Cartography of High Mountain Areas

Testing of a New Digital Cliff Drawing Method

Loïc Gondol, Arnaud Le Bris, François Lecordix
Institut géographique national, Saint-Mandé Cédex, France

Abstract

From now on, the French National Mapping Agengy (IGN France) is set up with the BDTopo®. This is a topographic vector database that covers the whole national territory. IGN decided to produce base maps at 1:25k and 1:50k from this database. On topographic mountain maps, rock areas are among the map elements that are the most difficult to produce with digital cartography. In the past, they have been drawn manually by experienced cartographers, using graphic means and working with aerial photographs. Now, we need to focus on 2 points with a digital approach. The first one is the detection and an automated classification of concerned areas. The next one is the development of an adapted cartographic representation of rocks and scree areas. This article presents the first results on these problems. As far as possible, we aim at having automated high mountain cartography with lower production costs. Also, we would like it to be as expressive as it was in previous maps. This is to keep the same cartographic quality of the current base map at 1:25k and 1:50k.

1. Context

1.1. The BD TOPO®

The French National Mapping Agency has decided to create a topographic database for several years. This is the BD TOPO®. This vector database provides some geographic information about road, rails, electric and hydrographical networks, but also about buildings, administrative boundaries, toponymy, land use and relief. The first version of the BD TOPO® (V1) was mainly acquired by digital restitution, and it included all the needed information for the map at 1:25k. However it required a huge workload and therefore too much time to realise this database on the whole territory. In 2000, IGN France chose a new lighter specification for the BD TOPO® that allowed its completion on the whole territory by the beginning of 2007.

Beyond various applications linked to GIS, the BD TOPO® is also useful to derive the base map, produced and diffused by IGN France. The base map includes a topographic map at 1:25k and another one at 1:50k. Since 1993, 450 out of 1800 maps at 1:25k have entirely been digitized from the BD TOPO® V1 on several areas of the national territory.

Nevertheless, up to now, no map covering a high mountain area has been done from the BD TOPO® V1. In fact, the cartographic representation of these areas is knotty dealing with a digital production. On high mountain areas, all current base map versions come from revisions of former versions drawn manually years ago. They are not originally from BD TOPO®. As a result, we currently have 2 distinct processes to collect data, update the database and the topographic map.

1.2. The New Base Map Project

In 2004, IGN France decided to launch the New Base Map Project in order to derive the base map from the BD TOPO® with its new specifications, and to reduce update costs of next base map versions. The process is planned to work on the whole territory, and then on high mountain areas.

Among other issues, this project has to provide solutions to retrieve the needed information for the map that is lacking in the new specifications of the BD TOPO®. In particular, the land use is one of the main incomplete themes. This recovery issue is especially perceptible in high mountain areas where a paramount part of the map information deals with mountain land use: rocks, scree, glaciers… Without these themes, mountain maps would appear uncluttered and could not satisfy users.

It is not enough to recover the needed information in high mountain areas. Indeed, another issue arises that has to be carried out by the New Base Map Project. It deals with the digital representation of these specific themes, in order to get the most expressive possible result on concerned areas.

1.3. From manual to digital drawing

During the history of cartography, a lot of solutions have been tested out for the cartographic representation of mountain areas on topographic maps. In (Imhof, 1982), a literature review of these solutions is presented. The relief aspect often comes from a combination of different techniques: hill shading, graphic means, contour lines with a colorimetry depending on areas (glaciers, rocks…), etc. But up to now, the solutions that have been carried out and the best provided results are only the outcome of traditional graphic techniques. Fig. 2 shows an extract of an IGN topographic map at 1:25k, where an example of this cartographic result on the Alps is shown.

In the beginning of the 2000's, IGN France launched the first studies with the purpose of considering the feasibility of substituting digital solutions by traditional methods (Le Men et al., 2002). These works focused on the automatic extraction of needed map information (rock areas, scree, glaciers) and provided the first steps for data representation. These study results provided in a digitally manner are presented on fig. 3. This is the same area that was used in fig. 2, where results are obtained manually.

The New Base Map Project has been continuing these first works. In particular, it looks at improving final cartographic results. Dealing with data retrieval, the MATIS, a research laboratory of IGN in image processing, has been carrying out the study.

2. Information retrieval

2.1. Problem presentation and proposed solutions

Two ways of getting back landcover information that lacks from BD TOPO® but is necessary to obtain the topographic map are possible since it can be extracted either from aerial (ortho-)images (through (semi-)automatic classification) or from present maps (owing to removing moiré patterns techniques). As the cartography of these missing landcover themes is not up to date in present maps, the first solution has been given up. So, the chosen solution consists in extracting landcover information out of aerial orthophotos from BD ORTHO® through a supervised classification method. The only lacking landcover themes necessary to make the map are rocks, scree and glaciers. However, the classification legend must contain more items than these three lacking themes to obtain a landcover classification of whole mountainous areas. In this instance, the legend classification consists of the six following classes: rocks, scree, glaciers, forests, high mountain pastures and water areas (lakes).

In high mountain areas, landcover extraction using aerial photographs is bothered by several phenomena:

- Shady areas are often spread out.

- The radiometry of a same theme can widely vary from one image part to another. This phenomenon can be due to lighting differences related to the rough relief. It can also be "artificial" (since the image is in fact a mosaic of orthorectified aerial images which have not been captured at the same time and have undergone several different radiometric treatments) or natural (as for instance in case of changes in geology).

