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ORIGINAL ARTICLE

Cartographic Accuracy Standard (CAS) of the digital terrain model of the digital and continuous cartographic base of the state of Amapá: case study in the city of Macapá

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Abstract:

The Cartographic Accuracy Standard (CAS) is a quality parameter used by the Brazilian standard to estimate the positional quality of cartographic products in their degree of precision, also including altimetry. The Digital and Continuous Cartographic Base of Amapá - BCDCA has a large amount of freely available spatial information, for the study of its territory within the state of Amapá. This project, a partnership between the Government of the State of Amapá and the Directorate of Geographical Services of the Brazilian Army (DSG), obtained a large amount of SAR data by interferometry. Among the resulting products, the Digital Terrain Model - DTM has a wide range of applications: watershed analysis, infrastructure program, diagnosis of environmental risks and so many others. Therefore, the present work aims to evaluate the altimetric data (DTM) provided by the BCDCA through 2172 orthometric points calculated from the Brazilian Network for Continuous Monitoring – RBMC measured in the field in the city of Macapá, capital of the State of Amapá. For the level curves, the results presented class A for the 1: 10 000 scale, at an equidistance of 5 m, showing that the DTM product is highly reliable for urban applications.

Keywords: CAS; DTM; Cartographic base; Macapá; RBMC.

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1. Introduction

Due to the advancement of technology, the use of digital elevation models elaborated from SAR (Synthetic Aperture Radar) data has become widespread and used in various fields of science and many of them are freely available.

It is possible to cite as examples; the global model of the SRTM mission (Shuttle Radar Topography Mission) provided by the United States Space Agency - NASA (National Aeronautics and Space Administration), the model provided by INPE (National Institute for Space Research / Brazil) through the Topodata platform and the model MDE – Ar supplied by the National Space Activities Commission of Argentina (CONAE).

Good examples of quality control tests involving these products are reported in Callahanand Berber (2022), Alba-Fernández (2021), Ariza-López and Reinoso-Gordo (2021), Rodríguez-Avi (2021), Ariza-López et al. (2017), Ariza-López and Chicaiza Mora (2018), Boulomytis et al. (2017), Egg et al. (2013), Ferreira (2014), França et al. (2019), Mesa-Mingorance et al. (2017), Mesa-Mingorance; Ariza-López (2020), Morais (2017), Morais et al. (2017), Mozas-Calvache et al. (2017), Orlandi et al. (2019), Polidori et al. (2014), Santos et al. (2016), Scalco et al. (2018), among others.

On the other hand, a project of the Government of the State of Amapá in partnership with the Directorate of Geographical Services of the Brazilian Army (DSG) has been producing a large volume of information through SAR sensors. This project was called Continuous Digital Cartographic Base of Amapá (BCDCA). The State of Amapá has little information about its own territorial limits, that is, there is a “cartographic void” mainly of its conservation areas destined to environmental protection (Santos Filho and Oliveira, 2019).

For this, the state and federal government has carried out air flights with radar sensor on board in the X and P bands, since October 2014. The end of the measurement campaign was in December 2017, where were delivered to the Government of the State of Amapá, among others, the following products: digital surface models (MDS) generated by the X band and digital terrain models (DTM) originated by band P (Ministry of Defense, 2017).

In this work, the quality of the DTM in the P band of the BCDCA is evaluated and its application at different scales in the urban perimeter of the city of Macapá, capital of the State of Amapá, taking as a reference 2172 points with orthometric altitudes transported and calculated from the geodetic network of the Amapá.

According to Menezes et al. (2012), traditional topographic models, generally costly and using more specialized equipment, have given way to more automated methods that jointly employ the Global Positioning System (GPS) and synthetic aperture radar interferometry (InSAR).

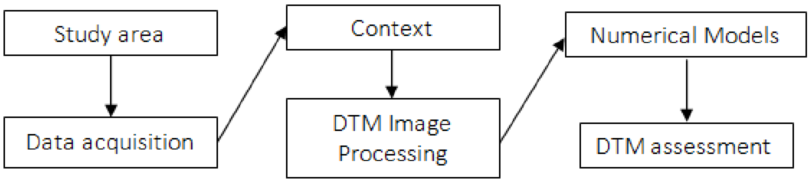
Amplitude and phase images can be generated from these RADAR signals, saved as complex images (Single look complex - SLC). With these representations, the interferometric pair is obtained and then, with the InSAR technique, a new image is generated, where the phase of each pixel is formed by the phase difference between the pixels of the two images. With knowledge of image acquisition geometry and InSAR techniques, it is possible to convert the phase difference into altitude (Hanssen, 2010).

It is worth highlighting the excellent response of radar products in the Amazon region, especially in dense and cloud-covered forest regions, such as in the State of Amapá, since they provide complementary data to optical satellite images that present greater limitations in these areas (De Oliveira and Paradella, 2008; Montalvão, 2019 and Salgado, 2019).

Therefore, the evaluation and validation of altimetric data provided by DTMs is a benefit in the study region, since this technology can be applied with a high degree of reliability to different areas of knowledge.

2. Material and method

For the evaluation of the DTM of the Continuous Digital Cartographic Base of Amapá (BCDCA), the methodological procedures detailed in the steps were followed: delimitation of the study area, acquisition of the DTM, the contextualization of data acquisition (altitudes and geoid model), processing of the image and generation of the Numerical Terrain Model (NTM) and evaluation of the generated inputs (Figure 1).



Source: The authors.

Figure 1: Flowchart of the steps of the procedures adopted.

