CO-051

PRELIMINARY ANALYSIS OF ACCURACY OF CONTOUR LINES USING POSITIONAL QUALITY CONTROL METHODOLOGIES FOR LINEAR ELEMENTS

UREÑA M.A., MOZAS A.T., PÉREZ J.L.
Universidad de Jaén, JAÉN, SPAIN

ABSTRACT

In this paper we preliminary study the use of a simple buffer implementation for controlling the positional accuracy of contour lines. This method consists on creating several buffers around each contour line using an increasing width in the XY plane. If we analyze two consecutive contour lines, both buffers (using the same width) generate, for each point in both contour lines, a height displacement of the profile line (in the normal distance) based on the slope. The methodology proposed in this paper consists on controlling the distribution function of a set of control points which lies inside each buffer width. These control point are obtained by a more accuracy source of data. The results have shown that the methodology used for controlling linear elements can be successfully applied to control contour lines. This method can determine the Z accuracy of these lines based on their XY displacement.

INTRODUCTION

Height representation has been traditionally achieved through contour lines, representing a continuous set of points having the same height. This representation is still in use despite of the development of new acquisition, processing and visualization technologies (Digital Surface Model DSM, Light Detection and Ranging or Laser Imaging Detection and Ranging LIDAR, etc). Nowadays, the main difference for obtaining hypsometric maps is related to the source used to determine contour lines. While traditionally they have been derived from phogrammetric restitution, now are usually obtained by interpolation from DSM or LIDAR. In this sense, several studies analyzing the quality of these products have been published, but they do not be concerned about their representation (contour lines). In this paper we analyze, from a preliminary point of view, the positional planimetric quality of contour lines using linear control methodologies instead isolated points. The determination of planimetric quality is directly related to height quality of contour lines which represent the relief.

The quality represents a basic requirement for every user of a product and cartography must be concerned about this demand. The basic components of quality of geographic data are positional accuracy, attribute accuracy, logical consistency, completeness and lineage (NCDCDS, 1988; ISO, 1999). Among these components, we consider that the positional accuracy is the main one because is the unique that describes the spatial dimension of the geographic data. Traditionally, the positional accuracy of height dimension of a GDB (Geospatial Database) has been determined independently of the accuracy of planimetric information. The positional accuracy is based on using a set of well-known control points obtained from a higher accuracy source. The selection of these control points must be concerned about allowing and guaranteeing their correct identification both in the higher accuracy source and in the tested source. There are several standards for evaluating positional accuracy of cartographic products based on point to point analysis (NMAS-USGS, 1947; EMAS-ASCE, 1983; ASPRS, 1990; NSSDA-FGDC, 1998; SDEM-USGS, 1998). Almost all of these methodologies are based on the independent determination of vertical error (e. g. difference between values, RMSE, etc.) of a sample of points and test if these values agree with a standard. This error is independently obtained from planimetric error. A more detailed description of these methods can be shown in Veregin and Giordano (1994). These methods are usually used for controlling the Z component of GDB. However, the positional accuracy analysis of contour lines (representing this Z component) has not been analyzed deeply.

An important factor for studying the positional accuracy of height component is analyzing the interpolation of points based on slope and the mean vertical error of the map (the Koppe error slope formula). This equation relates the vertical and horizontal error with the slope (using a regression and the tangent of the slope). The formula of Koppe (Eq. 1) can be used for analyzing both vertical and horizontal accuracy between the contour lines of two different maps (Gustafson and Loon, 1982; Imhof, 2007).

$$m = \pm(A + B\tan \propto) \qquad \text{Eq. 1}$$

where A and B are 2 empirically obtained constants of a particular map and α is the slope.

Using the previous equation, some institutions have established several thresholds based on slope and map scale (Imhof, 2007).

The most important studies, from a planimetric point of view, developed for analyzing the positional uncertainty of linear elements are mainly based on an uncertainly band (epsilon band) surrounding each and every entity. This band has been described by Perkal (1956) and extended by Blakemore (1983), where the real position of a line is inside a fixed displacement (epsilon) from the measure position (Zhang and Goodchild, 2002). This band is defined by two parallel lines to the most probable line and tangent to the error circles at the finish points. For example, Caspary and Scheuring (1993) suggest an error band having a minimum uncertainty placed at the centre of the segment. However, Cheung and Shi (2004) introduce an integrated error band based on elliptical distributions defined from a sample of points owned by the line.

