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Feasibility study of the use of bathymetric surface modelling techniques for intertidal zones of beaches

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Intro | Measurement techniques | Data acquisition | Results | Conclusion

Project SeArch: Belgian governmental funded scientific research focused on the preservation of archaeological relicts in the (North)Sea.

Collaboration between:

- Flanders Marine Institute (VLIZ)
- Flemish Heritage Agency (FHA)
- Deltares (Department of Geology and Geophysics)
- Ghent University
  - Renard Centre of Marine Geology
  - Maritime Institute
  - Department of Geography , with support of ENSTA (Bretagne, France)

Project SeArch: Belgian governmental funded scientific research focused on the preservation of archaeological relicts in the (North)Sea.

Purpose:

- Development of an efficient acquisition methodology for finding, locating and to draw up an inventory of archaeological relicts.
- To establish a sustainable management policy and legal framework for the preservation of archaeological relicts in the North Sea.

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Objective: 3D modelling of the intertidal zones (DSM) by selecting an accurate, cost-efficient, preferably innovative survey methodology

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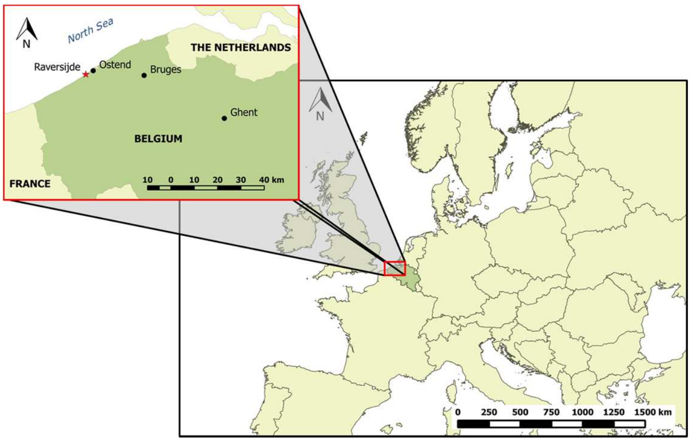
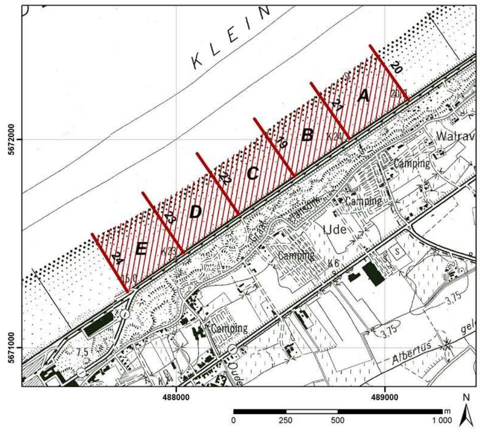
- **Field campaign** at the end of spring 2013
- Beach of Raversijde(Belgium), 300 m wide between breakwaters
- Every 350 m, breakwaters divide the beach in several parts
- Survey area A, B and C





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Coastal conditions in Belgium:

- Twice-daily tide
  - Sea level differs approximately 5 m
  - Beach slope of about 1° (1,7%)
- Sand beach (approx. 120 µm)

- High moisture content of the sand surface near the waterline
- High turbidity of the North Sea in shallow waters => small Secchi depths (dm-level)
- Weather conditions (especially wind) are rapidly changing

Selection based on the project requirements:

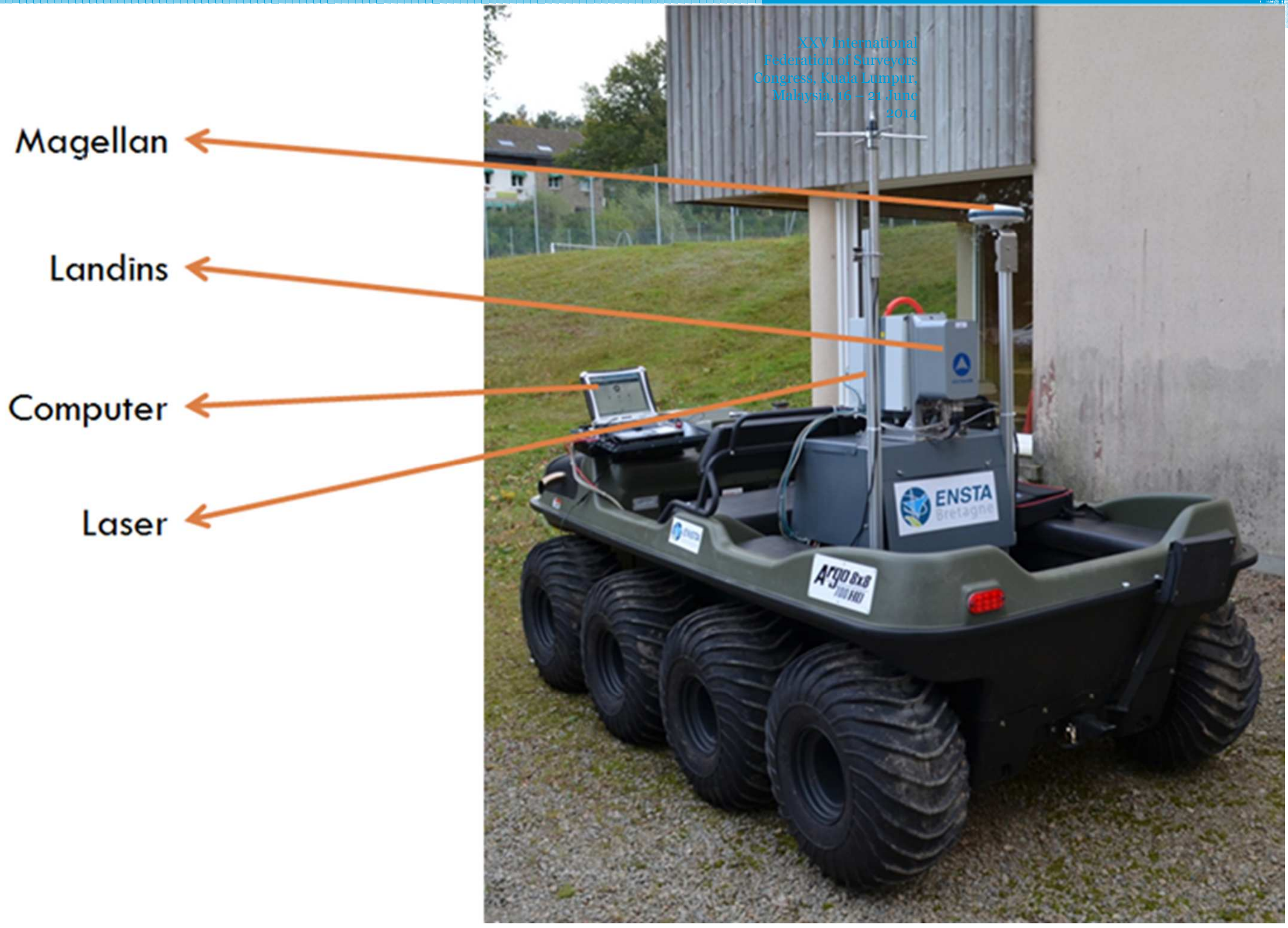
- Specified ground planimetric resolution of 15 cm
- Vertical accuracy of a few centimetre

