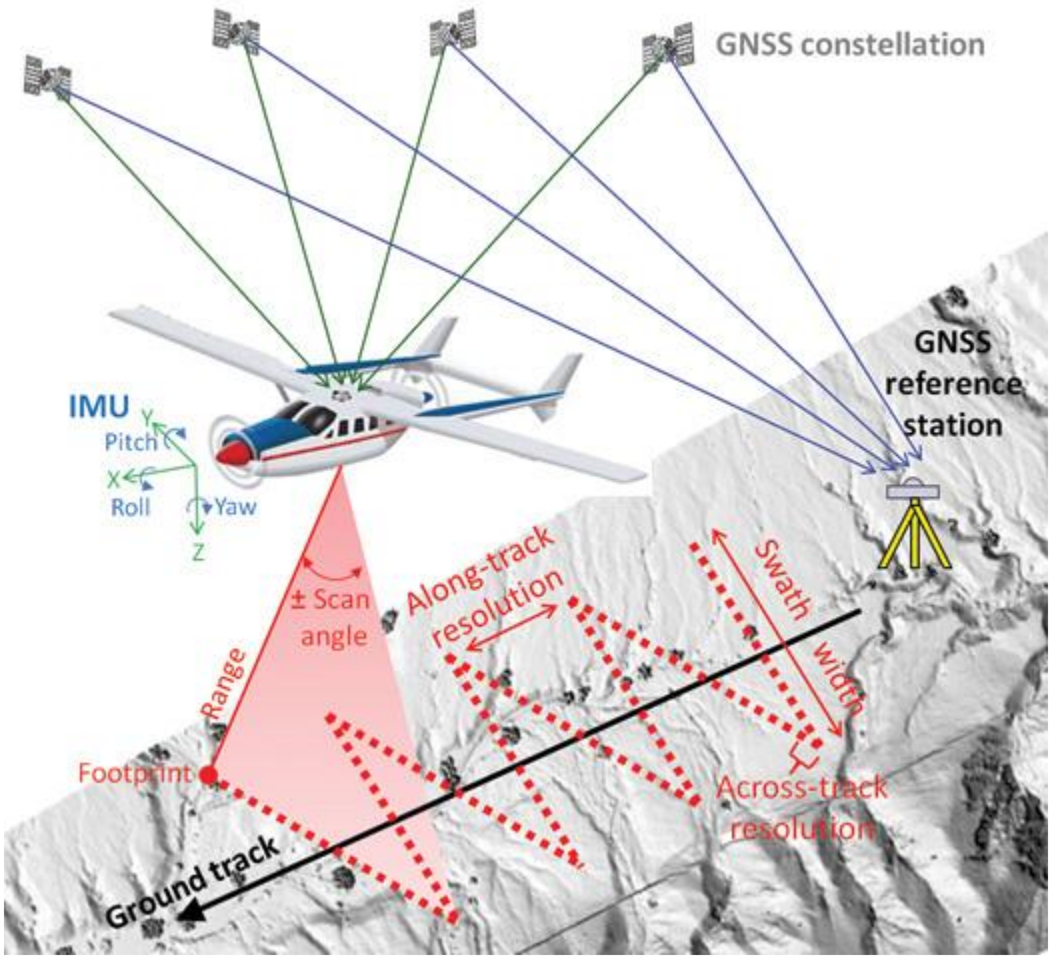
- **Local Coordinate System**
  - Elements of the 3D scene are supposed fixed and used as reference: houses, briges piles, …
  - . A dedicated software will « match » these elements between successive surveys
  - In the absence of fixed elements, dedicated target support need to be installed and reused for each lidar survey
    - This approach ensures the lowest registration error possible
    - Registration error is set by the instrument precision and resolution

< 0.2 cm
registration error



Terrestrial LiDAR
Google Earth view
60-70 million points
Scanning stations
Fixed targets
Flow direction
a : Point cloud with classified vegetation
150 m
Rangitikei river, NZ, Lague, 2013
ation between survey
bolted targets
~ 2-3 mm error (
60 m
1.5 m

Airborne LiDAR (Airborne Laser Scanning)



Flight altitude: 300 – 5000 m

Laser spot size: 0.1 – 1.5 m

1064 nm laser

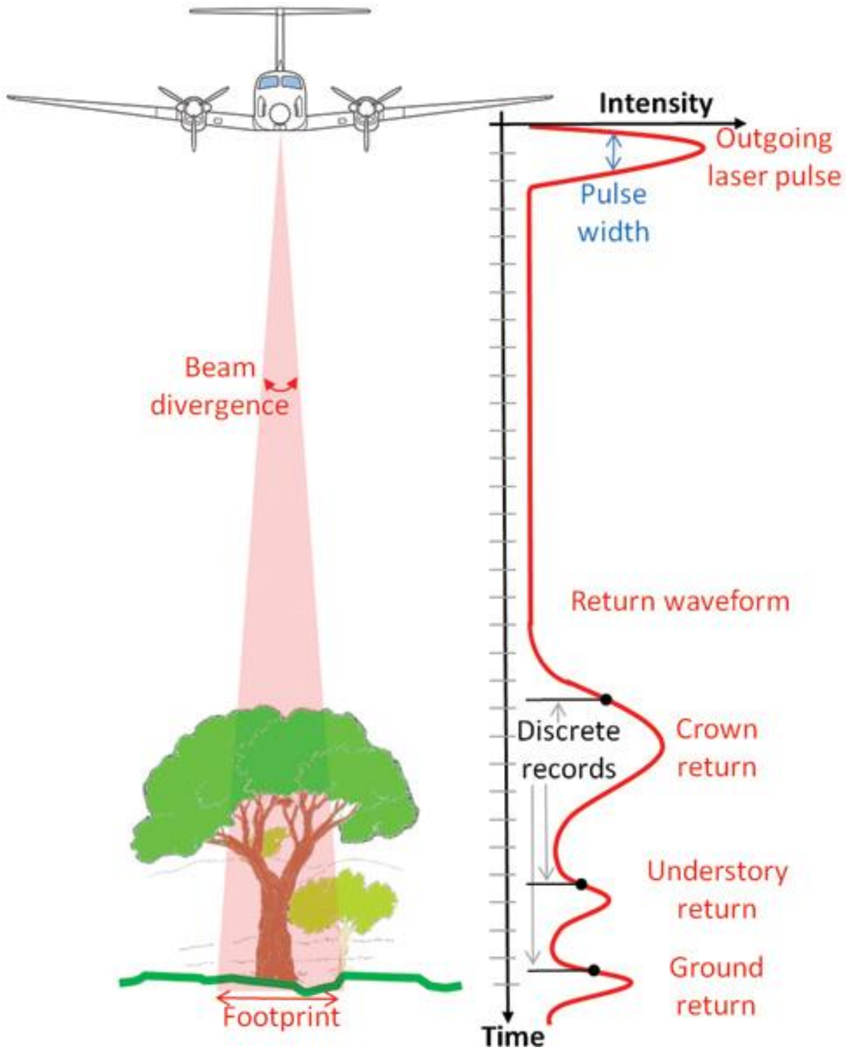
Point density
old generation : 1-4 pts/m²
new generation : 10-50 pts/m²

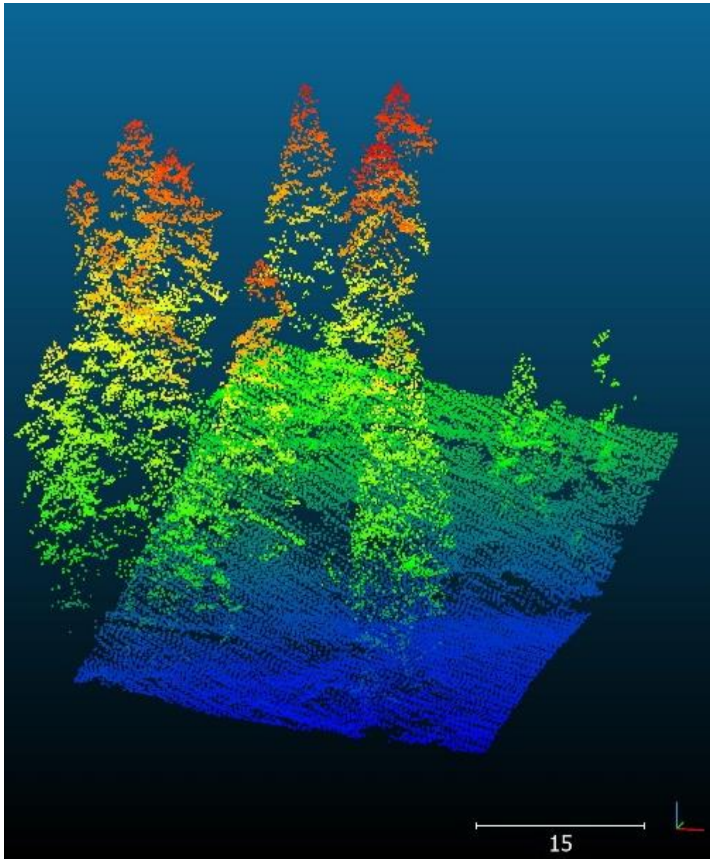
Vertical accuracy : 5 to 20 cm

Quite costly
From 30 €/km² for very large projects up to 2000 €/km² for very high resolution/small surveys

- **Inertical Measurement Unit and GNSS are essential for precise measurement.**

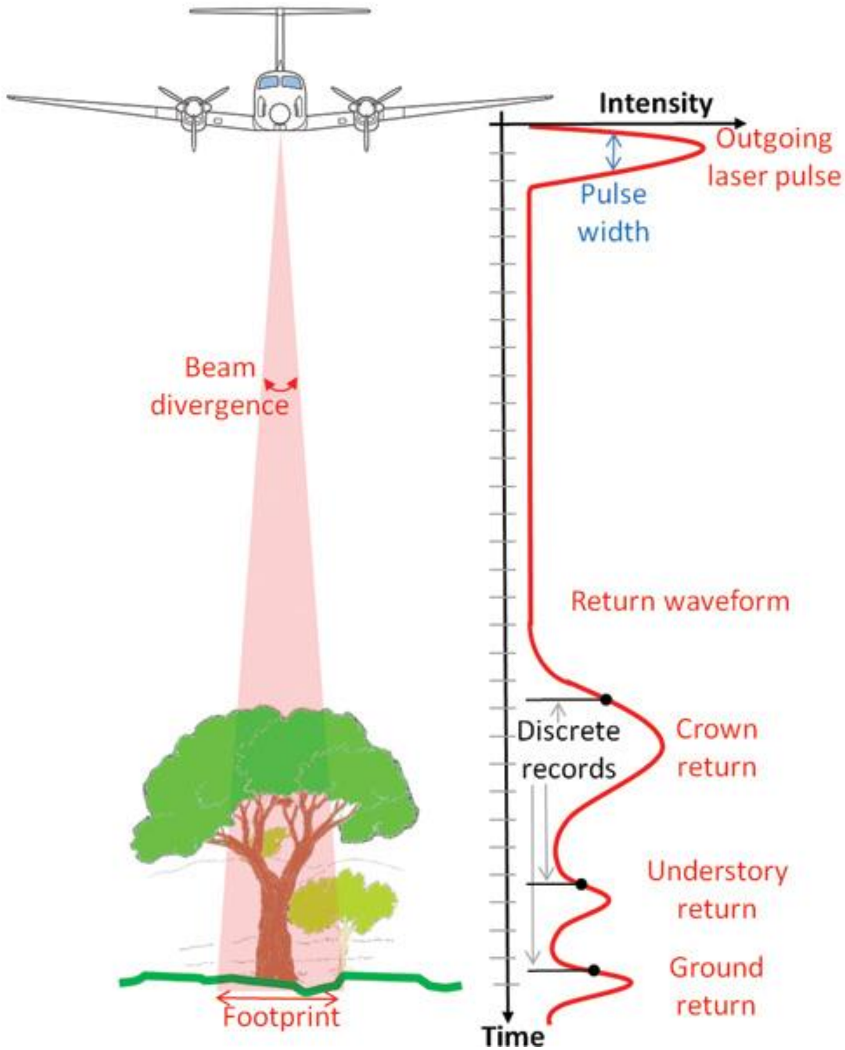
Multiple returns for a single lidar shot





Multiple returns are an essential characteristics of airborne lidar: **allows to penetrate vegetation (if the canopy is not too dense)**

Discret echoes vs Full Waveform (FWF)



The entire backscattered signal is called full waveform

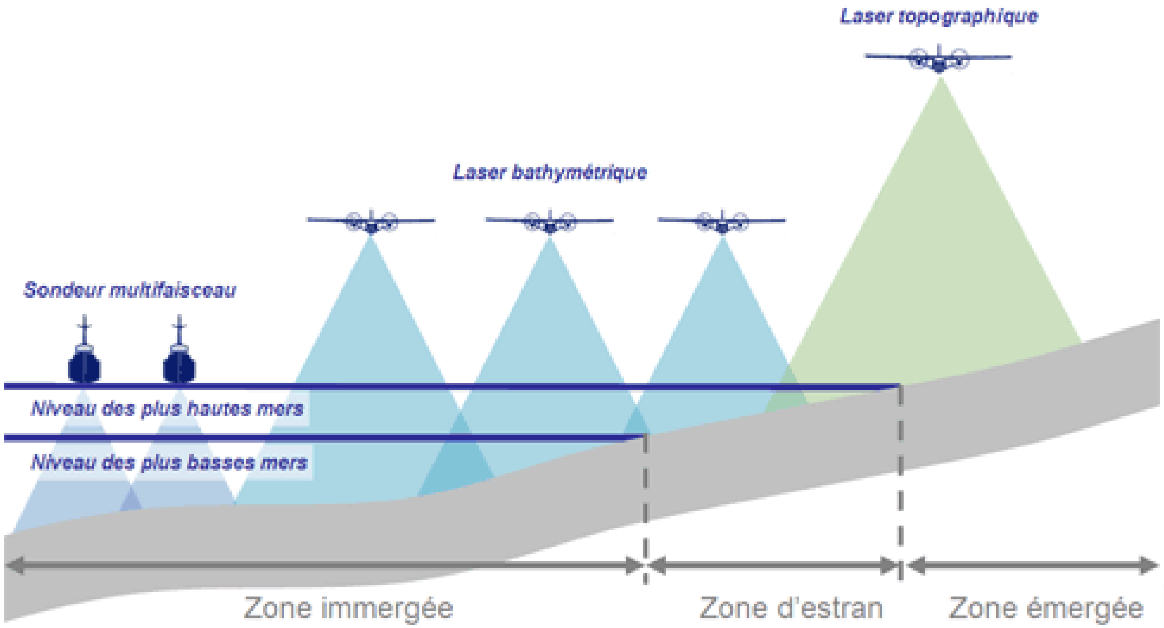
All sensors record only the main peaks of the FWF as discrete echoes:

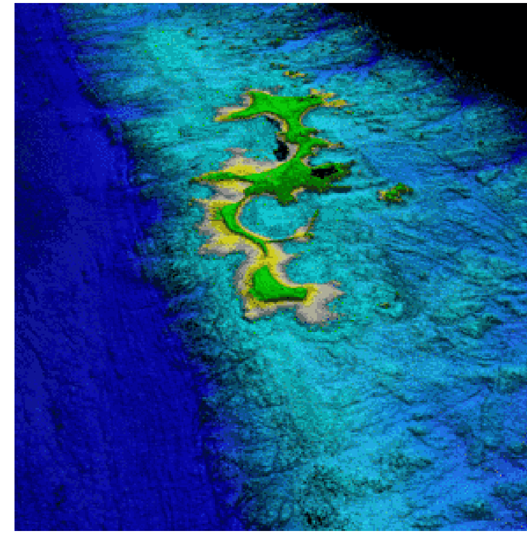
- **Lidar dataset contain 3 attributes per point:**
  - **<u>Return number</u>:** 1st is top of canopy, last can be the ground
  - **<u>Number of returns</u> for this shot**
  - **<u>Backscattered intensity per return</u>**

Some sensors record the FWF :

- Can be used for additional processing after the flight
- Contains additional information on the illuminated target (e.g., width of the echo)
- But quite complex to processs (expert knowledge)

Green lidar : BATHYMETRIC LIDAR

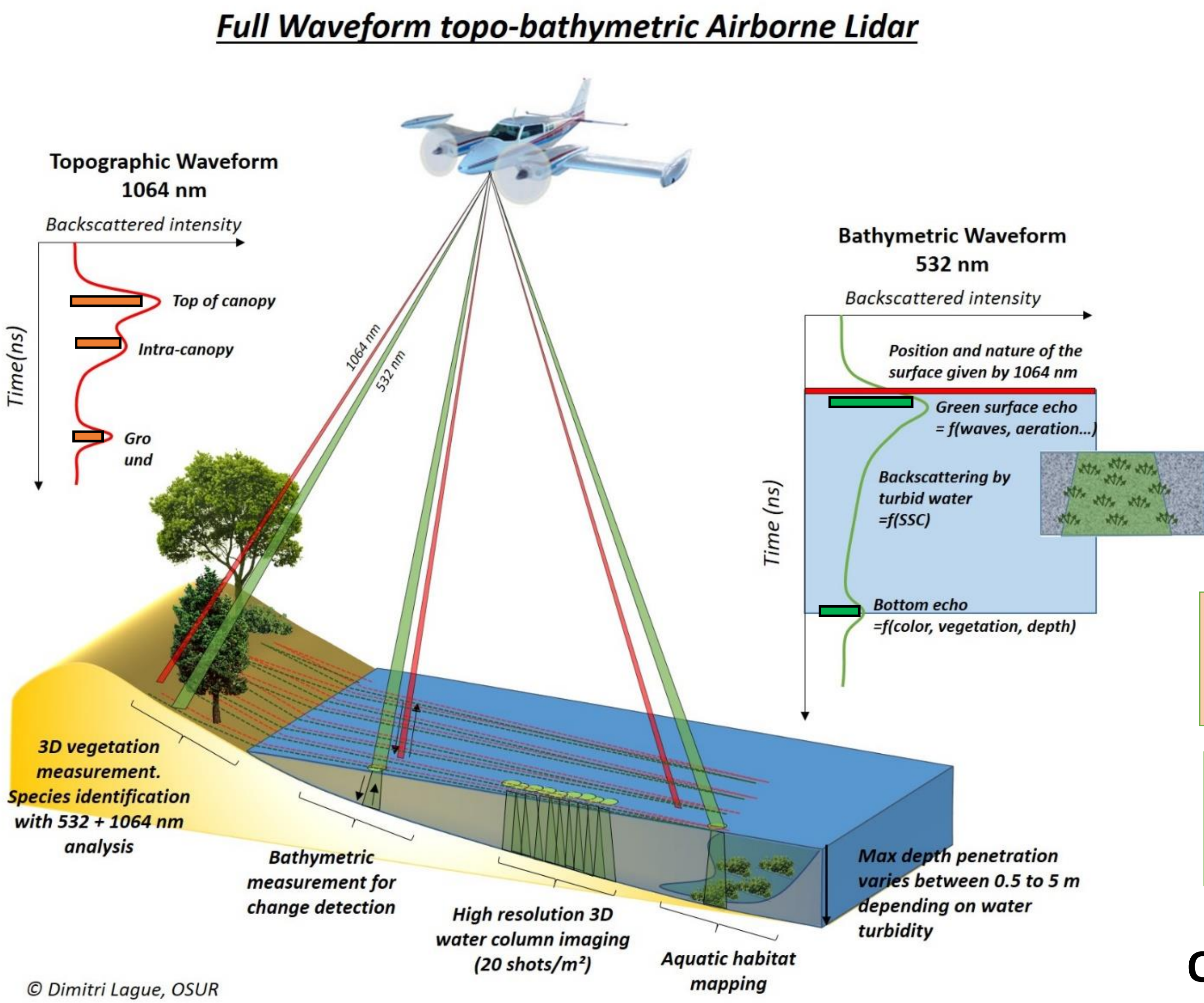


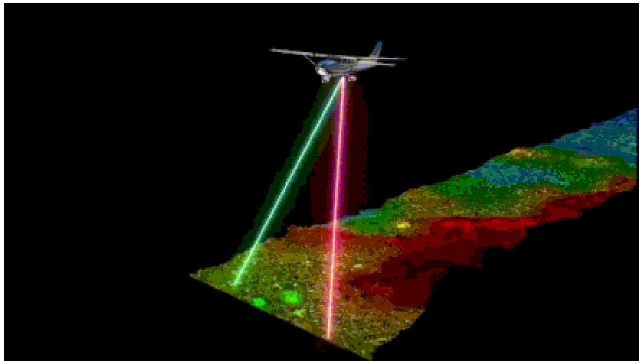


Ile de Sein, SHOM

- Use a 532 nm wavelength, one of the least absorbed by water
- Large spot-size > 1m compared to topographic lidar, and low point density ~ 1-4 pts/m²
- Up to 50 m depth penetration in very clear water, but hihgly sensitive to water clarity
- Costly system + low flight elevation (400 m) = very expensive data (4-5 sensors in the world)

New generation of bi-spectral lidar (532 nm + 1064 nm)
Topo-bathymetric lidar





GIF from eagle mapping

Depth Penetration
- ***Rivers: 0 à 4 m***
- ***Coasts and lakes: 0 à 15 m***

High resolution
- *Footprint ~* ***20-30 cm***
- *High point density:* ***15 – 20 pts/m² per laser***

High precision
- *Topography :* ***< 5 cm vertical***
- *Bathymetry :* ***< 10 cm vertical***

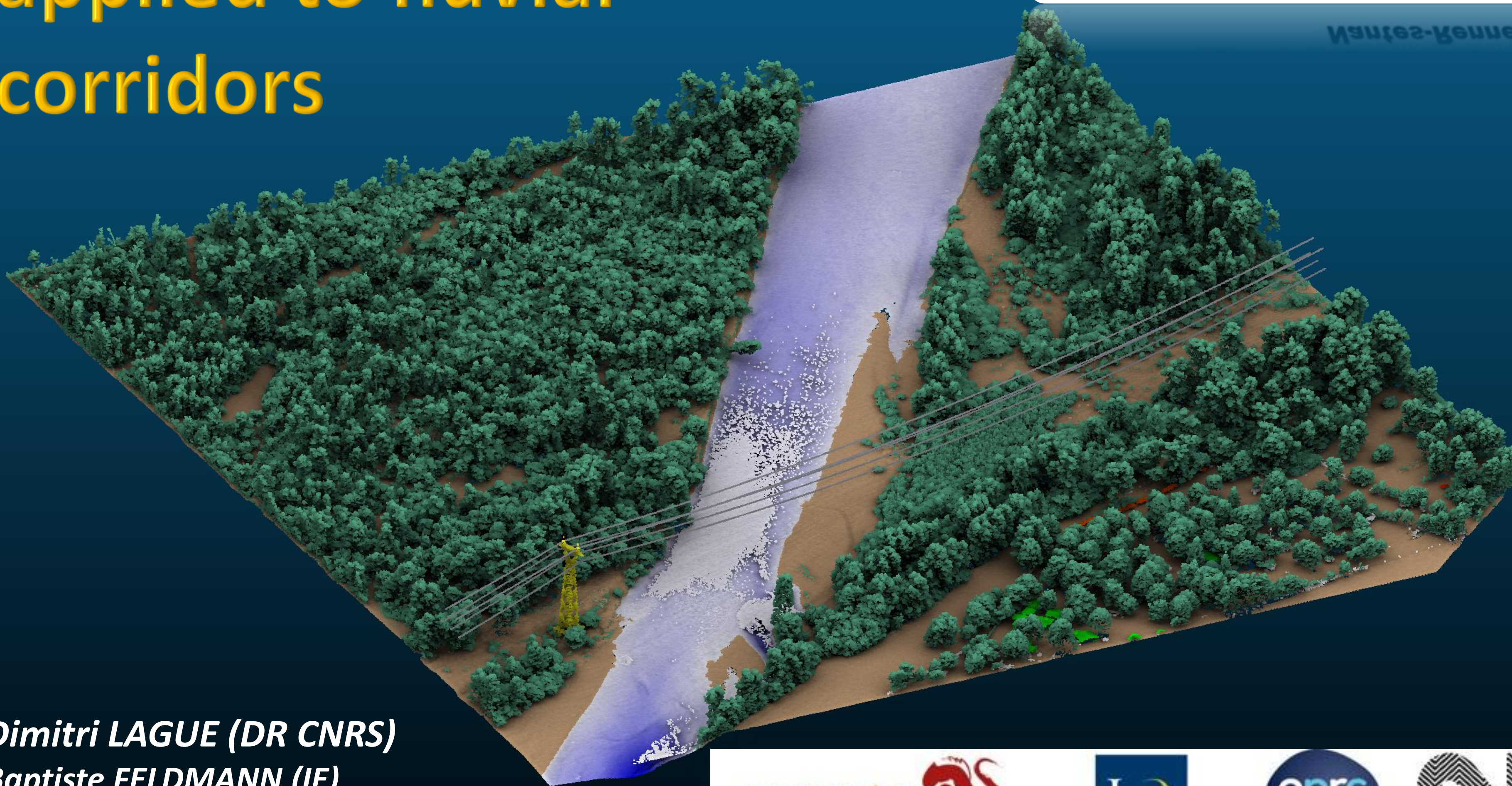
Instruments : Leica Chiroptera, Riegl VQ-880G, Optech Titan

See *McKean et al., (2009) (NASA EEARL), Mandlburger et al., (2015) (RIEGL), Pan et al., (2015), Launeau et al. (2017-18), Lague & Feldmann (2020) (OPTECH)…*

Optech Titan, only sensor of this type own by academia in Europe (University of Rennes and Nantes France)

Topo-bathymetric lidar applied to fluvial corridors

Plateforme **LIDAR topo-bathymétrique** Nantes-Rennes



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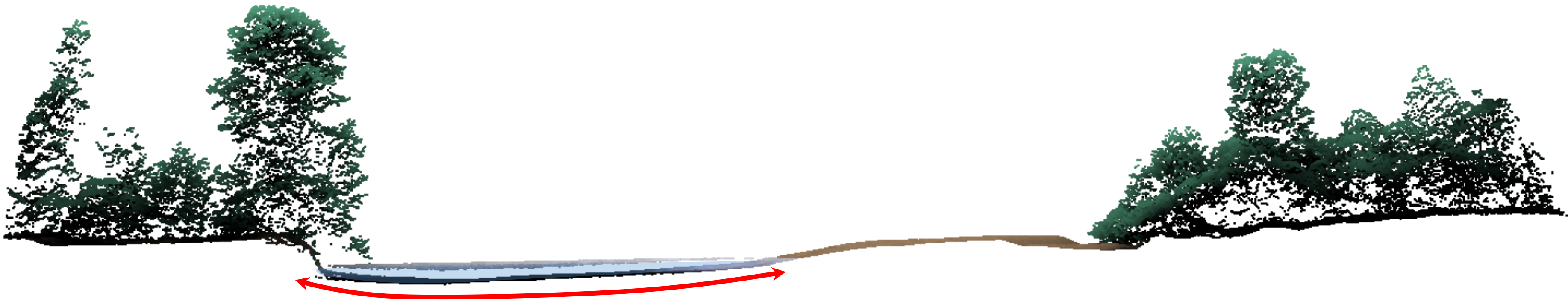
www.lidar-nantes-rennes.eu

Patrick Launeau (OSUNA/Université Nantes)

Why fluvial bathymetry matters



Where sediment and water transport occurs
Aquatic ecosystms

Flood prediction

Basic research on fluvial dynamics

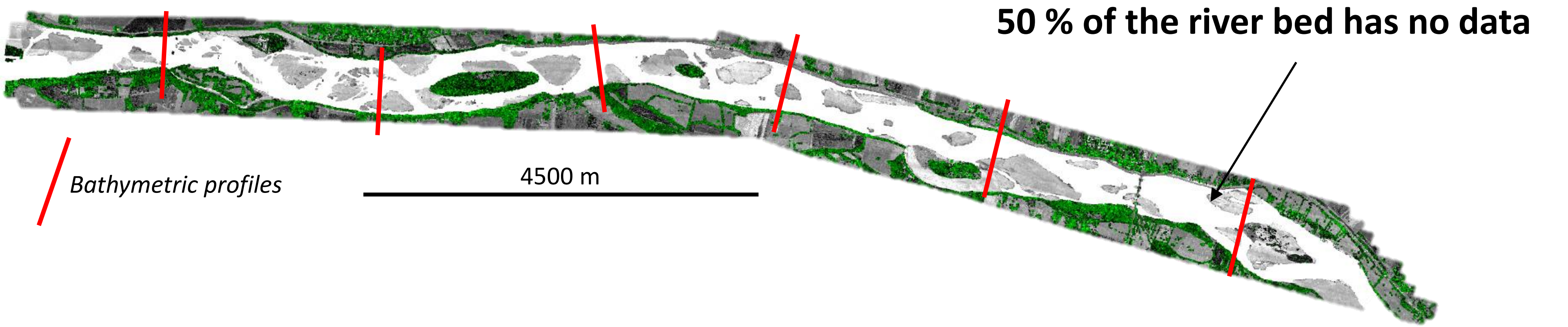
River restauration

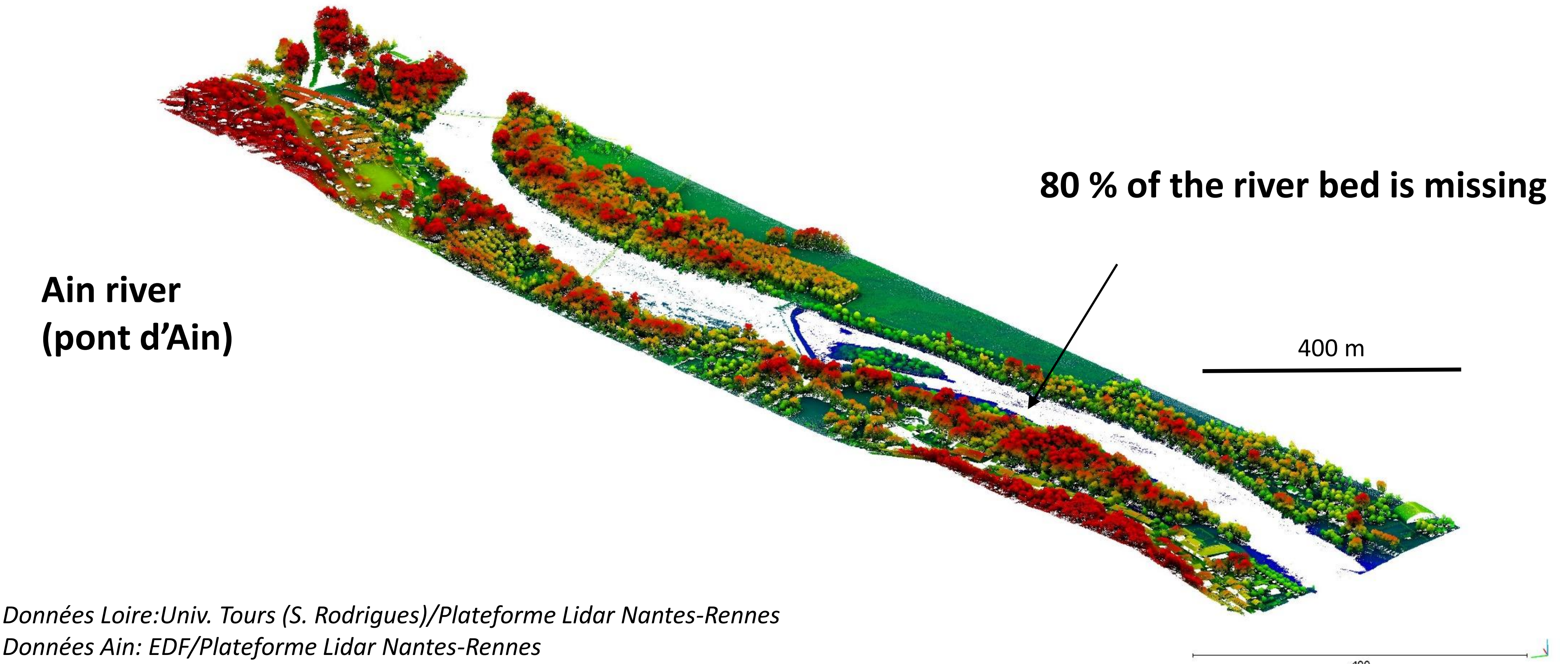
Managing gravel extraction

Bathymetry is missing in traditional topographic lidar

***Lidar topographique (1064nm)** : no water penetration*

Loire river near Angers during summer low flow



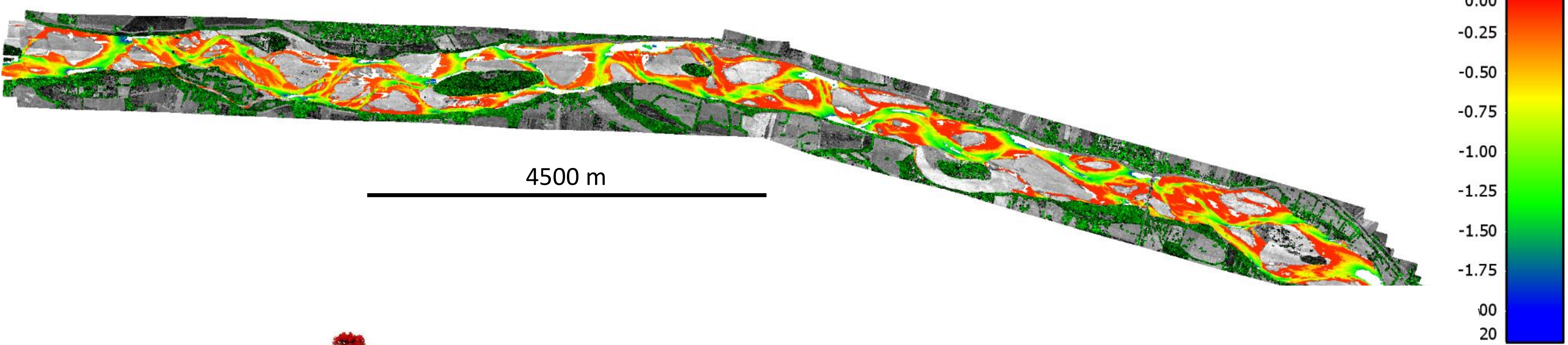


Données Loire:Univ. Tours (S. Rodrigues)/Plateforme Lidar Nantes-Rennes
Données Ain: EDF/Plateforme Lidar Nantes-Rennes