2.1 Delimitation of the Study Area

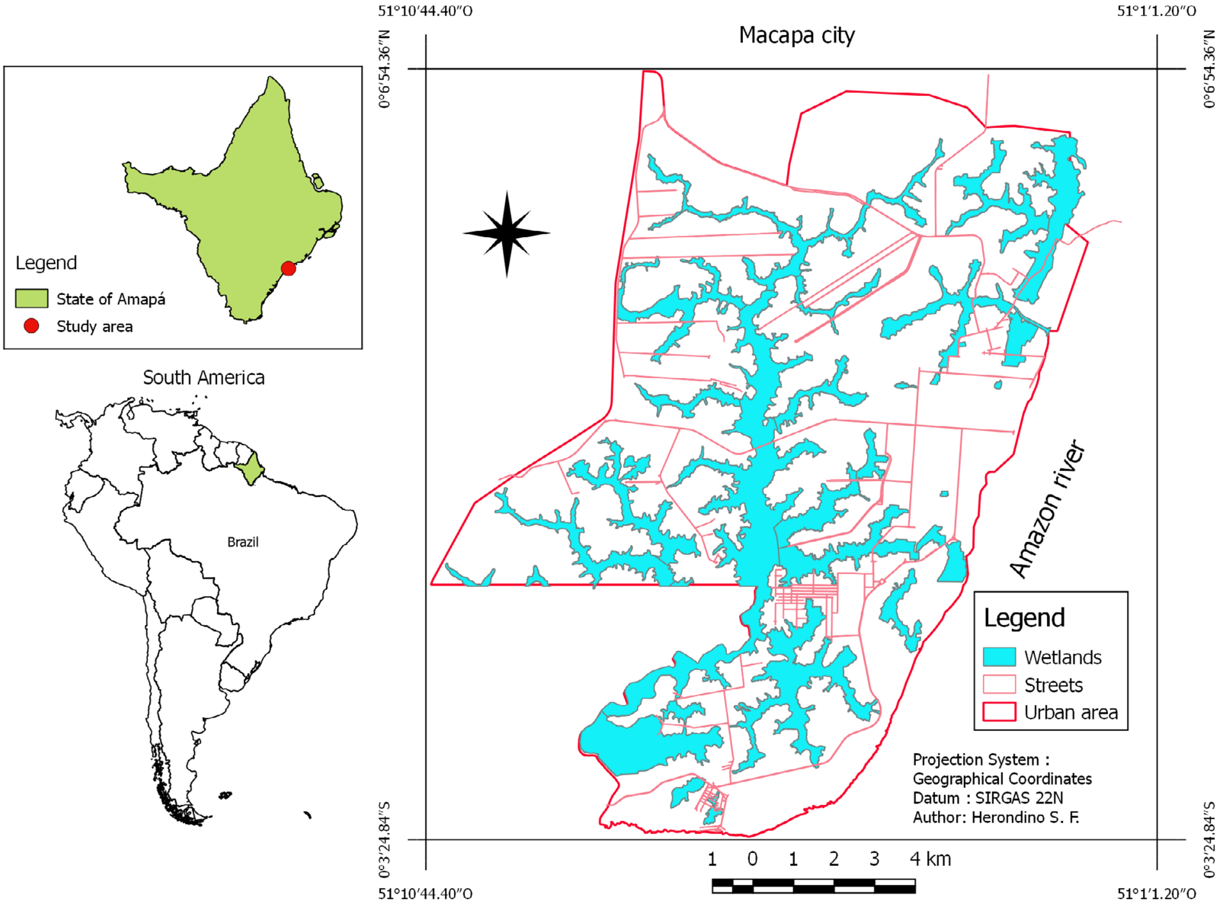
The study area of this work is the urban perimeter of the city of Macapá, capital of the State of Amapá. It is the only capital in the country crossed by the equator. At the same time, it is important to highlight the physiographic characteristics of this capital, located on the banks of the Amazon River, where the low altitude presents itself for its high environmental value wetlands.

These wetlands are part of a complex hydrographic basin within its urban perimeter. They are locally called “hangovers” (Figure 2).

According to Santos Filho (2011), the undertow covers about 20% of the urban perimeter of the city of Macapá. The city is located on the plain at the headwaters of the Amazon River, so it is subject to tidal action.

As a result, it is common that flooding occur during the rainy season and spring tides, especially in low-altitude areas such as “hangovers”. This further denotes the importance of evaluating altimetric data such as the one carried out in this study (Vaze et al., 2010).

Furthermore, in these wetlands, many immigrants, mainly from other states, find “free” space to build their homes. The lack of inspection by the responsible authorities, as well as the absence of social discussion, contributes to its degradation. Therefore, the understanding of its rise in relation to sea level must be a constant concern, especially in the public sector, for resilient and mitigating actions in socio-environmental areas (Santos Filho, 2011). Accurate altimetric numerical modeling of the city’s urban perimeter can enable planning that provides answers in case of environmental disasters and decision-making.



Source: The authors.

Figure 2: Location of the study area – City of Macapá – Amapá.

2.2 Acquisition of DTM

The representative product of the Digital Terrain Model (DTM) was obtained by free distribution carried out by the State Secretariat for the Environment - SEMA / AP. They were acquired in accordance with the technical specifications in BCDCA's own files, that is, in the UTM / Zone 22 projection system, SIRGAS 2000, in TIF format. Other information about the SAR product is shown in Table 1.

Table 1: Technical specifications of the SAR image.

Description	Specification
Product scale	1:25 000
DTM pixel dimension (m)	2.5 m x 2.5 m
Superposition of lines in Range	>= 66%
Superposition of lines in Azimuth	>=5 km
Swath	14 km
Flight height	19 000 to 25 000 ft
Average speed	360 km / h
Radiometry of the digital model	32 bits
P-band resolution	2.5 m
Maximum length of flight line	<=220 km
DTM Altimetric Accuracy (P Band)	In open areas: standard deviation 3.33 m (Class A for scale 1: 25 000, according to the old CAS). In areas with dense vegetation: standard deviation 4.56 m (Class C for scale 1: 25 000, according to the old CAS).
DTM Planimetric Accuracy	<= 7.5 m PEC class A
Geoid	MAPGEO 2010
Horizontal Datum	SIRGAS 2000
Projection	UTM

Source: BCDCA

In the technical specifications of the image contained in the BCDCA data, it does not inform about the vertical datum for this scale, although in the products of scale 1: 50 000 the reference shows the vertical datum of Imbituba-Sc.

