Rapid mapping tutorial

From the region to street furniture scale

Bernard Lortic

with the collaboration of Dominique Couret

IRD
Institut de recherche pour le développement

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Cover photos
From left to right, the new water tower, *Debre Birhan (2007) © B. Lortic* - Municipal Employees during the mapping training period, *Debre Birhan (2007) © B. Lortic* - New neighborhood, *Addis Ababa (2008), © B. Lortic* - Planning new collective habitats, *Addis Ababa (2008), © B. Lortic.*

Back cover photos
From left to right, Recent peripheral extension, *Debre Birhan (2007) © B. Lortic* - Studs for plots demarcation waiting to be installed, *Debre Birhan (2007) © B. Lortic* - New buildings under construction, *Debre Birhan (2007), © A. Aing* - GPS Record by students of the Faculty of Urban Planning, *Debre Birhan (2007), © B. Lortic.*
Debre Birhan (Ethiopia), composition

Debre Birhan (Ethiopia), Quick Bird, color composite image (02-12-2007).

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Titles on worksheet are in English.

Preface

For the small community of cartographers, and indeed for many other technological communities, today's world is providing extraordinary scope. The arrival of personal computing and spatial imagery in the 1980s, followed by that of GPS, and geographical information system software (GIS) alongside progress in geodesics, opened up numerous new avenues. But the movement did not stop there, and we have derived dividends from many other major advances. We can quote the following, in no particular order:

– digital photography available to the public at large
– personal computer memory capacities enabling the storage, management and processing of vast quantities of these images, and the development of orthophotography
– software for the processing of images, photogrammetry, and 3D
– satellite images with ever smaller pixels, often able to substitute for aerial photographs
– networks and telecommunications enabling exchange and consultation of geographical data across the world
– measurement of the Earth to a few millimetres, enabling access to a single geographical reference that is extremely precise
– realisation of the essential nature of geographical data for the intelligent management of territories, with the development of free-access geographical websites, whether institutional (e.g. Géoportail in France) or commercial (Google Earth, Virtual Earth, etc), providing a wealth of easily reachable information.
– a profusion of local, national and worldwide geographical databases, the use of which is considerably facilitated by developments in GIS software that are both powerful and user-friendly.

And this list is far from complete...

However, paradoxically, all this has not changed things very much for the cartographer. Certainly, cartographers now have quick and easy access to vast amounts of information, which has required them to acquire considerable skills in extracting relevant data. But ultimately, they nevertheless need to develop a feeling for graphics and even an artistic sense alongside their technical expertise, to make the data acquired easier to understand. While it has become an easy matter to produce a poor map, producing a good map is still a very delicate matter.

The present work is based on the long-term experience of the field cartographer and remote sensing expert Bernard Lortic. It offers a series of simple recommendations for the development of a map using few resources. In what follows, it is not the various theoretical developments that should be retained (there is already a wide corpus of literature on the subject for those who wish to go further) so much as the pragmatic, effective approach that articulates the use of geomatic tools and field work. This is accompanied by numerous concrete illustrations which can serve directly as examples for tomorrow's cartographers. In this respect, this manual forms an excellent basis for those who, although not possessing any specialisation in modern geomatics, wish to master methods for quick cartography, for instance for the purpose of development research in their country. I would like to wish all these people fruitful work, pursuing the millennial search for understanding of the environment in which we live so as to enable better management.

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Directeur de l'École nationale des sciences géographiques
—>l'École de la géomatique

Foreword

This manual sets out to provide as simple a description as possible of a quick cartographic method that can be adapted to any situation. The idea of this manual came to me following work that I conducted in Ethiopia from 2005 to 2008, where I was teaching remote sensing techniques and geographical information systems in the Ethiopian Civil Service College *, in a partnership agreement between the urban planning department of this Ethiopian higher education establishment and IRD * (Institut de recherche et de développement) research unit n° 029, Urban Environment. For IRD the aim was to approach urban development across geographical disciplines such as demographics, socio-economic structure, governance, national heritage, environment etc. I remember, at the start of the programme, presenting my Ethiopian colleagues with macroscopic research work on the morphology of the large world cities, highlighting the elaboration and the implementation of indicators such as density of built-up areas, social segregation, centrality, and dominant habitat types. These themes and the subject matter met the full agreement of the Ethiopian teaching staff, who certainly apprehended the interest of this approach. But what we had certainly not anticipated was the gap between our viewpoint and that of the Ethiopians: ours was the scientific perspective derived from French university teaching, consisting in first of all observing, and then "sorting" data, looking for the data that was the best suited to describing a "reality". The Ethiopians in contrast were caught up in the urgency of action. On the one hand they had little data, and more often than not the data they did have were rendered completely obsolete by the pace of the demographic and sociological changes taking place in the country. In addition, the Ethiopian priority was not to observe, but indeed to genuinely plan urban development. For this very concrete purpose, the Ethiopian teaching staff interested in planning issues each year required 4th year students to produce a "master plan" of a small town. In France, and in Europe generally, it is study bureaus that are contacted to perform work of this sort. For a task of this sort, they use the very large volumes of data that is already available - cadaster land registers, INSEE * data, IGN * data using Géoportail *, and so forth.

The situation in Ethiopia was rather different. Right from my first experience in a little town called Woldyia, which had been chosen as the field setting for the development of a "master-plan" in 2005, I was confronted with the mode of practice of the students They only had blue diazotype copies of maps that were barely legible, and in addition completely outdated. They spent hours working with measuring tapes, obtaining very precise measures but with absolutely no georeferencing. Neither the students nor the municipal authorities were blind to these shortcomings, but rather at a loss, since they had very few means of localising and integrating their knowledge, although it was extensive. In a country where the police are omnipresent and each inhabitant is registered by an identity card showing the person's home address, we observed that the senior staff from the urbanism department had great difficulty "locating" places correctly. This did not prevent them from issuing worthwhile diagnoses. This is how the task of correcting the shortfall and providing students with the means to appropriate geographical localisation techniques and georeferenced cartography appeared to me as a useful and important challenge.

We therefore very early on developed a "rapid mapping tutorial". Quick meant within a reasonable time lapse, commensurate with Ethiopian needs: three months, two months, or even just a fortnight. Within this time lapse, the task was to produce a complete plan of the town, including all the streets, all the buildings, the slopes, and all the administrative boundaries. There was also the need to master the geometric accuracy and the precision with which objects were mapped.

The three years that followed enabled the refining and the testing of the proposed method with the

* The star indicates that a definition is provided in the glossary at the end of this volume.

three successive yearly batches of student. Thus the idea of producing a "manual" briefly describing the theoretical principles, the different steps, and practical hints, gradually emerged.

The overall conceptual components of the method were established from 2005, but each step needed to be clearly described in a manual of a quite new kind. It should be understood that, at the time, it appeared unthinkable to provide non-initiated individuals with the means to map a town, a task that hitherto had been the job of professionals. A person without long years of topographical study behind him and not backed up by a large team of surveyors and topographers was not viewed as being able to complete a task of this sort. Yet with these Ethiopian students and their teaching staff it was achieved for several Ethiopian towns. With this manual I wish to demonstrate how this is so, and explain that today, thanks to evolutions in geographical sources and data processing, it is not only possible, but also quite easy. Expert professionals will find my advice and explanations trivial, but what I hope above all is that non-professionals will find them sufficiently clear and transparent to enable them to be implemented.

It is of course to be hoped that the usefulness of this manual will be only short-lived. People learn fast. Certain Ethiopian colleagues have thoroughly assimilated the method, and demonstrate it today by continuing to use it. It can be hoped that in a few years cartographic surveying will become more widespread, filling the inevitable gaps left by national organisations that do not possess the human resources required to respond to all their cartographic needs.

The first question I asked myself was: will the publishing of a manual be of use? Perhaps the existing literature is sufficient?

It seemed to me that the present-day French literature on the subject was intended for the "older" actors, trained in the use of earlier technical resources. The clear-cut difference between the job of topographers who establish geographical data and that of cartographers who publish the data can indeed be explained by the numerous technological difficulties that were previously encountered in each of these two areas. As a result, there was no question of any single person plying the two trades. Present-day literature reflects this historical divide. The literature intended for cartographers details the graphic semiology, and that intended for future expert surveyors focuses on the use of topograph survey stations. Works covering the whole process of cartography from surveying to publication of the map are very few – there has been a fairly strict closed-shop attitude over the last 50 years. However this may soon no longer be the case, on account of ongoing technological advances and GPS* This means a real change in the way operations are conducted, and the closed shops will no longer be run as independent entities, but co-managed. Google* and OSM* aim to call on web users to complete the worldwide cartographic data available on their websites. The present manual is however not intended for these amateur geographers using the Internet, but for another category of map producers – local territorial actors and planners. The aim is rather to provide municipal or regional actors with scope for creating and managing data relating to their towns or regions. Why is it useful to enable each actor to control and manage his own urban cartography, at a time when terrestrial data is readily available on the internet?

The OSM programme (OpenStreetMap), like Google Earth*, under licence of the Creative Commons* type, aims to map all the streets, roads, tracks and similar objects in the world on the basis of information provided by volunteers. The shared creed of Google and OSM is to make cartography available to all. Since 2009 I have been using these programmes, and I have sought to evaluate their advantages and their drawbacks in relation to the method proposed in this manual. The two programmes are largely based on the same lines of approach as the method proposed here, in particular the use of two tools derived from recent technologies: aerial and space (satellite) photography, and GPS. But overall it can be said that the method set out in this manual is better suited to the cartographic requirements of local urban actors and planners.

In relation to these requirements, the single format proposed by the Google and OSM programmes, corollary to the worldwide sharing of data, restricts their usefulness on local scale. For instance, for OSM the legend proposed is rather limiting, and oriented more towards a preconceived application for tourism than towards territorial management.

Google Earth makes wide use of imagery, but it only partially rectifies images. OSM uses GPS, almost exclusively when it started up. From the outset our method has articulated these two tools, following on from developments in IRD from 1992 to respond to needs expressed by local partners (municipalities, development actors): first of all the development of a simple method to rectify images and second the use of GPS surveying techniques in urban settings. The use of the data, and of the maps produced, is not really broached in this manual. Likewise, little will be said about semiology and the creation of spatial information. For these purposes there are numerous works available on "cartography" (see bibliographic references at the end).

This quick cartography manual is the description of a method that enables a map of a local territory to be developed in two months. It is not a map in the classic sense, but rather a database of geo-localised data in what is known today as a GIS*, LIS*, IULIS* and so forth. We will try to understand and use the concepts of geometric rectification of images, accuracy and precision, and relational databases. This method was elaborated using the SavGIS* system (IRD), but we will describe the different steps and procedures without referring to any specific software. However the exercises and demonstrations proposed in the form of video clips will be run under SavGIS, which is the only software with a free-access version enabling a satisfactory demonstration of the various operations to be made available.

The challenge is for this quick cartography manual to remain up to date, since the discipline of cartography is evolving fast, with new developments each week. Certain sections in the manual are thus already dated, and they will require updating by the users.

Presentation of the method

A cartographic method that is quick, simple and functional: two tools, six steps and a few rules

The rapid mapping method presented in this manual consists in designing a database from which the desired map can be assembled and printed. The financial cost of a cartographic database of this type can be quite small, and two months' work by one person are sufficient, whether the task is to produce a regional map, or a map such as the one developed for the municipality of Debre Birhan (Ethiopia), an instance that will be frequently used as an illustration. Finally, the development of a map of this sort is greatly facilitated by the now easy access to satellite images. Remote sensing has been used in the sphere of cartography for at least 40 years, but it is only recently, and in particular thanks to Google, that satellite images have become universally accessible. When viewing one of these images on Google Earth, it can be clearly seen that it comprises all the elements required to develop a map. It is thus perfectly simple to extract the information needed to map roads, buildings, certain urban fixtures, water courses and so forth from the satellite images available. Hence this manual will merely provide some advice, or indeed "recipes", for the ways in which to make use of this resource. Georeferencing, however, with its key role in developing a map both quickly and accurately, is explained in more detail. Likewise, a lot of space is devoted to presenting the second essential tool, GPS, which is today accessible to a very wide public. GPS use as presented here is as accurate, but less demanding, than that presented in the OSM programme.

This method is also derived from first-hand experience in the handling of these tools, and their confrontation with the requirements of quick, simple and functional cartography, in the course of 20 years of study and research in urban development. It was also for a large part derived from the very numerous logical and practical possibilities afforded by the SavGIS * programme. We have however endeavoured to be as "generic" as possible in this manual, avoiding any over-specific reference to SavGIS. Everything that is proposed here should be possible using any common GIS software. Unfortunately it should be said that when I monitored responses to questions on Georezo * and ForumSIG * I noted that problems that appeared to me to be simple to solve using SavGIS did not always find an easy solution using the alternative software.

Correct application of this quick cartography method requires that you proceed through each of the following six steps, and comply with a few rules.

1 - Always think through the design of the cartographic production according to your need

For this purpose, Worksheet 1 will help you model your cartographic objects, Worksheet 2 will help choosing the appropriate scale, and Worksheet 3 will assist in selecting the best-suited degree of precision and the right scale. Worksheet 4 will provide you with basic skills in the use of geodesic systems so that you can avoid the pitfalls that, unfortunately, are rather numerous when georeferencing your data and the objects you have selected for mapping. In Worksheet 27 you will find how to transfer your conceptual model into the cartographic database specifications and dictionary.

2 - Next determine the geographical area to be mapped

Google Earth is the simplest tool to localise and visualise the zone in which you are interested. Whatever your type of Internet access, Google Earth will function. Certainly with only 56ko, for the least favourable situation (that is to say an ordinary telephone line), it will take time and patience. For instance, in Ethiopia in 2006 I often needed to allow one hour of connection to have a first view of the zone. Worksheet 9 proposes a way of accessing the Google Earth server using the graphic editor Savedit.

To efficiently determine your zone of interest, you should provide for its outline to easily include all the thematic groupings of objects that you wish to map, because you will always require, almost simultaneously, a view of detail (buildings, isolated trees, sewer grids etc) and an overall view (the agricultural environment, the relief, the slopes, the watersheds etc).

3 - Choose and then capture the geographical data that is suited to your cartography project

Worksheets 5 and 6 explain how to acquire and use already existing maps, sketches or plans. Retrieving earlier data does indeed provide a source of information and a tool that should not be neglected.

Worksheets 7, 8 and 9 will help you find or search for material, will explain how to consult websites, what image to select and how to obtain it at the lowest possible cost among all the images "available", i.e. on offer in the catalogues of suppliers. It is useful to create a synoptic table in which images can be classified by resolution and date. Do not neglect older images, because they enable dynamic analyses.

Worksheet 10 provides you with information on sources of data for altitude and descriptions of relief that are available.

Generally speaking, it is more efficient and less costly in time and money to start designing your cartographic database from already available data. It is better not to wait for access to more recent sources of data if they are not rapidly accessible. Using outdated data naturally has the drawback of later having the task of updating, but it also has a sometimes double advantage of being easy to access and often completely free of cost. Finally, the occupation of geographical space is always evolving, but even in cities, where changes occur fast, a majority of the constructions last over several decades. It is therefore generally sufficient to add the new buildings to an older map to update it (see Worksheet 28 for details of the procedure for updating a map).

4 - Using the GPS tool for easy georeferencing of all the sources of the data acquired

The georeferencing step is all the more important where you have several different sources of geographical data. It is this step that will guarantee the quality of your cartographic production or database and its effective subsequent use. The use of a GPS for tracking geographical coordinates in the field rather than surveying isolated points is the best solution for quick, robust and successful georeferencing. Worksheet 11 gives you an introduction to the way in which GPS systems work. Worksheet 12 presents examples of the limitations of IGN's Géoportail and Google Earth for the combined georeferencing of geographical data obtained from different sources. Worksheet 13 describes the preferential georeferencing tool – the method of adjustment using tessellation*, originally developed to correct satellite images – and the central role of daymarks, those "conspicuous places" or features that you will need to detect both on the image that requires adjusting and on your georeference (map, image or GPS reading). The trick is to choose objects that are well-defined both on the image and in the field – for instance a single tree or an isolated house. You will need to consult Worksheet 8 to avoid the pitfalls of shadow and height.