Adding green laser data

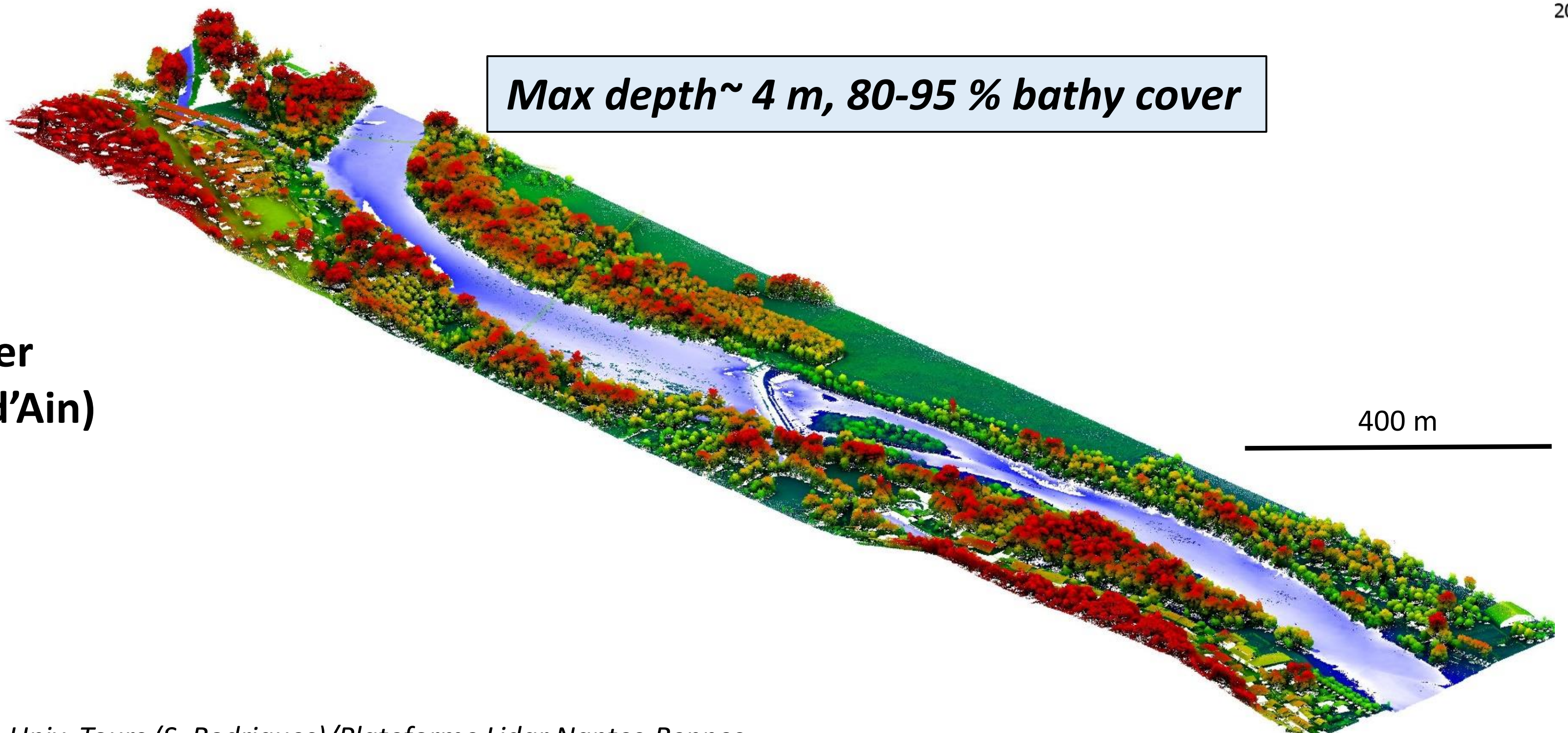
Loire river near Angers during summer low flow

Max depth ~ 2 m, 90 % bathy cover



Max depth~ 4 m, 80-95 % bathy cover

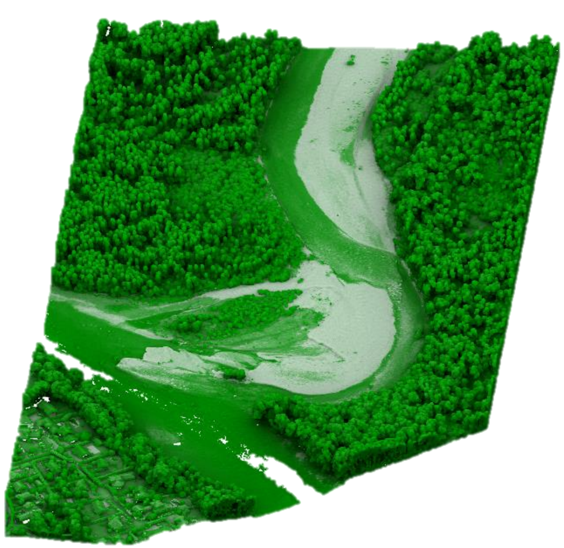
Ain river (pont d'Ain)



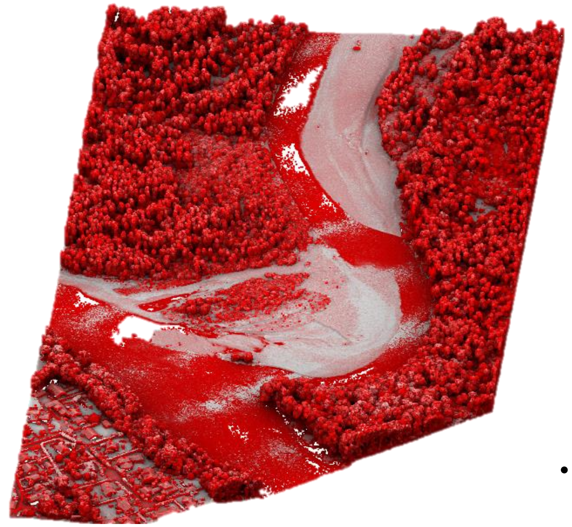
Données Loire:Univ. Tours (S. Rodrigues)/Plateforme Lidar Nantes-Rennes
Données Ain: EDF/Plateforme Lidar Nantes-Rennes

Two lasers = two point clouds

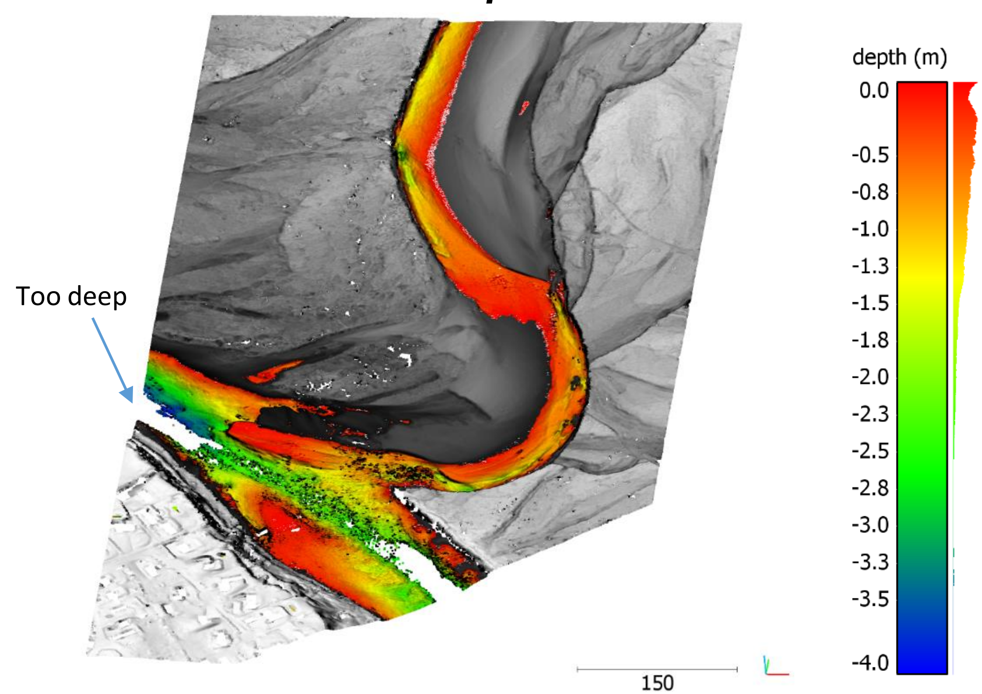
532 nm channel
topography + bathymetry



1064 nm channel
topography + water surface



Combined data with
. Ground/water/vegetation classification
. Laser refraction correction in water

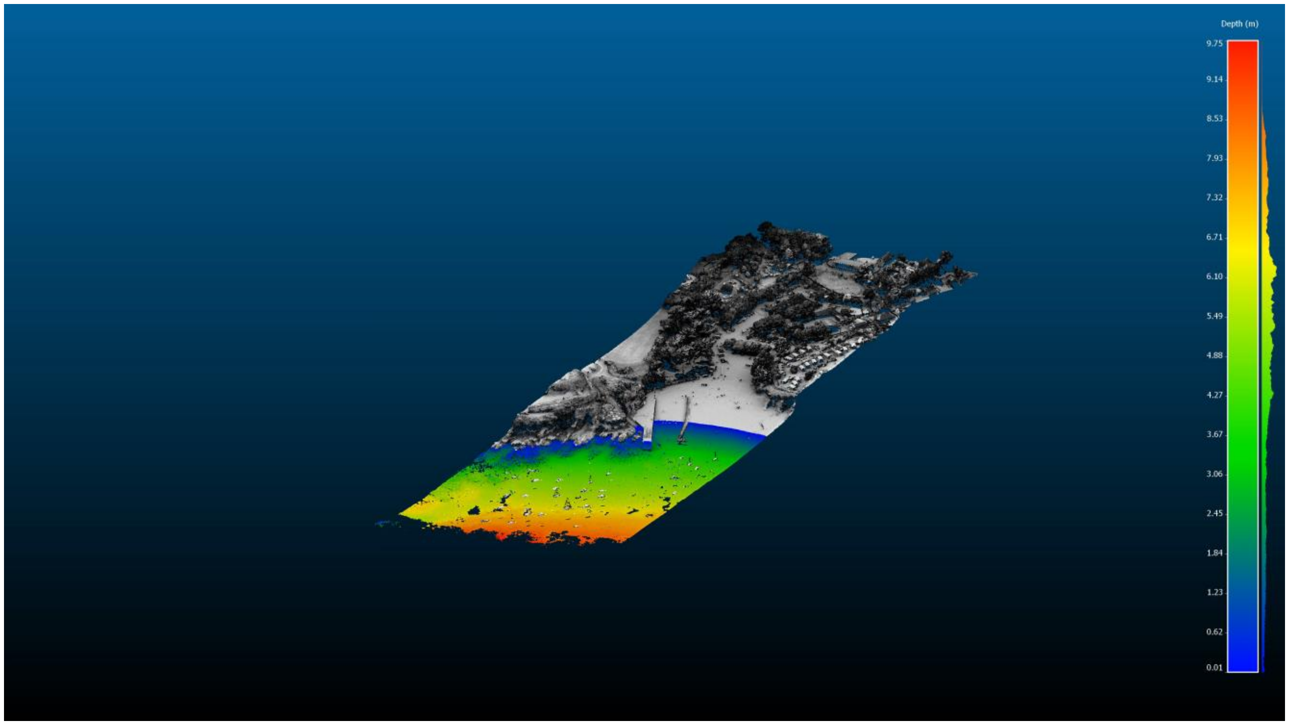


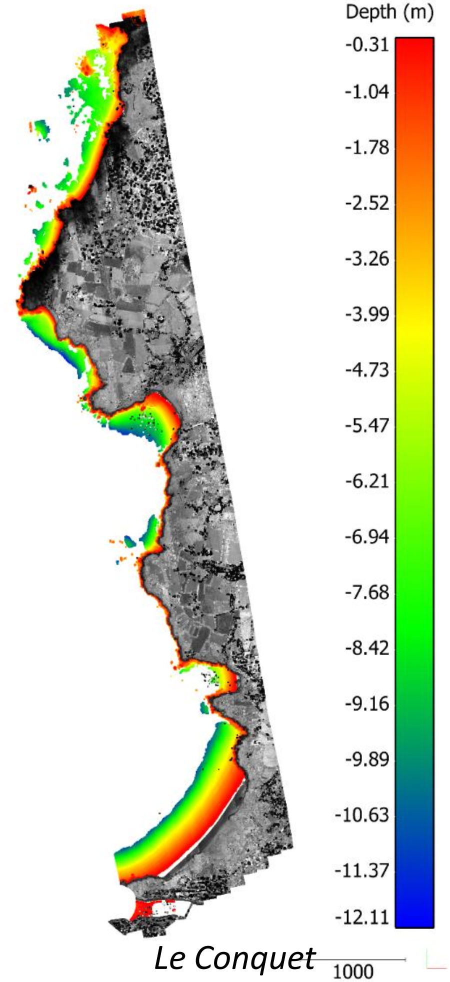
Confluence Ain/Rhône

From Lague and Feldmann, Remote Sensing in Geomorphology, 2020

Applications in coastal environments

Côte Bretonne, vols proche du Conquet





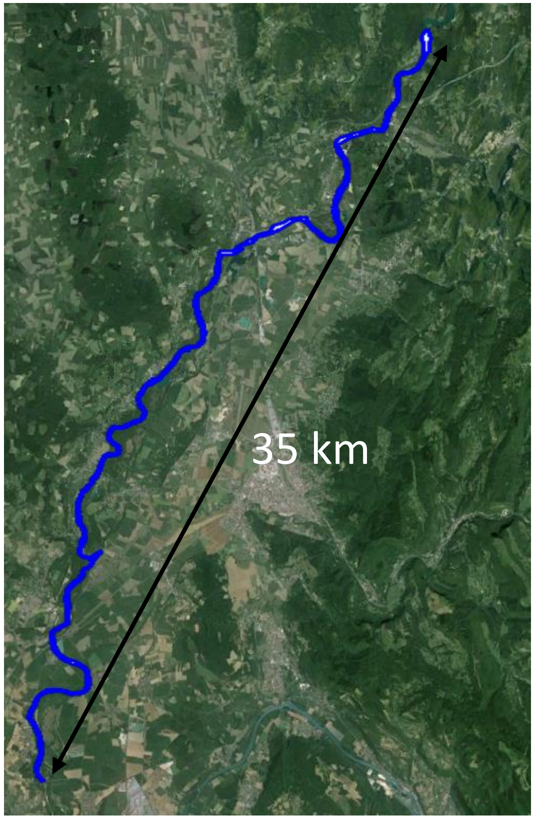
Anse de Bertheaume, Joint project IUEM/OSUR/OSUNA, 2017

Specific challenges in post-processing topo-bathymetric lidar data in rivers

Example from the Ain river survey

(data courtesy of Electricité De France)

1 day of acquisition, ~ 10 billions points, ~ 900 Go Data

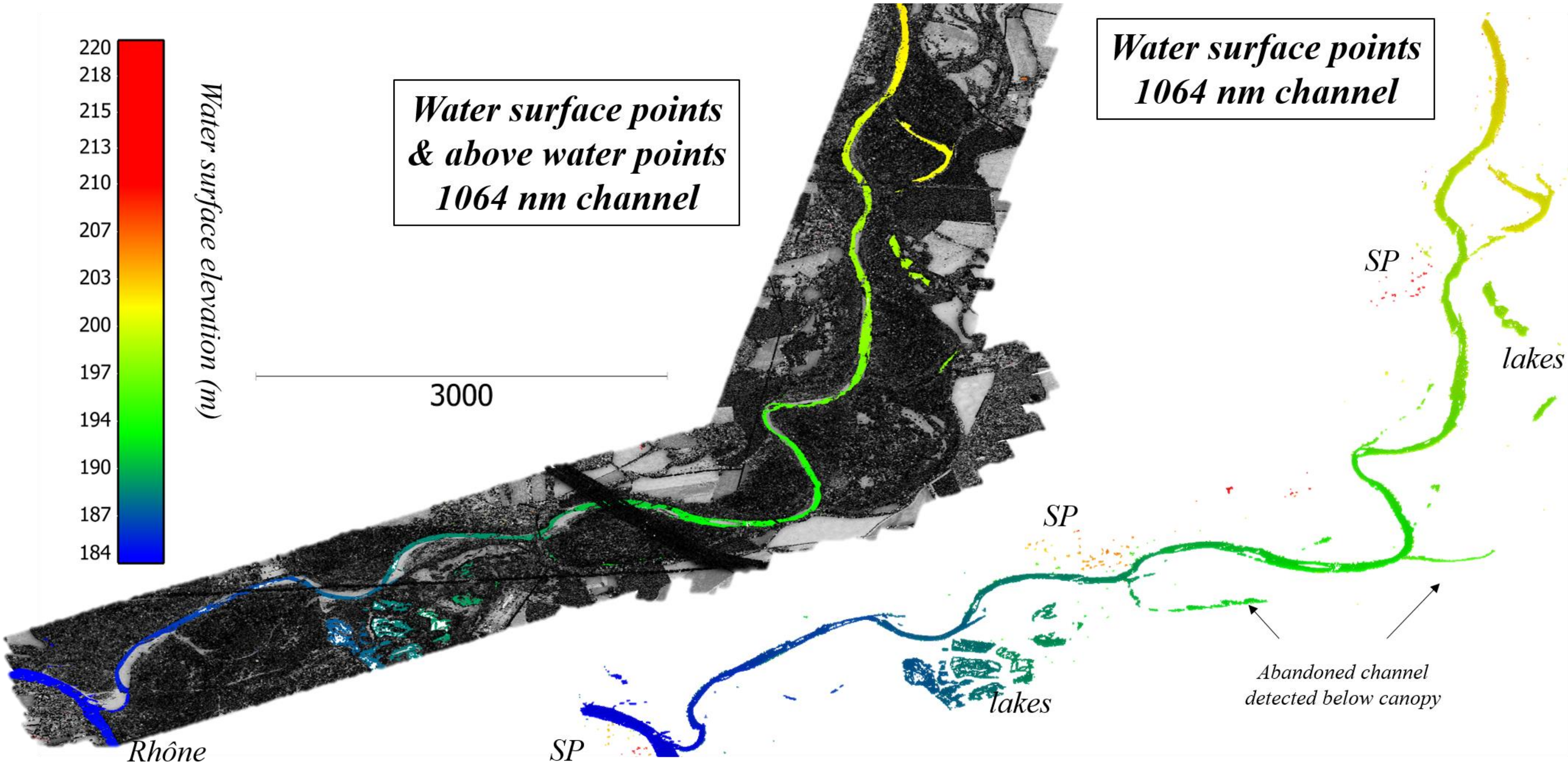


Operationnal challenge: ***automated post-processing***

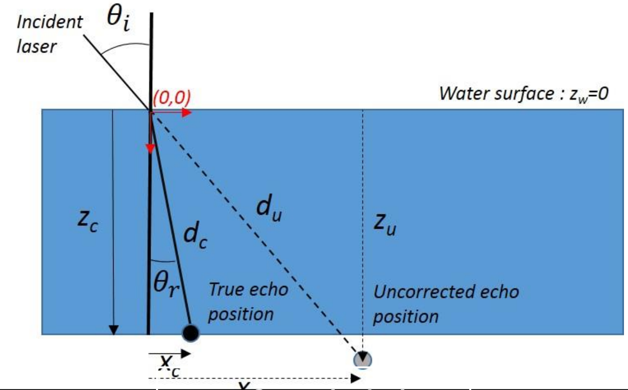
- **Land/water classification**
- **Water elevation measurement**
- **Green laser refraction correction for underwater points**
- **Detection of river bed echoes**

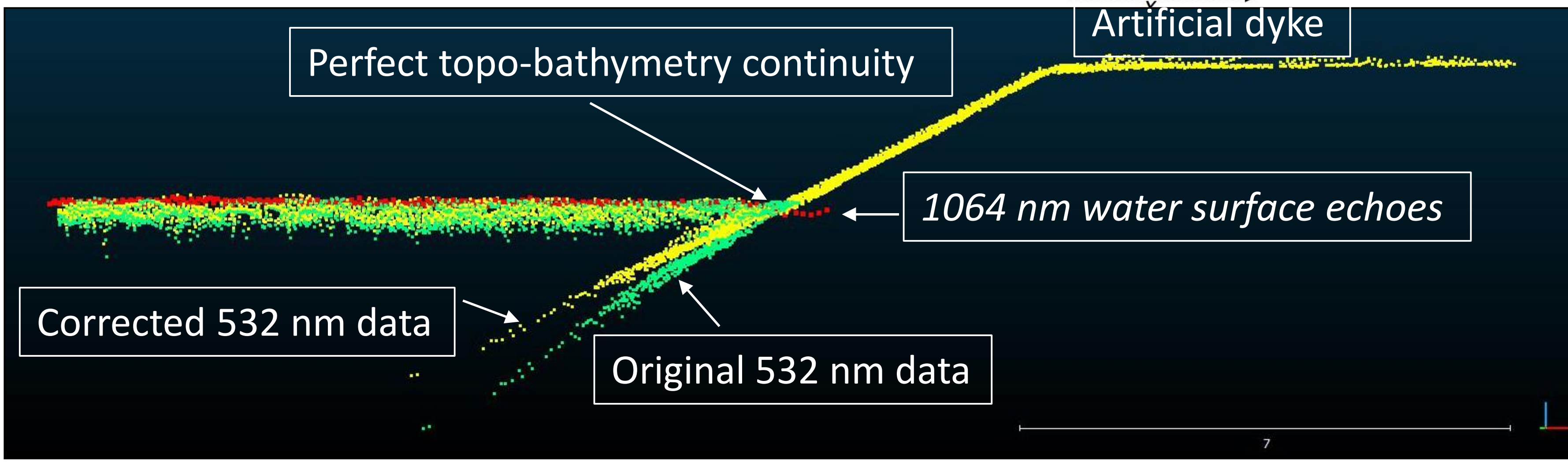
1. Automated land/water classification in 3D

Joint analysis of 1064 nm and 532 nm point cloud



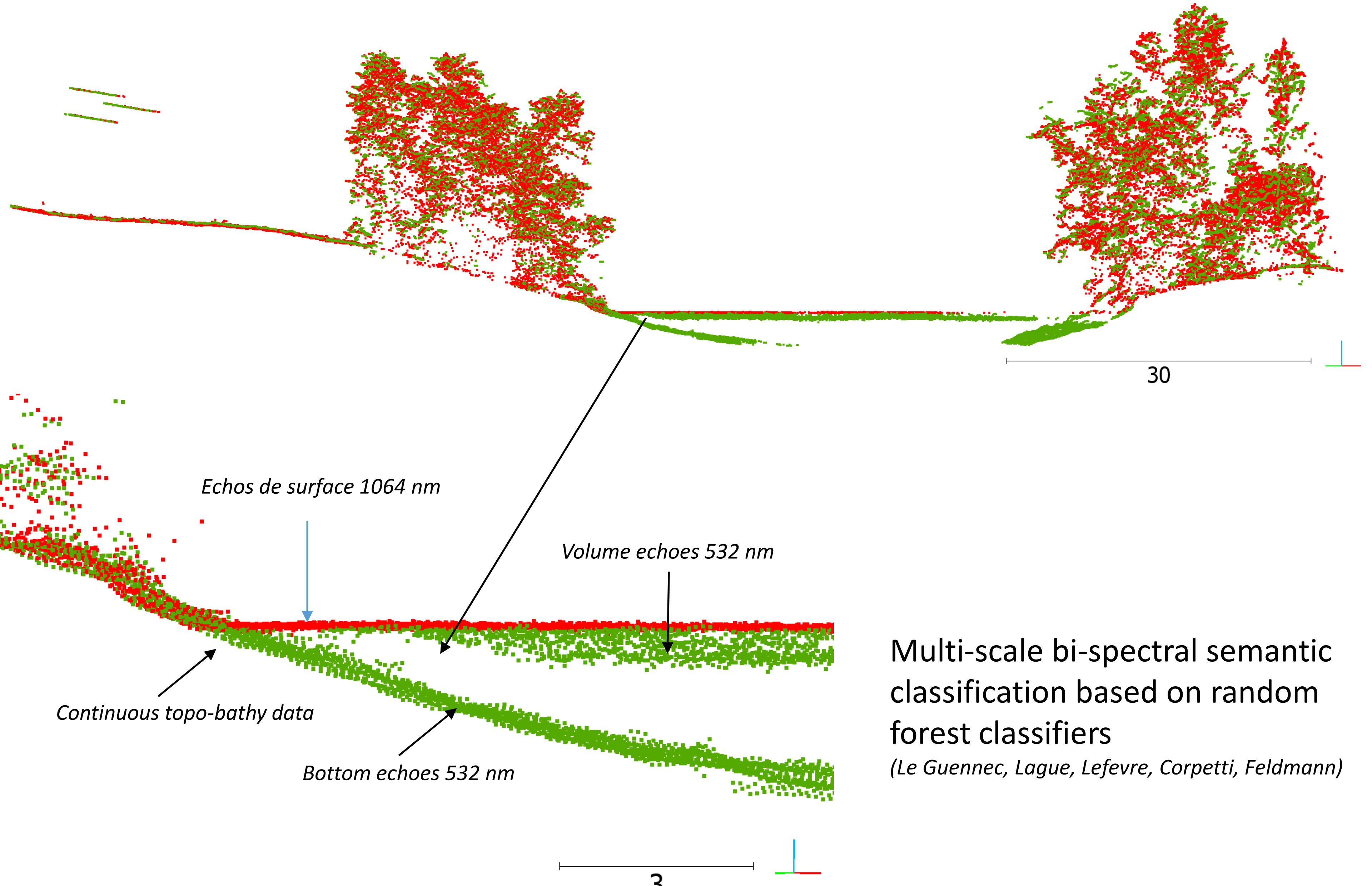
2. 3D Refraction correction for each point





Rhine Canal, highly turbid environment

3. Classification of volume and bottom echoes

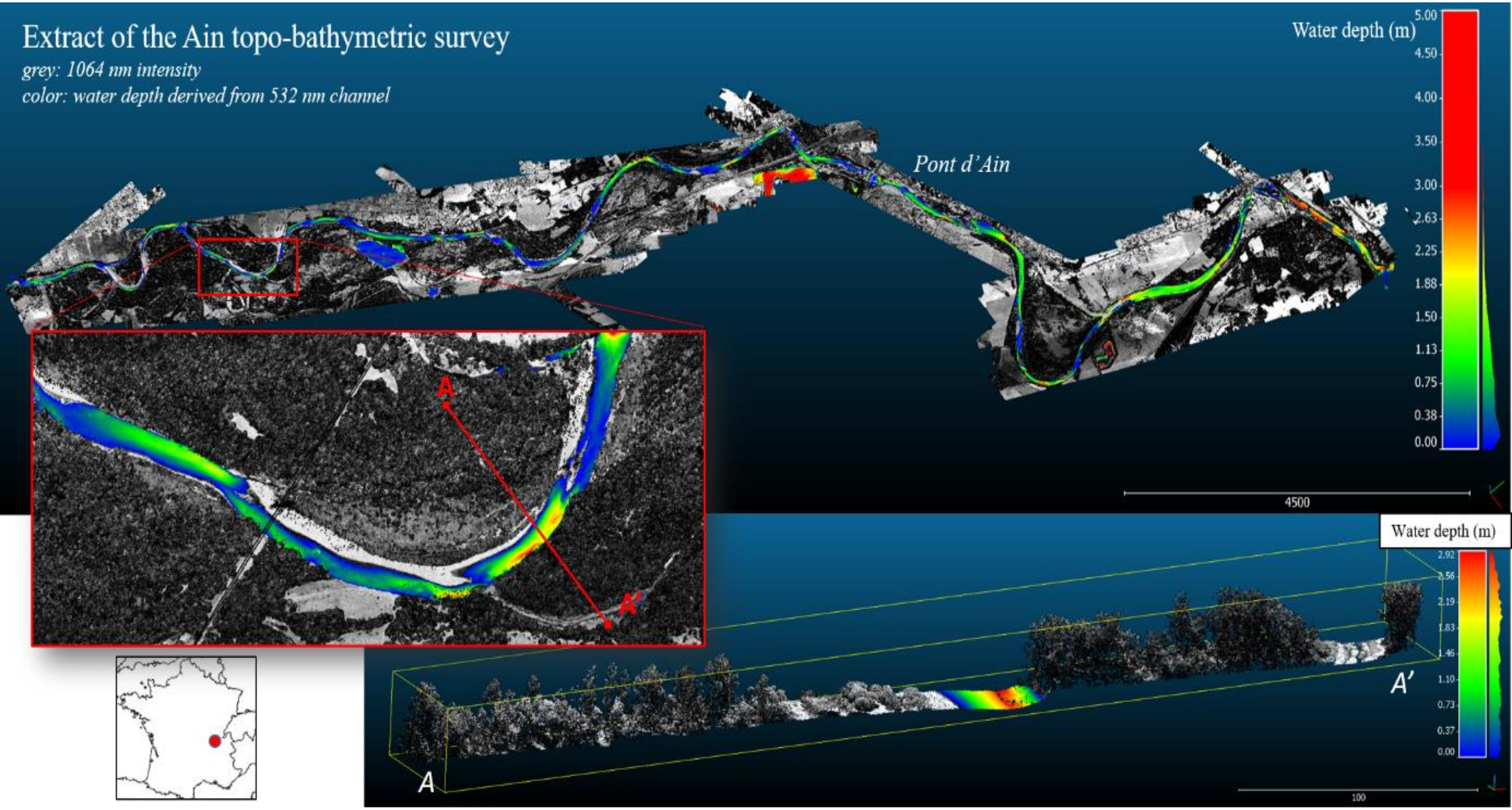


Multi-scale bi-spectral semantic classification based on random forest classifiers

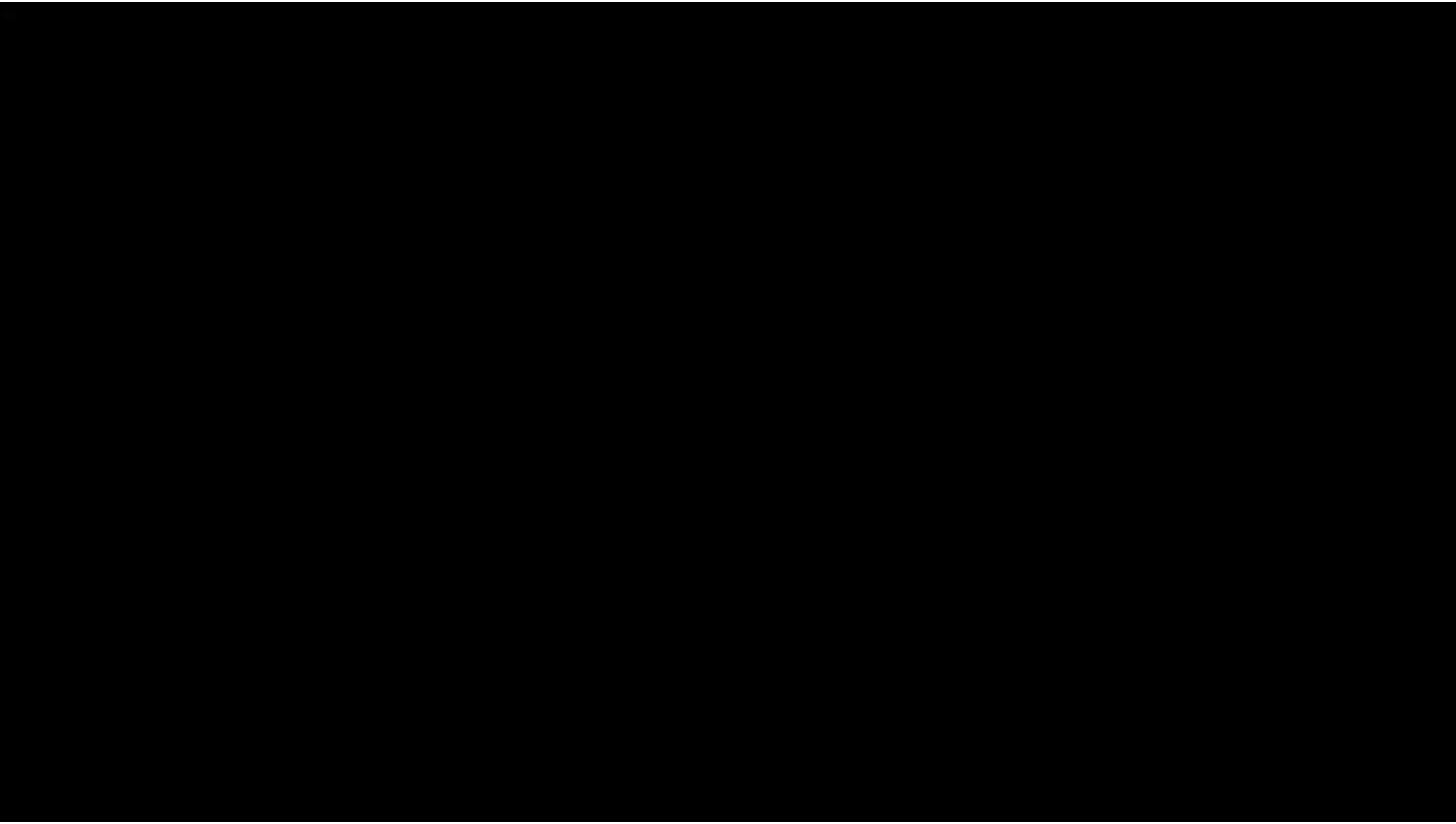
(Le Guennec, Lague, Lefevre, Corpetti, Feldmann)

From Lague et Feldmann, Topo-bathymetric airborne LiDAR for fluvial geomorphology analysis, Remote sensing in Geomorphology, 2020