Several methods have been developed in order to determine the uncertainty band of a line (Abbas et al. 1995; Skidmore and Turner 1992, Goodchild and Hunter 1997, Tveite and Langaas 1999, Mozas and Ariza 2010). The proposed methodologies can analyse this uncertainty using the whole line or the vertexes which compounds it. While the last are based on obtaining the Euclidian distance between vertexes of the two lines, the first applies the epsilon band concept to determine the most probable position of line and its uncertainty.

Studying the particular case of the contour lines, this error band is defined using the steepest slope direction and the mean error of the points which are included in contour line (Yoeli, 1984). This idea is extended and used by Gökgöz (2005) for contour line generalization, using the formula of Koppe for determining the points error which limits the maximum displacement allow for the line. However, this methodology requires the estimation of the planimetric error of the points in the contour line at a known scale (B and A variables of the formula of Koppe are estimated).

In order to avoid the estimation of planimetric error of contour lines, in this study we obtain an empirical value of positional uncertainty of the lines based on a higher accuracy height source. The empirical value is obtained through the methodology of simple buffer developed by Goodchild and Hunter (1997). This methodology determines a buffer surrounding the line of high accuracy or control line (Q) and then determines the percentage of the line to control (X) which is included in the buffer (Figure 1). The previous methodology is completed by increasing the buffer distance in order to obtain a distribution probability function of uncertainty of the controlled line.

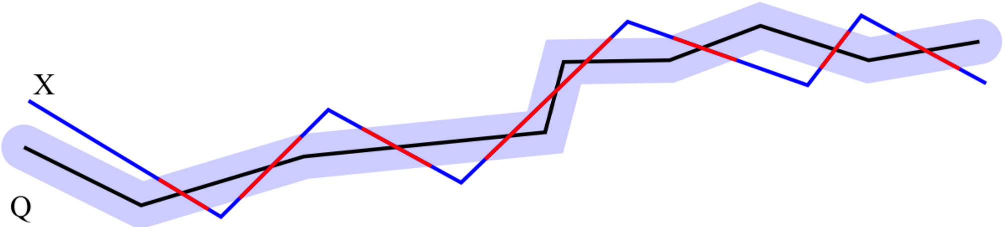

Figure 1. Simple buffer methodology described by Goodchild and Hunter, 1997

The methodology for determining uncertainty of linear elements previously described is widely presented in Mozas and Ariza (2010). In conjunction with other methodologies for controlling linear elements, this process is applied to control the planimetric positional accuracy of some elements.

METHODOLOGY

Under the previous constraints, we propose a methodology to determine the positional planimetric uncertainty of the contour lines based on the methodologies for controlling positional accuracy of linear elements (SBCLM – Simple Buffer for Contour Lines Methodology). The method is based on the one presented by Goodchild and Hunter (1997) for determining the uncertainty of planimetric lines but, in our case, applying the buffer to the steepest slope line between two contour lines. More concretely, the method consists on determining several buffers of different distances (in a planimetric way) for each contour line. The consequence of these buffers is the generation of another set of buffers in the profile passing through the steepest slope direction and their intersection points in each contour line (Figure 2). The proposed method consists on controlling the percentage of altimetric control points which are inside the defined buffer for a defined distance. Changing the buffer distance we obtain a probability distribution function that shows the uncertainty of the analysed contour lines.

