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ARTIGOS

EVALUATION OF ALTIMETRIC ACCURACY OF DIGITAL SURFACE MODELS IN THE URBAN AREA OF CAMPO GRANDE/BRAZIL

AVALIAÇÃO DA ACURÁCIA ALTIMÉTRICA DE MODELOS DIGITAIS DE SUPERFÍCIE NA ÁREA URBANA DE CAMPO GRANDE/BRASIL

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Resumo
Os Modelos Digitais de Superfície são utilizados em diversas aplicações, sendo essenciais para modelagem hidrológica. Descrevemos a precisão altimétrica de diferentes MDSs na área urbana de Campo Grande, Mato Grosso do Sul, Brasil. Como conjunto de dados de referência, usamos dois conjuntos de dados distintos com coordenadas GNSS 3D. Os modelos testados foram Tandem-X, ALOS AW3D30, SRTMc, TOPODATA, SRTM v.3 e Aster GDEM v.2. Estimamos as discrepâncias verticais em relação ao conjunto de dados de referência, usando as seguintes métricas: discrepância vertical mínima e máxima e média; DP; RMSE; e o padrão brasileiro de precisão cartográfica para produtos cartográficos digitais (PEC-PCD). O ALOS AW3D30 apresentou os melhores resultados em termos de RMSE (1,77 m), seguido pelo Tandem-X (RMSE de 2,80 m). Os demais MDSs apresentaram RMSE variando de 3,6 a 7,5 m. O ALOS AW3D30 e o Tandem-X mostraram compatibilidade com a escala 1:50.000, enquanto os demais modelos com a escala 1:100.000, conforme PEC-PCD classe A. Demonstramos que tanto o ALOS AW3D30 quanto o Tandem-X podem ser utilizados para realizar projetos relacionados à modelagem hidrológica em escalas menores ou iguais a 1:50.000. Já os demais MDSs devem ser adotados em projetos que envolvam escala menor ou igual a 1:100.000.

Palavras-chave: MDS; Padrão Brasileiro de Exatidão Cartográfica; PEC-PCD, Acurácia Vertical.

Abstract
Digital Surface Models are used in several applications, being essential in hydrological modeling. We describe the altimetric accuracy of different DSMs in the urban area of Campo Grande, Mato Grosso do Sul, Brazil. As reference, we used two distinct datasets with 3D GNSS coordinates. The tested models were Tandem-X, ALOS AW3D30, SRTMc, TOPODATA, SRTM v.3, and Aster GDEM v.2. We estimated the vertical discrepancies regarding the reference dataset, using the following metrics: vertical discrepancies minimum and maximum; mean and SD; RMSE; and, the Brazilian standard of cartographic accuracy for digital cartographic products (PEC-PCD). The ALOS AW3D30 presented the better results in terms of RMSE (1.77 m), followed by the Tandem-X (RMSE of 2.80 m). The others DSMs presented RMSE ranging from 3.6 to 7.5 m. The ALOS AW3D30 and the Tandem-X showed compatibility with the 1: 50,000 scale, while the other models with the 1:100,000 scale, according to PEC-PCD class A. We demonstrate that both ALOS AW3D30 and Tandem-X can be used to perform projects related to hydrological modeling at scales less or equal to 1:50,000. The other DSMs should be adopted in projects involving a scale less or equal to 1:100,000.

Keywords: DSM; Brazilian Cartographic Accuracy Standard; PEC-PCD, Vertical Accuracy.

INTRODUCTION

The Digital Surface Models (DSMs) are altimetric representations in digital terrain form and are used for several works, such as evaluating landslide susceptibility (Rabby et al., 2020; Arabameri et al., 2019), mapping rainforest environments (Rennó et al., 2008), mapping the groundwater potentiality (Gaber et al., 2020), analysis of hydrological sensitivity for flood risk assessment (Sharma et al., 2018) and, three-dimensional representation of the landscape (Marini et al., 2017). Although the DSM has several practical applications, these data are not always compatible with certain types of tasks, requiring the assessment of their vertical accuracy before its usage.