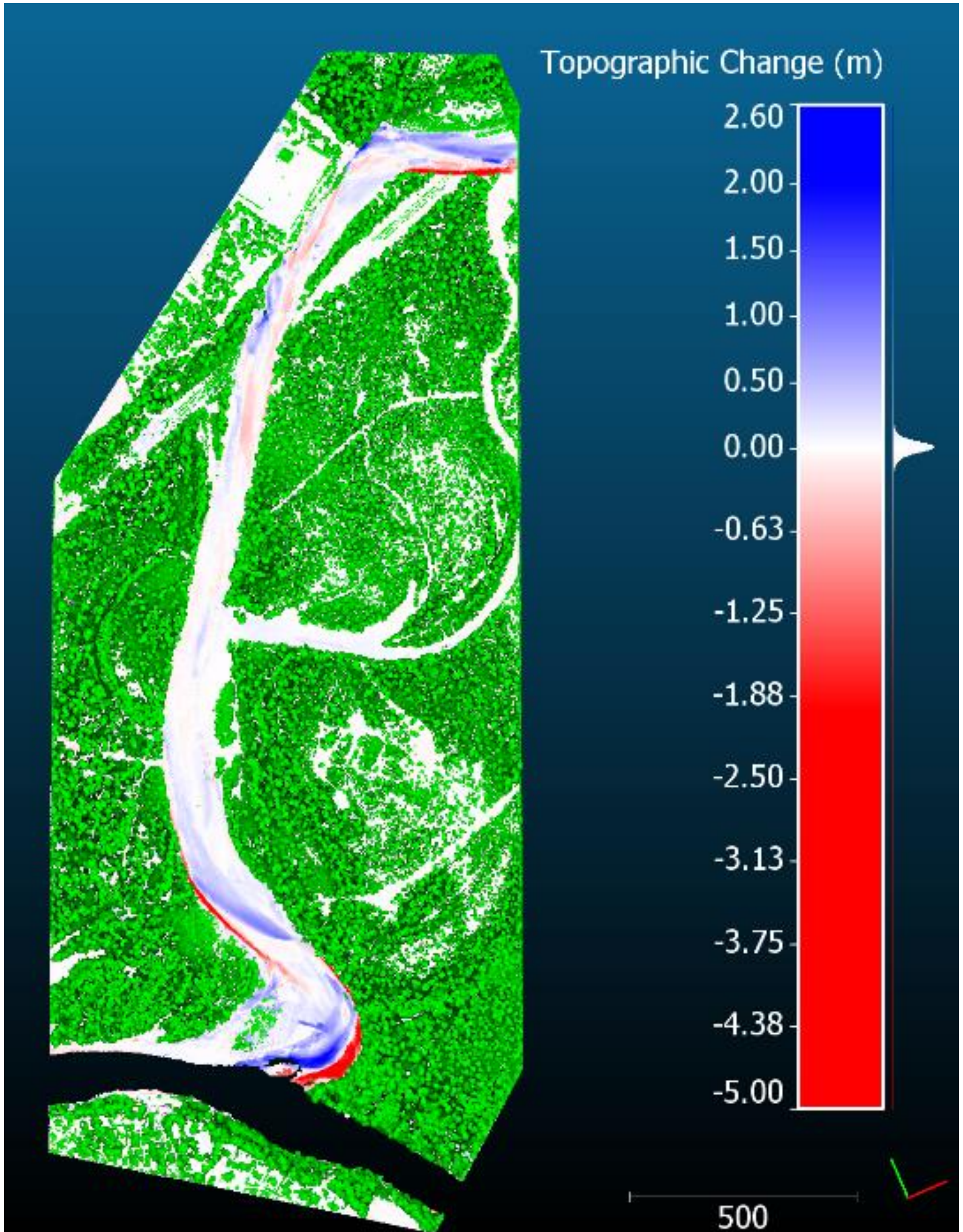
Final result: continuous topo-bathymetric data

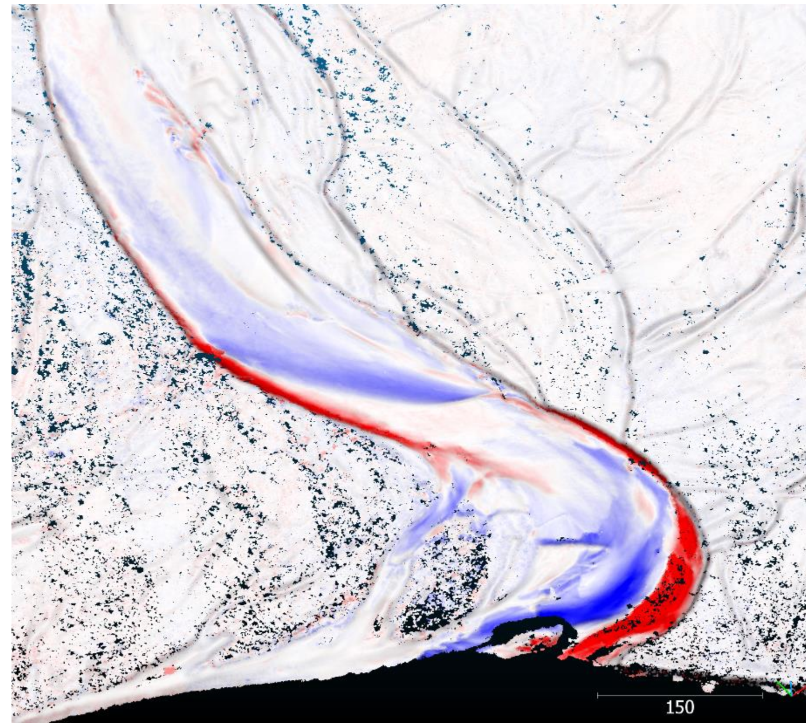


From Lague et Feldmann, Topo-bathymetric airborne LiDAR for fluvial geomorphology analysis, Remote sensing in Geomorphology, 2020



Applications: underwater change detection (2015-2016)



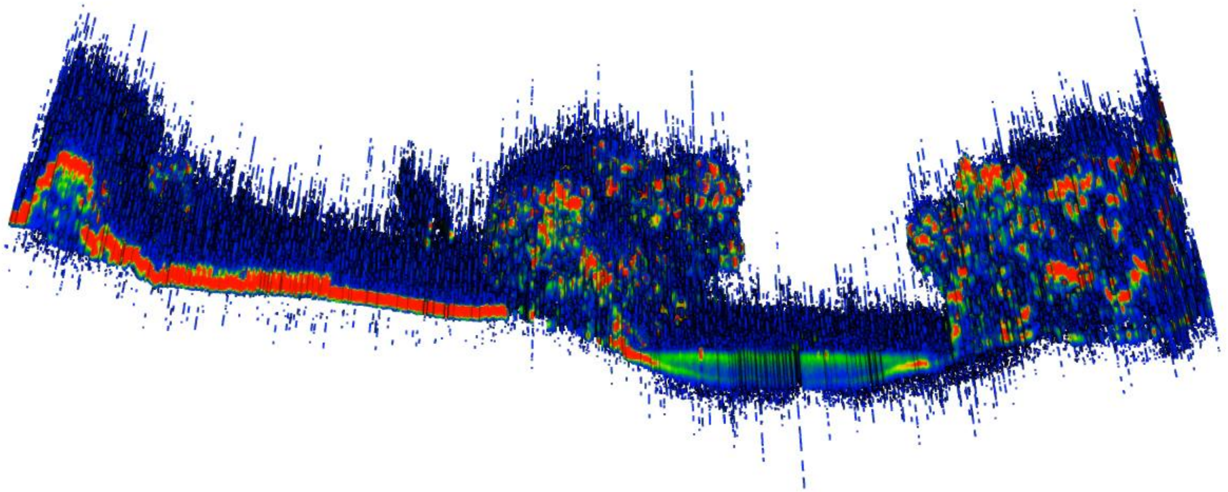


M3C2 algorithm (Lague et al, 2013)

Level of change detection (68%) : 5-8 cm !

Ongoing work : Using the FWF for advanced analysis of water bodies

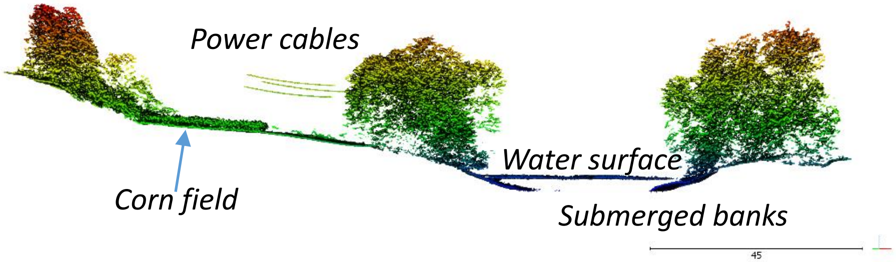
3D FWF shots converted to a point cloud with intensity (this is what lidar signal actually is)
(FWF plugin in Cloudcompare developped by the Lidar Platform)



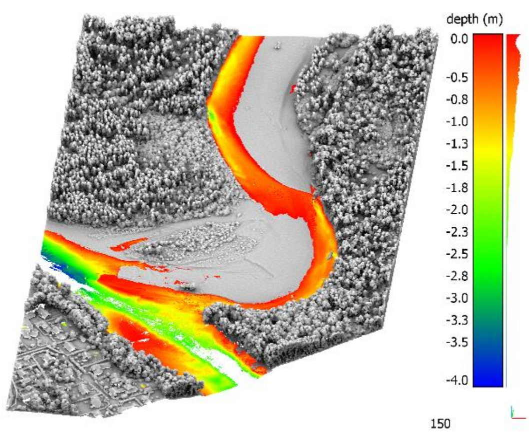
Key features:

- Bathy echoes are 10 - 100 times weaker than topo and veget -> **very low SNR**
- Discrete onboard echoes do not detect weak bottom echoes
- But the FWF 'cloud' clearly shows energy at the channel bed -> recoverable depth with algorithm that we are currently developping

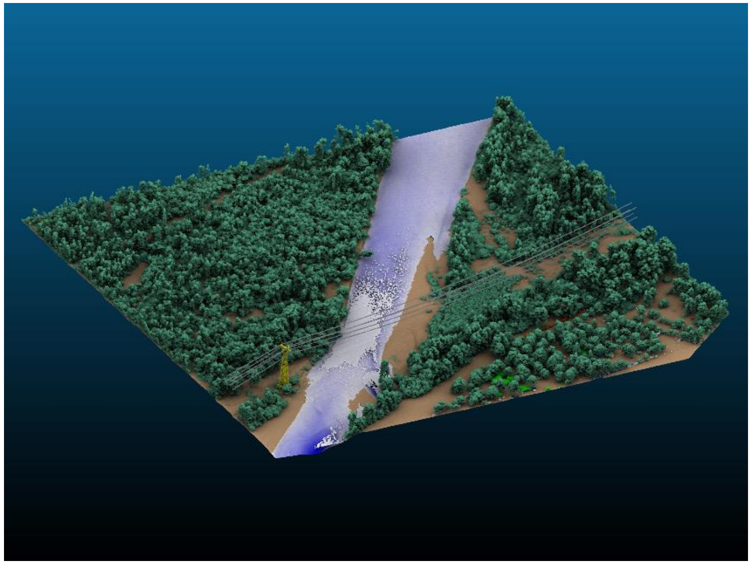
Discrete echoes 532 nm for reference

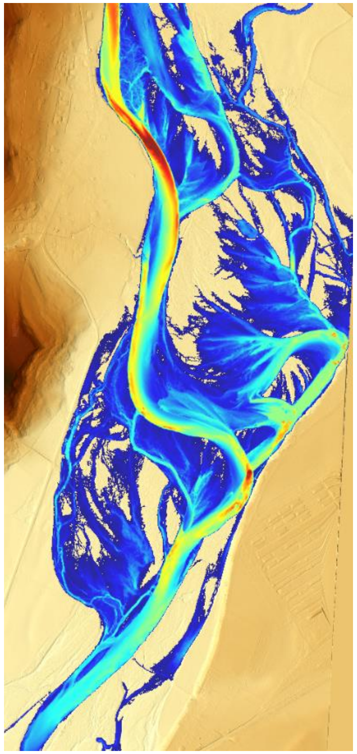


Topo-bathymétric Lidar for rivers



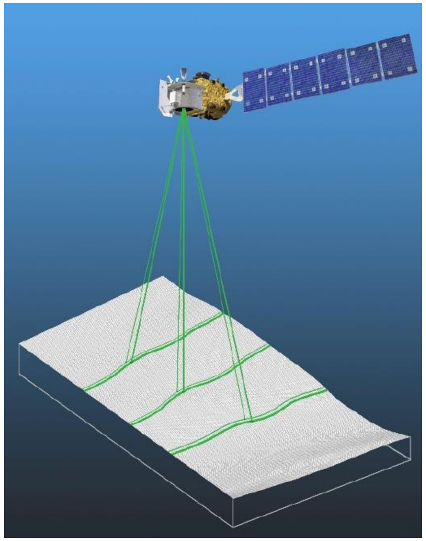
- High stakes data
- Some limitations due to water clarity
  - Not suitable for all rivers
- Interesting challenges in terms of post-processing with ongoing work on:
  - Semantic classification of point cloud
  - Full Waveform processing
  - Coupling of lidar processing with hydraulic modelling
- Contact me if you’re interested





Space Lidar : ICESat 2 (2018)

- For ice sheet elevation monitoring
- Elevation measurement with a precision +- 25 cm
- Footprint 25m on line spacing of 3 km
- 91 days resurvey
- Use photon counting



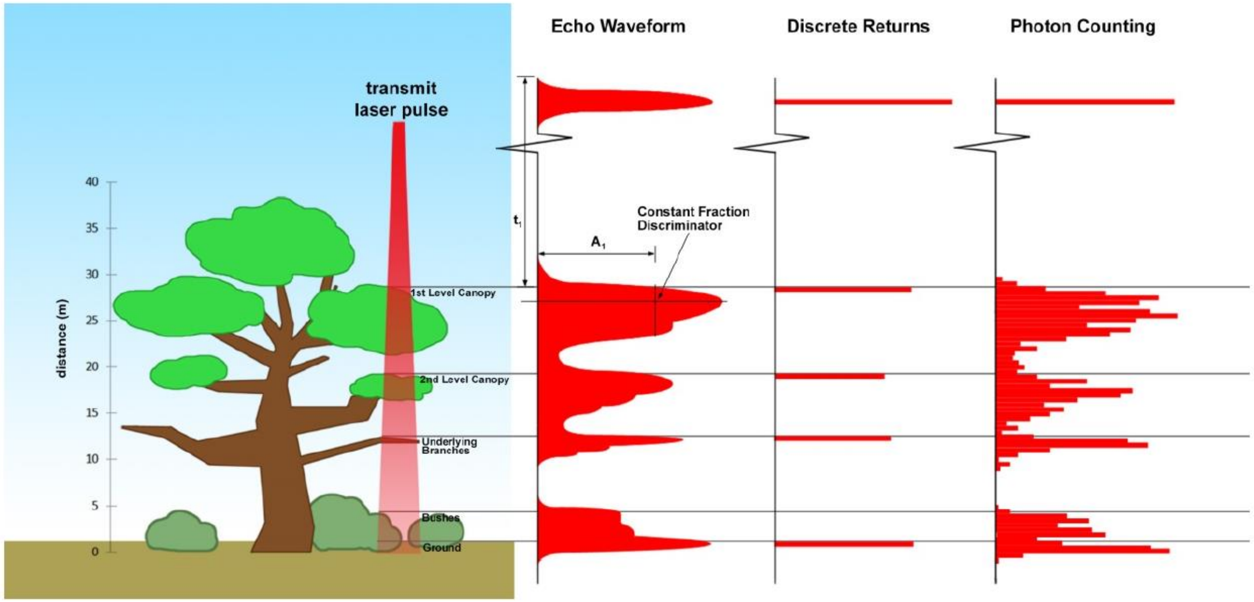
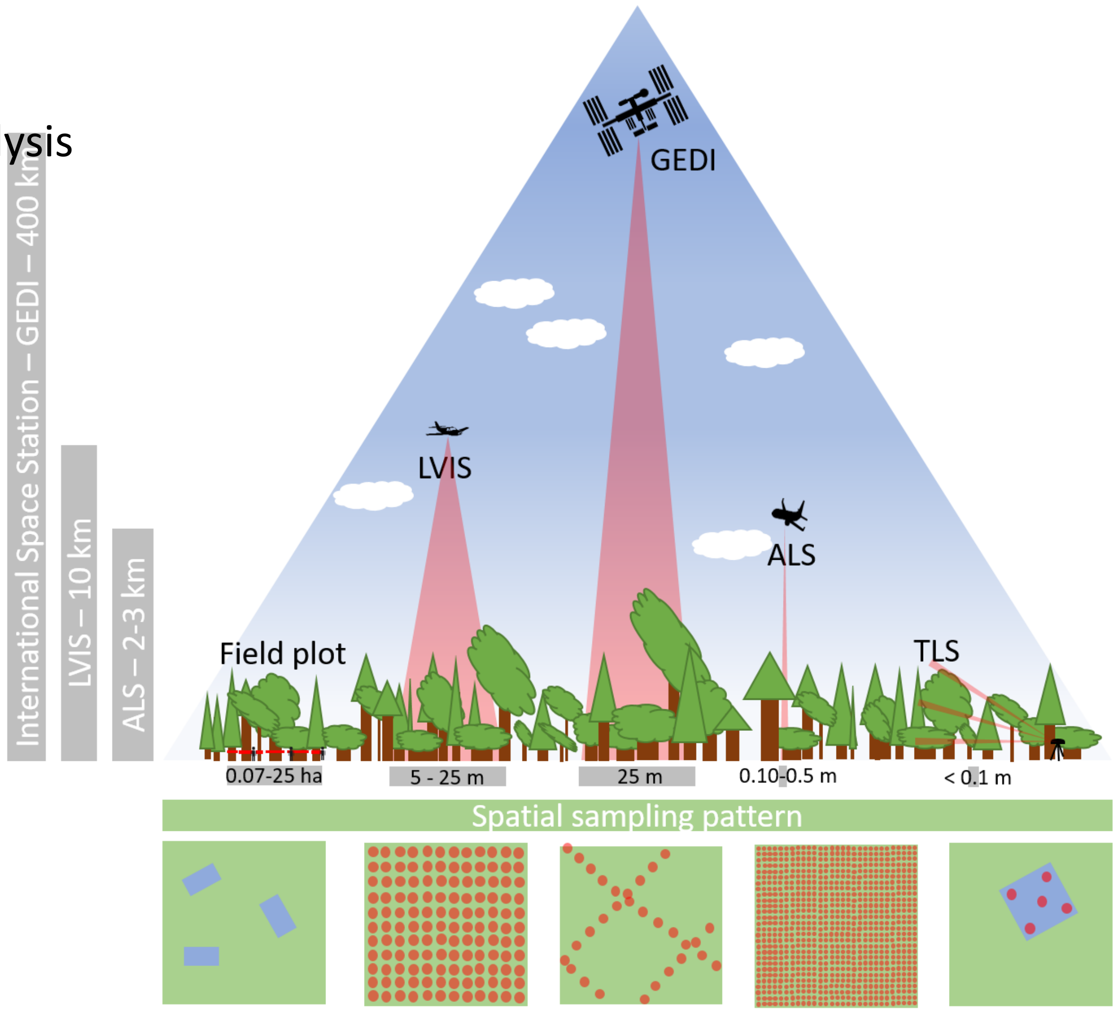


Figure 1.1. Various modalities of lidar detection. Adapted from Harding, 2009.

Lidar Spatial: GEDI (2019)

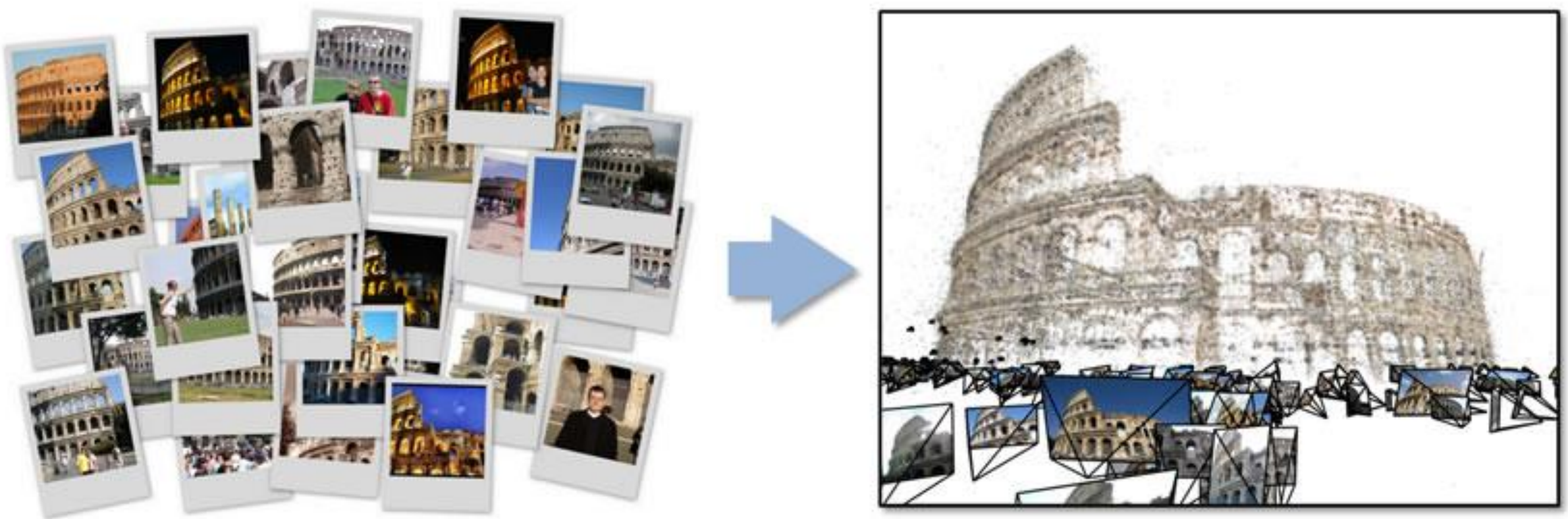
- Onboard the International Space Station
- Vertical precision +- 9 cm
- 25m footprint line every 1 km
- Photon counting
- Used for canopy structure analysis



https://gedi.umd.edu

Structure from Motion / Multiview Stereo

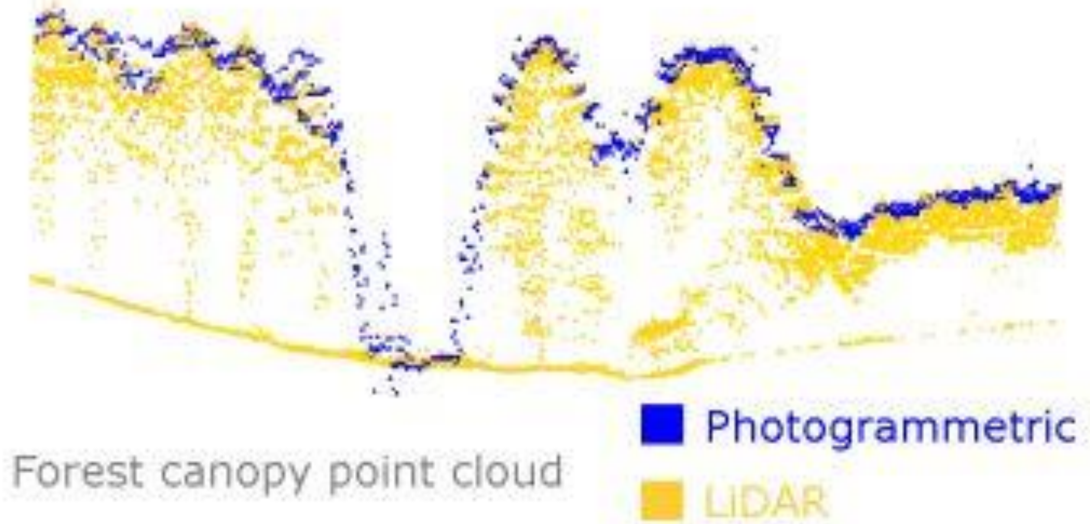
- This will be presented in greater detail in other courses.
- This is just a quick illustration to highlight the differences in the resulting 3D point cloud



Example of data obtained with a 1000 € UAV

(Mavic Pro (~ 1000 €)
Ed Baynes, Géosciences Rennes sur la dynamique des cascades en Nelle-Zélande)

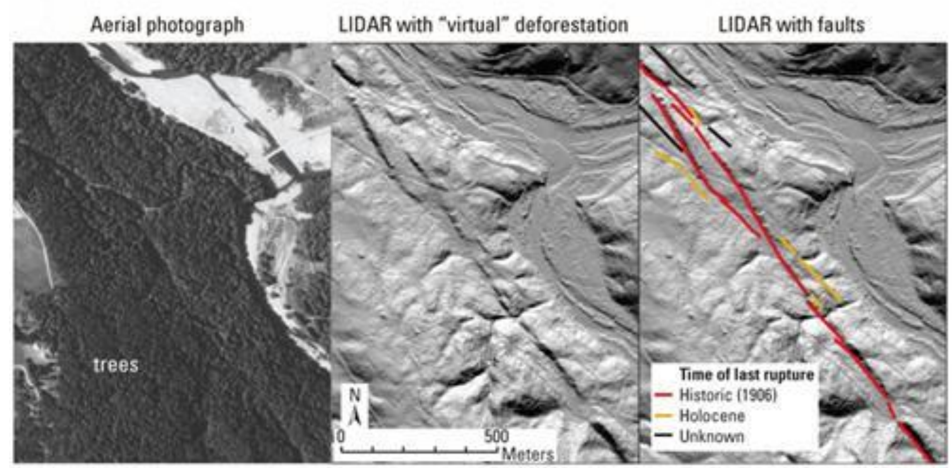
Lidar/SFM comparison



From Deseiligny, IGN

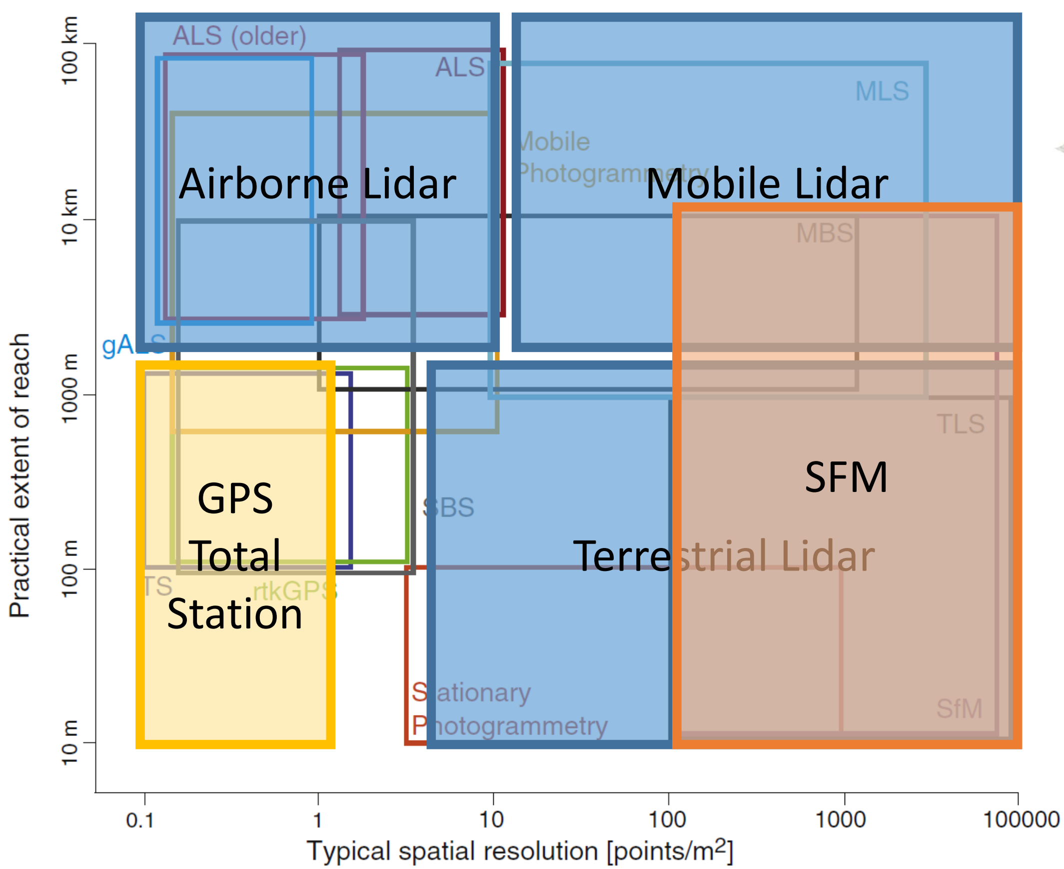
- LiDAR penetrate partially vegetation and may detect the ground below it.
- SFM CANNOT
- But on bare ground, SFM is an excellent alternative to lidar, much less expensive and resulting in much denser data.

Application : Geological fault detection



3D data : a large range of complementary techniques

P. Passalacqua et al. / Earth-Science Reviews 148 (2015) 174–193



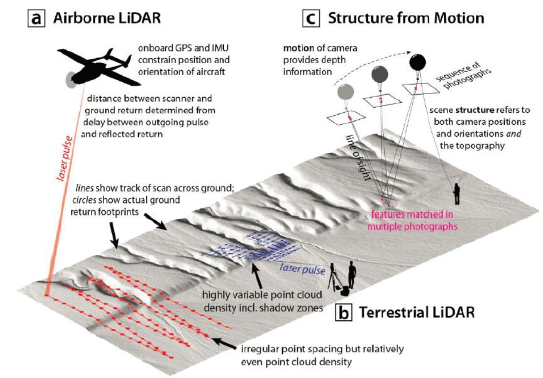
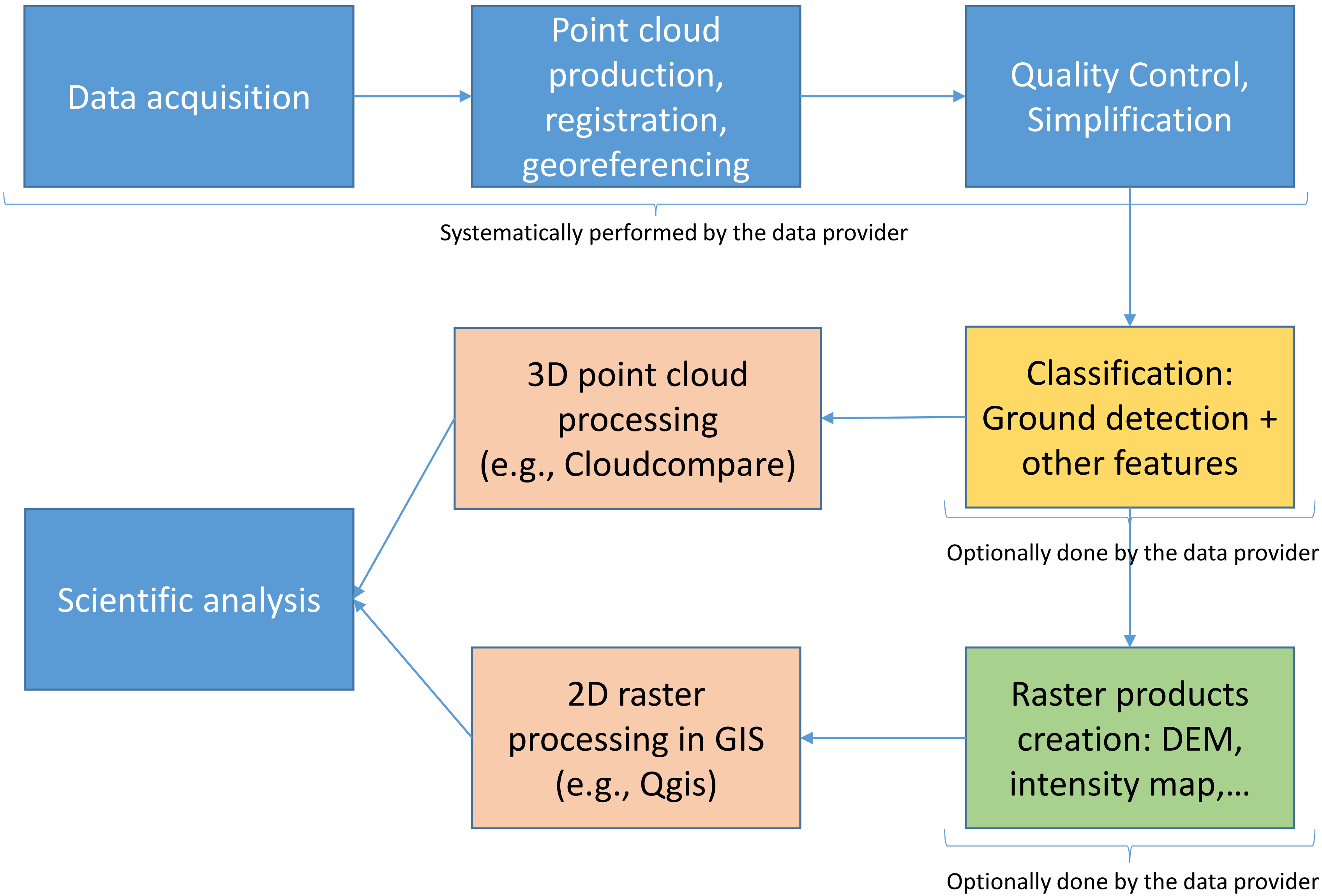


Fig. 1. Diagram of typical spatial resolution versus practical extent of analysis reach for Airborne Laser Scanning (ALS), green ALS (gALS), Mobile Laser Scanning (MLS), Total Station (TS), real time kinematic GPS (rtkGPS), single-beam SONAR (SBS), multibeam SONAR (MBS), stationary and mobile photogrammetry, Structure from Motion (SfM), and Terrestrial Laser Scanning (TLS).
Figure modified from Bangen et al. (2014).

