



ALOS PRISM (AW3D05 STANDARD) and Sentinel-1: Evaluation of New Sources of Digital Elevations Models

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ABSTRACT

Digital Elevation Models (DEM) have many uses and many characteristics that influence choice of model to be used depending on the scale and research objectives. With the advancement of technology, new DEMs have emerged, as well as credible and widespread products such as Sentinel-1 and Advanced Land Observations Satellite World 3D (ALOS AW3D), each with distinct configurations. The height quality evaluation was performed based on Cartographic Accuracy Standard (PEC-PCD) analysis, tendency tests and examination of a profile in a region with rugged relief. A comparison was made with traditional DEM such as SRTM, ALOS PRISM, ALOS PALSAR and ASTER GDEM 2 with new DEMs AW3D Standard and MDS generate from Sentinel-1. The news DEMs have been classified as PEC B at regional scales (1:50,000). The AW3D Standard offers the best result, being rated PEC C for 1:25,000 scale. Another aspect should also be considered, the standard AW3D is capable of presenting more details on the terrain surface, while the DEM from Sentinel-1 SAR data presents a smoothed pattern. Sentinel-1 compared with products of the same spatial resolution, it is concluded that SRTM, ALOS PRISM, ALOS PALSAR products presented superior altimetric accuracy. While that the AW3D, despite the improvement in spatial resolution and altimetric accuracy remained in the same category as the PEC-PCD of the others.

Keywords: Cartographic Accuracy; DEM AW3D Standard; DEM Sentinel 1

Introduction

Computation of land surface height values is obtained by several modes, including topographic/geodesic field surveys, aerophotogrammetric and images from terrestrial, airborne or orbital, optical or radar sensors and/or LiDAR (light detection and ranging). In many cases, the resulting products are costly in acquisition and analysis because they involve highly specialized teams, specific software and high-performance hardware, making it untenable for many applications (Oliveira et al., 2017).

Faced with this problem, a plenty of studies about the use of Geographic Information System (GIS) and Digital Terrain Models (DTM) or Digital Surface Models (DSMs) has been presented with the free and global alternatives. For each new DEM proposed in the market, researchers try to evaluate the product considering its applications in specific

areas of knowledge (Sategé et al., 2015; Silva et al., 2018; França et al., 2019; Viel et al., 2020). However, a lack of understanding of the inherent uncertainty of these products can produce misleading results because errors propagate and contaminate results (Wilson, 2018). In many cases the problems are caused by the lack of familiarity of the peculiarities of the DEM, which have different characteristics depending on the method of acquisition, processing, extension, spatial resolution or even by the type, digital surface model (DSM) or digital terrain model (DTM) (Egg et al., 2013).

In the year 2000 the Shuttle Radar Topography Mission (SRTM) mission collected interferometric radar data with the objective of working on the production of a digital database for the entire planet, necessary in the elaboration of a Digital Model Elevation (DEM) of continental lands. The 2003 public release of the 90 m Shuttle

Radar Topography Mission (SRTM) DEM and in 2014 with a 30-meter spatial resolution were released with coverage from 56° S to 60° N ushered in a new age of near-global digital topographic analysis (Purinton and Bookhagen, 2017). In 2009 was launched the Advanced Spaceborne Thermal Emission and Reflection Radiometer Global DEM (METI/NASA/USGS, 2009; ASTER GDEM, 2019) with 30-meter spatial resolution and in 2011 was released a second version of the ASTER GDEM (GDEM 2) with some improvements and altimetric accuracy of around 17 m.

Also, in 2006, the Advanced Land Observing Satellite (ALOS) was launched by the Japan Aerospace Exploration Agency (JAXA), with three sensors on board: the radiometer panchromatic remote-sensing instrument for stereo mapping (PRISM) used for the generation of the DEM AW3D, the radiometer multispectral advanced visible and near infrared radiometer-type 2 (AVNIR-2) focused on land use and coverage maps, and the microwave sensor Phased Array type L-band Synthetic Aperture Radar (PALSAR) (JAXA, 2019). This program allowed obtain two different DEM by PALSAR (ALOS PALSAR) and PRISM (ALOS AW3D30), both open access with 12.5-meter and 30-meter spatial resolution, respectively.

In addition, in 2014, with the launch of the Sentinel-1 system, the opportunity arose to generate DEM from interferometry based on images of Band-C synthetic aperture radar (ESA, 2019). Little is known about the ability of this product to generate quality DEM (ASF, 2019). From the PRISM sensor, the JAXA also launched the AW3D Standard private product series (2.5 m/5m resolution), the potential of which has been little explored (AW3D, 2019). Each DEM has peculiarities that need to be clarified for proper use in geoprocessing projects.

Some researches were proposed to evaluate the altimetric quality in Brazilian Grounds, although no study has been identified with the DEM generated by Sentinel-1 and AW3D Standard private product series in Brazil. Among the different studies with traditional DEM, we highlight Souza et al. (2020) that compared the DEM SRTM and ALOS AW3D30 in the state of Mato Grosso do Sul with a large portion of its territory covered by the wetland and demonstrated the effectiveness of the latter, in which 90% of the discrepancies between the reference points and the DEM are less than 2.7m. Duarte et al. (2019) compared the DEM SRTM, ASTER GDEM 2 and

ALSO PALSAR in the Amazon region and the last one presented the best result.