Many studies have evaluated the altimetric accuracy of DSMs. Falorni et al. (2005) assessed the altimetric accuracy of the DSM provided by SRTM (Shuttle Radar Topography Mission) for two areas in the USA and concluded that the relief has a strong effect on the accuracy of these data. Previous work also assessed the DSMs' accuracy for all of Australia (Hirt et al., 2010), for Northern Greece (Mouratidis et al., 2010), for areas in Peru (Sánchez et al., 2012), for the whole world (Mukul al., 2016), (Mukul al., 2017), for a city in India (Patel al., 2016), Istanbul, and Turkey (Alganci al., 2018). Those are examples of work carried out in different parts of the world on the same thematic of assessing the vertical accuracy of DSMs, aiming to check the reliability of these data. In the Brazilian context, examples of this type of work are those carried out by Morais et al. (2017), which evaluated the SRTM v.3, and Aster GDEM v.2 (Global Digital Elevation Model) for the area of Belo Horizonte, Minas Gerais. Franca et al. (2019) evaluated the models' Aster GDEM v.2 and SRTM v.3 for the region west of the State of Bahia. Marini et al. (2017) evaluated the vertical accuracy of the SRTM v.4, Aster GDEM v.2, and Topodata models for application in the 3D representation of the Nhecolândia Pantanal.

The DSM Tandem-X is a product of a 2010 global radar mission, with high spatial resolution, 12 meters. Grohmann (2018) evaluated the Tandem-X in seven areas, including different morphological contexts, vegetation cover, and land use, in Brazil, performing a visual analysis for comparing it with the SRTM v.3, Aster GDEM v.2, and ALOS AW3D30. The author concluded that Tandem-X has a high level of detail and consistency. Moreover, they pointed out that the effective horizontal resolution of the SRTM v.3 is greater than the nominal 30 m, and highlights the errors in Aster GDEM v.2 and ALOS AW3D30 due to the incompatibility between adjacent scenes in the photogrammetric process.

Avtar et al. (2015) evaluated the DSM provided by Tandem-X in Tokyo. They compared it with global (SRTM v.4.1, Aster GDEM v.2, and Tandem-X) and local (LiDAR and GSI) models, obtaining the lowest value of RMSE (Root Mean Square Error) among the global DSMs. However, to the best of our knowledge, there are no studies that have evaluated the altimetric accuracy of the DSM Tandem-X urban areas in Brazil. To fulfill this gap, this work evaluates the vertical accuracy of the DSMs, including Tandem-X, in the urban area of the municipality of Campo Grande, Mato Grosso do Sul, Brazil. The following questions are addressed in this work: "What is the largest cartographic scale that can be adopted in the urban area mapping the municipality of Campo Grande with the DSMs data?"; "What are the magnitude of the discrepancies in the vertical accuracy between the Tandem-X data and the other DSM (ALOS AW3D30, SRTMc, TOPODATA, SRTM v.3, and Aster GDEM v.2) in the urban area of the municipality of Campo Grande?". In urban areas, the DSM is an important source of data for planning; it helps in the identification of areas prone to landslides and flooding, also contributing to hydrological modeling, among other applications.