Worksheet 14 gives all the practical details for surveying by tracking GPS points, which will help you to determine the conspicuous features that will be used as daymarks. To ensure the best possible georeferencing, always draw a sketch map or a rough outline before you set out on the ground. Worksheet 15 explains the data to collect and in what form, to facilitate capture in the database. Worksheet 16 assists in the choice of your GPS, and 17 and 18 respectively detail the procedures to georeference map and image.

5 - Extract useful data and integrate it into the cartographic database

According to the source of data and the objects to be integrated, refer to Worksheets 19 to 26.

6 - Do not forget to describe the specifications of the database, and create a catalogue for the data

Worksheet 27 sums up the conception of this essential component, and it should be noted that this task runs from start to finish: you determine the specifications of the database at the outset, when you are thinking about the design of your mapping enterprise (the first step); and thereafter, for each creation and integration of a new piece of data, you insert its description into the catalogue.

(**Video sequence *Modelization of a geographical database***)

Worksheet 1
Modelling geographical objects

The model used here is a relational model of organized collections of objects linked together by topological relations.
Each collection is made up of independent objects but these objects share common attributes that define the collection.
Establishing a relationship between one collection and another is based solely on the localisation of their respective objects in the geographical space. A given house will belong to a given municipality because its geographical location lies within the municipal boundaries. The relationship between this house and a particular street will be established on the basis of actual geographical proximity, or the fact that the street in question enables the geographical access to the house.
This way of viewing the structure of information is the direct result of a heritage that is specific to IRD: the GIS software Savane *, the early version of SavGIS, was derived from this relational geodatabase model . At the time no GIS was available commercially, and we have retained a preference for this model.
Our aim is to map the main elements of the urban structure of the town or city considered. This structure is made up of different functional objects that are distributed across space. The aim is not to draw independently all the objects that can be detected on an image. The task is rather to model "reality", that is to say, to define each object in function of its relations with other objects of the same collection or of other collections. These collections of objects are represented by a type of graphic symbol that is specifically associated with the objects in each collection. In other words, a legend is created that retains only what appears useful to describe the town under consideration. This "intelligent" description (interpretation) of the cityintends to enable all kinds of quiries: technical studies on network, growth city management, planning, etc. While certain objects will be relevant for some issues, others will be specific to a particular question. We are going to use a GIS, and for this purpose we need to design our geodatabase model by creating collections of objects of the same type. The objects in a given collection are described by one set of attributes, i.e. shared numerical or functional characteristics. The collections can be of three different geographical types: point, line, or polygon. We start by considering the image that we possess, that is to say we perform a rapid, free photo-interpretation consisting in identifying objects or phenomena, in giving them a generic name, and in identifying the characteristics that describe them. From this first photo-interpretation, the geodatabase can be created: a name for each collection of objects, lists of useful attributes, description of modes for each attribute. It can be noted that in almost all GIS (and in SavGIS in particular) localisation attributes are implicit. It is the system that manages them for you in transparent manner.

Collection of objects : electric pylons, *type point*

Identifier	Ground cover (m^2)	Height	Material	Grid tension	...
0001	10	40		high tension	
0002	25	40		low tension	
0003	30	50			
0004	25	40			

"Point" objects have a position, but nno length nor surface area. It is possible, for each point, to attach an attribute describing a height, which can be estimated from the length of its shadow (if the image is well orthorectified).
It will then be possible to add different fields defining the characteristics of the object: the area of the object at ground level (here each pylon), its components... information that can be seen on the image or that has been gathered before. This surface area is unconnected with the surface area calculated by the GIS, since, as we have just remarked, a point by definition has no surface area. There is then the question of whether it is a good thing to immediately

determine a collection of objects termed "electric power lines". We consider that it is preferable to start defining the specifications in a simple manner, and then to complexify as needed at a later stage. The characteristics of the electric power line can all be deduced from those of the pylons, including its line itinerary which can be determined from the series of pylons. However the reverse is not true: it is not possible to deduce the characteristics of each of the pylons carrying an electric power line from the characteristics of that power line. Therefore, as a first step, it is preferable to use the object "pylon" in the model, and to introduce its belonging to a given electric power line as a descriptive attribute, with the characteristics of the power line (high or low voltage, etc).

The procedure for modelling urban or rural objects generally focuses on the function of the object, often ignoring the material features of its appearance. For instance, the model for the "urban dwelling" function can be a collection in which the objects are houses, for which the very simple generic description (a roof and walls) generally proves to be the most efficient, despite the fact that it sets aside numerous variants of colour, size, outline and materials.

Collection of objects : street segment, *type ligne*

Identifier	Name	Width (m)	Suface	Hard shoulder 1	Hard shoulder 2	Pavement 1	Pavement 2	...
0001	Rue Bernard	10	Cobble	2 m	3 m	1 m	1 m	
0002	Rue François	25	Asphalt	3 m	1 m	1 m	1 m	
0003	Rue Tania	53	Asphalt	1 m	1 m	3 m	1 m	
0004	Rue Chat	8	Gravel	1 m	1 m	2 m	3 m	

Street-objects are generally represented on a map by a double line. We consider that the way in which they are to be drawn is not necessarily something that needs to be defined in advance, but a choice to be made when the map goes to print. Thus the "drawing" operations are postponed until a later stage, distinct from the capture and integration of the objects in the database. This leaves you free to choose manners of representation. Indeed, the manner that is the best suited depends on a whole series of elements that cannot be anticipated at the time of data capture – for instance the attributes that we choose to qualify the object and that we wish to show on the map, and also the date of the data represented, the scale, and so forth.

When the modelling is performed and the objects and their attributes defined, we need above all to deal with what is going to characterise them. For example, for a street, the elementary object to model is liable to be the portion of street situated between two intersections and characterised by its length, the type of surface, its name, the presence of a hard shoulder or pavements, and so on.

Line-objects have a position and a length, but they do not a priori have a surface area. It will later be possible to calculate the surface areas by multiplying length by width, if a width can be attributed to a segment.

Collection of objects : building, *type zone*

Identifier	Owner	Function	Roofing	N° storeys	Walling Material	...	...
0045	Dupont	Dwelling	Zinc	1	Parpaing		
0044	Durand	Industry	Tuile canal	2	Brique		
0046	Dupond	Swimming pool	NA	NA	NA		

NA : means that it is not essential to complete all data for each object, since it can be that an object possesses no corresponding value or attribute.

Building-objects will be defined as zones.

Objects of the "zone" type have an outline and a surface area. In a given collection, two different objects cannot be in the same geographical place, nor can they be superimposed or partially overlap.

In the collections table, the order in which the objects are listed is unimportant.

For each collection of objects the following must be complied with:

- a single identifier per object
- a few topological rules, i.e. the geometric relationships between objects in a given collection (Worksheets 19 to 22)
- the construction of the dictionary (often referred to as "metadata")

Display of an image and outlining of the buildings in a GIS publishing module

Selected object
Other objects

Background image: Quick Bird, 50 cm pixel, Lima (Peru), 2005
Source : Google Earth

What to start with?
You should start with a list of objects that are both necessary and actually available. Indeed, certain data would be useful, but may not be easily accessible. For instance, it is always useful to have data on a sewage disposal system, but it will not be visible on an aerial photo or a satellite image.
Indeed, information on the sewer system may require considerable data collection work in the field in towns or cities in which detailed mapping has not occurred alongside the development of the infrastructures in question.
It is therefore much better to concentrate on what is immediately visible and available on existing images and maps.
These types of objects are listed below.

List of the first geographical urban objects to capture and for which information is generally easy to access

- administrative entities: municipalities, districts, urban sectors (kebele in the Ethiopian context);
- roads, streets, railways etc
- housing blocks
- buildings

  It can be noted that this list does not include plots of land. This is because the outlining of plots may not be possible without a lot of field work. However, where it is possible, or where plot divisions have already been mapped, it is very useful to include them in the list of the first urban objects to capture.
- water courses, ponds, lakes etc.
- bridges
- high-voltage power lines
- altitude (either raster or contours)
- vegetation (either as points for isolated trees, or as zones)
- agricultural land use

Hands Over the City

This fictional film (Francesco Rosi) is set in the city of Naples at the start of the 1960s. Eduardo Nottola has his own business, and he is also a city councillor. He manages to persuade the Mayor and his political friends to help him in an urbanisation project. An old building in a popular quarter, destabilised by the building work, collapses and kills two people.

One important point hinders the enquiry: the only map available does not make it possible to determine whether or not there were two separate walls, whether they were in contact one with the other, or whether there was just a single wall between the two buildings. Why is this? Because the precision of the map is inadequate: the single line used corresponds to a unit 5 metres thick, that is to say a width that could contain a single wall, but also two walls 2 metres thick separated by a gap of 1 metre. The legal procedures are brought to a standstill for lack of sufficient cartographic precision.

(Video sequence *Scale on IGN's Géoportail*)

Worksheet 2
Scale

Scale, which is expressed as a numerical ratio, is a notion that is useful for graphic representation, but which it is better to set aside when constructing a database, in favour of notions of semantic level and geometrical accuracy.
Scale is closely linked to map. Indeed, commercially available maps and plans are widely referred to in terms of their scale: you buy a Michelin* map on the scale 1:100,000, or a city map on the scale 1:2,000. Basically, the scale is the relationship between the real size of the geographical object and its representation drawn on paper. If I represent on paper a 1 km long runway (1,000 m) by a 10 cm long line (0.1m), I am working on the scale 1,000:0.1 = 10,000; it is then said that the scale is 1:10,000. If the line that I draw measures one centimetre, the scale is said to be 1:100,000. This use of the relationship between the size of the object that is drawn on the paper map and that of the object in the real world arises from a technical constraint that used to be unavoidable in mapping: the fact that map-makers were working on paper determined the precision of the scale in accordance with the size of the smallest object that could be represented, remaining visible to the human eye without magnification. (There is an amusing episode in this respect in Francesco Rosi's *Hands over the city* film). Earlier cartographers knew very well that this constraint determined their choice of scale for a map, and not any *a priori* relationship between the real size and the size of the representation. The scale chosen determined the precision of the map, since it was not really possible to draw a line with a precision greater than 0.1 mm. The scale 1:50,000 corresponds to a precision of 10 m; in theory it even corresponds to a precision of 5 m, but this assumes that an object drawn with a line 0.1 mm thick is legible. The arrival of Computer Assisted Design (CAD), i.e. digital cartography, has tended to push the notion of scale into the background. Indeed, the classic definition of scale is not really meaningful when you connect to Google Earth, where it is possible to "zoom" almost without restriction from the very small to the very large. Thus on our computer screens the scale that is displayed is never numerical, it is only graphic. The relationship between the distance measured on the screen and the distance that would be measured on the ground does not integrate the implicit concepts that accompany the notion of scale on paper maps. Scale can thus determine the level of precision of a map a priori. It then defines the minimum size of the objects that it will be possible to represent. Beyond, small objects are either excluded from the representation (simplification) or grouped and aggregated to form larger objects that can be represented (generalisation). This is the approach that led to the production of standardised maps, in France by IGN, on the scales 1:100,000, 1:50,000 or 1:25,000 for example. For each change in scale the linear precision is divided by two, and the surface area precision by four.

"*This use of scale is, obviously, normative. In France it has produced a cartographic sedimentation, generating a geographical mindset that affected several generations of geographers who learned to see and understand the world solely on certain scales that were imposed by the tools they were using (over which, moreover, they had little control). These standardised representations of space possessed a certain relevance in a world in which mobility and telecommunication were not widely developed, and in which the speed at which objects moved and information was transferred did not show very marked differentials – that is to say in the rural world of the 19th century with its tenacious structures inherited from the 18th century. However it can reasonably be said that they are no longer suited to the modern world in which both speed and slowness can be a luxury.*" (Patrick Poncet, La petite carte, EspacesTemps.net, Mensuelles, 06.02.2004).

In practice, Google Earth displays data that are collected at very different scales. For the cartographic representations on the Géoportail website, the modern generation of IGN cartographers have used the rules and standards already in existence for IGN paper maps. The presentation on this website takes more into account the actual size, function and meaning of the data than Google Earth, with the corresponding cost of a more restrictive norm, but one that is also more useful to the user.

The French website Géoportail displays three scales:
– a graphic scale: a distance on the ground in metres or kilometres is coupled to a line measuring 3 to 4 cm on the screen
- a numerical scale ranging from 1:500 to 1:1 000000 with rough whole values. The zoom is not continuous but proceeds in jumps that are close to the earlier norms. This value is often not exact, because the system does not efficiently take account of the size and the resolution of the user's screen.
– a symbol scale describing the level of use of the data: world, country, province, city, street, house.

This example shows us that scale is now, even more so that previously, a consequence of the level of precision at which the data was acquired. Consequently, the systems (Google Earth and Géoportail) choose not to display data collected with kilometric precision on a scale corresponding to the "building" level, although technically this would be perfectly possible.

For a cartographic representation, scale is derived from the surface area of the smallest object captured. A point cannot be used because it has no dimensions. Nor can a line, since it possesses solely a length. It is common to represent a point by a circle, the diameter of which is often unconnected with the size of the actual object. Likewise, on a paper map, the width of a road as it is represented does not correspond to its actual width.

With the advent of computing and GIS, scale, that is to say precision, is no longer a fixed value. Each collection of objects is associated with a degree of precision. The data we are to create can possess different levels of precision. As a result, for our work we will not refer to "scale", but to the "semantic" levels (regional, municipal, cadastral) and to the size of the smallest object captured in a given layer.

(Video sequence SavGIS *An accuracy precision problem*)

Worksheet 3
Accuracy

There are two notions that it is important to distinguish: precision and accuracy.

- **Precision: the fineness of detail or the refinement of the measure.**

The degree of precision depends on the use that is to be made of the object of the measure. Your taxation officer will not agree to measures of your plot that are expressed solely in kilometres, because unless you are extremely wealthy the surface area of a plot that you may own is liable to be less than one square kilometre, and therefore equal to zero if the degree of precision is one kilometre. He will therefore require you to give a measurement at least in metres, although he could be content with decametres, since the resulting error, once the measure is converted into hectares, is very small. But if you give a decametre measure to a workman who is to lay some tiles in the kitchen for an estimate of the cost, he will find it rather odd, as in this instance it is centimetre precision that is required (or possibly the decimetre would suffice). It is thus easy to see that "*it is solely the semantic definition of objects that gives the precision at which one should undertake to describe the localisation of these objects, since GIS enables the storage of objects without any provision for the scale on which they are to be represented*" (Marc Souris, 2000). Souris concludes that *"there is no point in describing particular zones with great precision if the validity of the information is not verified at that level of precision*".

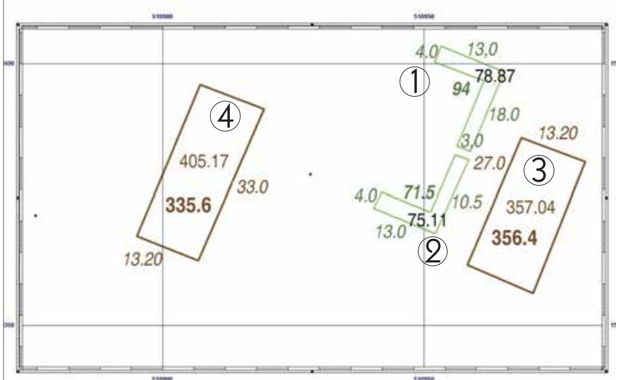
Given that precision has a cost, and that this cost is exponential, we need to determine the degree of precision we require to capture each collection of objects – kilometres, centimetres, or angstroms? These three levels of precision correspond to the modelling of three very different worlds.

The chosen precision of our measures will depend on the way in which the object measured is used. We might consider it useful to have precision to the decimetre when it is a building that is to be measured and described. This degree of precision is however likely to be completely useless – and therefore damaging since it has a cost – when what we set out to describe is the territory of a municipality.