- Some of the land use themes have a very close radiometry; they look like each other on the aerial photograph. For instance, scree (especially torrent bed scree) are sometimes as vivid as glaciers. Similarities between rocks and scree, shadows and water areas can also be quoted. This last phenomenon is deepened by the radiometry variance phenomenon, explained above.

As a consequence, image information is not sufficient to extract landcover using a semi-automatic classification. That's why complementary knowledge has to be introduced in the classification process. Two different kinds of external information are useful:

- On one hand, this is knowledge depicting relief since landcover strongly depends on altitude, slope and orientation in mountain areas. This information can easily be computed from a Digital Terrain Model.

- On the other hand, knowledge from another data base can also be used. In the present case, the European data base CORINE Land Cover 2000 (CLC2000) dealing with land use has been employed (Bossard et al., 2000). This data base is more generalised than the base map: the smallest mapped area is 25 hectares and the better scale to use the data base is 1:100k. Its legend is different as well: its semantic precision varies depending on cases. For example, a difference exists between kinds of forests whereas rocks and scree are contained within a unique class. In other cases, some CLC2000 classes are related to intermediate situations between several of our classes: "forest and evolving shrubby vegetation" is linked both to forest and high mountain pastures.

As the shadow areas are important on the image, they must also be taken into account to obtain a classification of the whole area. It is possible either to correct shadows (it means to detect shady areas and then to adjust the radiometry there) or to divide each landcover class "c" in two and then to get a class "c in shadow" and another one "c in light". Of course, these two classes are aggregated at the end of the classification. This last solution has been chosen since, in fact, a shadow correction would suffer from the consequences of DTM imprecision and doubts linked to the orthoimage. Remind us that the orthoimage is a mosaic of merged orthorectified aerial photographs captured at different times (and thus the precise capture time of each pixel of the orthoimage can not be known precisely) and having undergone different radiometric treatments. However, a method using radiometric correction in shady areas has been successfully developed by (Le Men et al., 2002) during the first studies about this issue.

Thus the technique described above is not used. Nevertheless, an approximate knowledge about shady areas can be taken into account. Even though the available information is not sufficient to precisely detect and correct shadows, it can be used to compute an approximate prior probability for each pixel of the image of being in shadow knowing the DTM (since the beginning and final time of data capture of all the images are known even if the exact capture time of each pixel of the orthoimage is not precisely known). It could help to discriminate dark themes (such as water) in light from themes in shadow. After its computation, this probability can be reintroduced in the classification process.

2.2. Method

The landcover extraction method encompasses two steps: segmentation and then classification.

First, the image is segmented, which means it is split up in several homogeneous regions (Fig.4). A description of the used segmentation tool can be found in (Guigues, 2004) and (Guigues et al., 2006).

The second step is classification strictly speaking: a class is given to each region of the segmentation. The main interest of classifying regions is to prevent from obtaining too noisy results. The classification method carried out in this case is a MAP classification method. All explanations about this technique are presented in (Trias-Sanz, 2006) and (Trias-Sanz and Boldo, 2005). Information is processed in terms of probability. The final class given to a region is then its most likely one.

The way image information is used by the classification algorithm is explained in details in (Trias-Sanz and Boldo, 2005). First, a model is computed from training data previously captured on the image by an operator. This is an n-dimensional radiometric and statistic model (with n standing for the number of channels used for the classification). To achieve this, for each class, a radiometric distribution, i.e. a histogram, is computed from training data before being modelled by statistical distributions such as simple histograms (raw or obtained by kernel density estimation) or parametric statistical laws (as Gaussian, Laplacian or even uniform laws). At the end, one of these models is chosen for each class by two criteria: its ability to describe ground truth (it means to fit to training data) and its complexity (Schwarz, 1978). The more complex the model is, the more degrees of freedom it has, the better it is able to describe training data. However, a complex model is also at risk to “stick“ too much to training data without describing the whole ground truth as well as a simpler one. So, at the end of this model estimation step, a model allowing to compute for each pixel s its probability of belonging to class c knowing its radiometry I(s) is available. By deduction, the probability for region R of belonging to a class c knowing the radiometry I(R) of its pixels can also be computed.

Useful channels for classification are not necessarily original image bands; that is to say red-blue-green-near infrared, but derived ones such as intensity, hue, vegetation index “NDVI”, or channels in another colorimetric space like the Karhunen-Loève one. An association of derived channels can bring better results since some channels are in fact more efficient than others to separate some classes.

External information is introduced in the classification process as prior probabilities in relation to this probability knowing image (Le Bris and Boldo, 2007). This requires an interpretation of this knowledge in terms of probability.

In mountainous areas, landcover is strongly related to relief. Thus it depends on altitude, slope and orientation, making it possible to compute the probability of finding the different themes knowing these three parameters. Such a model is proposed by (Le Men et al., 2002) from physical geography knowledge (such as such as the lowest and highest limits of the landcover themes…) presented by (Elhai, 1968) and (Lacambre, 2001). It consists of two distinct models (made of piecewise linear mathematical functions illustrated on figure 7) depending on the altitude and the slope. Orientation has a significant influence only on forests and glaciers areas. So this parameter is taken into account only for these themes.