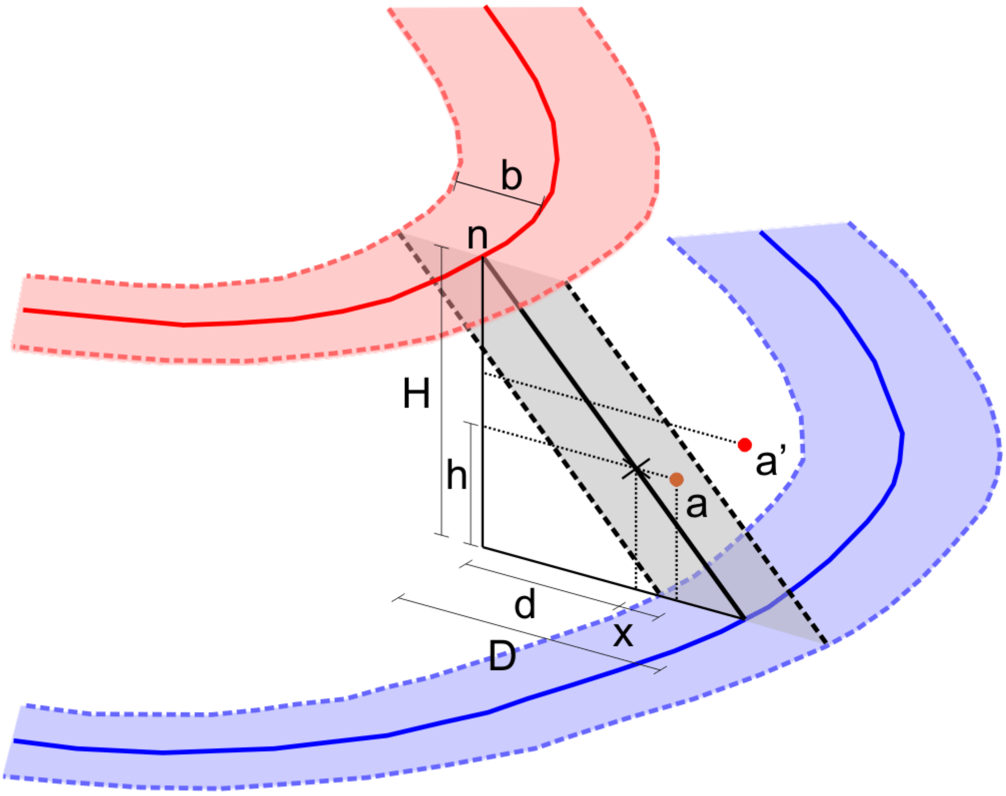

Figure 2. Simple Buffer for Contour Lines Methodology.

According to Figure 2, a point is included in the buffer if x distance is lower than buffer distance b. The d distance, corresponding to the projection of the height on the steepest slope path supposing this is the best way to interpolate height in contour lines maps, is obtained using triangle equalities. The Eq. 2 shows the formula used to determine this distance. In this way, the point a is inside the region defined by the buffer and the point a' is outside of this region, so the last point is not counted as an accuracy point.

$$d = D\frac{h}{H} \rightarrow \begin{cases} Abs(dist(a,n) - d) \leq b \rightarrow Accepted \\ Abs(dist(a,n) - d) > b \rightarrow Not\ Accepted \end{cases} \qquad \text{Eq. 2}$$

In order to obtain a sample set of control points, for analyzing height quality of contour lines, we propose using a Digital Elevation Model (DEM), or if not available, a set of points derived from GPS, LIDAR, or other source of height data (always having a higher accuracy than the contour lines to be controlled). The methodology described in this paper is based on the use of a DEM as the higher accuracy information because, nowadays, is fairly simple of acquire one for almost all Earth surface (e.g. the SRTM NASA mission, in its different versions, DEM developed by National Mapping Agencies, DEM derived from satellite platforms like ASTER and SPOT). With this idea in mind, the procedure for determining d and x distance was:

1. Calculate the slope of each control point: The slope is determined using the gradient of the DEM data in this point. All points having a zero slope are supposed to be part of a maximum or minimum height (sinks or peaks). Because the methodology only controls contour lines, these points are excluded.

2. Determine a set of contour lines surrounding the control point by a canonical cut at a defined distance (Figure 3). This distance limits de minimum allowed slope from the point.

3. Determine the two contour lines closest, in Euclidean distance, to the control point (Figure 3). Both distances must be determined using the representation element (spline, arc, linear element or others) and not only the vertexes that compound each contour line.

4. Test two particular situations of the previously determined contour lines with regards to the control point derived from a non-topological description of the data:

- The first is derived from datum differences (or transformation of datum), temporal discrepancies or any other circumstances that displaces contour lines producing a set of points not surrounded by the adequate lines (a contour line upper than the point and the other lower). These points are detected by the methodology and are interesting for analyzing huge discrepancies between the used DEM and the contour lines map.

