Characterization of Cuban relief using SRTM data

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1 INTRODUCTION

1.1 Background

The quantification of landform analysis from digital elevations is important for geomorphology. It has evolved from the long-recognized need to characterize topography in terms more exact than “flat”,” “rolling”, or “hilly” (Richard J. Pike, 1988). The advances in computer technology and the growing availability of digital altitude data improve the geomorphic analysis. First, the visual perception of topographic form should be possible to simulate using numerical methods and digital elevations. Ultimately this might be done well enough to distinguish landscapes shaped by different process. Second, such simulations can be used in a format that allows rapid and automated manipulation, mapping, and correlation of topographic form over large areas.

The most relevant advances in computer software for geomorphology are in three areas: image processing, an offshoot of remote sensing and spacecraft data reduction; geographic information systems (GIS), a powerful application of theoretical geography; and the analysis shape, or morphometry (Richard J. Pike and Dikau R 1995).

Since the 1980’s, the importance and the effort of geographic information systems (GIS) and digital elevation model within the earth science has been continuously increased. The digital elevation model represents one of these booming GIS applications, which help to get very fast and precise morphological information about the earth’s surface.

Digital elevation model provide an opportunity to quantify land surface geometry in terms of elevation and its derivatives (Pike R., 2000). The basic geometric properties that characterize the terrain surface at a point are: (1) elevation; (2) properties of the gradient vector-its magnitude defining slope, and its direction angle defining terrain aspect; (3) surface curvature: (4) convexity: and (5) surface-specific points and lines, i.e. local maxima (peaks), minima (pits), saddle points (passes), inflection points, break-lines, ridge and valley lines.

The digital elevation model is playing an increasingly important role in many technical fields in Cuba including earth and environmental sciences, hazard reduction, civil engineering, forestry and landscape planning. It is difficult to exaggerate the importance of the digital elevation model to geomorphology, because digital elevation models may ultimately replace printed maps as the standard means of portraying landforms. The contour map remains an important data source for digital elevation models, although techniques for measuring elevation directly from satellite images have been introduced in recent years.

The analysis of the current results of Cuban geomorphology research obtained until today reflects, the unequal and insufficient degree of study, which was mentioned by Hernandez, J.R. et al. (1993):

1. The existence of geomorphologic data, on average scale, of some isolated fragments of the national territory with considerable problems regarding to the genesis and age of the relief and morphometric aspect.
2. The diversity of conceptions and criteria adopted by the authors, specially, between regions of the western and central part of Cuba.
3. The different representation from the reality as a result of the diverse stages of the knowledge of the different dates in which the investigations developed (in central part 1974, the provincial of Pinar del Rio 1980, and in Havana province and Havana city in 1987).
4. Several specialists agree the scientific approach there are several aspects unknown in greater or smaller degree: age and genesis of the relief, deep structure and exogenous relief, processes and morphometry.

Different missions have obtained spatial data viewing the Earth from space. The resulting mosaic of different kinds of data sources with a multitude of horizontal and vertical data, accuracies, formats, map projections and resolutions in hardly a uniform and reliable dataset. A major restriction is also the impossibility to assess the accuracy of the resulting derived products. A recurring problem with the existing inventory of topographic data is the inhomogeneous data quality when attempting to integrate the acquired data into a global dataset. As a consequence the comparability of results suffers greatly. Constant data quality from a single data source is, therefore, imperative but with SRTM this is not a problem.

Shuttle Radar Topography Mission (SRTM) was launched in February 2000. The mission obtained elevation radar data on near-global scale to generate the most complete high-resolution digital topographic database of the Earth. This database allowed generating the digital elevation model of the Earth.

In this context, the principal propose of this research is: use the data of the Shuttle Radar Topography Mission (SRTM) with 90 m of resolution for Cuban geomorphometry characterization. The methodology is based on general geomorphometry. In this study, the basic geometric attributes were elevation, slope, and internal relief. Terrain modelling is implementing with the integrated use of: a) numerical differential geometry and b) statistical analysis

1.2 OBJECTIVES OF THE THESIS

The objective of this thesis is "geomorphometry characterization of Cuba by use Digital Elevation Model (DEM) from Shuttle Radar Topography Mission (SRTM) with 90 m of resolution".

1.3 SECONDARY OBJECTIVES

- Processing and editing the SRTM data for morphometric analysis.
- Generation of morphometric maps: slope, elevation and internal relief at 90 m.
- Apply the knowledge about ILWIS 3.2 for the analysis of the Cuban relief
- To increase the knowledge about the geomorphometric characteristics of Cuba

1.4 STUDY AREA LOCATION

The Cuban archipelago is elongated in the same direction as the parallels and is located near the Tropic of Cancer in the warm waters of the Gulf of Mexico, having the Florida Straits to the north and the Caribbean Sea to the south (Figure.2.1). The boundaries in Coordinate System Latlon "LatlonWGS84" are:

Top Left: 23°35'04.85"N, 85°06'46.07"W
Top Right: 23°35'04.85"N, 74°02'31.07"W
Bottom Left: 19°35'01.85"N, 85°06'46.07"W
Bottom Right: 19°35'01.85"N, 74°02'31.07"W

Figure.2.1. Geography position of Cuba

2 METHODOLOGY

2.1 Materials

In this research the following source data were used:

a) A digital elevation model, from SRTM data at 90 meter
b) Landsat thematic map colour composite mosaic at 30 meter
c) Legends from National Atlas of Cuba (1989) of the following maps:
    - Slope map at 1:1 000 000 (Magaz, A.R.)
    - Internal Relief Map at 1: 2 000 000 scale (Diaz, J.L.)
    - Hypsometric map at 1:1 000 000 (Magaz, A.R.)

The legends from the National Atlas of Cuba were used to classified to digital elevation model and compare results.