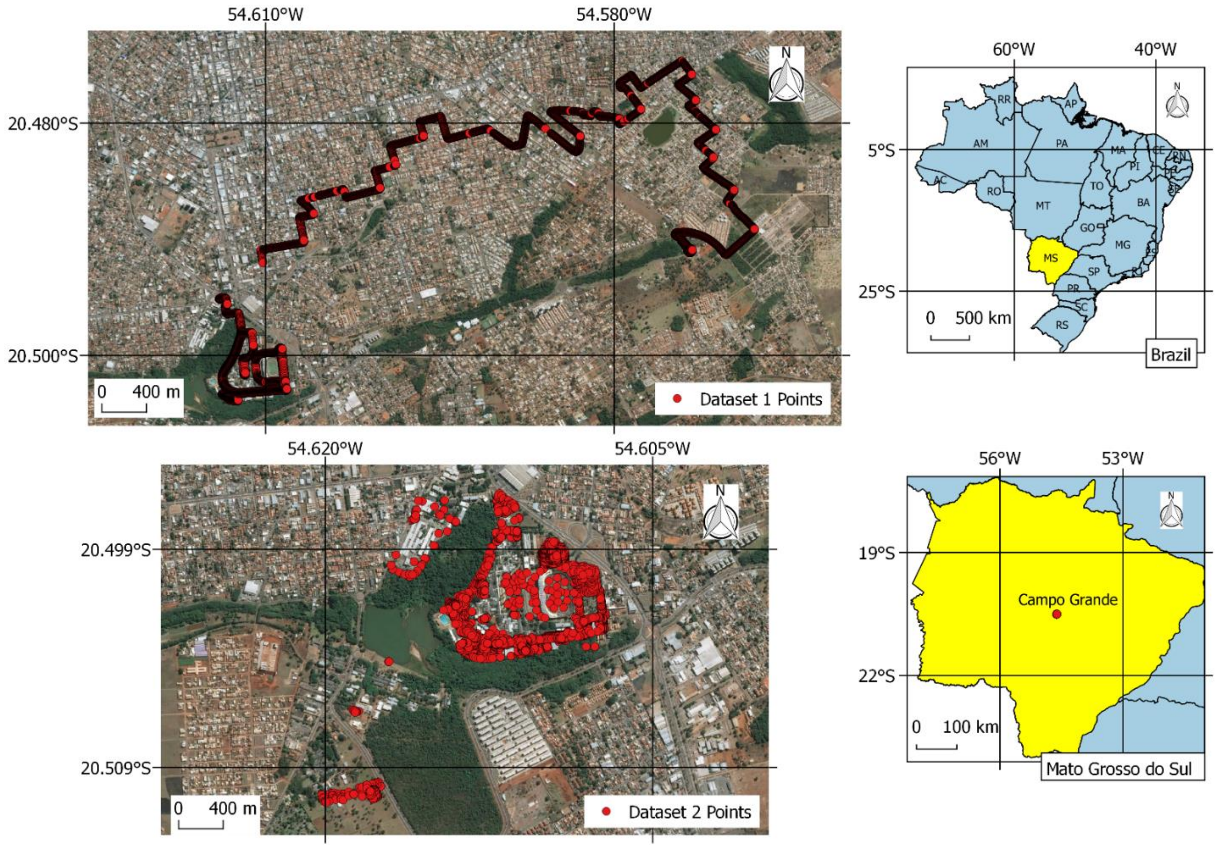
MATERIALS AND METHODS

The vertical accuracy of DSMs was evaluated in the urban area of Campo Grande, Mato Grosso do Sul, Brazil considering two datasets as reference collected by 3D GNSS (Global Navigation Satellite System) surveying. We evaluated the DSM based on the vertical discrepancies between the 3D GNSS points, and DSMs height value, and finally classified the DSMs based on the Brazilian Cartographic Accuracy Standard to Digital Cartographic Products (PEC-PCD).

Study area and reference data

The study area comprises the urban area of Campo Grande (Figure 1), which is the capital of Mato Grosso do Sul state and has a total area of 8,092.95 km² and 359.03 km² of the urban area (PLANURB 2017).

Figure 1 - Illustration of the portions of the study area, the Campo Grande city, in Mato Grosso do Sul state, Brazil, and spatial distribution of the GNSS points (in red color) adopted as reference datasets to evaluate the accuracy of the DSMs in this area.

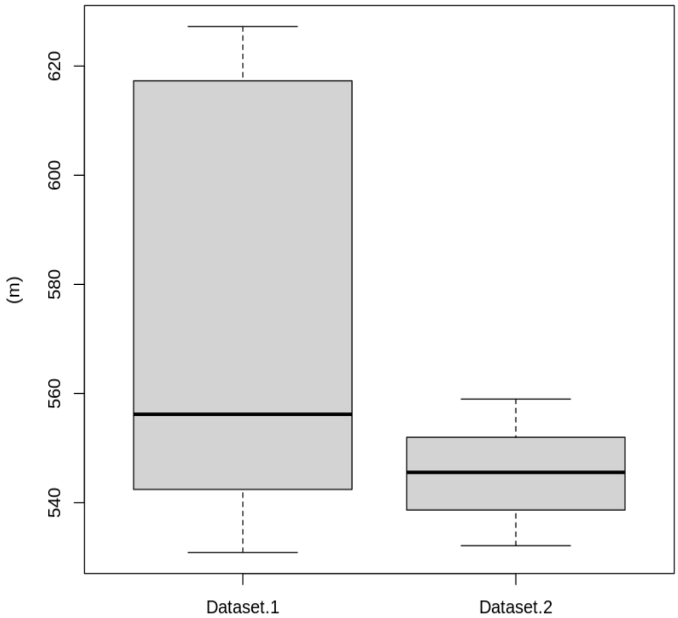


Source: Authors' elaboration.

To validate the DSMs, two datasets were used as references. The first dataset with 3D coordinates data was collected with a dual-frequency GNSS receiver in kinematic mode (1 second), adapted in a vehicle that traveled the streets of the urban area of Campo Grande. A total of 21,631 reference points were collected, which were obtained using the software Inertial Explorer Version 8.30.1007. The mean standard deviation of planimetry (latitude and longitude) and altimetry (Ellipsoidal height) of the GNSS points was approximately 0.10 and 0.16 m, respectively. After preliminary studies, we verified that in some regions, due to the vehicle stop, the points were concentrated, and this was removed applying a square filter of 1m, ensuring only one GNSS point per square meter. Finally, 14,907 points were used in the evaluation.