LiDAR data processing workflow



Introduction to Cloudcompare

Practical part 1

- Getting data LiDAR data from Opentopography
- Handling and basic visualization/processing in Cloudcompare
- Principles of 2D raster creation

Practical part 2

- Distance measurements and change detection

Practical part 3 (if we have enough time)

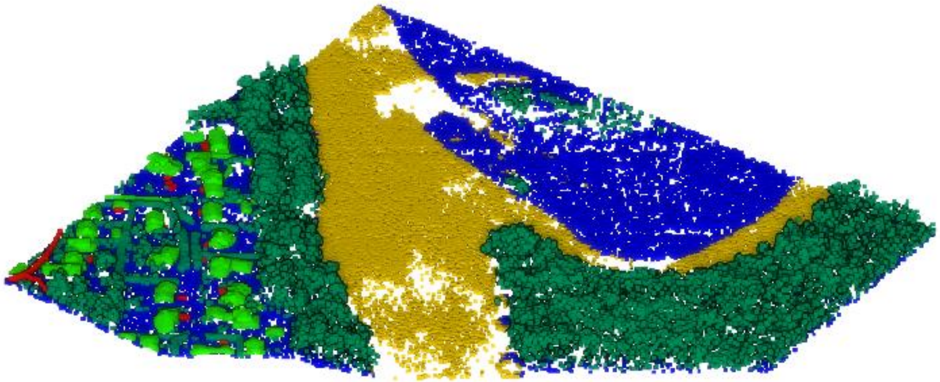
- Classification with qCANUPO

Point cloud classification

- **Semantic classification on <u>3D point clouds</u>: most of the points must be labelled (ideally all)**

Table 1. ASPRS Standard LIDAR Point Classes

Classification Value (bits 0:4)	Meaning
0	Created, never classified
1	Unclassified[1]
2	Ground
3	Low Vegetation
4	Medium Vegetation
5	High Vegetation
6	Building
7	Low Point (noise)
8	Model Key-point (mass point)
9	Water
10	Reserved for ASPRS Definition
11	Reserved for ASPRS Definition
12	Overlap Points[2]
13-31	Reserved for ASPRS Definition



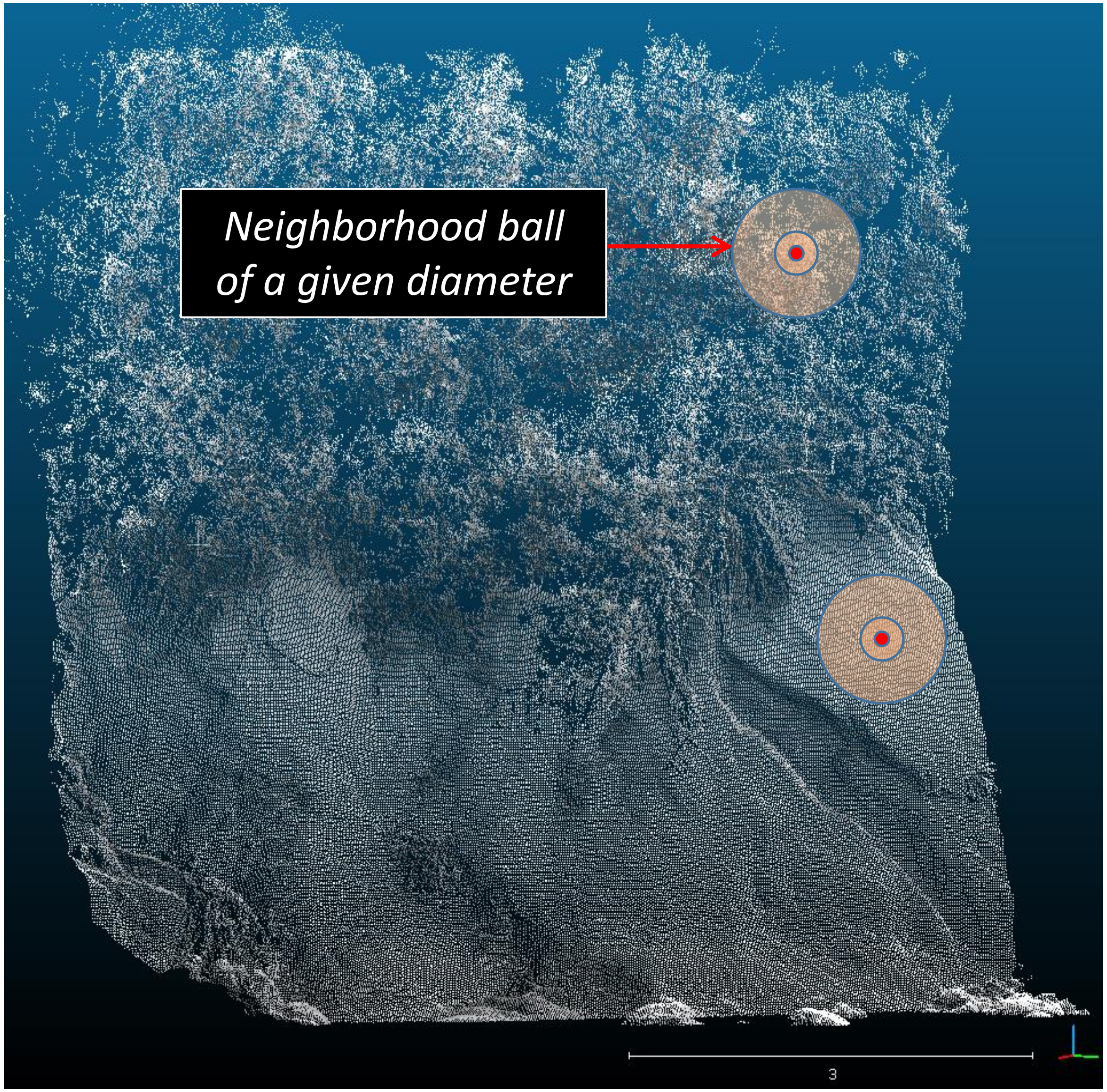
- **Essential task to extract data of interest:**
  - Ground for DEM analysis, topographic change
  - Vegetation for ecological studies

- **Airborne lidar:**
  - **Historically, rule based approaches (ground slope, angle between points, echo number ….)**
    - **Extraction of ground points (Note: the last echo below vegetation is not systematically the ground !)**
    - **Classification of above-ground features**
    - *Commercial softwares: Terrasolid, Lastools,….*
    - *Open source solutions: MCC, CSF*
  - **Recent trends: classical machine learning approaches based on point cloud features**
  - **Last 3 years: deep learning on 3D point cloud**

- **Terrestrial lidar:**
  - **Urban environments and man-made object classification: large research field driven by robotics and autonomous vehicle**
  - **Natural environments: few solutions ->** e.g., CANUPO algorithm (Brodu and Lague, 2012)

Example of semantic point cloud classification
Multiscale dimensionality classification, qCANUPO plugin

(Brodu and Lague, ISPRS journal, 2012)



Vegetation at <u>1-10 cm scale</u>

2D elements : leaves

1D elements : stems

Vegetation at <u>50 cm scale</u>

3D aspect : bush, canopy

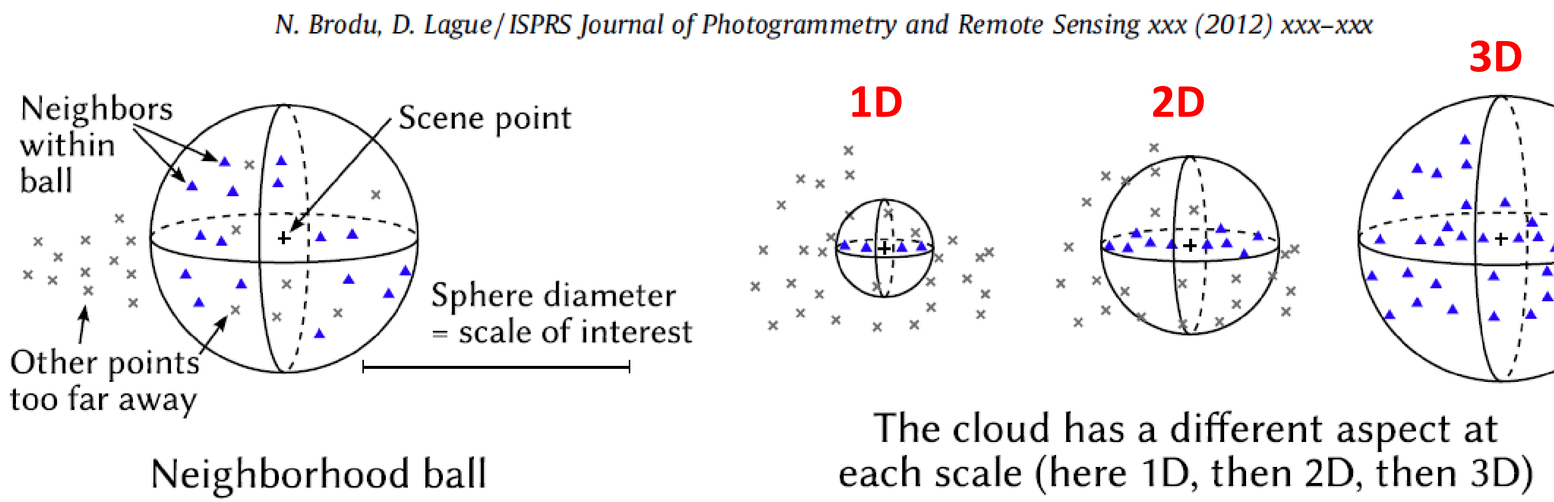
Bedrock at scales <u>up to 1 m</u>

~ 2D surface

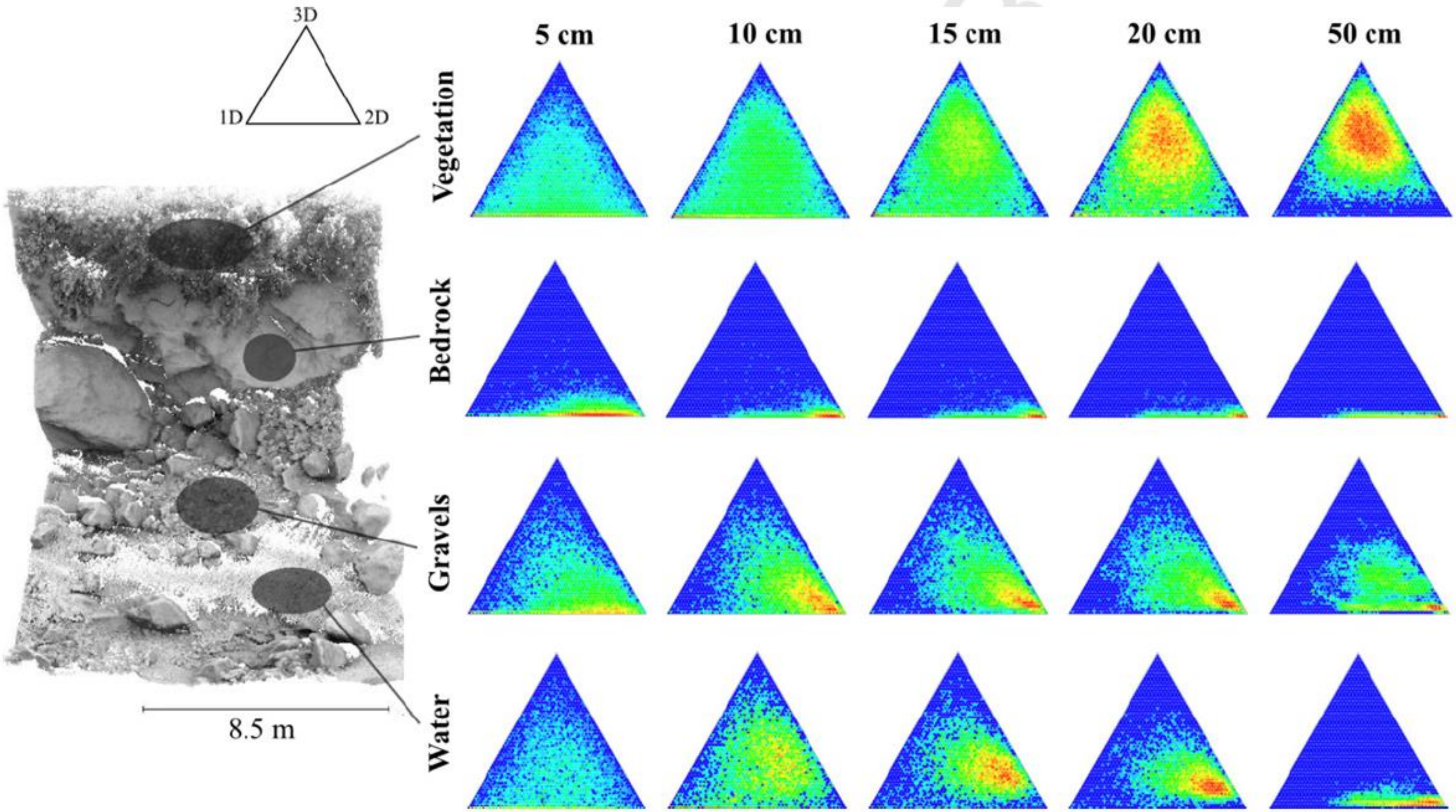
Scene elements are characterized by different combination of dimensionality over scales ranging from e.g. 2 cm to 1.5 m

Multi-scale dimensionality classification. Concept

- **Use the large range of spatial scales available in high res TLS data, e.g. 1 cm - 100 m**
- Define a simple 3D geometrical property of the point cloud : the local dimensionality (e.g. Vandapel et al., 2004)
  - Obtained using a principal component analysis on the neighbors of a scene point.

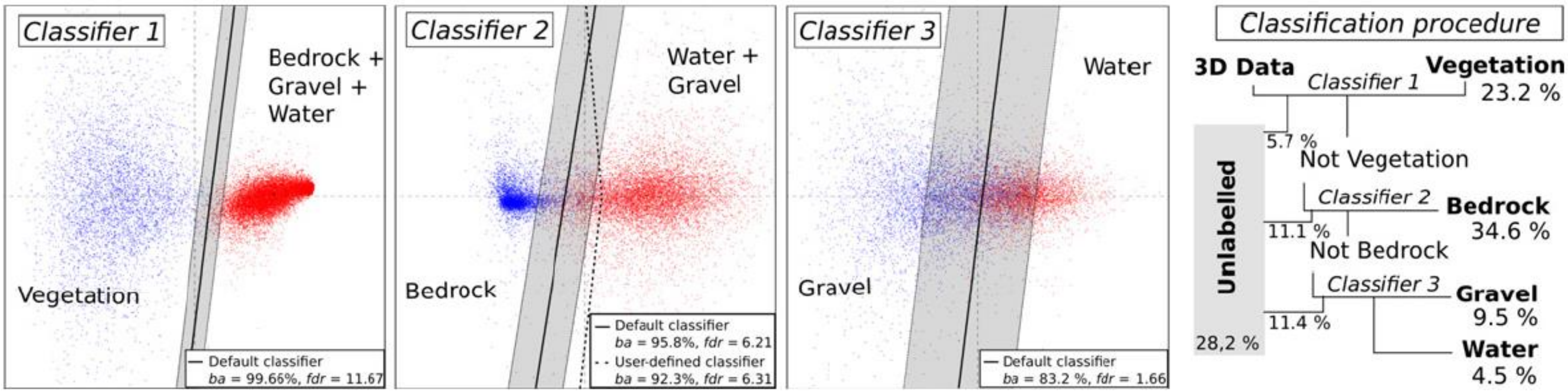


Visualizing dimensionality at various scales

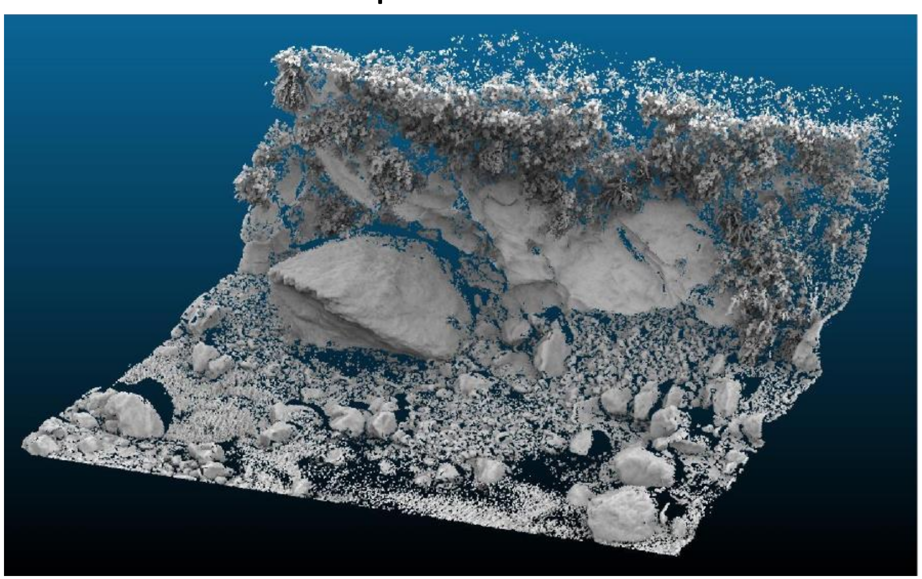


- Vegetation is clearly distinct from bedrock only at scale > 20-50 cm
- Vegetation cannot be clearly separated from gravels at any single scale
- Gravels and water surface have similar dimensionality signature at any single scale

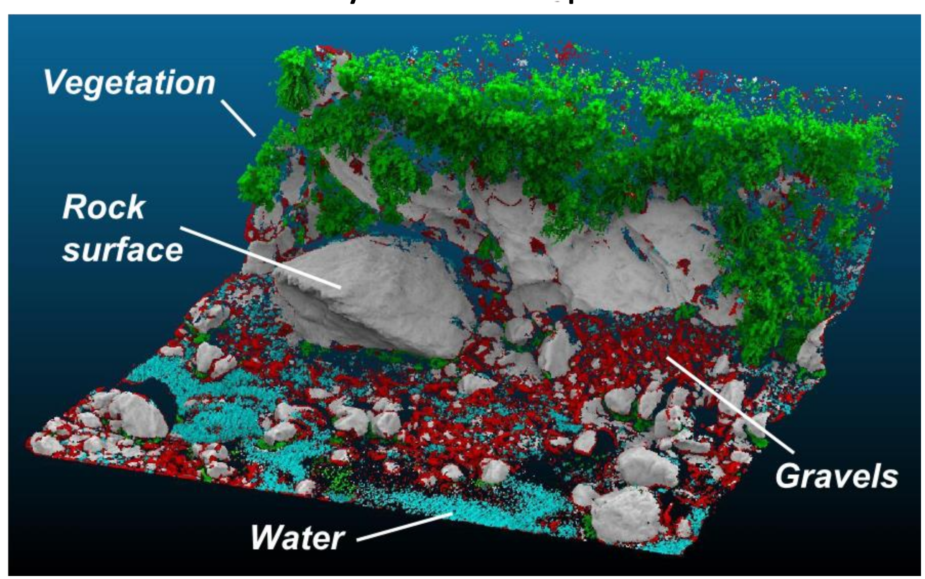
Classification results : complex case



Raw point cloud



Automatically classified point cloud



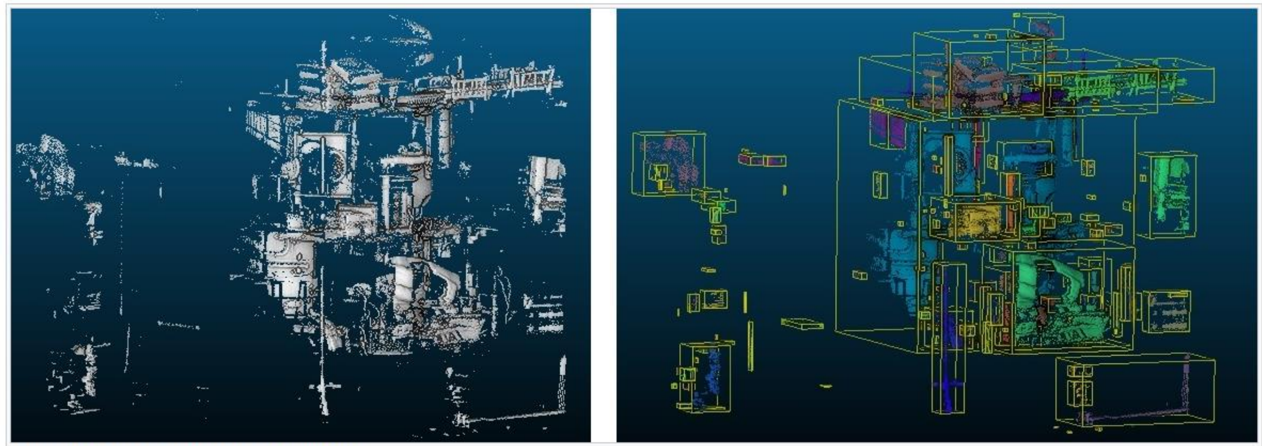
Examples of 3D clustering after classificaiton: boulder extraction in rivers

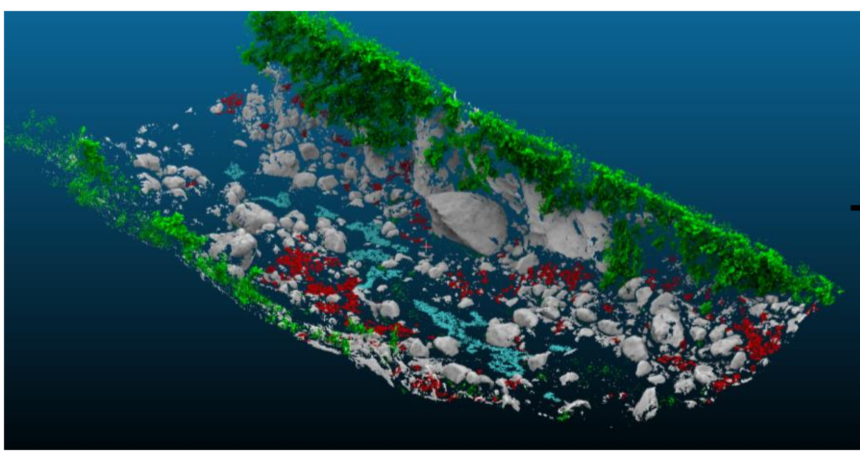
Label Connected Component (available in CC)

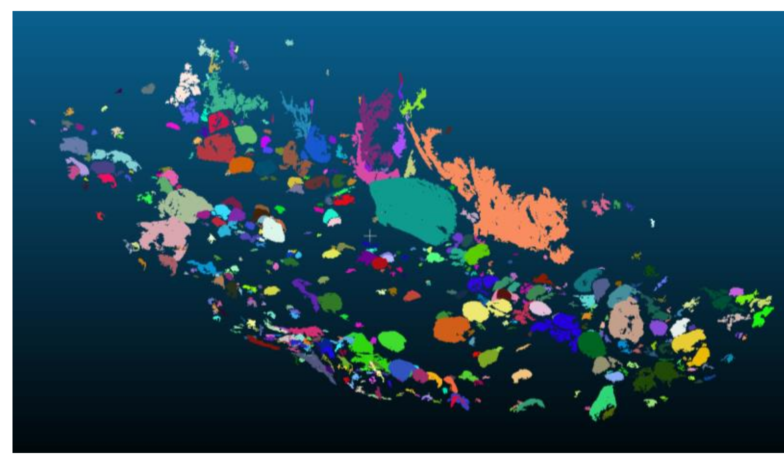
Clustering approach based on nearest neighbor distance calculation *d*

If d< threshold_distance

add to local_cluster

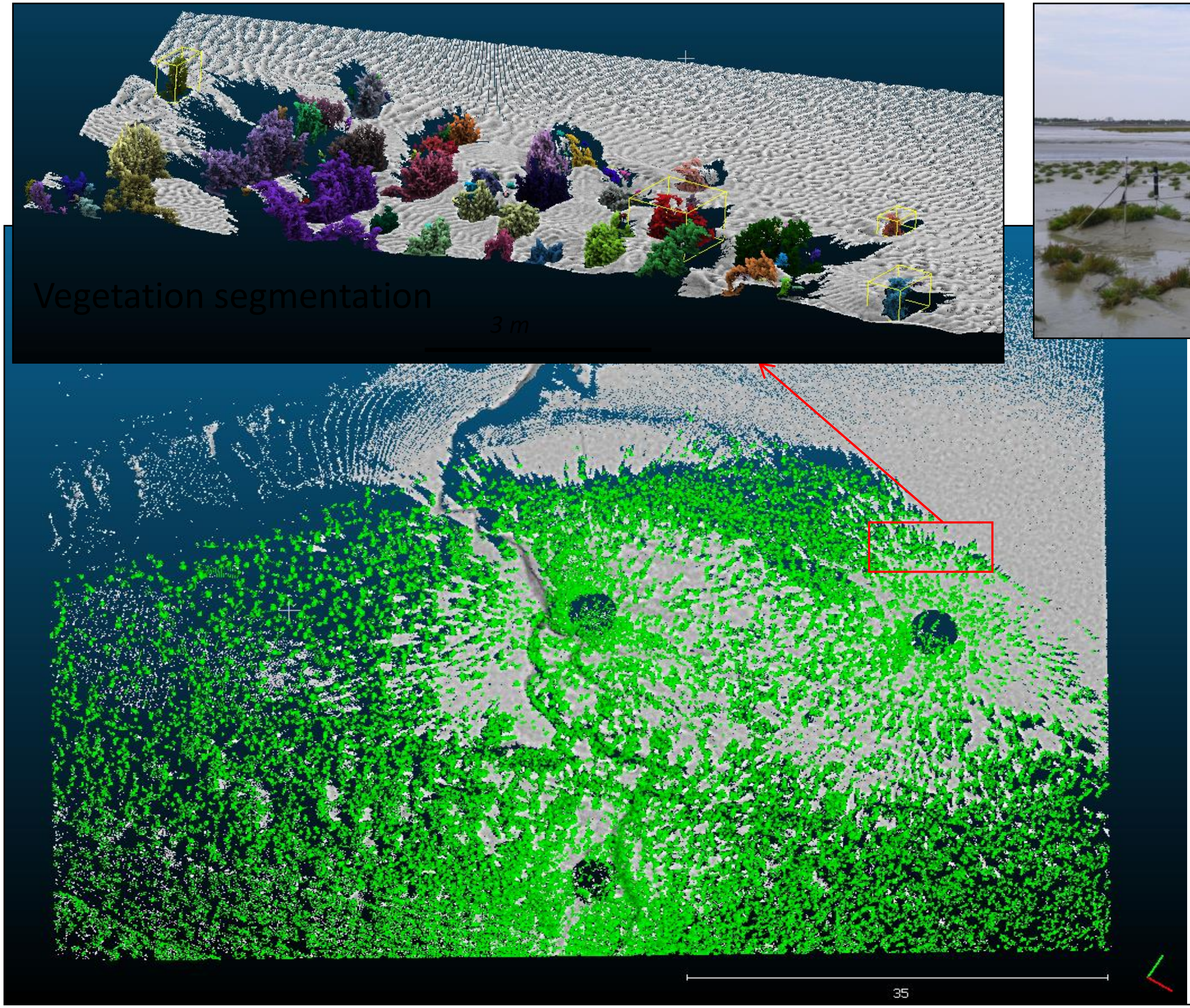






N individual clouds of boulders

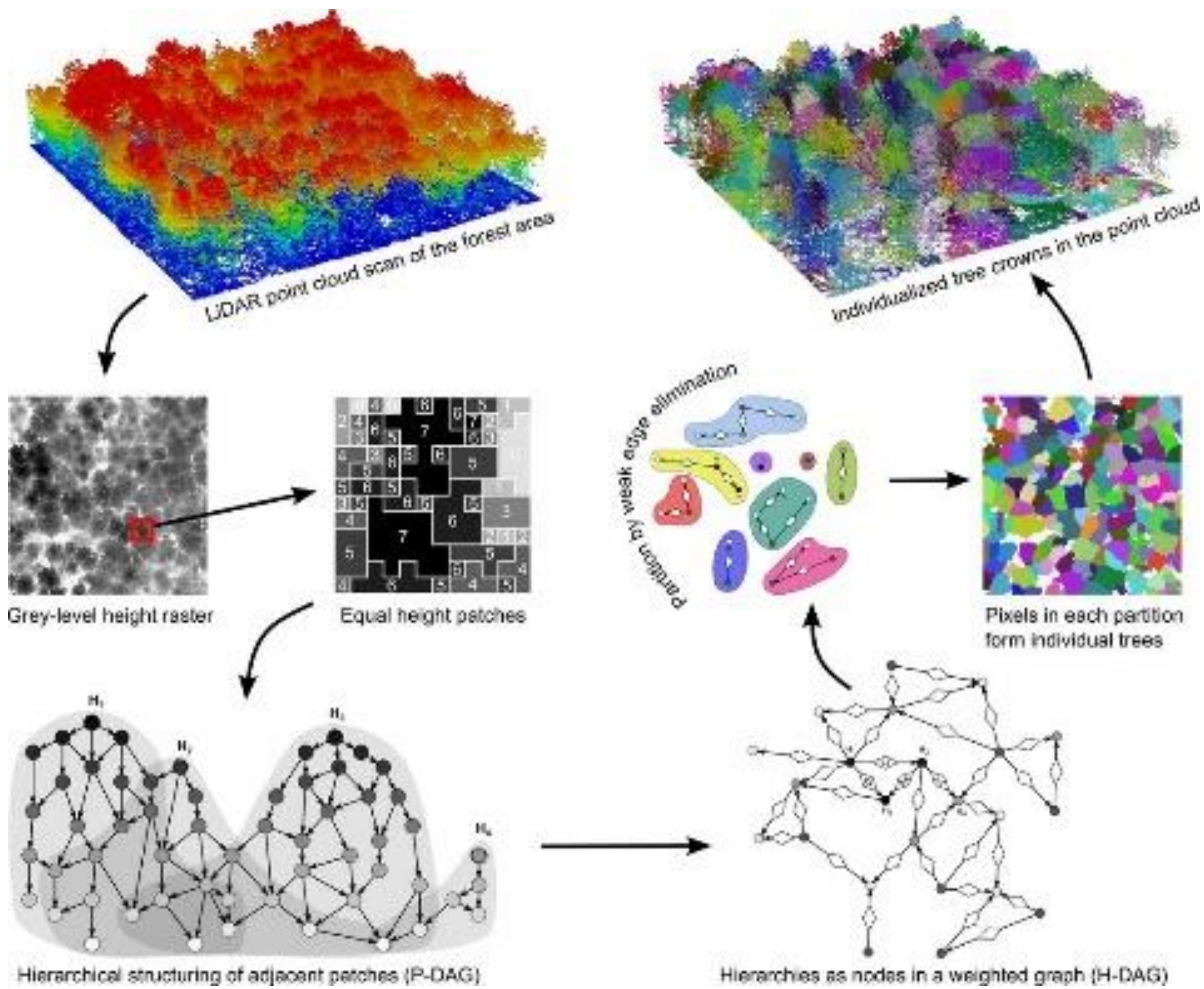
Ex: Vegetation in tidal environments



Classification accuracy on vegetation is up to 99.7 % in densely scanned zones

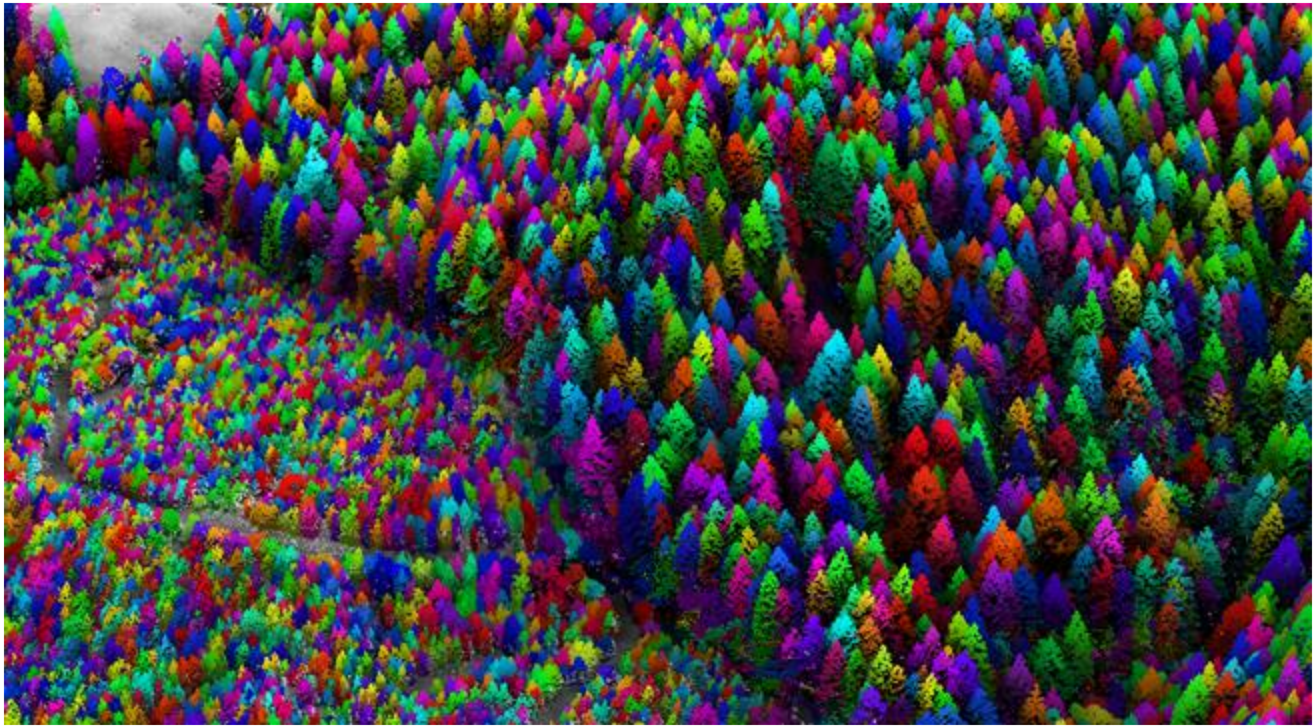
(J. Leroux's PhD)

Classification & segmentation of large 3D point clouds: very active research field



Strimbu & Strimbu, 2015, ***A graph-based segmentation algorithm for tree crown extraction using airborne LiDAR data***

3D forest with segmentationof individual trees

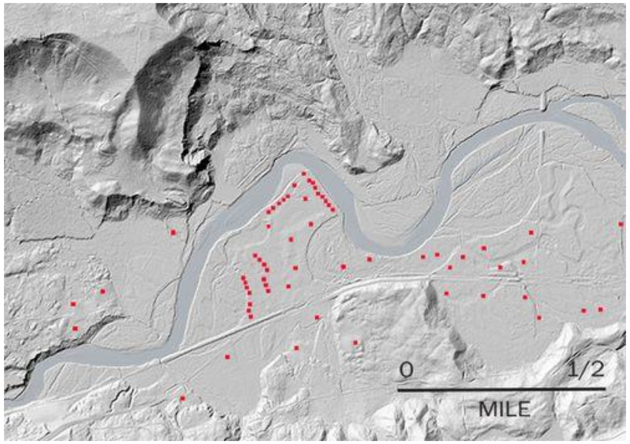


(quantum spatial)

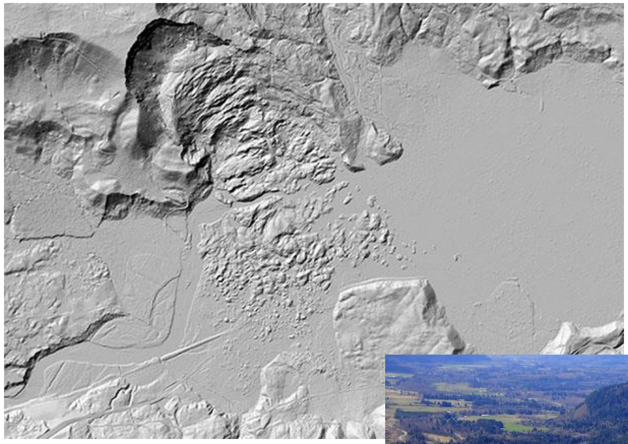
Change detection and distance measurement in 3D

- **Repeated measurement of the same landscape**: synoptic 3D tracking of environmental change
  - **Change in ground elevation** : erosion/sedimentation, earthquakes, landslides, extreme events,…
  - **Change in vegetation**: *in situ* growth monitoring, biomass changes, …
  - **Change in land use**: infrastructures, buildings,
  - Your ideas, the number of applications is vast !

