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SRTM 3" comparison with local information: Two examples at national level in Peru

Edson Plasencia Sánchez[1,*] **and**
Ruben Fernandez de Villarán[2]

[1] Universidad Nacional de Ingeniería, Lima, Perú

[2] Universidad de Huelva, Huelva, Spain

Abstract. The access to the high resolution digital terrain models (DEM) generated from the data collected by the Shuttle Radar Topography Mission (SRTM) of NASA is freely available to the public. Consequently it has become a source of topographic information which is of great value to scientists involved in geophysical or geodetic analysis. Despite the efforts of the Consultative Group on International Agricultural Research (CGIAR), to validate and complement the information contained in these DEMs (currently offered as version 4.1), they still need to be checked for their accuracy in certain regions of the planet.

In this paper, the vertical accuracy of the SRTM 3" version 4.1 DEM was analyzed in several areas of Peru using two sets of control points: the height of the district capitals (the minor politics units) and the heights of the weather and hydrological stations from the National Meteorology and Hydrology Service (SENAMHI) of Peru. The comparison shows that the height differences are independent of the altitude, latitude and longitude of the evaluated points. They are rather related to the aspect of the terrain and to the way the SRTM data were acquired. It shows that the mean square of the height differences at national level was ± 20 m for district capitals and ± 25 m for the SENAMHI stations. This is slightly larger than the overall accuracy of the SRTM ± 16 m.

Keywords. Digital elevation model, geographic information systems, SRTM comparison, Andes, Peru.

1 Introduction

The SRTM international project took place during 11 days of February 2000. It is described in [7, 19, 27] and its product is available to the general public through the internet in the form of several DEMs files in raster format [18].

Currently, there are two higher spatial resolution DEMs: one at 90 m of spatial resolution with information that covers almost the entire planet (80% of its land area), and the other at a spatial resolution of 30 m that covers only the United States of America.

Since the release of the SRTM data there have been several studies: topographic [5, 14], geomorphologic [10, 25] and urban [8]. Their accuracy has also been tested against height data from various sources, e.g., [11, 13, 15, 24, 26].

However, the lack of data – empty pixels in the DEMs, which occurred especially in mountain areas – limited their use and encouraged the application of different methodologies to circumvent these gaps [4, 13, 21].

Using a classification for areas lacking data, and a selection of interpolation techniques, the CGIAR-CSI now offers a DEM with corrected data at 90 m spatial resolution, which is known as SRTM 3" v4.1 [3].

Although the SRTM expected to obtain data with a vertical accuracy of ± 16 m [16], studies have shown that it often has a higher accuracy [2, 9, 22] except in areas with rugged topography, with dense cover of vegetation, or those subject to very dense cloud cover [6,21,22]. In those circumstances, one can expect that the SRTM's DEMs have uncertainties around ± 30 m [1] in South America and in mountainous areas of Peru, with differences ranging between -113 m and $+121$ m [20].

The comparisons made between the highest resolution SRTM's DEM and cartographic maps for certain areas of Honduras, Colombia and Peru, showed that the SRTM's DEM may have greater vertical accuracy than cartographic maps at a scale of 1:50 000, and that only the cartographic maps at a scale of 1:10 000 or larger would be more accurate than the SRTM's DEM [13, 20].

2 Methodology

Initially, the SRTM data version 2.1 was downloaded from USGS [18], but checks showed that there were many void pixels in Peru, and that the loss of information was significant, both in terms of their quantity and their proximity to some mountain areas with a large number of towns. It was therefore decided to work with the corrected SRTM 3" version 4.1 from the CGIAR. Figure 1[1] shows an example of

Corresponding author: Edson Plasencia Sánchez, Av. Tacna 329, Oficina 505, Cercado de Lima, Lima 01, Perú.
E-mail: contacto@edsonplasencia.com.

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[1] Figures and tables in this article are own elaboration unless otherwise stated.