2.2 SRTM specifications

2.2.1 SRTM data

The SRTM data sets result from a collaborative effort by the National Aeronautics and Space Administration (NASA) and the National Imagery and Mapping Agency (NIMA), as well as the participation of the German and Italian space agencies, to generate a near-global digital elevation model (DEM) of the Earth using radar interferometry. The SRTM instrument consisted of the Spaceborne Imaging Radar-C (SIR-C) hardware set modified with a Space Station-derived mast and additional antennae to form an interferometer with a 60 meter long baseline. A description of the SRTM mission can be found in ftp://edcsgs9.cr.usgs.gov/pub/data/srtm/.

Synthetic aperture radars are side-looking instruments and acquire data along continuous swaths. The SRTM swaths extended from about 30 degrees off-nadir to about 58 degrees off-nadir from an altitude of 233 km, and thus were about 225 km wide. During the data flight the instrument was operated at all times the orbiter was over land and about 1000 individual swaths were acquired over the ten days of mapping operations. Length of the acquired swaths ranges from a few hundred to several thousand kilometers. Each individual data acquisition is referred to as a "data take."

SRTM was the primary (and pretty much only) payload on the STS-99 mission of the Space Shuttle Endeavour, which launched February 11, 2000 and flew for 11 days. Following several hours for instrument deployment, activation and checkout, systematic interferometric data were collected for 222.4 consecutive hours. The instrument operated virtually flawlessly and imaged 99.96% of the targeted landmass at least one time, 94.59% at least twice and about 50% at least three or more times. The goal was to image each terrain segment at least twice from different angles (on ascending, or north-going, and descending orbit passes) to fill in areas shadowed from the radar beam by terrain. This 'targeted landmass' consisted of all land between 56 degrees south and 60 degrees north latitude, which comprises almost exactly 80% of the total landmass.

Digital elevation model encompasses the following five general tasks (Fig.3.3.1); for details see (Weibel & Heller 1991):

- Digital elevation model generation: Sampling of original terrain (data capture), and relating the diverse observations (model construction) to build a Digital elevation model.
- Digital elevation model manipulation: Modification and refinement of Digital elevation models, and the derivation of intermediate models.
- Digital elevation model interpretation: Analysis of Digital elevation models, information from Digital elevation models.
- Digital elevation model visualisation: Display of elements and properties of Digital elevation models and derived information.
- Digital elevation model application: Development and appropriate to specific disciplines (e.g., for erosion potential, surface water runoff, or noise pollution). Digital elevation model application forms the context embracing all other tasks of digital terrain modelling, and defining requirements for their use.

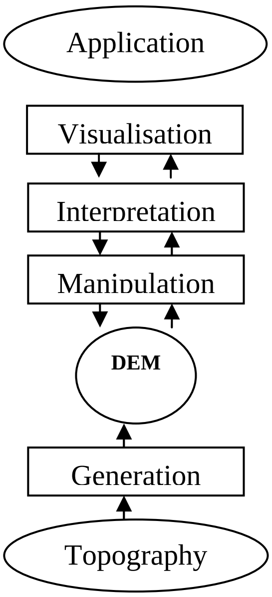

Fig.3.3.1. The main tasks of a digital terrain modelling system (after Weibel & Heller 1991). DEM application is the context for all other tasks, defining requirements for their use.

Interpretation results (obtained either through visual or quantitative analysis are of particular importance with respect to feedback and model improvement: they provide knowledge to enhance the performance of other modelling operations such as Digital elevation model generation.

3 RESULTS AND DISCUSSION

3.1 Results and discussion

The Table (Table.4.1) below shows the area of Cuba is 109 867.41 km2, this value is less than (992.59 km2) measures that the Cuban Geography Dictionary propose, the reasons maybe relationships with the methods that applied in the measuring of the island, and the criteria that use, take boundary by Coast line of the principle island and the more than 3000 small islands that constituted the Cuban Archipelago.

Table. 4.1. Area of Cuban Archipelago.

Sources	Dictionary Geography of Cuba	Dem SRTM data	Difference
Area total (Km2)	110 860	109 867.41	992.59

3.1.1 Elevation Classes Map

Different criteria were used to obtain elevation classes, as it was already explained the histogram of elevation frequency is shown in Figure 4.1. The elevation in the Cuba Archipelago is between 0 to 1970 meters. The mean elevation of the Cuba is 100.68 meters above sea level. The standard deviations are 152.10 meters and the median is 50 m (Annex.2.Table.1).

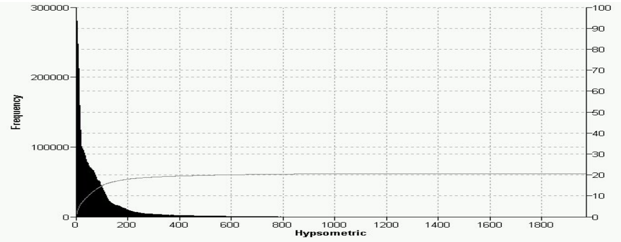

Figure 4.1.Histogram (domain: Value) of the frequency elevation of Cuba

From the two histograms (Figure 4.2 and 4.3) below, it is observed the principals break points such as between 5 to 6 meter, between 20 to 21 meters, between 39 to 40 meters, between 83 to 84 meters and between 123 to124 meters. It is observed that the elevation value frequency constitutive three principal group of distribution value, between 0 to 125 meters, 125 to 351 meters and 351 to 1970 meters, this group are the main hypsometric unit of the Cuban relief, plain, hill and mountain, respectively.

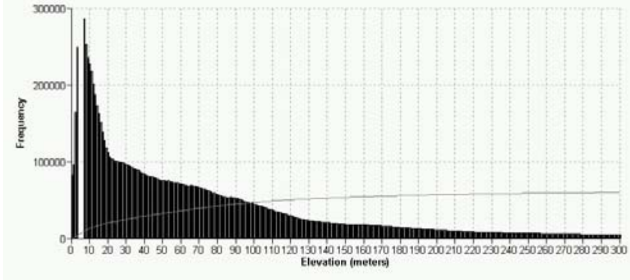

Figure 4.2. Histogram (domain: Value) of the frequency elevation of Cuba by interval of 10 with 0 to 280 meters of the stretching.