Acquisition technique*	Vertical accuracy	GSD	Reference
ALS	5 cm	10 cm	[Stal et al., 2013]
ALB	25 cm	1 m	[Doneus et al., 2013]
STLS	2 - 5 cm	2 cm	[Pertrie and Toth, 2009]
MTLS	5 cm	10 cm	[Bitenc et al.,2011]
Traditional survey	1 - 4 cm	-	[Taaouti et al., 2011]
SfM-MVS	2 - 15 cm	2 - 5 cm	[Ortiz et al., 2013]

*** ALS = Airborne Laser Scanning**
ALB = Airborne Laser Bathymetry
STLS = Static Terrestrial Laser Scanning
MTLS = Mobile Terrestrial Laser Scanning
Traditional Survey = using GNSS and total station
SfM- MVS = Structure from Motion and Multi-View Stereo (photomodelling)

Mobile Terrestrial Laser Scanning (MTLS):

- Mobile platform:
  - Amphibious all terrain vehicle – ARGO.
  - Ground pressure: 0,15 bar.



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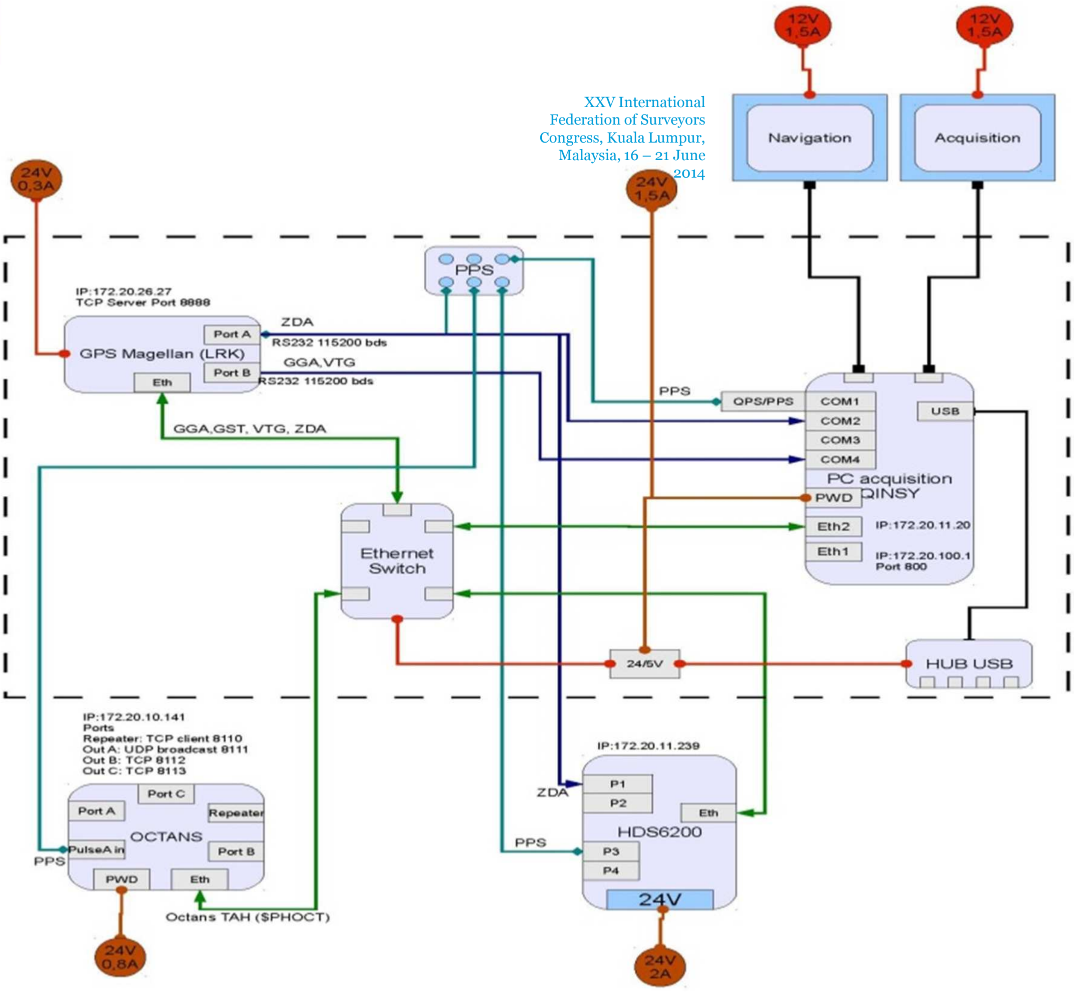
Sensors

GNSS: Ashtech Magellan Proflex 500
TLS: Leica HDS 6200
INS: Octans iXSea LandINS
PC: Rugged Panasonic
Softw.: QINSY

Argo (ENSTA)



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3D modelling of intertidal zones of beaches

System calibration ARGO (ENSTA)