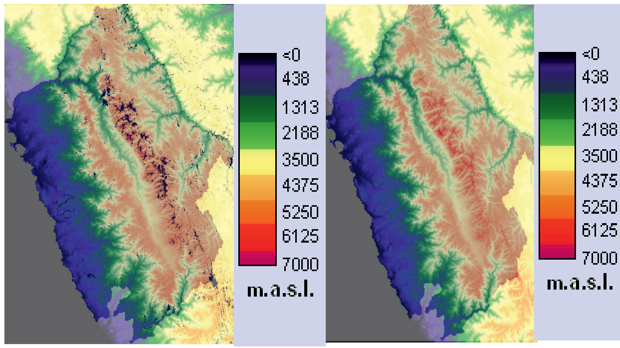

Figure 1. Ancash, Peru, as SRTM 3" version 2.1 (a) and version 4.1 (b).

Latitude (°)	Longitude (°)	Height (m a.s.l.)	District	Capital
−11.5975	−76.1356	4550	Morococha	Morococha
−14.6758	−69.5311	4660	Ananea	Ananea
−15.2386	−71.0800	4737	Ccarhuayo	Condoroma
−15.0642	−71.7483	4801	Ccatca	Suyckutambo
−5.0825	−81.1117	3	Paita	Paita
−8.2200	−78.9742	3	Salaverry	Salaverry
−13.0219	−76.4689	3	Cerro Azul	Cerro Azul
−12.0678	−77.1644	2	La Punta	La Punta

Table 1. District capitals at extreme heights.

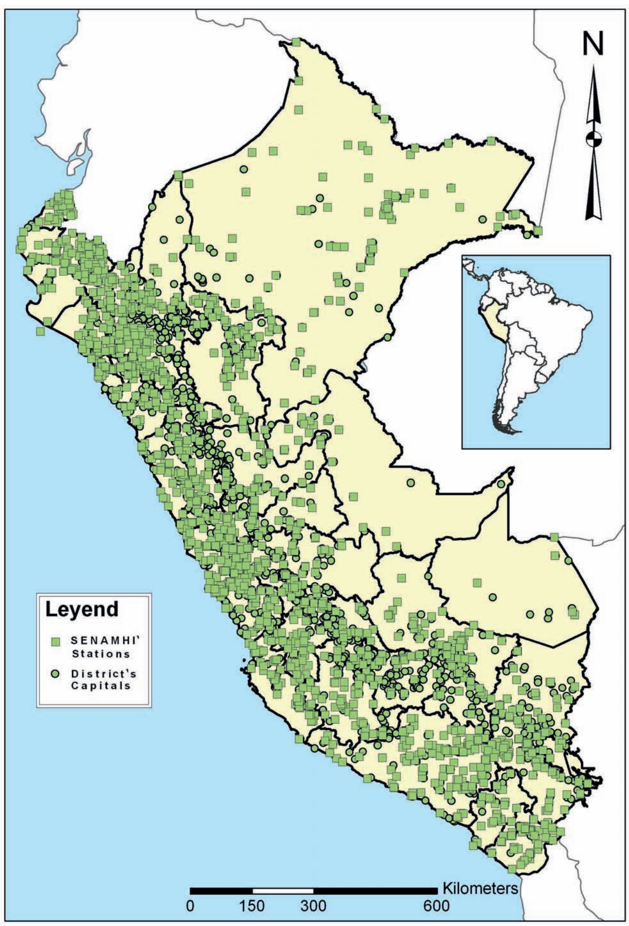

Figure 2. Distribution of the control dataset in the Peruvian territory.

Latitude (°)	Longitude (°)	Height (m a.s.l.)	Station	District
−12.5336	−75.6503	5219	Chuncho	Huantan
−15.8836	−71.8003	5038	Jollojello	Achoma
−10.4836	−76.7336	4900	Raura	Oyon
−11.6836	−76.3169	4750	La Pirhua	Carampoma
−10.7669	−76.6669	4700	Tabladas	Oyon
−13.1003	−75.0669	4685	Pultoc	Santa Ana
−15.3503	−71.1169	4680	Condoroma	Condoroma
−12.3167	−75.7229	4675	Yauricocha	Alis

Table 2. SENAMHI stations at extreme heights.