Therefore, the objective of this work was to evaluate the altimetric accuracy of the new DEMs, AW3D Standard and Sentinel-1. PEC-PCD (digital cartographic products) and traditional trend test were used to quality analysis. The products also were compared with classic DEM widely used in geosciences: SRTM 1 arc, ALOS PRISM, ALOS PALSAR and ASTER GDEM 2. In this way, it is believed, AW3D Standard and Sentinel-1 may have better accuracy and precision than other products available.

Methodology

The study area is located in the Serra de São Domingos, Formoso – MG, (Figure 1), between the cities of Buritis and Formoso, both in northwestern Minas Gerais, near the limit of the state of Goiás the center of Brazil (Figure 1). The study area is located within the Divisor Plateau São Francisco-Tocantins, represented by tabular surfaces with erosive edges and pronounced depressions where the drains are housed (Embrapa, 1979). Cerrado is the predominant biome and the main economic activity is agriculture, consisting of cattle ranching, logging and forestry (SEMA, 2008).

A map of the study area (Figure 1) shows an elongated feature oriented northwest-southeast, known as Serra de São Domingos. Such physiognomy is characterized by heights ranging from 500 m to 1000 m with flat relief at its top and side and base formed by the influences of geological structures and drainages (Alvarenga et al., 2013). Figure 2 presents the flowchart diagramming the research steps performed.

Field activities were started with knowledge of the physiographic aspects of the study area and collection of control points. 31 control points were obtained in August 2016 following the static fast relative positioning procedure using a pair of dual-frequency Topcon GPS Hiper Lite + GNSS receivers. Although there are no specific rules for quantifying and distributing the points control in the study area (Santos et al., 2016), the study sought to homogeneously distribute the control points. The greater concentration was in rugged areas and with coverage of the sample AW3D Standard. Figure 1 shows the location of the control points.

All control points had their orthometric heights (H) calculated using MAPGEO 2015

Desktop, a geoidal model developed for Brazil and made available by Brazilian Institute of Geography

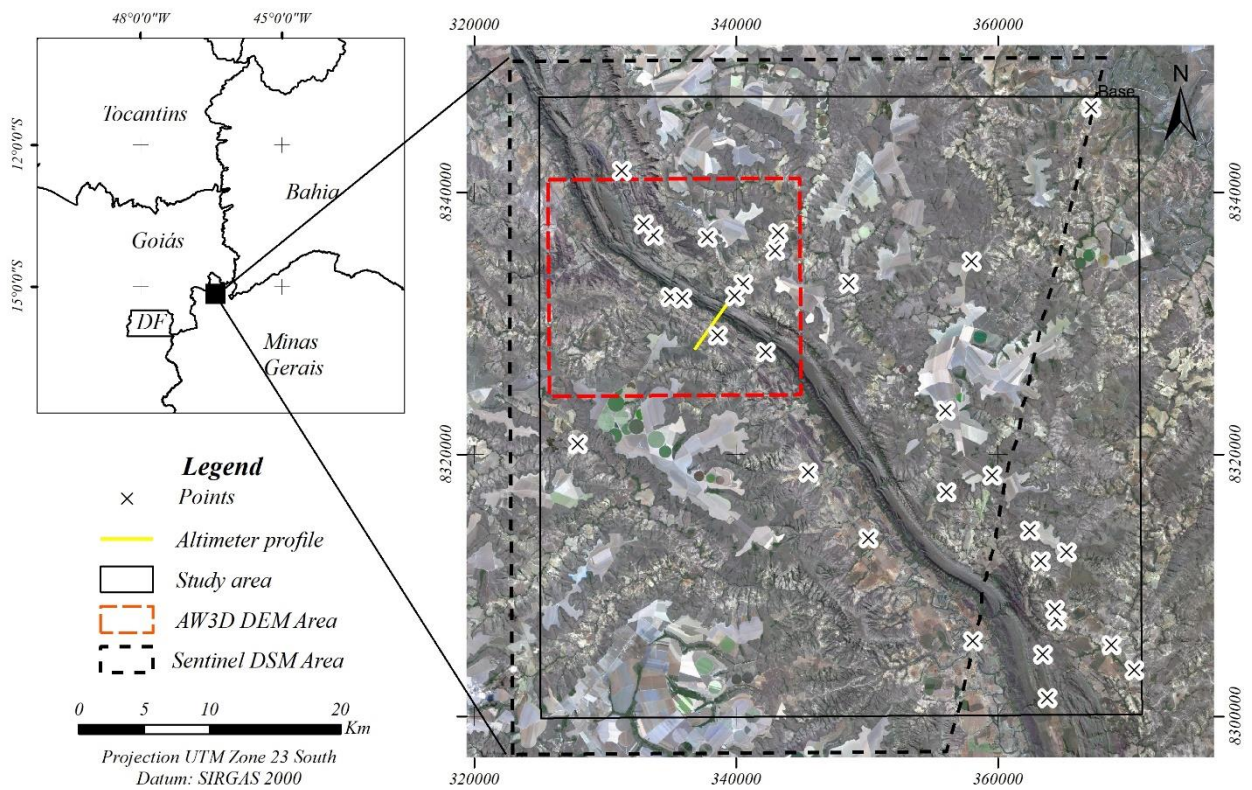


Figure 1: Study area location map with DEM AW3D Standard (dashed line frame), DEM Sentinel-1 (dotted line frame), and SRTM, ASTER GDEM 2, ALOS PRISM and ALOS PALSAR (full line frame) control and limitation location points.