The second dataset has 3D data obtained by surveying with GNSS receivers, using the Real-Time Kinematic (RTK) method, through Trimble R8s equipment. This dataset has distributed points in different environments: vegetation, buildings, and near a lake. The mean standard deviation of these points is 0.05 m for latitude and longitude and 0.10 m for Ellipsoidal height. 3,159 points were raised.

Figure 2 - Boxplot relative to a distribution of the Height GNSS points in the two datasets.



Source: Authors' elaboration.

In figure 2 we can see the distribution of ellipsoidal height GNSS, for dataset 1 it presents a greater amplitude of altitudes, since the points were collected in a larger area. According to Planurb (2017), the relief of Campo Grande is classified as smooth wavy.

Digital Surface Models

The following models have been evaluated (Table 1): Tandem-X, ALOS AW3D30, Bare Earth SRTM (O'loughlin et al., 2016) - SRTMc; TOPODATA (DSM generated with kriging based on SRTM, for the Brazilian territory) (Valeriano 2005), SRTM v.3, and the Aster GDEM v.2.

Table 1 - Main characteristics of the DSMs and links to download the data.

DSM	Spatial Resolution	Aquisition system	Altimetric Referential	Link to download
Tandem-X	12 m	InSAR	Ellipsoid (GRS80)	http://www.eoweb.dlr.de/
ALOS AW3D30	30 m	Photogrammetry	Ellipsoid (GRS80)	http://www.eorc.jaxa.jp/.
SRTMc	30 m	Processing based by SRTM	Geoid (EGM96)	https://data.bris.ac.uk/data/dataset/9d090aba1b9b3fe56dbb597b4b161e9f
TOPODATA	30 m	Processing based by SRTM	Geoid (EGM96)	http://www.webmapit.com.br/inpe/topodata/
SRTM v.3	30 m	InSAR	Geoid (EGM96)	https://earthexplorer.usgs.gov/
Aster GDEM v.2	30 m	Photogrammetry	Geoid (EGM96)	https://earthexplorer.usgs.gov/

Source: Authors' elaboration.

The surface reference for the Tandem-X and AW3D30 data is the GRS80 ellipsoid, while the others consider the EGM-96 geoid. Therefore, a pre-processing stage was necessary to allow the comparison among the models, as explained in the following sub-section.

Validation of the DSM

The ellipsoidal height values obtained with the GNSS is referred to the GRS80 ellipsoid. Thus, the height (vertical coordinate) represented in the Tandem-X and AW3D30 could be compared directly with the height of the checkpoints (GNSS points). For the other models, however, first, the GNSS ellipsoidal heights were converted to orthometric heights. For this, we used the International Center for Global Earth Models (ICGEM) (Ince et al., 2019), which is compatible with the orthometric height with height represented in the DSMs models, i.e., Geiod (EGM96).

To obtain the height of the DSM to each GNSS check point, the Point sampling tool of the Open Source GIS QGIS (QGIS 2015) was used, which allows the collection of model data in the same planimetric UTM coordinate (E, N) of the GNSS data. The height discrepancy was estimated using the GNSS height (H) and the DSM height (H DSM). The maximum and minimum discrepancies were verified, while the RMSE (Eq. 1), the mean (Eq. 2), and the standard deviation - SD (Eq. 3) were estimated.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\text{H DSM}_i - \text{H}_i\right)^2} \quad (1)$$

$$mean = \frac{1}{n}\sum_{i=1}^{n}\left(\text{H DSM}_i - \text{H}_i\right) \quad (2)$$

$$SD = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(\left(\text{H DSM}_i - \text{H}_i\right) - mean\right)^2} \quad (3)$$

where i varies from 1 to the number of checkpoints (n).

The models were evaluated using the PEC-PCD (DSG 2011). The DSMs can be classified in different scales (1: 100,000; 1: 50,000; 1: 25,000; etc.) and classes A, B, C, and D, according to Table 2.

Table 2 - Brazilian cartographic accuracy standard for digital cartographic products (PEC-PCD) values for the scales 1: 25,000, 1: 50,000 and 1: 100,000. Standard Error (SE).

PEC-PCD	1:25,000		1:50,000		1:100,000	
	PEC (m)	SE (m)	PEC (m)	SE (m)	PEC (m)	SE (m)
A	2.70	1.67	5.50	3.33	13.70	8.33
B	5.00	3.33	10.00	6.66	25.00	16.66
C	6.00	4.00	12.00	8.00	30.00	20.00
D	7.50	5.00	15.00	10.00	37.50	25.00

Source: DSG 2011.