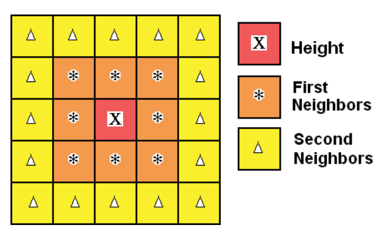

Figure 3. Pixels used for the statistical analysis.

the improvement for one of the higher zones in Peru (over 5000 m a.s.l.) when using SRTM 3" version 4.1.

The control dataset contains two subsets: (i) the nominal heights of district capitals, compiled from INEI's statistical compendium [12], with 1802 records, and (ii) the nominal heights of the SENAMHI weather and hydrological stations compiled from its website [23], with 1715 records.

Figure 2 shows that control points are less dense at eastern zones of Peru, where there is less dense population too, while Tables 1 and 2 show the range of heights between which are the control points.

The height of the pixels in which the district capitals and SENAMHI stations are located were extracted from the SRTM 3" version 4.1 DEM in order to compute the height differences. However, to investigate the local height variability in the DEM, for each control point we calculated the average height and standard deviation from their nearest pixels, using both a 3×3 pixel window (nearest neighbors) and a 5×5 pixel window (second nearest neighbors), as shown in Figure 3.

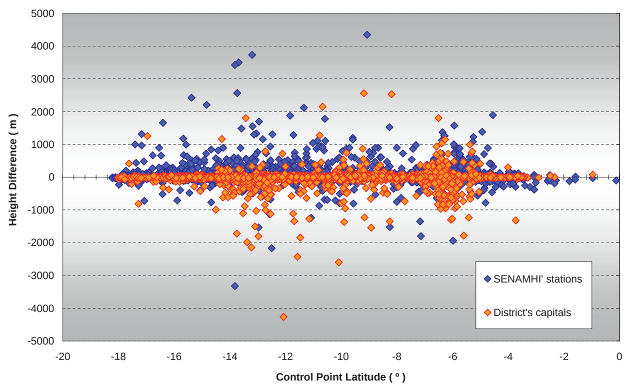

Figure 4. Height differences vs. control points' latitudes.

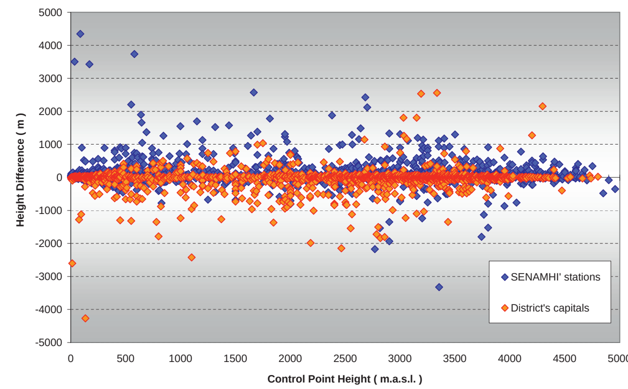

Figure 6. Height differences vs. control points' heights.

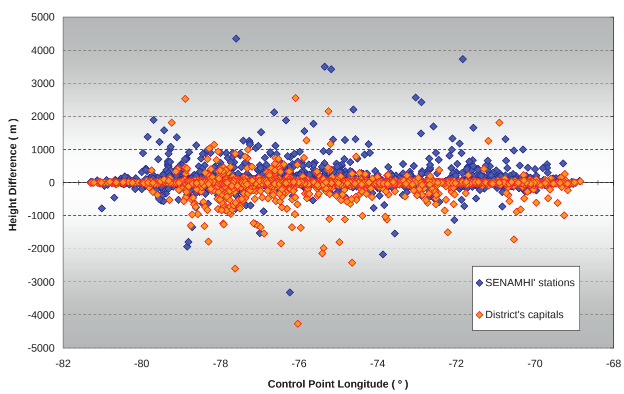

Figure 5. Height differences vs. control points' longitudes.