In addition, it is worth noting that the State of Amapá has its own altimetric network, with 481 points of geodetic stations with an altitude value referred to the mean sea level (Level Reference – RN). This network is not connected to the rest of the Brazilian altimetric network (datum Imbituba, reference origin in Santa Catarina), due to the impossibility of crossing the Amazon River with the geometric leveling technique.

The Amapá geodetic network is based on the Santana datum and was implemented in the early 1980s (Pereira and Silva 2013). In other words, in Brazil there are officially two altimetric *datums*: Imbituba–SC and Santana–AP (Paranhos et al. 2021; Santana and Dalazoana 2020).

These two networks are part of the Vertical Reference Network of Brazil - RVRB, where aspects still remain to be overcome to obtain their link to a global altitude system, unifying the two networks (Santacruz Jaramillo and Freitas 2021).

Thus, two fundamental concepts are addressed to understand the context of the data under study: geometric altitude and physical altitude.

2.3 Ellipsoidal altitude and physical altitude

The ellipsoidal altitude (h) – also called geometric – is purely mathematical, and it is measured along the normal between the reference ellipsoid and the point of interest. When coordinates are represented on the surface of the ellipsoid, they are also called geodesics, and they are quickly achieved through GNSS positioning receivers. Furthermore, they are not related to the terrestrial gravity field (IBGE, 2017).

On the other hand, physical altitudes are linked with the Earth's gravity field. Naturally, mean sea level (MMN) is taken as a vertical reference for geodetic networks around the world, as the seas are apparently subject to the force of gravity. However, it is not enough for its modeling, as it involves other variables such as the mean sea level topography (MSLT) (Luz, 2016).

Thus, there are three types of altitudes mentioned by the norms of the Brazilian geodetic survey regarding the modeling of its physical altitude: orthometric, normal and orthometric-normal (IBGE, 2019).

The orthometric altitude (H) uses the so-called geopotential number (C), defined as the difference between the geopotentials from the geoid to the observed point, which in turn is divided by the average value of the actual gravity observed in this path (g^{vert}), that is, given by the Equation (IBGE, 2017):

$$H = \frac{C}{g^{vert}} \tag{1}$$

As it is generally impossible to know the mean vertical gravity of the interior of the Earth's crust, it is also difficult to know the orthometric altitude with exactitude.

The normal altitude (H^N) also uses geopotential differences (C) and its normal altitude refers to the quasi-geoid. Since its denominator is the average value of normal gravity (γ^{vert}), that is, given by (IBGE, 2019):

$$H^N = \frac{C}{\gamma^{vert}} \tag{2}$$

Orthometric-normal or normal-orthometric (H^{NO}) altitude uses normal gravity values and considers them in the calculation of normal geopotential differences (ΔC^N) (IBGE, 2017) as,

$$\Delta C^N = \Delta H^{NO}{}_{12} \cdot (\gamma_1 \cdot \gamma_2)/2 \tag{3}$$

In practice, they are calculated from the unevenness resulting from the geometric leveling (ΔH^{NO}) and the mean values of the observed gravity (γ) in the leveling section.

The orthometric-normal altitude was formally used by the Brazilian government until July 30, 2018, being provided by the Brazilian Geodetic System to its users through level references (LR) (IBGE, 2019). The data analyzed in this study were acquired from October 7, 2013, to January 20, 2014, from the level references (LR), that is, they are orthometric-normal data.

After July 2018, as of the disclosure of the readjustment of the altimetric network, the IBGE Geodetic Database has presented normal altitudes to its users, following guidelines from the Geocentric Reference System for the Americas – SIRGAS (IBGE, 2019).

On the other hand, the relationship between the physical altitudes can be made from the geometrical altitudes through the geoid undulation models.

2.4 Geoid model

The relationship between the geoid undulation model - also called geoid altitude (N) - with the geometric (h) and orthometric-normal (H^{NO}) altitude is possible through the formulation:

$$N = h - H^{NO} \tag{4}$$

MAPGEO2010 has been the official geoid undulation model in Brazil since 2010 (Blitzkow et al., 2016). From any latitude and longitude coordinates, MAPGEO2010 can find the value of the geoid height (N) at this point.

For the elaboration of this geoid model, the association of geodetic (ellipsoidal) and orthometric-normal altitudes, here called orthometric, was performed (Matos et al., 2012).

MAPGEO2015 was an update of the Brazilian geoid model. In this model, new surveys were carried out, and new technologies were used, such as gravity information from LAGEOS (Laser Geodynamics Satellite), GRACE (Gravity Recovery and Climate Experiment) and GOCE (Gravity Field and Steady-State Ocean Circulation Explorer) satellites (Blitzkow et al., 2016).

From the readjustment of the Altimetric Network with geopotential numbers in 2018 (Realt2018), a new almost geoid model was created that allows the relationship between ellipsoidal and normal altitudes. For this readjustment, the observed and interpolated values of severity in the LR were considered to calculate the geopotential differences. MAPGEO2015 also served as the basis for the development of the current model. The most current model is called hgeoHNOR2020 (IBGE, 2021).

As in the 2015 model (MAPGEO2015), from the latitude and longitude coordinates it is possible to obtain the conversion factor (η). This factor allows finding, from GNSS measurements, the normal altitudes modeled according to the formula (IBGE, 2021):

