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EVALUATION OF ALTIMETRIC ACCURACY IN THE INTEGRATION OF GNSS DATA WITH GLOBAL AND REGIONAL DIGITAL TERRAIN MODELS IN THE CONTEXT OF RURAL PROPERTY GEOREFERENCING

Authors:

Melito Júlio Avalinho |UFPR| melito.avalinho@ufpr.br

Paulo Sérgio de Oliveira Jr. | UFPR| paulo.junior@ufpr.br

Caio dos Anjos Paiva |UFPR| anjospaiva@ufpr.br

Fábio Pagliosa Ulkowski |INCRA| fabio.pagliosa@incra.br

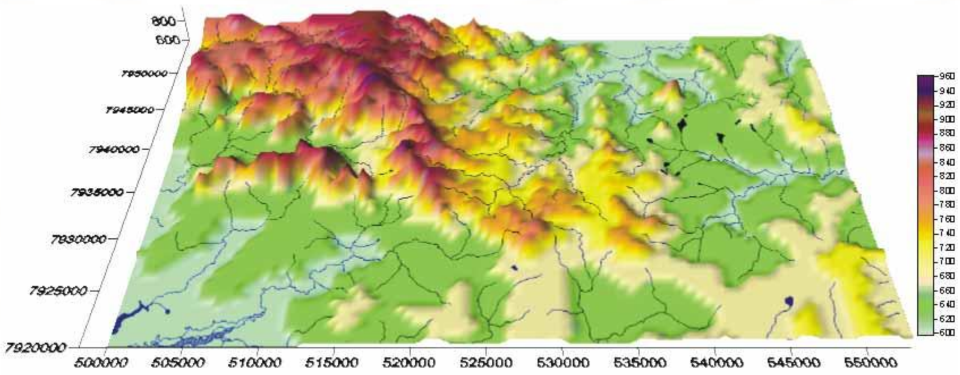
STRUCTURE OF THE PRESENTATION

1. INTRODUCTION
2. METHODOLOGY
3. RESULTS
4. CONCLUSION
5. PERSPECTIVES (FUTURE STEPS)

BIBLIOGRAPHIC LIST

1. INTRODUCTION

DTMs are essential for representing geospatial data and Earth's surface relief (Mohamed et al., 2024).

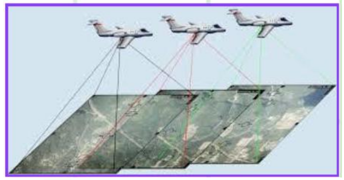


Credits: Sá et al. (2007)

Data Sources:

1. GNSS, LiDAR, InSAR, bathymetry, photogrammetry

2. Global models (SRTM, ASTER, AW3D30, TanDEM-X, Copernicus DEM) (Ouédraogo et al., 2014; Montealegre et al., 2015; Zhang et al., 2016).



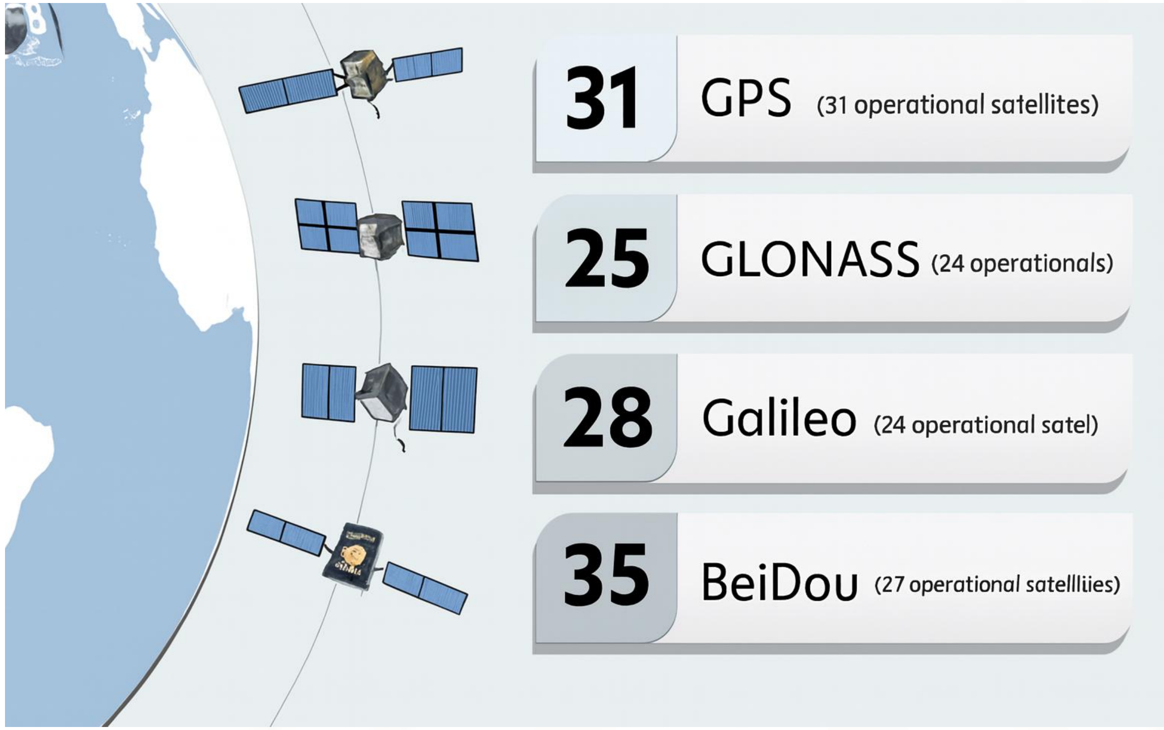
GEOREFERENCING OF RURAL PROPERTIES

The Georeferencing of Rural Properties produces geospatial information, such as the perimeter, the area and the unequivocal location of rural properties, through geospatial information surveys.