CORINE Land Cover 2000 (CLC2000) information must also be introduced into the classification process as prior probability. This database is more generalised than the expected results: as a consequence, a CLC2000 area is likely to contain several classification themes. Besides, as its legend is not the same, several themes of our classification can be related to one specific CLC2000 legend item, and vice versa. Therefore the introduction of information from CLC2000 in the classification process must deal with those two kinds of uncertainties. An empiric probability model has been put forward to cope with this: a correspondence probability value P(Tclassif|Tclc) has been empirically assigned to each CLC2000 item Tclc and to each classification class Tclassif. For instance, for the CLC2000 class named “forest and evolving shrubby vegetation”, the probability of finding water areas and glaciers is null. It equals 77% for forests, 20% for high mountain pastures, 1% for rocks and 2% for scree areas.

In the same way, shadow knowledge is taken into account using probabilities of being in shadow knowing the relief, i.e. the DTM, and the time interval of image capture.

A balance between these different information sources is applied. This allows to give more or less strength to some of them but also to modify the degree of generalisation of the result (the higher the CLC2000 weight is, the more generalised the result is).

To sum up, the class c given to a specific region R is the one that maximises the product of the probabilities for this region of belonging to c, knowing the different information sources. In fact, region R’s final class is its most probable class according to these different information sources.

2.3. Results

This method has been tested in two study cases. The first test zone located in the Alps, near St-Christophe-en-Oisans has already been the test zone of the preliminary study (Le Men et al, 2002). All the classification themes are present there, but only an old 3-bands (red-green-blue) orthoimage made from argentic scanned photographs is available. Due to large radiometry variations within the image, it was sometimes difficult, even for an operator, to identify classes. The second test area is situated in the Pyrenees, around the Ossau peak. Orthoimages have been produced from 4-bands (red-blue-green-infrared) digital photographs. All classification themes, except for significant glaciers, were present.

Results have been visually evaluated by looking at the whole area revealing no major errors (Fig. 7 and 8). In addition, most of the classification regions have a meaningful size to be relevant on the topographic map. Results have also been numerically evaluated (on smaller test zones in the image), by computing confusion matrices comparing test data captured by an operator to classification result s. More details about these results can be seen at Fig. 1. On the second test area, almost 88% of pixels are classified in a right way whereas without any external knowledge, 75% of them are well classified. On the first test zone, results are not so good, which can be explained by the poorer quality of images, leading to the case where it is sometimes difficult even for a human operator to identify classes. Us-ac corresponds to the probability for a classified pixel of being really part of its class whereas Pr-ac stands for the probability for a ground pixel belonging to a given class of being well classified.

For this classification, several parameters have been tested. In particular, these tests have shown that many channel combinations are able to provide satisfying results that are almost equivalent. The channels association "intensity - hue - NDVI (Normalized Difference Vegetation Index)" and the three channels of the Karhunen-Loève colorimetric space (Wang, 2003) are among the channels combinations giving the best results. The significance of the external knowledge and the importance of the balance between them have also been proven.

At the end of the classification, the divided classes "c in the shadow" and "c in the light" are aggregated in a unique class "c". Then, we only keep missing themes from BD TOPO®, it means rocks, scree and glaciers since information dealing with other themes is either already available or manually digitized. So all needed land use information is available in order to make the 1:25k-scale topographic map. Now, it needs to be mapped.

2.4. Further processes for the cartographic representation

Additional processes have been carried out in order to enrich and simplify data for cartographic requirements.

For instance, on one hand, too small areas are filtered out because they would be irrelevant and unreadable at a given scale, i.e. 1:25k in this case.

On the other hand, some processes aim at extracting more information from relief and the previous classification in order to improve the final cartographic representation. So steep slope areas, slope orientations, upper borders of rocky areas and steepest slope lines are retrieved in scree areas. Each one of this additional data is obtained using a specific process.

The aim is to represent scree in steep slopes (where slope is greater than 50%) with growing points along the slope. That is why steepest slope lines are gotten back in these areas taking into account density constraints. Here is the way of doing this: each node of a mesh covering the area is visited. The current node is then considered as a starting point of a slope line along which we go down until being situated outside of a scree area or nearby another existing line.

Upper borders in rocky areas characterised by a steep slope (i.e. where the slope value is higher than 100%) have to be extracted since this is relevant to get back these linear objects so that map readability can be improved. To get these lines, only outline sections of rocky areas with their slope angled within the area are kept. Besides, pixels of these sections must have a higher altitude than at least half of their neighbours and these sections have to be longer than a threshold.

Another classification depending on the slope orientation is performed. This is to suit cartographic requirements and it only concerns rocky areas, which are split up one more time following their orientation with a 20° step. Then several rocks classes between n x 20° and (n+1) x 20° (with $0 \le n \le 18$) are gotten. A particular representation is applied to each of these classes, as explained in the next paragraph.

3. Cartographic representation

3.1. Data and tools used

To complete these digital cartography tests, several data sources were needed. All data have been retrieved with tools developed by the MATIS laboratory. They have been presented in the previous paragraph.

Scree and rock areas are among the different land use areas detected on aerial photographs. They form the heart of the cartographic representation. They delineate areas we are interested in here, in the present study. In fact, the mapped area for this test is located in the Pyrenees, nearby the Ossau peak, and does not include any significant glacier. So, they have not been taken into account for these tests, but we have to know they contain specific problems, dealing with cartographic representation.

A Digital Terrain Model (DTM) allows us to superpose these land use areas with slope information, which is provided by the DTM. Then, it is possible to separate rock and scree areas depending on the slope value. Thus, we can associate a proper symbolisation to these different kinds of areas. A threshold allows us to distinguish steep slopes from gentle ones: a 100% slope is the limit for rock areas and it is 50% slope for scree ones.

Of course, this is only an interpretation of terrain characteristics.