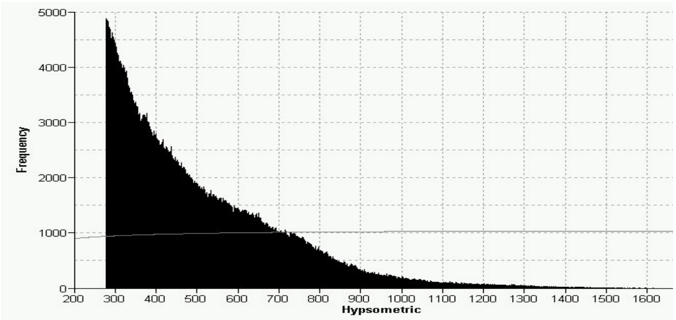

Figure 4.3. Histogram (domain: Value) of the frequency elevation of Cuba by interval to 100 meters with 200 to 1970 meters of the stretching**.**

Other observation are that each group have different irregularity in the curve, this mean that should be include others subgroups. These correspond with the formation and evolution of the Cuban relief, where neotectonic have the great important factor, because the origin of different level of the plains, hills and mountain has strong relationships with tectonic process.

The Figure number 4.4 and Table 4.2 shows different elevation classes according with Magaz, Cuban National Atlas, 1989; Diaz, et al1,1993; the criteria about the break points in histogram and the last using mean +/- ½ STD values.

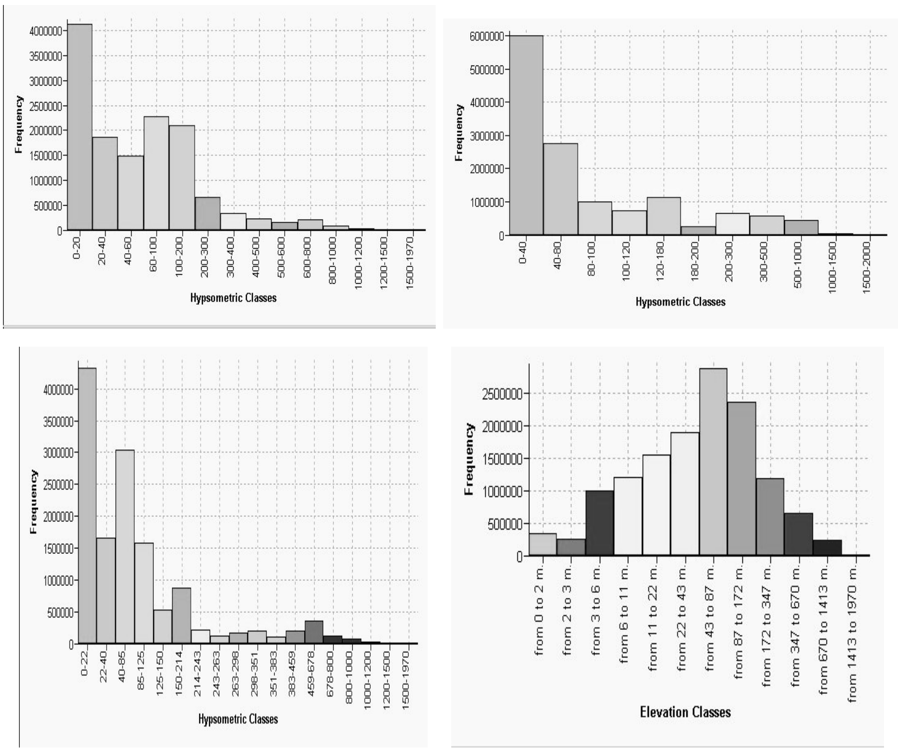

Figure 4.4. Histograms shows the different elevation classes according with Magaz, Cuban National Atlas,1989(upper left); Diaz, et al1,1993(upper right); the lower left, using criteria

about the break points in histogram and the right (lower right), by using mean +/- ½ std values.

The elevation classes in the Hypsometric map from Cuban National Atlas in section IV Relief (IV.1.2.3) scale 1: 1000 000, shows fourteen classes. This appear that Cuba has 5 level of plains, 4 level of hills, one of sub-mountain and 4 for mountains. According with this classification the plain (0-200 m) occupied around 87.4 % of Cuba, 7.8 % for hill (200-600 m) and the 4 % the mountain (600-1970 m). (Table 4.2)
The elevation classes according Diaz et al, (1993) Cuba has 11 elevation classes. In this way, Cuba has 5 levels of plains (0-180 m), 3 of hills (180-500 m) and 3 of the mountains (500-2000 m). The plain has 77.3 %, the hill has 19.19 % and the mountain occupied more than 3 %.
The classes derivate from histograms (break point, STD, peak, etc) were 18. It has 4 levels for plains (0-125 m), six for hills (125-351 m), two for sub-mountains (351-459 m) and six for mountain (459-1970 m). The plain has 68.19 %, the hill occupied 15.44%, the sub-mountains have 2.15 % and the mountains have more than 4 %. This procedure is most effective in the differentiation of the hill and the mountains.
The last histogram applies the antilogarithm values and using mean +/- ½ STD values shows 12 elevation classes. In this case, Cuba Hypsometric was characterized for 8 levels of the plains (0-172 m), 2 levels of hills (172-670 m) and 2 for mountains (670-1970 m). The plain has 84.76 %, 13.54 % by hill and more than 2 % for mountain. These histograms classify more effective the plain classes than another procedures. But is less effective than the rest for the mountain's classes.
The final classification considers all this criteria and procedure. The Figure number 4.5 shows 10 elevation class, where the plain occupy 4 levels, the hills about 3 levels, sub-mountains 1, and the mountains has 2 levels. The plain is the large area about 88.4 %, following hills with 7.39 %, Sub-mountains 3.37 % and the mountain approx 1 % of the Cuban territory.
There are relatively large frequencies of elevation between 0 and 20 m and 20 and 40 m, between 40 and 85 m, between 85 and 125 m, (Table 4.2). This range corresponded with Plain classes. The large peak at 5 m represents the low plain associated in the Cuban case with the lower surfaces. They are the youngest, usually quite flat and predominantly abrasive and abrasive-accumulative. At the present time,

the marine plains, this formed at higher sea levels, grade into fluvio-marine plains, which are basically no more than relatively thick deltaic deposits.