$$H^{N} = h - \eta \tag{5}$$

2.5 Image processing and numerical model generation

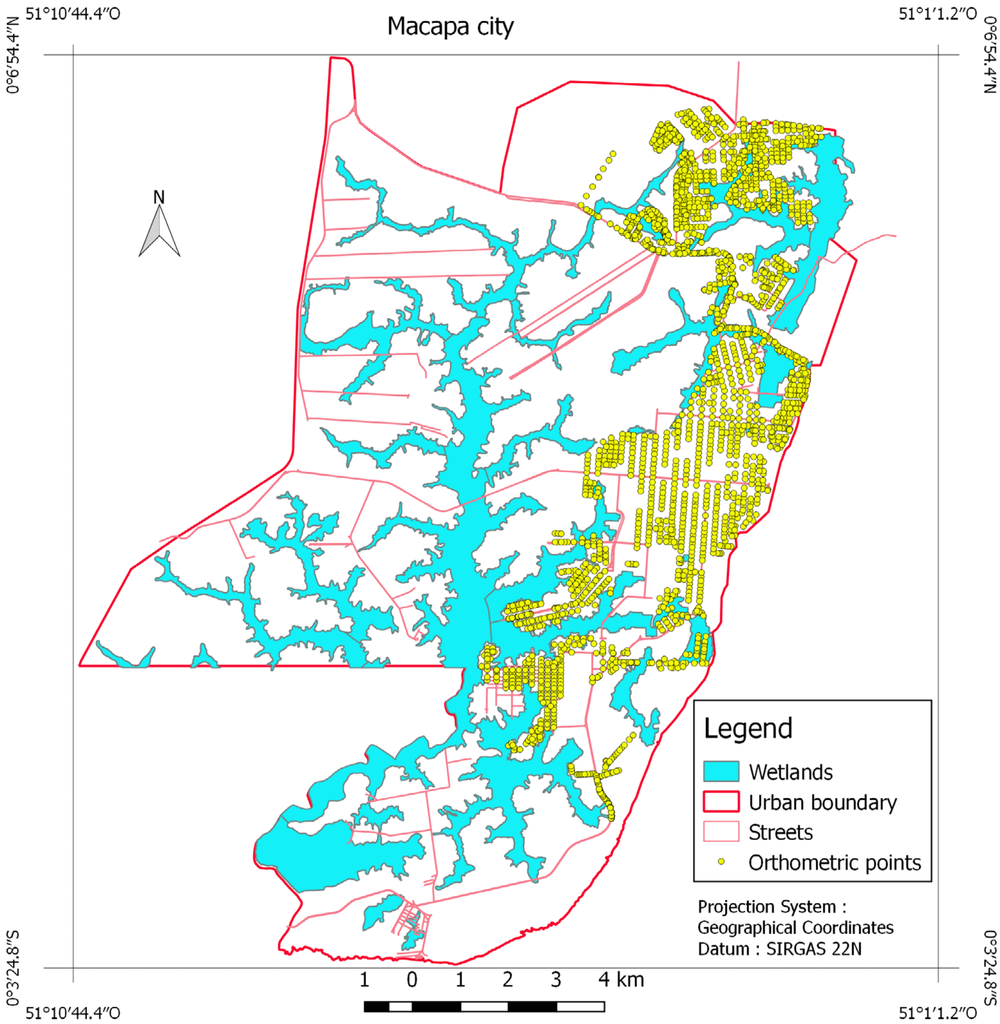
As for its processing, four DTM images at scale 1: 25 000 with a spatial resolution of 2.5 m from the BCDCA, according to the technical specifications observed in Table 1, were used to generate a mosaic using the nearest neighbor technique. This technique was used because the study area is in two hemispheres, that is, it is cut by the equator, and its images must be referenced for a single projection. This procedure showed no change in the DTM model.

The conversion of 2172 orthometric points transported from the RBMC (reference to the Santana datum) from the .dwg (CAD) format to the .shp (shapefile) format was also performed, with the help of ArcGIS version 10.1. The use of this GIS was restricted to this purpose only. For the other tasks developed in this work, QGIS was used. For example, level curves were generated in QGIS from its “contours” option.

In this way, using the Point Sampling Tool complement developed for Qgis (QGIS Org., 2020), it was possible to obtain the coordinates of the 2172 orthometric points referenced to the RBMC, in the orthometric points of the altitudes of the BCDCA represented by the mosaic of DTM images, establishing in the same way the relationship between the two sets of points by their coordinates.

2.6 DTM Assessment

To study the reliability of the product of the cartographic base, the Digital Terrain Model in its orthometric component was compared with, 2172 orthometric points of road crossings transported and calculated from the Brazilian Network for Continuous Monitoring - RBMC, vertical datum of Santana-AP (Figure 3).



Source: The authors.

Figure 3: Points with orthometric altitude referred to the Santana-AP vertical datum adjusted to the Brazilian Network for Continuous Monitoring – BNCM.

The orthometric points were obtained by the topographic company Amacol LTDA, by transporting the heights of the IBGE level reference points (LR) to the place of interest, using a Leica NA724 level (accuracy of 2.5 mm / km in leveling and counter-levelling) and two Leica Sprinter 150M levels (accuracy 1.5 mm / km in double levelling).

The coordinates of the DTM related to the homologous points of the RBMC were obtained using the Point Sampling Tool.

In the evaluation of the DTM, the representation of its vertical height was directly compared with the height of the orthometric points transported from the RBMC through statistical analysis using the following parameters: Pearson's coefficient [R], coefficient of determination [R^2], mean error (ME), mean percentage error (MPE), mean squared error (MSE), standard error (SE) and the Cartographic Accuracy Standard – CAS.

It is important to mention that the square of Pearson's correlation (R^2) is called the coefficient of determination and is also used as a measure of correlation (Currell and Dowman, 2009).

The mean square error is given by Eq. (6):

$$MSE = \frac{\sum_{i=1}^{N} (y_i - \hat{y}_i)^2}{N-2} \quad (6)$$

where N is the number of observations subtracted from the degrees of freedom, y_i the real response and $\hat{y}_i$ the estimated response of the observations.

Statistics R version 4.0.2 was used as a tool to perform calculations and statistical graphics.

2.6 Cartographic Accuracy Standard (CAS)

The Cartographic Accuracy Standard was established by Decree 89 817 of June 20, 1984 of the Brazilian government (Presidency of the Republic, 1984). According to the Geographical Service Directorate - DSG of Brazil (Ministry of Defense, 2016), the Cartographic Accuracy Standard is an indicator of statistical dispersion, relative to a 90% probability, which defines the accuracy of cartographic works, also referred to by Santos Filho and Oliveira (2019), Sampaio (2018) and Ariza-López et al. (2017).

In the Decree (Presidency of the Republic, 1984) the probability is 90% corresponding to 1.6449 times the standard error (SE), Eq. (7):

$$CAS_{FOUND} = 1.6449 \times SE \quad (7)$$

The values to be evaluated must be compared with the data in Tables 2 or 3, as the case may be, taking into account that the CAS found must be smaller than the tabulated CAS, that is, according to Eq. (8):

$$CAS_{\mathrm{FOUND}} < CAS_{\mathrm{TABLE}} \quad (8)$$

Table 2: Cartographic Accuracy Standard of altimetry (contour lines) of Digital Cartographic Products.