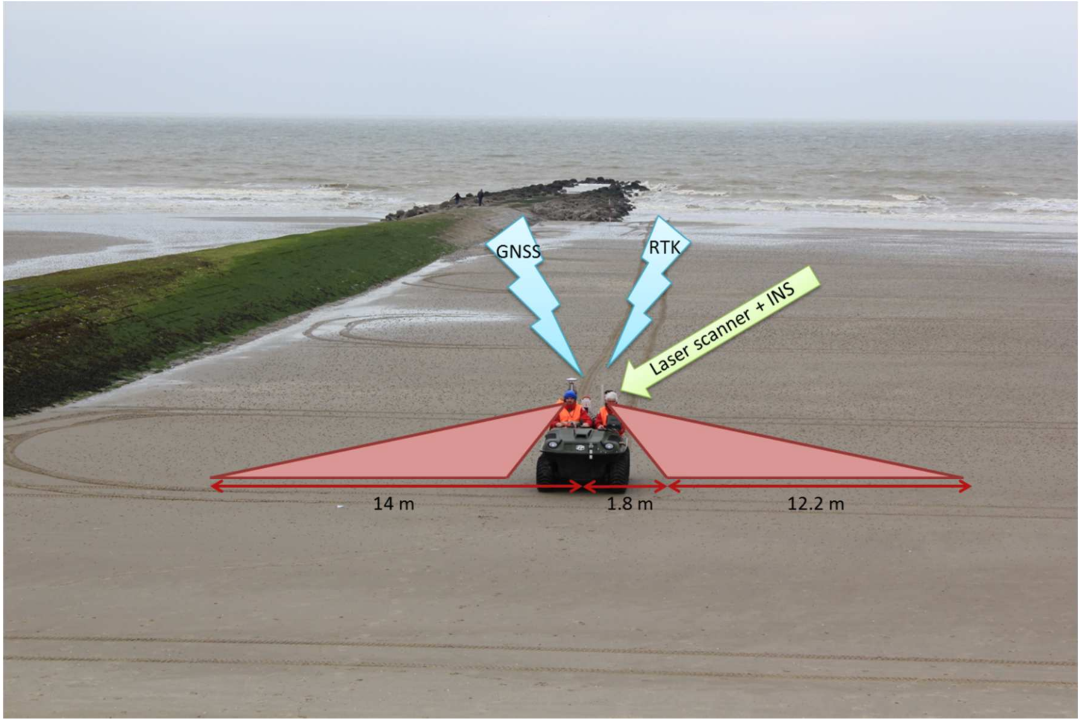
Lever arms: by total station and TLS validation;
Bore sight: by scanning a vertical object from different angles
Latency: by fitting of a sphere

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{Navigation} = \begin{pmatrix} x \\ y \\ z \end{pmatrix}_{GPS} + R_{IMU}\left[R_{Boresight} \times \begin{pmatrix} dx \\ 0 \\ dz \end{pmatrix} + \begin{pmatrix} a \\ b \\ c \end{pmatrix} \right]$$

R_{IMU} = Rotation matrix containing angular dynamic bias given by the IMU

$R_{Boresight}$ = Rotation matrix containing angular bias

Intro | Measurement techniques | **Data acquisition** | Results | Conclusion



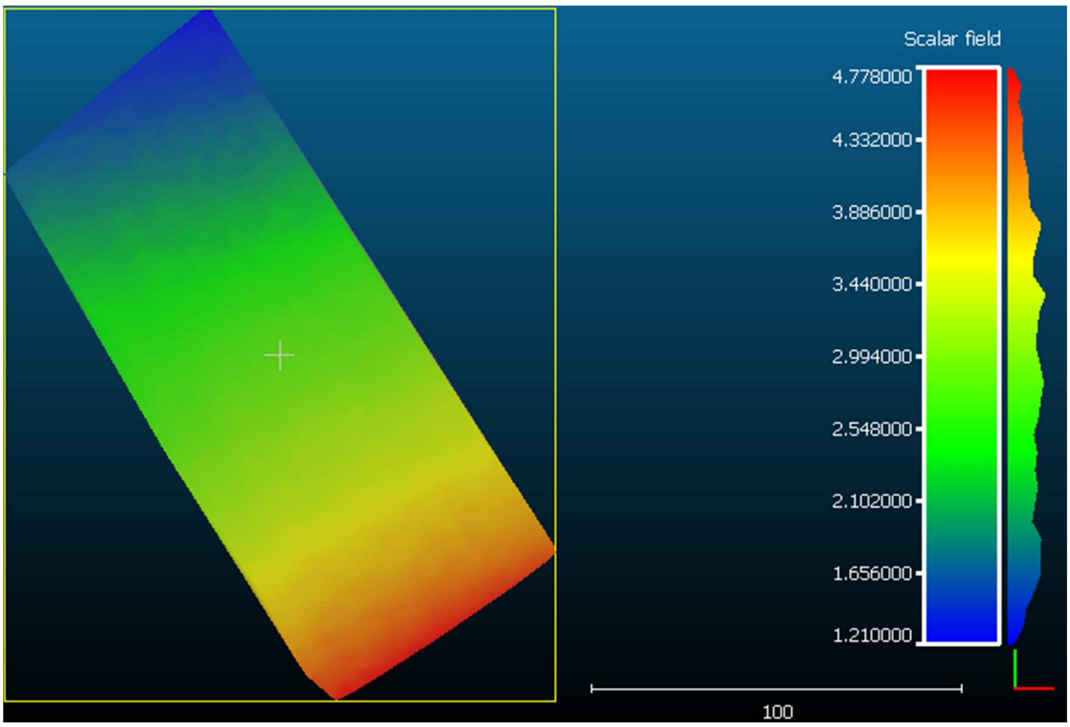
Future perspectives

- Increase 'seaproof-ness' of the platform
- Add SBES and water penetrating LS
- Advanced backscatter analysis of LS data