A rock area classification following the slope orientation criterion has been done. The target of this classification is the same as previously, as we aim at differentiating the cartographic representations depending on areas. On one side, this classification has to contain enough details in order to illustrate as best as possible the terrain diversity and complexity. On the other side, areas have to be big enough if we want them to be readable on a map at 1:25k. After several tries, it has been agreed that the creation of 18 classes at 20 degrees regular intervals was the best choice in our case. However, be careful not to generalise without any cares this result. The first point is to respect qualitative criteria explained above.

Finally, rock areas are divided in 36 different classes, depending on the slope orientation and the slope value.

Linear data complement the set of data within land use areas. Scree areas are characterised by steepest slope lines inside steep slope areas. Those lines are useful as they can be considered as the symbolisation skeleton in these areas. In addition to that, other lines are at the top of steep slope rock areas. They illustrate breaks in slopes. They are considered to be especially dangerous for hikers.

Two different software applications have been necessary in order to match data and have a resulting paper map. The first one is the GIS Geoconcept, produced by Geonconcept SA ltd. Data were prepared thanks to this software. They were imported and georeferenced. Then, they were exported and integrated in a cartographic symbolisation software. This second product is Mercator, produced by Star-Apic ltd. It enables us to manage all data representation with layers in order to do map-printing. This software has been used at IGN France for a long time to manage the end of topographic maps production lines, until maps are printed.

3.2. Method

In the previous paragraph, we looked at useful data for cartography in mountain areas. Now we need to assign a symbolisation to these data. This is what the user really sees and reads on the map. The whole issue is to represent in the best possible way the terrain complexity. The main point is to understand accurately the map, so that users can not be mistaken and thus avoid dangerous zones for example. When most users look at the topographic map at a big scale, they trust in its accuracy. This kind of map has to keep this asset.

Besides reflecting the reality, the representation has to be as automatic as possible, as one of the main purposes of this study is to reduce the map production cost. Up to now, rocks have been drawn manually by experienced cartographers, using graphic means and working with aerial photographs. This technique produces very good results but the point is that it is very expensive. Hurni et al. (2002) have studied some methods to automate the cartographic representation. However, they advocate the combination of manual tasks with automatic ones. According to them, digital methods can be applied only in a limited spectrum of tasks. Control of the full process by an experienced operator is still necessary and desirable, in order to keep the graphic quality that is characteristic of Swiss maps. At IGN France, we wonder as well how we can improve current results in digital cartographic representation. So we have kept carrying out some researches about this issue.

According to several case studies done in mountain areas, hachures seem to be a relevant way for rocks representation. They provide both a good perception of relief and an appreciated graphic result. This technique outcomes from a former more general one, used historically to depict the relief with hachures. They were generally drawn along the steepest slope so that the user could mentally think mounts and valleys. In our study case, we judge necessary to have ridge-lines depicting major contours and ridge crests so they complement hachures representation. Maps from the Swiss National Map Series produced by the Federal Office of Topography illustrate this way of representing rocky areas. Fill hachures are plotted manually either along the steepest slope where this one is steep or along contour lines. An operator estimates the slope value looking at aerial photographs. As the human eye is a subjective tool, there is no mathematic threshold to determine if a slope is steep or not.

This way of representing rocky areas has been adapted in this study, trying to incorporate it in a digital process. A hatched pattern has been designed to fill in rocky areas where the slope exceeds the given threshold of 100%. In order to have a fine visual perception, (Imhof, 1982) gives in particular some advices dealing with hachures design and related parameters. They have been taken into account to draw up this pattern. Following the different orientation slope classes, this one is always angled according to the steep slope. For instance, rocky areas with a slope angled from 0 to 20° will have a 10° angled hatched pattern. The classification depending on the slopes orientation is necessary to let the pattern follow the neighbour steep slope, whatever the slope orientation value is.

Another hatched pattern has been defined for rocky areas with gentle slopes. In this case, hachures are more spaced. Added point symbols and areas randomly disposed are part of the pattern to mean the presence of isolated rocky blocks. The pattern is angled following the average tangent to the contour line for each class. The hachures logic spacing used in this case is the same for contour lines. The denser they are, the steeper the slope is, and vice versa.

Hachures are voluntarily irregular to better imitate the real world. In fact, structure lines and the general rocks texture are hardly ever regular and geometric. Thus, when we had to design a pattern, we paid special attention to the possibility of reproducing it without any spatial discontinuity. An off-setting on the edge of the pattern does not produce a satisfying visual effect. This is especially true if there are no structure lines to hide it.

The scree representation is characterised by point symbols. There are small round points and irregular round shapes that mentally suggest to the map reader stones or rocks. Where there are steep slopes, scree tends to form streams because of unsteady rocks rolling down. These rocks crumbling leave a trace on the ground that can be observed on aerial photographs. We tried to duplicate as precisely as possible those characteristics. Depending on the slope value, we differentiated the scree representation.

Lines along the steepest slope are only extracted in scree areas where the slope rises above 50%. They are necessary for the representation support in these zones. In fact, round points symbols are computed and placed at regular intervals along these lines. The symbols diameter increases in a linear way when we go down along the slope. Visually, the crumbling effect appears thanks to the lines support. They are not visible on the map but we can easily imagine them.

Dealing with scree representation located in slopes under 50%, a pattern has been drawn. It is made up of point symbols and irregular round shapes, and suggests rocks randomly disposed. On the contrary of pattern used in rocky areas, this last is not angled. This is to keep the randomness of these zone structures.