In Brazil, INCRA certifies these processes based on Law 6.015/73 and the Technical Standard for Georeferencing of Rural Properties (NTGIR), updated in 2022.

This update incorporated the use of altimetry, improving the calculation of areas that depends on the Local Geodetic System (SGL).

GNSS TECNOLOGY



Fonte: Adaptado de EOS Positioning Systems

Constelation	Orbital plane	Altitude	Ephemerides	Reference system	Orbital inclination
GPS	6	20200	Keplerian elements	WGS84	55°
GLONASS	3	19100	P,V,T	PZ-90	64,8°
Galileo	3	23222	Keplerian elements	GTRF	56°
BeiDou	3	21500	Keplerian elements	CGCS2000	55°

ORBITAL SENSOR AND GLOBAL MODELS

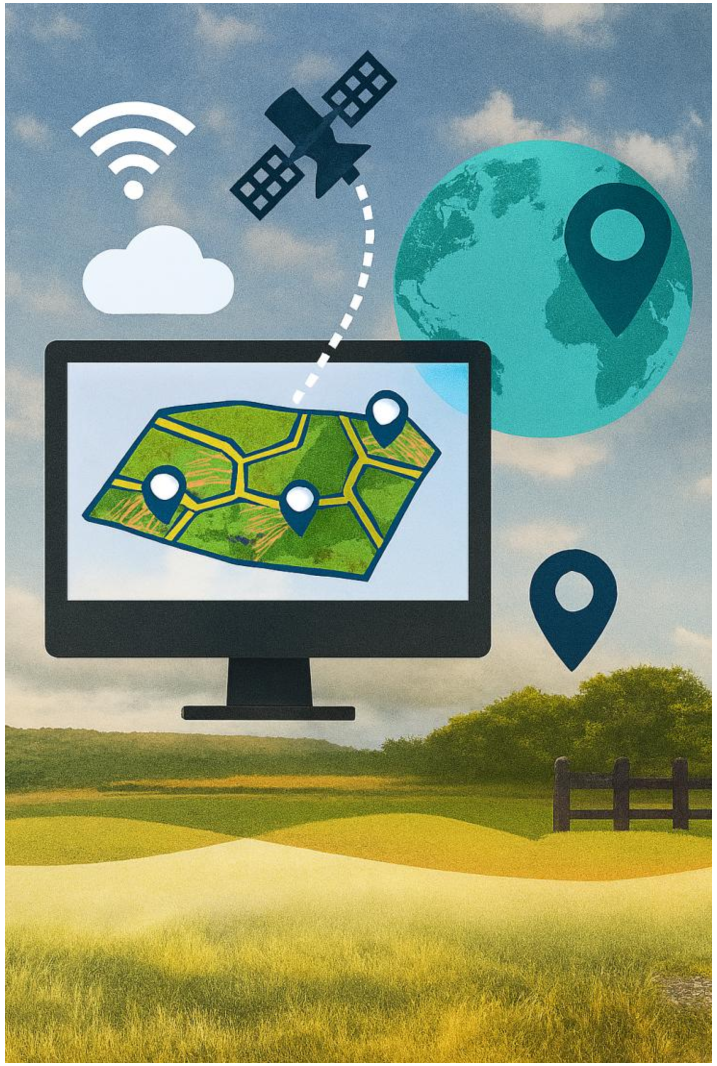
Global model/orbital sensor	Developer	Latitudinal coverage	Spatial resolution	Launch year
SRTM	NASA & NGA	~60°N to ~56°S	30 m (1 arc-sec)	2000
ALOS PALSAR	JAXA (Japan)	~80°N to ~80°S	12.5 m	2006
SENTINEL-1	ESA (Europe)	Global	10 m (GRD)	2014
Copernicus DEM	ESA & Airbus	Global	30 m / 10 m	2019

ALTITUDE ACCURACY

Altimetry is a new element to consider to meet current regulations;

DTMs provide altimetric data for property insertion in SIGEF, though challenges remain in balancing cost and accuracy.

The influence of altimetric quality on Local Geodesic System area calculation is uncertain, as the georeferencing manual lacks defined altitude precision criteria.



DATA INTEGRATION

Da Silveira & Silveira (2017) integrated contour, elevation, and hydrographic data to classify Paraná’s geomorphology and generate a regional terrain model.

Druzina & Souza (2010) integrated data from charts, ASTER, and SRTM to generate a hybrid DEM for a region in Porto Alegre, Rio Grande do Sul.