T_1



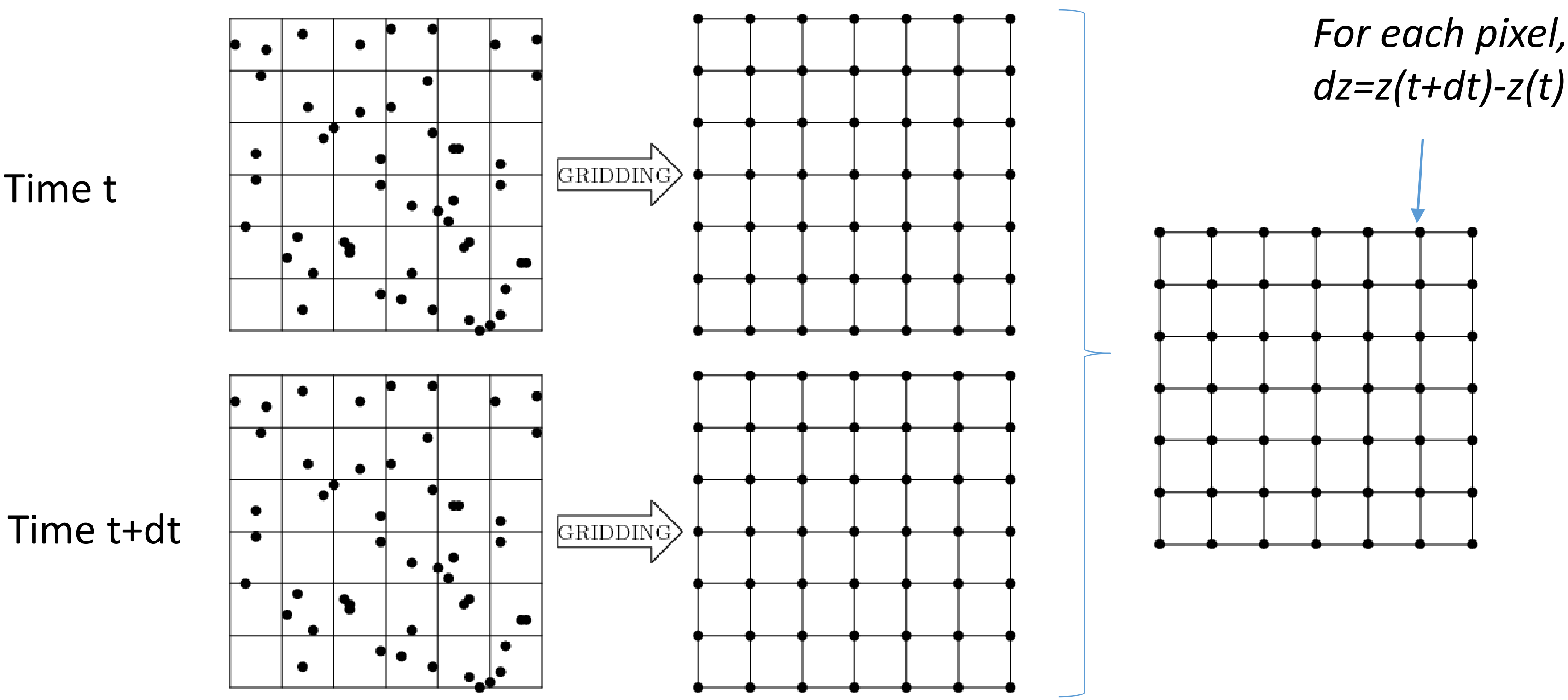
T_2



USGS

OSO Landslide, March 2014, US

Classical approach: difference of DEM

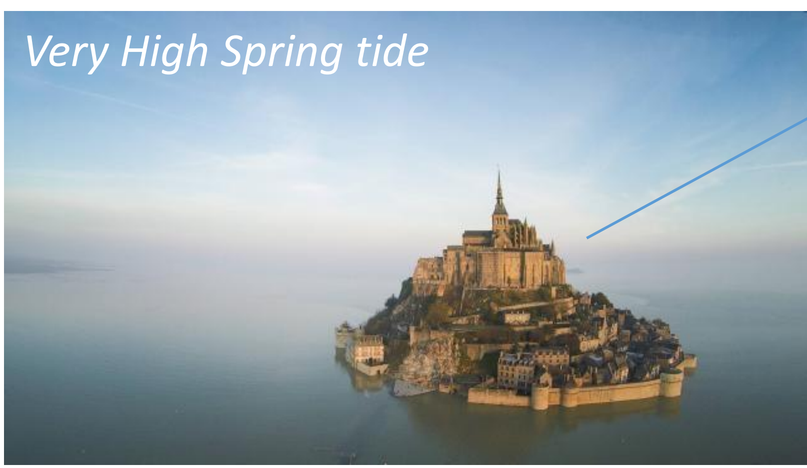


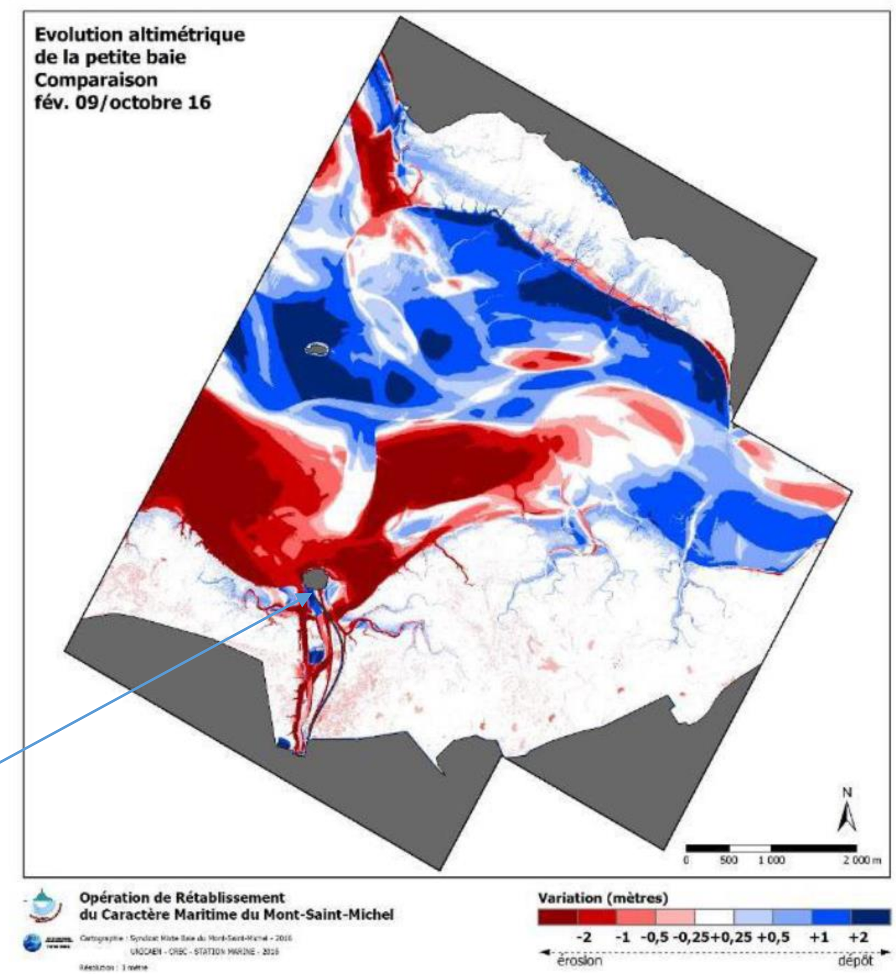
Regular grid of VERTICAL difference

A Digital Elevation Model is created for each epoch

Very easy to perform in any GIS software

Application example: erosion/sedimentation in the Mt St Michel bay



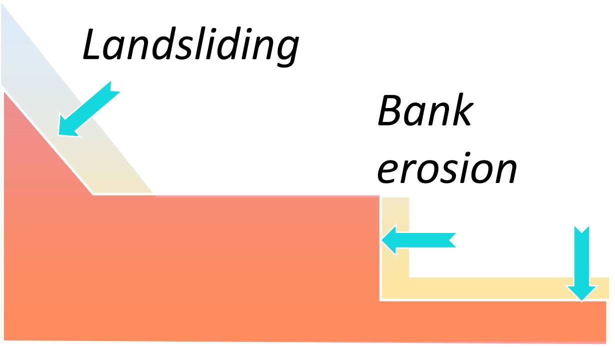


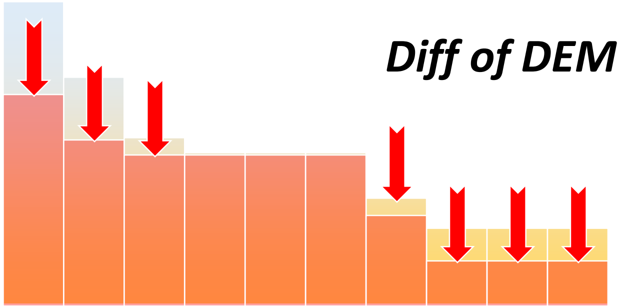
Repeated airborne LiDAR survey over 7 years

Advantages and limitations of Difference of Dem as a change detection method

- **Pros**
  - Regular sampling, compact format
  - Easy vertical differencing (Difference of DEM=DoD)
  - Simple volume calculation

- **Cons**
  - Loss of resolution on edges
    - *Cannot represent vertical surfaces*
  - No oriented difference
    - *E.g., Bank erosion requires rotating the data*
  - Interpolation on complex surfaces
    - *Sensitive to ground classification*
  - Cannot represent 3D above ground

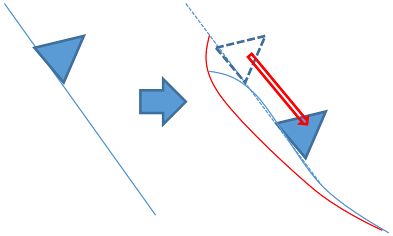




Raster DEM

Change detection in 3D (not vertical)

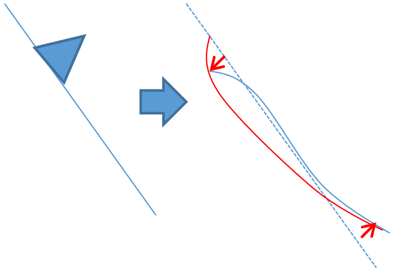
- Hyp: 2 point clouds acquired at different time, registered in the same coordinate system (local or global)
- 2 cases:

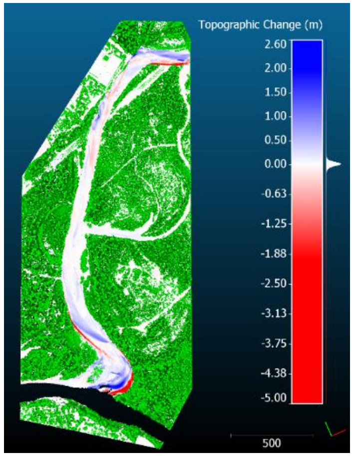


1. **No erosion, sedimentation, significant vegetation change, or planar surface with texture**
   - **« Feature matching » techniques :** tracking shapes in 2D or 3D allowing to compute a 3D displacement field

Features to track : houses, the landscape itself,….

2. **Erosion, sedimentation, vegetation change or planar surface without texture**
   - No correlation possible between surfaces
   - **Orthogonal distance measurement**





1. Feature matching change detection on raster using Particle Image Velocimetry

Often used to track hillslope movements (e.g., landslides)

- Derived from techniques of 2D image correlation but using a Digital Elevation Model (raster of elevations)
  - *3D displacement field*
- *Aryal et al., JGR, 2012*: Using cross-correlation techniques developped for Particle Image Velocimetry
  - ~ m scale change detection
  - Requires features to track

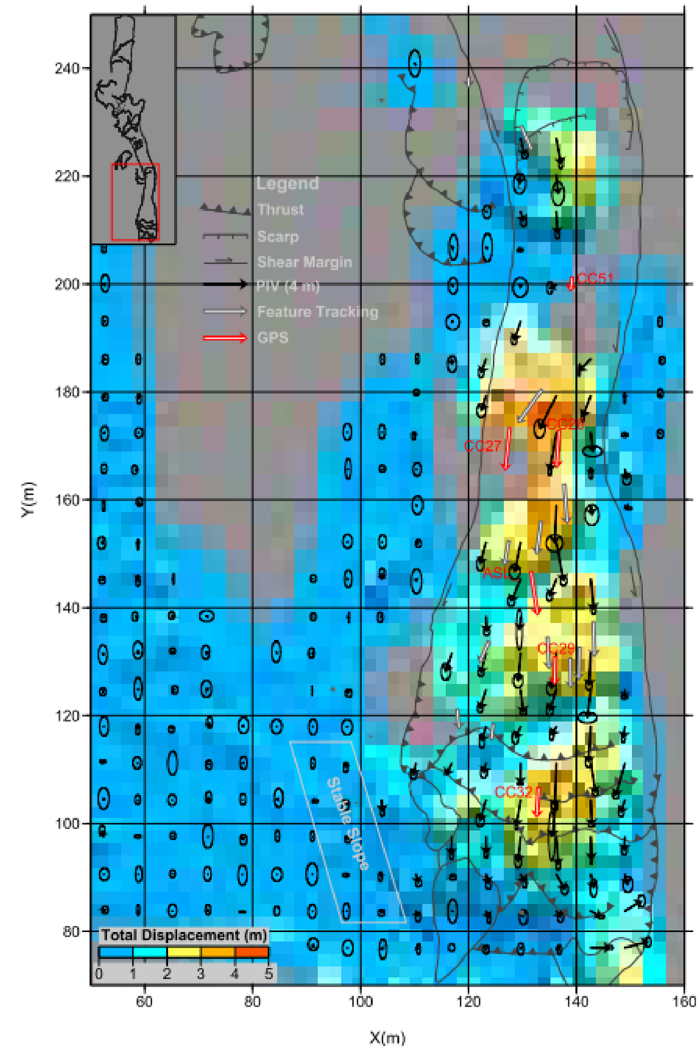
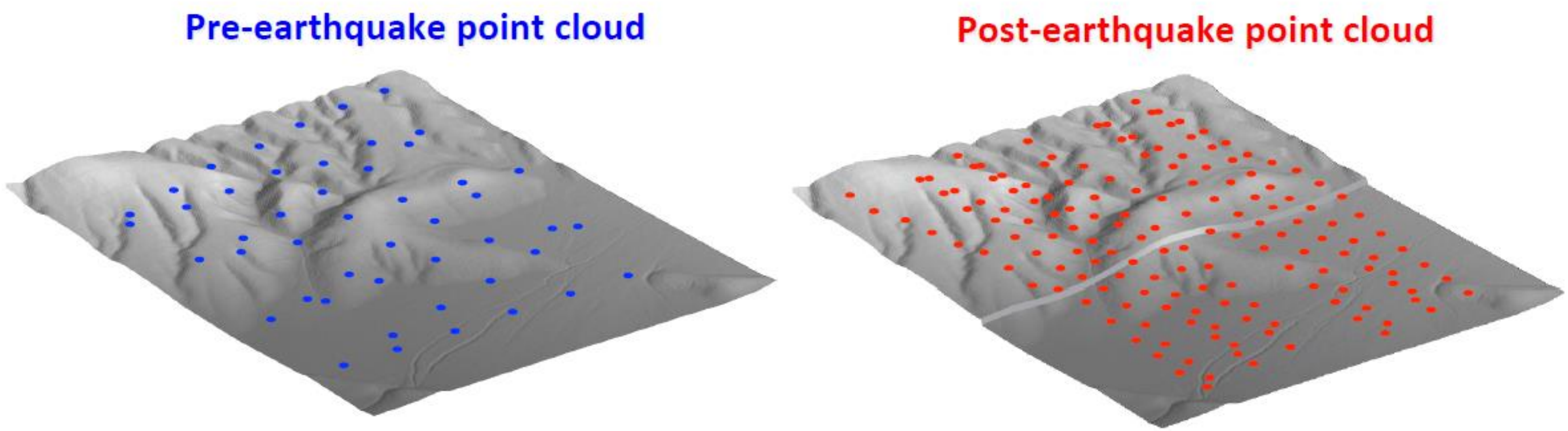


Figure 6. PIV estimated total displacement field and vectors (black) with error ellipses (95% significance) of CCL between June 2005 and January 2007. GPS horizontal-displacement vectors (red) and displacement vectors of features identifiable in the point cloud data (white) are plotted using the same scale as the PIV vectors. Landslide surface features (scarps, thrusts, and boundaries) are adapted from *Reid et al.* [2003].

1. Feature matching on 3D point cloud change detection by piecewise ICP



The **Iterative Closest Point** algorithm: a method for registering (aligning) two sets of points

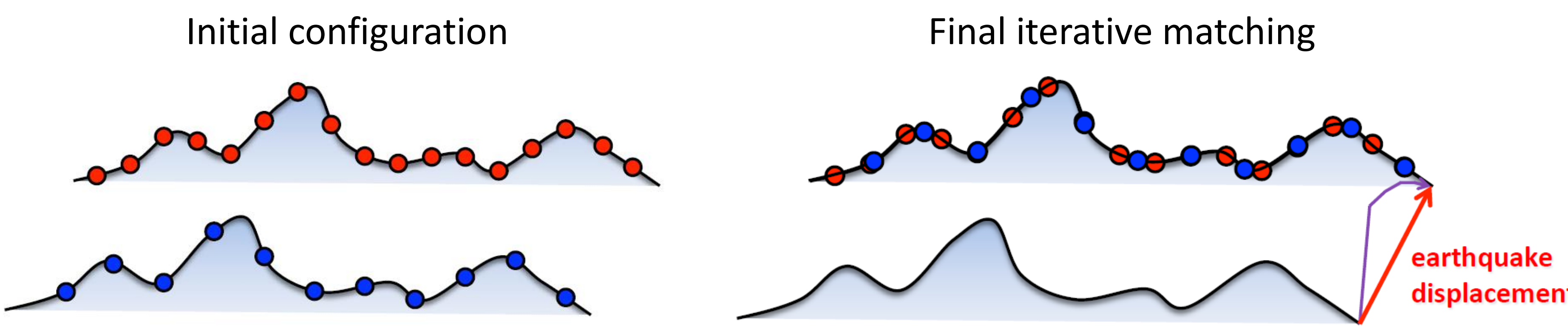
Fig. 4. Iterative point-based registration of phantom face range data

From Ed Nissen's course on OpenTopography

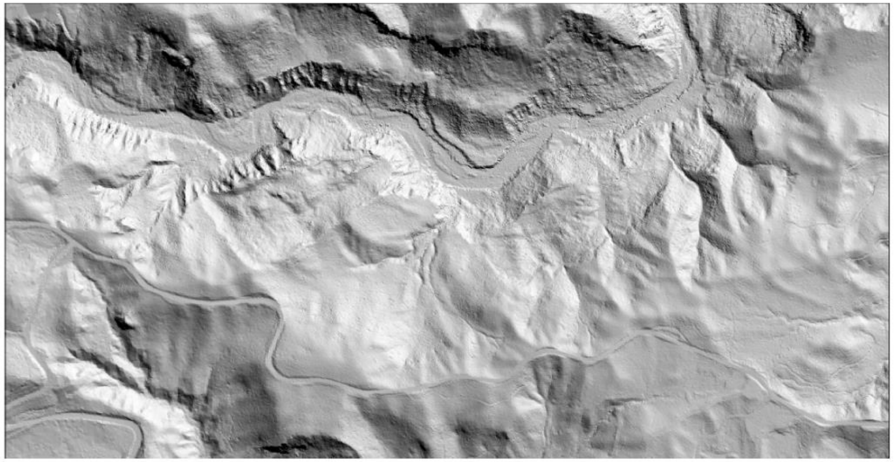
The **Iterative Closest Point** algorithm: a method for registering (aligning) two sets of points

- the two point clouds are first split into square "windows", 50 m in diameter
- ICP is run separately on each pair of windows. (An additional "fringe" of 5 m is included in the post-event window in order to capture the coseismic displacement)
- ICP finds the displacement and rotation that best aligns the pre-event and post-event point clouds.
- This alignment corresponds to the local coseismic displacement for that window.

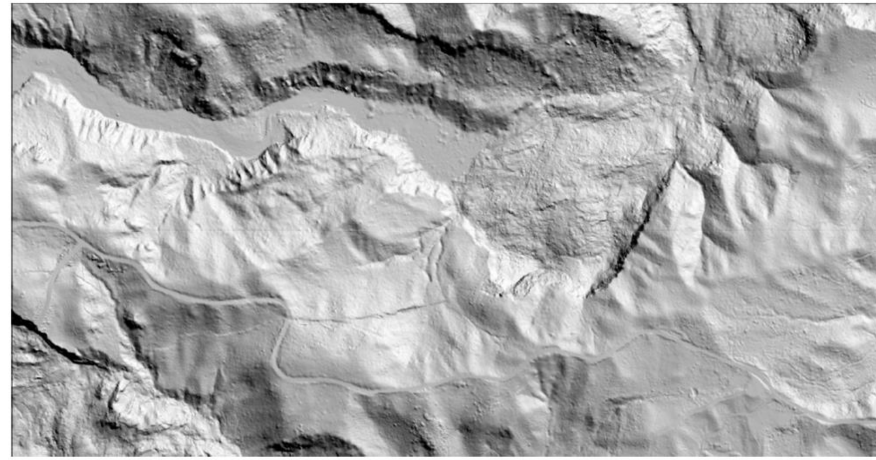
see Nissen et al. (2012), Geophys. Res. Lett., for details



From Ed Nissen's course on OpenTopography

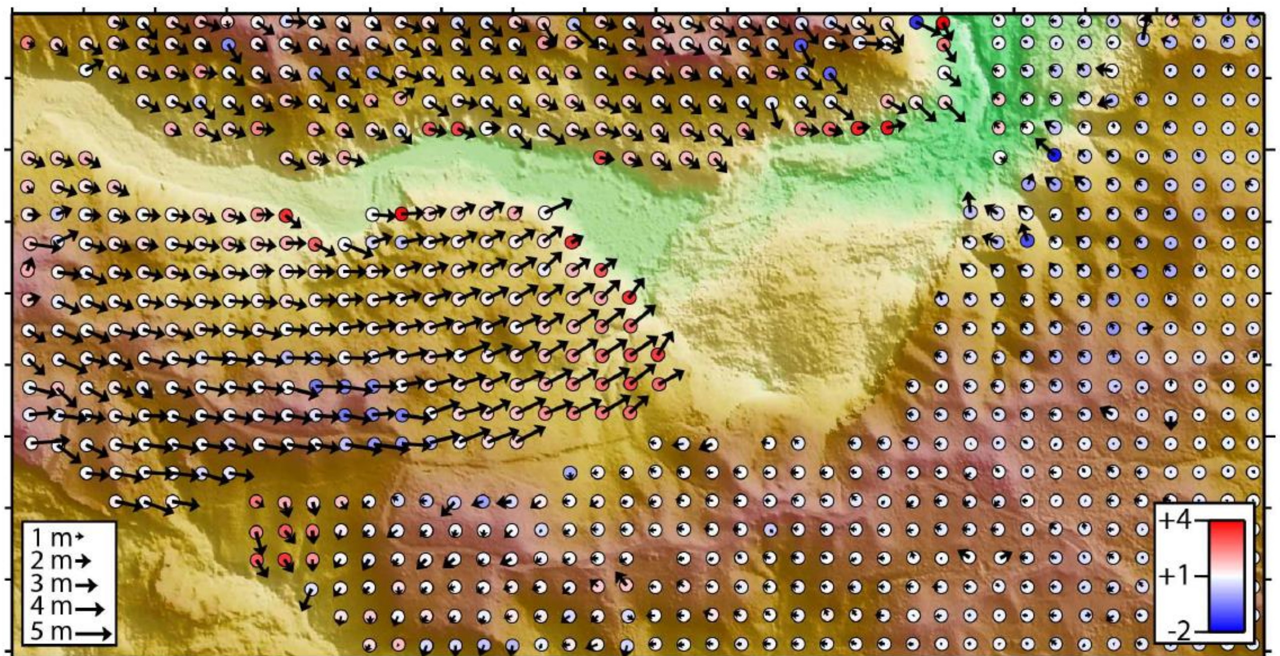


Pre-earthquake DEM (2m)



Post-earthquake DEM (1m)

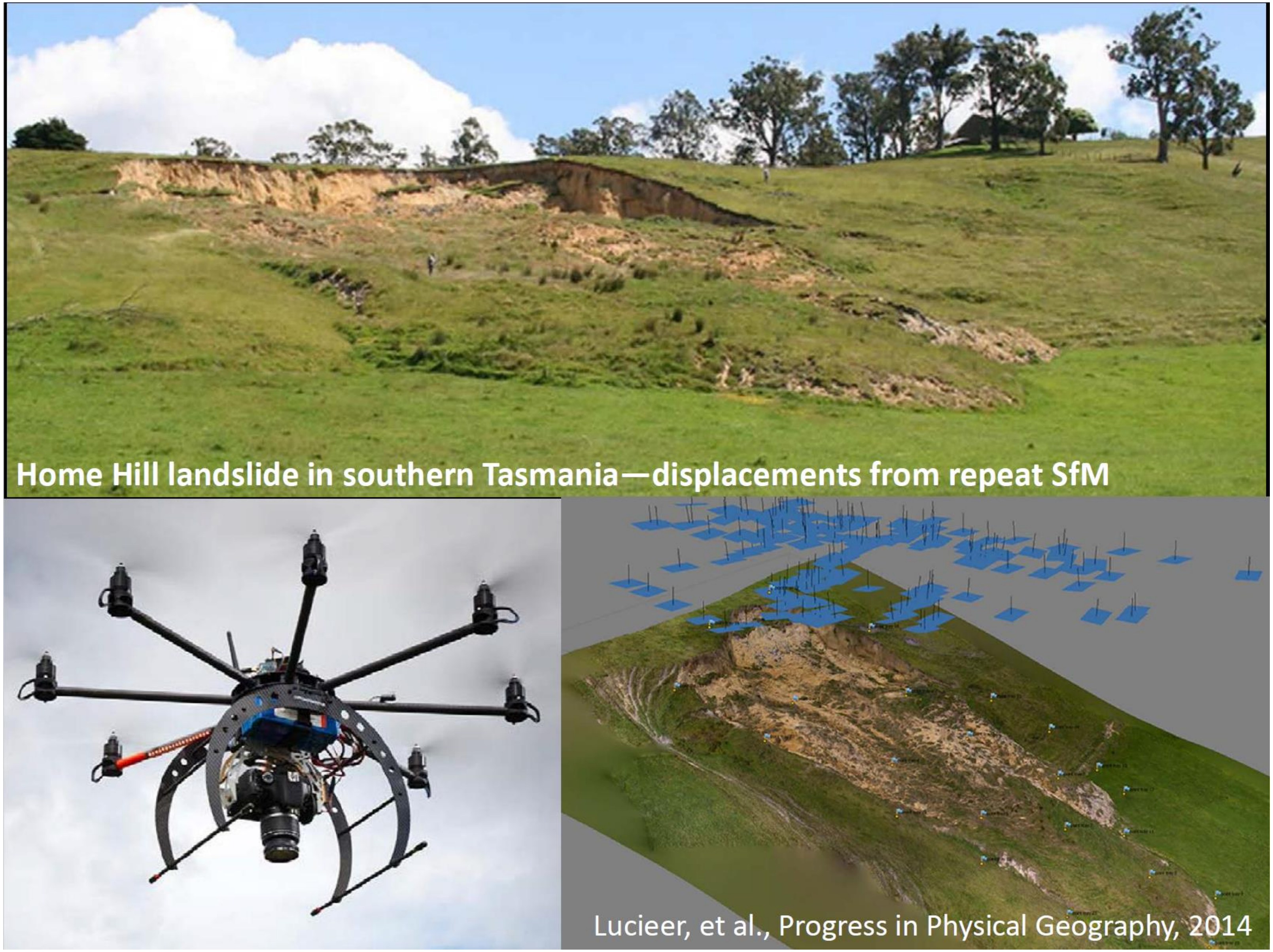
The 2008 Iwate-Miyagi earthquake (Mw 6.9), Japan

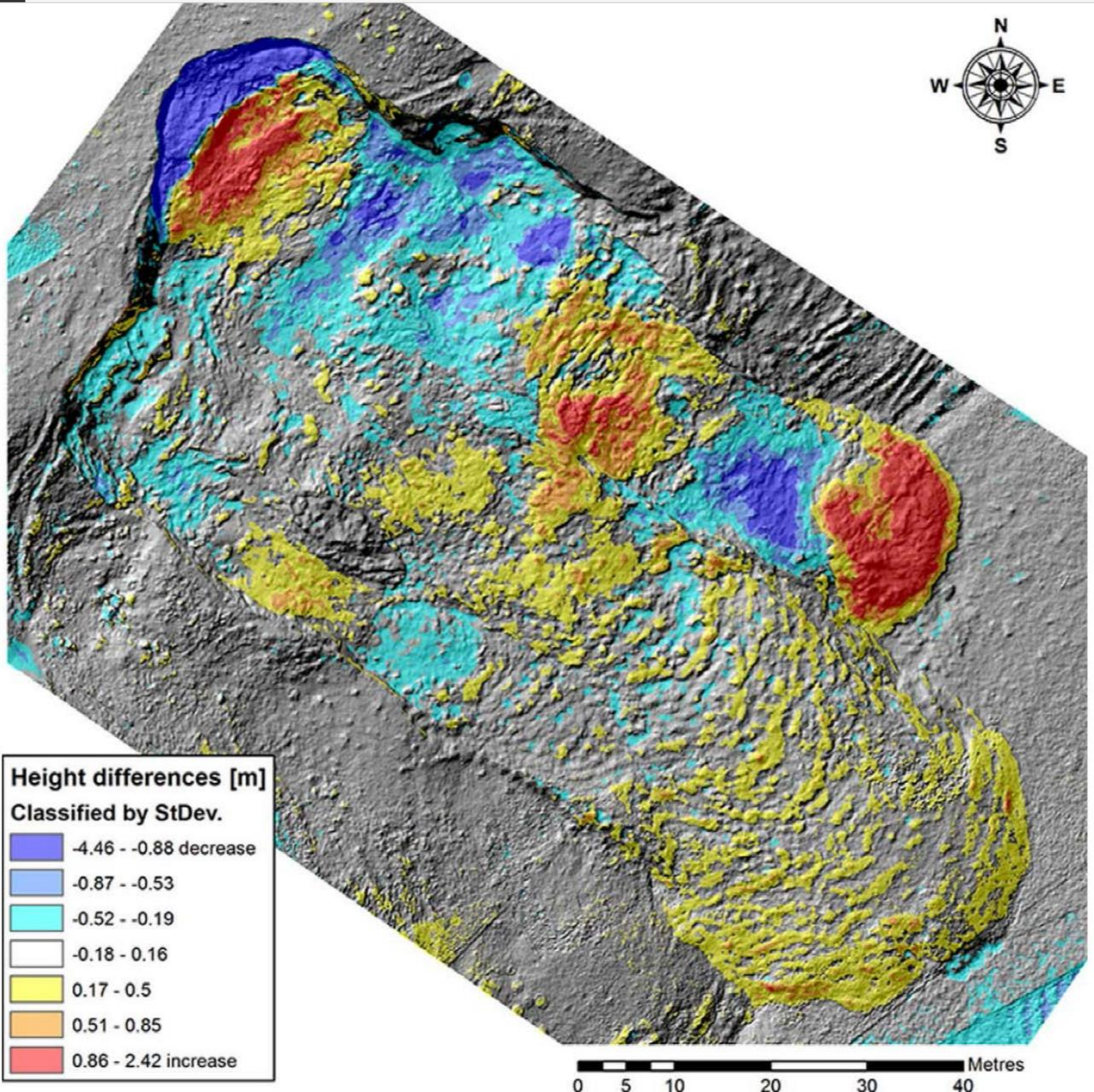


Dense 3-D displacements in an area InSAR cannot image

From Ed Nissen's course on OpenTopography

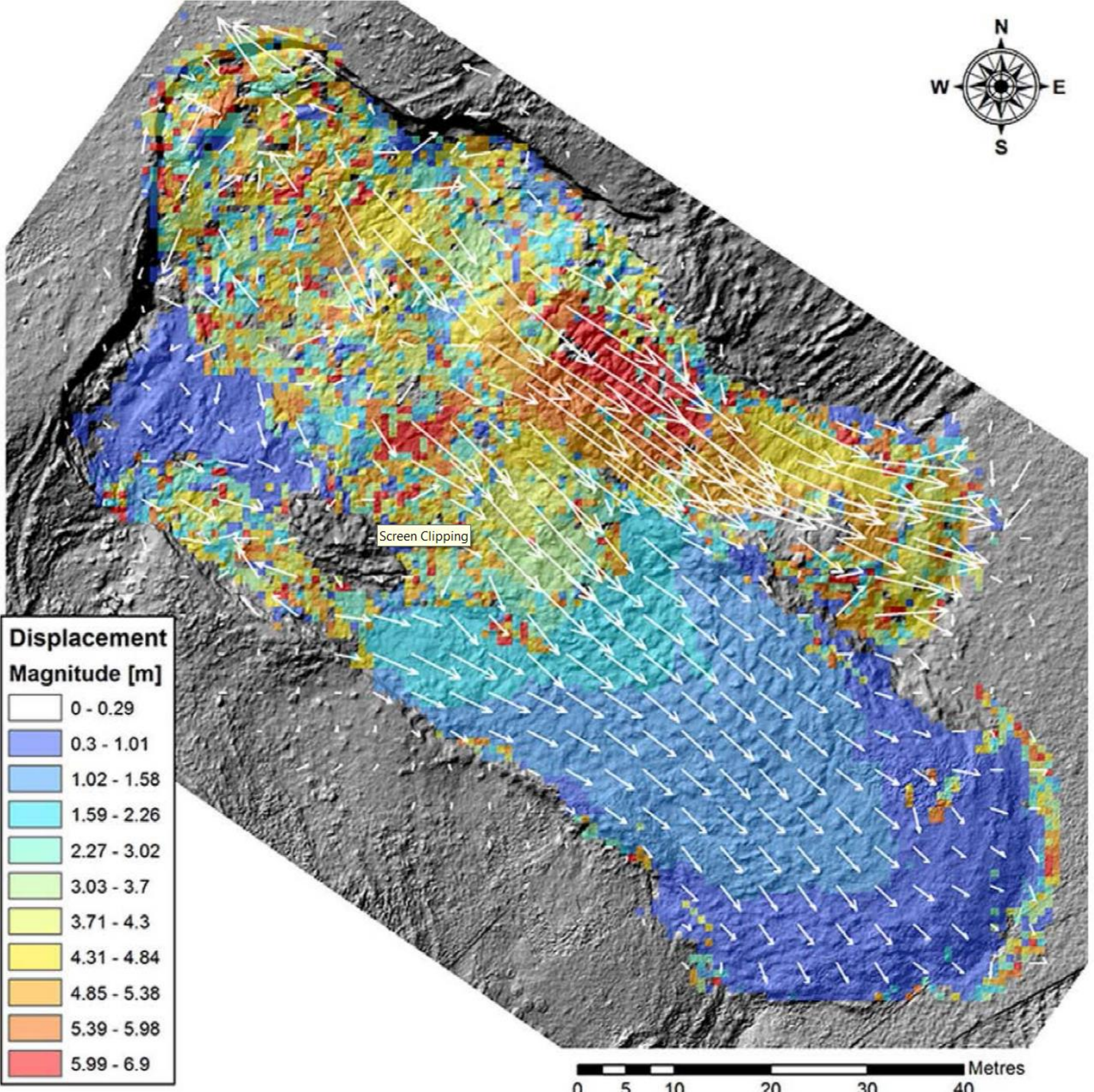
Topographic change detection, comparison of techniques