For the DSM to be classified as class A on the 1: 50,000 scale, for example, it is necessary to present an RMSE less than or equal to 3.33 m, and 90% of the discrepancies must be less than or equal to 5.50 m. It should be noted that this approach to assess the vertical accuracy of DSM based on the PEC-PCD is consolidated in the literature, considering as reference data points obtained by field survey (Marini et al., 2017; Morais et al., 2017; Franca et al., 2019; Franca and Silva, 2018).

RESULTS

The results were divided into two sections one with the results of the first reference dataset and another with the results of the second reference dataset.

Results dataset 1

The results of the statistical analyzes applied for the evaluation of the DSMs, with the first dataset, are shown in Table 3 and Figure 3.

Table 3 - Minimum and maximum vertical discrepancy, RMSE, Mean and Standard Deviation (SD) for the urban area of Campo Grande, Brazil.

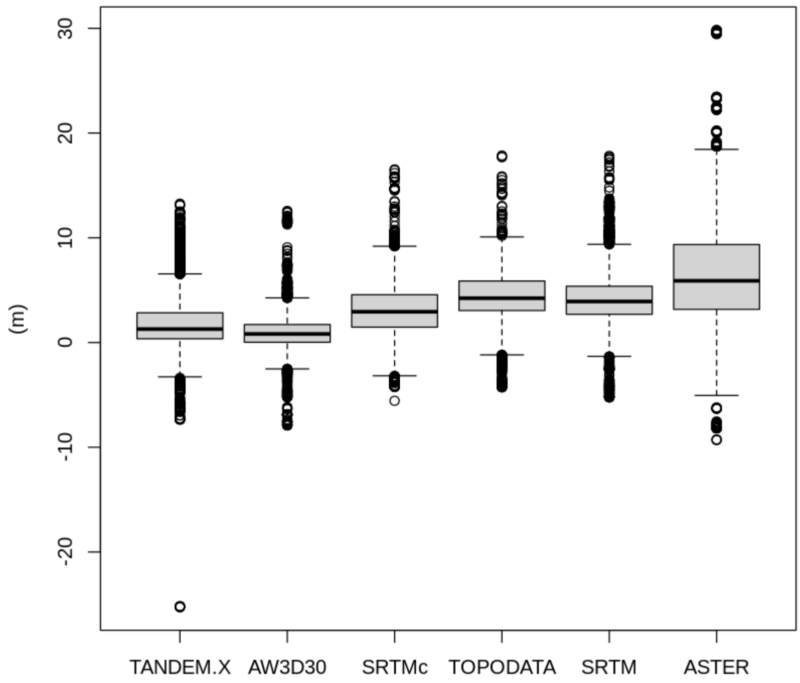
	Tandem-X	ALOS AW3D30	SRTMc	TOPODATA	SRTM v.3	Aster GDEM v.2
Minimum vertical Discrepancy (m)	-25.27	-7.92	-5.56	-4.27	-5.24	-9.32
Maximum vertical Discrepancy (m)	13.25	12.56	16.53	17.85	17.82	29.83
RMSE (m)	2.80	1.77	4.08	4.95	4.92	8.05
Mean (m)	1.69	0.89	3.16	4.49	4.22	6.35
SD (m)	1.63	1.08	2.02	1.63	1.87	3.82

Source: Authors' elaboration.

ALOS AW3D30 showed the best result (RMSE 1.77 m), followed by Tandem-X with an RMSE of 2.80 m. However, it should be considered that the difference between the RMSE of the ALOS AW3D30 and the RMSE of the other DSM was always at least twice the value of the RMSE, except for the Tandem-X.

The SRTMc showed a result (RMSE of 4.08 m) lower than the SRTM v.3 (RMSE of 4.92 m), which was expected since it was generated with the proposal to be a DTM (Digital Terrain Model) (O'loughlin et al., 2016). SRTM v.3 and TOPODATA presented RMSE very close to each other (4.92 and 4.95 m, respectively). It is worth remembering that TOPODATA is also generated from SRTM data (Valeriano 2005). Aster GDEM v.2 had an RMSE of 8.05 m, which corroborates with (Marini et al., 2017; Graf et al., 2018) that also evaluated the DSM Aster GDEM v.2, which proved to be the model least accurate vertically. Additionally, when we analyze the Boxplot (Figure 3), the Aster GDEM v.2 model presents the highest variability compared to other models. While the ALOS AW3D30 model showed the least variation between discrepancies, with a median close to zero, and with most of the discrepancies between 10 m and -10 m.