DATA INTERPOLATION

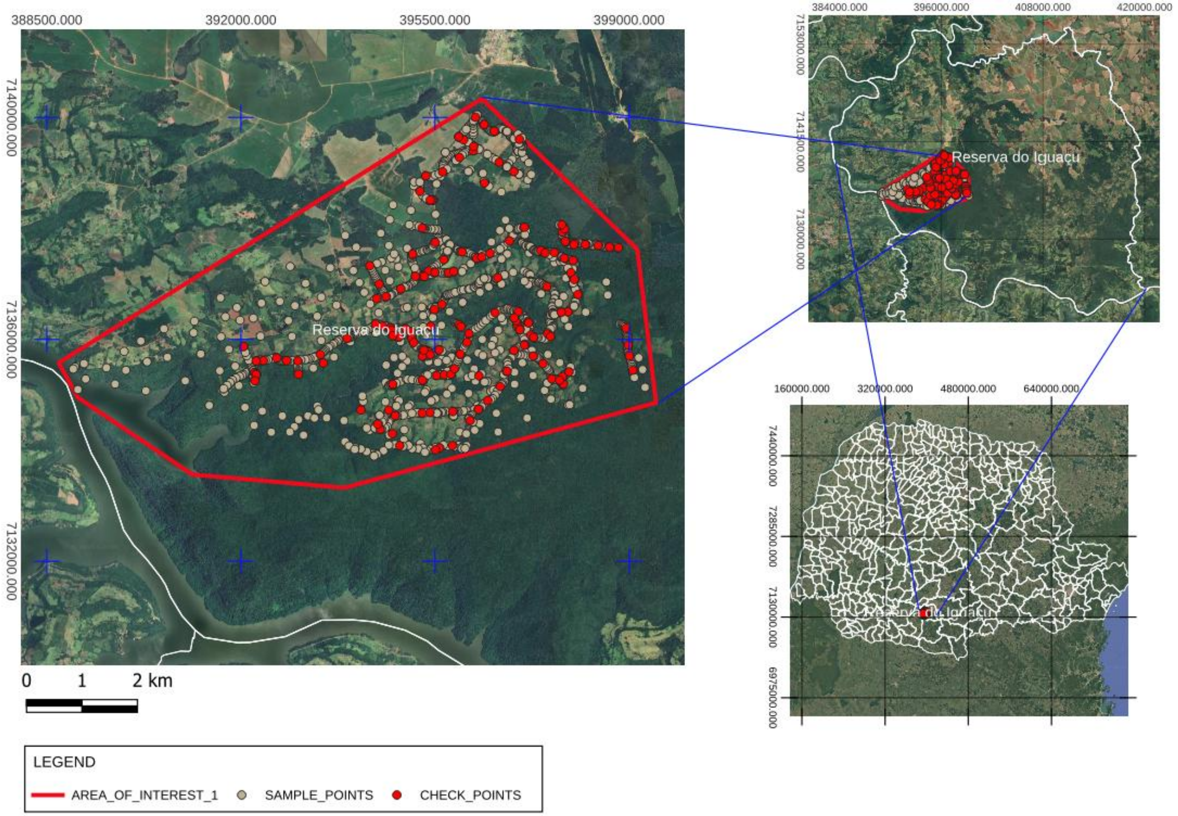
Several interpolation methods exist, including deterministic (TIN, polynomial, IDW) and geostatistical approaches (kriging) (Fan et al., 2014)

1. 2. OBJECTIVES

This study assessed DTM altimetric accuracy using GNSS data as a reference and for model integration.