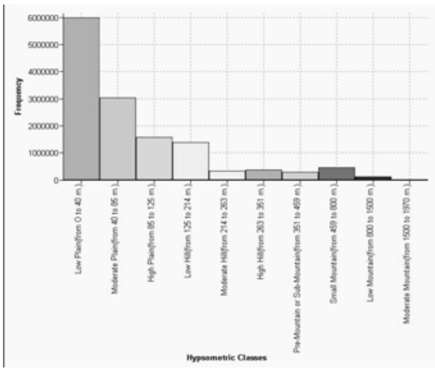

Figure 4.5. Histogram of the Final Elevation Classes of Cuba

The high plains (85-125 m) (Figure 4.6) are associated with the denudational process; cover large areas in the interior parts of Cuba, usually at elevations of between 100 and 125 m. They are the product of a long period of fluvial process; the highest are quite hilly, while the lowest are more gently undulating.

Others example of the high plains is the series of marine terraced surfaces. It's distributed around the periphery of the Isle of Cuba and the principle keys ranging in elevation from sea level up to 100-120 m (Figure 4.6).

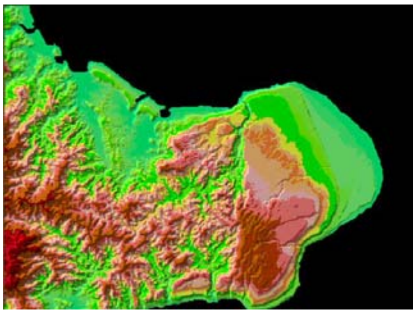

Figure 4.6. Part of the shade map of Cuba, example the high plains (85-125 m), Punta de Maisi (Marine Terraced)

The higher surfaces (80-90 and 100-120 m) are older, more extensive, often hilly, and complex. They are classified as abrasive and abrasive-denudative; the middle surfaces (40-45, 50-60, and 75-80 m) are strongly dissected, and are classified as abrasive and abrasive-erosive. It is possible to conclude that the Plain occupied the large area in Cuba. It corresponds to the zone of relative less tectonic movement. The hills, (125-351m) (Figure 4.7) are characterized by irregular geography distribution, they occupy small area. It's associated with the principal's mountain system of Cuba (Sierra de Guaniguanico, Grupo Guamuhaya, Grupo Sagua-Baracoa and Sierra Maestra) or they are a small marginal group.

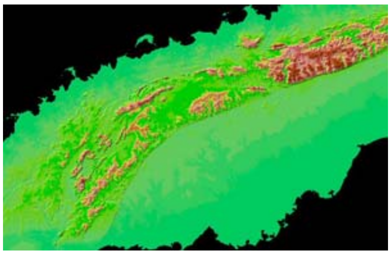

Figure 4.7. Part of the shade map of Cuba, example the high Hills (125-351 m) associated

With the mountain (Cordillera de Guaniguanico, Western Cuba).

The mountain occupies a small part of the Cuban territory. It's distributed in 4 principals groups separated by the plains. The elevation class that defined in this research should be related with the genetic mountain class group of Cuban relief. The horst and block-napped systems (Cordillera de Guaniguanico, western Cuba), its elevation range is associated with small mountain class with values from 459 to 800 meters. The dome-block and massive horsts, with 800 to 1500 meters, Sierra de Trinidad, highest point Pico San Juan with 1140 meters (Figure 4.8). The stepped horsts, monoclinal and intrusive step-faults with 1500 to 1970 meters of altitude, Sierra Maestra with the highest peak of Cuba, Pico Turquino 1970 m.

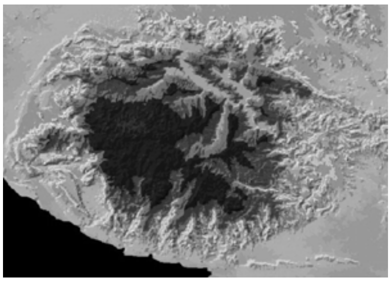

Figure 4.8 Shade map of Cuba, example the low mountain (800-1500 m), Central Cuba.

3.1.2 Slope Classes Map

The following criteria were taken into consideration: 1) The simple curve observation such as minimum and maximum value, break point value and the local maximum value (peak). 2) The frequency of the value of point attributes and their moments, such as mean, range and standard deviation, over the whole area or its parts. 3) The range proposed in the slope map A. R. Magaz, scale 1: 1000 000, National Atlas of Cuba (1989). 4) The geomorphologic characteristics of the Cuban relief.

The histogram of Slope frequency is shown in Figure 4.9. The Slope in the Cuba territory has range between 0 to 66.34 degrees. The mean gradient slope of the Cuba is 3.47 degrees. The standard deviations are 5.76 degrees and the median is 1.29degrees.

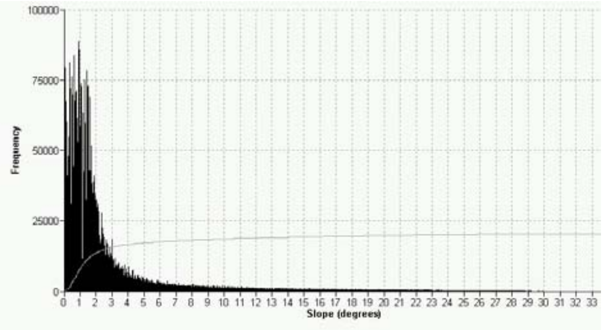

Figure 4.9. Histogram of the frequency slope angle of Cuba (domain: Value)

From the two histograms (Figure 4.10) below, it is observed the large peak at 0.43 degrees represent the more gently sloping class of Cuba. The 5 principals peaks were observed in the slope range between 0 and 1.82 degrees. It were at 0.14, 0.43, 0.60, 1.06 and 1.44 degrees. Other important peak was 1.90 degrees included in the range 1.82 and 4.29 degrees, and 6.47 degree in the range 4.29 and 7.80 degrees. The most important break points are from 0.19 to 0.21 degrees; 0.45 to 0.47 degrees; 0.66 to 0.68 degrees; 1.22 to 1.25 degrees and 1.81 to 1.83 degrees.