CAS-DCS		A	B	C	D
1 : 1000 (Eqd=1 m)	CAS (m) SE (m)	0.50 0.33	0.60 0.40	0.75 0.50	1.00 0.60
1 : 2000 (Eqd=1 m)	CAS (m) SE (m)	0.50 0.33	0.60 0.40	0.75 0.50	1.00 0.60
1 : 5000 (Eqd=2 m)	CAS (m) SE (m)	1.00 0.67	1.20 0.80	1.50 1.00	2.00 1.20
1 : 10 000 (Eqd=5 m)	CAS (m) SE (m)	2.50 1.67	3.00 2.00	3.75 2.50	5.00 3.00
1 : 25 000 (Eqd=10 m)	CAS (m) SE (m)	5.00 3.33	6.00 4.00	7.50 5.00	10.00 6.00
1 : 50 000 (Eqd=20 m)	CAS (m) SE (m)	10.00 6.67	12.00 8.00	15.00 10.00	20.00 12.00
1 : 100 000 (Eqd=50 m)	CAS (m) SE (m)	25.00 16.67	30.00 20.00	37.50 25.00	50.00 30.00
1 : 250 000 (Eqd=100 m)	CAS (m) SE (m)	50.00 33.33	60.00 40.00	75.00 50.00	100.00 60.00

Source: Ministry of Defense (2016).

Table 2 presents the technical specifications of the altimetry data that show the equidistance between the level curves and the respective values calculated from the Cartographic Accuracy Standard of altimetry, for their corresponding classes A, B and C, according to the Decree 89 817 (Presidency of the Republic, 1984). At the same time, Table 2 refers to the values of the Cartographic Accuracy Standard of Digital Cartographic Standard (CAS-DCS, originally in Portuguese, *ET-CQDG, Especificação Técnica - Controle de Qualidade de Dados Geoespaciais*) of altimetry, taken from the Technical Specification for Geospatial Data Set Products (Ministry of Defense, 2016).

For class D, its calculations differ given by 1 equidistance and 3/5 of the equidistance of the cartographic product, according to the Technical Specification for Geospatial Vector Data Acquisition for Land Force Defense - ET-ADGV Defense FT (Ministry of Defense, 2016).

The values presented in Table 2 describe the CAS values and their standard error (SE) for the large (1: 5 000 to 1: 50 000) and small (1: 100 000 and 1: 25 000) scales. Also, for projects (large scales, i.e. 1: 1000 and 1: 2000). Together they show their variability classes within each scale.

Likewise, Table 3 refers to the values of the Cartographic Accuracy Standard for Digital Cartographic Standard (CAS-DCS). For digital products produced from the publication of the ET-PCDG and to complement those established, for printed products, in Decree No. 89 817, of June 20, 1984 (Presidency of the Republic, 1984).

Table 3: Cartographic Accuracy Standard of altimetry of DTM, DEM and DSM points for the generation of digital cartographic products.

CAS-DCS		A	B	C	D
1 : 1000 (Eqd=1 m)	CAS (m) SE (m)	0.27 0.17	0.50 0.33	0.60 0.40	0.75 0.50
1 : 2000 (Eqd=1 m)	CAS (m) SE (m)	0.27 0.17	0.50 0.33	0.60 0.40	0.75 0.50
1 : 5000 (Eqd=2 m)	CAS (m) SE (m)	0.54 0.34	1.00 0.66	1.20 0.80	1.50 1.00
1 : 10 000 (Eqd=5 m)	CAS (m) SE (m)	1.35 0.84	2.50 1.67	3.00 2.00	3.75 2.50
1 : 25 000 (Eqd=10 m)	CAS (m) SE (m)	2.70 1.67	5.00 3.33	6.00 4.00	7.50 5.00
1 : 50 000 (Eqd=20 m)	CAS (m) SE (m)	5.50 3.33	10.00 6.66	12.00 8.00	15.00 10.00
1 : 100 000 (Eqd=50 m)	CAS (m) SE (m)	13.70 8.33	25.00 16.66	30.00 20.00	37.50 25.00
1 : 250 000 (Eqd=100 m)	CAS (m) SE (m)	27.00 16.67	50.00 33.33	60.00 40.00	75.00 50.00

Source: Ministry of Defense (2016).

The expected values for class A (CAS-DCS) are defined by Eq. (9):

$$CAS - DCS = 0.27 \times \text{Equidistance of the cartographic product} \quad (9)$$

and also its standard error (SE) is defined by Eq.(10):

$$SE = 1/6 \times \text{Equidistance of the cartographic product} \quad (10)$$

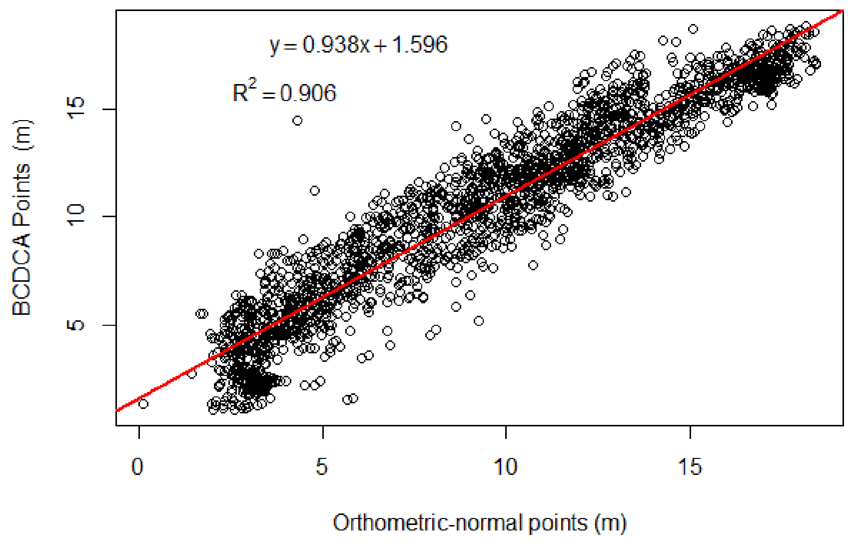
Classes B, C and D of the CAS-DCS correspond, in order, to classes A, B, C of the altimetric CAS provided for in Decree 89 817, of June 20, 1984 (Ministry of Defense, 2016).