2. MATERIALS AND METHODS

Localization of the study sites

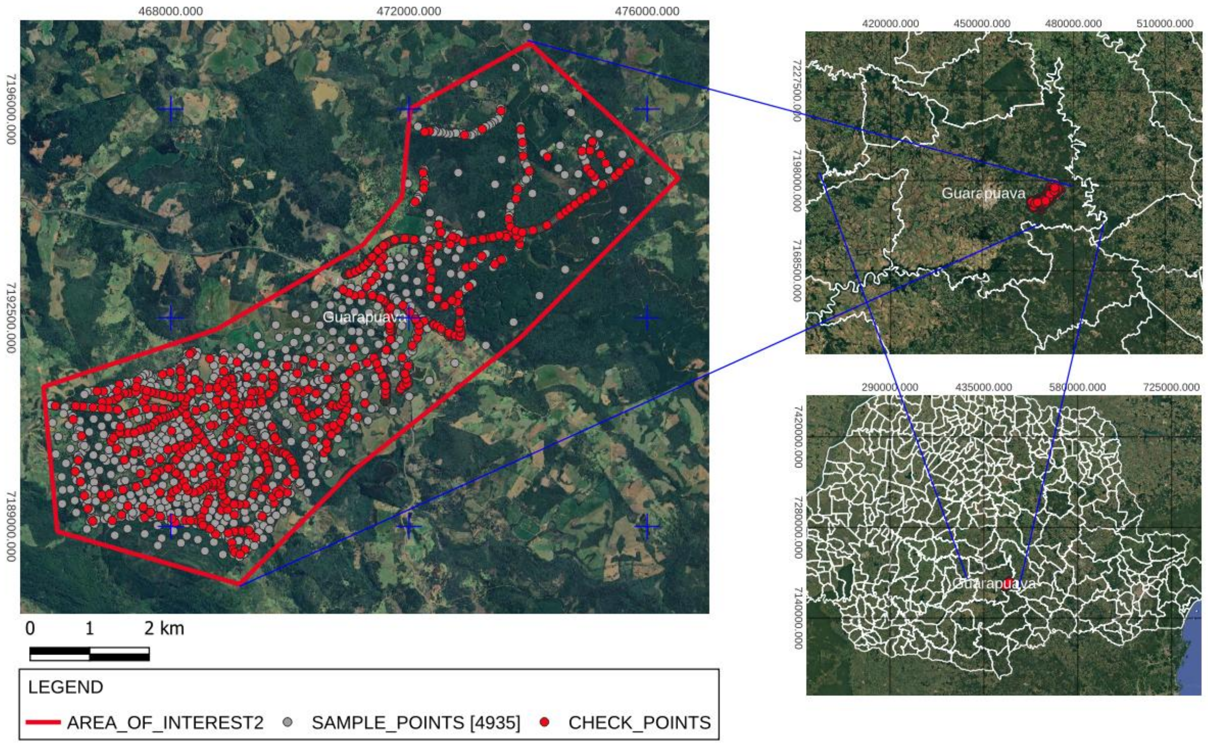


Study site in Guarapuava

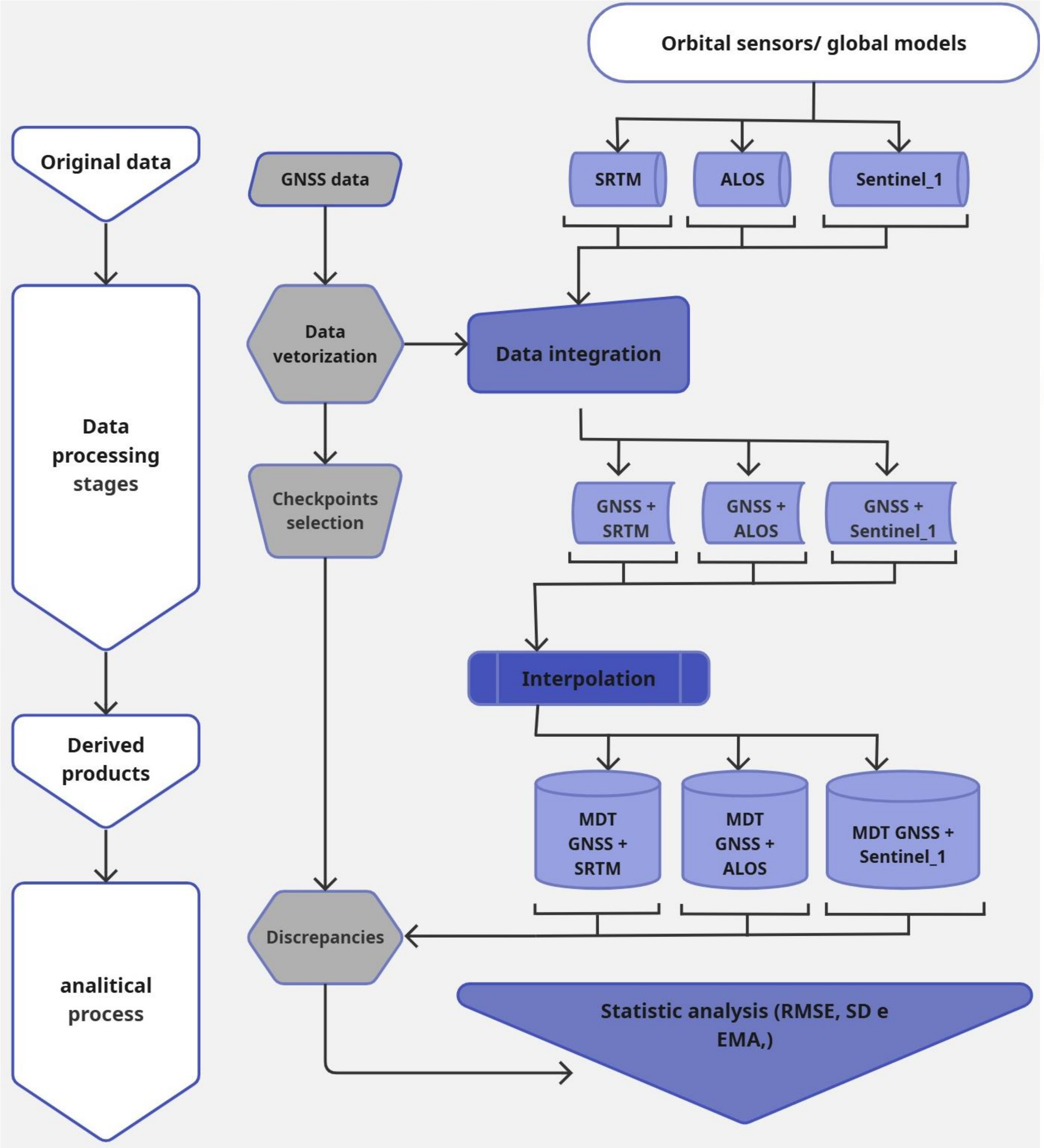
(25.3933° S; 51.4553° W)

Study site in Reserva do Iguaçu

(25.8450° S; 52.0278° W)



METHODOLOGY FLOWCHART



DATA INTERPOLATION

TIN

$$Z(x, y) = ax + by + c$$

IDW

$$Z_{(so)} = \sum_{i=1}^{n} w_i Z_{(si)} = \frac{\sum_{i=1}^{n} Z_{(si)} d_{io}^{-p}}{\sum_{i=1}^{n} \frac{1}{d_{io}^{-p}}}$$

With the coefficients **a**, **b**, and **c** are obtained by solving the linear system formed by the coordinates of the three known vertices.