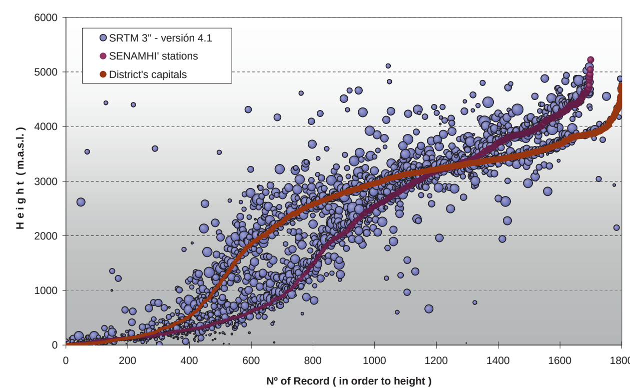

Figure 7. Uncertainty in heights of SRTM 3" version 4.1 and control points.

3 Results

The height differences between SRTM 3" version 4.1 and the control points show a very large range, varying from about −4000 m to +5000 m. Figures 4, 5 and 6 show that largest height differences are scattered over the whole range of values. That is, they seem to be related neither to the control points' location (latitude and longitude) nor to their heights.

The heights of all control points from INEI were obtained by interpolating the heights of the nearest contour from the official topographic maps (1:100 000), while the heights of control points from SENAMHI were obtained by a microbarometer (the oldest ones) or by GPS (the new ones). As a result, the control points' heights have an intrinsic uncertainty of between 10 m and 50 m.

Taking into account that voids in the SRTM's DEMs were filled by interpolation, every pixel's height in SRTM 3" version 4.1 has an intrinsic uncertainty which is related to the heights of its nearest pixels. It is therefore felt that the standard deviation of heights at second neighbor level (like 225 m around) is an acceptable measure of such uncertainty.

Accordingly, one could say that SRTM 3" version 4.1 and control points' heights match if these values overlapped when their respective uncertainties were accounted for in the height values. This situation is represented graphically in Figure 7.

The cases in which height differences are greater than 500 m in the absolute sense merit special attention because they exceed every expected error. First, they are distributed over the entire height range of control points. Also, in most cases, there is not a significant difference between the standard deviation of the heights, either at the first neighbor level or at the second neighbor level. They thus seem to be unrelated to DEM variability or to the way in which control points' heights were estimated. Finally, as shown in Figure 8, it is practically impossible that control points at low elevation would have a height difference as large as thousands of meters with respect to its corresponding pixels in the SRTM 3" version 4.1. Even at the second neighbor level (taken within 225 m), this is still the case.

When these cases are reviewed, some typing errors or misprints may be found, and this could explain some of the large differences (Table 3). However, it should also be kept in mind that these cases represent only about 10% of the records (Figure 9) and that, if they were removed, there would be no significant loss of representation at control points level for any part of Peruvian territory (Figure 10).

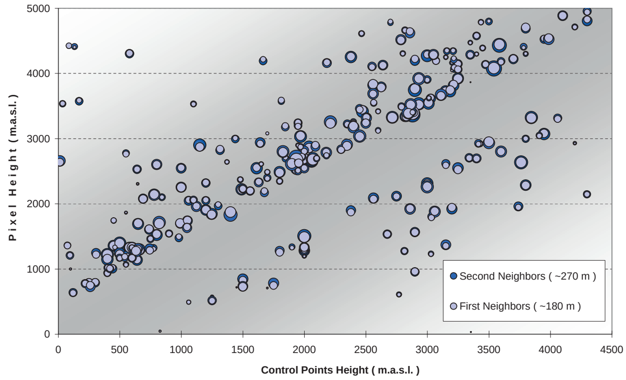

Figure 8. Cases with largest height differences between SRTM 3" version 4.1 and control points.

