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The Requirement of Accuracy Improvement of TLS for Structural Monitoring Tasks

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ABSTRACT

The application of geodetic instruments plays a vital role in structural monitoring tasks and deformation analyses. Over the past few decades, there has been a transition from traditional point-based measurements to point cloud observations for these procedures. In this context, Terrestrial Laser Scanning (TLS) offers several advantages over photogrammetric optical sensors, particularly for small-sized projects, due to the easiness and rapidity in data acquisition. Radar-based instruments such as Synthetic Aperture Radar (SAR) are another alternative for large-scale monitoring tasks. Both these techniques provide a practical solution for such monitoring objectives, where direct site access in the majority of cases (e.g. mining walls, dam sites and other mega infrastructures) is not typically possible (i.e. prohibited or restricted due to safety issues). Moreover, the acquisition of reliable datasets requires advanced remote sensing approaches that provide a high level of accuracy with minimal uncertainty to end users. The focus of the work is to establish standards for accuracy improvement (verification and/or calibration) of long-range data collection methods, to distinguish between actual geometric changes and uncertainties caused by measurement procedures. This study aims to reproduce datasets acquired from long-range scanners (Maptek and Leica), as well as samples of SAR data, with reference to preliminary results. The results outlined in this presentation demonstrate that the calibrated sensors deliver more accurate 3D point clouds. As such, this eventually enhances the precision of structural monitoring tasks.

KEYWORDS: *Calibration, mining, structural monitoring, terrestrial laser scanning.*

Content

- Transition of Monitoring tasks from point-based to cloud-based (Examples of monitoring tasks (done previously with our research partners in Strasbourg, France))
- International TLS-Defo projects
- Error Sources
- Laboratory calibration
  - the requirement of accuracy assessment
  - Preliminary results
- Field calibration (potential areas)
  - Expected results

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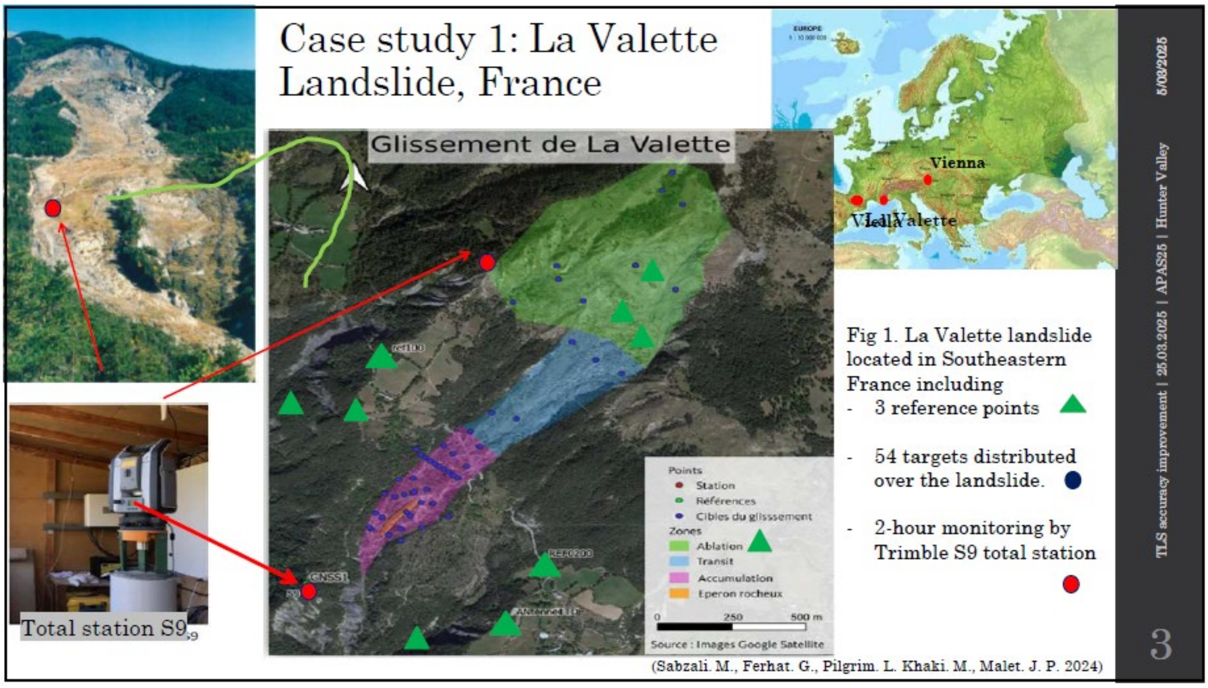