At the same time, the degree of precision is determined by the measurement tools. Digitising an object to decimetre precision is pointless if we are working with Thematic Mapper * images, where each point is a pixel measuring 15 metres square. However other satellites now provide us with images made up of 50 cm pixels, or even less. In this case decimetre precision will be valid.

Comparison of lengths and surface areas between a survey using a decametre and the same objects traced on an image in a GIS

Background image Quick Bird, 50 cm pixels, Bondy (France) 2007
Source: Google Earth



Surface areas according to decametre measurement:

① Lawn: 94 m^2
② Lawn: 71.5 m^2
③ Building : 356.4 m^2
④ Building : 335.6 m^2

Surface areas according to Quick Bird:

① Lawn: 76 m^2 => 81% of the surface area calculated using a decametre
② Lawn: 58.5 m^2 => 82%
③ Building: 357 m^2 => 100.16%
④ Building: 424 m^2 => 97.33%

Precision and accuracy

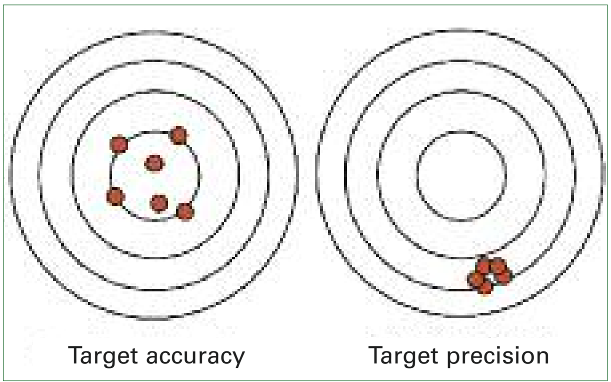
The cost of precision is determined by three parameters:

– the cost of the images (aerial or satellite photos) from 0 to 30 euros/sq.km
– the cost of GPS receivers, from 250 to 10,000 euros
– the cost of the time required: 4 agents/month.

The usual cost of developing a map of a city of 50,000 inhabitants on the scale 1:2,000 is 400,000 euros. For this manual, precision to the decimetre, and in some instances to the metre, has been chosen to describe the town that is studied.

- The second term, **accuracy**, refers here to **the the qualification of the positioning**.

The precision of a measure does not give the accuracy of the positioning



Source: Departamento de Fisica Matematica y Fluidos - Laboratorio MAI - UNED

The precision of a measure can affect the percentage of error in the measurement of the size of an object. It is thus said that Eratosthenes (3rd century BC), using a system of measurement, estimated the circumference of the earth to be 39,375 kilometres, and this evaluation demonstrates very good precision if we compare it to the modern measurement, 40,075.02 kilometres. The discrepancy, that is to say the precision error, was therefore under 2%. This is however very approximate since we do not know what standard measure Eratosthenes used to measure the distance from Syene and Alexandria, which was the basis of his calculation.

Thus the term precision is often wrongly used as a synonym for accuracy of positioning. We can encounter three mains sources of error with regard to the exactness of the final positioning.

1 - Working in a system of local coordinates not linked to a recognised, described geodesic system

This is a classic instance, even today: we have chosen almost maximum precision, and we have measured the building with a decametre tape. We have measured the angles. So far so good! We have great precision, and an error of the order of less than 2% for the overall surface area covered by the building. In the space of one month we have surveyed some 100 buildings in this way, and placed them on a plan on the scale 1:500. But where are we exactly? Despite great care in applying the triangulation methods, we have no way of linking up the work we have done with that performed by other operators. The coordinates that we have indicated on the map are useless, since they only have a value within the setting of our own measures and our own map. Today any tourist will say "your map is wrong!" without even considering all the trouble you have taken to avoid the propagation of error. This is also true of maps, especially on large scales, that are drawn up by surveying bureaus, where the surveyors, for lack of time and money, could not link even one point in the zone to a recognised and described geodesic system. Before the popularisation of GPS, you could very well have a degree of precision of 10 cm but with no means of positioning what you have measured (*see worksheet 6*).

Today GPS (Global Positioning System) makes it possible to position yourself very accurately. The values of measures on a given point have a precision of a tenth of a second.

Etrex*: longitude: 2° 29' 08.3", latitude: 48° 54' 49.1"
Google Earth: 2°29'08.3"; 48°54'49.07".
The difference is of the order of 2 metres.

2 - Failing to check the geodesic system used

If the geodesic system is not ascertained, errors of 300 m in general positioning can occur, or even more, and you can find yourself like Thomson and Thompson in Tintin's adventures, using a sextant to calculate the position from the deck of a boat, already well out to sea, sailing off to find Red Rackham's treasure, with Captain Haddock saying to them "*Gentlemen, please take your hats off, we are now standing inside Westminster Abbey*" (*see worksheet 3*).

3 - Failing to take into account of the acquisition angle of the image

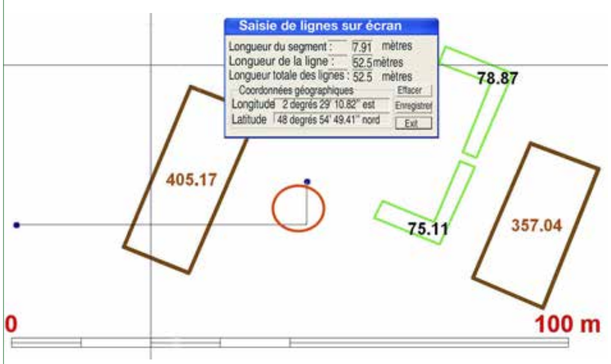
This can lead to apparent displacements for objects with considerable elevation (water tower, towers, rocky needles) reaching several metres (*see worksheet 19*).

Worksheet 4
Geodesic systems

(Video sequence SavGIS *Changing the datum Changing from WGS84 to the Ethiopian geodesic system*)

Our cartography method is based for a very large part on the use of receptors, known as GPS, that give us geographical localisations.
We will now set out to perform a GPS reading for the centre of the circular tank to the south-west of the IRD plot in Bondy, near Paris. We can read the following values: longitude: 2° 29' 08.3", latitude: 48° 54' 49.1".
On our IGN map this same point has a longitude of 2° 29' 10.88" and a latitude of 48° 54' 49".
This amounts to a difference of 0.1 seconds in latitude and of 2.58 seconds in longitude. Following projection on a plane in metric coordinates, we find a difference of 7.8 metres in latitude and 52.6 metres in longitude (this being true whatever the method used).

Results for GPS survey and corresponding coordinates on the IGN map



SavGIS visualisation

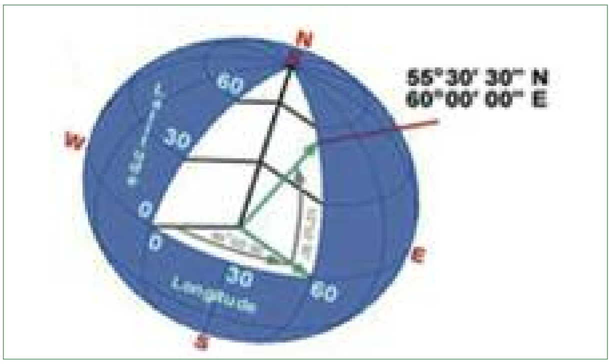
Background image available on Google Earth

The same operation in Ethiopia gives different results. Let us consider a GPS point: longitude 39°32'0", latitude 9°41'0". On our regular map of Ethiopia this same point has a longitude of 39°31'56.8", and a latitude of 9°40'56.42", i.e. a differences of 170 and 95 metres in projected coordinates.
We can thus see that the geographical coordinates of a point are not absolute, they are relative to a reference system. The differences observed above arise from the fact that we have three different references. GPS works with the system known as WGS84, the IGN map was developed within the NTF system, and the Ethiopian map belongs to a modified Clark 80 ellipsoid system, the Adindan Ethiopia datum.
Localisation of objects on a spherical, moving surface is performed using angles. To plot a position the sun or a star can be used.

• Localisation in terms of latitude

The earth offers a virtually constant natural reference marker: its axis passing through the two poles. A plane that is perpendicular to this axis and passes through the centre of the earth is defined, giving the equatorial plane. The latitude of a place is determined from the angle between the straight line linking the centre of the earth to the point and the straight line from the centre of the earth to the Equator. A point on the Equator has a latitude of 0°, and a point at the Pole has a latitude of 90°.
In practice, this angle used to be estimated by measuring the height of the sun at midday on the day of one of the two equinoxes. At that time, the rotation axis of the earth is perpendicular to the direction of the sun. It is then sufficient to measure the elevation of the sun in relation to the horizontal, that is to say the angle between the direction of the sun and the vertical, to obtain the degree of latitude of the place.
From this measurement, tables for the heights of the sun in different places and at different times in the year were developed. Thus, equipped with these reference tables, it is possible to determine latitude from the place one is standing using an ordinary sextant.

The principle of localisation by latitude and longitude



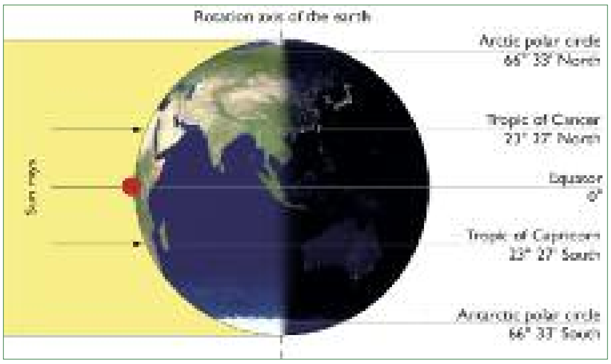
• Determining longitude

We measure longitude perpendicular to the latitude. The origin - the meridian 0° - is today conventionally fixed as the meridian plane that passes through Greenwich Observatory (London). This is perfectly arbitrary. Indeed, for a long period two different references were used, the Greenwich meridian and the Paris meridian. To measure longitude, in theory you "merely" determine the time given by a watch adjusted to Greenwich time at the moment when the sun reaches its highest point above the place to be located. However, exact determination of the longitude requires the time on the reference meridian to be known extremely accurately. It was only at the end of the 18th century that the first seaworthy chronometers were able to ensure sufficient accuracy to reduce error to a few minutes or nautical miles.

If the earth was a perfect sphere, there would not really be a problem, since it would be possible to determine the centre of the earth and the radius. If the earth had homogeneous density, the verticals would all converge on the same centre. However as we have seen it is the vertical, and therefore gravity, that determines the value of the angle measured. Satellites have enabled us to discover the shape of the earth in very precise manner, and at the same time this improved knowledge makes it easier to predict their orbits.

Today two different volumes are described: the first is the gravimetric volume, also referred to as **geoid**, which defines the mean level of the seas. The representation obtained for the globe, exaggerating the differences in altitude, gives a potato shape flattened at the poles (see the image opposite: if it were not exaggerated, this irregularity would not be visible on this scale of representation). Being acquainted with this geoid is important, because the calculation of satellite trajectories is performed from this geoid. Conversely, the more minutely the trajectory of satellites is calculated, the better the modelling of this geoid. The volume of the geoid corresponds in fact to a representation that is very close to reality, but it

Diagram of the situation of the earth on one of the two annual equinox days



23° 27' South	Coordinates in latitude of the Tropic of Capricorn.
●	Place where it is exactly midday (the vertical of the place is perpendicular to the axis passing through the poles)

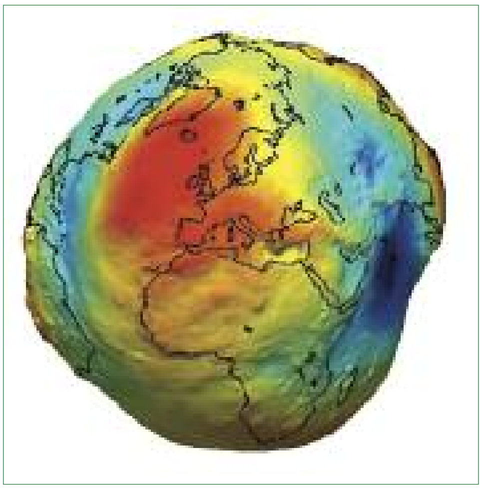
Source: Earth-lighting-equinox-EN.png from Wikimedia Commons

is not really practical for the needs of cartography, because the volume is irregular and calculations using this model are lengthy and complex.

In cartography we generally use a regularly shaped model that enables a mathematical approach: an ellipsoid.

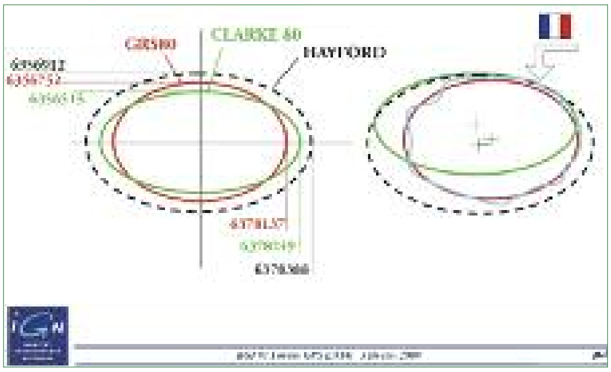
As forecast by Newton (1687), and (inaccurately) verified by Maupertuis and Godin (towards 1740), the earth's diameter according to the north-south axis is smaller than the diameter of the circle formed by the Equator. Astronomers and geo-physicians gradually reached agreement, and we began to model the shape of the earth by assimilating it to an **ellipsoid** (Bessel's ellipsoid, 1841). A shape of this type is defined by the respective values of a large axis and a small axis. About 300 different axes have been defined. For one and the same ellipsoid it is possible to determine several systems by positioning the cen-

The terrestrial geoid, with its lumps and hollows, of course very exaggerated

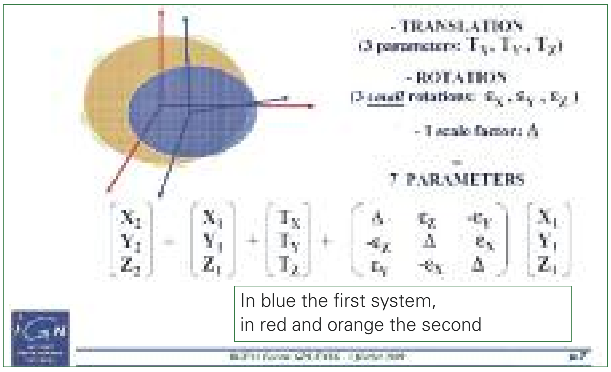


© Esa

The three most widely used ellipsoids: Hayford, GRS80, Clarke 80



Changing the reference system



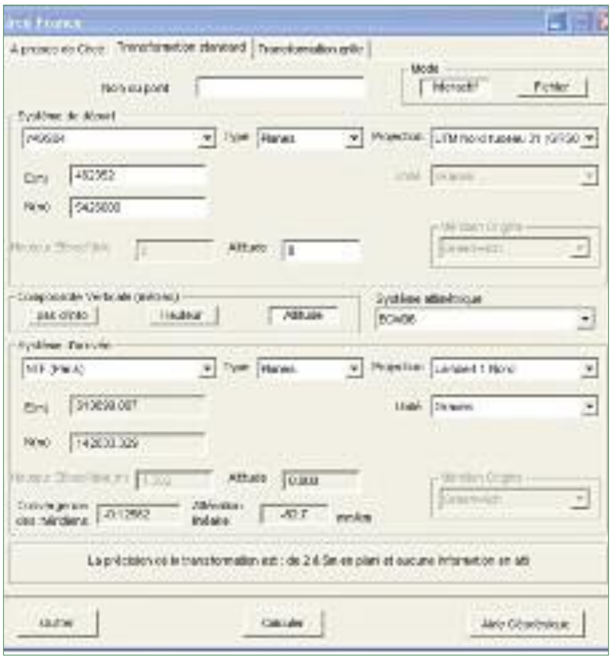
tre differently. This position is determined by the *datum**. The EPSG* (the European Petroleum Survey Group) thus references more than 3,000 different systems. A datum is a point on the earth (often referred to by a place name) the vertical of which will pass through the centre of the ellipsoid. These different systems use the best local correspondence between the geoid and the ellipsoid adopted. The discrepancies between the geoid and the ellipsoid in the French NTF system are given as not exceeding 14 cm in altitude (S. Milles & J. Lagofun). But, as we have seen, the angular discrepancies between the two systems can reach 3 arc seconds.