- The second situation corresponds to a problem derived from the general cuts of maps in sheets (it will not arise if we use a continuous set of data) or derived from the analysis of contour lines and not peaks or sinks. In both cases, the two closest contour lines do not correspond to the contour lines that must be used to interpolate point height.

5. Both cases are detected using the same methodology that is to control if the vector that starts on the control point and ends in the minimum distance direction to the second closest contour line do not intersect the closest contour line. If the intersection is obtained the point is in a position related to the particular situations and cannot be used for controlling contour lines (and it is not even interesting for controlling quality). If no intersection is achieved, the point can be used safely.

6. Filtering the previous set of data for assuring that distances approximate to steepest slope path between contour lines and includes the control point. The selected point has an angle between the vectors from it to both contour lines limited to 30º. (Figure 3).

7. Determine all statistical data for each control point and selected contour lines (minimum planimetric distances, intersections point, angle between vector, local slope, etc.).

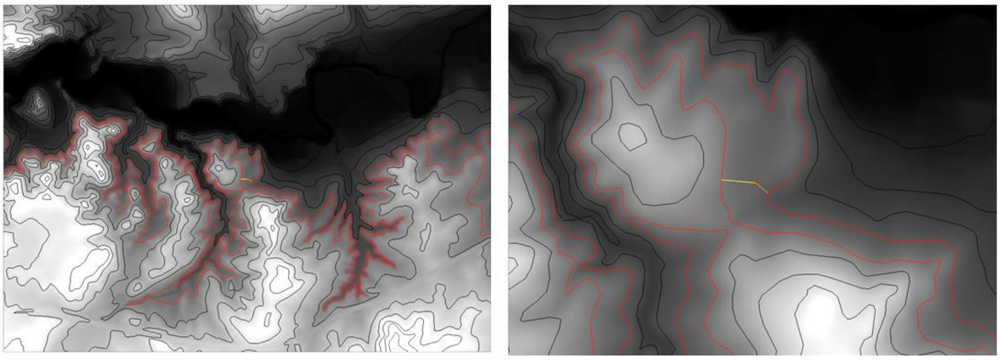

Figure 3. Procedure used for determining distances and slopes for each control point vs. The contour line map: Left) Canonical cut; Right) Detail of the selected control point.

After obtaining all control points and all statistical data defined in step 6, the set of buffers is created. Then, we proceeded to determine the percentage of points included for each buffer distance, determining the statistical distribution function of the included points. This function represents the probability of an interpolated point to agree with the distance for being considered correctly interpolated from contour lines. For this reason, the previous function defines the positional uncertainty of the contour line.

APPLICATION AND RESULTS

The proposed methodology has been applied to an area of 14700x9300 meters for controlling a contour line map at 1/25000 scale having a equidistance of 10 meters (CN25k. Lines of Figure 4). This contour line map was extracted from the National Topographic Map of Spain produced by Instituto Geográfico Nacional (IGN), the datum is European Terrestrial Reference System 1989 (ETRS89). The source of higher accuracy was a DEM of 10 meters spatial resolution (DEM10m. Background grey image of Figure 4) produced by Instituto de Cartografía de Andalucía (ICA), with and original datum European Datum 1950 (transformed to ETRS89 using IGN algorithm with a maximum error of 0.15 meters). Because the cartographic information is developed by different mapping agencies and having a different time of data survey, we derived a dependant contour line map from DEM10m. This new map has the same equidistance than 1/25000 map and we have called CN10m. This map was obtained by creating a Triangular Irregular Network (TIN) composed by all points of DEM10m. Then, this TIN is converted in contour lines using ArcMap 9.2 (TIN contour from 3D Analysis) with a lineal interpolation inside each triangle. Table 1 shows a brief description of the two contour lines maps applied in this study and the general values of the DEM10m.

	CN25k	CN10m
Number of contour lines	145	388
Number of vertexes	14442	131656
Mean length	2909 m	1114 m
Mean sinuosity (non-closed polylines)	4.8	>1e6 (Automatically obtained)
Mean height	564.3 m	565 m
Minimum height	510 m	510 m
Maximum height	630 m	630 m
Mean slope	16.8%	18.1%
Minimum slope	1.5%	2.0%
Maximum slope	851.4%	157.3%

Table 1. Statistics of the contour lines controlled and the DEM used for controlling.