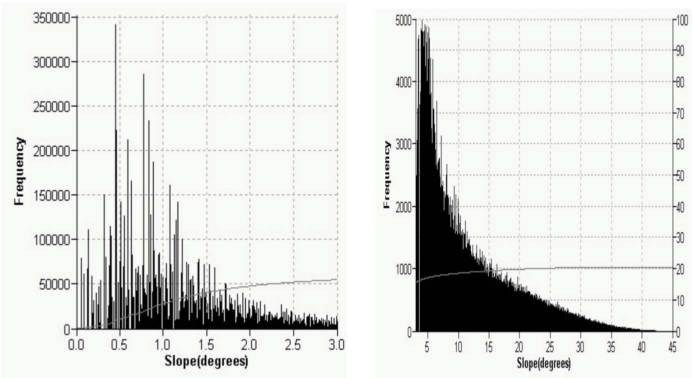

Figure 4.10. Histograms (domain: Value) Slope of Cuba by interval of 0.5 from 0 to 3 degrees, (left); and 5 degree of the interval, and from 3 to 45 degrees (right).

The cumulative-percentage area-slope (Anex.2.Table.2) by using the quartiles shows that in 25 % of the area the slope is less than 0.75 degree, of which about half is less 0.43 degree. Each value is being represented by a break point in the curve of the histograms (Figure 4.10).

The 50 % quartile as shows that the area with slope is less 1.29 degrees; represent the low and moderate plains. The 75 % the area have slope with less than 2.87 degrees. It is concluded that the major percentage area-slope of Cuba is related to the plain areas. Other conclusion is related to the mountain territory with slope angle less than 2.87 degrees. Its only possible for small intra-mountain valleys, and the few areas associated with the small old surfaces plains.

The slope map (Annex.1Fig.8) in the Cuban National Atlas in section IV.5 Slope Angle (IV.2.2-3) scale 1: 1000 000, shows 9 classes. The according with this classification the slope from 0 to 1 degree occupied about 38.66 % of Cuba, 37.20 % by 1-3 degree; 3 to 15 degree has 17 % and more than 15 degree has 7 %. The first groups correspond to the plain areas, the last group to the mountain areas.

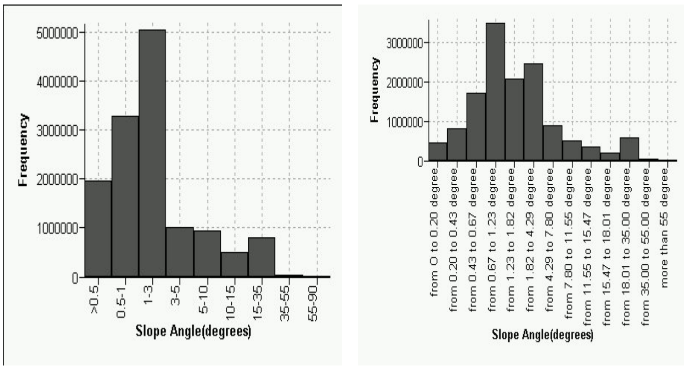

Figure 4.11. Histograms of the slope classes, by Magaz, 1989, Cuban National Atlas (left) and by Histograms Value (right).

The slope classes (Figure 4.11) and (Annex.1.Fig.7) derivates from histograms (break point, STD, peak, etc) were 13. The first 5 classes (0-1.82 degrees) are related with the plain areas, the others 4 classes (1.82-15.47 degrees) of slope are associated with the hills areas, and the 3 last classes (more than 15.47 degrees) with the sub-mountain and mountain regions.

3.1.3 Internal Relief Classes Map

The histograms of Internal Relief frequency are shown in Figure 4.12. The internal relief in Cuba range between 0 to 471 meters. The mean internal relief of Cuba is 23.68 meters.   The standard deviation is 39.79 meters and the median is 7 meters.

The two histograms (Figure 4.12) below, shows the large peak at 4 m. The principal peak was observed in the range between 3 and 7 m. The most important break points were from 6 to 13 meters. The geomorphology interpretation of this changes, should be associated with the moderate tectonic movement, it may be the boundary between hypsometric classes, like the moderate plain and high plain.

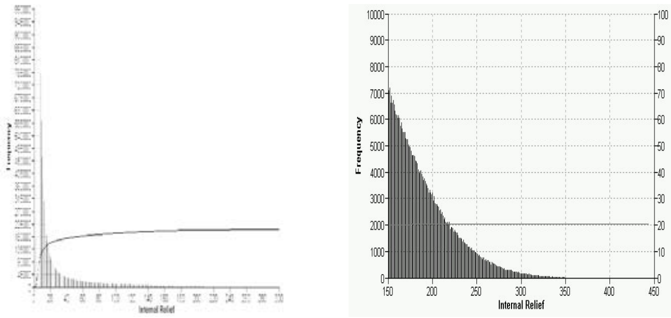

Figure 4.12 Histograms (domain: Value) Internal Relief of Cuba by interval of 20 meters from 0 to 300 meters, left); and of 50 meters of the interval, from 150 meters to 450 meters /hectare (right).

The measurement of the internal relief that was used in this research (m/hectare) is different to the use in the Cuban National Atlas (m/km2), it indicated that, comparing both, may obtain bad results, for this reason only the results obtained will be shown.