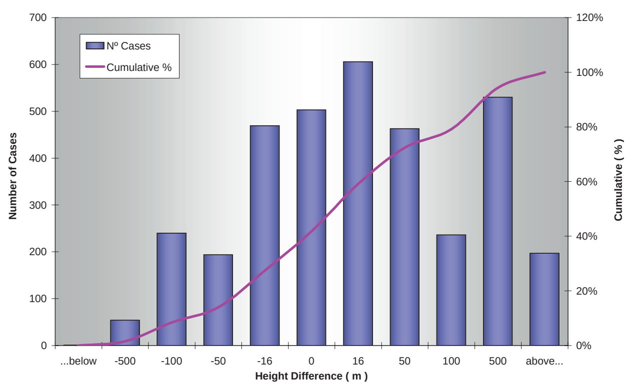

Figure 9. Statistical distribution of height differences between SRTM 3" version 4.1 and control points, all records.

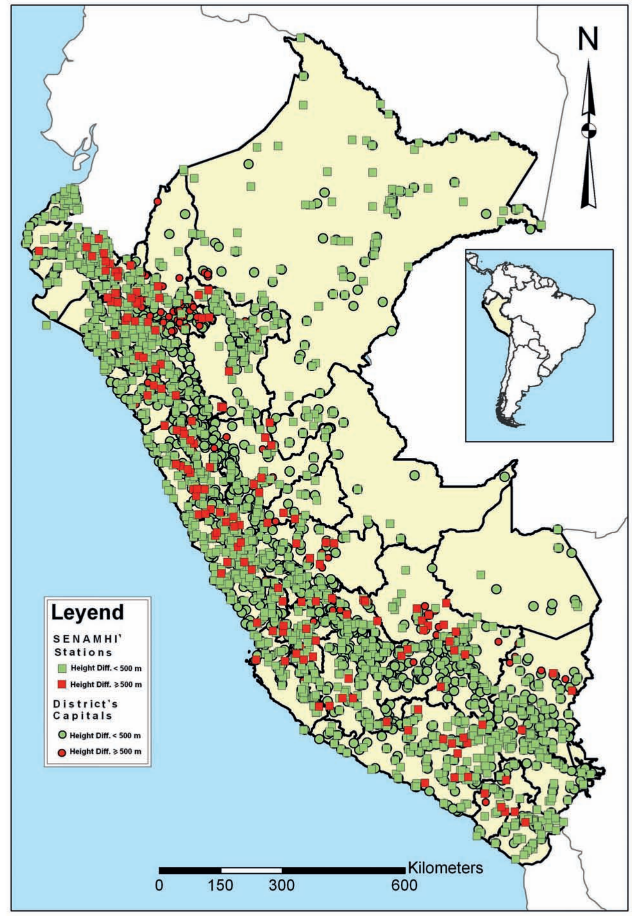

Figure 10. Spatial distribution of control points with height differences lower than 500 m (absolute sense).

4 Discussion

All control points with height differences, with respect to SRTM 3" version 4.1, greater than 500 m (in the absolute sense) will be excluded for the following analysis, because it is most probable that they contain gross errors which will introduce significant downgrades in the analysis.

The amount and the level of match between SRTM 3" version 4.1 and the control points are particularly significant because they are distributed throughout the whole range of control points' heights and over the whole territory of Peru. Figures 11 and 12 and Table 4 illustrated these facts.

From Table 4 we see that the root mean square difference (RMSD) of the height differences between the SRTM 3" version 4.1 and the (edited) control points is ±113 m for district capitals (1696 cases) and ±150 m for SENAMHI stations (1545 cases). However, if one considers, as did Fan, Xie and Shen [6], that the presence of clouds may be responsible for many of the differences above 100 m and thus exclude all records with heights differences greater than 100 m, then the RMSD for the 95% (1374 cases) of the edited records for district capitals would be ±26 m and the RMSD for the 95% (972 cases) of the clean records for SENAMHI stations would be ±37 m.