$\boldsymbol{Z_{(so)}}$ is the estimated elevation of the point of interest

$\boldsymbol{w_i}$ is the weight of the reference point;

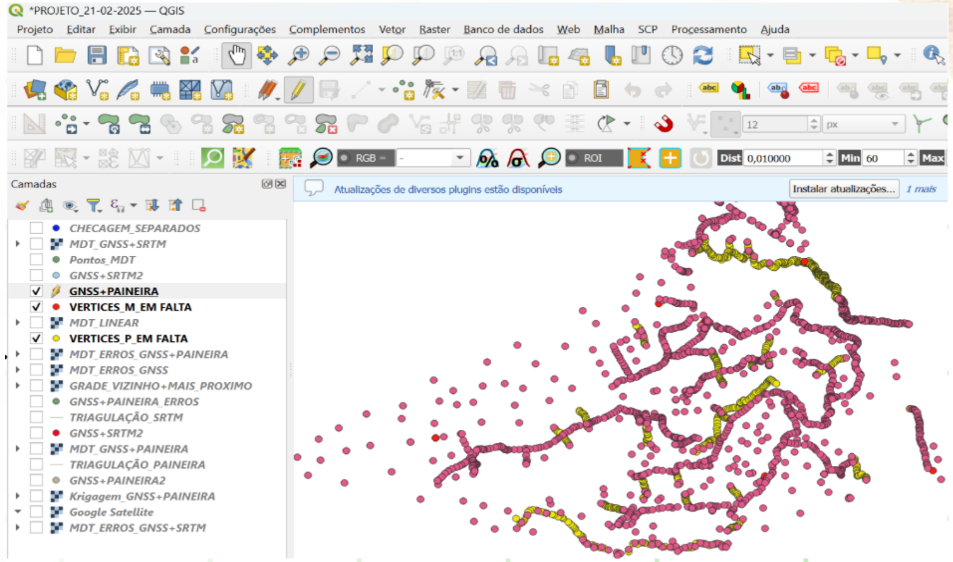
$\boldsymbol{Z_{(si)}}$ is elevation of the reference point;

p is the exponent used to determine the weight of the reference point (most often, ***p*** = 2);

n is the number of landmarks in the immediate vicinity of $\boldsymbol{s_o}$; and $\boldsymbol{d_{io}}$ is the distance between points with known and unknown elevation.

DATA INTEGRATION

- GNSS+SRTM
- GNSS+ALOS PALSAR
- GNSS+SENTINEL-1



STATISTICAL ANALYSES

$$Bias = \frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)$$

$$EMA = \frac{1}{n}\sum_{i=1}^{n}|y_i - \hat{y}_i|$$

$$SD = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x}_i)^2}$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}$$

Where:

n is the number of observations

x_i is the ith value of the observed variable

$\bar{x}_i$ is the sample mean of the values x_i

y_i is the observed (actual) value in the ith observation

$\hat{y}_i$ is the value foreseen in the ith observation

3. RESULTS

Chart 1: RMSE, SD, MAE AND bias for Reserva do Iguaçu

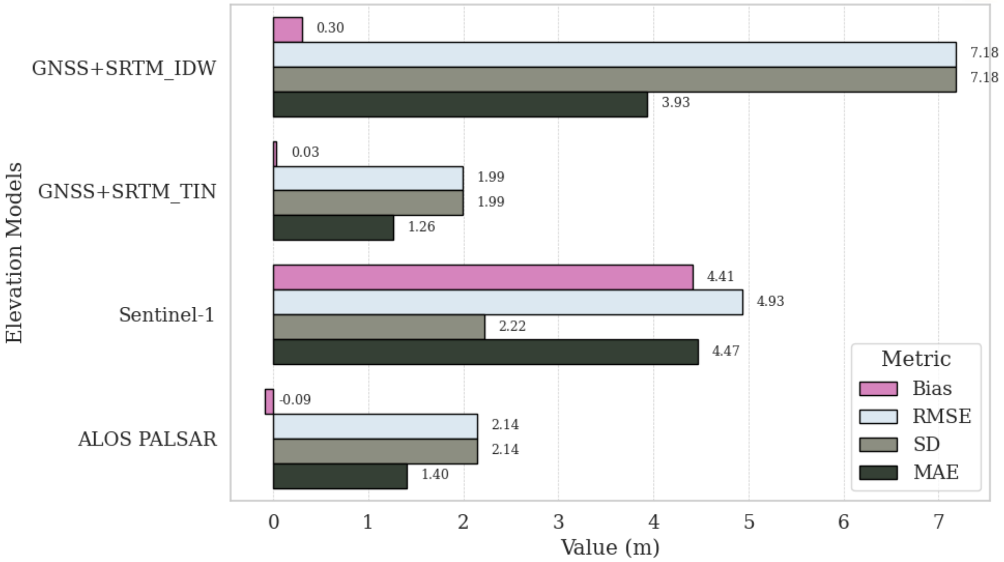


Chart 2: RMSE, SD, MAE AND bias for Guarapuava

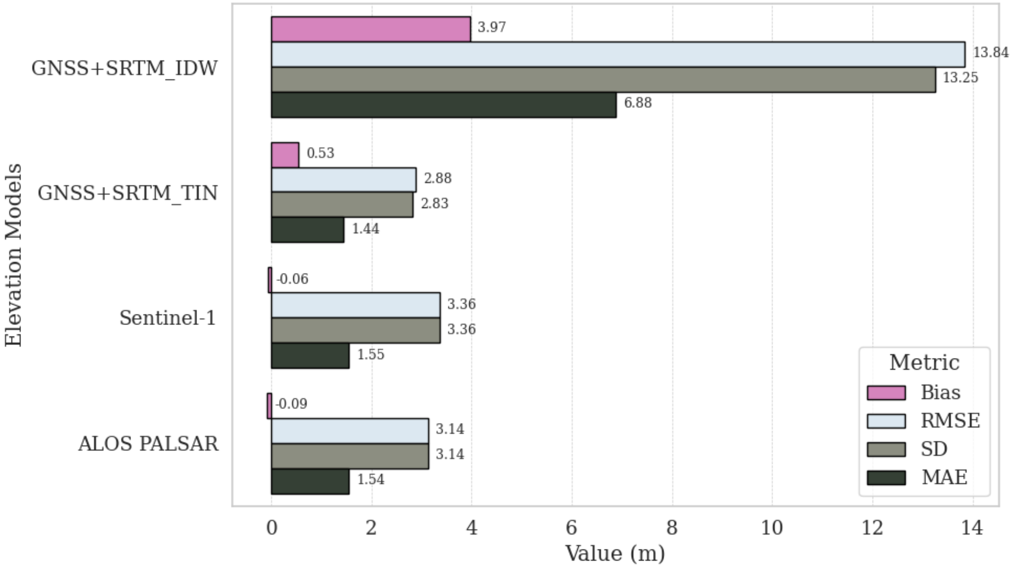


Chart 3: Percentiles 50, 68 and 95 for Reserva do Iguaçu

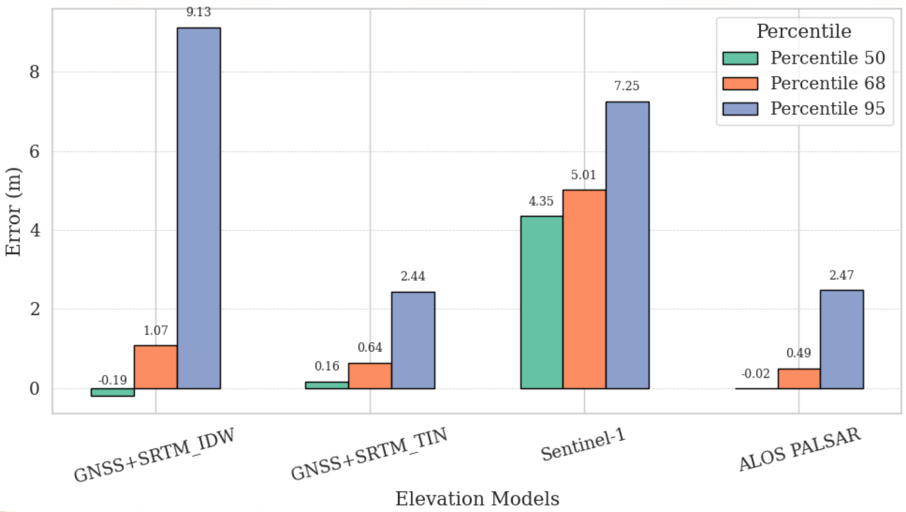


Chart 4: Percentiles 50, 68 and 95 for Guarapuava

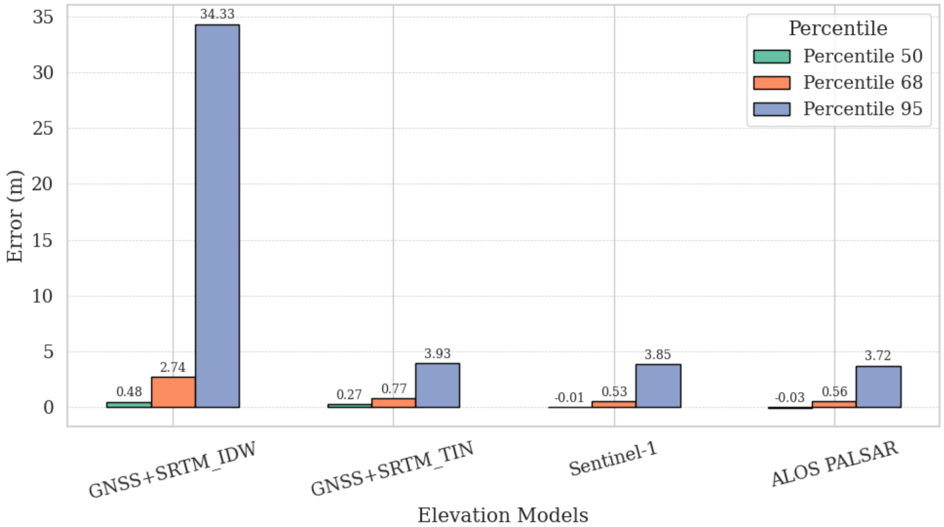


Chart 5: Error density distribution for the region located in the municipality of Reserva do Iguaçu

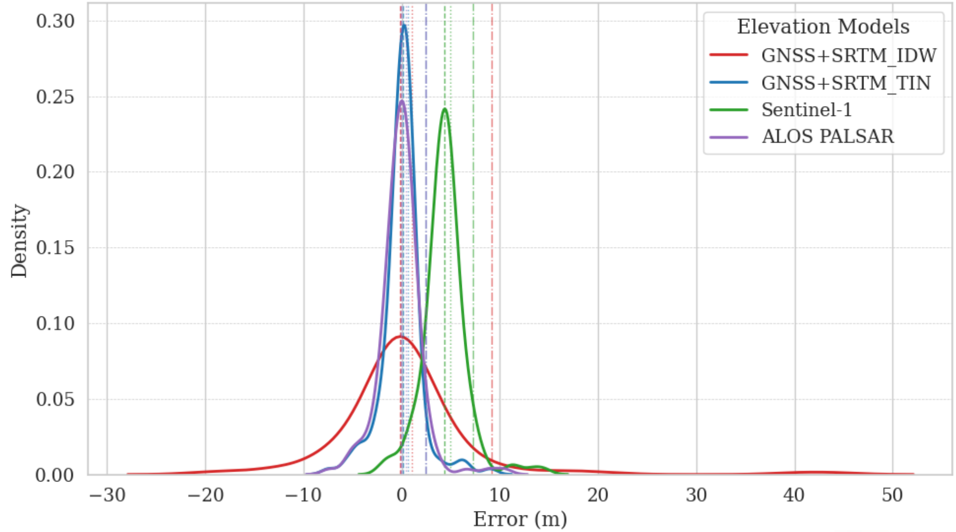


Chart 6: Error density distribution for the region located in the municipality of Guarapuava