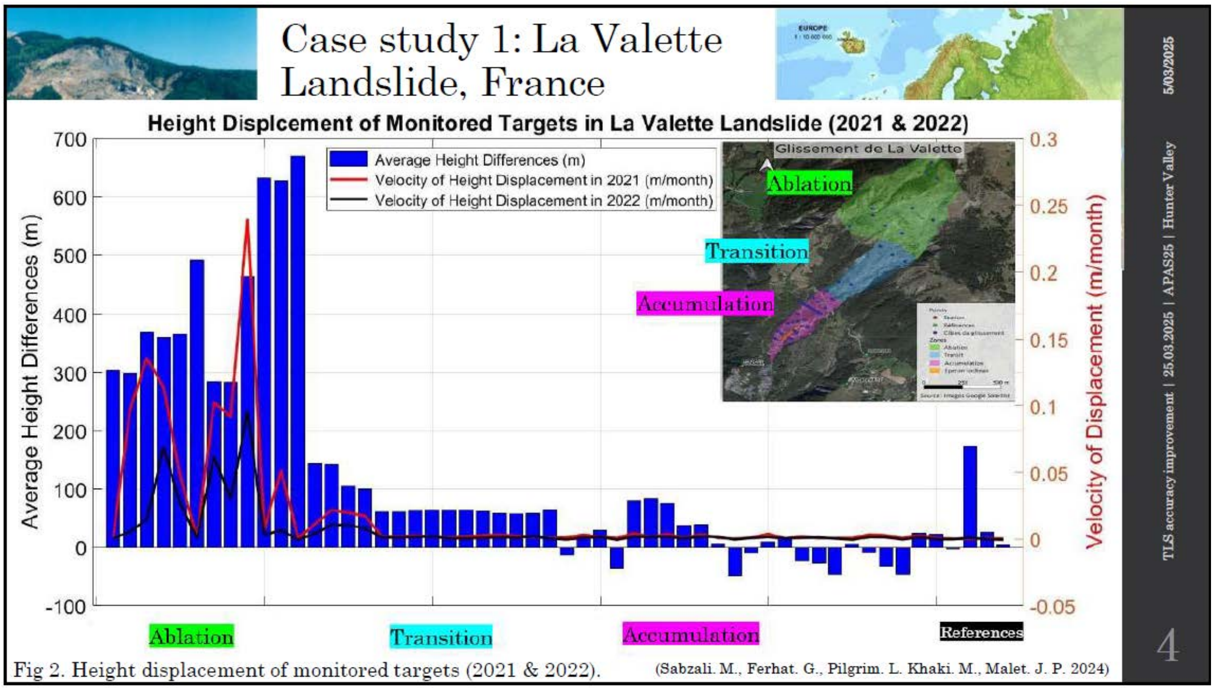
Case study 1: La Valette Landslide, France
Height Displcement of Monitored Targets in La Valette Landslide (2021 & 2022)
Average Height Differences (m)
Velocity of Displacement (m/month)
Average Height Differences (m)
Velocity of Height Displacement in 2021 (m/month)
Velocity of Height Displacement in 2022 (m/month)
Glissement de La Valette
Ablation
Transition
Accumulation
References
700
600
500
400
300
200
100
0
-100
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
Fig 2. Height displacement of monitored targets (2021 & 2022).
(Sabzali. M., Ferhat. G., Pilgrim. L. Khaki. M., Malet. J. P. 2024)
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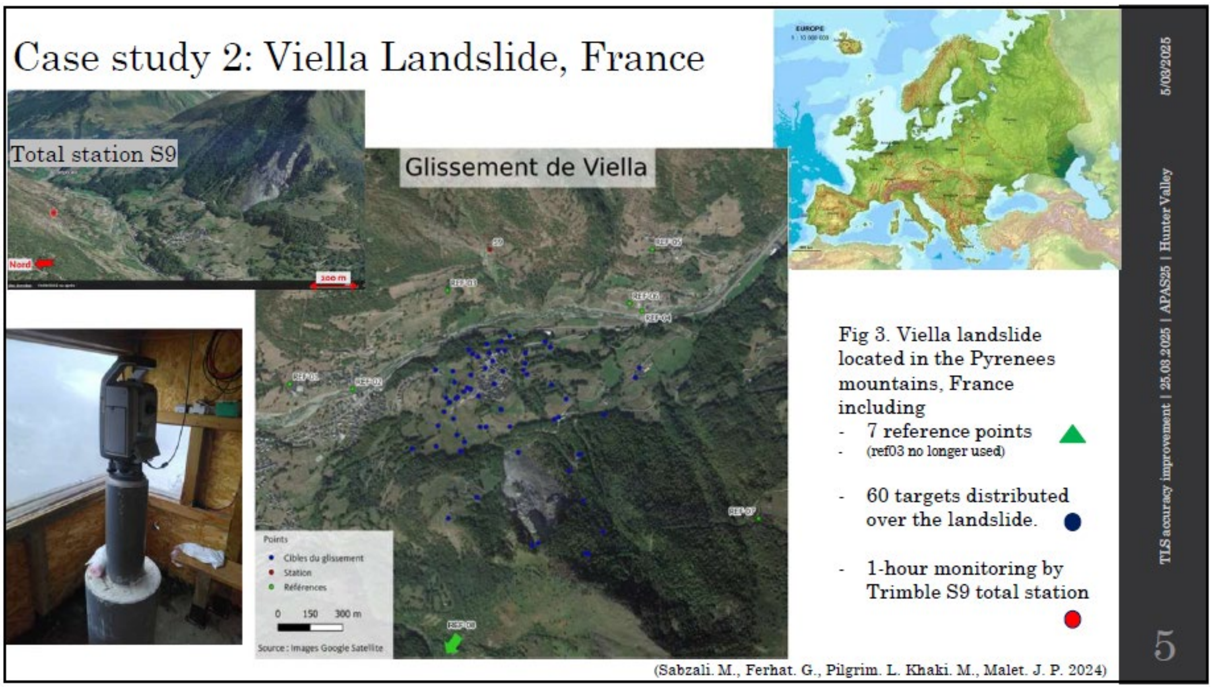
Case study 2: Viella Landslide, France
Total station S9
Glissement de Viella
Points
Cibles du glissement
Station
Références
0 150 300 m
Source : Images Google Satellite
Fig 3. Viella landslide located in the Pyrenees mountains, France including
- 7 reference points
- (ref03 no longer used)
- 60 targets distributed over the landslide.
- 1-hour monitoring by Trimble S9 total station
(Sabzali. M., Ferhat. G., Pilgrim. L. Khaki. M., Malet. J. P. 2024)
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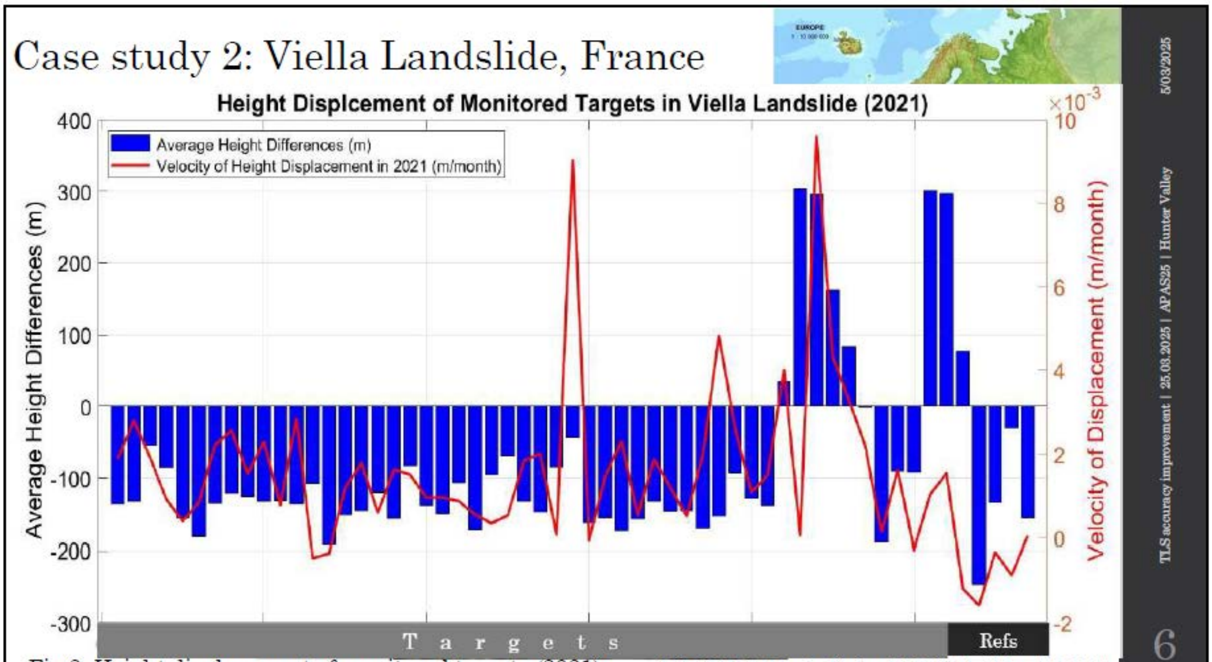