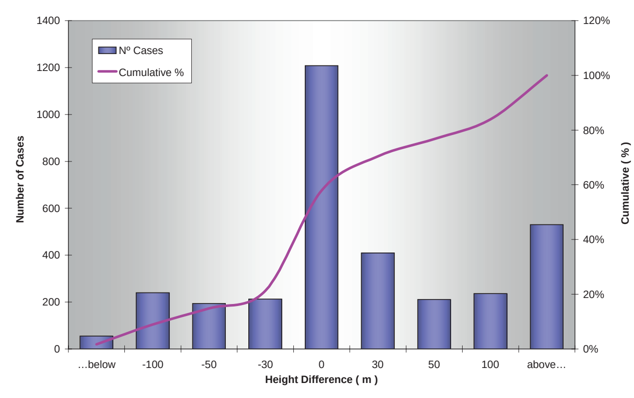

Figure 11. Statistical distribution of height difference between SRTM 3" version 4.1 and control points, suspect records deleted.

Remembering that control points' heights have an intrinsic uncertainty of as much as 50 m, we can reasonably assume that only cases with height differences less than

District	Capital	Height (m a.s.l.)	Latitude (°)	Longitude (°)	Height difference (m)	Observation
La Victoria	La Victoria	133	-12.0650	-76.0311	4266	must be $-77°$ as Lince o El Cercado
Caleta De Carquin	Caleta De Carouin	14	-10.0892	-77.6267	2602	sea is in $-78.18°$ at these latitudes
Los Olivos	Las Palmeras	75	-11.1525	-77.0706	1277	must be $-11.98°$ as Independencia
Uco	Uco	3336	-9.1853	-76.0928	-2559	it is out of Ancash, could be $-77°$

Table 3. Possible misprints in control points records.

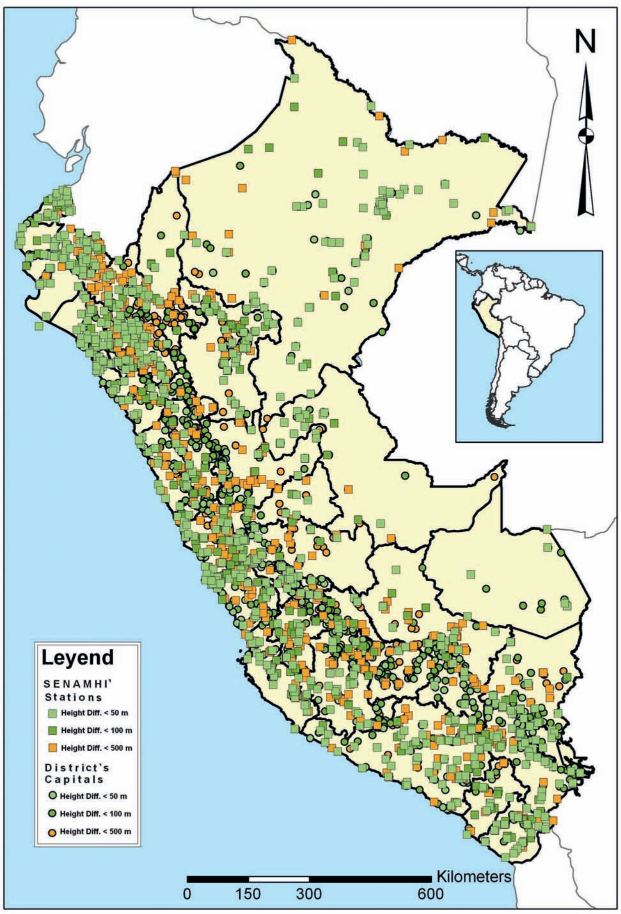

Figure 12. Spatial distribution of height difference between SRTM 3" version 4.1 and edited control points.

District capital	No. of cases	%	RMS (m)
Height difference < 50 m	1259	70%	20
Height difference < 100 m	1446	80%	32
Height difference < 500 m	1696	94%	113
Height difference < 5000 m	1798	100%	271
SENAMHI stations	**No. of cases**	**%**	**RMS (m)**
Height difference < 50 m	771	45%	25
Height difference < 100 m	1023	60%	42
Height difference < 500 m	1545	91%	150
Height difference < 5000 m	1695	100%	332

Table 4. Root mean square of absolute height differences between SRTM 3" version 4.1 and control points.