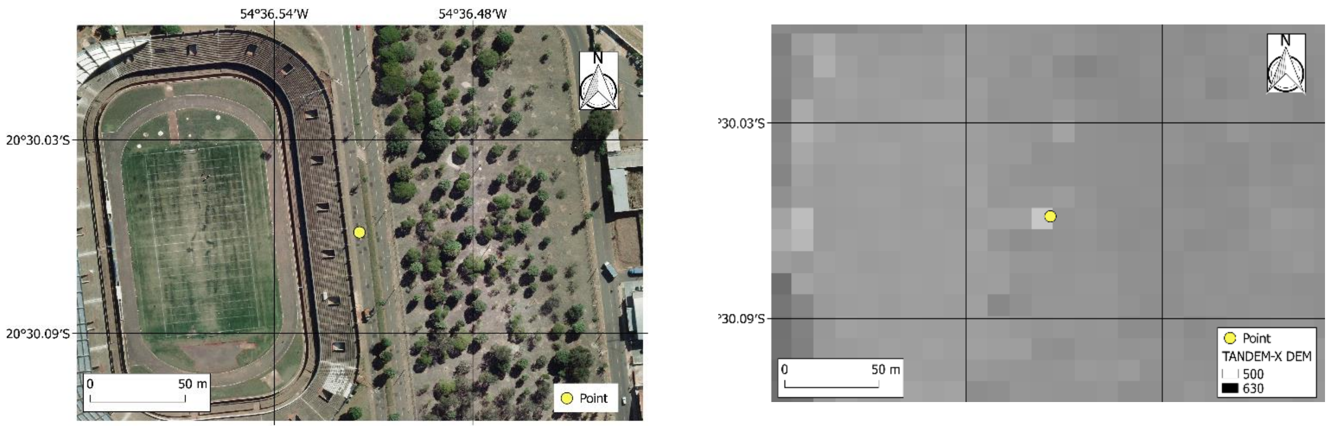
Figure 3 - Boxplot of DSM discrepancies regarding the 3D GNSS points for the urban area of Campo Grande, Brazil.



Source: Authors' elaboration.

We verified that the Tandem-X presented an isolated outlier, which was presented in Table 3 (minimum discrepancy of -25 m). This outlier is in a single-pixel (Figure 4), which has one point collected with GNSS. The same situation was not observed for the others DSM as the presented minimum discrepancies were between -10 and -5 m, approximately (Figure 3). SRTMc, Topodata, and SRTM v.3 obtained similar boxes, SRTMc with a lower median but with more distribution of discrepancies. Aster GDEM v.2 is the median furthest from zero and with the greatest dispersion of results.

Figure 4 - Location of the minimum discrepancy point (yellow) for the MDS Tandem-X, (a) in an orthorectified image, (b) in the Tandem-X model.



(a) (b)

Source: Authors' elaboration.

For the maximum discrepancies (Table 3), the ALOS AW3D30 had the lowest value, 12.56 m, followed by the Tandem-X (13.25 m) and the SRTMc (16.53 m). The Aster GDEM v.2 model has presented the worst results being the maximum discrepancy of 30 m approximately. The results of the altimetric assessment of the DSMs for the urban area of Campo Grande based on the PEC-PCD are presented in Tables 4 and 5.

Table 4 - Classification according to the PEC-PCD, considering the Standard Error for class A.

Scale	**Standard Error (m)**	**RMSE (m)**					
		Tandem-X	**ALOS AW3D30**	**SRTMc**	**Topodata**	**SRTM v.3**	**Aster GDEM v.2**
1:25,000	**1.67**						
1:50,000	**3.33**	2.80	1.77				
1:100,000	**8.33**			4.08	4.95	4.92	8.05

Source: Authors' elaboration.

Table 5 - Percentage of points with discrepancy below the PEC-PCD, for class A.

Scale	**PEC - PCD (m)**	Tandem-X (%)	ALOS AW3D30 (%)	SRTMc (%)	Topodata (%)	SRTM v.3 (%)	Aster GDEM v.2 (%)
1:25,000	**2.70**	71.81	90.70	45.93	17.83	24.34	19.51
1:50,000	**5.50**	**93.88**	**98.93**	83.27	69.48	76.41	45.41
1:100,000	**13.70**	**99.96**	**100**	**99.89**	**99.89**	**99.87**	**93.30**

Source: Authors' elaboration.