Outboard motor   Floating shell   SBAS

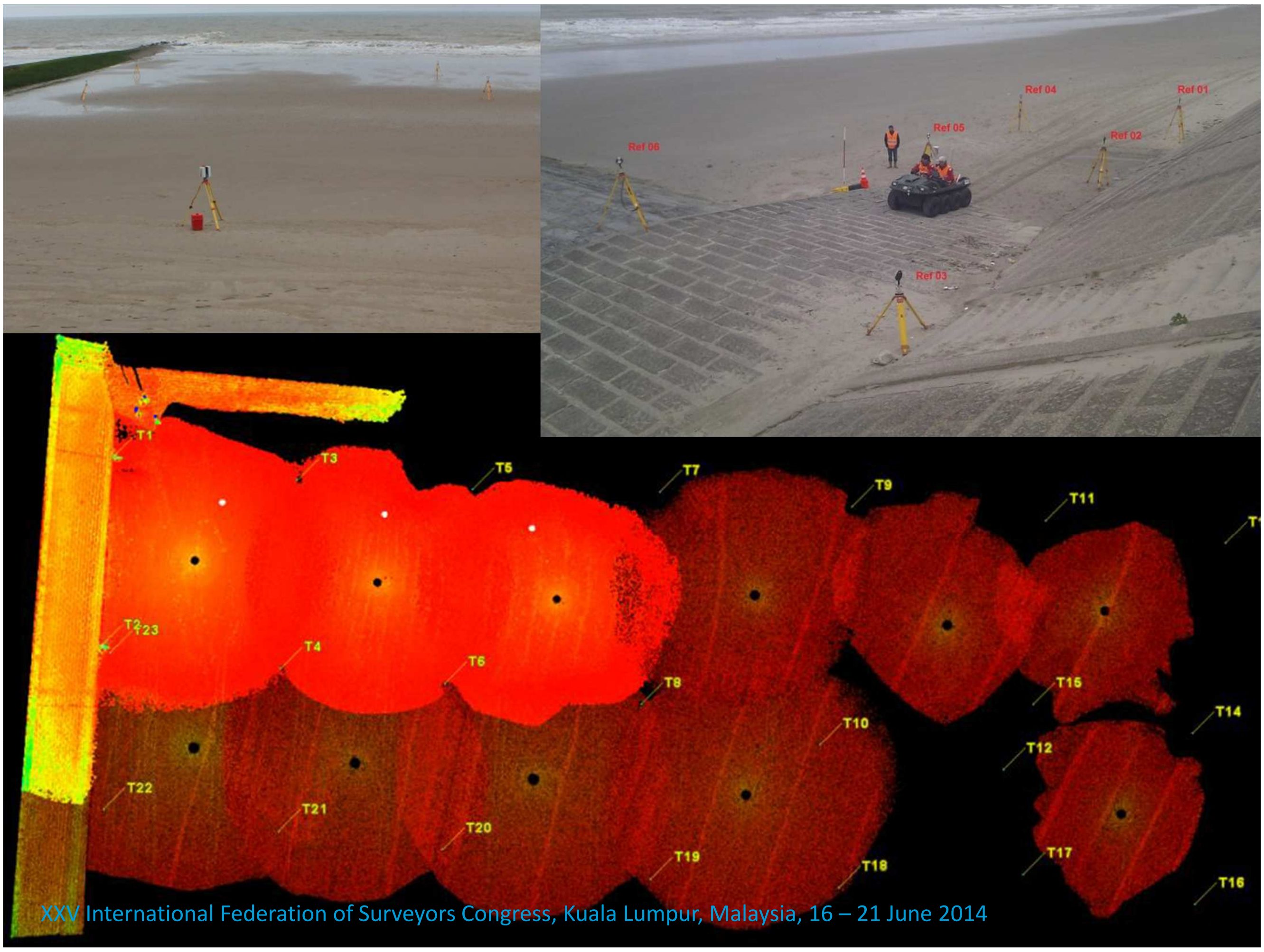
Ground Truth 1 by conventional surveying: grid model measured by Global Navigation Satellite system (GNSS)

- Trimble R8 RTK-receiver on 2.35 m pole
- FLEPOS (FLEmish POSitioning) RTK network
- Approx. 1000 points were measured
- RTK accuracy of 1 till 2 cm in planimetry
- RTK accuracy of 2 till 4 cm in altimetry
- One point per 2.5 m in continuous RTK mode
- Line separation of approx. 5 m



Ground Truth 2 by Static Terrestrial Laser Scanning (STLS):

- Leica HDS6100 phase scanner
- Up to 500.000 points/sec
- Nominal range of 50 m (18 % albedo)
- Nominal accuracy of 0.5 - 5 mm
- 15 set-up points
- Approx. 50 million points per set-up
- Scanner height: 1.4 m
- Resolution H/V: 6.3 mm at 10 m distance (0.07°)
- Scan time: 3 min. 22 sec.



Intro | Measurement techniques | **Data acquisition** | Results | Conclusion

Quality of the DSMs of laser scanning techniques are influenced by various factors:

- Surface properties
  - Grain size
  - Sand moisture
    - Twice-daily tide
- Range and incidence angle
  - Quality decreases with increasing range or incidence angle
  - Surface of the beach is more or les flat (limited slope ± 0,95°)

$$tg(incidence\ angle) = \frac{scanning\ height}{range}$$

- Speed of the mobile platform (only MTLS)
  - Max 6 km/h

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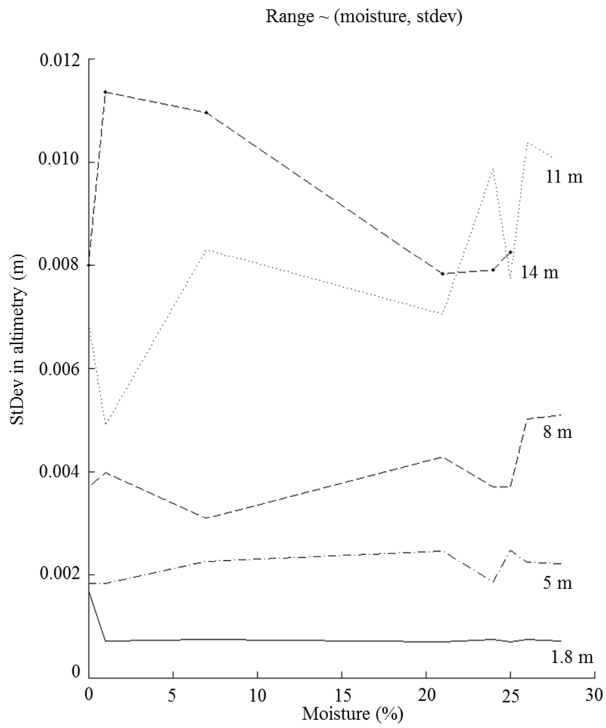
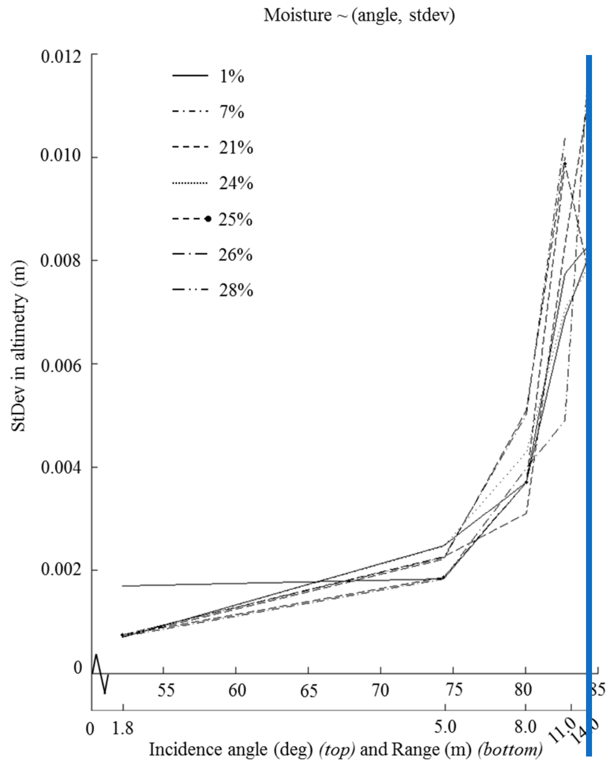
Laboratory experiment to test the influence of the:

- Range (related to the incidence angle)
- Humidity of the data quality

Net resulting average point number per dm² (scanning height 1.4 m, resol. 0.07˚)

	Range (m)				
Moisture (%)	**1,8**	**5**	**8**	**11**	**14**
1	1550	150	41	13	3
7	1467	147	41	13	3
21	1477	150	42	11	3
24	1482	148	40	11	2
25	1498	142	40	8	2
26	1475	146	28	6	0
28	1513	148	18	5	0

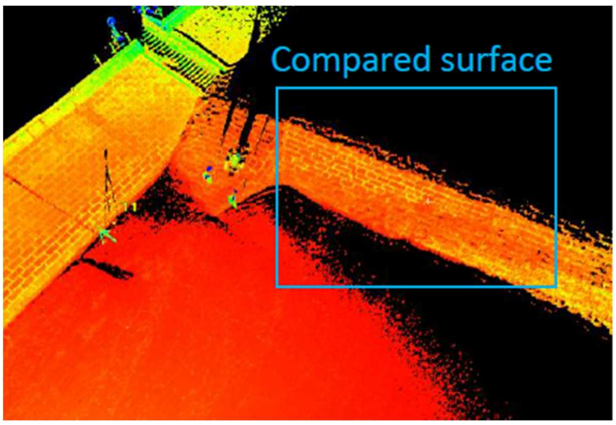


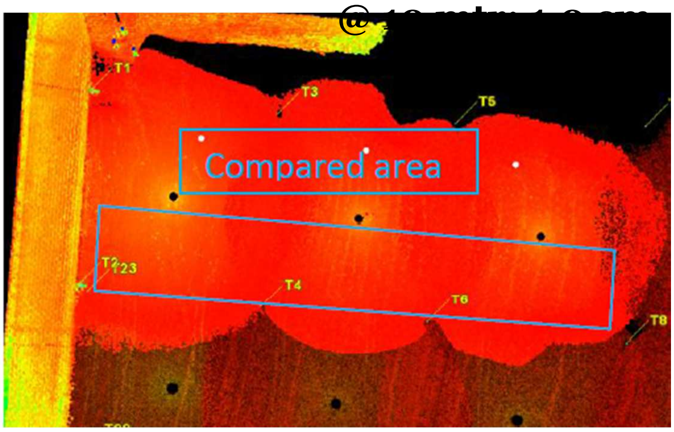


MTLS Model validation by comparison

GNSS: 0.9 cm (XY), 12 cm (Z)