Fig 3. Height displacement of monitored targets (2021). (Sabzali. M., Ferhat. G., Pilgrim. L. Khaki. M., Malet. J. P. 2024)

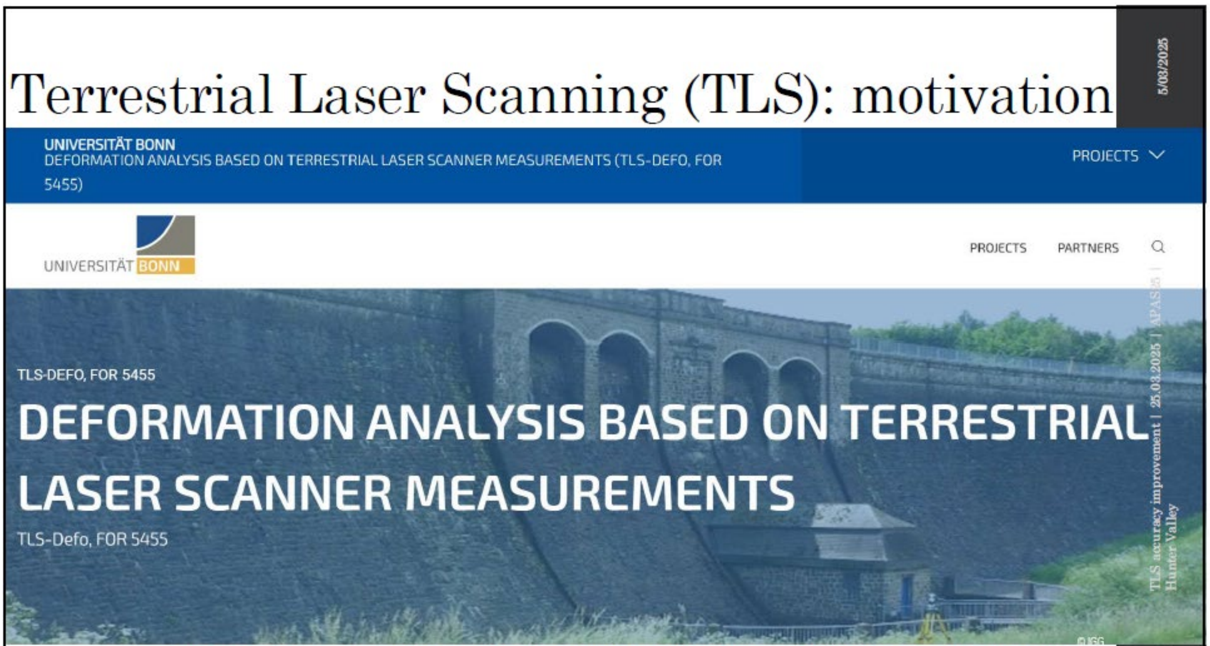

Fig 4. TLS-Defo projects proposed in Germany 2023 (available on Bonn University platform).

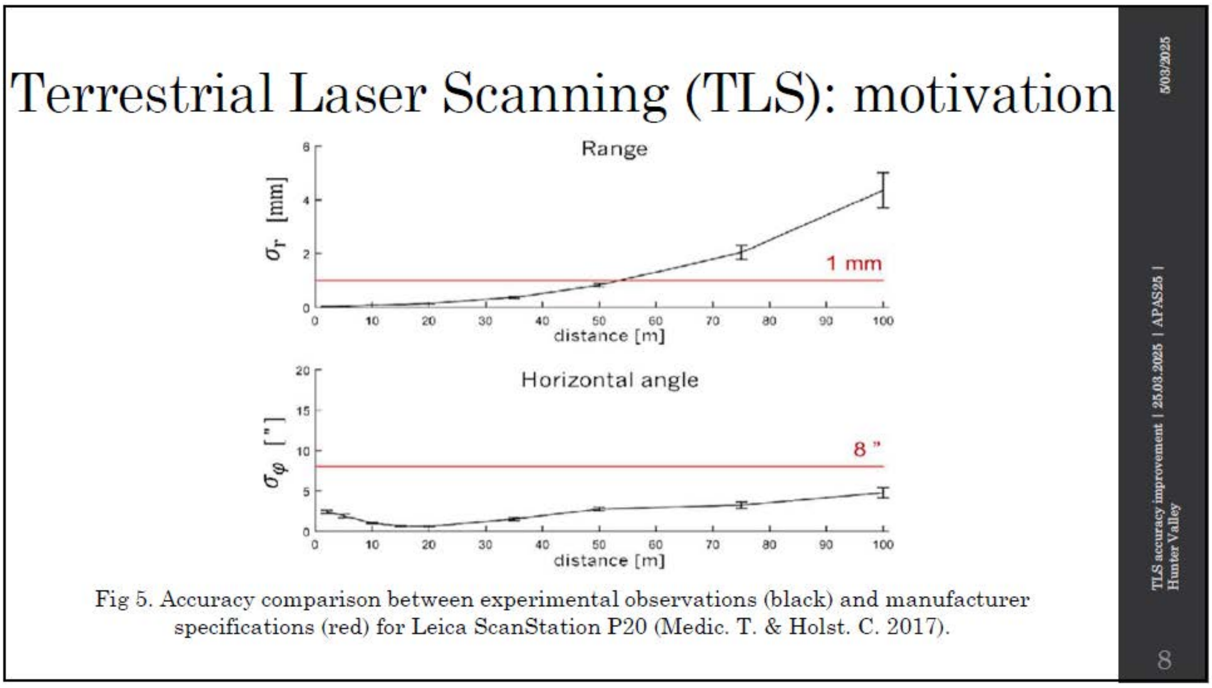

Fig 5. Accuracy comparison between experimental observations (black) and manufacturer specifications (red) for Leica ScanStation P20 (Medic. T. & Holst. C. 2017).