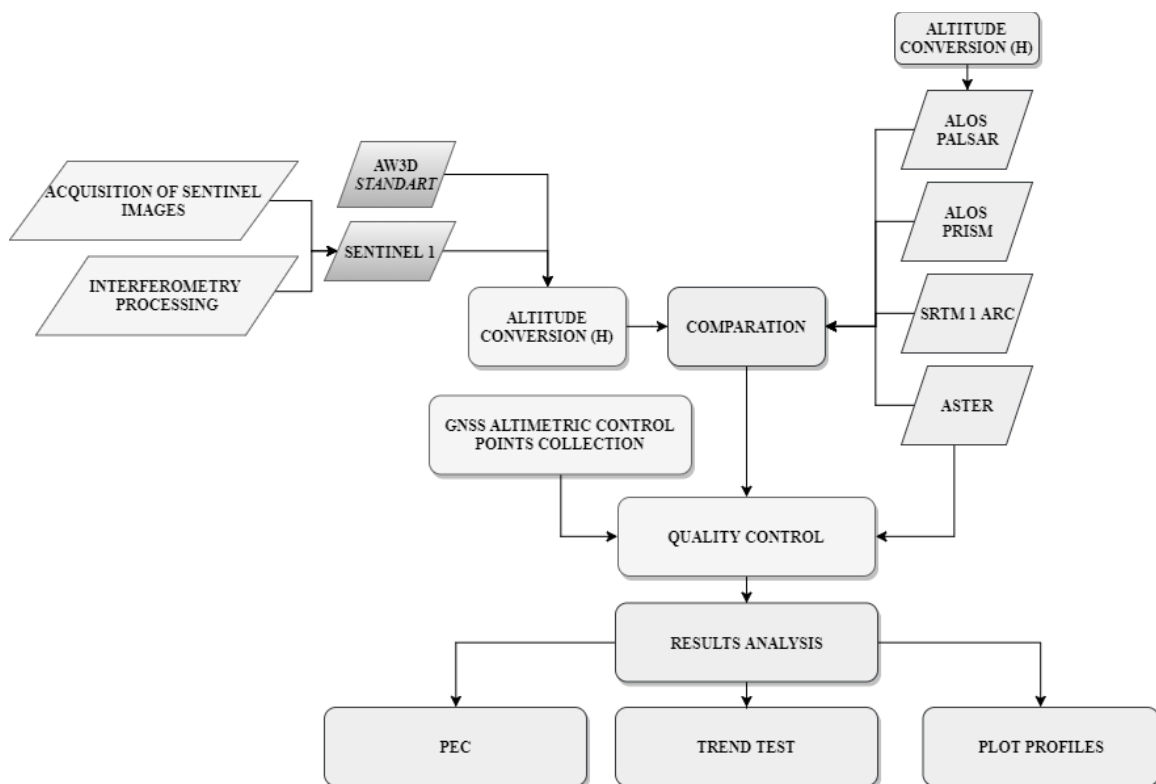


Figure 2: Flowchart of research activities.

and Statistics (IBGE). The consistency between the geoid heights obtained through the interpolation with the model and the direct values obtained from the connections present a mean square error of $\pm 0,17$ m (IBGE, 2019). Although the DEMs used had their orthometric heights estimated by the geoidal model extracted from the EGM96 Global Geopotential Model (Earth Gravitational Model 1996), this work did not perform transformation because assumes that both models are compatible to considered scale (Freitas et al., 2004). More recent geoid models, such as EGM2008 and EGM2020, were not used because the free DEM images are offered in EGM96 and the conversion process normally is not executed by geospatial scientists.

To evaluate the performance of AW3D Standard and Sentinel-1, was elaborated the Table 1, with the main characteristics of the DEMs most commonly used by the scientific community. For each type of DEM obtained, it is important to understand that the products are distinguished between DSM and DTM, that is, the first refers to elevation values considering the features on the surface (vegetation, constructions, etc.), while the second product refers only to the ground. For DSM coming from short wavelength radar data (Band X and Band C), where penetration capacity is limited as compared to the L Band because they cannot penetrate the canopy of trees (Lucas et al., 2007). Thus DEMs with different acquisition settings can be used even though they belong to the DSM category.

Table 1: Acquisition characteristics and general configurations of the AW3D Standard, Sentinel-1 and other DEMs commonly-used by the scientific community.

DEM Name	Source	Sensor	Acquisition Method	Resolution	Surface Type	Type	Source
ALOS PRISM (AW3D Standard)	Satellite ALOS Daichi	Radiometer PRISM	Stereoscopy	1/4 arc second, equivalent to 5 m/2.5 m	h	DSM	JAXA
DEM from Sentinel-1 SAR	Mission Sentinel-1	C-band synthetic aperture radar (SAR) at 5.405 GHz	Interferometry - Band C	20 m	h	DSM	Access to Sentinel-1 raw: ESA and ASF (https://www.asf.alaska.edu/)
SRTM	Mission SRTM	SRTM	Interferometry - Band X and Band C	1 arc second, 30m	H - EGM96	DSM	USGS (https://earthexplorer.usgs.gov/)
ALOS PRISM (AW3D30)	Satellite ALOS	Radiometer PRISM (Panchromatic Remote-Sensing Instrument for Stereo Mapping)	Stereoscopy	30m	H - EGM96	DSM	JAXA and ASF (https://www.asf.alaska.edu/)
ALOS PALSAR	Satellite ALOS	PALSAR (Phased Array type L-band Synthetic Aperture Radar)	Interferometry - L Band	12 m	h	DSM	JAXA and ASF (https://www.asf.alaska.edu/)
ASTER GDEM 2	Satellite Terra,	ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer)	Stereoscopy	1 arc second, 30 m	H - EGM96	DSM	USGS (https://earthexplorer.usgs.gov/)

Observation: (H) orthometric height; (h) geometric height; (DSM) Digital Surface Model; (DTM) Digital Terrain Model.