Upper borders in rocky areas complement the cartography and give a global structure of these mountain areas. They are useful to mean cliff tops and broken grounds. They are drawn with two lines. The first one is black to underline the break; the other one is dark grey to mean the shadow, which is a frequent characteristic within these zones. The black line has a varying width. This is to avoid a symbolisation that would appear too geometric. Besides structuring the map in mountainous areas, these upper borders warn against potential dangers that may have not been clearly seen with hachures.

Previously listed elements are put together with more classic and often used ones: I mean contour lines and hill shading.

3.3. Results

For the time being, we only tested this representation in a unique zone, in Pyrenees nearby the Ossau peak. Nevertheless, we got some results that seem to be hopeful. The map has a good global readability. The whole coherency between themes is satisfying as no layer overrides others. Furthermore, we can easily distinguish the different kind of symbolised zones. The representation rationale and the patterns used here allow the map reader to associate the ground nature. Finally, this is promising all the more that this cartography has been entirely done in a digital way, which was one of the goals.

A comparison has been made with the former map manually produced. It enables us to identify a weakness dealing with the digital hill shading. In fact, it is far less expressive than the old one drawn manually. So it still needs to be improved, given that there are a lot of current researches in this field.

Of course, this method is to be reproduced on other mountain areas. Remind us that the New Base Map project aims at producing a homogeneous representation on the whole territory, and in particular concerning rocky areas. Currently, this is not the case in France. The result is different and depends on both cartographers and when it has been produced. In order to test the reliability and the scalability of this method, we understand better why this kind of test has to be generalised to other areas. Soon, it is planned to draw up Modane region and the Vanoise national park, in Alps. This test enables us to appreciate the general survey of large rocky areas. We would be able as well to give rise to specific problems linked to glaciers.

4. Conclusion

The New Base Map project carried out several studies dealing with image processing and mountain cartography. One of the main purposes is to get an automated digital high mountain cartography as good as the one we had before with manual processes. This study has been done combining several data sources, i.e. orthophotos, DTM and external knowledge, an automated extraction of rock, scree and glacier areas, and additional relief-related data. These data allow to realise an automated cartographic representation that aims at improving the relief and the “expression” of high mountain zones.

The first results obtained in Pyrenees are hopeful. So it has been decided to test this experimental method on another bigger area, located in the French Alps. Further tests could include a customer survey, especially concerning mountain map users. Remarks from clients could enable us to improve the final process and specific stages, in particular the hill shading. Then, we might be able to introduce this global solution within the IGN base map production line.

	St-Christophe-en-Oisans (Alps)		Ossau (Pyrenees)	
	with complementary knowledge			
	us-ac	pr-ac	us-ac	pr-ac
Water (Lakes)	/	/	100.0	76.4
Forest	81.9	65.2	89.0	95.8
Pasture	71.1	52.2	96.3	85.1
Rocks	76.4	69.9	71.0	87.2
Screes	54.7	73.3	88.0	83.1
Glaciers	58.6	69.5	98.3	72.2
Well classified pixels	67,0 %		87,4 %	
	only image information			
Well classified pixels	55 %		75 %	