Difference between the 1 cm DEMs of 19 July 2011 and 10 November 2011

Lucieer, et al., Progress in Physical Geography, 2014

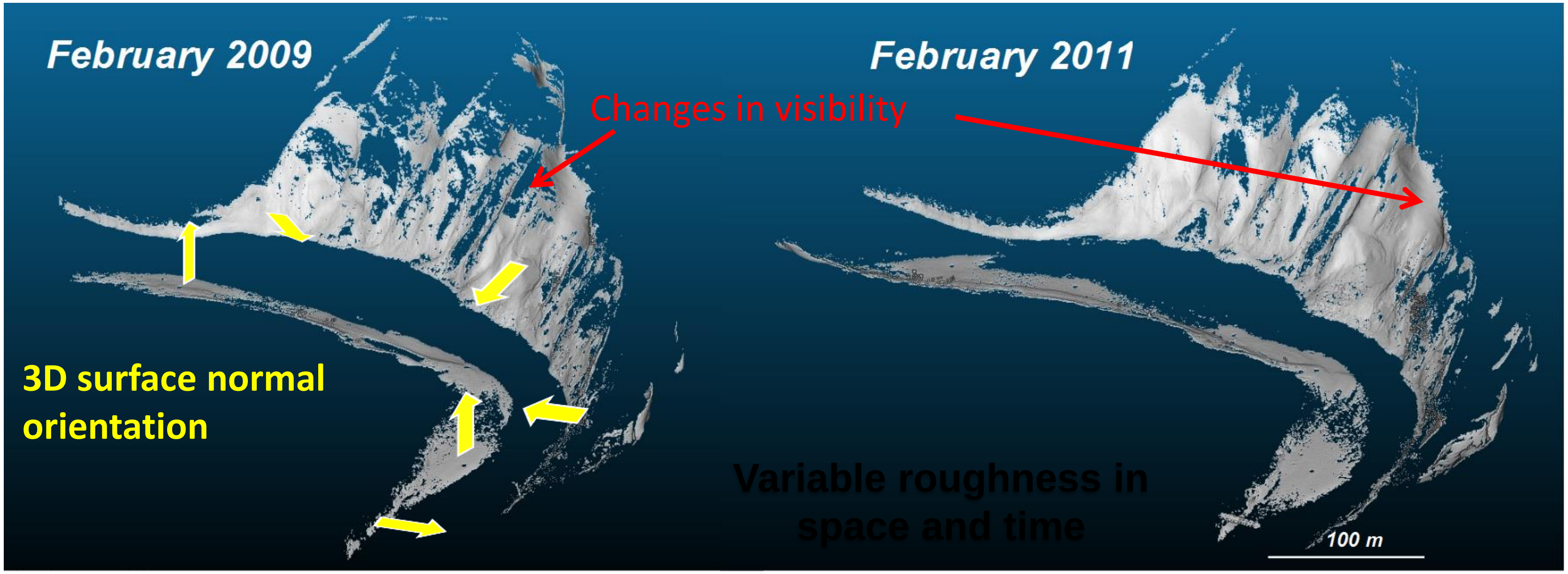


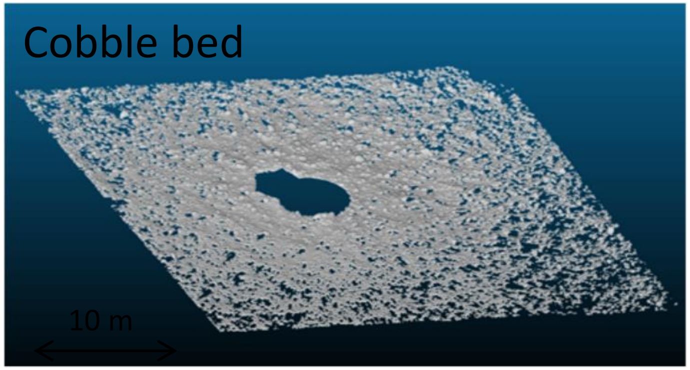
Displacement of the Home Hill landslide between 19 July 2011 and 10 November 2011 using the COSI-Corr algorithm (Leprince, et al., 2007)

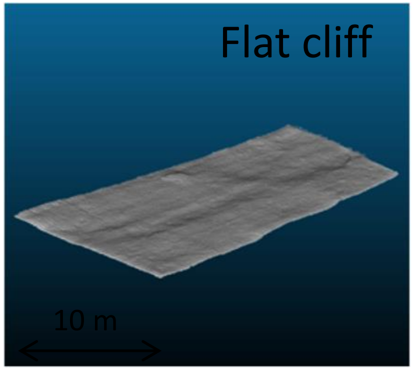
Lucieer, et al., Progress in Physical Geography, 2014

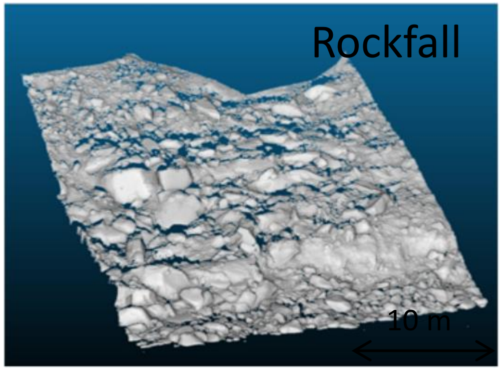
2. 3D point cloud comparison and change detection in the absence of feature matching

Rangitikei river, New-Zealand





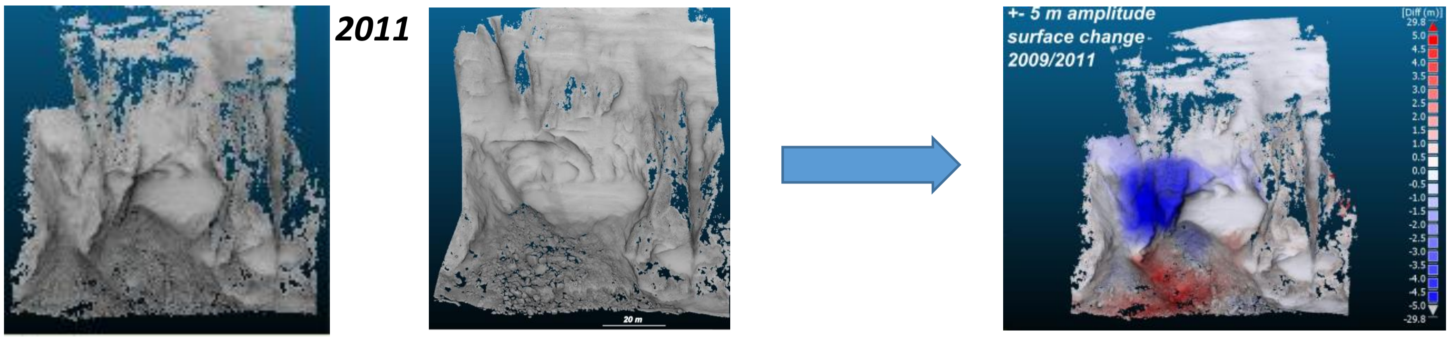


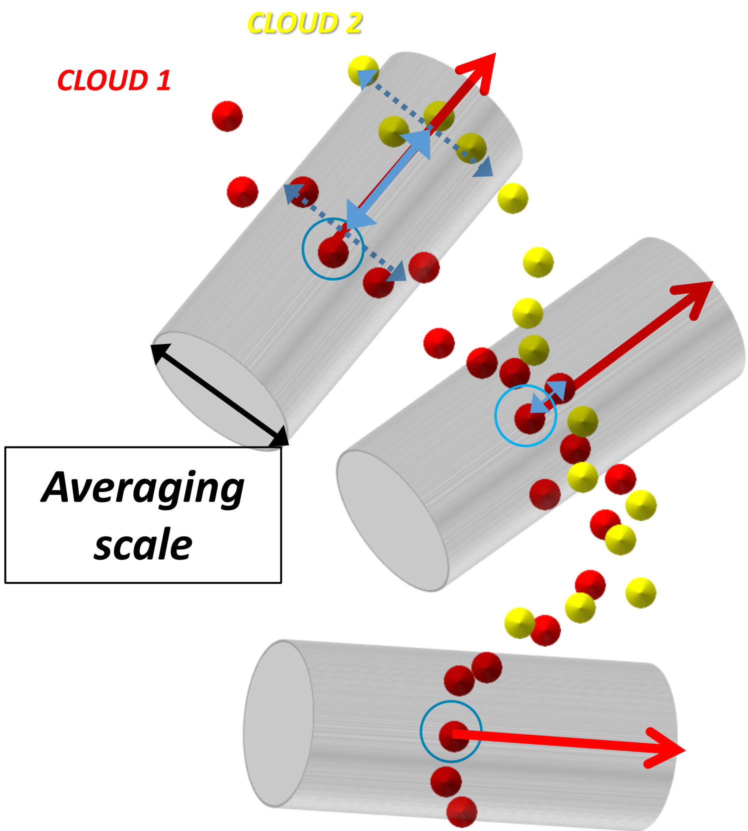


Roughness creates uncertainty in the comparison of surfaces

M3C2: 3D point cloud differencing *(Lague et al., 2013)*

2009 **2011**





1: Normal direction calculation on cloud 1

→ **Oriented difference**

*2: **Average distance** between the two PC*

→ **Noise and roughness averaging**

*3: **Local confidence interval calculation***

→ **Local roughness**

→ **Local point density**

→ **Global registration**

4: Distance smaller than confidence interval

→ **statistically not significant**

5: No intercept with other cloud

→ **no calculation**

→ **no need to trim the data**

Example: Meandering bedrock river, NZ

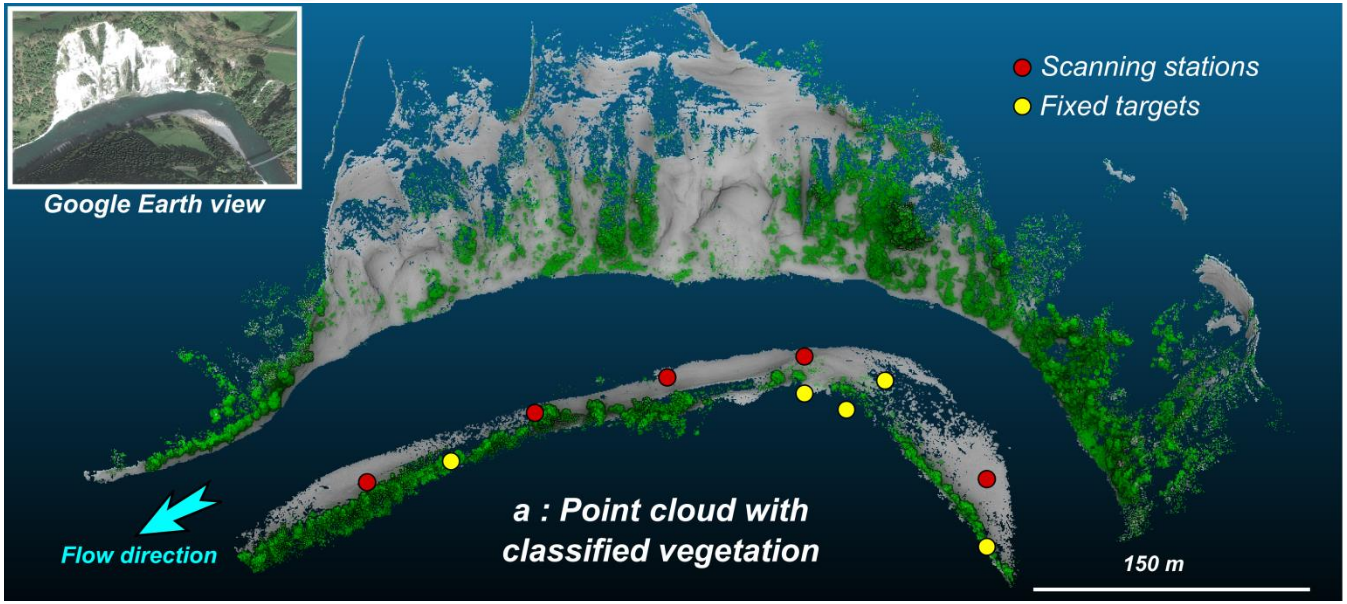
Target based registration

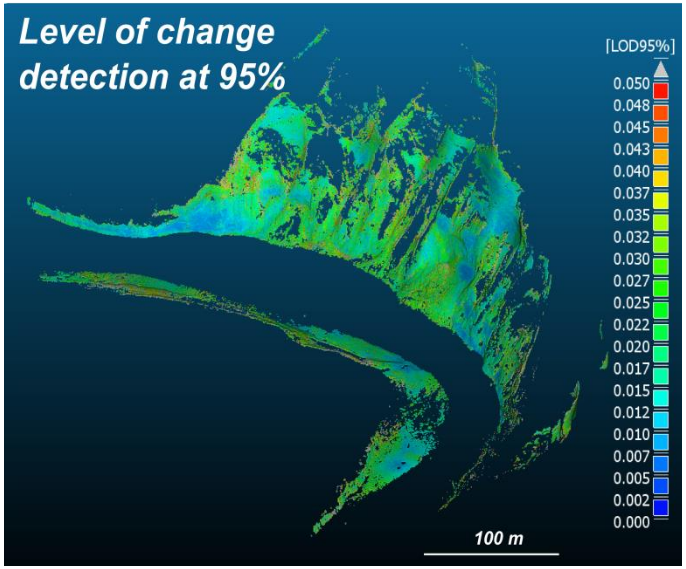
↓

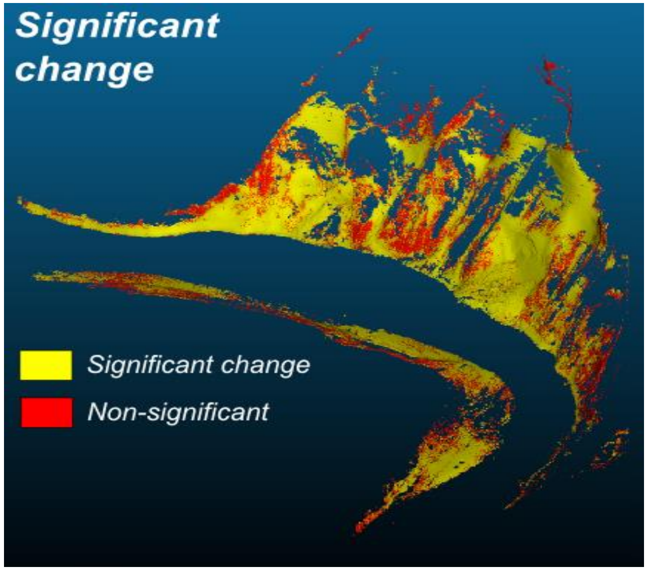
qCANUPO vegetation removal on raw data

↓

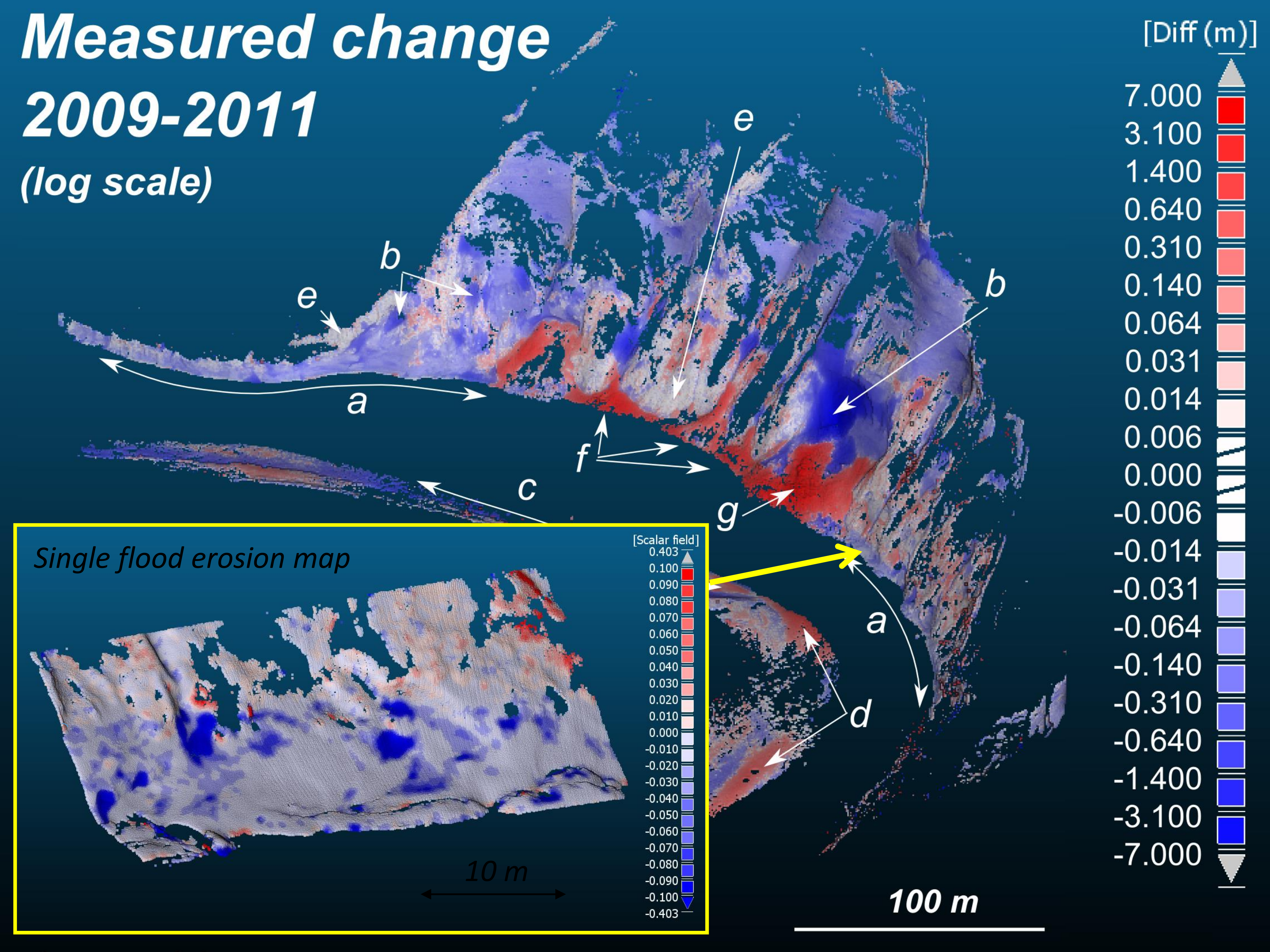
qM3C2
3D difference



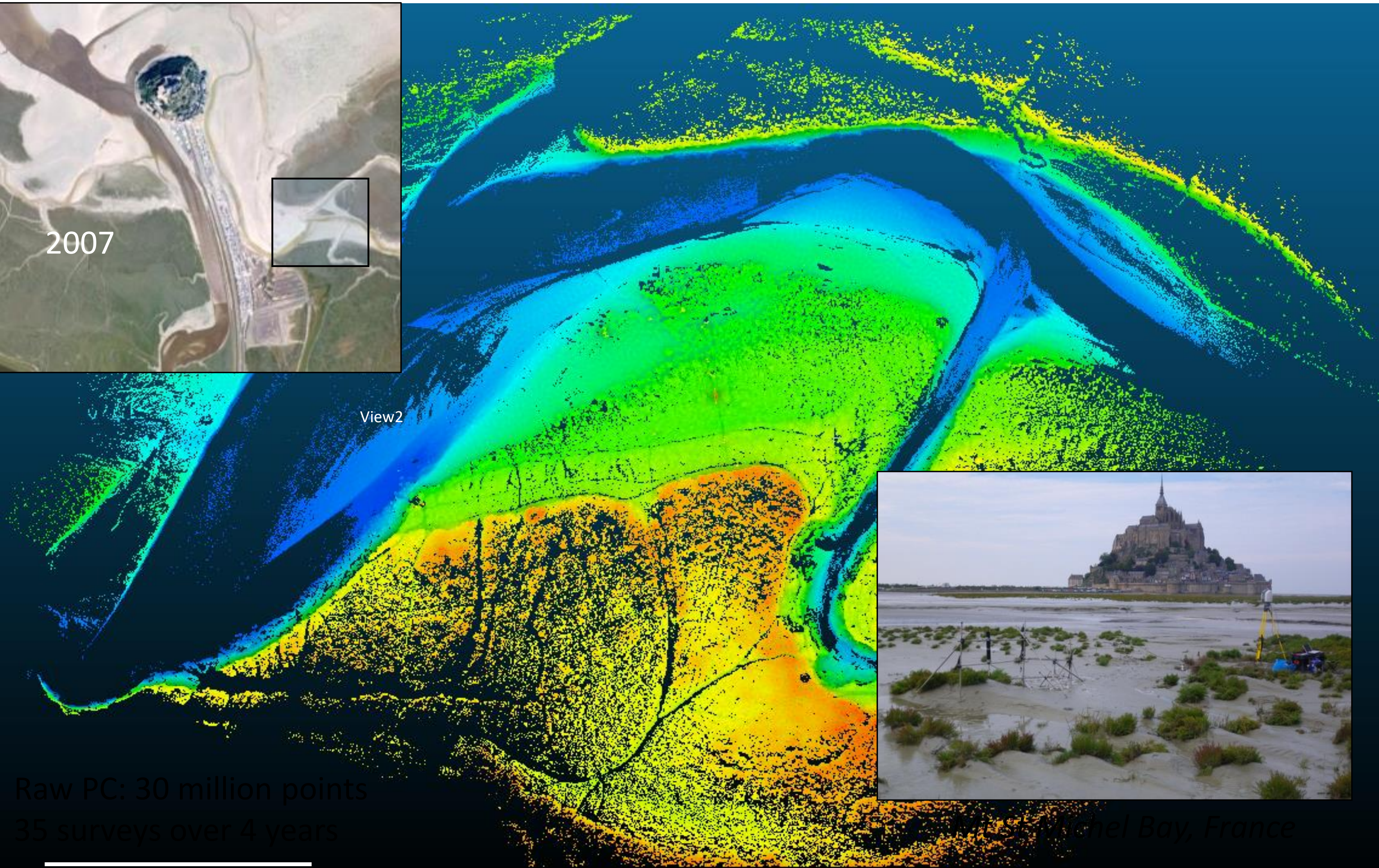




Lague et al., ISPRS, 2013


Measured change
2009-2011
(log scale)
[Diff (m)]
7.000
3.100
1.400
0.640
0.310
0.140
0.064
0.031
0.014
0.006
0.000
-0.006
-0.014
-0.031
-0.064
-0.140
-0.310
-0.640
-1.400
-3.100
-7.000
a
b
c
d
e
f
g
100 m
Single flood erosion map
[Scalar field]
0.403
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
-0.070
-0.080
-0.090
-0.100
-0.403
10 m

Example: meander dynamics in mega-tidal salt marshes



Point bar : Vertical difference with core points grid

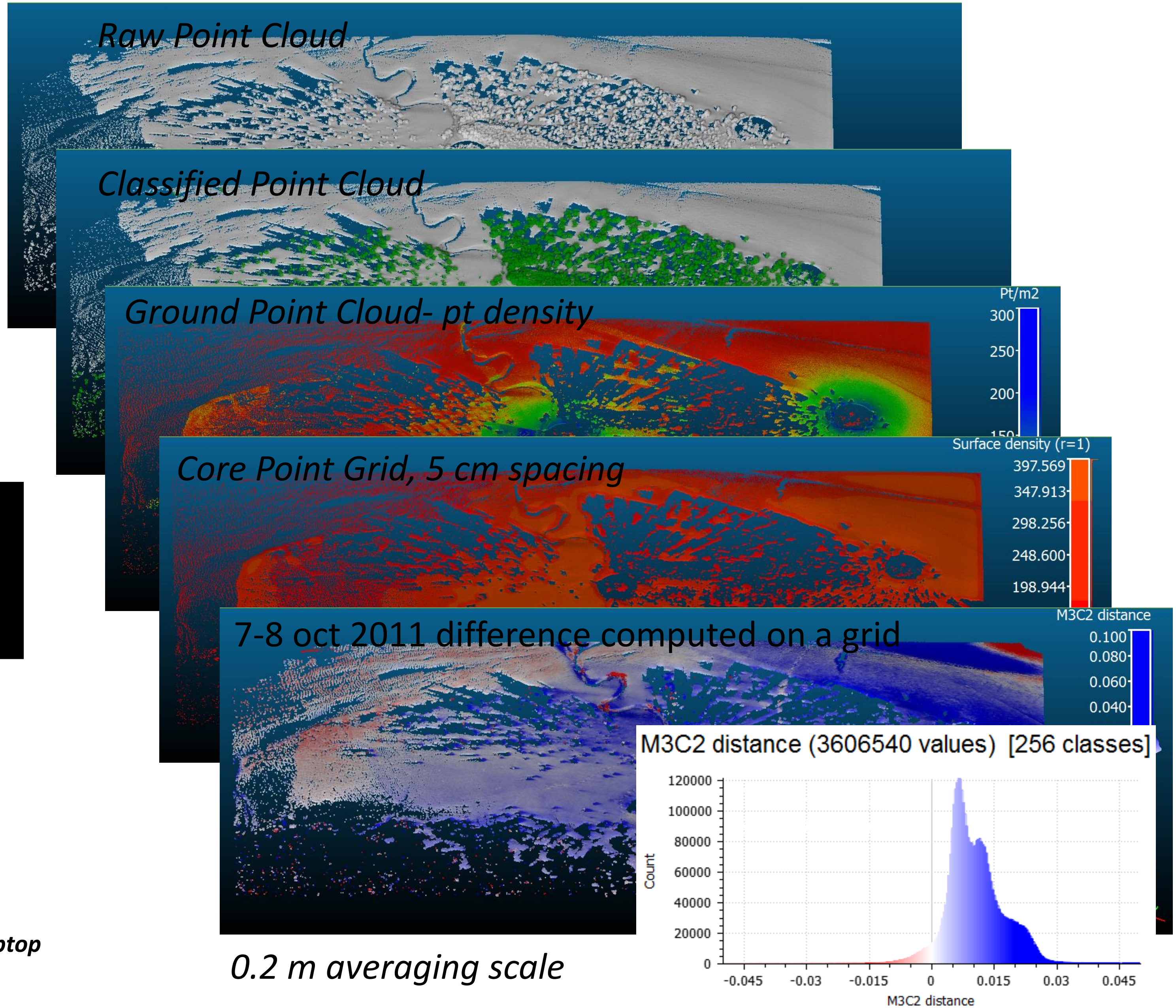
Target based registration

qCANUPO ground classif on raw data

Core points grid at 5 cm from first epoch

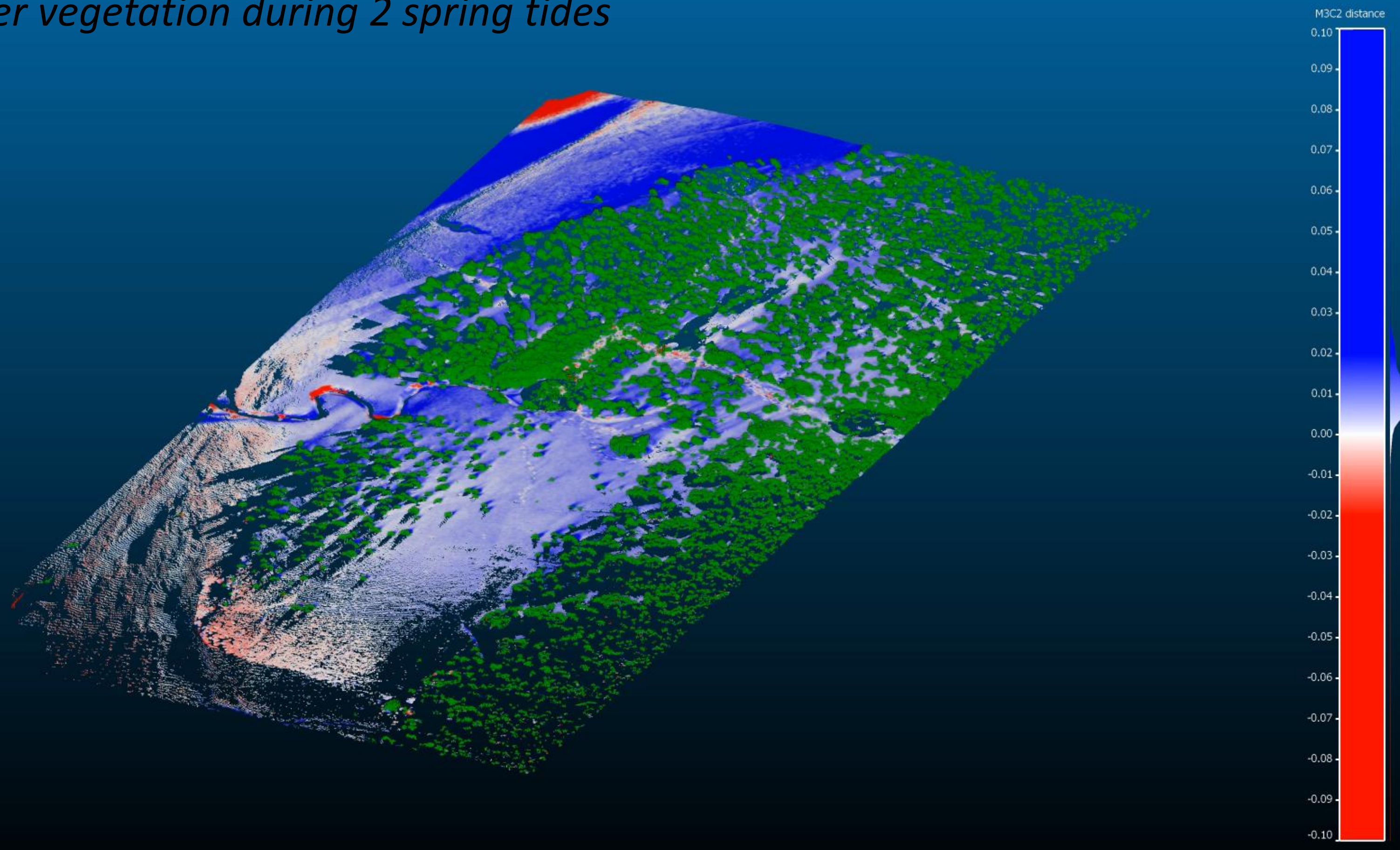
qM3C2
Vertical difference on GROUND 7-8 oct 2011

5 minutes on a quadcore laptop



0.2 m averaging scale

Accretion in pioneer vegetation during 2 spring tides



- *High accuracy : detect 5 mm change at 95 % confidence interval*
- *High resolution : ~ 1 pt/cm²*
  - *Captures vegetation structure*
  - *Captures heterogeneity of topographic change*
  - *Direct spatial upscaling from cm to 100's m*

Core point based ROI analysis within CloudCompare ex: exploring the influence of vegetation