Regarding data acquisition, the 20 km by 16 km DEM AW3D Standard (5 m) was kindly given by JAXA. This is a private product in which JAXA markets the 2.5 to 5 m spatial resolution models (AW3D 2019). Some recent works, such as Purinton and Bookhagen (2017) and Misra et al. (2018) and, have also performed analyses to verify the quality of DEM AW3D Standard product for use in China and Argentina, respectively.

For the generation of DEM from Sentinel-1, an interferometric procedure defined in Alaska Satellite Facility (ASF, 2019) was applied by the authors to raw images. The Sentinel-1 Interferometric Wide (IW) swath mode acquires data with a 250km swath at 5m x 20m spatial resolution (single look). The IW mode captures three sub-swaths using the Terrain Observation with Progressive Scans SAR (TOPSAR). Interferometric process creates a DSM for each interferometric pair. More information about the mosaic technique can be seen in Nikolakopoulos et al. (2015). This processing was based on co-registration, then application of a series of filters to reduce noise, and finally, automatic georeferencing of images. The procedures were performed using SNAP software provided by the European Space Agency (ESA). For the other products, the DEMs were downloaded directly from the sites indicated in Table 1.

Preprocessing of the DEM was performed using the ArcGis 10.6 software, which applied the delimitation procedure of the study areas and the re-projections of the cartographic products. No smoothing methods or deletion data procedures were applied in DEM. In addition, for compatibility of altimetric units, it was decided to work with data on orthometric heights (H). So, the data ALOS PALSAR, AW3D Standard and Sentinel-1 data were converted from geometric heights (h) to orthometric height (H) by the EGM96 model using the online application Geoid Height Calculator (UNAVCO, 2019).

It is important to note that every data acquisition is accompanied by an error. The

objective of any cartographic/geodetic survey is to deal with the error inherent in the process, be it the acquisition of new information or simply its conversion, in which the error cannot be eliminated but managed and/or minimized.

In Brazil, the assessment is realized using the Cartographic Accuracy Standard (PEC) defined in Decree-Law no. 89,817 of 1984, which regulates the classification of cartographic products according to their positional accuracy. In 2010, the Directorate of the Geographical Service of the Brazilian Army (DSG- Diretoria do Serviço Geográfico do Exército Brasileiro) published the Technical Specifications for Acquisition of Vector Geospatial Data (ET-ADGV). In one of its items creates a new PEC, with more restrictive class for digital cartographic products (PEC-PCD) (DSG, 2015). Thus, this standard was used to evaluated the quality of DEM.

The ET-ADGV clarifies that the classification of the chart with respect to accuracy must comply with the PEC according to the following criterion: 90% of the well-defined control points in a card, when tested in the field, should not present an error higher than the PEC. Thus, the altimetric values of the pixels overlapping the control points were extracted for the PEC calculation for the DEM AW3D Standard and Sentinel-1. The same procedure was performed for the DEM ALOS PALSAR, ALOS PRISM, ASTER and SRTM 1 arc. Thus, to determine the altimetric accuracy, control points with an average positional precision of millimeters were used. These data points were the reference for the application of the PEC-PCD (digital cartographic products). The Table 2 shows the limit in meters of PEC per class A, B, C or D. It is also observed the standard error (EP) that defines the RMSE (root mean square error) of positional discrepancies of analyzed points, which must be equal to or less than the “EP” tolerance defined by the standard, for each scale and class tested.

Table 2: Mapping accuracy standard for digital mapping products (PEC_PCD) values for scales 1: 25,000, 1: 50,000 and 1: 000,000. Standard error (EP).

SCALE	A		B		C		D	
	PEC (m)	EP (m)	PEC (m)	EP (m)	PEC (m)	EP (m)	PEC (m)	EP (m)
1:25.000	2.7	1.67	5	3.33	6	4	7.5	5
1:50.000	5.5	3.33	10	6.66	12	8	15	10
1:100.000	13.7	8.33	25	16.66	30	20	37.5	25

In order to facilitate the analysis of the results, a boxplot was created with the median, average, maximum value and minimum value of the Root Mean Square Error (RMSE). A graph also shows the limit of PEC-PCD by EP of each scale and class, plus the EP value achieved for DEM.

As proposed by Carvalho and Silva (2018) for the all the mentioned DEM, a trending test based on student's t-test (Merchant, 1982) was applied after the data normality analysis using the Shapiro-Wilk method. The trend test is based on the hypothesis test on the mean and the standard deviation of the residuals observed in each of the altimetric measurements. The analysis consists in verifying whether the average of the discrepancies (difference between the altimetric study value extracted from the DEM and the same one obtained in the field) can be considered equal to zero (Carvalho and Silva, 2018).

We also performed a second analysis, proposed by the same authors, regarding the accuracy of the data. This analysis was based on comparing the standard deviation of the sample with the standard error predicted in the PEC decree. For this, a test of variance comparison was used, using the chi-square distribution in which the value of σ_x^2 was taken to be equal to the standard error (EP) of PEC, predicted in the decree, according to the scale with a significance level of 5% two-tailed (Carvalho and Silva, 2018).

The quality analysis was also constructed with an altimetric profile, with distinct relief and vegetation patterns (flat and rugged) in order to evaluate the altimetric patterns with major discrepancies. For this procedure, an altimetric profile was drawn (Figure 1) and later converted to control points, according to the spatial resolution of each DEM. Then, the DEM was converted to orthometric height using the MAPGEO2015 model to standardize the profiles (IBGE, 2019). In this case it was decided to correct them using MAPGEO2015 to evaluate the data with better accuracy. The profiles were then compared and analyzed.