The Internal relief classes in a Cuban National Atlas in section IV.2 Internal Relief (IV.1.4) scale 1: 2 000 000, shows 12 classes. According with this classification the internal relief values between 0 and 10 m/ha has the 61.35 % of the Cuban territory, this mean that the low and moderate plain are associated whit this range. The ranges between 10 and 50 meters/ha have the 26 % of the area associated with high plain and low hill. The ranges between 50 and 100 meters/ha occupied 6.70 %. It's included in the hills classes. The ranges more than 100 meters were associated with the high hill and mountain classes its represent about 7 % of Cuba. (Figure 4.13)

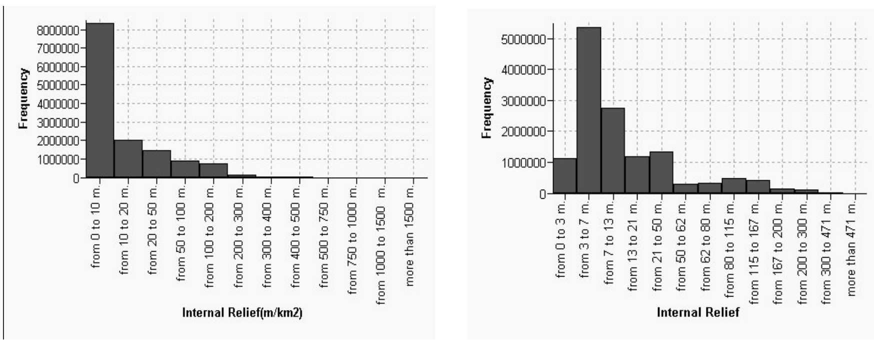

Figure 4.13. Histograms of the Internal relief classes of Cuba, by Diaz et all, 1993 and by histograms value

The classes derivates from histograms (break point, STD, peak, etc) were 13. The 86.55% (0-50 meters/h) of the internal relief it is associated with the plain class, divide in three groups for the Low plain (0-3 meters/h of the internal relief) with 8.27 %, moderate plain (3-21 meters of the internal relief) with 68.72 % and the high plain

(21-50 meters) with 9.96 %. The hills class (50-115 meters) with 8.01 % divides in three groups: low hill 2.11%, moderate hill 2.46 % and high hill 3.44 %. The sub-mountain corresponds 3.11 % and 1.93 % (Annex.2.Table.3). It is conclude that this data is a good element for characterize of the Cuban relief basically in the association of two morphometric attributes. This relationship shows that in Cuban geomorphology, the tectonic process is a very important factor.

The cumulative-percentage internal relief-area by using the quartiles shows that in 25 % of the area the internal relief is less than 4 meters/h. Each value is represented by a break point in the curve of the histograms (Figure 4.12). This area is associated with low plain.

The 50 % quartile shows that the internal relief is less than 7 meters /h representing the low and moderate plain classes. The 75 % the area the internal relief is less 18 m/h. It is conclude that the major percentage area of internal relief of Cuba is related with the plain classes. Other conclusion that is Cuba has different levels of the Plain classes and it is the results no only of the denudational process, but for the action of the endogenous processes. This research indicated that tectonic factor should be influence in the Cuban relief.

4 CONCLUTIONS AND RECOMENDATION

Conclusions:

- The digital elevation model of entire Cuba archipelago was edited, cleaned and cut from the Shuttle Radar Topography Mission (SRTM) data at 90 m of the resolution to analyze the relief, the slope angle, internal relief and hypsometric features.
- It was the first time that the digital elevation model of the whole country was created at 90 meter. The Digital elevation model provides more accurate and more precise estimates of derived summary statistics, which will be useful for characterized some morphometric attribute of the Cuban relief.
- The three morphometric attributes: elevation, slope angle and internal relief, represent decisive parameters for the delimitation of the morphometric characteristic of the Cuban relief. Its was obtained new quantitative data about the morphology of Cuba, such as hypsometric mean of Cuba is 100.68 meters, Slope mean is 3.47 degree, Internal relief mean is 23.68 m/h. The

standard deviations are 152.10 m of the hypsometric, 5.76 degrees of the slope and 39.79 m of the internal relief.

- These morphometric attributes were classified in 10 elevation classes, 13 slope classes and 13 internal relief classes. It was compared with traditional methods. It was 75 % of the Elevation is less than 110 meters above sea level, with less than 18 meters /h of the internal relief and less than 2.87 degree. And they characterize the plain areas of the Cuban territory constituted this percentage of Cuban territory and their characterized of the plain Classes.
- The using of the GIS such as ERDAS 8.6, ENVI 4.3 and ILWIS 3.2, was useful for the capture, processing and editing the data of the SRTM.

Recommendations:

- For future research on Cuba geomorphology it is recommended to include other morphometric attributes like curvature profile, slope aspect, slope shape, slope longitude.
- The (geo) statistical relief characterization could be done by comparing digital elevation models subsets from different physiographic regions in the Cuban Archipelago.
- Bi-variable and multivariable analysis is recommended to recognized the relationship between the morhometric parameters and to characterized the different landforms.
- These types of analysis it is recommended in order to homogenized the geomorphological characterization of the Cuban Archipelago.

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ANNEX-1

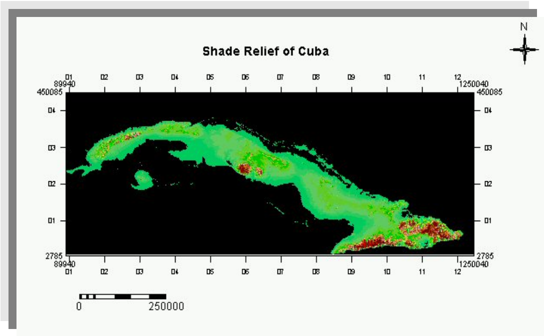

Figure.1. Shade Relief of Cuba

Figure.2 Shade Relief of Cuba (Gray scale)