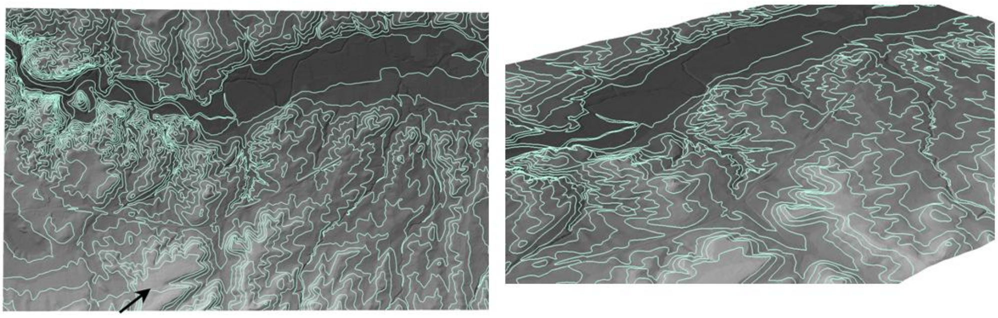

Figure 4. Dataset used for testing the methodology. The lines represent CN25k, the background represents DEM10m in a grey scale (each grey represents 10 meters of height, white levels represent higher values). Left) Top view. Right) Perspective view (using ArcScene).

The set of control points (DEM10m), after the filtering phase described in the methodology is composed of more than 70000 points for comparison between DEM10m and CN25k and more than 60000 points for comparison between DEM10m and CN10m. The last set of points was also limited by the point used in the first set.

The result obtained by applying the proposed methodology is shown in Figure 5, the lower line represents the statistical distribution function of the testing of CN25k while the upper line represents the testing of DEM10m. Both lines show an increasing trend when the buffer distance increases. As we expected, the line representing the comparison with CN10m shows better percentage than the one representing CN25k. This allows us to confirm that CN10m can be used as a control set for the methodology. This line of CN10m reaches a great percentage of inclusion of 90% at a buffer distance of 18 meters, thus a low uncertainty. However, the line of CN25k needs a higher distance, 40 meters, to achieve the same 90% of inclusion, a higher uncertainty than the previous contour map. If we watch to 50% of inclusion percentage, we can see that CN25k needs 10 meters of buffer distance while CN10m needs only 3 meters (3 times lower than the original spatial resolution of the DEM from the contour lines are derived). The difference between both statistical distributions is shown in Figure 6. The difference function shows its maximum at 5 meters ascending rapidly previously to this value and descending softly after the threshold value.

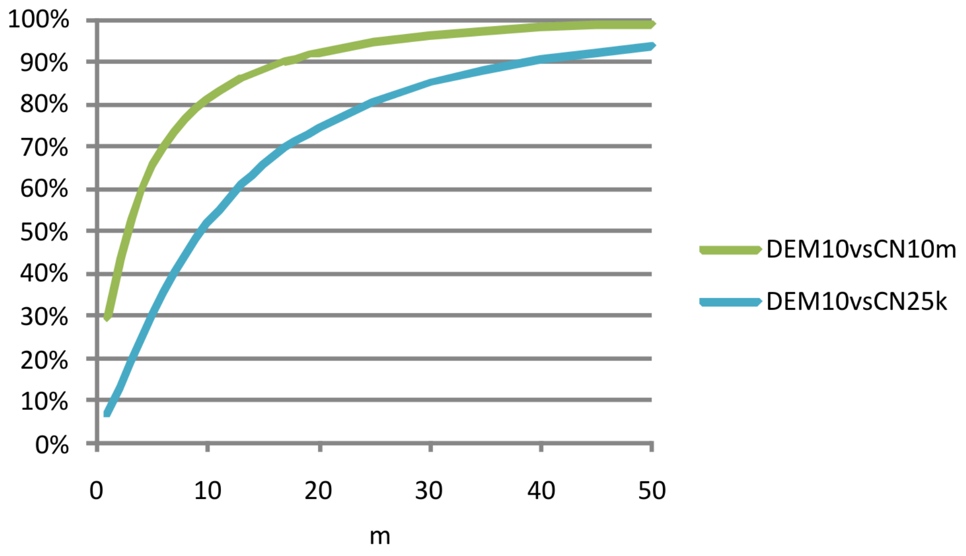

Figure 5. Statistical distribution functions for CN10m and CN25k.