Results and Discussion

The analyses were performed with the purpose of understanding and evaluating the quality of the AW3D Standard and Sentinel-1. Figure 3 shows the 6 relief classes in a zoom on a portion of the analyzed territory to visualized characteristics of the different DEM. The standard AW3D, for example, is capable of presenting more details on the terrain surface, while the DEM from

Sentinel-1 SAR data presents a smoothed pattern. Such differences may be resulted from the type of data acquisition, processing type or the scale of work. Visually, the ASTER GDEM has a noisy aspect, mainly in smooth relief or smooth-wavy relief.

In statistical analyses, it is important to note that the techniques used for validation, that is the punctual reference data (geodetic control points), were acquired from the ground. However, the images evaluated came from the DSM, so the analysis of precision and accuracy does not consider the quality for variability caused by local vegetation or other types of structures on the surface. First, for a descriptive analysis of the sampling elements by RMSE, a boxplot was generated from AW3D, Sentinel-1 and other DEMs (Figure 4).

According to Figure 4, which indicates the variability of data between the upper and lower quartiles, the degree of data dispersion and outliers are observed by the spaces between the different quartiles. Regarding the normality test, Shapiro Wilk test, only the DEM generated by Sentinel-1 presented behavior that was out of normal, so for this case, the trend and accuracy analysis may be wrong, according to Carvalho and Silva (2018).

It is evident, from Figure 4, that the smallest discrepancy between data was observed in the AW3D Standard, followed by DEM ALOS PRISM and ALOS PALSAR. It should be noted that DEM ALOS PRISM is a by-product generated from the AW3D Standard resampling (Takaku and Tadono, 2017). Regarding Sentinel-1, the discrepancies were primarily negative and with high values, similar to those obtained by the DEM ASTER GDEM 2 and SRTM. A few outliers represented by vertical strokes in the lower part of the figure were observed in the DEM SRTM, ASTER GDEM 2 and ALOS PALSAR. Maybe these outliers refer the noise presence in some pixels, that normally are corrected by fill techniques.

Table 3 shows the descriptive statistical for each DEM. According table 3 the study area provided a height variation of 400 meter, approximately. It is important to note that the analyzes considered the differences in degrees of freedom for the DEM created from SENTINEL-1 and AW3D standard, due to the differences between sizes of the study areas. The average discrepancy shows that the greatest values were observed for the product DEM Sentinel-1. According Nikolakopoulos et al. (2015) the accuracy of the DEM that is achieved using only

one interferometric pair is usually low. So, the results could have been better if other interferometric pairs had been inserted in the model. About the standard deviation of discrepancies were greatest for ASTER GDEM 2 reinforced the presence of noise in data. For

González-Moradas and Viveen (2020) the ASTER GDEM2 showed a much larger variance in differential elevation values when compared with other models.