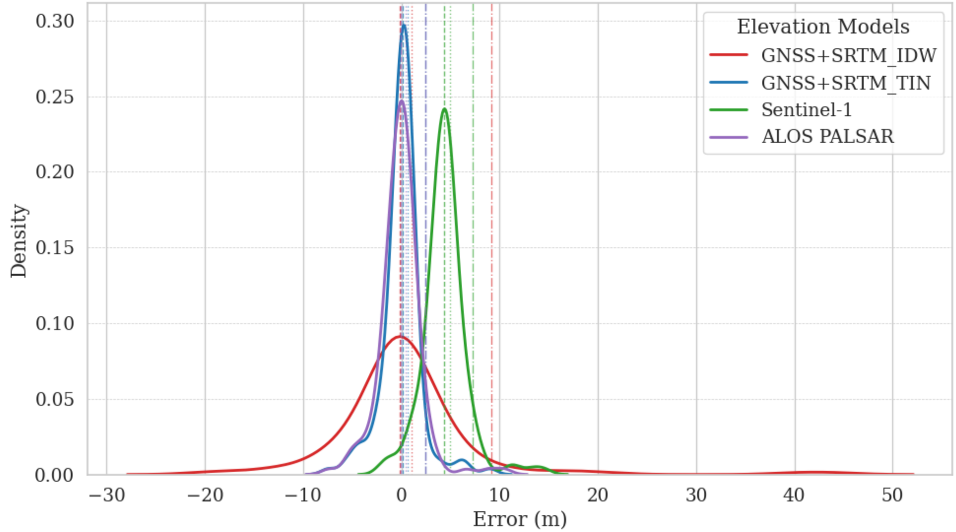


Chart 7: Boxplot of the errors for the region located in the municipality of Reserva do Iguaçu

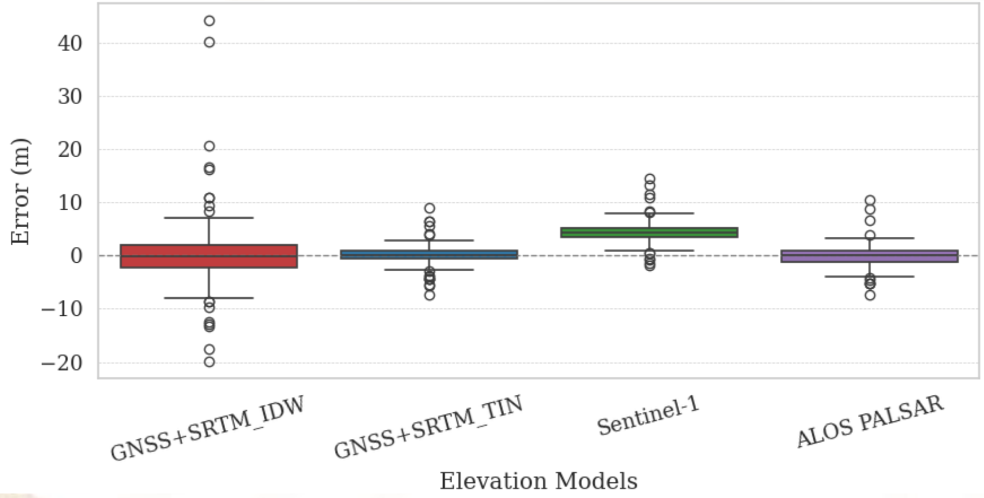


Chart 8: Boxplot of the errors for the region located in the municipality of Guarapuava

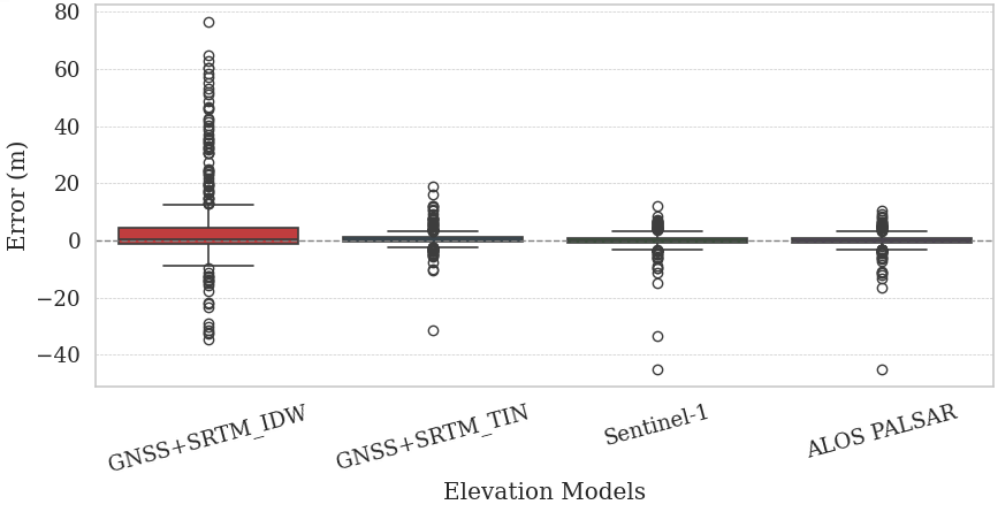


Chart 9: Moran's Index plots for the region located in the municipality of Reserva do Iguaçu