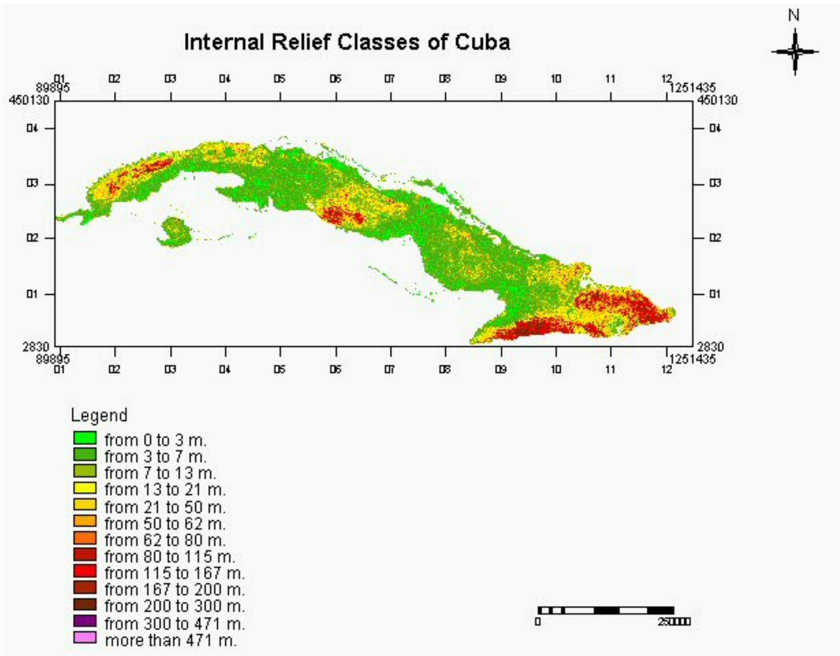

Figure 3. Internal Relief Classes Map of Cuba.

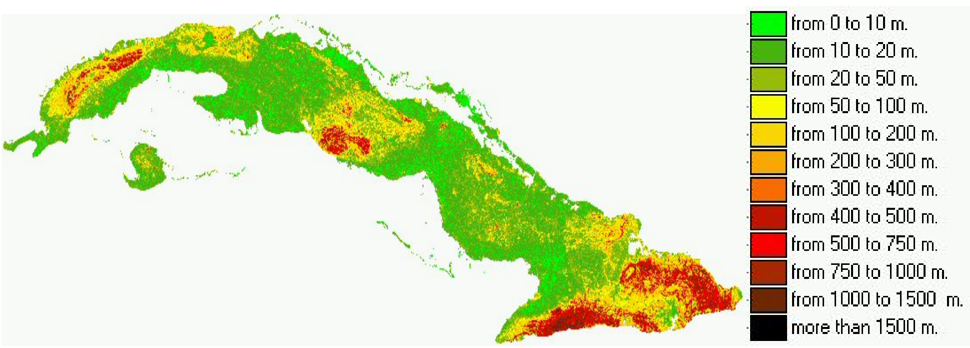

Figure4. Internal relief derivates from classes of the Cuban National Atlas

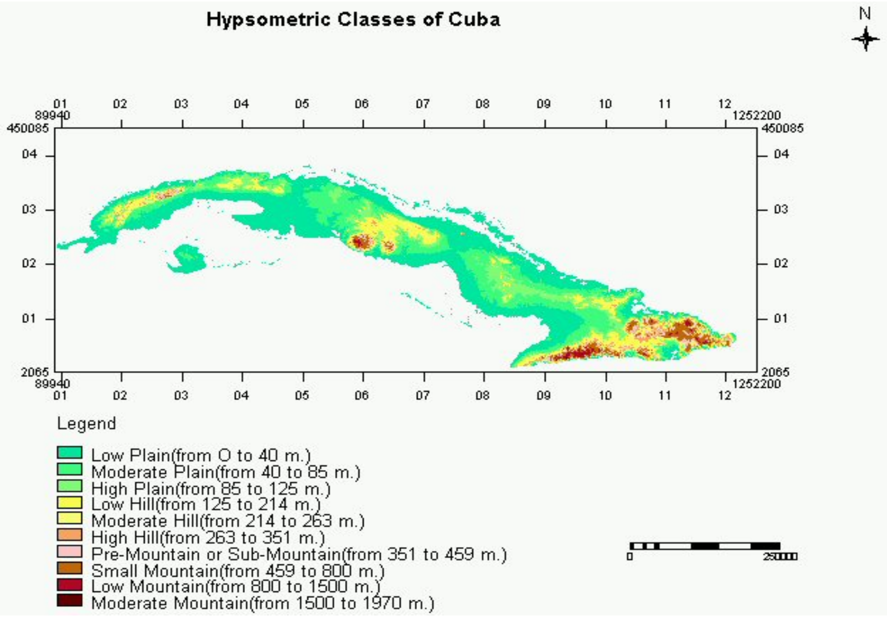

Figure.5. Hypsometric Classes Map of Cuba

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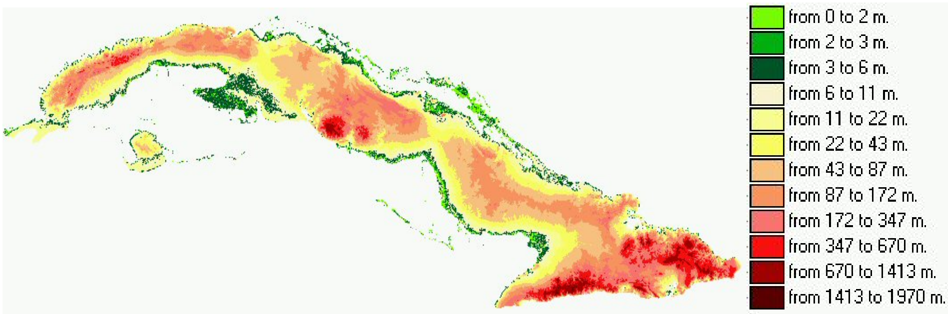

Figure 6. Hypsometric derivates form classes that used in Cuba National Atlas

Quartiles	**Hypsometric** (meters)	**Slope** (degrees)	**Internal Relief** (m/ha)
0 %	**0**	**0**	**0**
25 %	**14**	**0.75**	**4**
50 %	**50**	**1.29**	**7**
75 %	**110**	**2.87**	**18**
100 %	**1970**	**66.34**	**471**