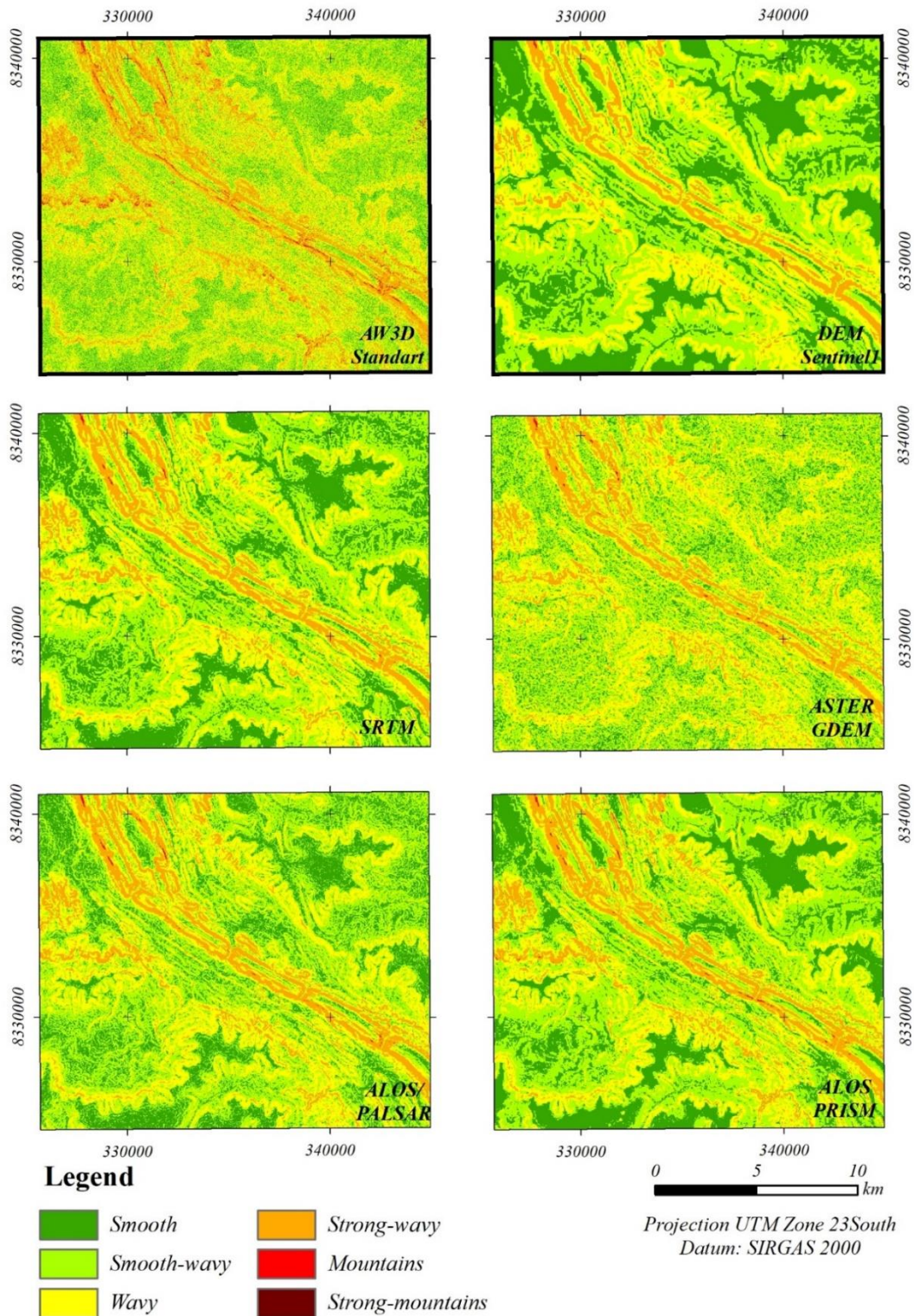


Figure 3: Relief classes (Embrapa, 1979) of the different DEMs analyzed in the region highlighted in red in figure 1.

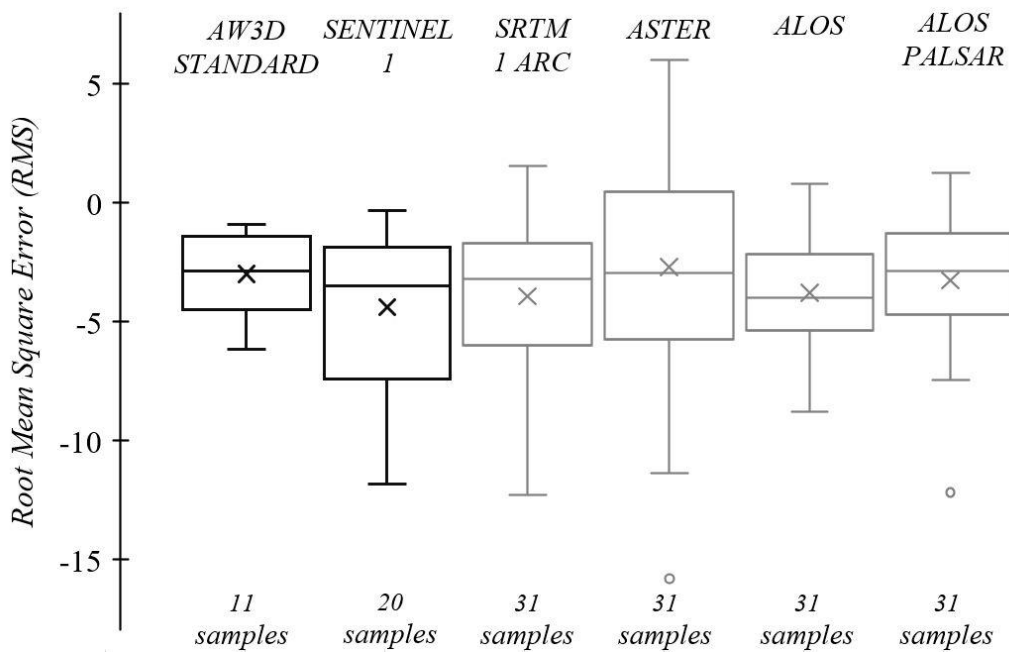


Figure 4: RMSE extracted by the DEM. Crosses represent averages and numbers in the axis X are the numbers of control points obtained for each DEM. Source: Author.

The least RMSE and standard deviation was observed to AW3D standard, which can indicate, the best data quality. Although the number of degrees of freedom could be insufficient for conclusive analyzes.

The evaluation of the PEC-PCD takes place in two steps. Firstly, we calculate the RMSE for each DEM and compare it with the standard error (EP) to the scale of interest. The RMSE of the models can be viewed in table 3. We verified by this criterion that all DEM meet the scale of 1:50,000, class B. Thus, all the computed PEC was lower than 10 m and RMSE lower than 6.66.

For illustrate the Figure 5 presents the values obtained for the altimetric PEC-PCD and the limit by EP for the categories (A, B, D and D) for the 1:100,000, 1:50,000 and 1:25,000 scales. Evaluating the figure, it is noticeable that the results of all analyzed DEM are classified as class A for the scale of 1:100,000 and class B for the scale of 1:50,000. For a small difference, the standard AW3D product did not fit into the PEC A 1:50,000 category (indicated by the arrow). Mishra et al. (2018) obtained 3.55 m of vertical RMSE for the built-up class for the AW3D5. The author compared this RMSE with the single-story high structures often seen in residential areas. This value was very similar with this work with 3.59 m. Therefore, these products and their derivatives can be used at these scales as well as intermediate scales between them. This type of scale is

applicable for world and regional scale maps; in this case, the generation of contour lines, earthquake, flood inundation modeling, automated drainage network extraction and surface creation can be employed (Yamazaki et al., 2017; Mishra et al., 2018).

For the 1:25,000 scale, the DEM AW3D Standard was rated as class C. While the DEM Sentinel-1 was rated as PEC D from the 1:25,000 scale, because the EP values were higher than the standardized. It is noteworthy that this category and situation was the same as the products SRTM 1 arc and ASTER. For the ALOS PRISM and ALOS PALSAR products, a slight improvement was observed in terms of accuracy, as these products, despite meeting PEC D for the 1:25,000 scale, however the EP values were lower than the standardized. This scale is used for regional and local aspects.