We observed that the Tandem-X and ALOS AW3D30 were compatible with the scale 1:50,000, class A, according to the standard error criteria (RMSE 2.80 and 1.77) and percentage of points below the PEC-PCD (93.88 and 98.93), respectively. By the percentage criterion, the ALOS AW3D30 could be classified on a larger scale; however, the RMSE, although close, prevents this classification. The other evaluated DSMs are classified on the scale of 1: 100,000, class A, for the area under study.

Results dataset 2

The results of the statistical analyzes applied for the evaluation of the DSMs, with the second reference dataset, are shown in Table 6 and Figure 5.

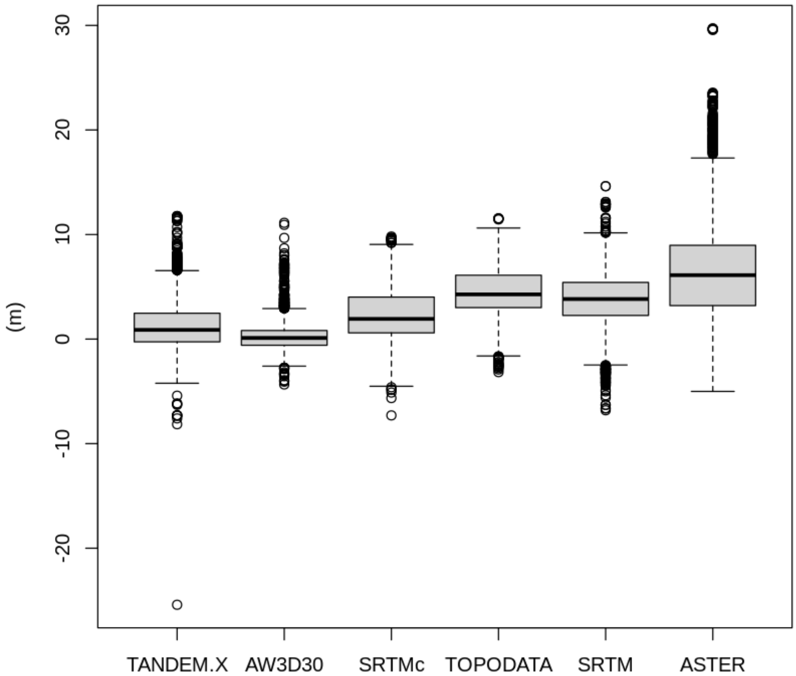
Table 6 - Minimum and maximum vertical discrepancy, RMSE, Mean and Standard Deviation (SD) for the urban area of Campo Grande, Brazil.

	Tandem-X	**ALOS AW3D30**	**SRTMc**	**TOPODATA**	**SRTM v.3**	**Aster GDEM v.2**
Minimum vertical Discrepancy (m)	-25.40	-4.34	-7.30	-3.16	-6.81	-5.00
Maximum vertical Discrepancy (m)	11.77	11.13	9.81	11.54	14.62	29.71
RMSE (m)	2.68	1.57	3.41	5.06	4.73	8.30
Mean (m)	1.31	0.33	2.30	4.42	3.72	6.73
SD (m)	2.34	1.54	2.52	2.47	2.91	4.86

Source: Authors' elaboration.

As shown in Table 6, the RMSE of the ALOS AW3D30 is the smallest (1.57 m), followed by the Tandem-X (2.68 m). For this Dataset the ALOS AW3D30 has RMSE twice as low compared to the models except for the Tandem-X.

Figure 5 - Boxplot of DSM discrepancies regarding the 3D GNSS RTK points for the urban area of Campo Grande, Brazil.



Source: Authors' elaboration.

The distribution of discrepancies was observed in figure 5, with the ALOS AW3D30 with the smallest box, indicating that the discrepancies are uniform and close to zero, as well as the Tandem-X, whose box is shifted to values above zero, this is observed with the median above zero and the box shifted to values above the median. For the SRTMc, TOPODATA, and SRTM v.3 models, the boxes have similar dimensions, although the SRTMc with the Box is closer to zero and the SRTM with the more compact box.

Table 7 - Classification according to the PEC-PCD, considering the Standard Error for class A.

Scale	Standard Error (m)	RMSE (m)					
		Tandem -X	**ALOS AW3D30**	**SRTMc**	**Topodata**	**SRTM v.3**	**Aster GDEM v.2**
1:25,000	**1.67**		1.57				
1:50,000	**3.33**	2.68					
1:100,000	**8.33**			3.41	5.06	4.73	8.30

Source: Authors' elaboration.