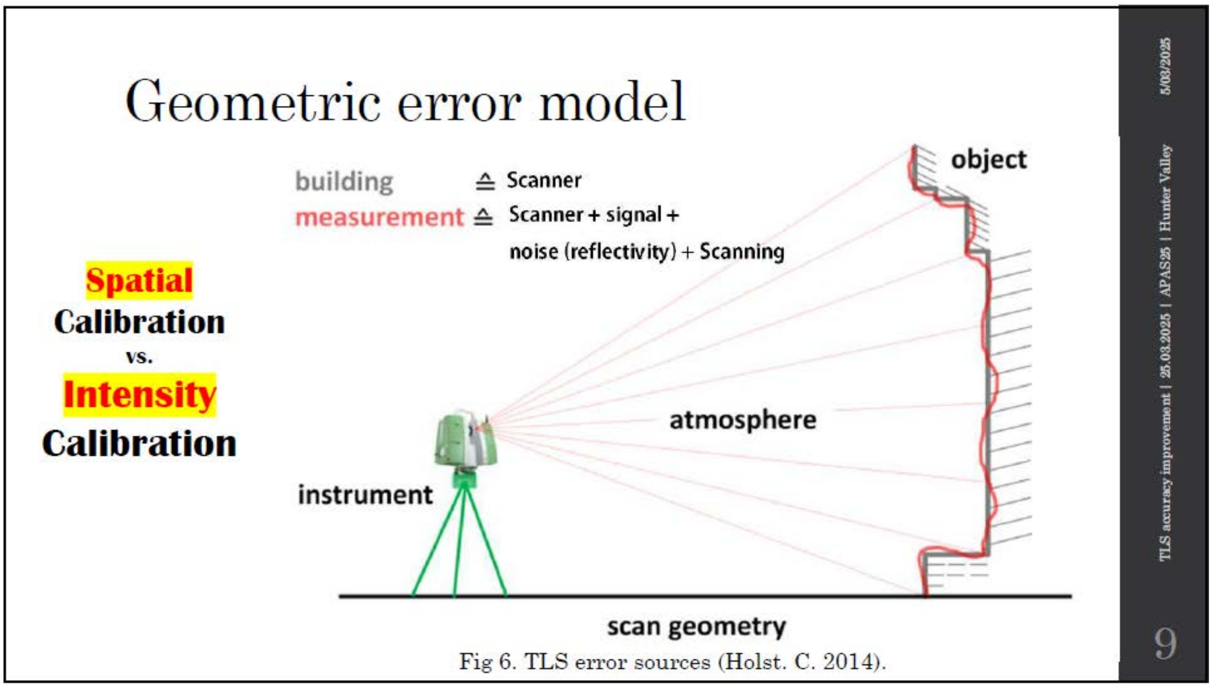

Fig 6. TLS error sources (Holst. C. 2014).

Tab 1. Computed precision of each CP.

Precision of Calibration parameters (CPs)			TLS: Leica ScanStation P50			Leica ScanStation C5			Maptek I-Site 8820			Trimble SX10			Leica RTC360		
Range (mm)	Transit offset	a_2	2.6			3.8			7.9			2.4			2.4		
	Constant zero error	a_{10}	0.06			0.2			0.4			0.03			0.1		
Vertical angle ($D°M'S"$)	Beam offset along horizontal plane	a_{1n}	0	0	3	0	0	4	0	0	30	0	0	22	0	0	6
	Beam offset along vertical plane	a_{1z}	0	0	16	0	0	23	0	1	27	0	0	32	0	0	31
	Transit offset	a_2	0	8	56	0	13	4	0	27	2	0	3	2	0	8	12
	Vertical angle index offset error	a_4	0	0	16	0	0	23	0	1	27	0	0	32	0	0	31
	Beam tilt angle along horizontal plane	a_{5n}	0	1	2	0	1	28	0	26	50	0	1	18	0	1	59
	Beam tilt angle along vertical plane	a_{5z}	0	0	2	0	0	1	0	0	2	0	0	3	0	0	2
	Vertical angle encoder eccentricity along x plane	a_{9x}	0	0	1	0	0	1	0	0	1	0	0	3	0	0	1
	Vertical angle encoder eccentricity along y plane	a_{9y}	0	0	4	0	0	5	0	0	24	0	0	23	0	0	7
	Second order scale error in vertical angle encoder in horizontal plane	a_{12a}	0	0	8	0	0	11	0	0	48	0	0	53	0	0	15
	Second order scale error in vertical angle encoder in vertical plane	a_{12b}	0	0	1	0	0	2	0	0	4	0	0	6	0	0	2
Horizontal angle ($D°M'S"$)	Beam offset along horizontal plane	a_{1n}	0	0	2	0	0	3	0	0	9	0	0	8	0	0	3
	Beam offset along vertical plane	a_{1z}	0	1	30	0	2	3	0	36	57	0	1	36	0	2	49
	Mirror offset	a_3	0	0	27	0	0	44	0	0	5	0	0	35	0	0	58
	Beam tilt angle along vertical plane	a_{5z}	0	0	2	0	0	2	0	0	7	0	0	5	0	0	2
	Mirror tilt angle	a_6	0	0	2	0	0	2	0	0	7	0	0	5	0	0	2
	Transit tilt angle	a_7	0	0	27	0	0	37	0	10	13	0	0	48	0	0	51
	Horizontal angle encoder eccentricity along x plane	a_{8x}	0	0	19	0	0	43	0	0	9	0	0	33	0	0	32
	Horizontal angle encoder eccentricity along y plane	a_{8y}	0	0	3	0	0	4	0	0	30	0	0	22	0	0	6
	Second order scale error in horizontal angle encoder in horizontal planes	a_{11a}	0	0	16	0	0	23	0	1	27	0	0	32	0	0	31
	Second order scale error in horizontal angle encoder in vertical planes	a_{11b}	0	8	56	0	13	4	0	27	2	0	3	2	0	8	12

Fig 7. Laboratory calibration network at UON and six undertaken TLSs for the investigation (acquired on Dc 10th, 2023) (Sabzali. M., & Pilgrim. L. 2024).

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Tab 2. Maximum permissible precision for each single calibration parameter.

Maximum precision for CPs	TLS: Leica ScanStation P50	Leica ScanStation C5	Maptek I-Site 8820	Trimble SX10	Leica RTC360
Vertical angle ($M'S"$)	16"	23"	1'27"	32"	31"
Horizontal angle ($S"$)	4"	5"	24"	23"	7"

Tab 3. Computed precision for each CP from modified calibration method.