M3C2 grid of difference | Vegetation layer

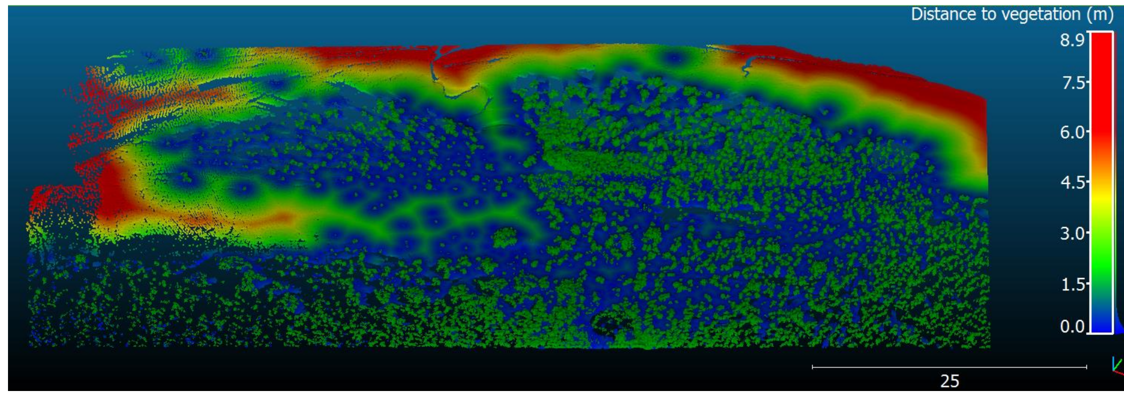
↓

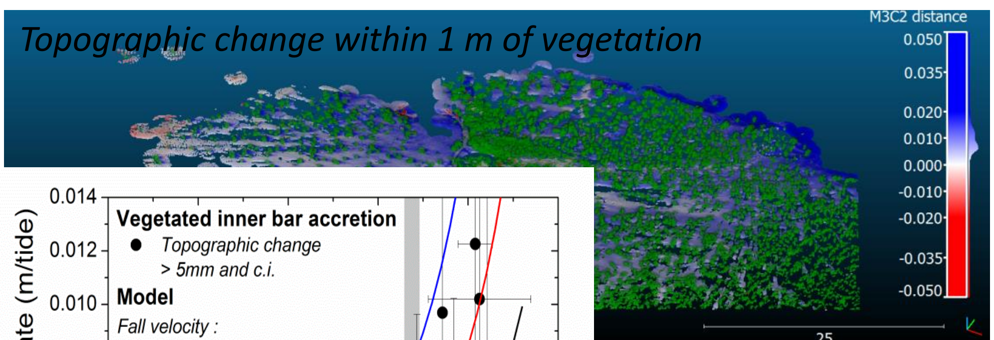
CC: closest point calculation

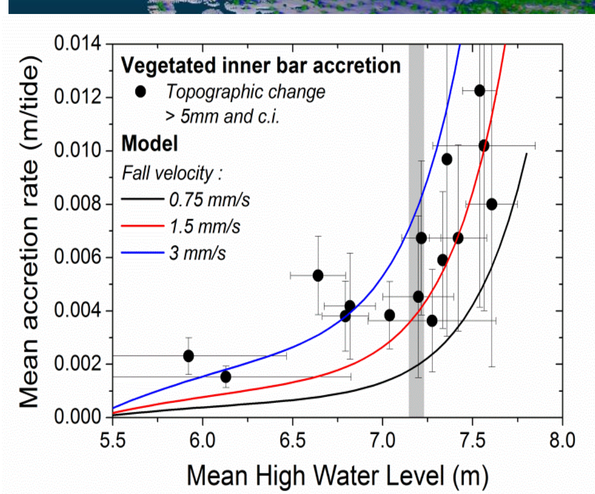
↓

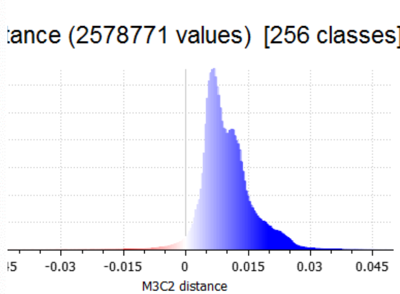
Segmentation by distance to vegetation

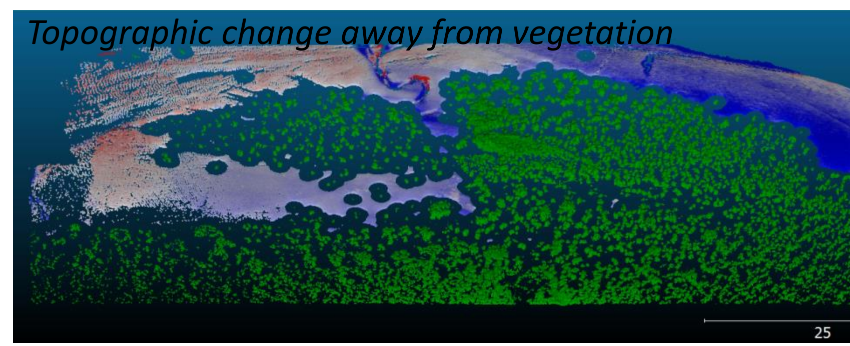
Distance to vegetation calculation

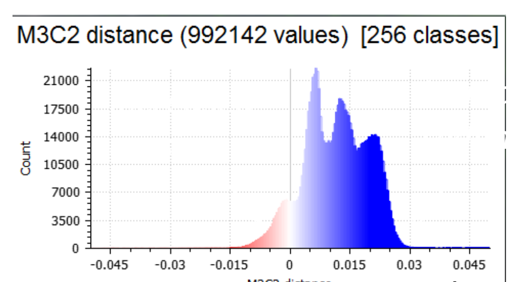












(Leroux et al., in prep)

Meander outer bank retreat

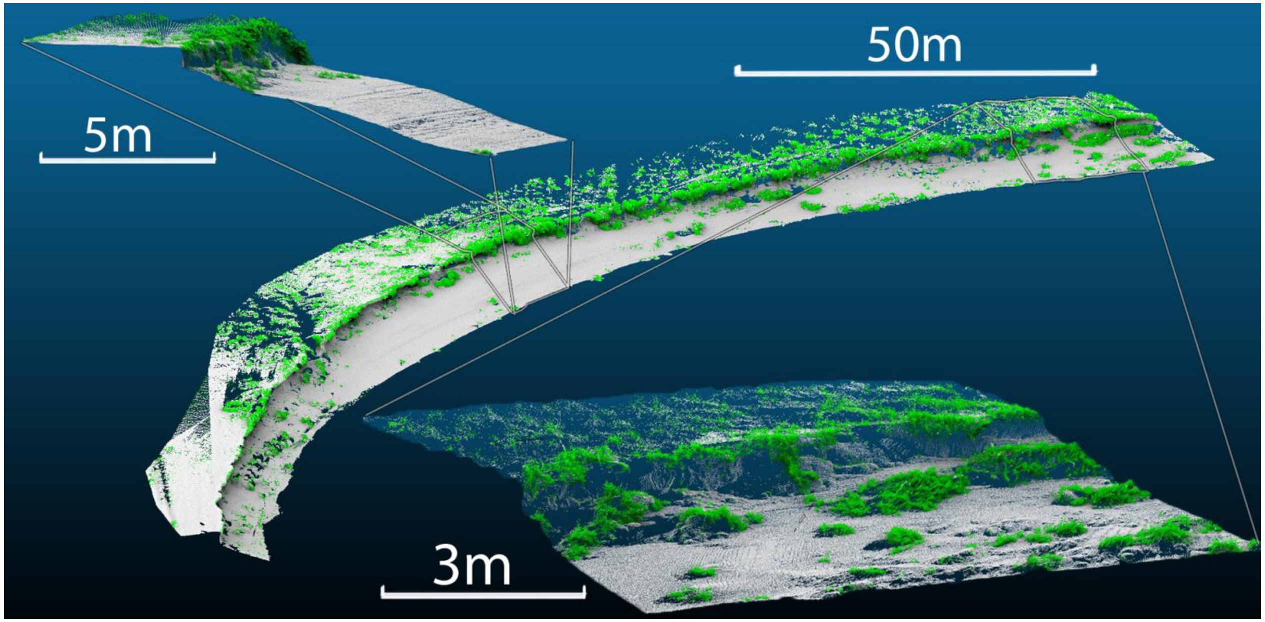
qCANUPO vegetation removal

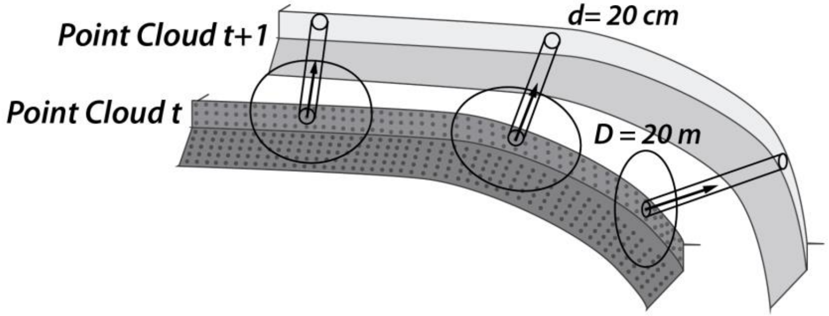
↓

Vertical core point grid

↓

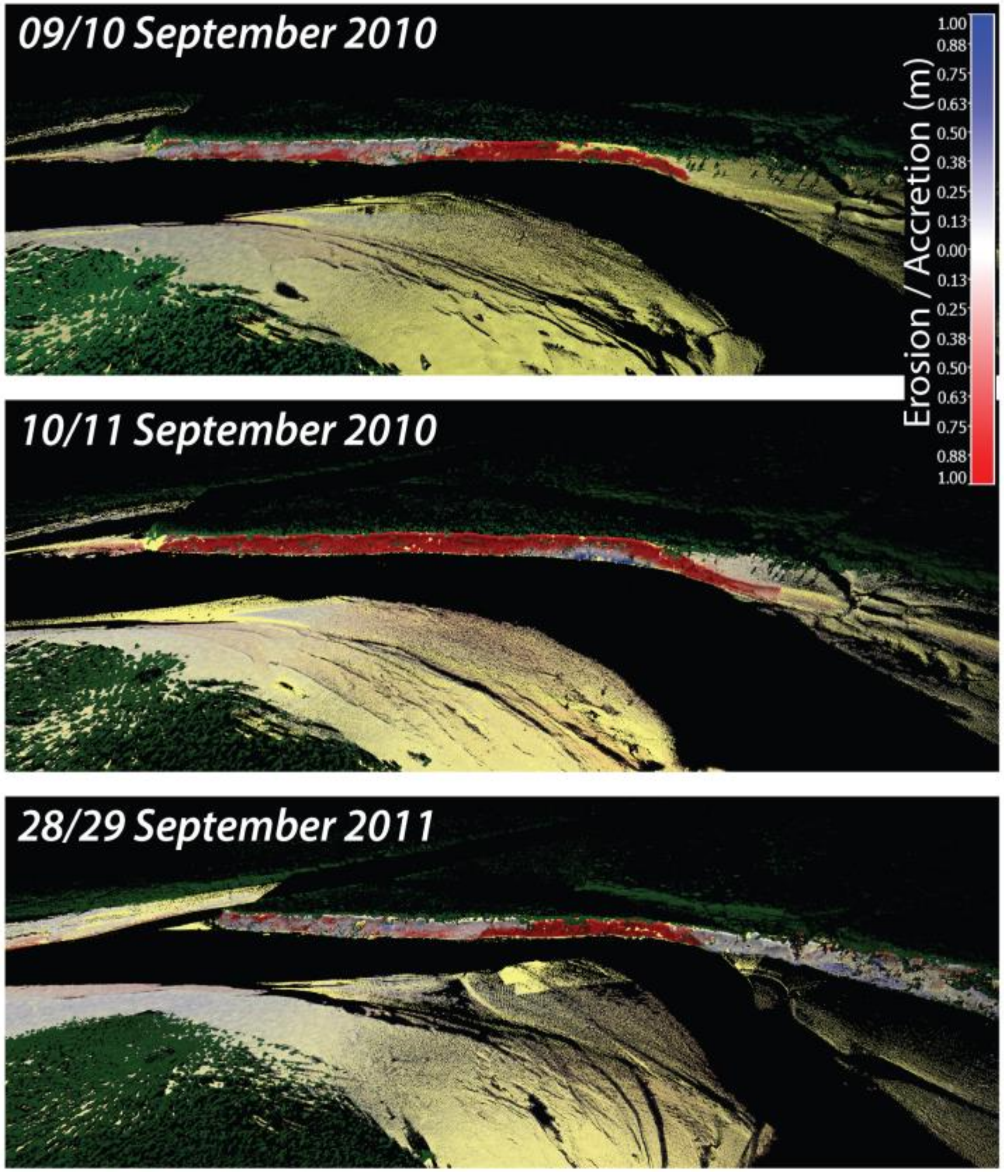
qM3C2
Horizontal difference

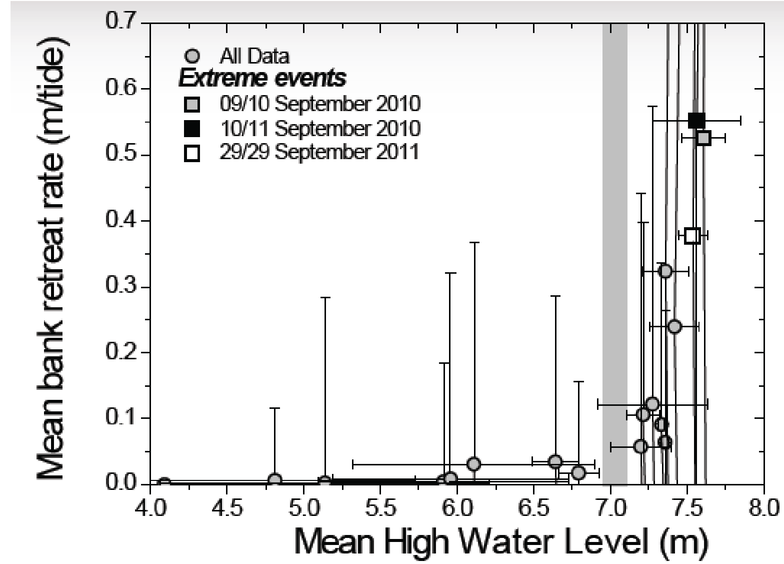




Automatic tracking of the variations in sinuous bank orientation

Meander outer bank retreat

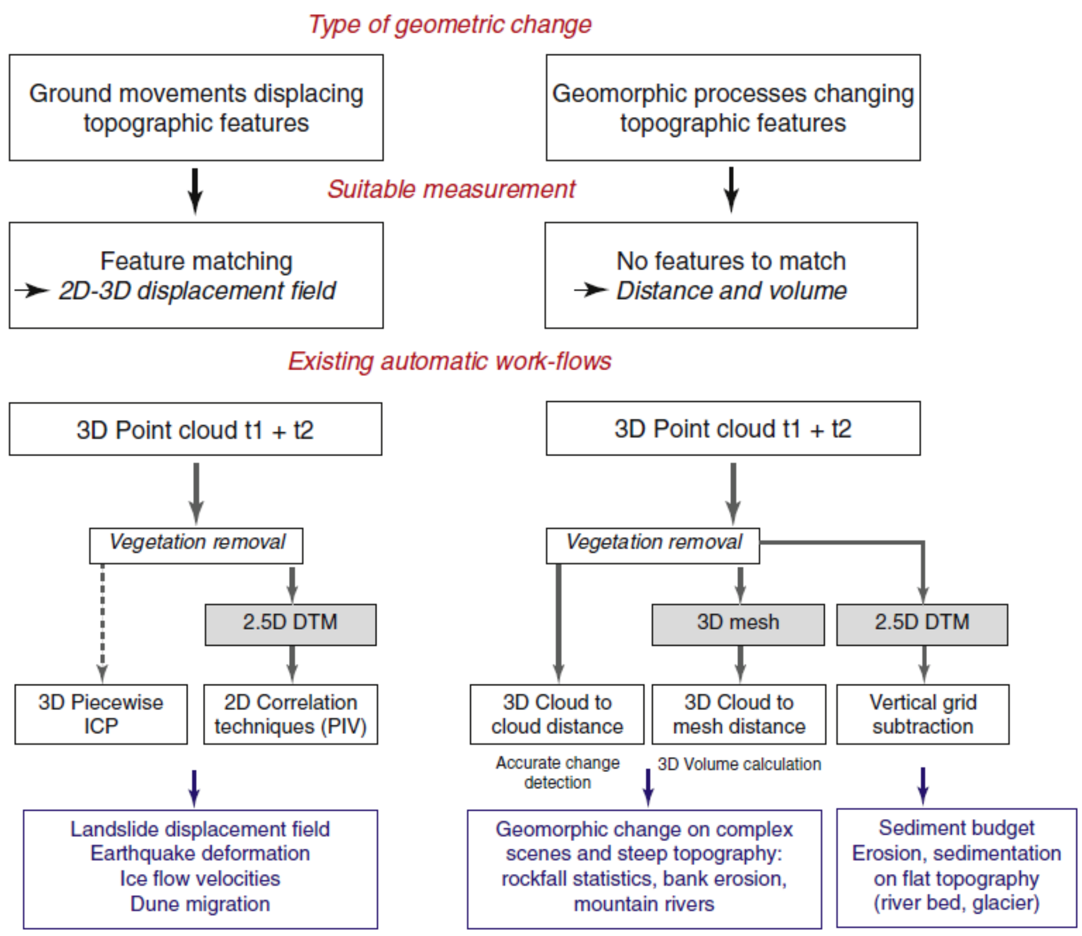




- Highly localized bank erosion
- Dominance of overmarsh tide events on bank erosion
- Frequency-magnitude analysis implies that largest annual event governs total annual bank retreat

(Lague and Leroux, in prep)

Synthesis on 3D Change Detection in environmental monitoring



From Passalacqua et al., Analyzing high resolution topography for advancing the understanding of mass and energy transfer through landscapes: A review, Earth Sciences Reviews, 2015

Sources d’erreur

<table>
<tr><th></th><th></th><th>Error sources</th><th colspan="3">Best case error magnitude (1σ)</th></tr>
<tr><td rowspan="5">Positional uncertainty</td><td rowspan="3">ALS/mobile case</td><td>Sensor precision +
GPS/IMU + scan geometry
Range, incidence angle,
and assembly calibration</td><td>ALS case</td><td>500 m
altitude</td><td>3000 m
altitude</td></tr>
<tr><td rowspan="2"></td><td>Vertical[a]</td><td>0.06 m</td><td>0.15 m</td></tr>
<tr><td>Horizontal[a]</td><td>0.20 m</td><td>0.60 m</td></tr>
<tr><td rowspan="2">TLS case</td><td>Sensor precision + scan
geometry
Range, incidence angle,
and shadowing</td><td colspan="3">Short Range: 2 mm

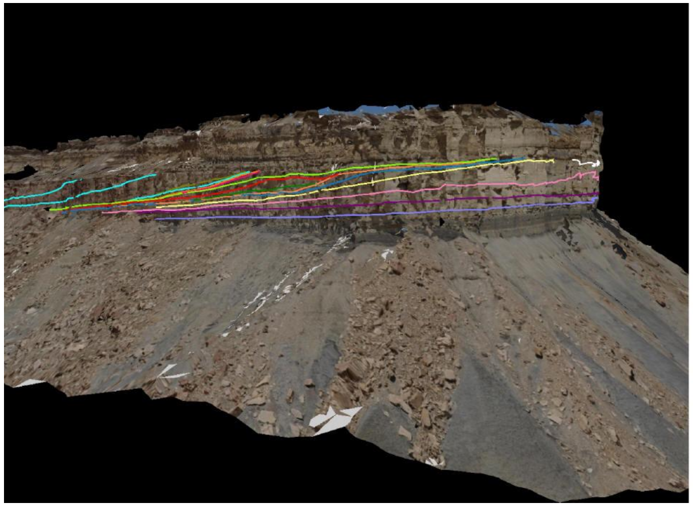
Long Range: > 10 mm</td></tr>
<tr><td>Registration
Local: fixed targets, and ICP
Georeferencing: GPS</td><td colspan="2">Local

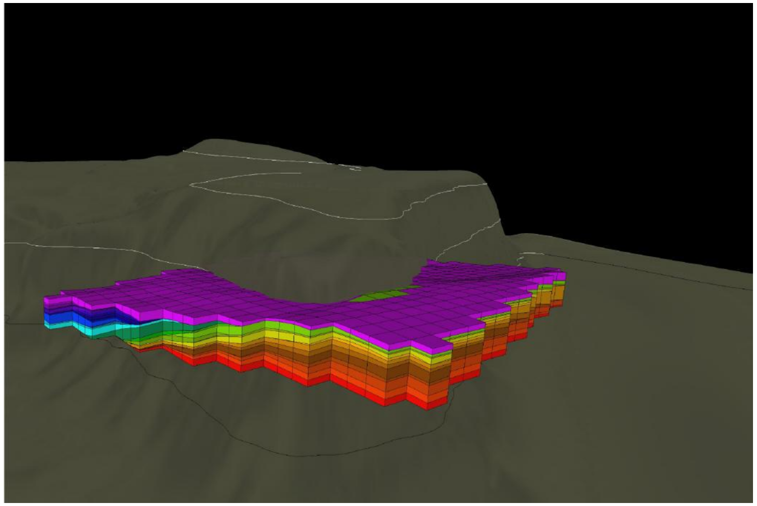
Global</td><td>0.002 m

0.05–0.10 m</td></tr>
<tr><td>Classification uncertainty</td><td>Point cloud</td><td>Bare earth extraction
Made complex by vegetation,
steep slope, roughness,
and artifacts</td><td colspan="3">Extremely variable: from 0 mm (2D bare surface at normal incidence) to vegetation height if it cannot be removed (e.g., grass)</td></tr>
<tr><td>Surface representation uncertainty</td><td>DEM</td><td>Resolution +
interpolation method
Made complex by vegetation,
water, 3D elements, and steep
slopes</td><td colspan="3">Extremely variable: negligible (i.e., 10^{-3} to 10^{-2} m) in densely sampled, smooth surfaces, large (i.e., 10^{0} to 10^{1} m) in topographically complex areas with coarse resolution and poor interpolation areas (wetted or occluded parts) and on rough/steep</td></tr>
</table>

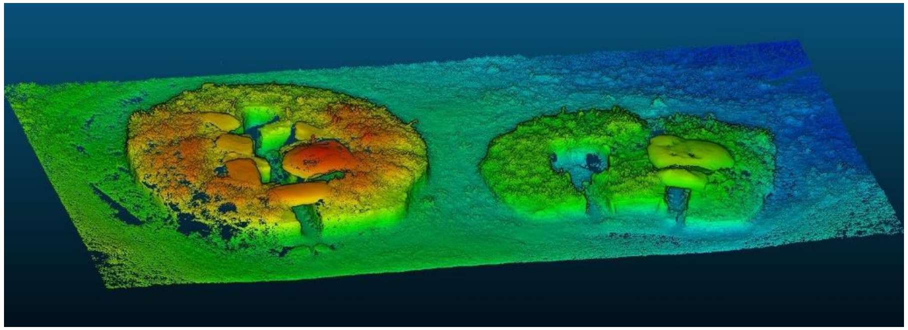
3D archives of the environment

- Geomodelling





- Numerisation in situ (e.g., paleontologie, archeologie)



Forestry applications (huge research field)

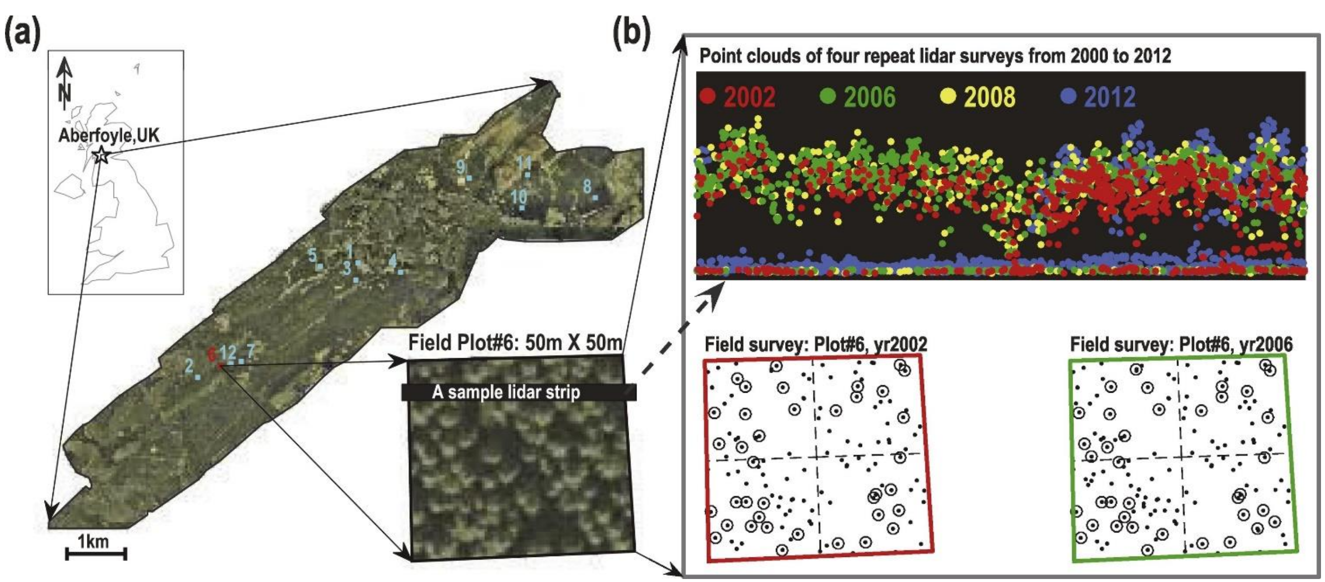
Remote Sensing of Environment
Available online 28 September 2017
In Press, Corrected Proof

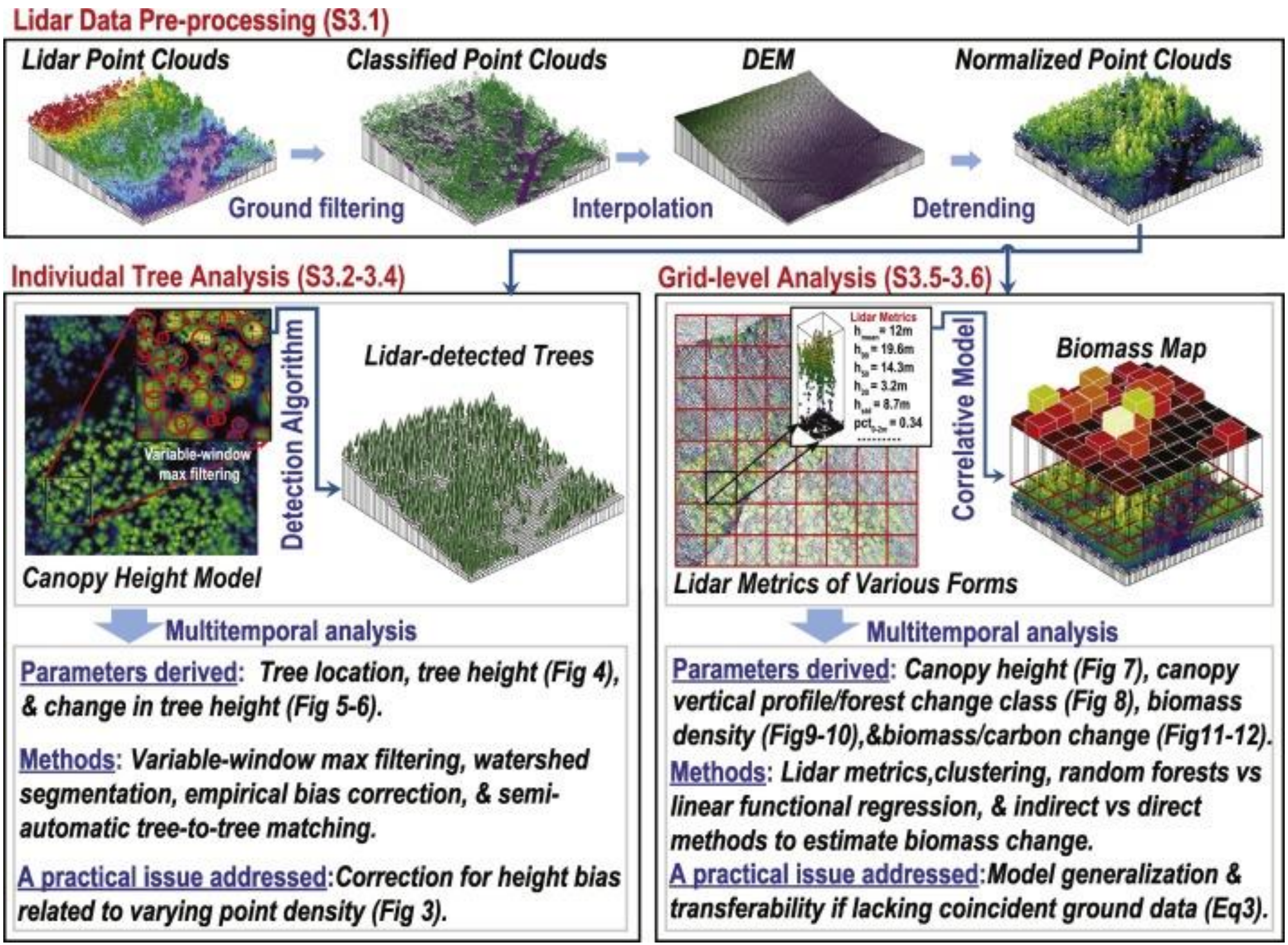
Utility of multitemporal lidar for forest and carbon monitoring: Tree growth, biomass dynamics, and carbon flux

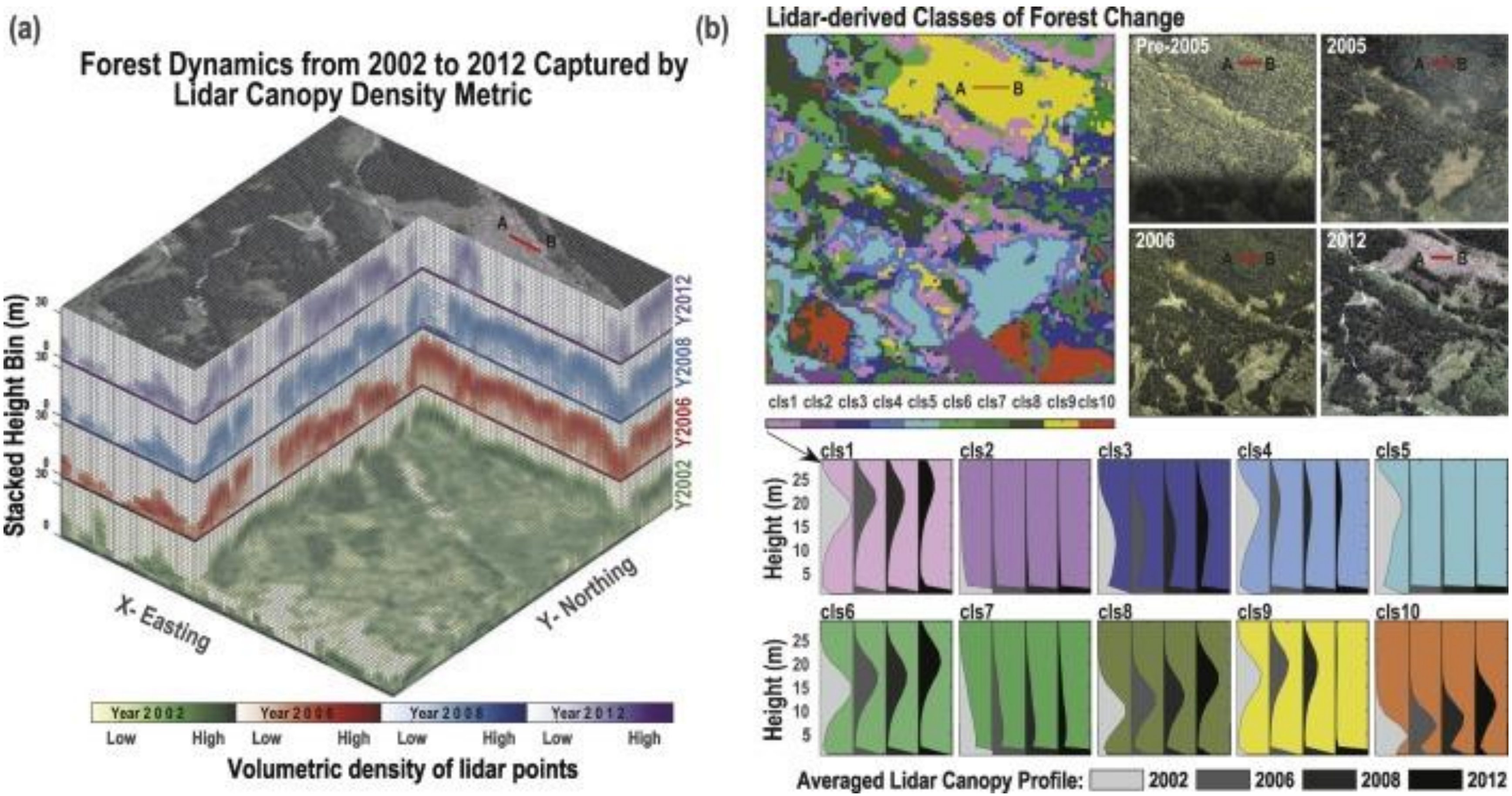
Kaiguang Zhao [a, b], Juan C. Suarez [c], Mariano Garcia [d], Tongxi Hu [b], Cheng Wang [e], Alexis Londo [b]