Due to the simplicity and deficiency of the analyses proposed for the PEC and PEC-PCD, there are several tests reported in the literature that have been employed to complement them in order to verify trends and evaluate the accuracy of the sample data more objectively (Carvalho and Silva, 2018). In this case, according to the results, the trend test was applied, in which it is possible to infer that there is a direct tendency in the RMSE of all DEM data, because the calculated values for products, in module, were higher than the tabulated value. We refute the hypothesis that the sample

mean is equal to the population mean and accept the alternative hypothesis, that the mean of sample discrepancies is different from zero. In this case, it can be affirmed the presence of a systematic error,

possibly linked to failures caused by technical and environmental conditions. Inaccuracies may also be associated with the attitude and configuration of the satellite at the time of data acquisition.

Table 3: Mapping accuracy standard for digital mapping products (PEC-PCD) values for scales 1: 25,000, 1: 50,000 and 1: 100,000. Standard error (EP).

PRODUCTS	SRTM 1 ARC	ASTER GDEM 2	DEM SENTINEL 1A	ALOS PRISM	ALOS PALSAR	AW3D STANDARD (AW3D5)
Degrees of Freedom (n-1)	30	30	19	30	30	10
Minimum (H)	549.5	540	550.35	545.75	549.33	646,32
Maximum (H)	959	959	958.02	961	957.08	957,42
Average discrepancy	-3.94	-2.70	-4.39	-3.80	-3.28	-3.0
Standard deviation	3.01	4.90	3.40	2.21	2.89	1.73
RMSE*	5.01	5.63	5.65	4.45	4.41	3.59
Computed PEC	8.24	9.25	9.29	7.32	7.25	5.90
PEC-PCD – 1:50,000	B	B	B	B	B	B
Percentage (%) of points showing discrepancies below the PEC-PCD*	100%	96%	100%	100%	100%	100%
Calculated T	-7.29	-3.07	-5.76	-9.55	-6.3	-5.74
Reference T	2.0423	2.0423	2.093	2.0423	2.0423	2.2281
Trend Analysis Result	Trendy	Trendy	Trendy	Trendy	Trendy	Trendy
Calculated Chi-square	32.65	86.75	26.48	17.66	30.16	2.59
Reference Chi-square	43.773	43.773	30.144	43.773	43.773	18.307
Precision Analysis Result	Need	Need	Need	Need	Need	Need

*Below the reference value of PECB 1: 50,000 of 10 m and below the reference value of EP equal to 6.66 m

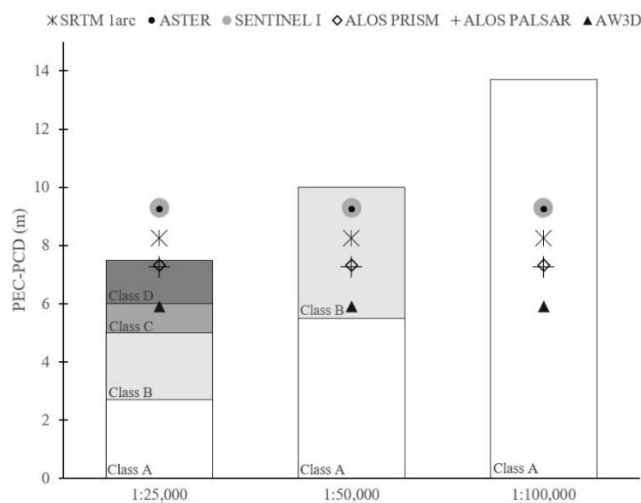


Figure 5: Adequacy of the analyzed DEMs to the PEC-PCD.

Regarding the precision analysis, the chi-square test compared the standard deviation of the sample with the standard error predicted in the PEC decree. Precision tests showed that data can be considered accurate for scales greater than 1:50,000, and for this scale, class A had a positive result for accuracy. For larger scales, replication of the test is suggested because for the present work, we chose to use the analog PEC category in which the data obtained class A, that is 1:50,000 (Table 3).

Another possible discussion point regards pixel size because the reference elements acquired by spatial geodesy have a positional error inherent in the data of millimeters. DEMs work with a pixel size that varies from 5 to 30 m. This means that the reference data have a scale that is incompatible with the analyzed data, which may hinder trend and accuracy analyses (Satgé et al., 2015).

In order to observe trends and discrepancies as a function of geomorphological variations, the DEM AW3D Standard and Sentinel-1 were compared with other DEMs (Figure 6). Digital topographic models produced from satellite images can have a direct influence on the geometry of data acquisition by the sensor and the topography of the terrain.

It is clear that the DEM Sentinel-1 presented smoothed features as a result of pre-processing to reduce noise. The DEM AW3D Standard had a noisier appearance, which may be due to higher spatial resolution or greater interference from vegetation because this model is a product resulting from stereoscopy.

From the data presented in Figure 6B, it was evident that flat areas with little vegetation showed lower variability between the DEM heights. However, regions with rugged relief or dense vegetation can make a greater distinction between values obtained by DEM from radar data and optical sensors (Figure 6C). ASTER data was the noisiest in the entire profile. AW3D Standard was able to detect details of winding terrain not visible in the other models.

These results highlight the need to establish appropriate sampling schemes for the quantification and distribution of the sampling

elements (geodetic control points), aiming at a data quality analysis that incorporates all geomorphological specificities in the case of DTM generation. Another point to consider is the way of preprocessing the DEM. The literature proposes many tools for correction of imperfections and noise removal not applied in this research.