Precision of Calibration Parameters (CPs)		TLS: Leica ScanStation P50			Leica ScanStation C5			Maptek I-Site 8820			Leica RTC360		
Range (mm)	a_2	0.1			0.4			1.6			0.1		
	a_{10}	0.04			0.1			0.4			0.06		
Vertical angle ($D°M'S"$)	a_{1n+2}	0	0	3	0	0	4	0	0	11	0	0	7
	a_{1z}	0	0	12	0	0	22	0	1	26	0	0	18
	$a_{5n+9x+12a+4}$	0	0	1	0	0	1	0	0	2	0	0	1
	$a_{5z+9y+12b}$	0	0	14	0	0	25	0	2	49	0	0	19
Horizontal angle ($D°M'S"$)	a_{1n}	0	0	3	0	0	4	0	0	25	0	0	6
	a_{1z+3}	0	0	1	0	0	1	0	0	1	0	0	1
	a_{5z-7+6}	0	0	1	0	0	1	0	0	1	0	0	1
	a_{8x}	0	0	1	0	0	2	0	0	4	0	0	2
	a_{8y}	0	0	1	0	0	2	0	0	8	0	0	3
	a_{11a}	0	0	1	0	0	2	0	0	7	0	0	2
	a_{11b}	0	0	1	0	0	2	0	0	5	0	0	2

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Tab 4. Estimated calibration parameters under the lab test field.

Systematic errors (A) and correction factors $[dr_{i,i} \quad dv_{i,i} \quad dh_{i,i}]$	TLS											
	Leica ScanStation P50			Leica ScanStation C5			Maptek I-Site 8820			Leica RTC360		
A_2	-0.01			0.05			0.0004			-0.04		
A_{10}	-2			-11.5			-28.4			-0.4		
$dr_{i,i}$ (mm)	**-2**			**-11.5**			**-28.4**			**-0.5**		
A_{1n+2}	0	0	3	0	0	-1	0	-1	43	0	0	-3
A_{1z}	0	0	1	0	0	20	0	0	-5	0	0	-1
$A_{5n+9x+12a+4}$	0	0	45	0	2	22	0	-6	2	0	0	-20
$A_{5z+9y+12b}$	0	0	-4	0	0	-35	0	0	-16	0	0	1
$dv_{i,i}$ (D°M'S")	**0**	**0**	**42**	**0**	**1**	**26**	**0**	**-7**	**56**	**0**	**0**	**-20**
A_{1n}	0	0	17	0	0	29	0	0	31	0	0	-24
A_{1z+3}	0	0	10	0	0	4	0	0	1	0	0	-3
A_{5z-7+6}	0	0	-4	0	0	-2	0	0	-1	0	0	4
A_{8x}	0	0	2	0	0	-3	0	0	-17	0	0	1
A_{8y}	0	0	-2	0	0	6	0	1	18	0	0	1
A_{11a}	0	0	17	0	0	-1	0	0	14	0	0	1
A_{11b}	0	0	-3	0	0	-1	0	0	-1	0	0	-3
$dh_{i,i}$ (D°M'S")	**0**	**0**	**32**	**0**	**0**	**39**	**0**	**2**	**20**	**0**	**0**	**-26**

Tab 5. Comparison with manufacturer-based specifications.

Correction factors $[dr_{i,i} \quad dv_{i,i} \quad dh_{i,i}]$	TLS											
	Leica ScanStation P50			Leica ScanStation C5			Maptek I-Site 8820			Leica RTC360		
$dr_{i,i}$ (mm)	**1.2**			**4**			**3**			**1**		
$dv_{i,i}$ (D°M'S")	**0**	**0**	**8**	**0**	**0**	**12**	**0**	**0**	**8**	**0**	**0**	**18**
$dh_{i,i}$ (D°M'S")	**0**	**0**	**8**	**0**	**0**	**12**	**0**	**0**	**8**	**0**	**0**	**18**

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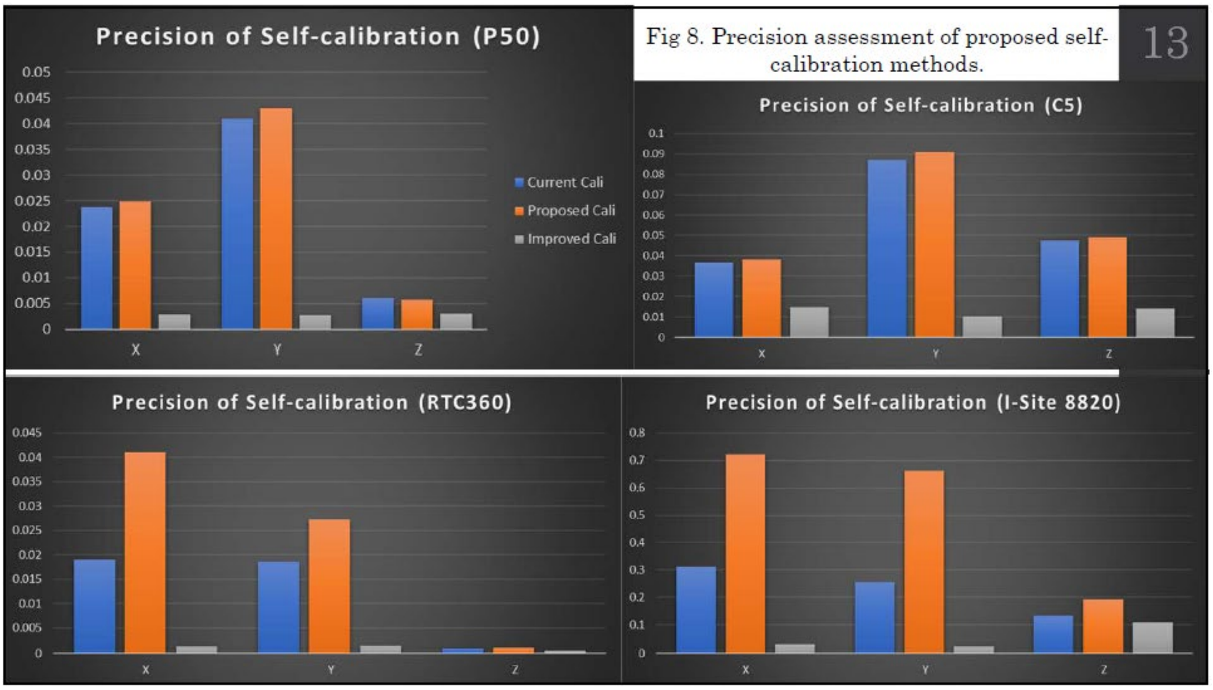

Fig 8. Precision assessment of proposed self-calibration methods.