3. Results

The results were analyzed in their orthometric-normal comparison and also by comparison from their conversion using the geoid models and conversion factor hgeoNOR2020.

3.1 Orthometric-Normal Altitude and the DTM Altitude

Figure 4 shows the correlation graph between the orthometric points transported from the RBMC with reference to the Santana-AP datum and the orthometric heights estimated from the cartographic base (BCDCA), resulting in a coefficient of determination R2 of 0.91, a value that indicates a very strong correlation between the two variables, that is, the height values of the cartographic base DTM are explained in 90.63% by the orthometric values derived from the level references.



Source: The authors.

Figure 4: Correlation between the orthometric-normal points derived from the LR (reference to the Santana-AP datum) and the orthometric height values of the Cartographic Base.

The statistical results showed a good adjustment of the DTM values of the Continuous Digital Cartographic Base of Amapá - BCDCA. Pearson's correlation reaches values of 0.95, presenting a high correlation, as shown in Table 4.

Table 4: Comparative statistical parameters between the orthometric-normal points derived from the LR and those from the orthometric height of the BCDCA.

Parameters	**Values**
Mean error	0.005
Mean Square Error	1.972
Mean percentage error	6.575
Pearson's coefficient	0.952
Determination coefficient	0.906
Standard Error (SE)	1.404

Source: The authors.

Furthermore, in the CAS assessment (2.31) found, the elevation class with reference to the level curves is in class A, equidistance 5 m, scale 1: 10 000, as shown in Table 5. This presents a large precision for works carried out on a large scale and in the domain of urban areas, being applied in the estimation of areas subject to flooding and identification of wetlands. These works are being carried out by Santos Filho (2021), Santos Filho et al. (2021a) and Santos Filho et al. (2021b).

Table 5: Class found in the elevation model for altimetry (contours) for a CAS = 2.31, SE=1.40 at an equidistance of 5 m.

Class	BCDCA
A	2.50
B	3.00
C	3.75

Source: The authors.

The BCDCA model presents for the altimetry of the orthometric-normal points and the DTM model for digital cartographic products Class A in scale 1: 25 000 and Class B in scale 1: 10 000 as shown in Table 6.

Table 6: CAS found for DTM altimetric model products for a CAS = 2.31, SE=1.40.

Class	Eqd = 5 m (1:10 000)	Eqd = 10 m (1:25 000)
A	1.35	2.70
B	2.50	5.00
C	3.00	6.00
D	3.75	7.50

Source: The authors.

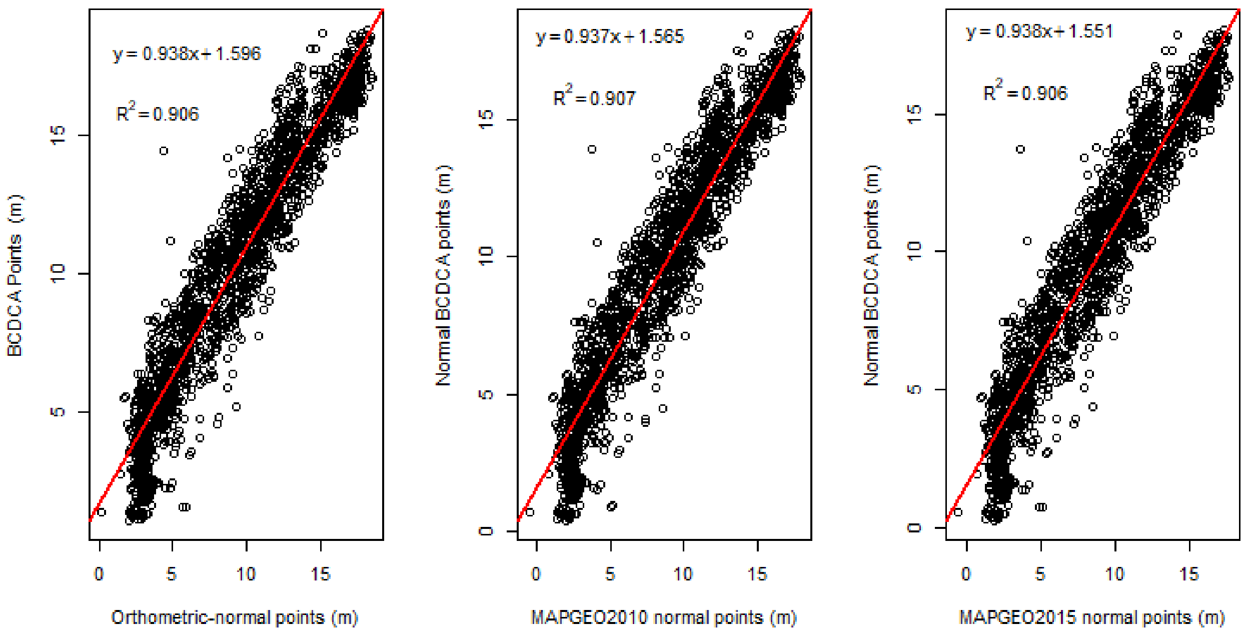
3.2 Orthometric-Normal Altitude vs. Normal Altitude

From the latitude and longitude coordinates, MAPGEO2010 allows finding the height value of the geoid at any point. In this way, the height of the geoid undulation (N) of the 2172 points was obtained. Adding this value to its normal-orthometric (H) altitude the ellipsoidal heights of the two sets of variables were found (Eq. 4). Then, with Equation (5), the normal altitude model was obtained. Likewise, the same procedure was performed for the MAPGEO2015 model, as shown in Figure 5.