"*Numerous datums have been chosen to optimally adjust the ellipsoid of the earth's surface, according to its local curvature, and the scope for measuring positions in close succession. Certain datums are defined by purely geo-physical parameters enabling the equation of the revolution ellipsoid and the position of its centre to be approached, the latter then corresponding to the centre of the masses. These datums are no longer dependant upon a condition of tangency at a particular point, and they are used for the earth overall (WGS84*, GRS80* for instance)*" (M. Souris, 2001).

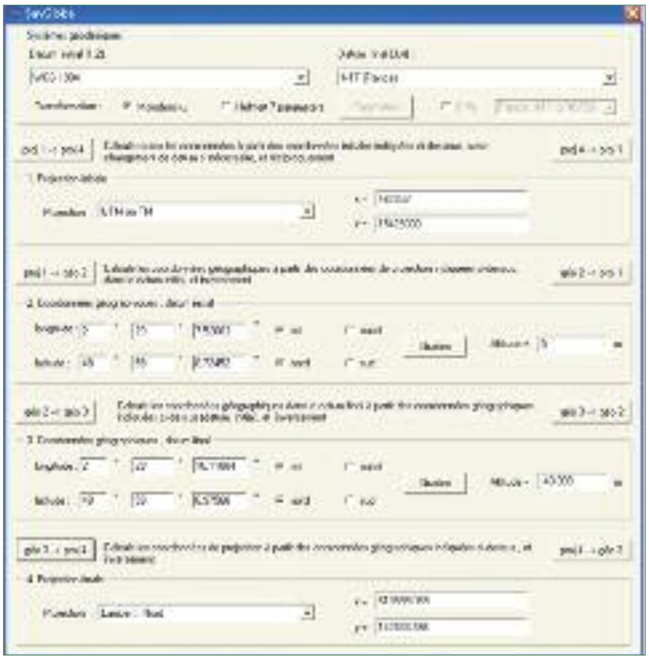
Practically speaking, as far as we are concerned, we need to choose the system in which we are going to create the database and use it thereafter. To date there is no GIS that can work simultaneously with several geodesic systems. In fact we have two options:

- to work with a "global" system like WGS84, fairly recently established (or in France with RGF93* which is practically equivalent). This is obviously the simplest option - it enables you to avoid having to convert GPS data. In the field, the receptor can be used with the default programming;
- or to work with the national system. For instance, in Ethiopia a modified Clarke 1880 ellipsoid associated with the Adindan Ethiopia datum. The use of the

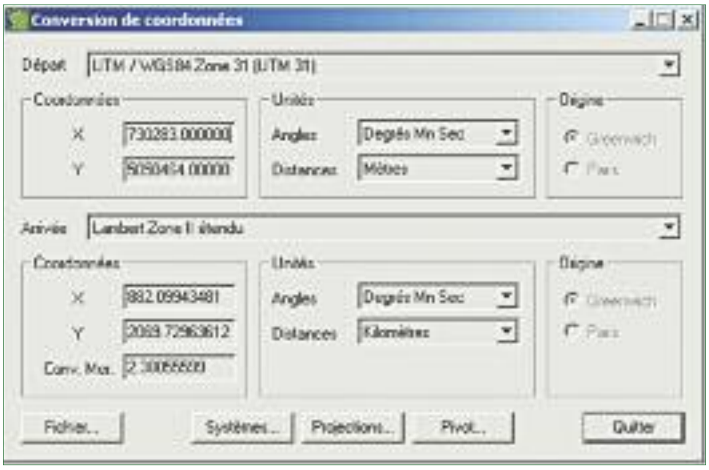
Circé software (IGN)



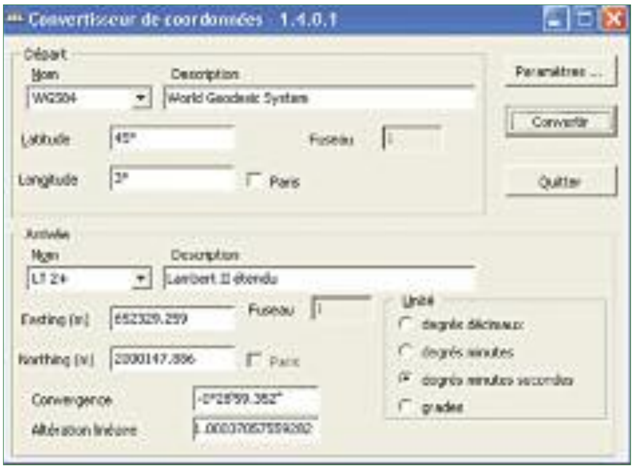
SavGIS software (IRD)



Changing the geodesic system using the Convers * programme



Changing the geodesic system using the converter developed by Eric Sibert



national system will facilitate the integration of existing maps, and comparisons between data that we create and these existing data, but it will also make the concomitant use of GPS in the field more delicate. This is because we will need to convert all the GPS data, since they are native to the WGS84 system

When we have older, pre-existing maps, it is often a good idea to make use of them. It is important to check that the systems implemented are identical. Otherwise they will need converting. Fortunately there is software that enables these voluminous calculations, whether for a particular point or for a set of coordinates in a file.

We can also mention the IGNmap programme. However this is dedicated to the French territory alone.

• Projection

When the decision has been reached on the geodesic system to be used, a projection method to accompany it can also be chosen. Each method will lead to distortions. For a plane tangent projection, only the areas close to the tangency point will not show distortion. The further one draws away from this point, the greater the difference between the length of the arc and that of its projection.

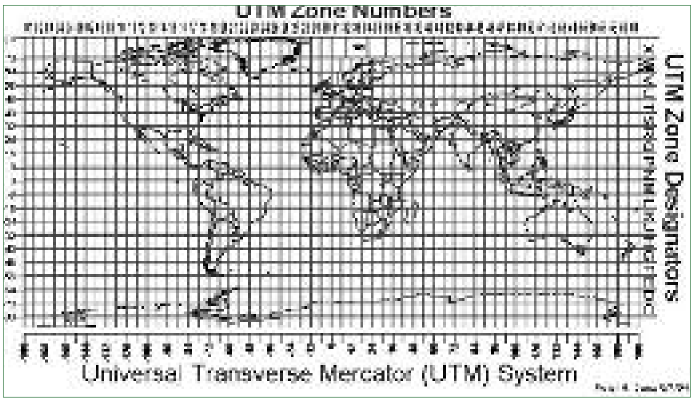
For countries close to the Tropics, it is classically a transverse cylinder projection that is used, where only the segments situated on a meridian line (tangential projection) - or two lines in the case of intersecting projections - will show no distortion of the scale. Thus the scale factor at the central meridian of a UTM projection is not 1.0000 but 0.9996. The exact scale (factor 1) is found on either side of the central meridian, and will become 1.0004 on the edge of the UTM zone.

It is of course always possible to choose the central meridian as that of the centre of our territory, but in practice it is preferable to choose one of the 60 possibilities provided by the UTM system, U meaning universal.

In practice, GIS generate projections automatically, the calculations are simple, and do not result in approximations.

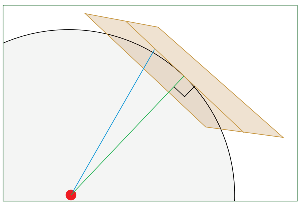
The distortions that arise on the edges of UTM zones possess equal values: the scale error on the edge of zone 36 is equal to that on the western edge of zone 37.

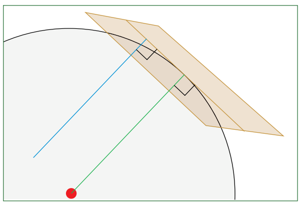
Représentation of the UTM system



Two azimuthal projections

Gnomic azimuthal plane tangential projection: the centre of the projection is the centre of the earth





Orthographic azimuthal plane tangential projection: the centre of the projection is taken to infinity

(Video sequence)

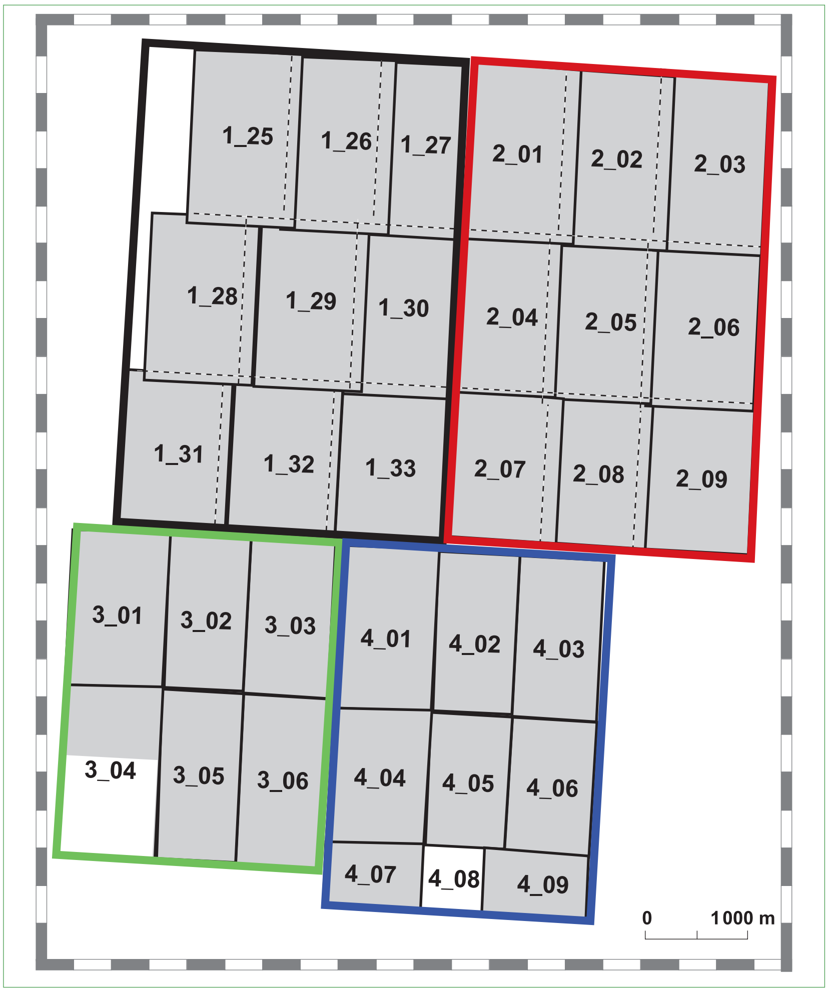
Worksheet 5
Scanning a map

The operation described here consists in digitising a paper map using a scanner. The result is an image (raster), i.e. a matrix of pixels which can then be processed by a computer like any other image. Places for which no maps whatsoever exist are very rare.
The descriptive maps that are found are often in the form of rather unmanageable documents on large sheets of paper, A1 or A0. If you do not have a large format scanner available, it is possible to use an A4 office scanner, and to scan the document in A4 portions, and then to adjust by tessellation (*Worksheet 13*) so as to obtain the appropriate mosaic of all the pieces of the map. The result may even be better than that obtained on certain large format scanners. Where geographical data exists, it is a pity not to use it.
Certain rules need to be observed to perform this task properly.

Organisation rules

- You need first of all to make a **rough assembly plan** to facilitate the assembly of the mosaic of A4 portions of the original map. Original sheets in A1 format (about 75 x 55 cm) require 9 A4 pieces to cover the whole.
- when you divide up the map, and for each A4 section, **retain an overlap zone between the different adjacent pieces**.

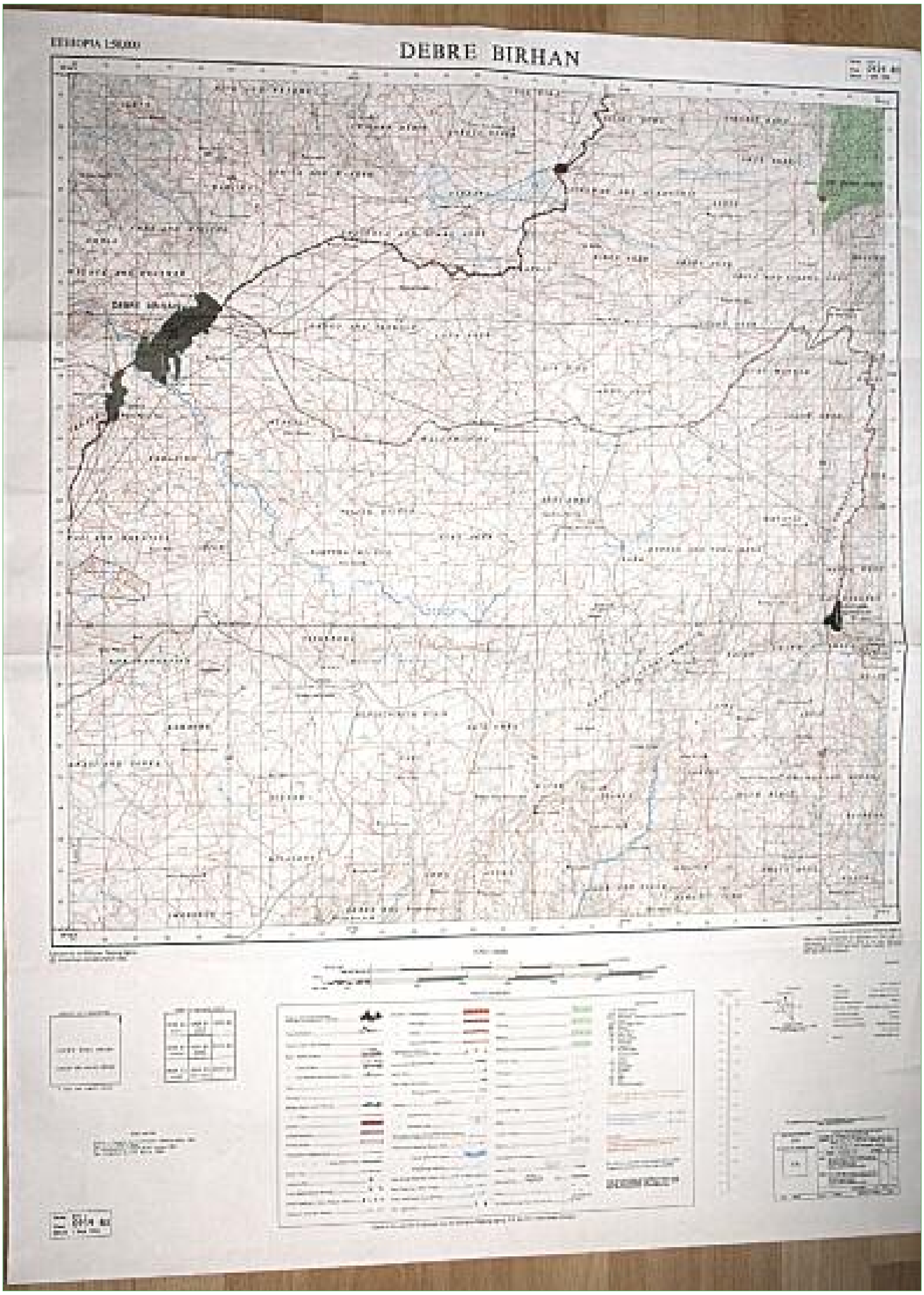
Example of a scanner plan for the four sheets of the map on the scale 1:2,000 of the town of Hossaena established for PUPI (Federal Urban Planning Institute) in 1998



The four sheets
Scanned A4 portion
White zones: no data
Overlap zones between two A4 portions

What sources of geographical data?