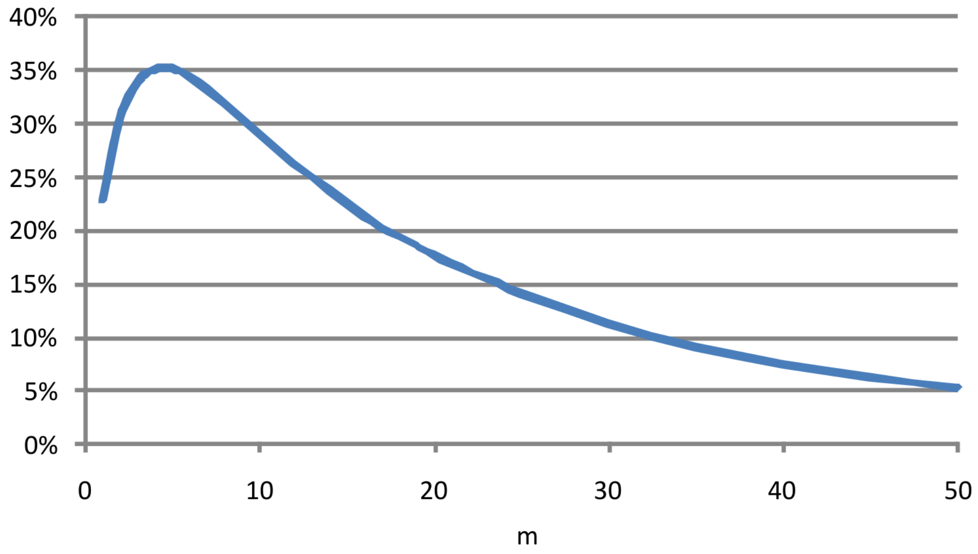

Figure 6. Difference between statistical functions of CN10 and CN25k.

When the analysis is made by classifying the control points using the local slope we obtained the result shown in Figure 7 (CN25k) and Figure 8 (CN10m). The slope is distributed in different ranges from 1% to more than 100%. Both figures show similar trends, the inclusion values are higher when the buffer distance increases, but, as we have described for the accumulated case (Figure 5 and 6), the percentage of inclusion is always better for CN10m than for CN25k.

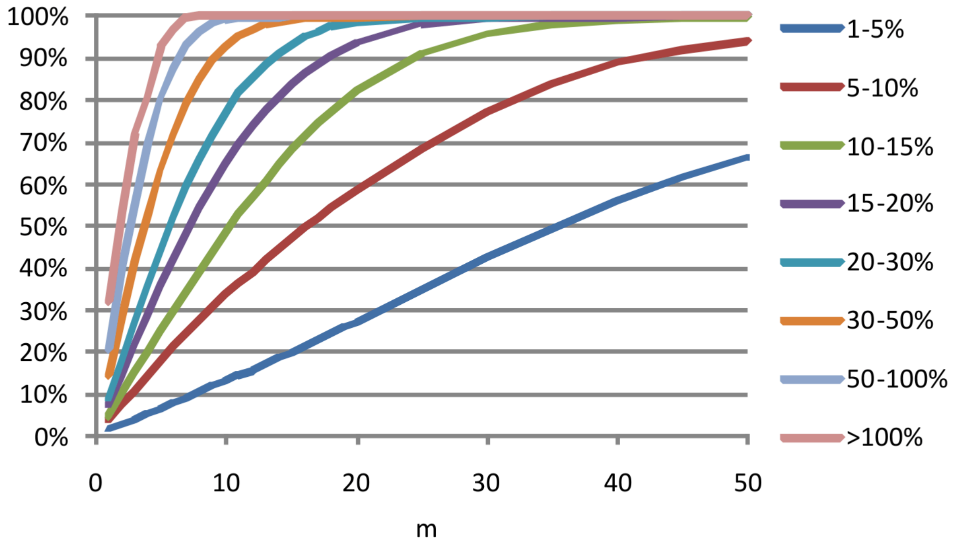

Figure 7. Results of CN25k classified by slope ranges.