STLS: 2.8 cm (concrete)
1.0 cm (sand)
Std at overlapping MTLS: general: 0.5 cm

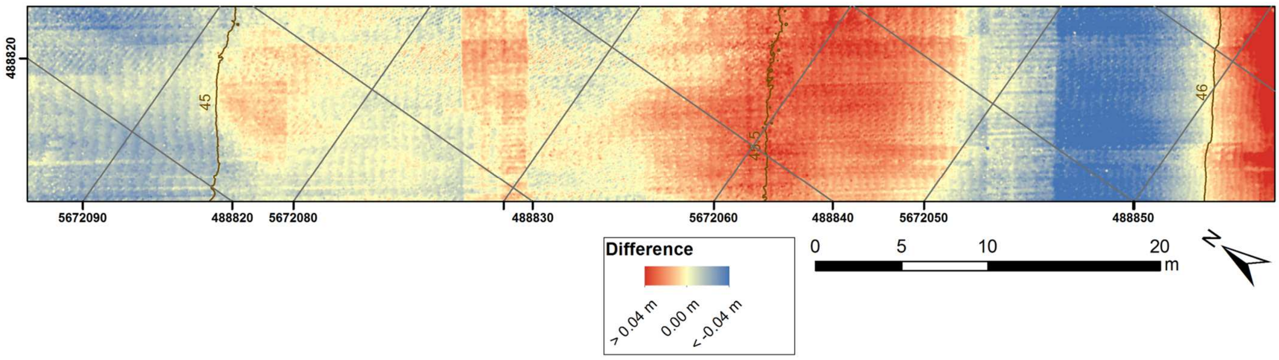




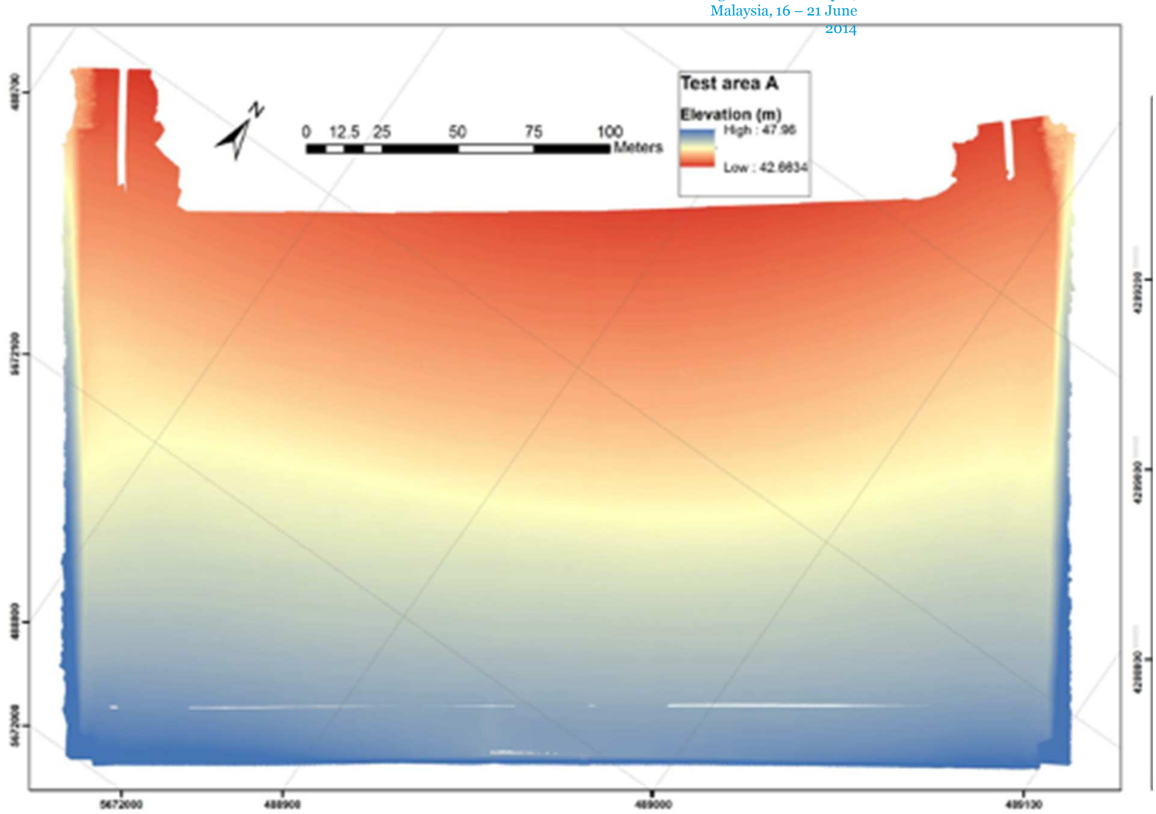
STLS ⇔ MTLS

Point to mesh computation

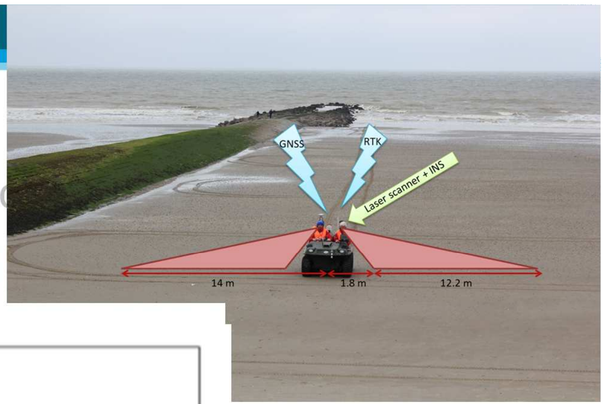
Deviations in altimetry: approx. 1 cm

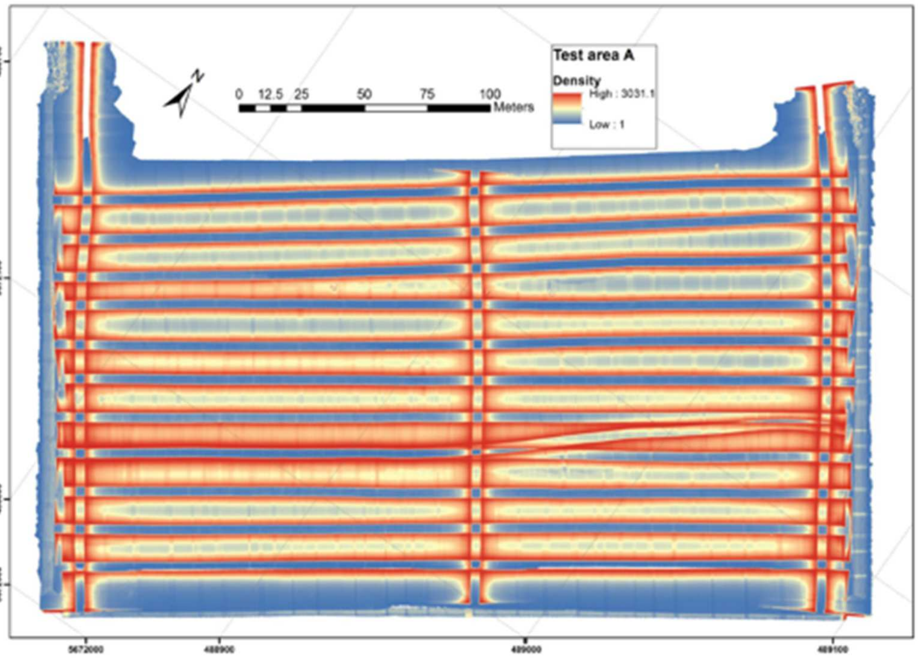


3D modelling of intertidal zones of beaches: MTLS surface model

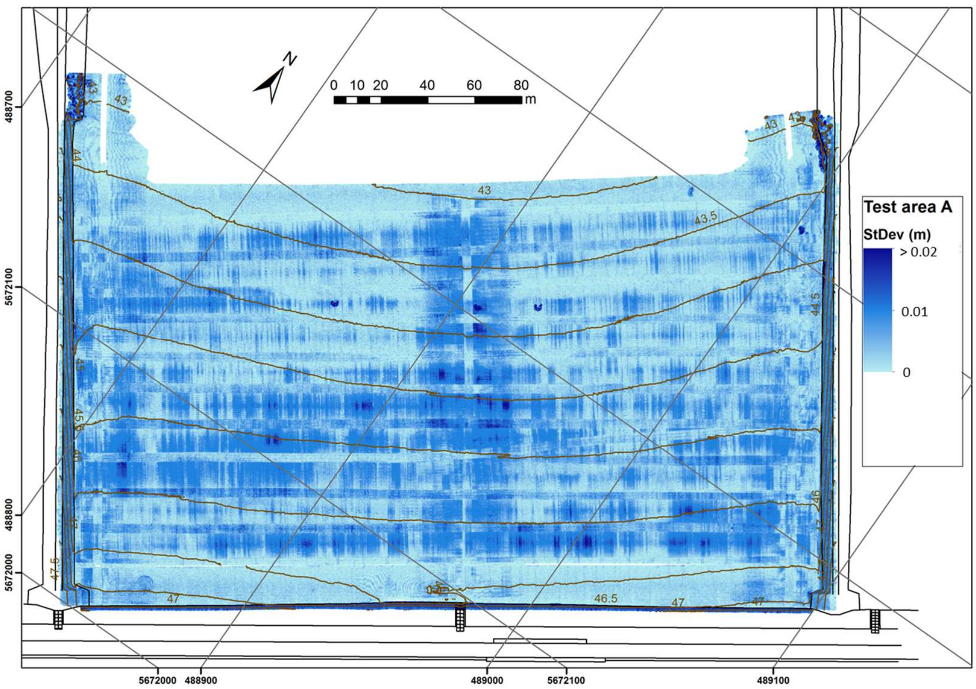


Point density of MTLS