The first correlation (graph on the left) shows the relationship between the normal orthometric points carried from the RBMC and the DTM points from the BCDCA. The following graphs (center and right) show the association of the same relationships using the hgeoHNOR2020 model through the conversion factor (η) in conjunction with the MAPGEO2010 and MAPGEO2015 geoid models.

Their linear equations are almost the same for the three models, with their coefficients only undergoing some change after their millesimal part. The same happens with the coefficient of determination, where the conversion hgeoHNOR2020 presented a small improvement when using the MAPGEO2010 model (Fig. 5 in the center).

It also occurs with its Pearson coefficients: 0.9519, 0.9524 and 0.9521 for their respective graphs, from left to right (Fig. 5).



Source: The authors.

Figure 5: Correlation between orthometric points transported from RBMC and points from DTM (BCDCA) and their normal conversion with MAPGEO2010 and MAPGEO2015.

Furthermore, applying the MAPGEO2015 model (Blitzkow et al. 2016), its results were almost of equal value to the parameters obtained by MAPGEO2010 (Matos et al. 2012). It is worth highlighting the notorious difference between the mean percentage errors (MPE), where MAPGEO2015 has the best result, as shown in Table 7.

Table 7: Comparative statistical parameters between normal-orthometric points transported from the LR and DTM from the BCDCA, normal conversion (hgeoHNOR2020) using the MAPGEO 2010 and MAPGEO 2015 models.

Parameters	Orthometric-normal	Normal (MAPGEO2010)	Normal (MAPGEO2015)
Mean error	0.0050	0.0062	0.0006
Mean Square Error	1.9728	1.9696	1.9711
Mean percentage error	148.1299	220.7127	24.3895
Pearson's coefficient	0.9519	0.9524	0.9521
Determination coefficient	0.9063	0.9072	0.9066
Standard Error (SE)	1.4045	1.4034	1.4040

Source: The authors.

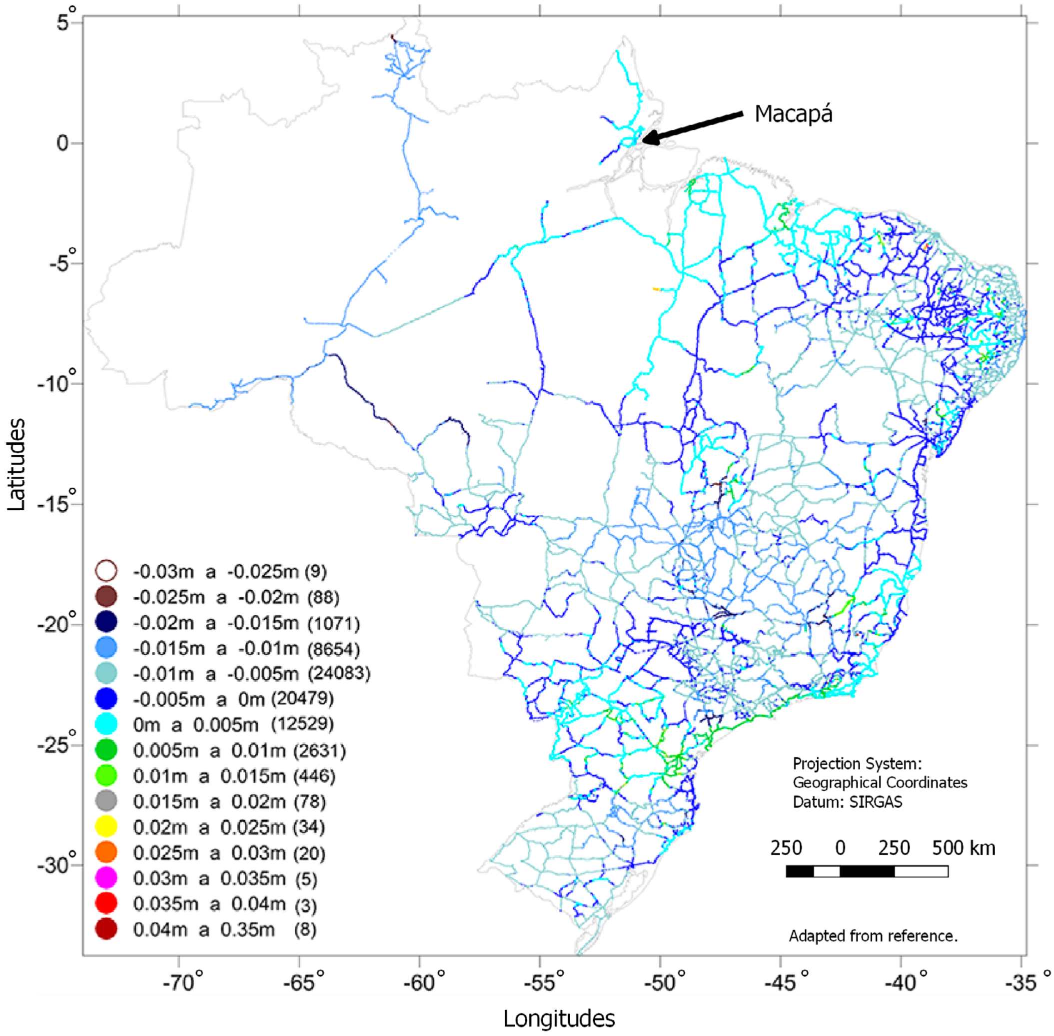
The difference between the mean error of normal orthometric altitudes and the normal models of MAPGEO2010 and MAPGEO2015, is in a better correction of the models, using the normal converter hgeoHNOR2020. The lower the value of the average error presented, the better the representation of the model under analysis. In a similar way, it presents the results of the mean percentage error, that is, if positive errors are compensated for by negative errors, the result is closer to zero. Therefore, MAPGEO2015 has a better representation after applying hgeoHNOR2020.

It is important to highlight in this table that its standard errors (SE) have the same value up to its proximate part. This informs us that there is no difference regarding the Cartographic Accuracy Standard (CAS).

4. Discussion

This discussion will be done by comparing the two variables of the results found for the orthometric-normal height in the study area with normal height using the η conversion factor of the hgeoHNOR2020 model and information from the IBGE itself.