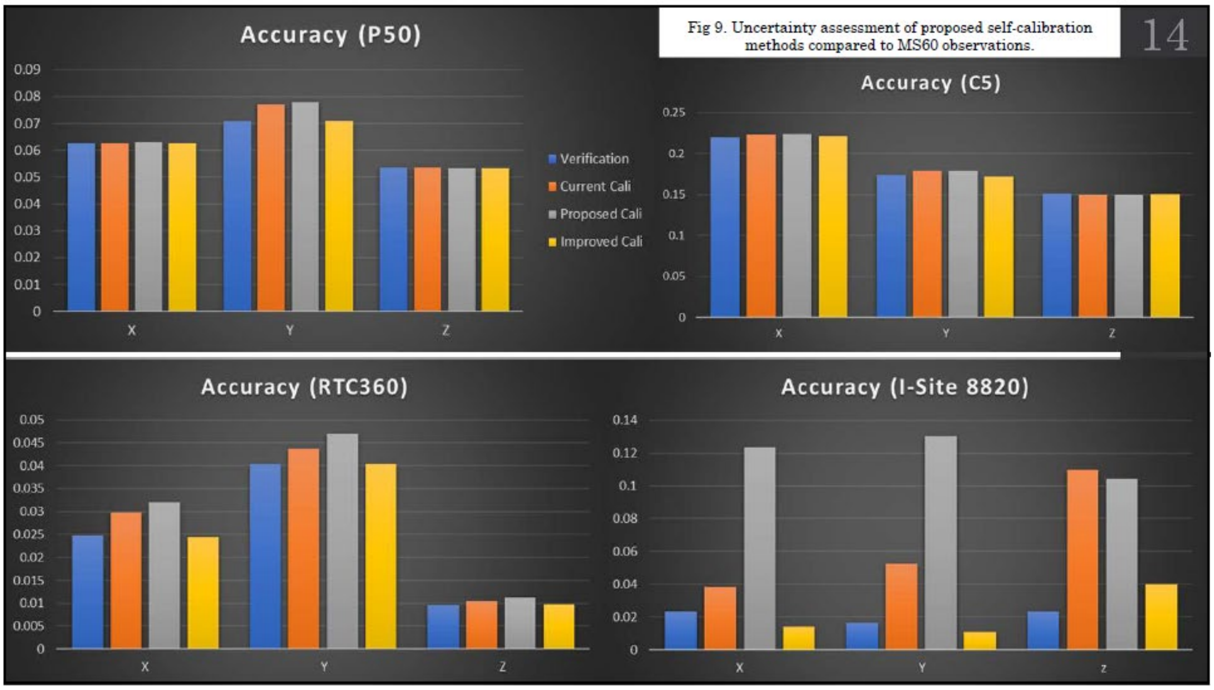

Fig 9. Uncertainty assessment of proposed self-calibration methods compared to MS60 observations.

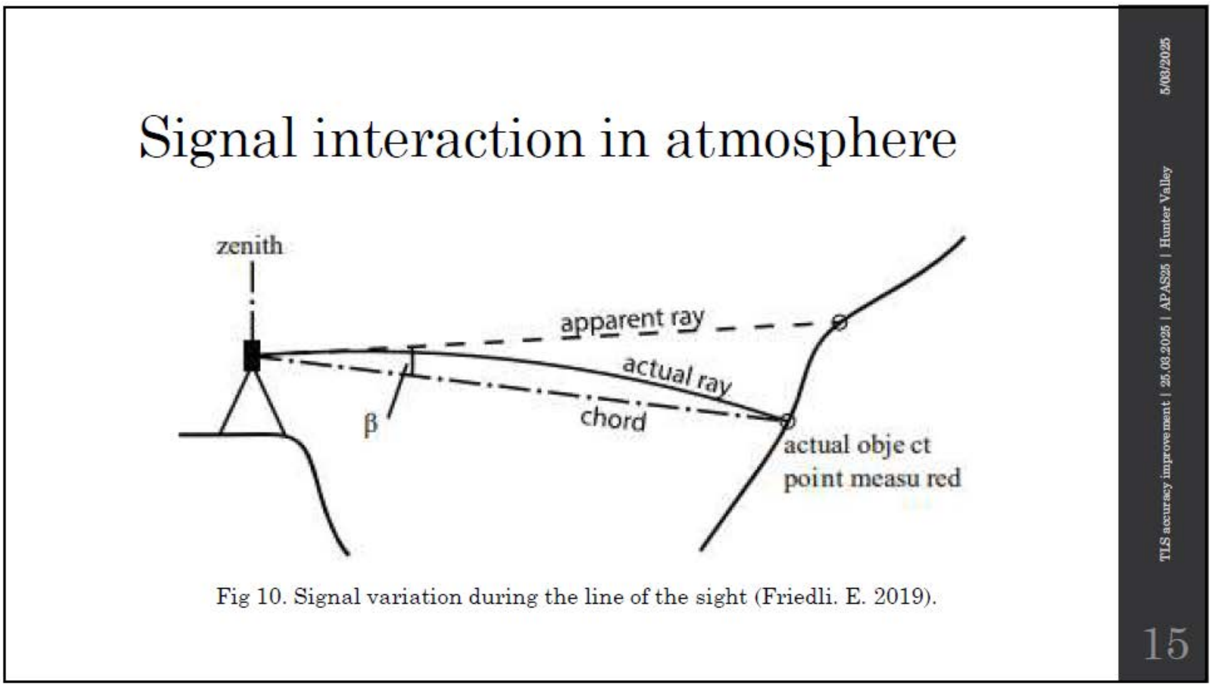

Fig 10. Signal variation during the line of the sight (Friedli. E. 2019).

Signal interaction in atmosphere

Tab 6. Expected results caused from variation of signal into atmosphere (Sabzali. M. & Pilgrim. L. 2023a, 2023b, 2022).

Uni Variation in $1000m$	Temperature (°C)	Pressure (hPa)
Range	$0.9\ mm$	$-0.3\ mm$
Vertical angle	2.6″	0.4″
Horizontal angle	0.003″	insignificant

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Call for collaboration

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Notices

UoN Research Assistance Request

The AIMS NSW Committee has received a research request and are supportive of the research being undertaken.

We are sharing this with our members in the hope that a number of mines might be able to provide access to a site and/or scanner that can be used in the research.

Please contact Mansoor directly per below if you can assist.

Request received from:

M.Sc. Mansoor Sabzali
PhD candidate, Surveying / Laser Scanner Engineer
at The University of Newcastle
Mansoor.sabzali@newcastle.edu.au

My name is Mansoor and currently doing my PhD on calibration of terrestrial laser scanning for the precise monitoring and deformation analysis at the university of Newcastle under the supervision of Dr. Lloyd Pilgrim. As the part of my studies, we aim to identify the influence and model the impact of refraction on the laser line of the sight occurred due to the atmospheric conditions. This error will be more significant in the long-range scanning and deviates the uncertainty of 3D point cloud within a few centimetres.

We are seeking the assistance in identifying suitable survey sites (particularly mining sites or others), preferably those with the flexibility in range for long-range scanning opportunities of 100 meters or more. The longer the range, the better suited it would be for our research. Additionally, we would be happy to apply our previously developed laboratory and potential field calibration testing and algorithms to your scanner if one is available.