50 m would represent agreement between the heights from SRTM 3" version 4.1 and the control points. On this basis the RMSD in height is ± 20 m for district capitals (1259 cases) and ± 25 m for SENAMHI stations (771 cases). This is slightly larger than the expected global accuracy of the SRTM datasets.

In any case, the resulting RMSD in heights for edited control points are within the confidence range of SRTM 3" version 4.1 found in other studies performed in mountain areas, including those that use field data [1, 6, 20].

It appears that those control points showing absolute height differences of greater than 100 m are mostly located in the headwaters of the basin at an altitude greater than 3500 m and are usually on the western and eastern flanks of the Andes For example, the *Amazonas*'s territory is one of the areas with the highest concentration of these points. Figure 13 shows the location of those control points with respect to terrain height and Figure 14 shows them in relation to typical land cover and cloudiness, while Figure 15 shows the details of the path taken by the sensor that acquired the data for SRTM when it flew the point located in the 78.708 degrees west longitude and 4.292 degrees south latitude.

According to the path shown in Figure 15 and the distribution of control points with significant height differences, as shown in Figures 13 and 14, it seems that these points were those located in the "shadows" of the land, i.e., under a particular incident angle. This could well be an artifact of the sensor over this area, as similar effects were reported by Carabajal [2], Reuter, Nelson and Jarvis [21], Gorokhovich and Voustianiouk [9], and Racoviteanu et al. [20].

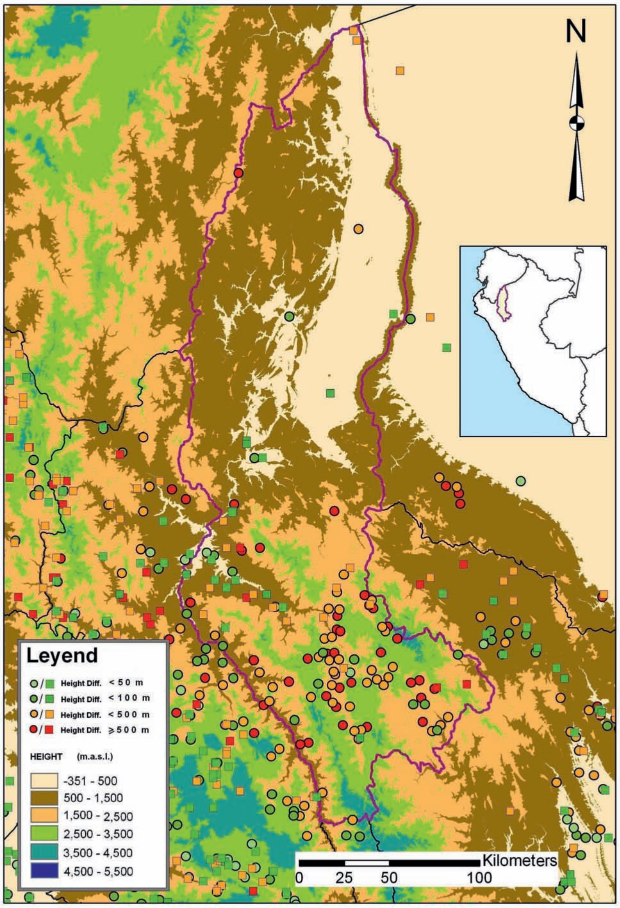

Figure 13. Control points in *Amazonas*, according to height difference with respect to SRTM 3" version 4.1.