Regarding Sentinel-1 data processing, it is important to note that data processing does not yet present a trivial solution for the generation of DEMs since data processing requires high-capacity hardware.

Conclusions

Although AW3D has better altimetric accuracy with lower average error and standard deviation, it is still a costly solution as fees for accessing the product are required. It may be indicated for the elaboration of products on the scale of 1:25,000, altimetric PEC-PCD C.

Sentinel-1 processing yielded an altimetric quality DEM similar to SRTM and ALOS PRISM and lower than ALOS PALSAR. Given the processing steps and the need for powerful hardware, such a solution becomes impractical.

The ALOS PALSAR and ALOS PRISM products, although fitting in category PEC B, 1:50,000 showed lower RMSE and standard deviation in results when compared with ASTER and SRTM.

The fact that MAPGEO 2015 achieves geoidal undulation (N) only on point data limits the conversion of full DEM to better orthometric heights, causing users to continue to manipulate the DEM in the EGM96 global geoidal model.

Despite being a national regulation, PEC-PCD is a method that needs improvements for quality analysis of the DEM. Mainly because it does not consider inherent aspects of data with continuous variation. A recurring problem would be the lack of pattern in the distribution of the sampling elements in different relief types and the quantification of the points, especially in a number of sampling elements able to represent the population in a sample.

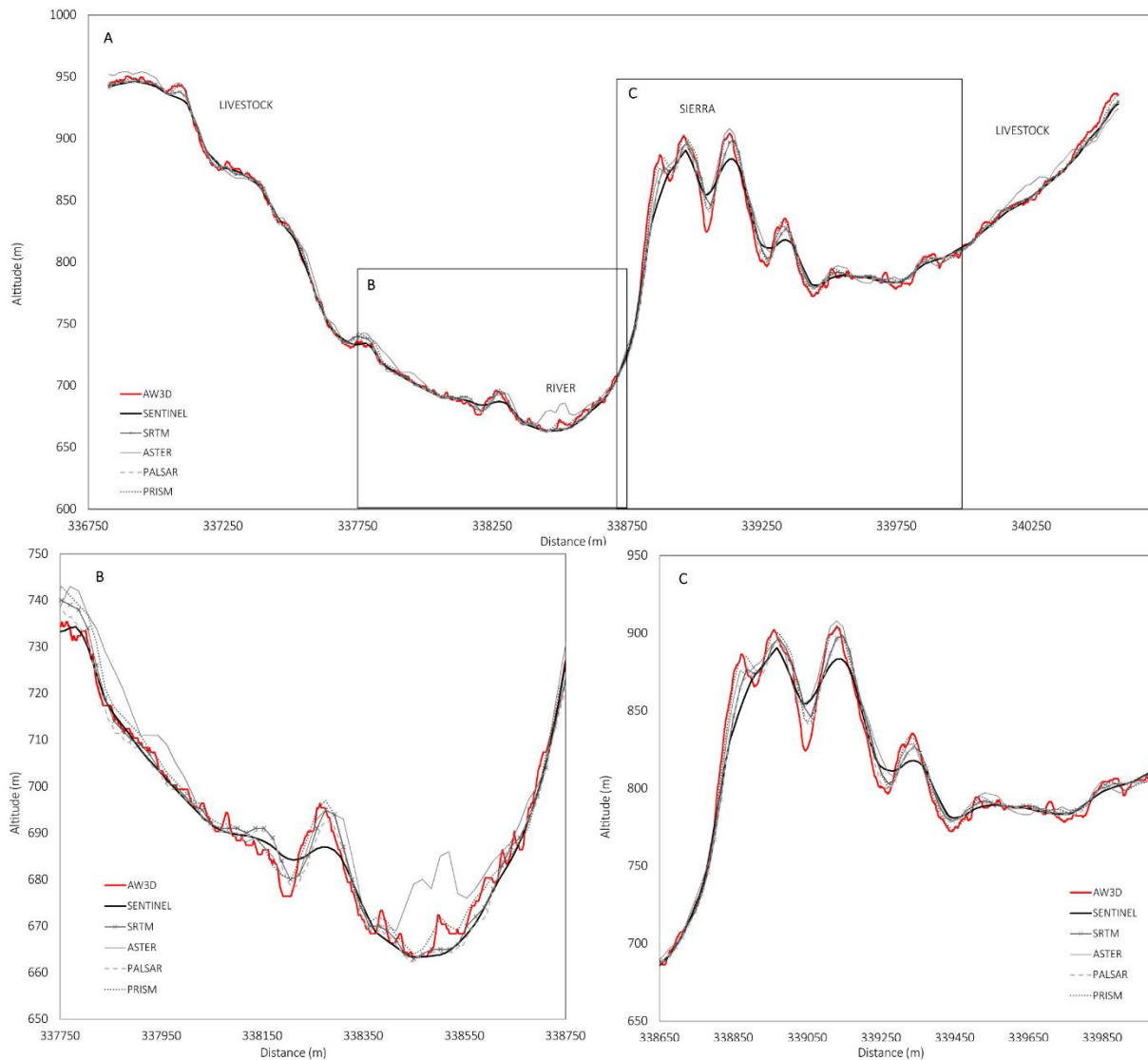


Figure 6: DEM altimetric profiles (Figure 1) highlighting AW3D Standard (red line) and Sentinel-1 (black line). A: Zoom in to a flatter relief region. B and C: Zoom in to a rugged relief region.

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