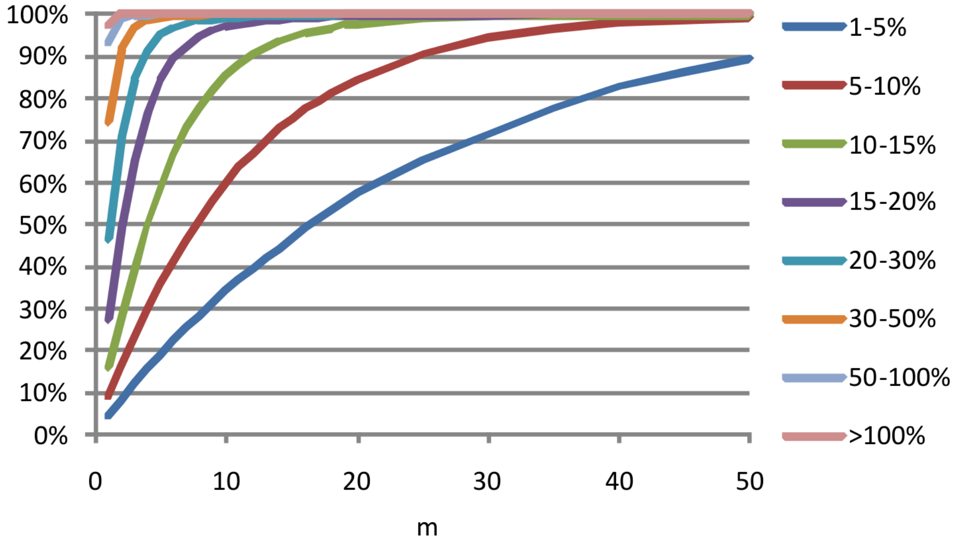

Figure 8. Results of CN10m classified by slope ranges.

ANALYSIS

The difference between the statistical distribution functions of both contour lines maps (CN25k versus CN10m) determines the goodness of the height precision of an interpolated point. The planimetric uncertainty obtained using the proposed methodology shows a light difference between both maps. The result corresponding to CN10m presents higher percentages for lower buffer distance (Figure 5). This uncertainty can be initially considered as a part of the spatial resolution of the DEM (10 m in planimetry), for this reason any value which is lower than the spatial resolution in the diagonal (14.4 m). Moreover, the process used for obtaining the control set (CN10m) and the used equidistance alters both the configuration and distribution of contour lines (but in our case the equidistance is fitted to 10 meters because it has to be equal to the one defined by CN25k, and the methodology only allow low displacement because the original DEM10m is fitted to 10 meters spatial resolution).

The result for the CN25k has lower percentage of inclusion for the same buffer distance than CN10m (Figure 5). This uncertainty is better observed for the 90% of inclusion that needs a buffer distance of 40 meters. This can be due to some possible reasons: the first, the planimetric and altimetric positional differences between the DEM10m and the CN25k; the second can be the representation of contour lines which absorbs the non-representative elements of the relief; finally the methodology used for obtaining the contour lines (which can differ for CN25k and CN10m). However, the obtained comparisons (DEM10m with CN10m and DEM10m with CN25k) show similar trends despite of the initial differences detected by visually review. These differences were attributed to datum difference in height and a temporal difference.

But, the proposed methodology is good enough to determine the increase in precision of the CN10m with regards to CN25k.

The analysis of Figure 6 determines a maximum value for the difference function at 5 meters of buffer distance. From this value the decreasing trend is clearly observed but having a low rate. If this rate is higher both contour line maps are more similar, so the DEM is well represented by the contour line. The distance of 5 meters of maximum difference can represent the difference in the planimetric position or an offset of the DEM10 data with regards to CN25k.

The obtained result shows, a generally assumed idea, that the statistical distribution function representing soft slopes (Figures 7 and 8) has more planimetric uncertainty than the ones representing high slopes. This assertion coincides with the mean error definition derived from the formula of Koppe (Gustafson and Loon, 1982; Imhof, 2007). In this case, Imhof (2007) proposes changing the width of each section of contour lines based on the uncertainty values derived from the slopes, but with our methodology we can determine these values based on the buffer distance for a desired percentage of precision.

Following the idea described in the previous paragraph, in order to keep a defined level of positional uncertainty, the representation of the contour lines can be improved by including a new set of intermediate contour lines based on the slope (Imhof, 2007) in order to reduce the planimetric uncertainty in zones having low slope.