I believe this cooperation will broaden more interest in our future work with the university to provide the improved user-oriented calibration tests for the manufactured scanners resulting in the precise monitoring and deformation tasks.

I would be happy to discuss the details further and provide any additional information you may require.

I do appreciate all for considering my inquiry in advance. Looking forward to hearing more from you.

M.Sc. Mansoor Sabzali
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Mansoor.sabzali@newcastle.edu.au

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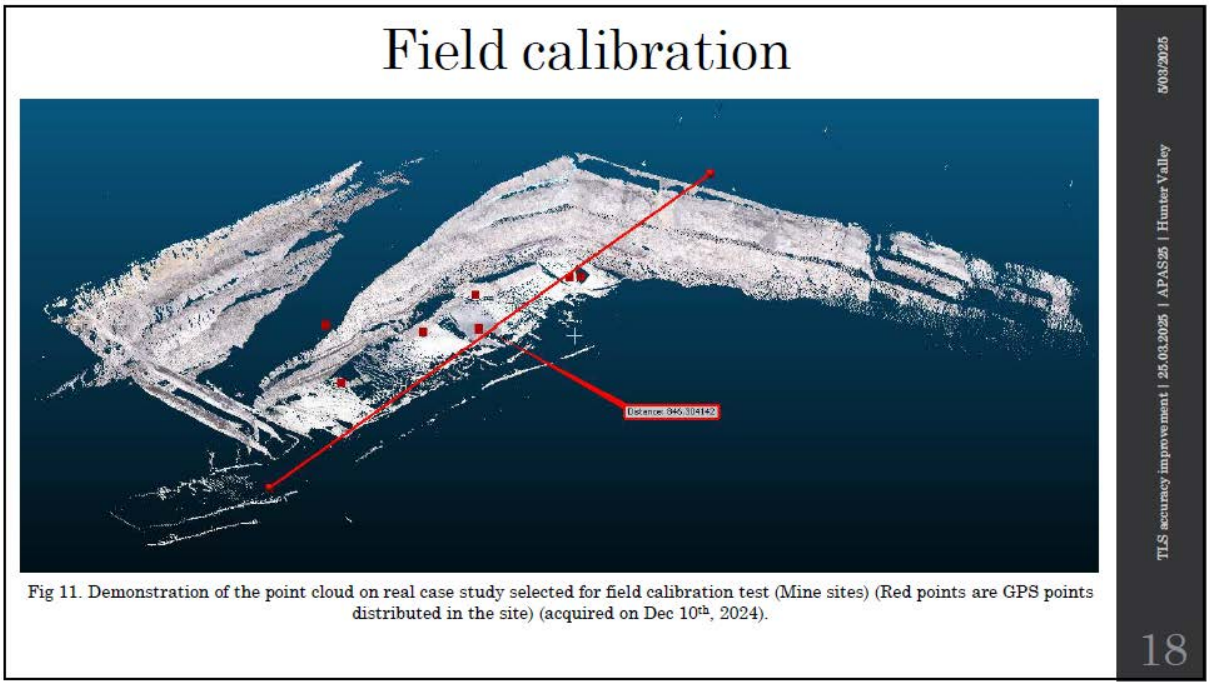

Fig 11. Demonstration of the point cloud on real case study selected for field calibration test (Mine sites) (Red points are GPS points distributed in the site) (acquired on Dec 10th, 2024).

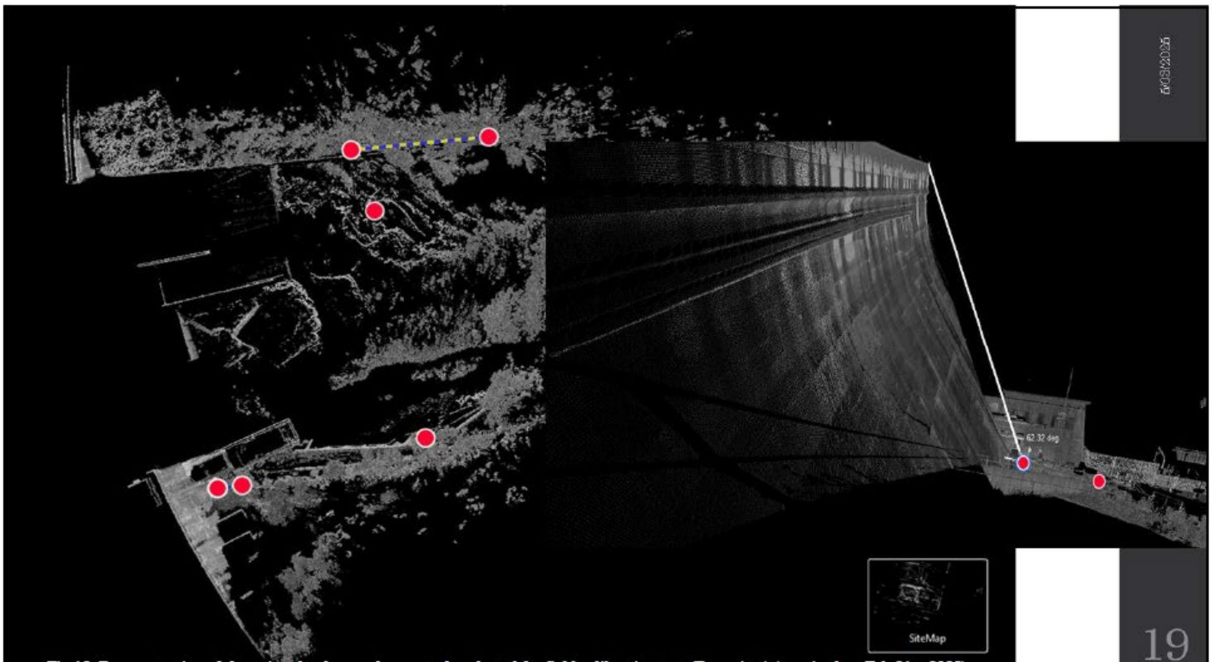

Fig 12. Demonstration of the point cloud on real case study selected for field calibration test (Dam sites) (acquired on Feb 21st, 2025).

Intensity Calibration

Fig 13. Laboratory calibration at UON and three employed TLSs (i.e., the experiment has been taken under fully dark room on Dec 1st, 2024).