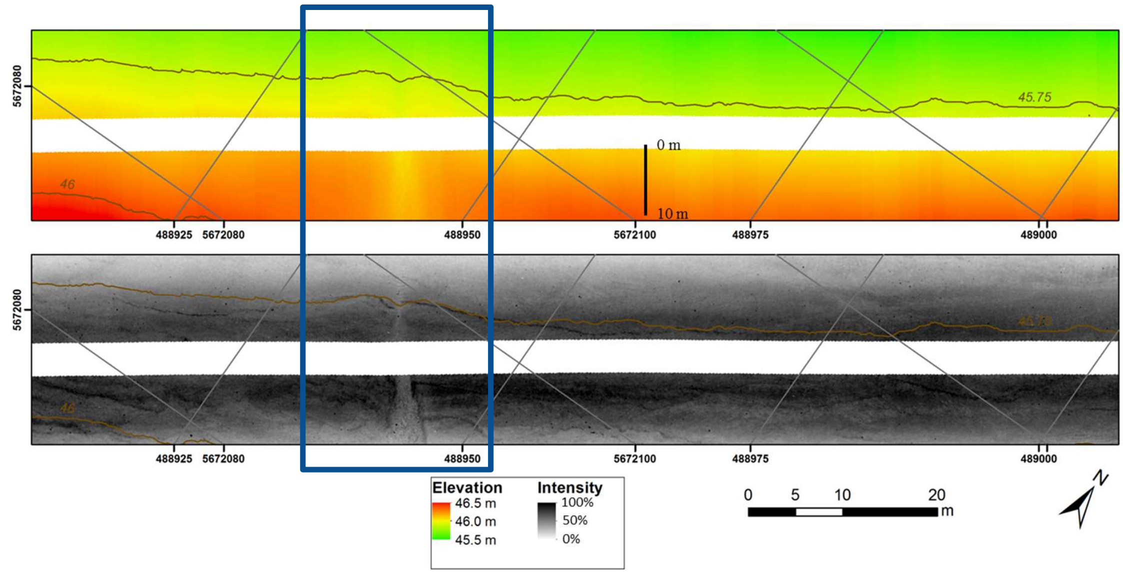


Standard deviation of MTLS (computed with 0.5 m radius)



Intro | Measurement techniques | Data acquisition | **Results** | Conclusion

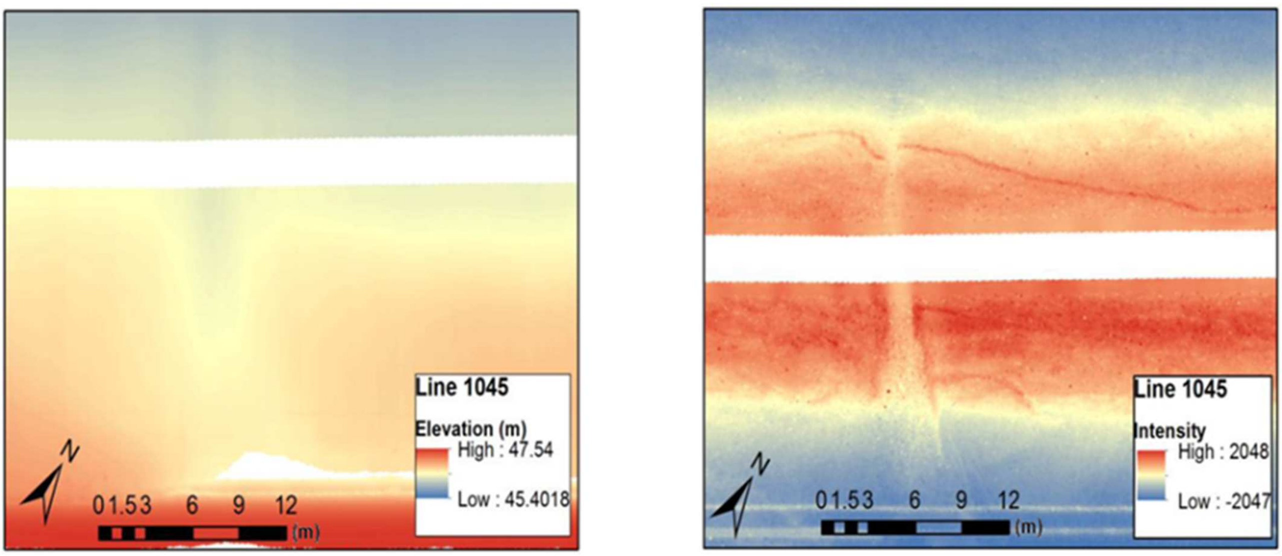
Elevation and intensity values



Elevation map (top) and intensity map (bottom) acquired from the same track line

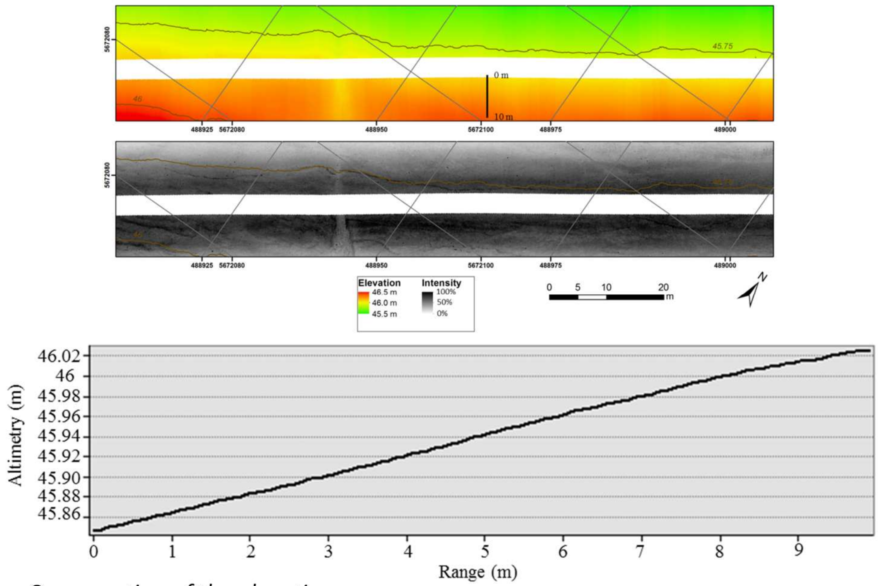
Intro | Measurement techniques | Data acquisition | **Results** | Conclusion