CONCLUSIONS

The preliminary study presented in this paper has demonstrated the viability of the methodology for controlling the height quality based on linear elements, in our case contour lines. This methodology allows determining the precision in the height of the planimetric uncertainty of the contour lines. The result obtained by comparing the tested data (CN25k) with a control data (CN10m) shows that is possible to determine and quantify the planimetric errors between a DEM and a contour line map independently of temporal discrepancies and altimetric datum differences.

This work is a starting point for developing a complete analysis of the quality of a height map based on contour lines. In future works we will isolate the altimetric precision of the contour lines from the used slope, we will apply to another sets of data (not only contour lines from traditional methodologies but from LIDAR or photogrammetric matching methodologies). We also will analyze and try to discriminate the uncertainty derived from the methodology used for creating the CN10m control set.

REFERENCES

Abbas, I.; Grussenmeyer, P.; Hottier, P. (1995). Contrôle de la planimétrie d’une base de données vectorielle: une nouvelle méthode basée sur la distance de Hausdorff: la méthode du contrôle linéaire. Bul. S.F.P.T., 1 (137): 6-11.

American Society of Civil Engineers ASCE (1983). Map Uses, scales and accuracies for engineering and associated purposes, Committee on Cartographic Surveying, Surveying and Mapping Division, New York.

American Society for Photogrammetry and Remote Sensing ASPRS (1990). ASPRS Accuracy Standards for Large-Scale Maps, Photogrammetric Engineering and Remote Sensing, 56 (7): 1068-1070.

Blakemore (1983). Generalisation and Error in Spatial Data Bases. Cartographica, 21: 131-139.

Caspary, W.; Scheuring, R. (1993). Positional accuracy in spatial databases. Computer, Environment and Urban Systems, 17: 103-110.

Cheung, C.K.; Shi, W. (2004). Estimation of the positional uncertainty in line simplification in GIS. The Cartographic Journal. 41(1): 37-45.

Federal Geographic Data Committee FGDC (1998). Geospatial Positioning Accuracy Standards. Part 3: National Standard for Spatial Data Accuracy (FGDC-STD-007.3-1998), F.G.D.C., Washington, D.C.

Giordano, A.; Veregin, H. (1994). Il controllo di qualitá nei sistema informative territoriali. Il Cardo, Venecia, Italia.

Goodchild, M.; Hunter, G. (1997). A simple positional accuracy for linear features. Int. Journal Geographical Information Science, 11 (3): 299-306.

Gökgöz, T. (2005). Generalization of Contours Using Deviation Angles and Error Bands. The Cartographic Journal, 42 (2): 145-156.

Gustafson, G.C.; Loon, J.C. 1982: Contour accuracy and the National Map Accuracy Standards . Surveying and Mapping, 42: 385-402.

International Standard Organization ISO (1999). ISO-15046-13: Geographic Information-Quality principles. ISO/TC 211/WG 1

Imhof, E. (2007). Cartographic Relief Presentation (reprint), edited by H. J. Steward, ESRI Press, Redlands, USA.

Mozas, A.; Ariza F. J. (2010). Methodology for positional quality control in cartography using linear features. The Cartographic Journal, 47 (4): 371-378.

National Committee for Digital Cartographic Data NCDCDS (1989). Spatial data transfer Standard (SDTS).

Perkal, J. (1956). On epsilon length. Bulletin de l'Academie Polonaise des Sciences, 4. pp. 399-403.

Skidmore, A.; Turner B. (1992). Map Accuracy Assessment Using Line Intersect Sampling. Photogrammetric Engineering and Remote Sensing, 58 (10): 1453-1457.

Tveite, H.; Langaas, S. (1999). An accuracy assessment meted for geographical line data sets based on buffering, Int. Journal Geographical Information Science, 13 (1): 27-47.

United States Geological Survey USGS (1947). United States National Map Accuracy Standards.

United States Geological Survey USGS (1998). Standards for Digital Elevation Models.

Yoeli, P. (1984). Error-Bands of Topographical Contours with Computer and Plotter (Program KOPPE), Geo-Processing, 2: 287–97.

Zhang, J.; Goodchild, M. (2002). Uncertainty in Geographical Information. Ed. Taylor & Francis. London, New York.