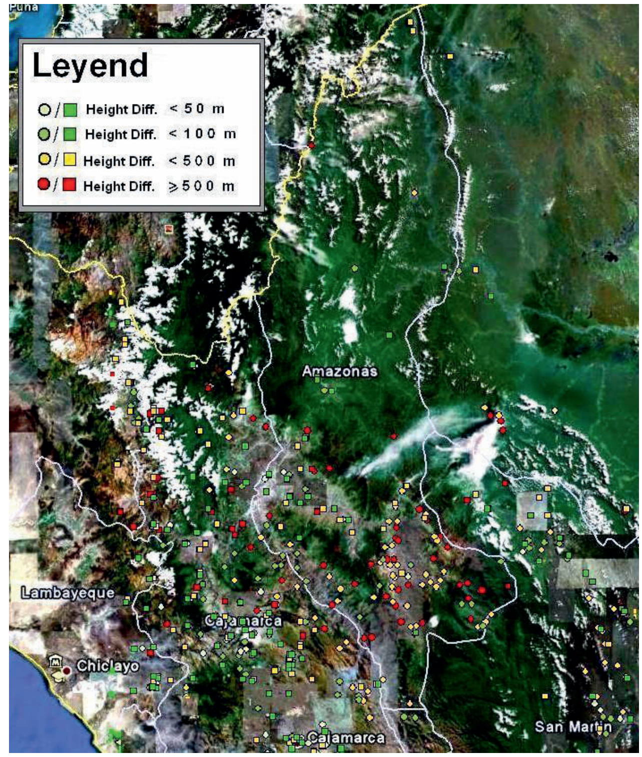

Figure 14. Satellite view of *Amazonas* (taken from Google Earth) showing the location of the control points, according to height differences with respect to SRTM 3" version 4.1.

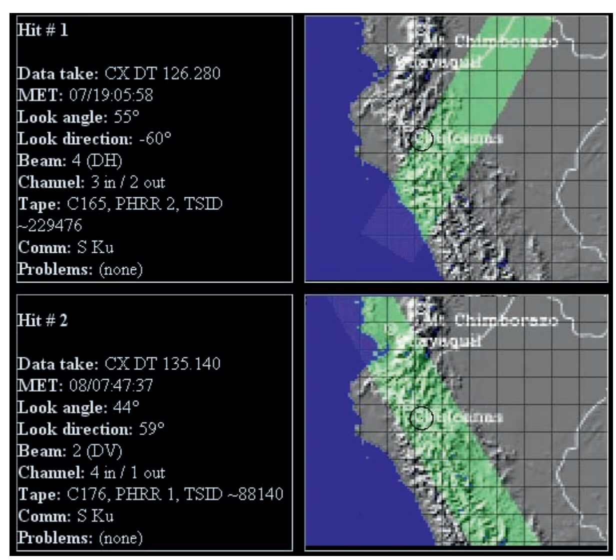

Figure 15. Technical details on the acquisition of data for SRTM on a point over *Amazonas* [17].

5 Conclusions

After validation and editing of the control data, the information from the SRTM 3" version 4.1 was statistically compatible with the local information used in the analysis. This implies that the SRTM 3" could be used to re-examine and/or be extended to studies at a national level, and may be especially useful in such disciplines as climatology, hydrology, demography, urban or highway/road planning.

The amount and quality of matches between the local databases and SRTM 3" version 4.1 infers that this latter data may be superior to the local data sets, because the SRTM transcend the dates and techniques used in the local determinations. It is also superior because of its wide coverage, relatively high precision and its free availability to the public.

It is most probable that height differences greater than 500 m are a result of errors, e.g., misprints, in the local databases, and are not due to systematic failures in SRTM 3" version 4.1. Height differences greater than 100 m could be caused by a combination of topographic and weather effects and their impact upon the SRTM mission sensor which could cause some problems in the data gathered from this sensor.

Statistically, over the whole territory of Peru, the SRTM 3" version 4.1 would have an average vertical accuracy of between 70 and 117 m, while in 56% of the evaluated cases, it should reach an accuracy of between ±20 to 25 m.

The accuracy of the SRTM 3" version 4.1 over the Peruvian territory appears to depend neither on the height nor on the geographic location of a particular location. It rather seems to be a function of the cloud cover and the elevation angle of the sensor when it acquired the data over these locations.

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