Table 8 - Percentage of points with discrepancy below the PEC-PCD, for class A.

Scale	PEC - PCD (m)	Tandem -X (%)	ALOS AW3D30 (%)	SRTMc (%)	Topodata (%)	SRTM v.3 (%)	Aster GDEM v.2 (%)
1:25,000	**2.70**	76.95	**92.66**	58.59	21.02	27.13	18.04
1:50,000	**5.50**	**94.62**	**98.39**	88.25	69.32	75.46	43.83
1:100,000	**13.70**	**99.97**	**100**	**100**	**100**	**99.94**	**91.48**

Source: Authors' elaboration.

According to tables 7 and 8, the ALOS AW3D30 can be applied at 1:25,000 scale according to the PEC-PCD, since it presented RMSE (1.57 m) lower than the standard error limit for the class (1.67 m) and more than 90% of the data are below the error limit of the PEC-PCD of 2.7 m, of the evaluated models the only one with such classification.

Tandem-X was rated for the scale of 1:50,000 according to the PEC-PCD class A. With RMSE 2.68 being the standard error accepted for class up to 3.33 m and more than 90% of data below the limit of 5.50 m. The other models fit the 1:100,000 scale according to the PEC-PCD class A.

DISCUSSION

A DSMs is used as input data to attend different applications, such as in the studies involving relief mapping in urban areas, which requires data on a larger cartographic scale. Evaluating a DSM's altimetric accuracy, before its adoption, is a project requirement. Here we characterized the altimetric accuracy of different DSMs in the urban area of Campo Grande using two datasets. Additionally, we identified the recommended scale based on the PEC-PCD criterion. ALOS AW3D30 and Tandem-X are the best options, being indicated for supporting studies at a scale of 1: 50,000.

Using two distinct reference datasets, one with a more linear points distribution and the other with a circular distribution, we noted that the RMSE values and discrepancies in height are similar to the ALOS AW3D30 model and the Tandem-X. However, the values of the PEC-PCD for the second reference dataset are even better, indicating that the ALOS AW3D30 can be used to map on the scale of 1:25,000. Another model that improved the result was the SRTMc, which was classified on the scale of 1:50,000. We believe this is due to the lower number of points 3,159 in the second dataset against 14,907 in the first dataset.

Kramm and Hoffmeister (2019), and Grohmann (2018) argue that, depending on the topography of the study area, the ALOS AW3D30 presents just as well as the Tandem-X. To demonstrate the accuracy of the Tandem-X and ALOS AW3D30, Kramm and Hoffmeister (2019) concluded that they could represent a landscape with the same precision as very high-resolution DSMs with a 5 m GSD. According to Avtar et al. (2015), the estimated RMSE for Tandem-X is considerably lower than SRTM v.4.1 and Aster GDEM v.2.

In urban areas there are constructions that interfere in the representation of the terrain by the MDS, Avtar et al. (2015) found that urban areas and forest regions are sources of error in the MDS. In both datasets there are small buildings, except for the stadium, which interfered in the Tandem-X (Figure 4), so the RMSE remained low. For future work one can investigate areas with large buildings to see if the RMSE remains low.

Most of the vertical accuracy assessment works use data from LiDAR (Morais al., 2017; Grohmann et al., 2018; Kramm and Hoffmeister 2019), as well as high-resolution photogrammetry data (Alganci al., 2018; Kramm and Hoffmeister 2019). In the absence of this type of data, we have works that use GNSS data (Franca et al., 2019). Due to the number of GNSS points, with good precision and the two datasets presenting similar results, we believe that this has been compensated.

CONCLUSIONS

A comparative analysis was developed on the altimetric accuracy of different DSMs for the urban area of the municipality of Campo Grande, Brazil, using more than 18 thousand GNSS points. The Tandem-X has higher altimetric accuracy than the traditional DSM (SRTM v.3, Aster GDEM v.2). In this study, the freely available DSM ALOS AW3D30 was the one with the highest altimetric accuracy. However, its results are still similar to those obtained for the Tandem-X in terms of PEC-PCD classification.

For the municipality of Campo Grande, it is concluded that the Tandem-X and ALOS AW3D30, are compatible with the scale 1: 50,000, and the models SRTMc, Topodata, SRTM v.3, and Aster GDEM v.2 with the 1:100,000, when considering the PEC-PCD, class A. It is important to highlight that in this work, it was used a large number of GNSS points were collected for the validation of the DSMs. The quantity used is much higher than that adopted in many studies for the validation of digital surface models.

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