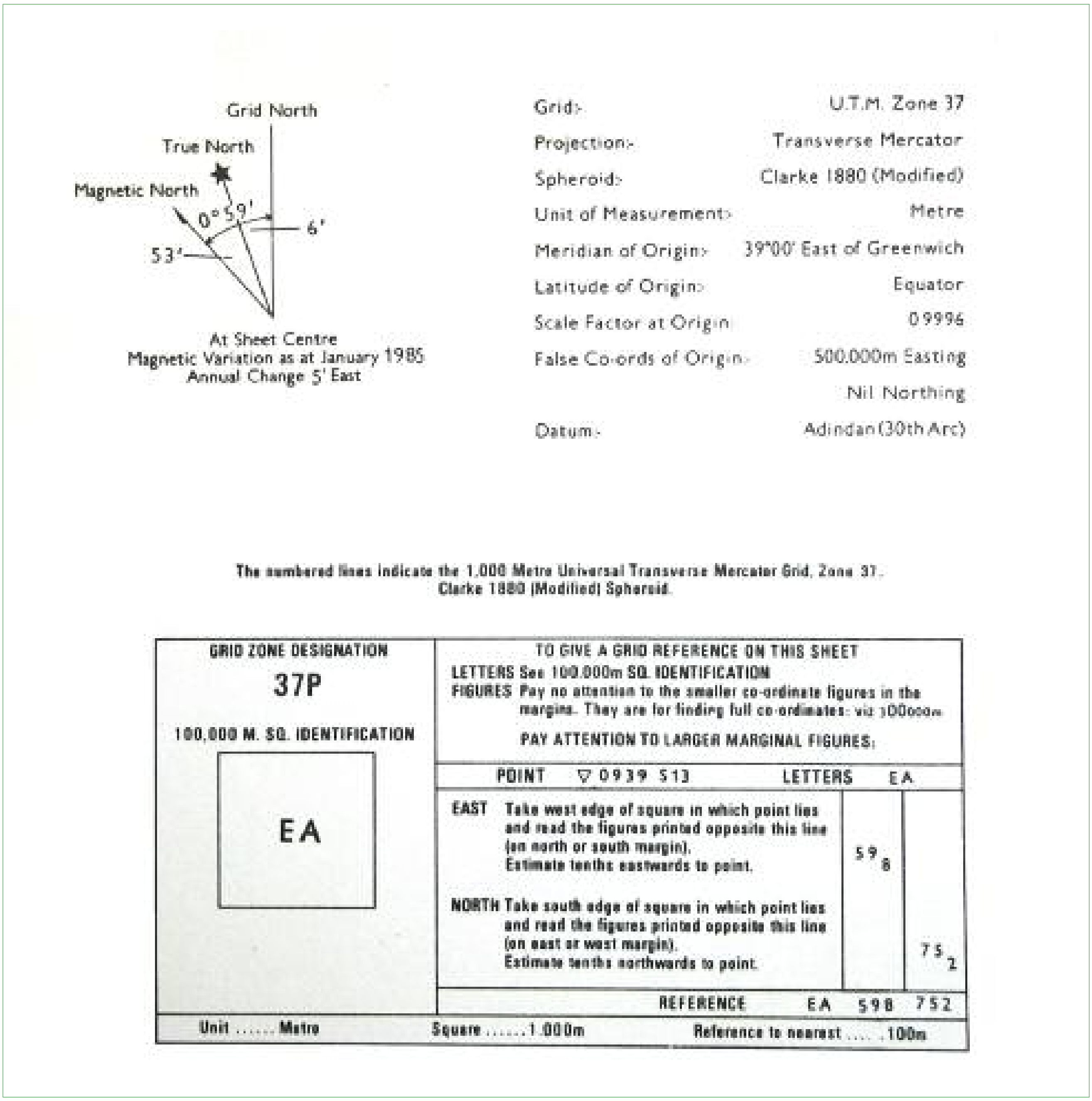
Photograph of the whole map measuring 79x99 cm (original paper document)



Source: EMAP (Ethiopian Mapping Agency), Addis Abeba (Ethiopia), 1986

- By definition, a map always shows coordinates expressed in terms of a geodesic system (otherwise it is a plan or a sketch map). This geodesic system is described literally on the map. It is very important to **collect all the information relating to this georeferencing system**.
- Be sure that **the coordinates indicated on the edges of a map have been included in the scanned zone**. They are values that will be used later, and they will no longer be accessible once you have returned the paper map to its owner.

Photograph of the essential insets or legends describing the geodesic system used



Source: EMAP (Ethiopian Mapping Agency), Addis Abeba (Ethiopia), 1986

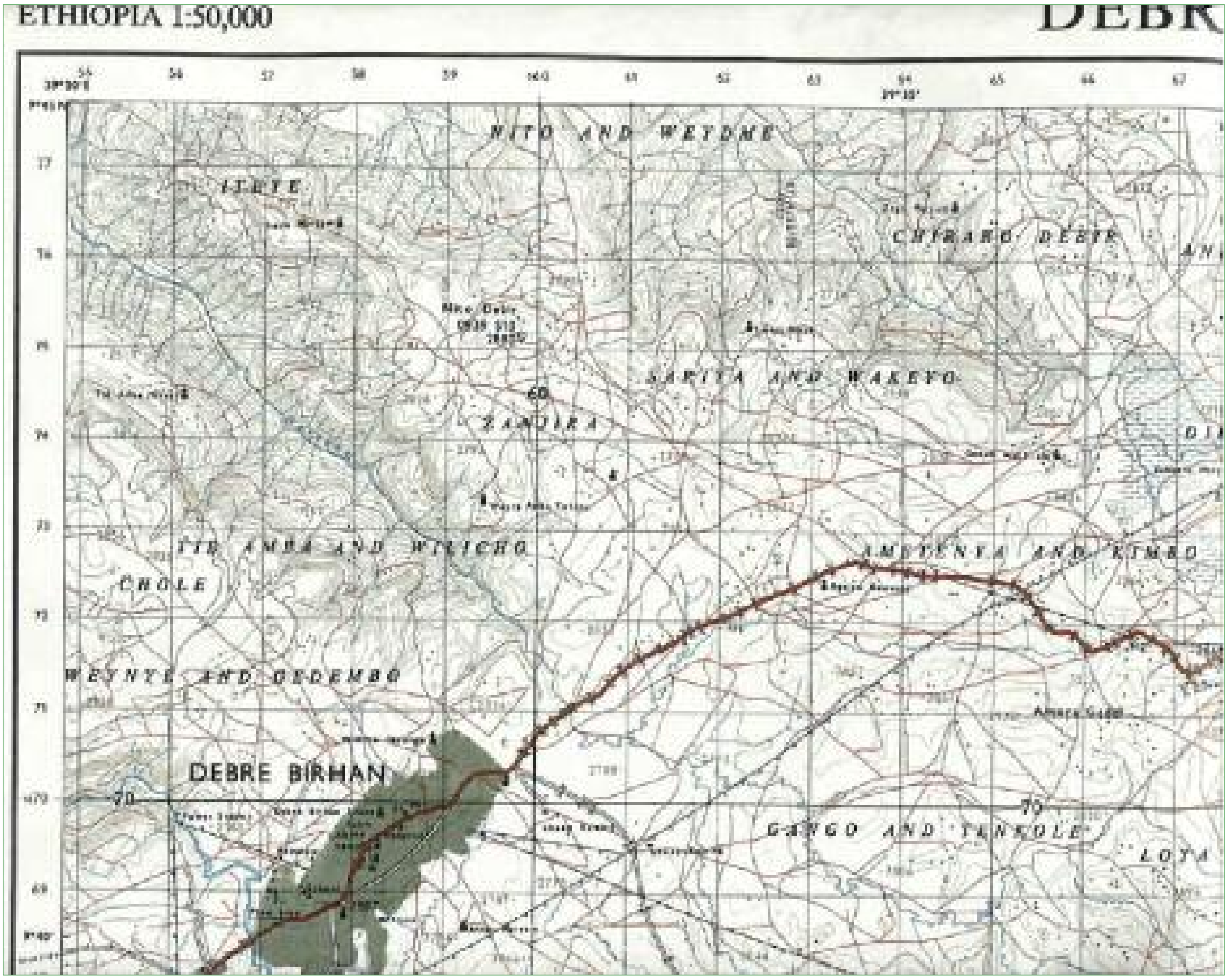
- Likewise, it is a good thing to **scan and store the inset or legend describing the geodesic system used** for the map. It would be a pity for an identification error at the outset to render the scanned map subsequently unusable for lack of the original information enabling its adjustment.

Adjusting the scanner

be too pale so as to avoid the loss of fine lines (watch for the legibility of relief contours). For this purpose you should exit from the automatic mode and adjust the brightness so that the whites are pale grey. It is often necessary to reduce the contrast value so as not to lose information.

- Adjust to black and white (shades of grey) for monochrome documents and to RVB (24 bits) for colour documents.
- There is no need to scan opaque documents with a resolution of more than 400 dpi. Greater resolu-

Le fichier scanné correspondant à une portion A4 de la carte topographique au 1 : 50 000 de la ville de Debre Birhan (Éthiopie)



Source: EMAP (Ethiopian Mapping Agency), Addis Abeba (Ethiopia), 1986

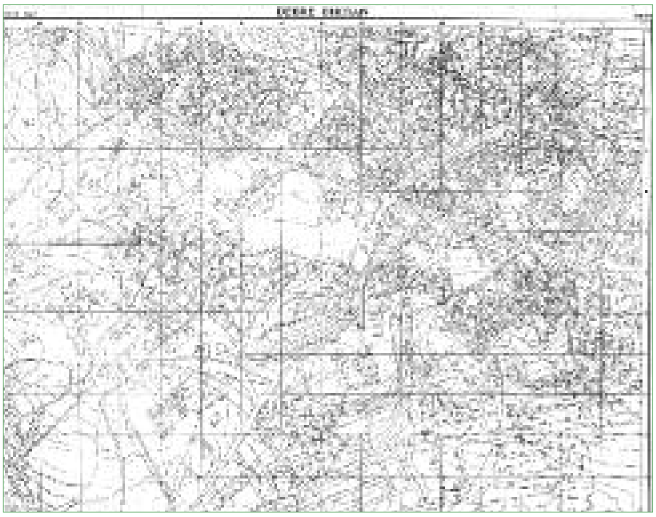
(Video sequence)

Worksheet 6
Scanning a plan or a sketch-map

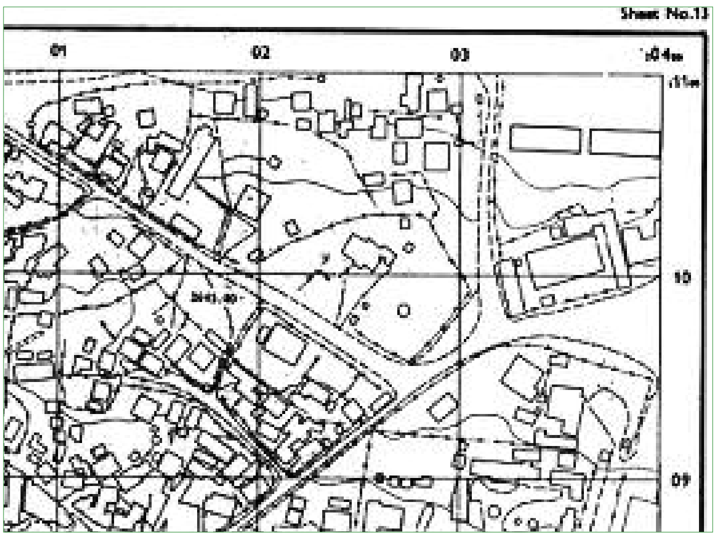
A cartographic document on which no geodesic system is indicated is not properly speaking a map. In this case we will refer to a "plan" or a "sketch-map". For instance, the plan of a city is often divided into squares noted 1,2,3 etc. horizontally and A,B,C etc. vertically. This squared subdivision cannot be used directly because there is no correspondence, either geodesic or on the ground. Likewise the majority of documents either on paper or in computerised form of the Illustrator or PDF type should be considered as sketch maps if there is no georeferencing information. This holds even if the documents provide an exhaustive inventory of the land cover or use and the objects present in a given space. They do however often provide detailed information that is already established and potentially very useful, provided that it can be fitted into a geographical framework. Fitting such data by way of tessellation makes it possible to integrate information contained in a plan or a sketch-map into a georeferenced data base, on the level of precision of the original document.

Here is a plan of Debre Birhan, drawn up by a private firm which is no longer in existence for the Ethiopian Mapping Authority. The surveying was performed using a local geodesic system that is not described. It has a precise squared grid, but this grid is akin to that found on street plans, since it is not possible to connect the values on the map to any international geodesic system.

A detailed plan of Debre Birhan (Ethiopia)



Extract from the above plan

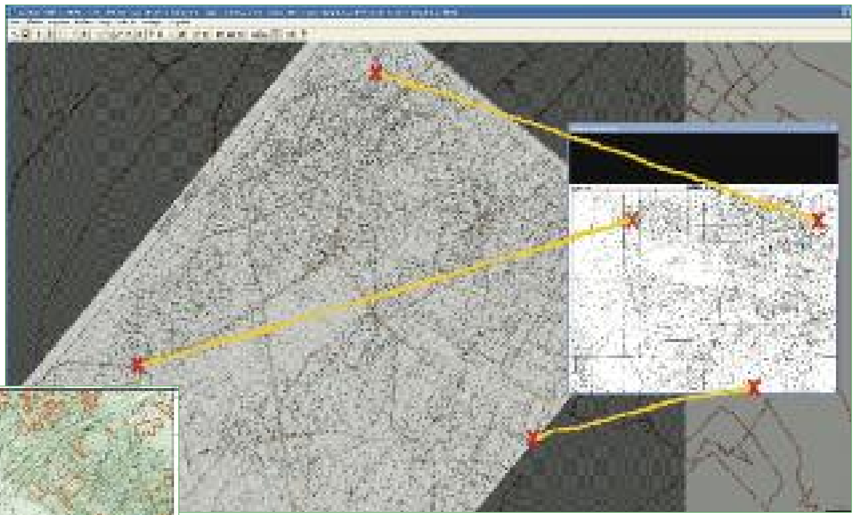


The squaring system, in metres, is clearly printed, but it cannot be linked to anything. We do not even know the origins of the coordinates x and y.

What sources of geographical data?

Correspondences established for three points located by similarity of forms

We can however adjust to GPS data that we have obtained (red crosses).



Extraction of buildings after adjustment

Top right can be seen the scanned FUPI sheet without coordinates.
To the left is shown the superimposition once it has been adjusted from GPS data (in red). Thus the extraction of the older built-up area (1995) is possible.

Do not hesitate to photograph the document with a digital camera, even if it is not a professional model. The results will of course be less precise than that obtained using a scanner, but it will produce perfectly useable images. The document (on the left) was hung on a well-lighted wall, but without direct lighting (take care to avoid reflection) in the municipal offices in Debre Birhan in Ethiopia, and then photographed with a digital camera. The image obtained shows all the information quite adequately: the boundaries of the administrative units (known as "*kebeles*"). The source document had no geographical coordinates as such. However it was possible to position and georeference the administrative boundaries on the basis of similarities in shape and certain contours derived from other data available on another map that did have geographical coordinates.