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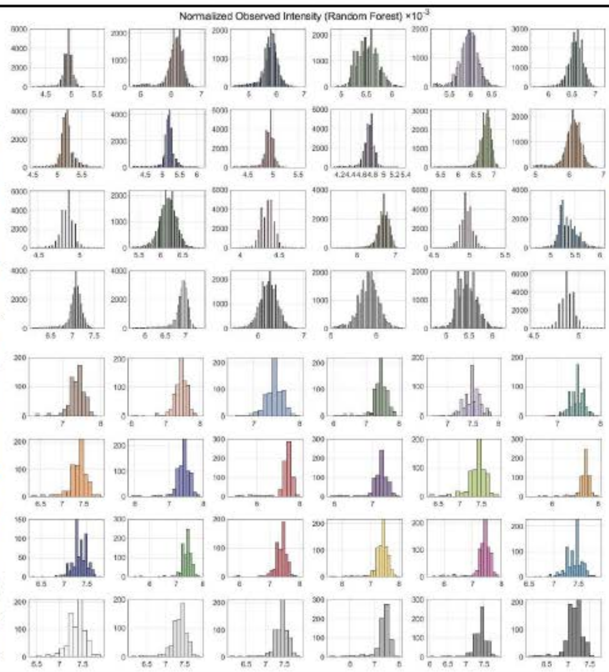

Fig 14. Histogram of normalised observed intensity values (i.e., (top) Leica ScanStation C10, and (down) Leica RTC360).

Leica ScanStation C10

Leica RTC360

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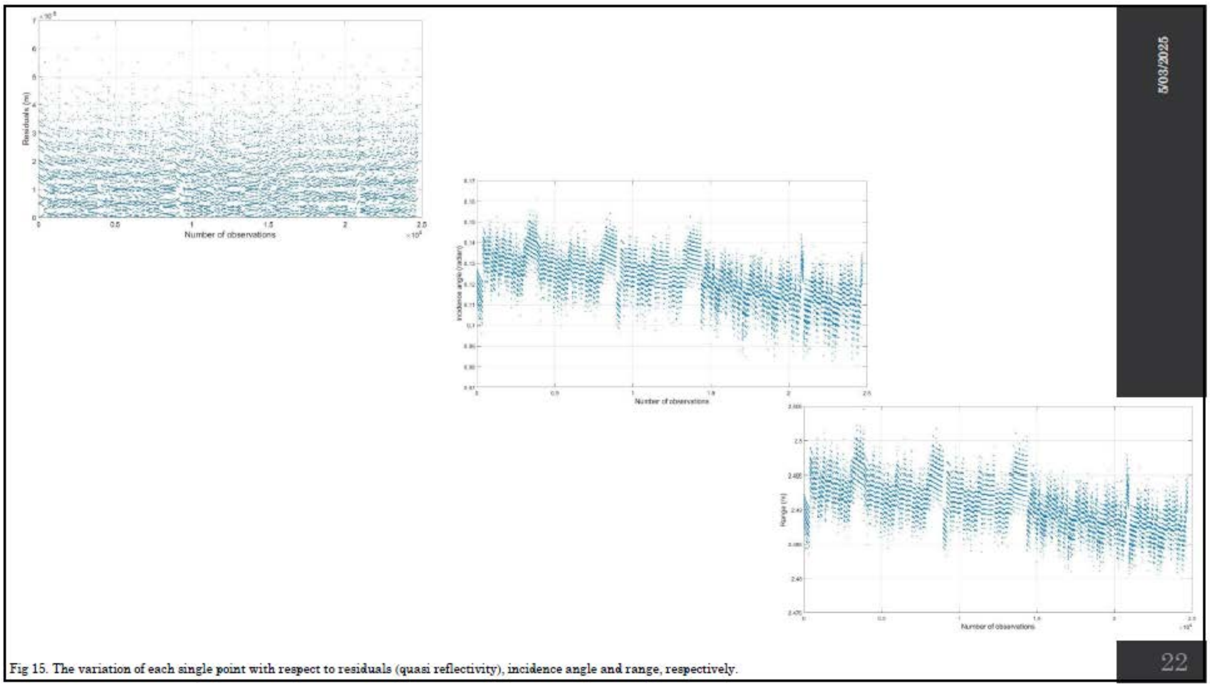

Fig 15. The variation of each single point with respect to residuals (quasi reflectivity), incidence angle and range, respectively.

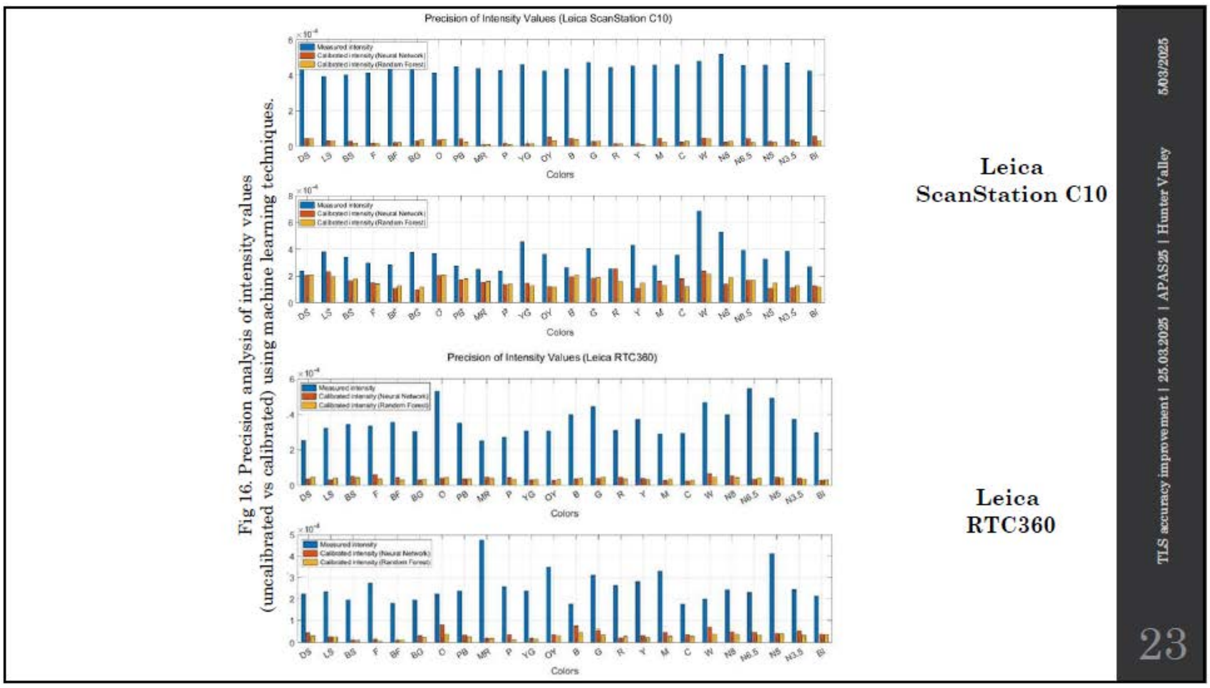

Fig 16. Precision analysis of intensity values (uncalibrated vs calibrated) using machine learning techniques.