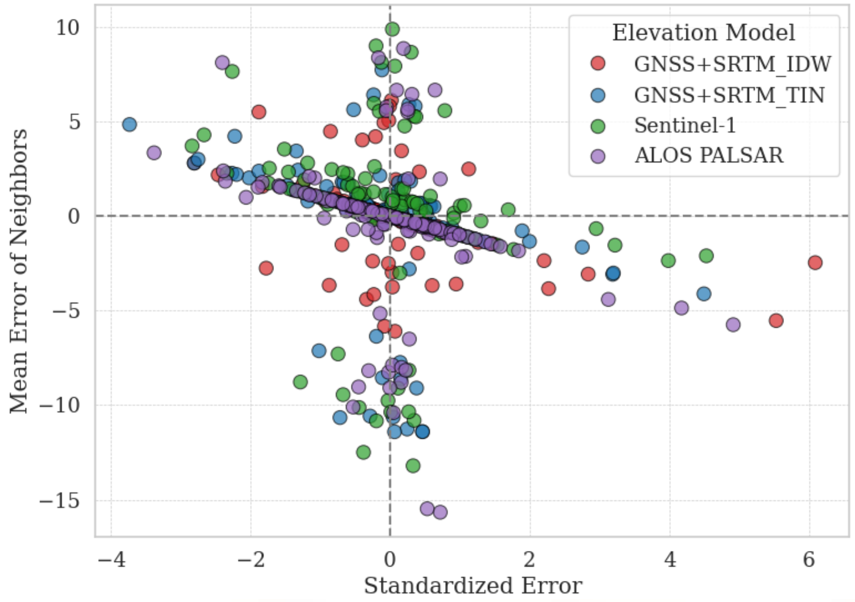


Chart 10: Moran's Index plots for the region located in the municipality of Guarapuava

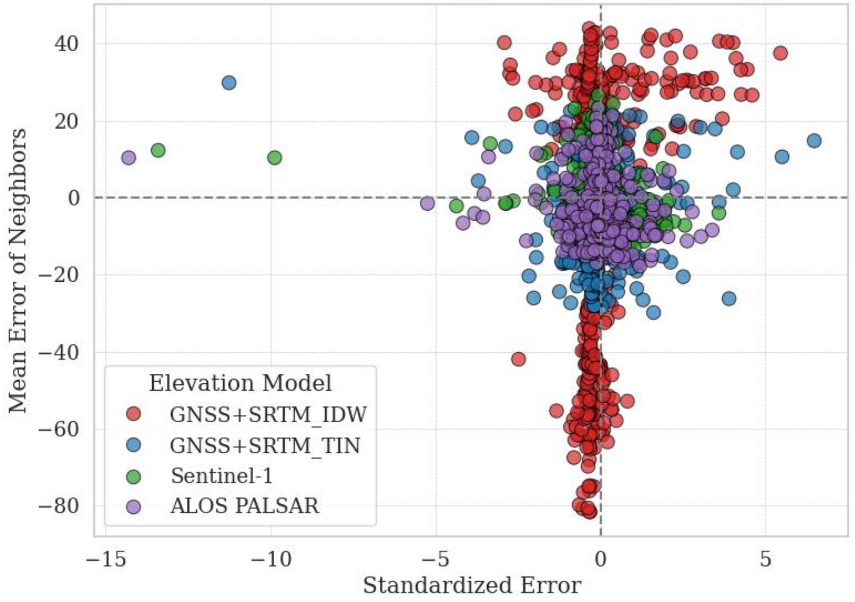


Table 1: Overview of the performance results across the statistical metrics evaluated

STUDY SITE		METRIC						
	Model	Bias (m)	RMSE (m)	SD (m)	MAE (m)	Percentile 50 (m)	Percentile 68 (m)	Percentile 95 (m)
RESERVA DO IGUAÇU	GNSS+SRTM_IDW	0.30	7.18	7.18	3.93	-0.19	1.07	9.13
	GNSS+SRTM_TIN	0.03	1.99	1.99	1.26	0.16	0.64	2.44
	Sentine-1	4.42	4.93	2.22	4.47	4,35	5.01	7.25
	ALOS PALSAR	-0.09	2.14	2.14	1.40	-0.02	0.49	2.47
GUARAPUAVA	GNSS+SRTM_IDW	3.97	13.84	13.25	6.88	0.48	2.74	34.33
	GNSS+SRTM_TIN	0.53	2.88	2.88	1.44	0.27	0.77	3.93
	Sentine-1	-0.06	3.36	3.36	1.55	-0.01	0.53	3.85
	ALOS PALSAR	-0.09	3.14	3.14	1.54	-0.03	0.56	3.72

4. CONCLUSION

- Terrain morphology and land cover significantly influence DTM reliability and accuracy.
- TIN interpolation provided the best performance, while IDW showed the lowest accuracy.
- GNSS integration with global or orbital elevation models can be a cost-efficient route for enhanced vertical accuracy in cadastral contexts.
- Radar-derived DTMs offered balanced performance, with variations across terrain types emphasising sensor choice matters

NEXT STEPS AND RECOMMENDATIONS

- Evaluate possible strategies for integration and complementarity between technologies;
- Test other combinations of integrated data, including different interpolation methods;
- Classify the quality of DTMs according to PEC-PCD
- Evaluate the sampling of points in the generation of DTMs as well as the appropriate selection of checkpoints.

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