1 - A map showing the administrative boundaries of the town of Debre Birhan without any geographical coordinates, available in the municipal offices

2 - Establishment of correspondences on the EMAP topographical map on the scale 1:50,000, which provides geographical coordinates

3 - Overlaying on the Aster satellite image after digitising

(Video sequences ***Exploring the DigitalGlobe website***
Capturing images with Google API
Exploring the GeoEye website)

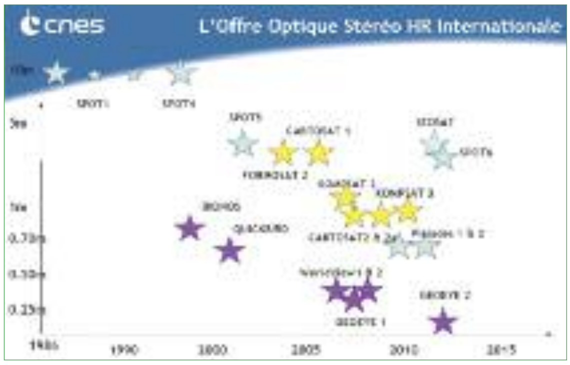
Worksheet 7

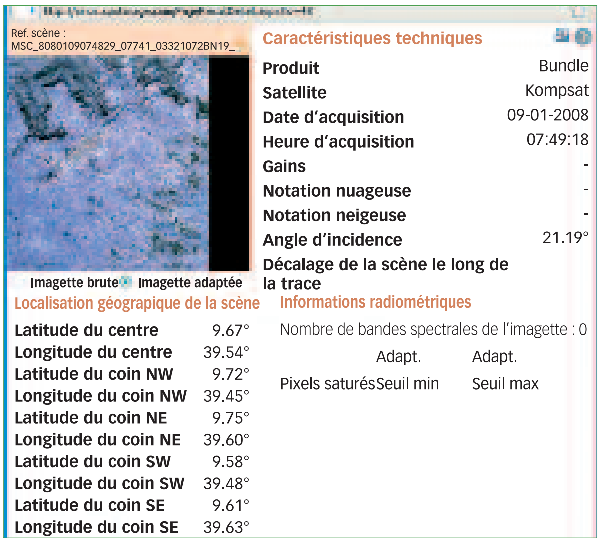
The offer in the area of very high spatial resolution imagery (VHSR)

There are numerous satellites today devoted to image capture. A dozen national space agencies and private operators have enlarged the offer, but we need not list all the systems. We can, perhaps arbitrarily, fix our required level of precision as that enabling buildings to be represented with a reasonable margin of error (10 to 20%) for their surface area. This being so, what can we use from the resources known as "very high spatial resolution" imagery?

Available resources are: GeoEye 1, Quick Bird, Ikonos, Kompsat2, Resurs-DK1; and more recently, after 2010: GeoEye 2, WorldView 2, Pleiade. In this list we have not included the systems that provide panchromatic images, i.e. images solely in black and white, which are very good for creating relief contours by photogrammetry, but much more difficult to use in photo-interpretation.

The offer in high spatial resolution imagery according to CNES





For these five types of image, it is possible to ascertain on websites whether the image presents the required qualities for our particular purpose. It is also possible to order the images. It is not however easy to give information on how to use the different websites, as they regularly change their presentations.

Ikonos and **GeoEye** on the GeoEye website: http://geofuse.geoeye.com/landing/Dafault.aspx.

It is preferable to use Online Maps. We can also note the existence of free access through the GeoEye Foundation: http://www.geoeye.com/CorpSite/corporate/foundation

Quick Bird (25$/km2) and WorldView-2 on the DigitalGlobe website, http://www.digitalglobe.com, click on "Find imagery".
Kompsat-2, followed up by Pléiades, is accessible on the Spot Image website. The CNES programme ISIS offers acquisitions at very low cost (when the image is to be used in a scientific research programme with a French partner).
Resurs_DK1 is more difficult to apprehend. It is not easy to access the catalogue, which takes a long time to consult: http://eng.ntsomz.ru/zakaz/data_cat/catalog.
Cartosat_2: http://www.antrix.gov.in/main/Antrix%20Cartosat-2%20International%20Price%20List.pdf
http://www.nrsc.gov.in/c2coverage.html
Formosat-2: http://www.spotimage.com/web/945-les-caracteristiques-des-images-formosat-2.php.
Prices indicated on the websites.

For those who cannot afford 500 euros to purchase an image, there are other options, rather rough-and-ready, but acceptable.

1 Launch SavGIS and click on "Google Earth". You will directly obtain the most precise image in the Google catalogue (generally QickBird) and you will be able to pursue you work in a functional framework.
  This solution requires you to follow the Google georeferencing system. While its system is fairly precise for Europe and the USA, it is far less precise for countries for which Google does not have sufficient references. For instance for Ethiopia, discrepancies of 50 metres are frequent. This can be a real problem, as your GPS measures will diverge by as much (*for details see Worksheet 9*).
2 Use Google API to download the data:
  – Enlist
  – Type in the entry key in the Java script (*key*=[your personal key]), adjust the central point of your zone of interest, adjust the size of the pixels in your zone. Launch the following script under Internet Explorer

```
<!DOCTYPE html PUBLIC "-//W3C//DTD XHTML 1.0 Strict//EN"
"http://www.w3.org/TR/xhtml1/DTD/xhtml1-strict.dtd">
<html xmlns="http://www.w3.org/1999/xhtml">
<head>
<title>SavGIS et Google</title>
<script language="JavaScript" type="text/JavaScript">
<script src="http://maps.google.com/maps?file=api&amp;v=2&amp;key=[votre clé personnelle]"type="text/javascript">
</script>
<script type="text/javascript">
var x=36.892495;
var y=10.851218;
function load()
        {
        if(GBrowserIsCompatible())
                {
                var mapCity = new GMap2(document.getElementById("map"));
                mapCity.setCenter(new GLatLng(y,x));
                mapCity.setMapType(G_SATELLITE_MAP);
                mapCity.setZoom(18);
                }
        }
</script>
</head>
<body onload="load()" onunload="GUnload()">
<div id="map" style="position:absolute; width: 16000px; height: 16000px; left: 0px; top: 0px;">
</div>
</body>
</html>
```

  – Use a screen capture application such as Fastone capture. The image obtained will then need georeferencing *(to do this see Worksheet 13).*

(Video sequence *The specific features of VHSR*)

Worksheet 8

The specific features of very high spatial resolution (VHSR) imagery

• Very "voluminous" images
An image may take up more than 1 giga-octet. The size of the file for a given image depends on the number of pixels that compose the image. If we have pixels of 50 cm, the image of a territory measuring 10 km square will comprise 20,000 x 20,000 pixels, or 400 millions for each band. Thus very high spatial resolution images can be problematic in terms of volume in relation to the capacity of the computer you are using. It may be sufficient, as a first step, to use programmes such as MultiSpec (free software) that make it possible to read only a part of the image file.

• The ground swath * is variable, but often narrow.
The VHSR captors that we can use today have a ground swath of about 15 km at most. If our study zone covers more than 200 km^2, we will need two images. In this case, the images available will not necessarily carry the same date.

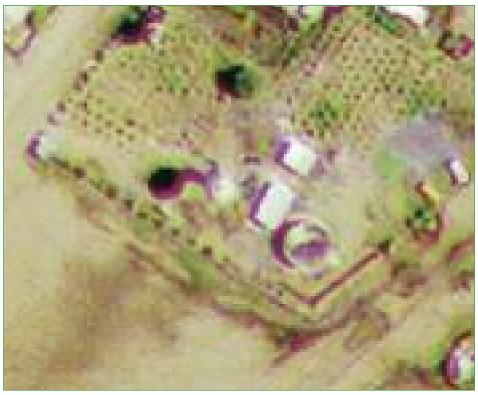
• The diversity of radiometric response for one and the same category of objects is much greater here than in the case of large pixels. The precision of the image means that a given type of object can have very different colours. There are cars that are black, blue, red, white etc. The range of colours for roofs is almost as large, and in addition one and the same roof will have a very different colour and value according to its orientation. Thus an approach using multi-spectrum radiometry can be come very problematic. This is why we are in favour of photo-interpretation: the eye can "recognise" a roof or a car, whatever its colour, on the basis of its shape and local context.

GeoEye image of Mexico, 2010, 50 cm pixels

This GeoEye image of Mexico shows roofs of all sorts of different colours. It can also be seen that the pixels of one and the same tree have very different values according to whether the tree is fully lighted or in the shade.

• The angle of view is often oblique.
Present-day satellites are said to be "agile", this means that, unlike the Landsat system, they are able to capture views from an oblique angle. The corollary of this is that we rarely have vertical views.

Ikonos image of the town of Awash (Ethiopia) in June 2002. Angle of view 100°, direction of the sun 250°, obliqueness 20°, 1 m pixels

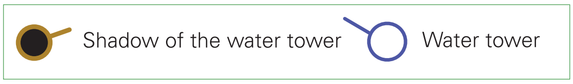


In most cases, one of the sides of the different buildings can be seen, and the surface area cover of the roof is out of line with the ground space covered. The consequences of relief are proportionally greater for very high resolution images than for high resolution images.

Ikonos image of the town of Awash (Ethiopia) in October 2003. Angle of view 190°, direction of the sun 300°, obliqueness 22°, 1 m pixels

Ikonos image of the town of Awash (Ethiopia) in June 2002. Angle of view 100°, direction of the sun 250°, obliqueness 20°, 1 m pixels

Ikonos image of the town of Awash (Ethiopia) in October 2003. Angle of view 190°, direction of the sun 300°, obliqueness 22°, 1 m pixels



Here all the objects with any height are shifted (or apparently displaced) towards the right of the image in relation to their base. This is very conspicuous for the top of the water tower (labelled water tank on the image). But it is also true for the roofs and the canopies of the trees.

This means that we will need to avoid selecting elevated objects for georeferencing or adjustment of the image.

Here all the elevated objects are shifted (displaced) towards the bottom of the image in relation to their base.

It can also be seen that when houses, for instance, are digitised, obliqueness introduces an error that varies according to the height of the building.

Image with a vertical view

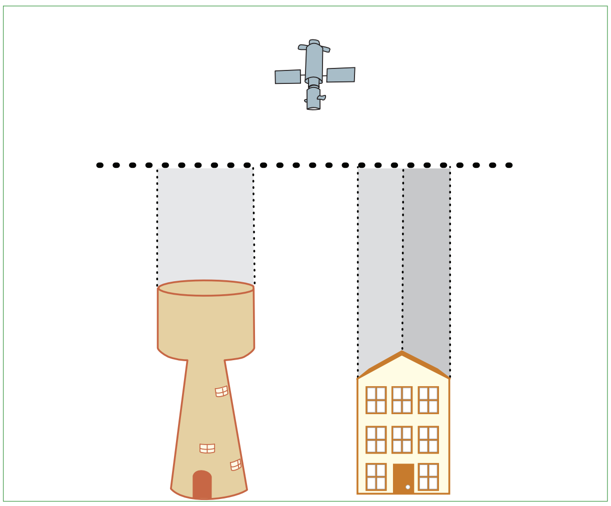
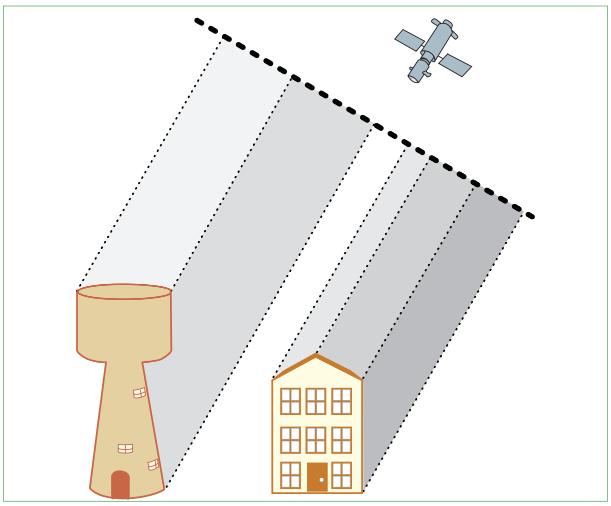


Image with an oblique view



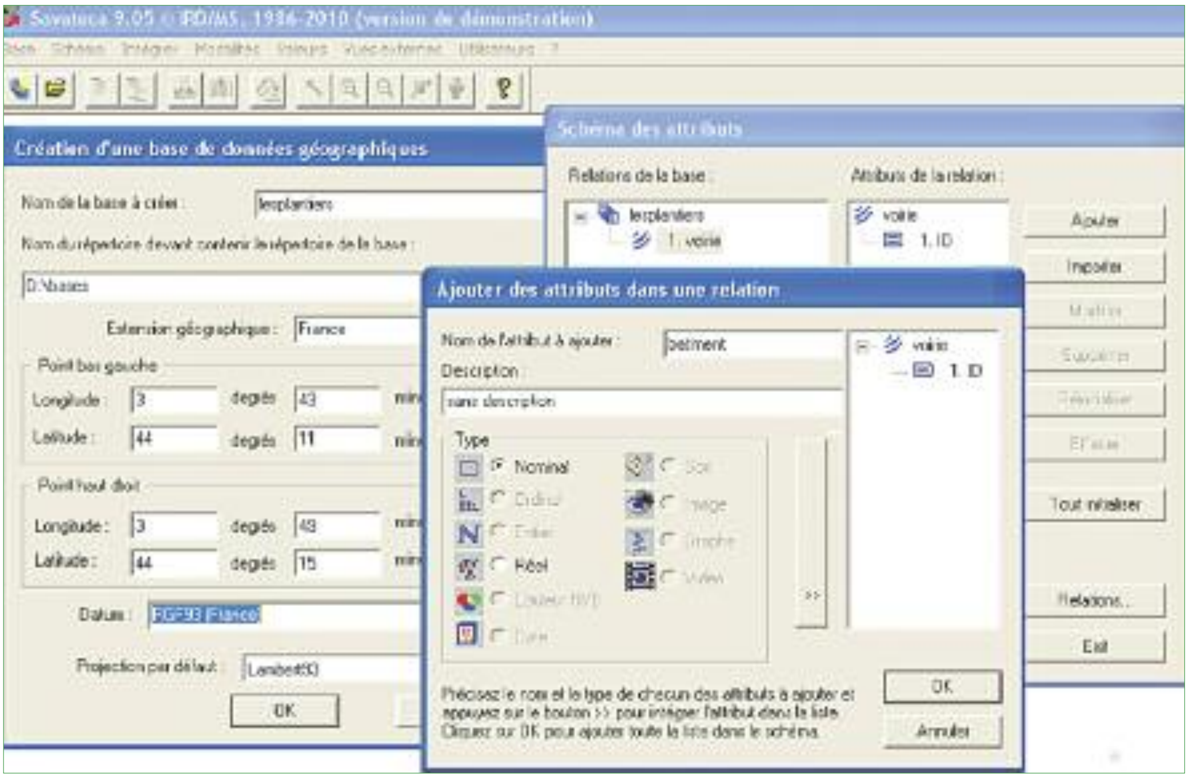
(Video sequence SavGIS)

Worksheet 9
The Google Earth server *via* Savedit

It is possible today to produce maps from the interpretation of images provided by Google Earth or any other virtual globe. As the image resolution is getting greater, it is true, as we said earlier, that the accuracy of the positioning is also getting more precise, even if it is still variable according to regions. The quality of Google Earth is improving all the time, but the Google company still decides which resolution and information it will deliver on Google Earth. This method enables us to do without the GPS surveying work described earlier or as recommended by Open Street Map. If the accuracy is inadequate, we can correct the result in accordance with GPS data that we have collected.
We will now describe this process by creating map in Lozère (France). This region is very well mapped by the French National Geographic Institute (IGN), but the maps are note exhaustive on the themeswe are interested in.
Prerequisites: a computer under Windows and an Internet connection, even without broadband (56 ko are sufficient).

• Step 1 – Creation of the database
Download SavGIS software (*www.savgis.org*) and install it by double click on the Savpack file. Create a new database named "lesplantiers". Draw the geographical area to be covered.
Create the database scheme, i.e. the layers to create (by theme and by kind of representation – point, line, polygon). Do not forget to create an "external view".