Fig. 1: Evaluation of the classification results on the three test zones

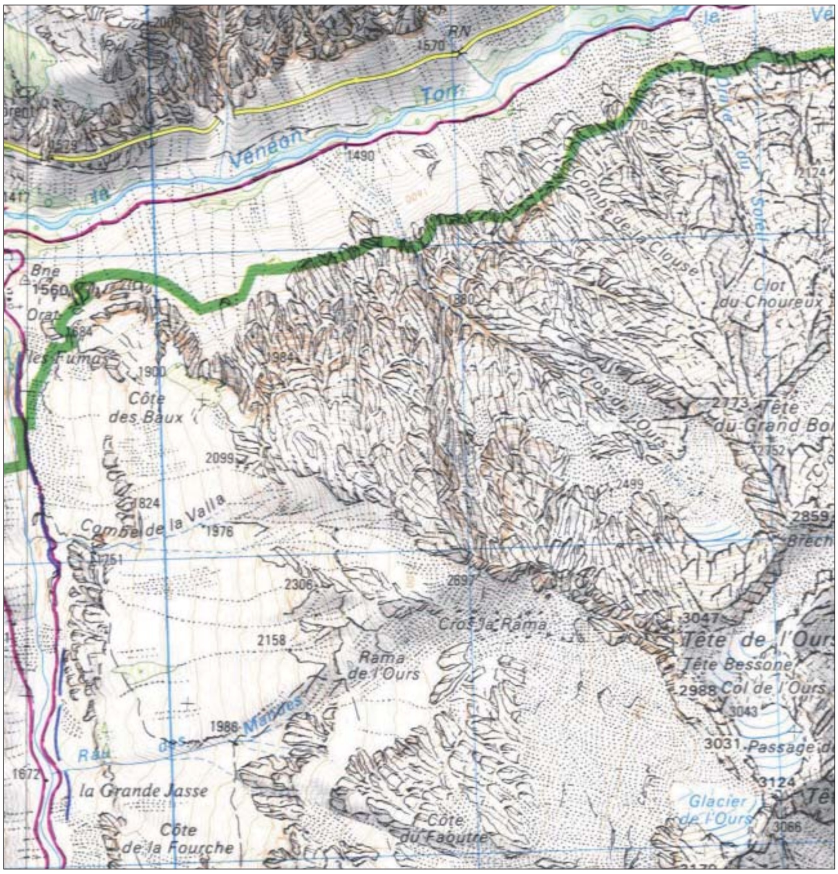

Fig. 2: Example of a handmade topographic map at 1:25k in Alps

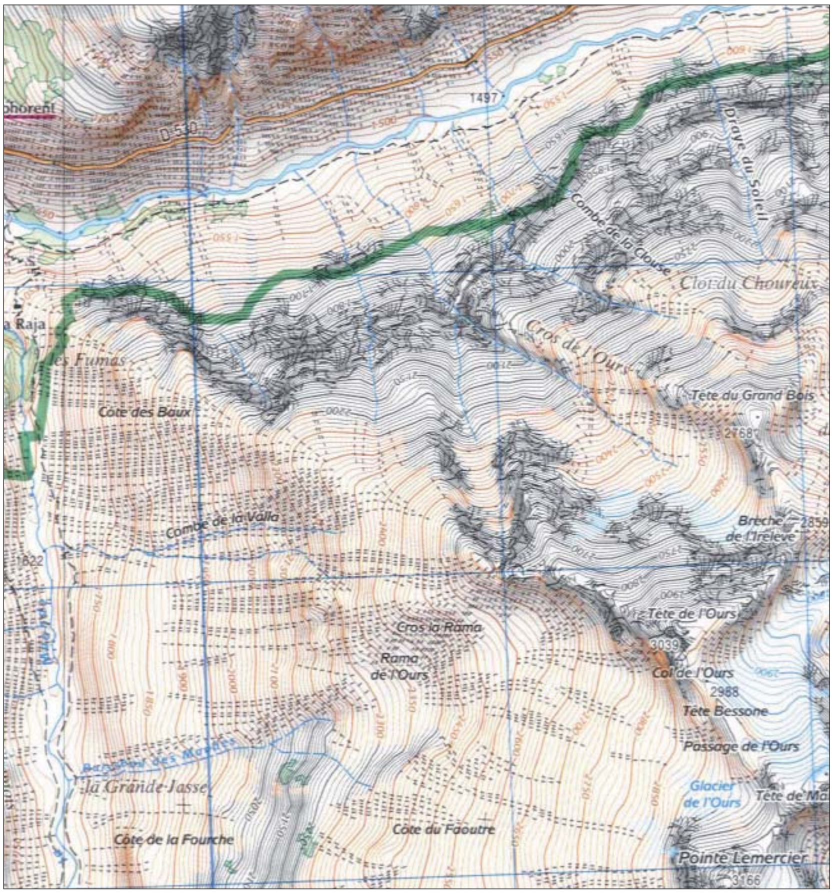

Fig. 3: First map digitally obtained by Le Men et al (2002) of the same area

Fig. 4: Extract of orthoimage used during the process

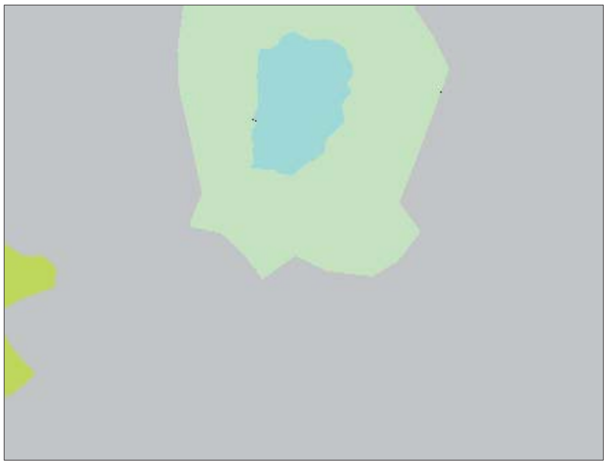

Fig. 5: Extract of Corinne Land Cover land use on the same area