⊞ Show more

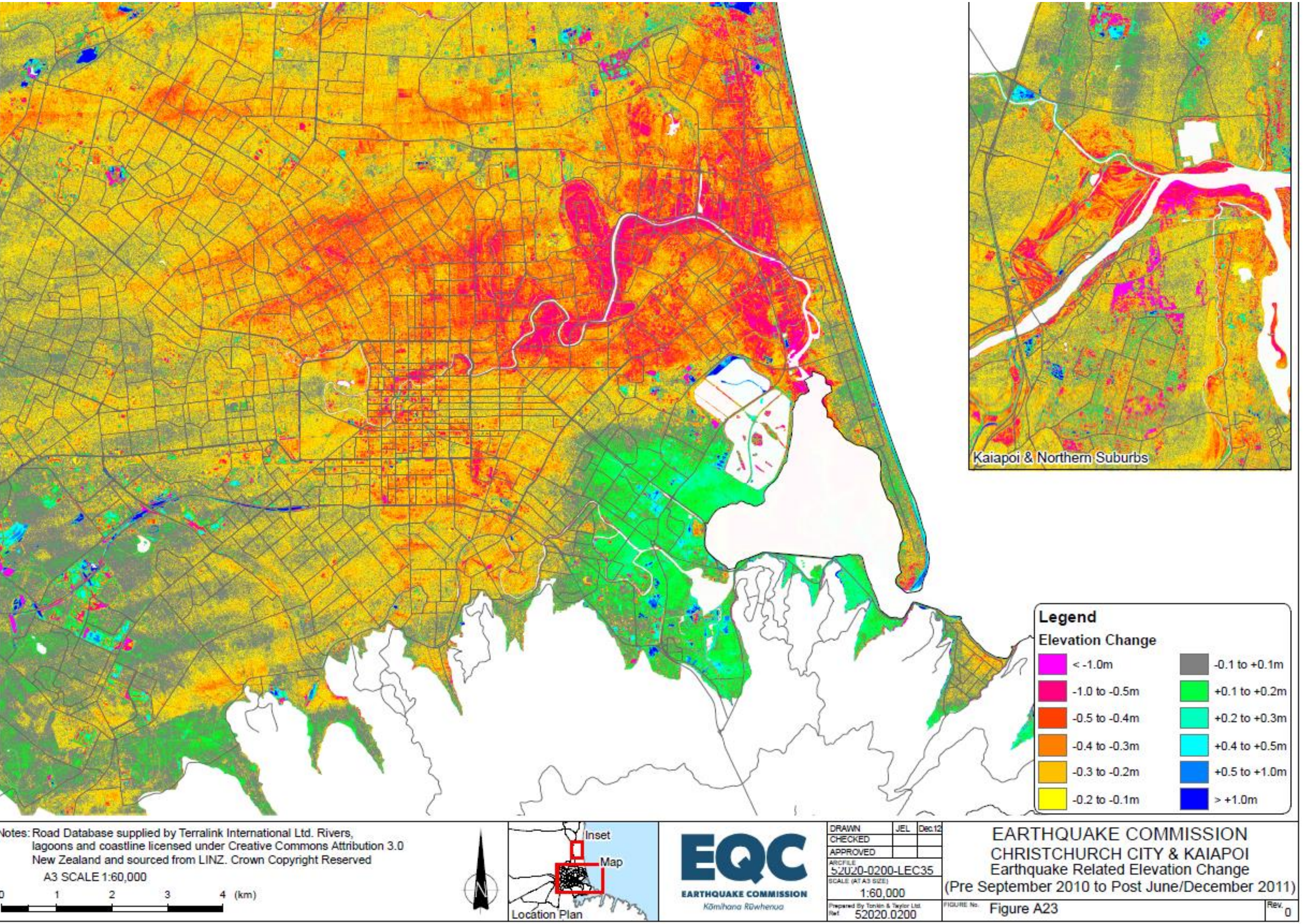
https://doi.org/10.1016/j.rse.2017.09.007



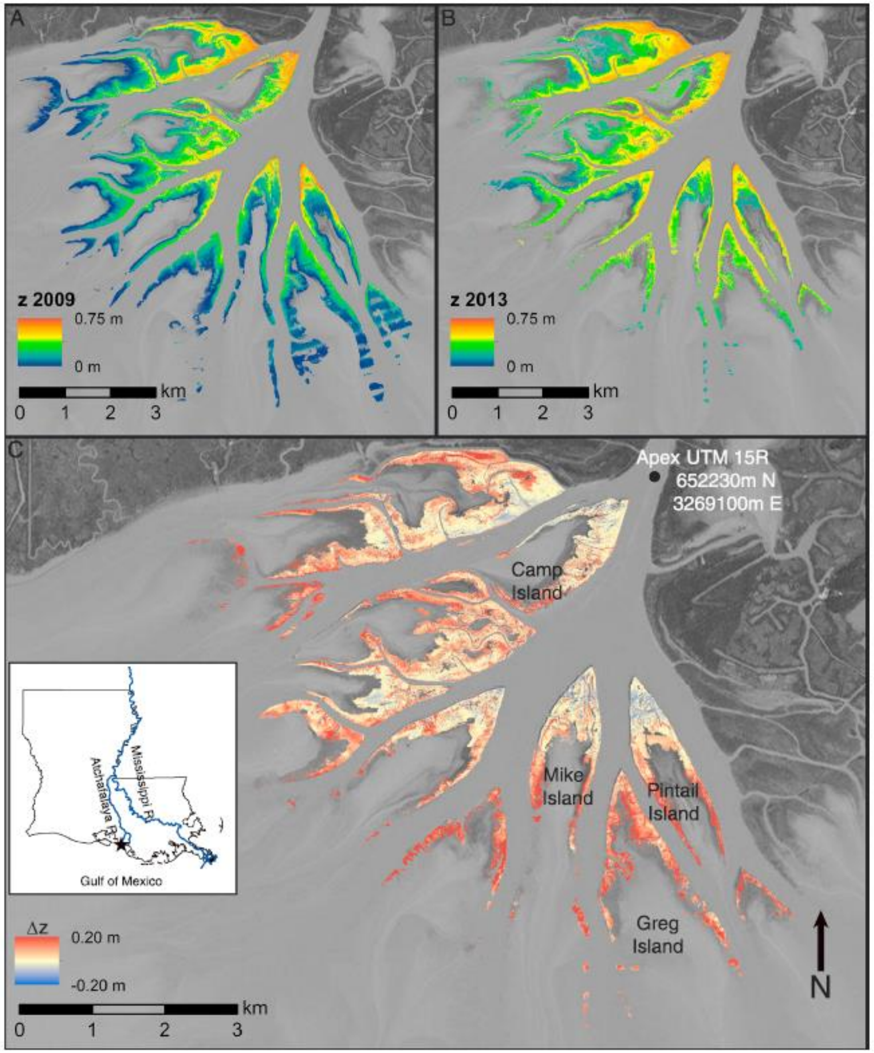

Lidar Data Pre-processing (S3.1)
Lidar Point Clouds
Classified Point Clouds
DEM
Normalized Point Clouds
Ground filtering
Interpolation
Detrending
Indiviudal Tree Analysis (S3.2-3.4)
Variable-window max filtering
Detection Algorithm
Lidar-detected Trees
Canopy Height Model
Multitemporal analysis
Parameters derived: Tree location, tree height (Fig 4), & change in tree height (Fig 5-6).
Methods: Variable-window max filtering, watershed segmentation, empirical bias correction, & semi-automatic tree-to-tree matching.
A practical issue addressed: Correction for height bias related to varying point density (Fig 3).
Grid-level Analysis (S3.5-3.6)
Lidar Metrics
Correlative Model
Biomass Map
Lidar Metrics of Various Forms
Multitemporal analysis
Parameters derived: Canopy height (Fig 7), canopy vertical profile/forest change class (Fig 8), biomass density (Fig9-10),&biomass/carbon change (Fig11-12).
Methods: Lidar metrics,clustering, random forests vs linear functional regression, & indirect vs direct methods to estimate biomass change.
A practical issue addressed: Model generalization & transferability if lacking coincident ground data (Eq3).


(a)
Forest Dynamics from 2002 to 2012 Captured by Lidar Canopy Density Metric
Stacked Height Bin (m)
Y2012
Y2008
Y2006
Y2002
A
B
X- Easting
Y- Northing
Year 2002
Year 2006
Year 2008
Year 2012
Low
High
Low
High
Low
High
Low
High
Volumetric density of lidar points
(b)
Lidar-derived Classes of Forest Change
Pre-2005
2005
2006
2012
cls1 cls2 cls3 cls4 cls5 cls6 cls7 cls8 cls9 cls10
Height (m)
Averaged Lidar Canopy Profile: 2002 2006 2008 2012

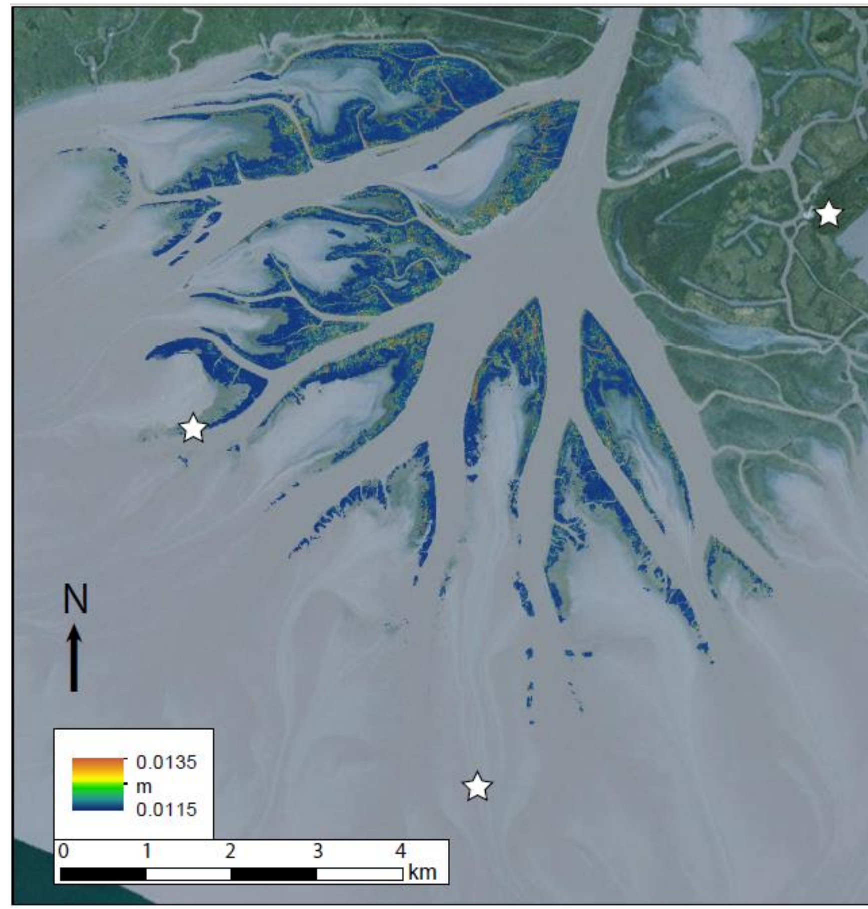
Vertical topographic difference related to the Christchurch Earthquake



Change detection on Mississipi Delta using repeat Airborne Lidar surveys



Uncertainty map combining roughness and registration effects

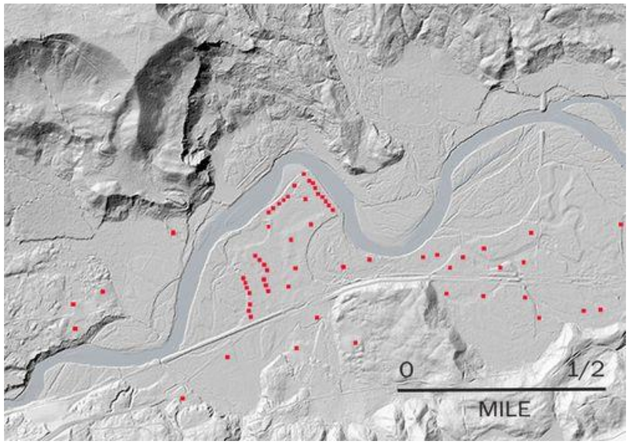


(Wagner, Lague, Morhig, Passalacqua, Shaw, Moffett, GRL, 2017)

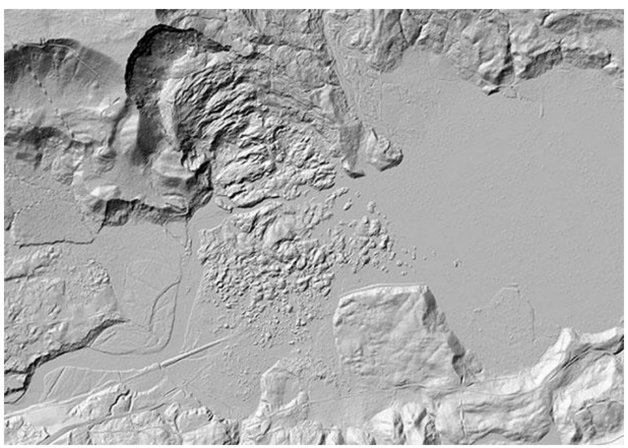
Landslide hazards

OSO Landslide, March 2014, US

T$_1$

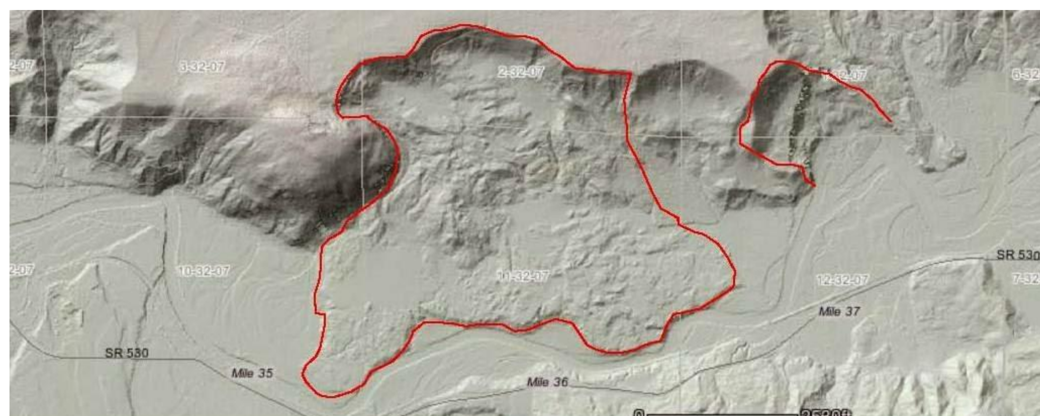


T$_2$



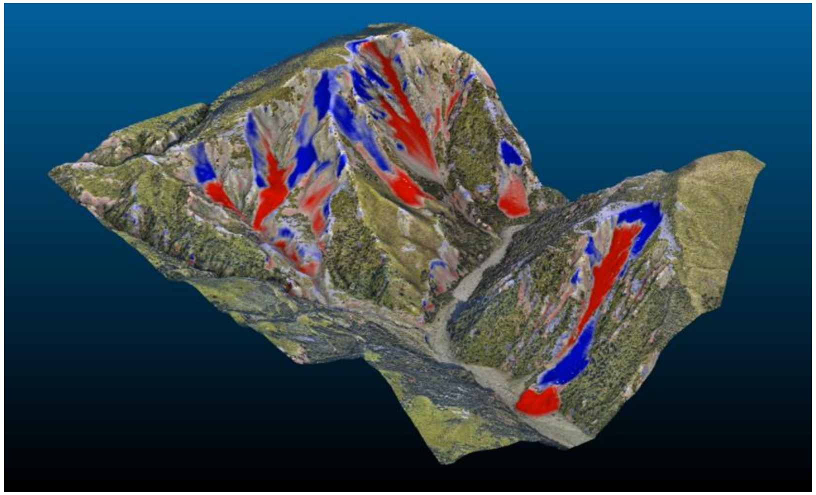
USGS

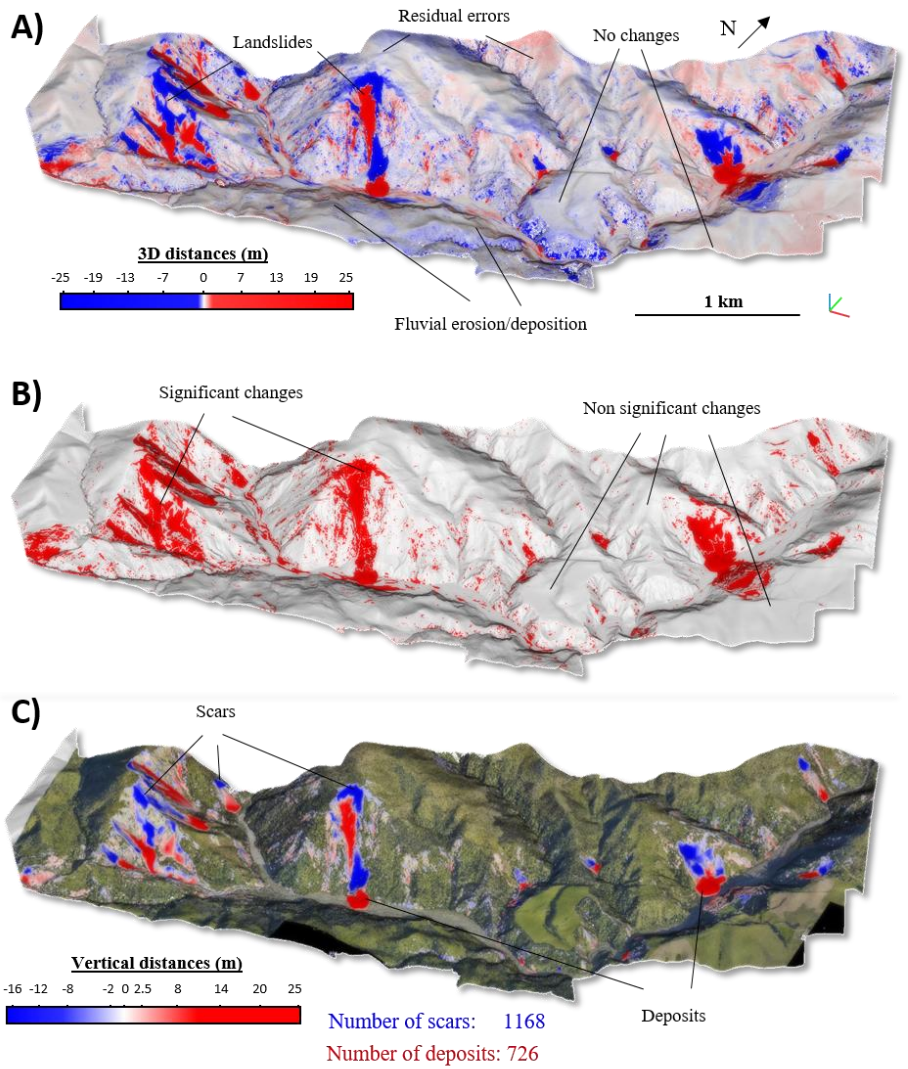
Without vegetation, old landslides can easily be detected



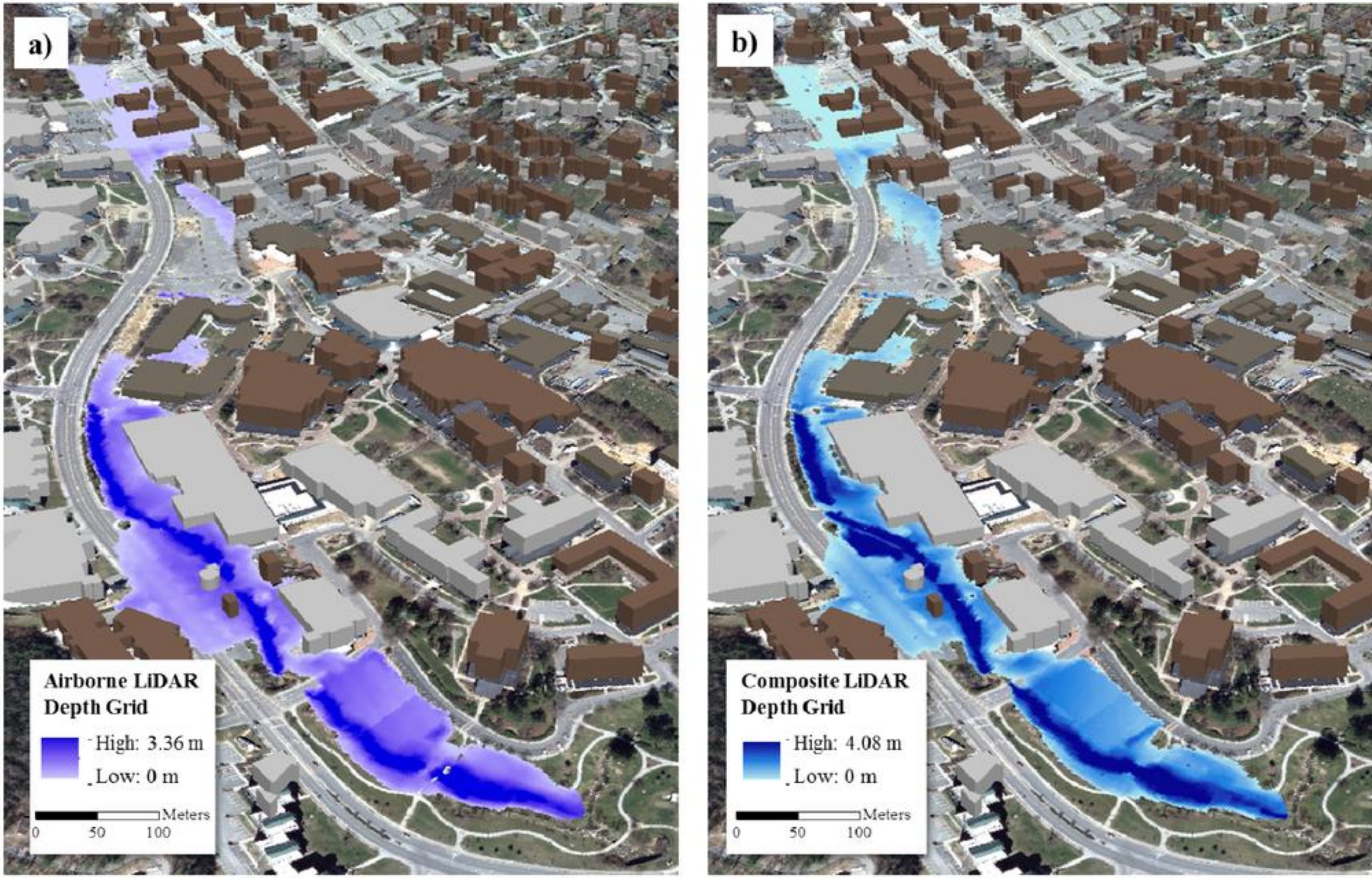
Automated detection and segmentation of Landslides in repeat ALS

Data that we'll use in the practical





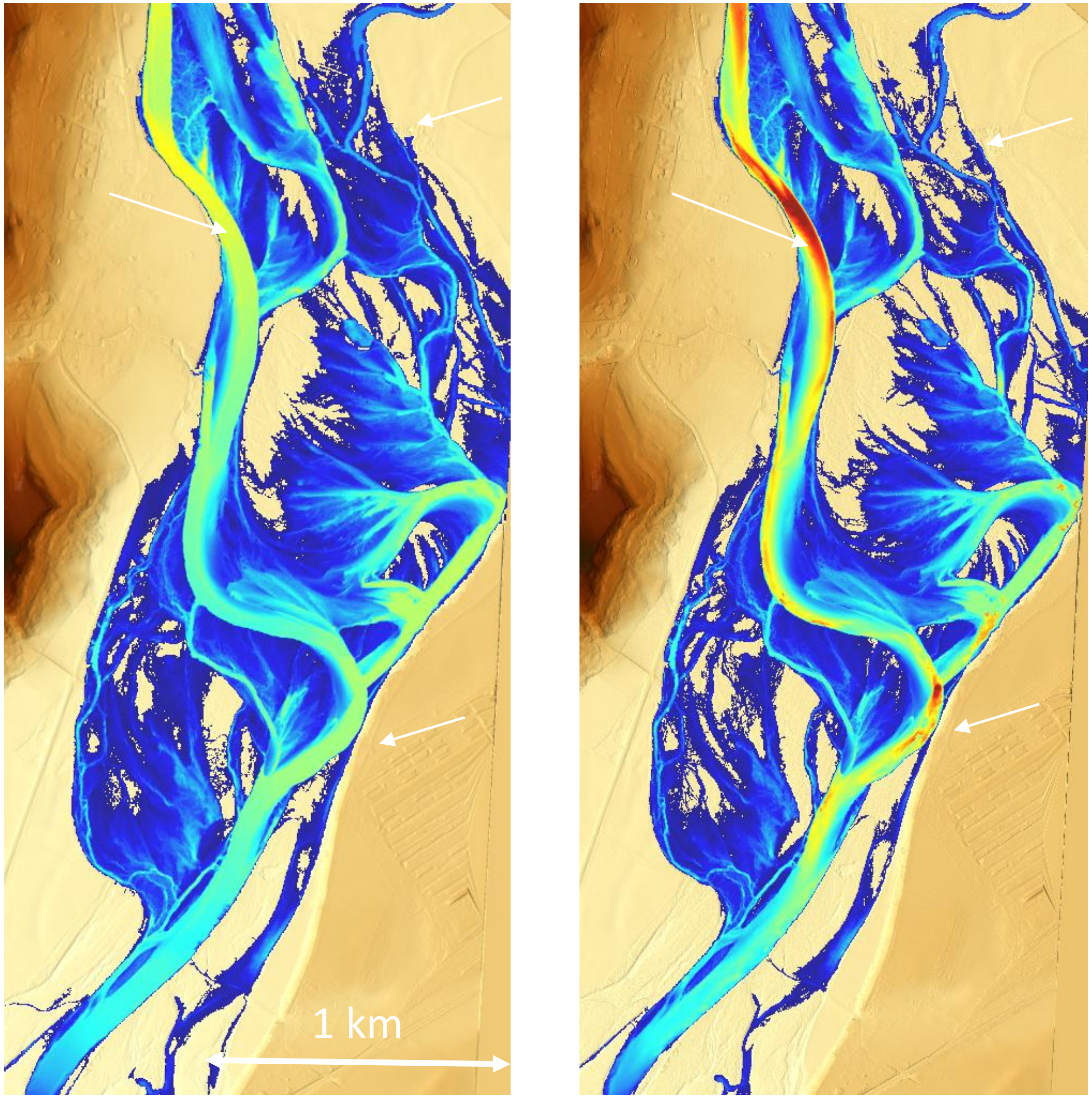
High resolution flood modelling



Improvement with topo-bathymetric lidar

Predicted depth
« Traditional » topo lidar

Predicted depth
with true bathymetry



1 m Raster DTM

Prediction from code Floodos *(Davy et al., JGR, 2017) resolving 2D St-Venant equations*

Uniform Manning friction = 0.035

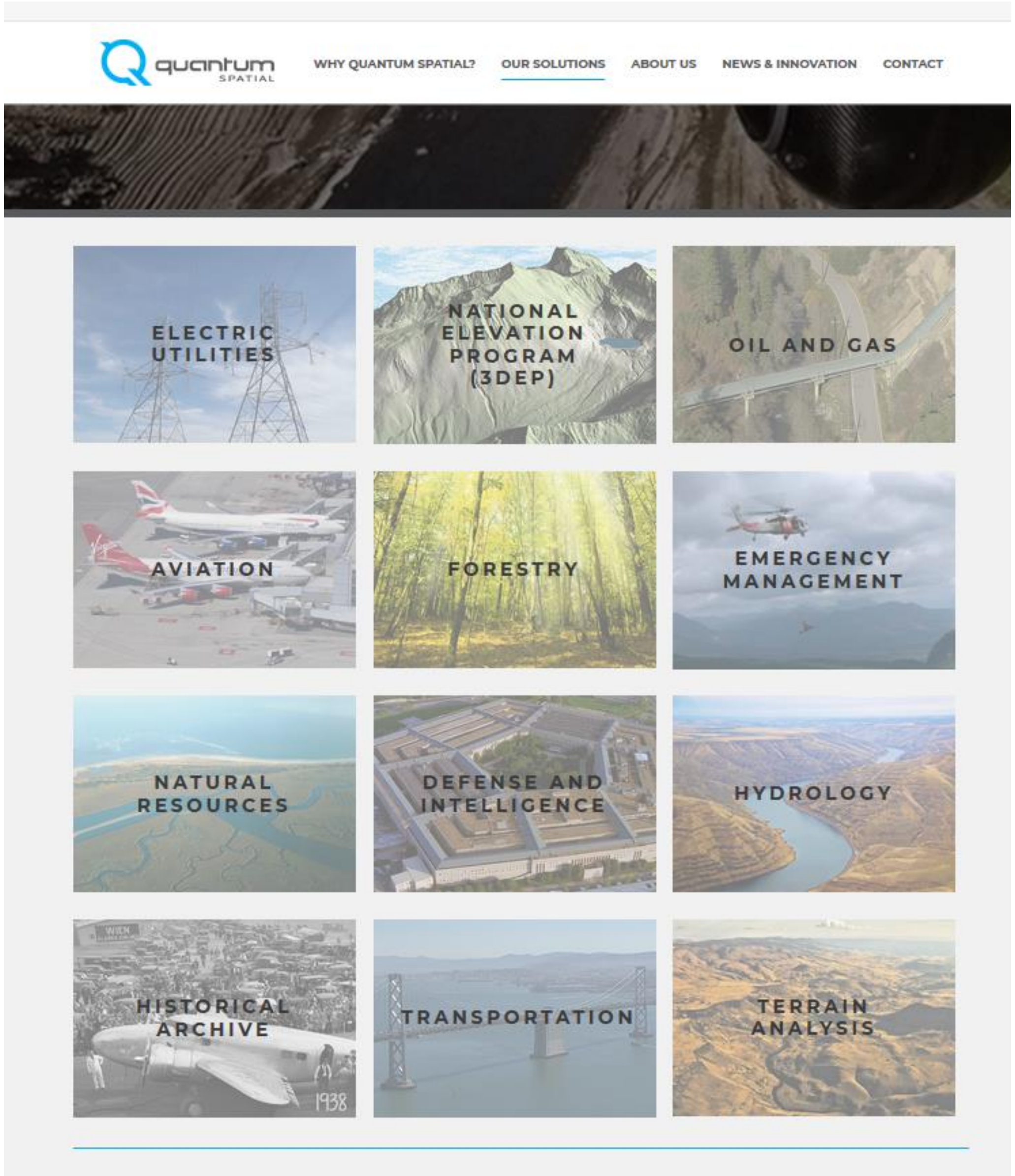
Q = 300 m3/s (3 times Qmean)

Exemples d’applications

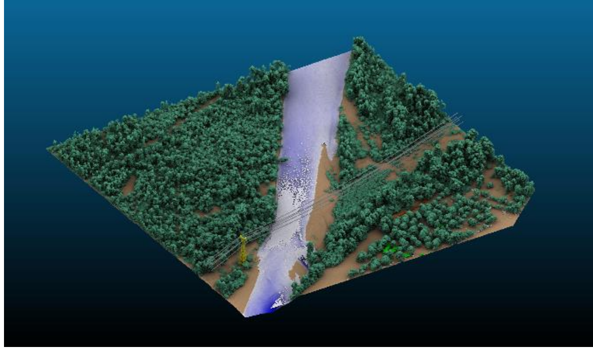
- Site web de Quantum Spatial

je n’ai aucune affiliation avec cette entreprise, mais leur site est particulièrement bien réalisé !!!

https://quantumspatial.com



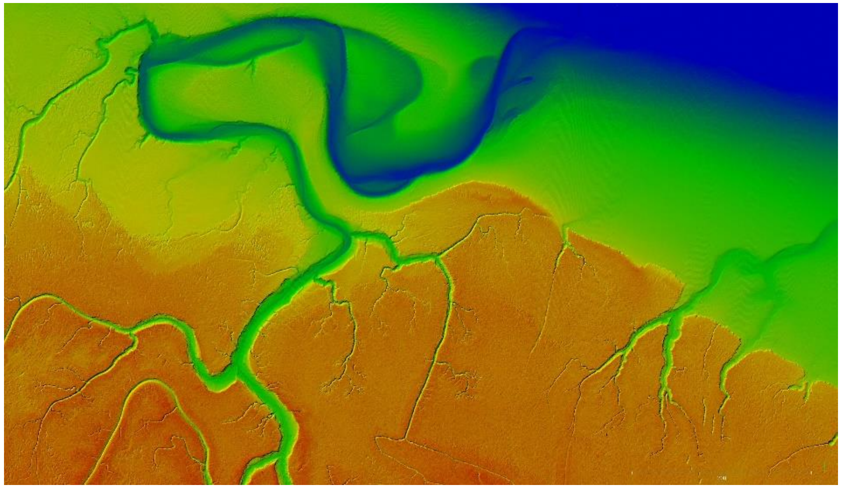
LiDAR and 3D monitoring of the environment at high resolution

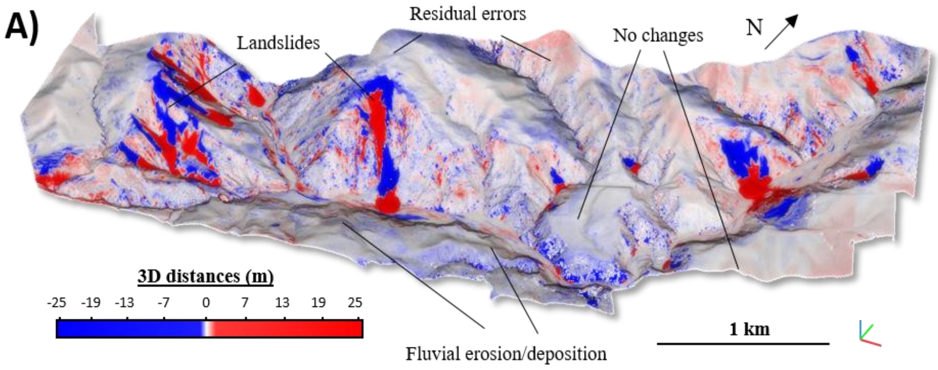


- **LiDAR**: key data for synoptic environmental monitoring, capturing ground, vegetation and infrastructures

- **Structure From Motion is a viable alternative, but is limited when there is vegetation**

- **3D processing tools are far less advanced than 2D ones, but there is rapid progress on classification and change detection**





Contact: dimitri.lague@univ-rennes1.fr