The SavGIS window, module Creation of a geographical database

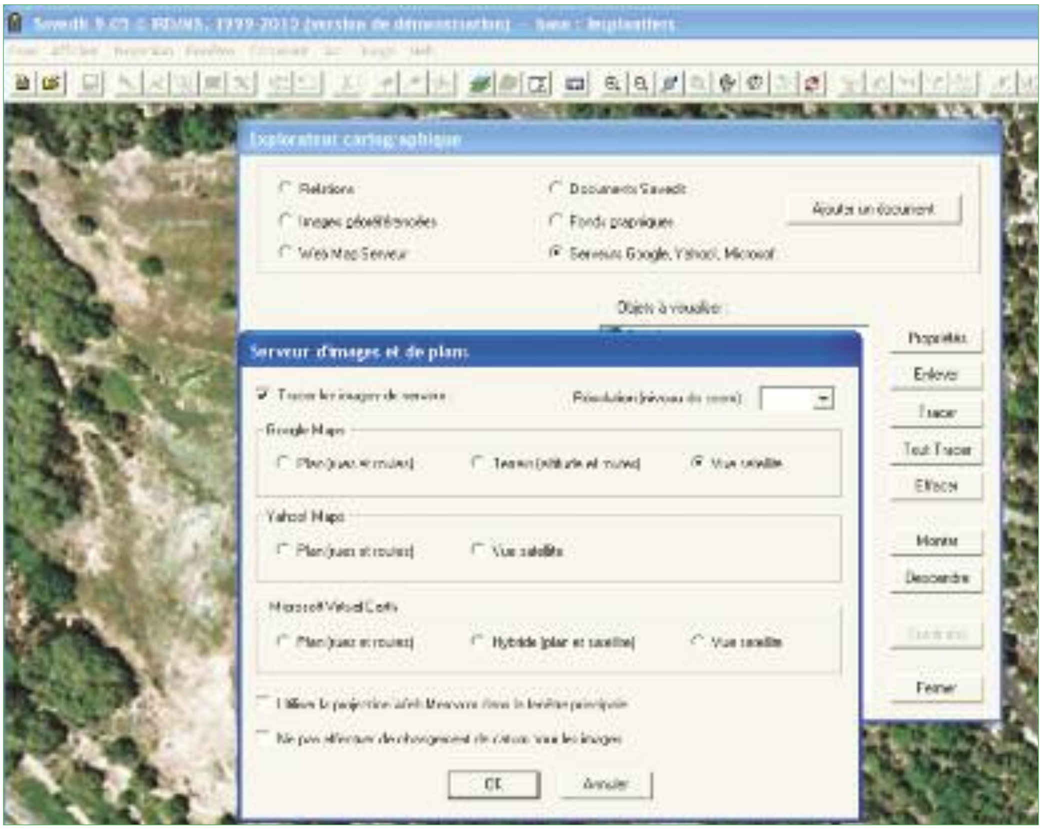


- **Step 2 – Digitalization of the road network using Savedit**

This database is then opened (at present still empty) in Savedit. Call for the display of the content of the Google Earth server.

The image available on Google Earth is then displayed quite simply, taking into account the projection and the geographical frame chosen for the database "les-plantiers".

SavGIS window, Savedit module, graphic capture, import and digitalization



SavGIS window, line capture module

We can start the digitalization directly by opening a new "line" document for the roads. The digitalization can be performed at the required level of precision, since the zoom is available at all stages.

We can also draw the buildings as polygons.

SavGIS window, polygon capture module

We obtain two sets of georeferenced data, one for roads and one for buildings. Once the image has been exploited, it can be closed. But before that, remember to carefully register its characteristics (satellite, acquisition date...) in the metadata accompanying the two sets of data.

(Video sequence SewGIS *Integrating SRTM*
***Integrating GDEM*)**

Worksheet 10

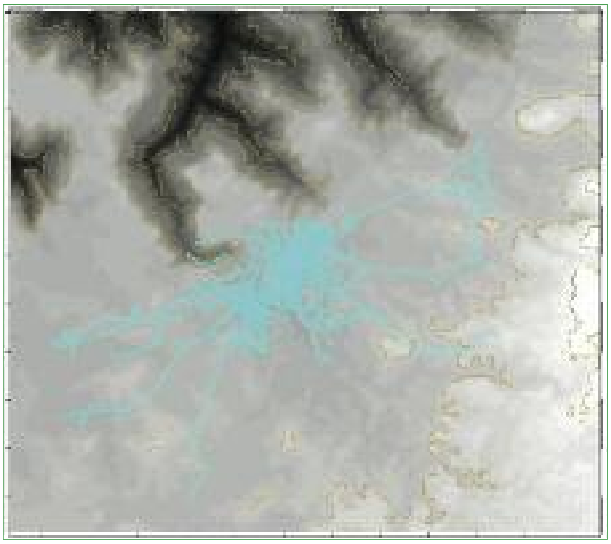
Elevation data – SRTM – GDEM – Reference3D

SRTM

The Shuttle Radar Topography Mission (SRTM*) initiated by NASA* consisted in using the space shuttle to record radar data for almost the whole earth (between 60°N and 54°S) for a period of 11 days in February 2000. This data was processed using interferometry with a view to cartography the earth elevation surface. The absolute vertical accuracy is specified as less than 16 metres.
An evaluation of the precision is provided by Martin Gamache:
http://www.terrinmap.com/downloads/Gamache_final_web.pdf
The grid unit is 30 metres for north America and Europe and 90 metres for the rest of the world.

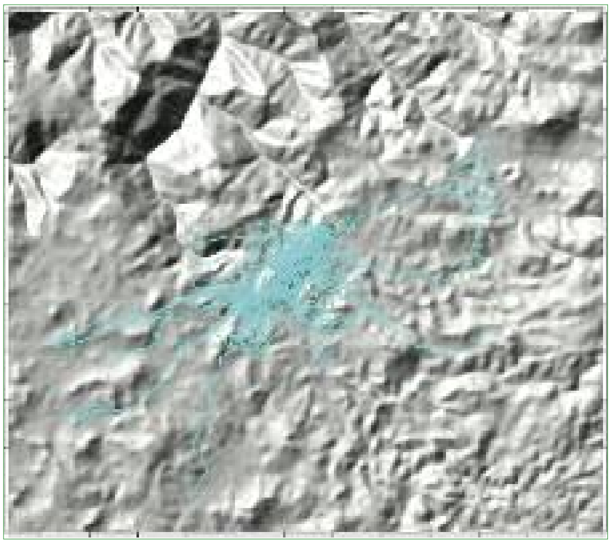
The data can be downloaded from several websites:
- CGIAR_CSI version 4 data, format GeoTif* or Arcinfo ASCII (http://srtm.csi.cgiar.org/Index.asp). Then click on SRTM Data Search and Download
- The JPL website (http://www2.jpl.nasa.gov/srtm/) sends you to USGS* which proposes version 2, hgt format
- The Maryland University website (http://glcf.umiacs.umd.edu/data/srtm/) proposes GeoTif files and also connects to partner websites: NASA (JPL), USGS, NGA, DLR, and ASI.

SRTM visualisation of elevation data, Debre Birhan (Ethiopia)



From white to black: increasing elevation values
Blue lines: Debre Birhan road network
Map source: EMAP (Ethiopian Mapping Agency), Addis Abeba (Ethiopia), 1986

Visualisation of relief using shading, Debre Birhan (Ethiopia), position of the sun northwest



Blue lines: Debre Birhan road network
Map source: EMAP (Ethiopian Mapping Agency), Addis Abeba (Ethiopia), 1986

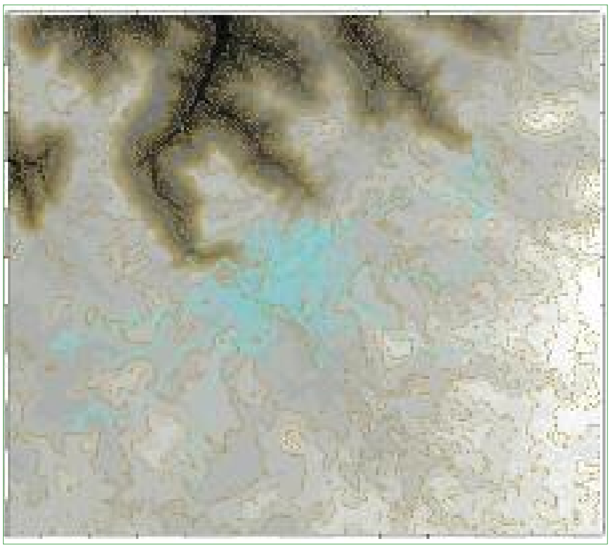
GDEM

JPL * (http://asterweb.jpl.nasa.gov/gdem.asp) provides a homepage for ASTER Global Digital Elevation Model * which corresponds to data created by stereogrammetry from Aster images derived from the visible part of the spectrum. Two download websites are displayed:

- the JPL website (http://asterweb.jpl.nasa.gov/gdem-wist.asp)
- the Earth Remote Sensing Data Analysis Center (ERSDAC *), (http://www.gdem.aser.ersdac.or.jp/index.jsp)

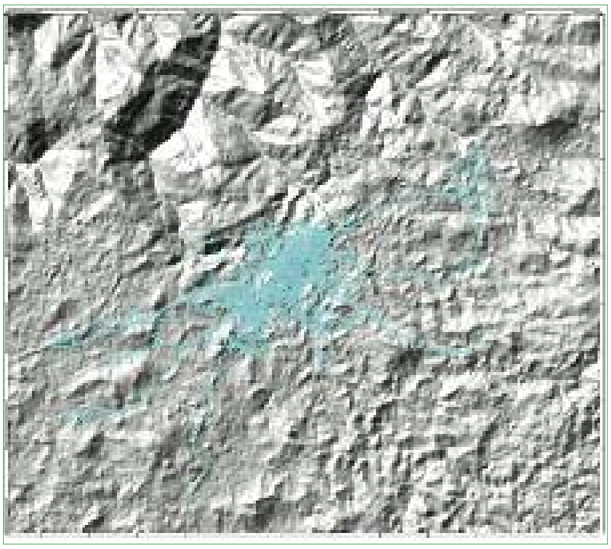
To access these two websites you have to register, and the data is made available under certain conditions of use.
This data is in raster form, in which each pixel measures 30 m square.

**GDEM visualisation of altitude values
Debre Birhan (Ethiopia)**



From white to black: increasing altitude values
Blue lines: Debre Birhan road network
Map source: EMAP (Ethiopian Mapping Agency), Addis Abeba (Ethiopia), 1986

**Visualisation of relief using shading,
Debre Birhan (Ethiopia), position of the sun northwest**



Blue lines: Debre Birhan road network

Source carte : EMAP (Ethiopian Mapping Agency), Addis Abeba (Ethiopia), 1986

Reference3D

In the same way, the Spotimage company created DEMs * from SPOT satellite data. The resolution is the same as for GDEM *, i.e. 30 m, but with greater accuracy (absolute vertical accuracy: 10 m and absolute horizontal accuracy: 15 m). Unfortunately the cost is high: 2.30 euros/km^2 and a minimum order of 3,000 km^2.

Worksheet 11
How a GPS works

GPS is a system that has three components.

- The "spatial" component is formed by **24 satellites** orbiting round the earth in 12 hours at an altitude of 20,000 km. Each satellite is equipped with an atomic clock and emits a signal comprising the time of the emission and the position of the satellite at the moment when that emission occurs. The emission of the signal forms a sphere the centre of which is the satellite.

- The component that is on the ground comprises **5 fixed stations** that calculate the position of each satellite and send this information back to the satellite so that it can then transmit the information to users' receivers.

- The third component is the user's **receiver** which detects and captures the data from each satellite. The receiver (the user component) calculates the position of its aerial, i.e. the points of intersection between the spheres of the signals emitted by the different satellites. The minimum required number of spheres is three, corresponding to three different satellites. It is this overall system that enables the receiver to integrate information concerning the radius and the position of each satellite. The GPS receiver "listens" to the messages, i.e. the electromagnetic signals emitted by the satellites. These signals contain very precise information on the instantaneous position of the satellite at the time when the message is emitted; this information is derived from the calculations performed by the fixed stations and relayed by the satellite.

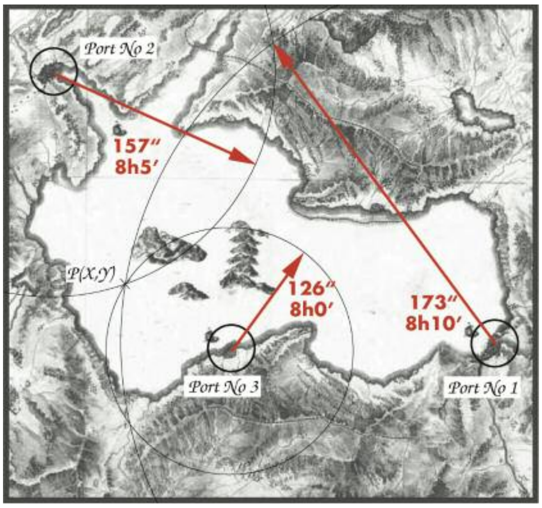
The GPS receiver calculates the time taken by the message to reach it from the satellite (of the order of 60 milliseconds) and can therefore deduce the radius of each sphere (radius = time taken for the message to arrive X speed of light).

GPS (Global positioning system): Fixed stations on the ground

Source: Peter H. Dana, 1995.

It builds equations corresponding to different "visible" satellites and resolves them using an iterative method.

For a better understanding of GPS functioning: the fable of the lake in constant mist



To understand this complex calculation more easily, you can read the fable that Pierre-André Chevalier produced for this purpose: it is the story of a lake constantly under mist and fog so that visual navigation is impossible. An ingenious system of communication with a boat sailing on the lake using the sound of cannon shots from three different ports was therefore devised and set up by the chief territorial engineer. The system enabled the boat to use this sound "landscape" to know its position despite the fact that the three ports could not be sighted from the boat.

Source : Comment le GOPS calcule-t-il sa position ? Une introduction didactique à la géométrie du GPS, https://staff.hti.bfh.ch/cip1/gps/index.html
La traversée du Grand-Lac. Une histoire imaginaire, https://staff.hti.bfh.ch/cip1/gps/ressources/histoire.html
Pierre-André Chevalier, professor at the Engineering School of Biel/ Bienne, Bern University, March 2002

(Video sequence *Using Google Earth*)

Worksheet 12

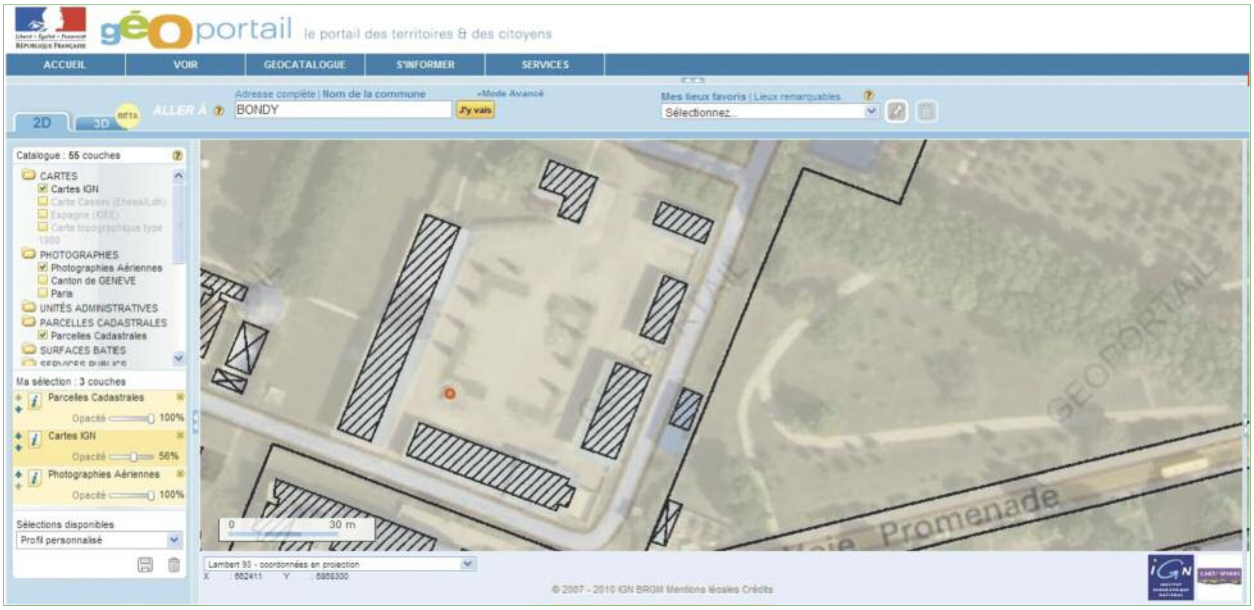
Using IGN Géoportail or Google Earth

The method for tracking GPS points provided in this manual enables the accurate positioning of a satellite image or an aerial photograph, since this georeferencing step is essential for the usefulness of the map that is to be developed. This surveying procedure is so far the only method that is fast and at the same time sufficiently accurate. Of course, in many countries this may not be required, since for many countries Google Earth provides up-to-date geographical data, and in France for instance IGN Géoportail provides aerial images and maps that are fairly well georeferenced. However we recommend always checking that the material available is adequate for the aims of your project at the outset, in particular for Google Earth.