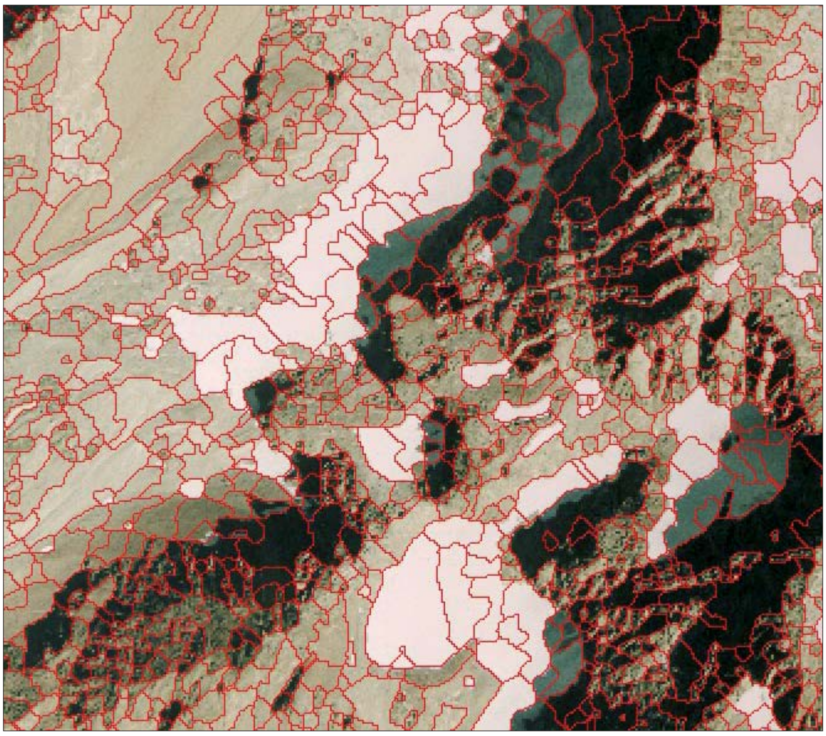

Fig. 6: Segmentation of the orthophoto in homogeneous regions

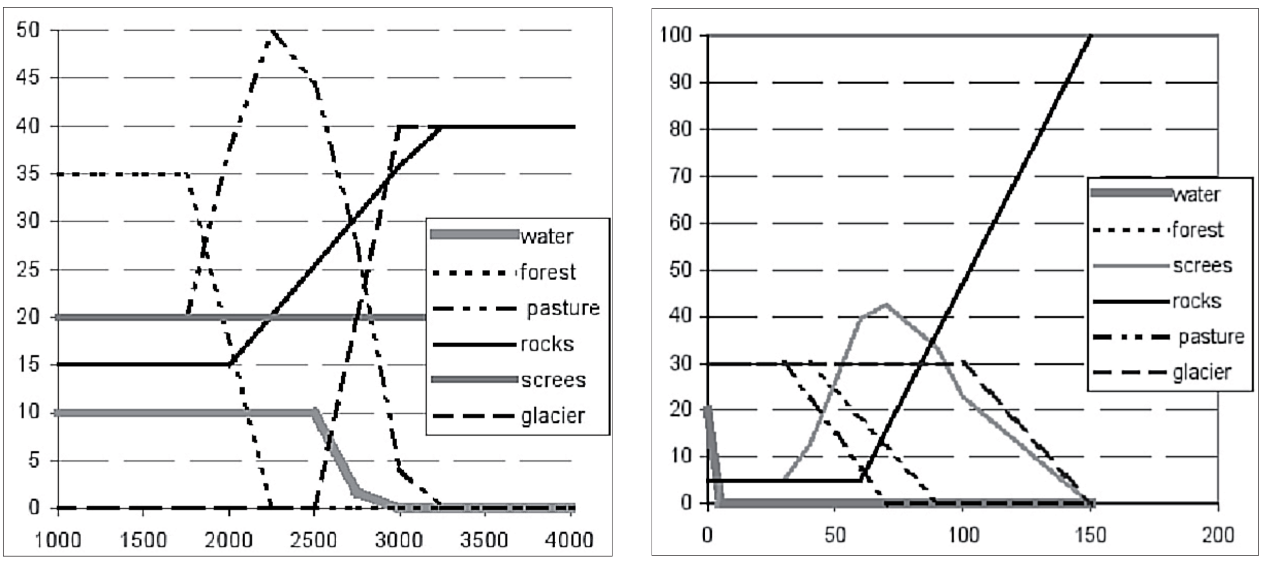

Fig. 7: Probability of finding themes knowing altitude (left) and slope (right)

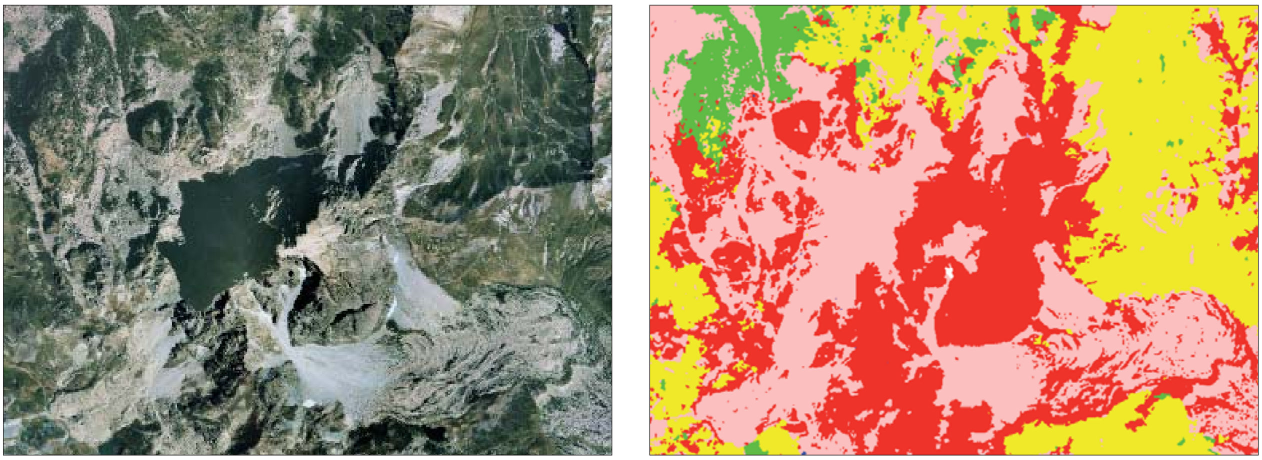

Fig. 8: Orthoimage (left) and classification (right) in Pyrenees (Ossau peak region)
(Red = Rocks; Green = Forests; Yellow = Pastures; Pink = Scree)