Elevation and intensity values



Zoom of elevation map (left) and intensity map (right)

Elevation and intensity values



Cross-section of the elevation map

Intensity values

The received backscatter of the emitted signal, theoretically described by the laser range equation, which is simplified as:

$$I = \rho \frac{\cos\alpha}{r^2} \eta_{Sys} C$$

$I =$ intensity value
$\rho =$ surface properties
$\alpha =$ incidence angle
$r =$ measured distance
$\eta_{Sys} =$ system transmission factor
$C =$ constant factor

A second order polynomial regression model with two predictor variables was estimated:

$$I = \boldsymbol{\beta X} = \beta_0 + \beta_1\alpha + \beta_2 r + \beta_{11}\alpha^2 + \beta_{22}\alpha r + \beta_{12} r^2 + \varepsilon$$

β_0 incorporates the assumed constant factor η_{Sys}
$\varepsilon =$ error value (represents the adjusted intensity value after removal of the effects caused by the incidence angle and measured distance)

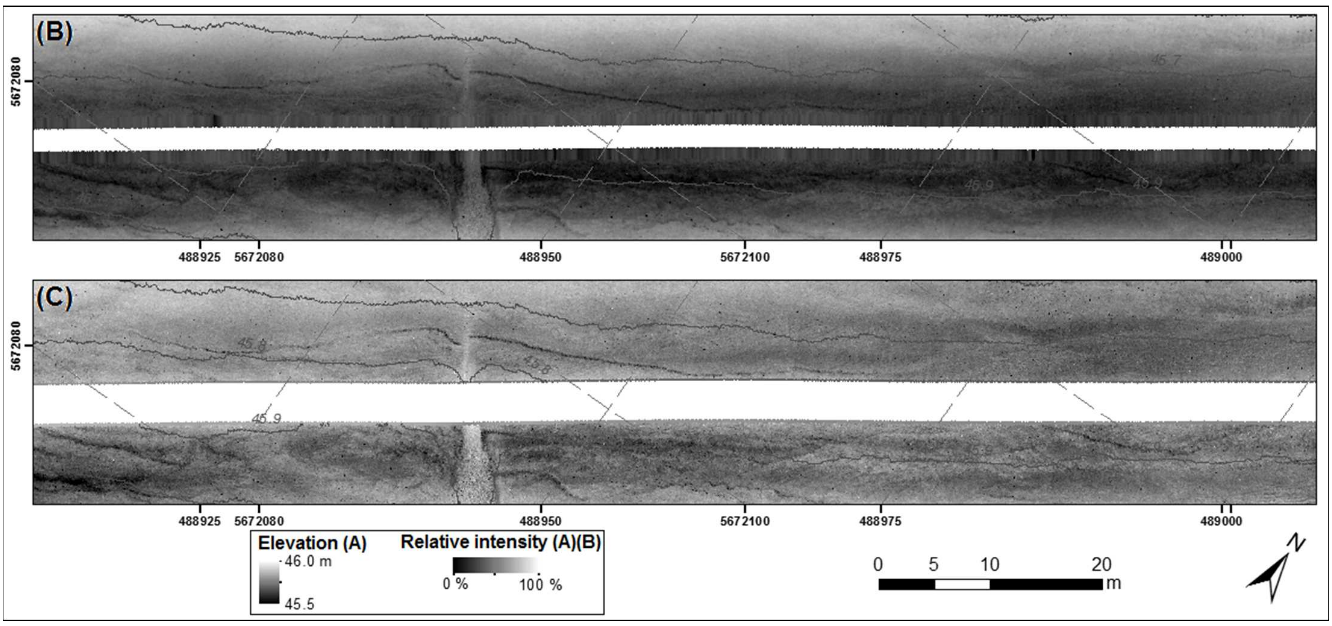
Intensity values

- Computed regression parameters are significant (95% confidence interval) => valid model
- These parameters permits to eliminate the effect of incidence angle and distance

	Static_1	Static_2	Static_3	Kinematic
$\beta_0\ (2\sigma_{\beta 0})$	-0.055 (0.018)	-0.019 (0.009)	0.023 (0.013)	1.038 (0.018)
$\beta_1\ (2\sigma_{\beta 1})$	0.129 (0.016)	0.04 (0.008)	0.024 (0.010)	-0.083 (0.005)
$\beta_2\ (2\sigma_{\beta 2})$	0.002 (< 0.001)	0.004 (< 0.001)	-0.001 (< 0.001)	-0.064 (< 0.001)
$\beta_3\ (2\sigma_{\beta 3})$	-0.014 (0.004)	0.01 (0.002)	0.009 (0.002)	-0.003 (0.003)
$\beta_4\ (2\sigma_{\beta 4})$	-0.005 (< 0.001)	-0.005 (< 0.001)	-0.004 (< 0.001)	0.018 (< 0.001)
$\beta_5\ (2\sigma_{\beta 5})$	< 0.001 (< 0.001)	< 0.001 (< 0.001)	< 0.001 (< 0.001)	0.001 (< 0.001)
SSE	3.717	2.251	3.410	373.700
R^2	0.735	0.689	0.623	0.693
RMSE	0.016	0.012	0.015	0.054

Intensity values

- Before and after correction for the incidence angle and distance



Intro | Measurement techniques | Data acquisition | Results | **Conclusion**

1) MTLS = very suitable survey technique for modelling intertidal zones

2) An innovative system for intertidal areas of beaches was presented, using integrated configuration of TLS, INS and GNSS;

Main advantages of the proposed MTLS method:

- **Survey time**
- **Point density**
- **High accuracy (cm-level)**
- **Amphibious vehicle**

3) In the near future:

- **more research regarding the intensity values**
- **new acquisition campaign with improved ARGO platform**

Thank you for your attention

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