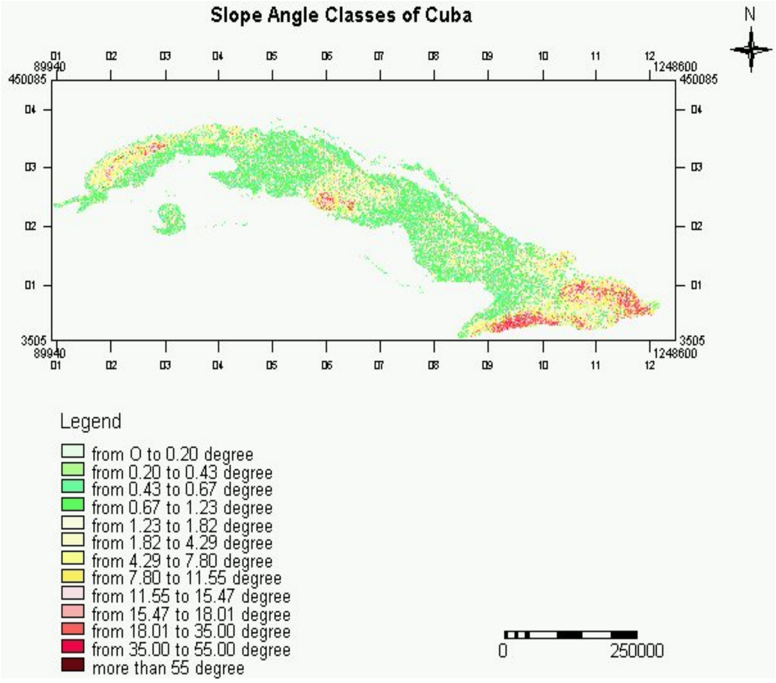

Figure.7. Slope Classes Map of Cuba

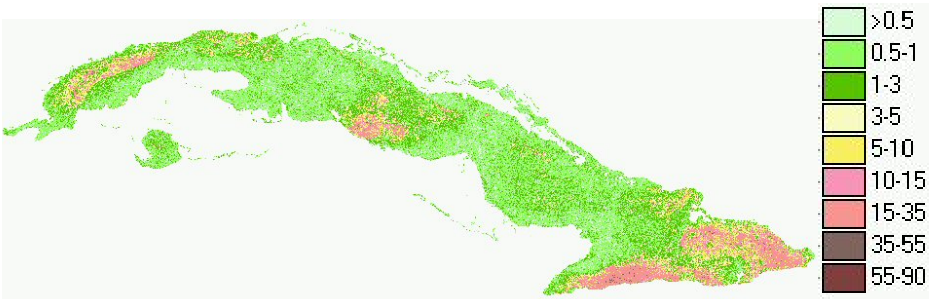

Figure 8. Slope derivates from classes that used in Cuba National Atlas

ANNEX-2

Table 1. Statistic Descriptor of the morphometric attributes of Cuba

Table 2. Quartiles of the morphometric attributes of Cuba

Statistic Descriptor	Hypsometric (meters)	Slope angle (degrees)	Internal Relief (metres/ha)
Minimum	0	0.00	0
Maximum	1970	66.34	471
Mean	100.68	3.47	23.68
Median	50	1.29	7
Std. Dev	152.10	5.76	39.79

Class No.	Hypsometric (Unit: meters)								Slope Angle (Unit: degree)				Internall Relief (Unit: m/km2)			
	Magaz, 1989		Diaz, Article		Histograms 1		Histograms 2(log)		Magaz, 1989		Histograms 1		Diaz, 1989		Histograms 1	
	Range	Area	Range	Area	Range	Area	Range	Area	Range	Area	Range	Area	Range	Area	Range	Area
1	0-20	30.40	0-40	44.17	0-22	31.91	0-2	2.49	>0.5	14.51	0-0.20	3.40	0-10	61.35	0-3	8.27
2	20-40	13.77	40-80	20.38	22-40	12.25	2-3	1.80	0.5-1	24.15	0.20-0.43	5.99	10-20	14.90	3-7	39.64
3	40-60	10.97	80-100	7.38	40-85	22.35	3-6	7.35	1-3	37.20	0.43-0.67	12.71	20-50	10.69	7-13	20.38
4	60-100	16.78	100-120	5.30	85-125	1.68	6-11	8.83	3-5	7.46	0.67-1.23	25.84	50-100	6.70	13-21	8.70
5	100-200	15.48	120-180	8.39	125-150	3.82	11-22	11.45	5-10	6.91	1.23-1.82	15.31	100-200	5.46	21-50	9.96
6	200-300	4.80	180-200	1.79	150-214	6.38	22-43	14.03	10-15	3.68	1.82-4.29	18.17	200-300	0.85	50-62	2.11
7	300-400	2.52	200-300	4.80	214-243	1.59	43-87	21.35	15-35	5.86	4.29-7.80	6.48	300-400	0.04	62-80	2.46
8	400-500	1.69	300-500	4.21	243-263	0.89	87-172	17.46	35-55	0.24	7.80-11.55	3.63	400-500	0.00	80-115	3.44
9	500-600	1.19	500-1000	3.30	263-298	1.26	172-347	8.80	>55	0.00	11.55-15.47	2.64	500-750	0.00	115-167	3.11
10	600-800	1.56	1000-1500	0.27	298-351	1.50	347-670	4.74			15.47-18.01	1.34	750-1000	0.00	167-200	1.04
11	800-1000	0.55	1500-2000	0.01	351-383	0.73	670-1413	1.69			18.01-35.00	4.25	1000-1500	0.00	200-300	0.85
12	1000-1200	0.17			383-459	1.42	1413-1970	0.03			35.0-55.0	0.24	>1000	0.00	300-471	0.04
13	1200-1500	0.09			459-678	2.55					>55.0	0.00			>471	0.00
14	1500-1970	0.01			678-800	0.82										
15					800-1000	0.55										
16					1000-1200	0.17										
17					1200-1500	0.09										
18					1500-1970	0.01										

Table 3. Classes and percentage of elevation, slope and internal relief of Cuba. Areas in percentage (%)