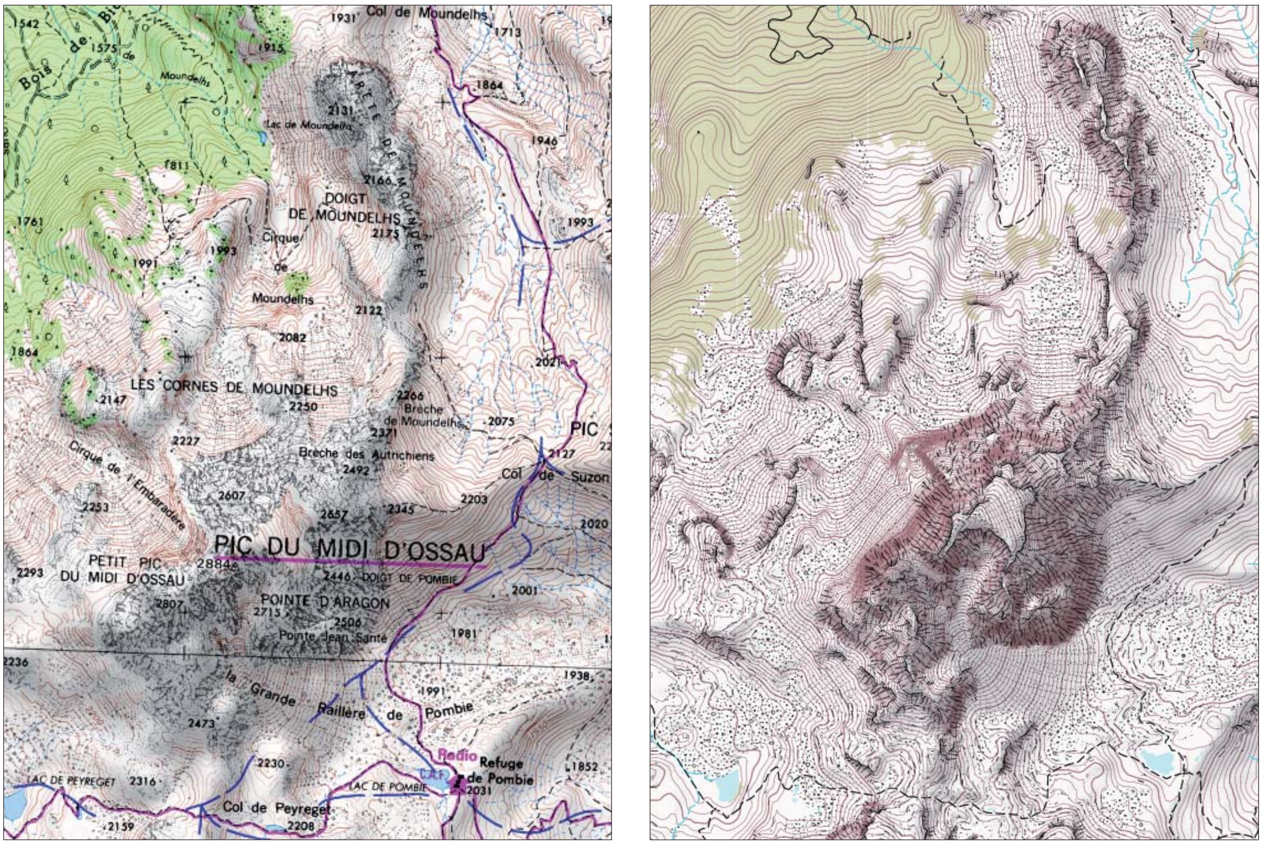

Fig. 9: Present handmade topographic map (left) and the new fully digital made map (right) in Pyrenees (Ossau peak region) at 1:25k

References

Bossard, M., Feranec, J., and Otahel J., (2000) : CORINE Land Cover Technical Guide – addendum 2000. Technical report n° 40. Technical Report, European Environment Agency.

Elhai, H. (1968) : Biogéographie. Armand Colin, Paris.

Guigues, L. (2004) : Modèles multi-échelle pour la segmentation d'images. Ecole doctorale Sciences et Ingénierie de l'Université de Cergy-Pontoise, Cergy-Pontoise, 302 p.

Guigues, L., Coquerez, J.-P. and Le Men,H. (2006) : Scale sets image analysis. International Journal of Computer Vision, 68(3), 289–317.

Hurni, L., Dahinden, T. and Hutzler, E. (2001): « Digital Topographic Drawing for Topographic Maps: Traditional Representations by Means of new Technologies ». Cartographica, 38 (1/2), 55–65.

Imhof, E. (1982) : Cartographic Relief Presentation. W. De Gruyter.

Lacambre, A. (2001) : Aléas et risques naturels en milieu montagnard; apport et limite d'un système d'information géographique. Université Paris 4, Paris.

Le Bris. A. and Boldo, D. (2007): « Extraction of landcover themes out of aerial orthoimages in mountainous areas using external information ».In: Proc. of the ISPRS Conference Photogrammetric Image Analysis (PIA), Munich, Germany, 6 p.

Le Men, H., Trevisan. J., and Boldo, D. (2002): « Automatic extraction of landcover themes on digital orthophotos in mountainous area for mapping at 1/25k ». In: Proc. of the ISPRS Commission II, Xi'an, China, 8 p.

Schwarz G. (1978): Estimating the dimension of a model, The Annals of Statistics n° 6, p. 461-464.

Trias-Sanz, R. (2006): Semi-automatic high-resolution rural landcover classification. Université Paris 5, Paris, 374 p.

Trias-Sanz, R. and Boldo, D. (2005): A high-reliability, high resolution rural land cover classification into forest and non forest. In: Kalviainen, H., Parkkinen, J. and Kaarna, A. : Proc. of the Scandinavian Conference on Image Analysis (SCIA), Lecture notes on computer science. Vol. 3540, Springer, Joensuu, Finland, 831–840.

Wang Z., Ziou D. and Armenakis C. (2003): Combination of imagery – a study on various methods. Proceedings of the IEEE International Geoscience and Remote Sensing Symposium (IGARSS), Toulouse, France.