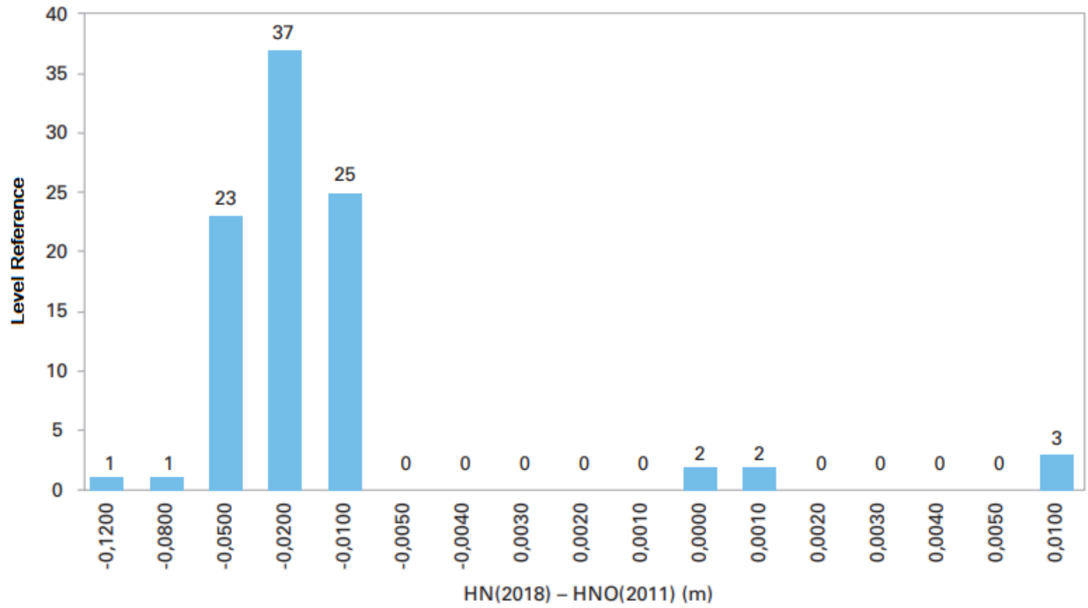
The difference between normal and orthometric-normal heights after the readjustment of the altimetric network in 2018 for the study area, was between 0 and 0.005 m, as shown in Figure 6 and is also confirmed by Table 7, with the mean error value of 0.0006 m when applying the MAPGEO2015 and in the relation of orthometric-normal values (BCDCA points x collected points) of value 0.005 m.



Source: IBGE (2019).

Figure 6: Differences between normal 2018 readjustment altitudes and orthometric-normal altitudes in Brazil (Adapted from source).

The readjustment of the Altimetric Network in Amapá, where the physical reality of the stations implemented in 1980/1981 was verified, is shown in Figure 7.



Source: IBGE (2019).

Figure 7: Difference between normal (2018) and orthometric-normal (2011) altitudes of Amapá's LR (Adapted from source).

This graph presents the differences between normal and orthometric-normal altitudes contained in the Geodetic Database of IBGE until July 2018 (IBGE, 2019).

From this readjustment, the orthometric-normal (HNO) and normal (HN) altitudes present, in 24.46%, a difference of -5 cm; 39.36% of this difference was -2 cm and 26.60% of this readjustment showed a difference of -1 cm. It is worth mentioning that 97.87% present variation between 0 and 5 cm (absolute values). This fact confirms the average error found in Tables 4 and 7.

5. Conclusions

In this work statistical methods and quantitative analyzes were applied to evaluate the quality and altimetric precision of the BCDCA's DTM, comparing it with more than 2000 orthometric points measured from of Brazilian Network of Continuous Monitoring – RBMC of Amapá. Therefore, the comparison of the DTM with the normal orthometric data derived from the Amapá RBMC using classical statistics and the Cartographic Accuracy Standard is fully feasible and is justified by the present job.

The determination coefficient informs that 90.63% of the altimetric data of the BCDCA are expressed by the orthometric-normal data.

When comparing the orthometric-normal values with the normal model (hgeoHNOR2020), this model did not influence the Cartographic Accuracy Standard (CAS), despite a slight improvement in its values, especially in the mean percentage error parameter.

The Digital Terrain Model of the Continuous Digital Cartographic Base of Amapá was evaluated in this work as very reliable, being able to generate topographic maps (altimetry / contour lines) on a large-scale regional scale, such as those compatible with the representation of the geographic space of the city. The data found, in comparison with those defined in the Cartographic Accuracy Standard (CAS), show excellent results for the topographic representation of the contour lines of the urban perimeter of Macapá on the scale of 1: 10 000 (equidistance of 5 m), as in class A. In general, this scale is used in plans and cadastral charts.

For the altimetry of the bounded points in the DTM model, digital cartographic products reach class A on the scale 1: 25 000 and class B on the scale 1: 10 000.

The great contribution of this work lies in the presentation of a solution for a complicated area from the point of view of the cartographic and geodetic infrastructure. This was exposed in the topic of the connection between official networks, as well as in the solution that was addressed in this research.

It should also be noted the climatic conditions of the region, predominantly humid, which makes it even more difficult to carry out an efficient mapping and with totally adverse and unusual conditions in most of the regions of Brazil. The results obtained show positive points that effectively overcame these adversities.

Conventional mapping is not efficient for some regions of Brazil, such as the region under study. Due to the large amount number of clouds or the abundant vegetation cover, the use of SAR technology presents itself as an important tool for cartographic mapping of these areas.

Another relevant factor for future research will be studies involving different topographic conditions and different vegetation cover.

AUTHOR´S CONTRIBUTION

Hendino dos Santos Filho wrote the manuscript, carrying out its study and evaluation of the MDT. Cecilia Cornero contributed in the orientation, focusing on cartographic knowledge. Ayelen Pereira made contributions and criticisms in relation to the altimetric models used in the evaluation and Marcelo Nero with ideas about the use of the ellipsoidal model to validate the data used in addition to other contributions.

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