• Présentation of data on IGN Géoportail: http://www.geoportail.fr/

If we return to the example of the IRD yard in Bondy, we can read the coordinates of the little pond (red outline) in Lambert-93: longitude 662300; latitude 6868303.

Géoportail (http://www.geoportail.gouv.fr/)



• Présentation of data in Google Earth: http://earthgoogle.fr/

The coordinates read on Google Earth (in UTM, WGS84) are: longitude 462311.41; latitude 5417980.41. The conversion of these UTM values into Lambert-93 using the Molodensky formula gives: longitude 662298.996; latitude 6868303.517.

Google Earth (http://earthgoogle.fr

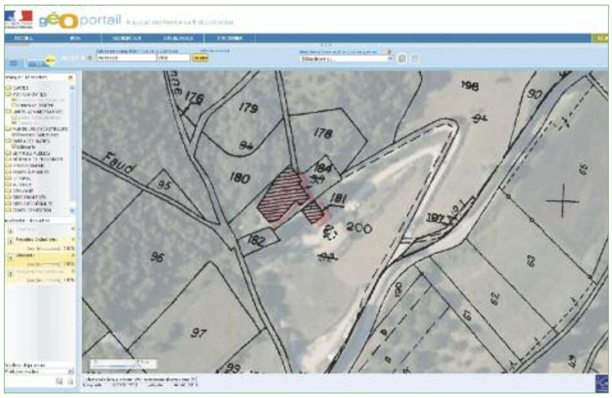
These two sets of data are in agreement **to one metre** with the data provided by our Garmin 60 GPS.

• Examples of discrepancies between data on one and the same portal

It should however be noted that the Paris area is somewhat privileged. If we consider a region further south in France, things can be different. For instance for the portion of the Drôme area (south-east France) shown below, if we consult the data available on IGN's Géoportail, concordance is good between the aerial photograph and the IGN map. However the discrepancy with the cadaster (land registry) can prove to be more than ten metres. This does not result from an error by IGN, since it has the means to correct its own aerial cover using a method similar to the one we recommend. It arises from legislation applying to the cadaster, whereby IGN is not allowed to alter the cadaster, even if it is inaccurate.

IGN aerial photograph with the rivers traced in blue, available on Géoportail

The same aerial photograph overlaid with the non-matching outline of the cadaster plan and the numbered plots



For this same portion of the Drôme, the accuracy of Google Earth is not perfect either. Although Google Earth provides maps and images that have the appearance of being fairly precise, we consider that it is wise to check them using GPS. It is not rare to find differences of more than 50 metres between images available on Google Earth of one and the same place but taken on different dates.

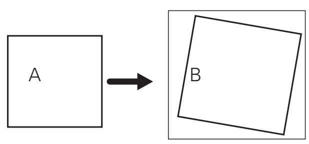
Spot image with the roads shown by Google Earth super-imposed

(*Video sequence* SavGIS *Georeferencing an image on a map*)

Worksheet 13
Adjustment by tessellation

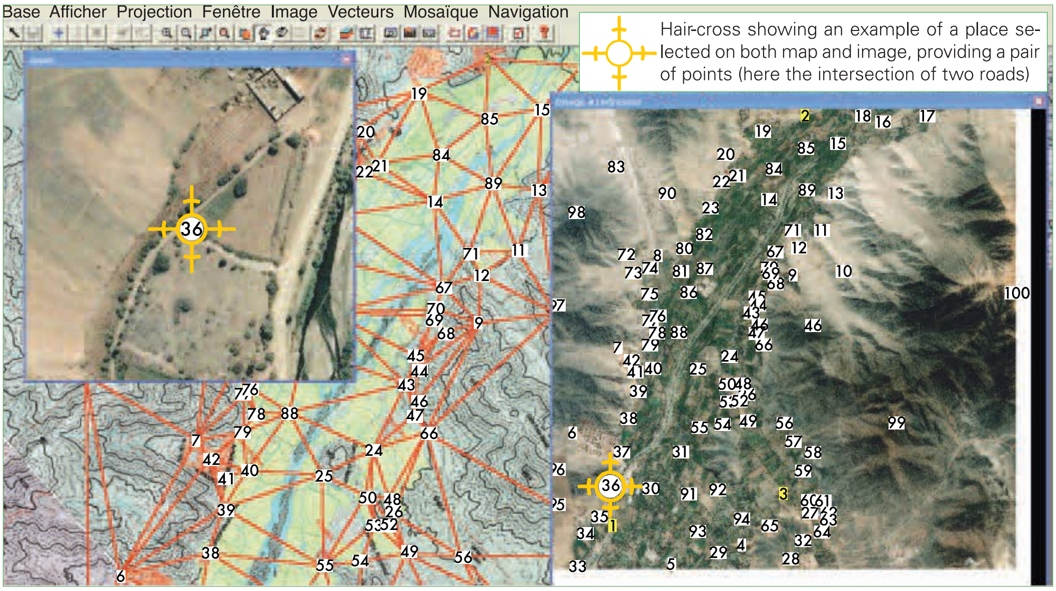
A raster image, whether a satellite image, an aerial photograph or a scanned map, includes no georeferences as such: the pixels, it is true, are referenced, but only from the coordinates of the matrix. A given line number and a given column number correspond to a given pixel. Repositioning an image consists in creating a new matrix of pixels in which each line and each column number corresponds respectively to a longitude value and a latitude value. For each pixel there is then a corresponding geographical localisation in plane coordinates, generally in metres in relation to an origin that is well-defined by the system used. The basic method consists in establishing, in the geographical projection that you intend to use, the coordinates for at least three pixels in the original non-georeferenced matrix image. Using the geographical coordinates of these three points you can then, in a single operation, alter the scale, the orientation in relation to the north, and the positioning in terms of longitude and latitude for the whole of the original matrix image. The matrix image, also called a raster, has thus been repositioned or adjusted, that is to say that each of its pixels is positioned geographically, and that for any element present in the image, a geographical positioning is available.
As the image is a rectangular matrix, after georeferencing we obtain a new rectangular image, generally distorted in relation to the first, but in which each pixel will have a precise geographical position in the projection system selected. In a vector "representation", the points forming the line or the surface area can have relatively independent values one from the other. In an orthonormalised plane matrix representation, that is to say projected onto a predetermined geodesic system, each pixel is dependent upon the others. The position of a pixel can be deduced from the position of any of its neighbours on the basis of the size of the piece of ground represented by a pixel.
By using three adjustment or repositioning points, we position the pixels in the chosen geographical projection system, which amounts to creating a new matrix in which the position of each pixel may have altered, but not its situation in relation to its closest neighbours. In this new matrix, each pixel is correctly positioned geographically, and the associated luminance value is the value of the pixel that, in the original matrix, proves to be the closest to a position calculated by a single mathematical function applied to the image as a whole (first degree polynomial). The method of repositioning by tessellation works on the same principle as this basic method of the three adjustment or repositioning points (see worksheet 11). The more numerous are the adjustment points, the more accurate is the end result. These points serve to determine triangles (using Delaunay's triangulation algorithm). Inside each triangle a specific (polynomial) distortion is applied which can be defined from the three vertices. It can be noted that while the distortion will be different for each triangle, it will be virtually identical for all the places positioned on either side of the separating line between two adjacent triangles. In theory there should be a larger number of points when the relief has marked features, because this leads to more marked distortions. Here is an example of the adjustment of an image to a map. The control points are fairly easy to choose intuitively, for instance road intersections or boundaries of street blocks. In this case the precision of the repositioning obtained depends on the precision of the map (here 1:25,000).
To perform the tessellation or triangulation, pairs of points need to be defined: one on the georeferenced material (in the example below, the map on the scale 1:25,000 forming the background), and the other on the image that needs adjusting (here a Quick Bird image, shown (non-rectified) in the right-hand inset). The small inset top left, overlaying the map, is a

Change of image frame with repositioning



A Original matrix image or raster
B After conversion or georeferencing

Tessellation of an image using a map

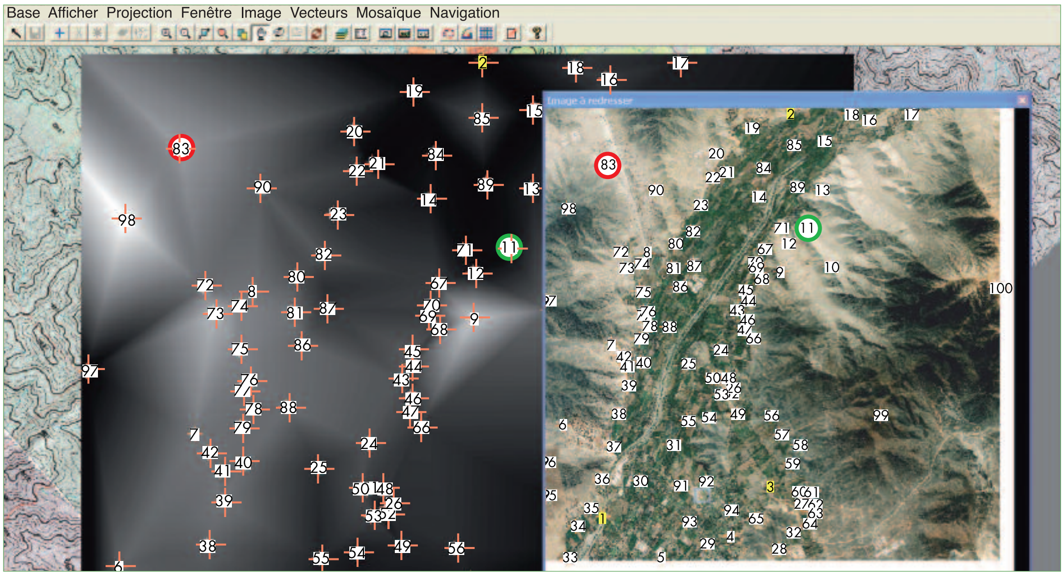


Background image, Peruvian IGN map on the scale 1:25,000, Lima (Peru).
On the right Quick Bird image, 50 cm pixels, 2009

zoomed replica of the image on the right. This function provided by a zoom is extremely useful for more accurate point determination.
Each pair of points identified in this manner gives one apex of a triangle, the sides of which are shown in red. In each triangle the distortion will be different, and will depend on the quality of identification on the map and the image. What anchor-points should we use? Many methods use small objects on the ground, for instance IGN geodesic points materialised by markers, for which very precise coordinates are available. Unfortunately these points, although clearly marked on maps, are not generally easy to spot in an image. To overcome this difficulty, we prefer to use intersections of linear elements that are easily identifiable on both the map and the image, such as the point given as an example in the above image.

The distortions occurring in each of the triangles will have different values, as shown in the graphic representation opposite. The dark areas represent small displacement values, while light areas correspond to high displacement values.
As the greatest distortions are generated by relief features, it is preferable to allow for a denser cover of points along dividing ridges or valley bottoms, i.e. slope boundaries where the profile of the slope changes.
The nearest-neighbour method consists in attributing to each target point a combination of the values of the source points that are closest to its antecedent by inverse transformation. This is a 0 order polynomial interpolation.
We prefer this method because it is well-suited to the adjustments we need to perform, that is to say those in which the size of the pixel changes very little.

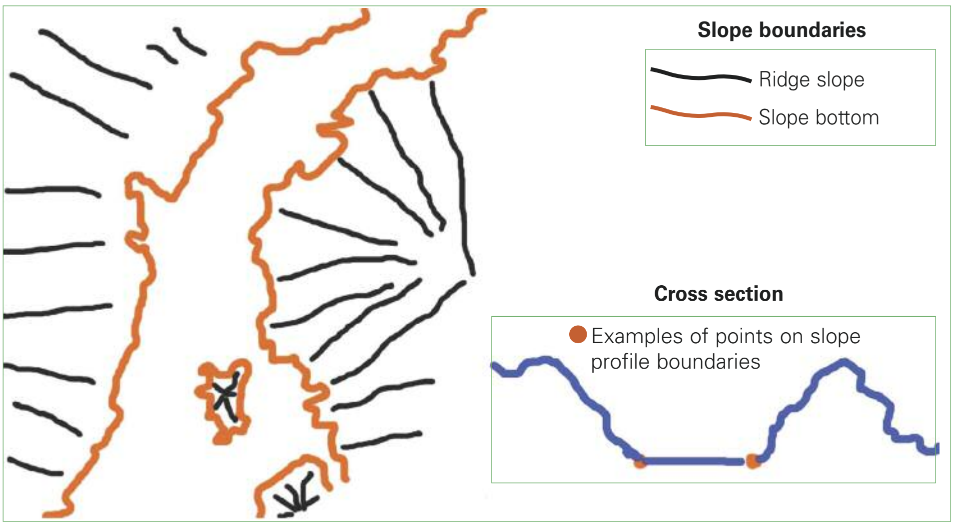
Spatial representation of the displacement values for the points corresponding to the distortion algorithm applied



Background image, Peruvian IGN map on the scale 1:25,000, Lima (Peru).
Overlay: graphic representation of the levels of distortion for each pixel in the image
On the right Quick Bird image, 50 cm pixels, 2009

Point 83
Point 11

Diagrammatic example of the localisation of the main slope boundaries where it is advisable to allow for a denser cover of points

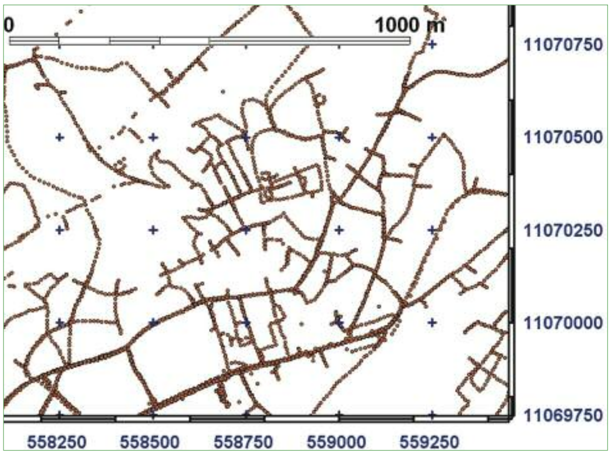


Worksheet 14

Surveying by GPS tracking points

When someone is given a GPS and asked to survey a zone without due preparation, generally only a small amount of data is produced (sometimes reduced to the four corners of a public square) accompanied by notes describing the place where each reading was made. This method makes the exploitation of the results quite a complicated task. In addition, numerous points may have to be removed because of obvious incoherency between the description of the point and its surveyed localisation. For this reason we recommend surveying without any field notes. The method described here in fact consists in generating a map of all GPS tracking points. Below you can see part of the surveying results obtained in one week for the town of Debre Birhan (Ethiopia, 50,000 inhabitants). Certain tracks were surveyed on a motorbike, others on foot. Once we have this main outline, it is fairly easy to determine a hundred or so control points merely by analogy of shape between the image and this GPS tracking "map". It can be seen that road intersections are a main focus, and that the main route followed is exhaustively surveyed, but only the first 50m into the streets with which it intersects.. There is no need to survey the whole street system to recognise characteristic shapes.

Map of GPS tracking points

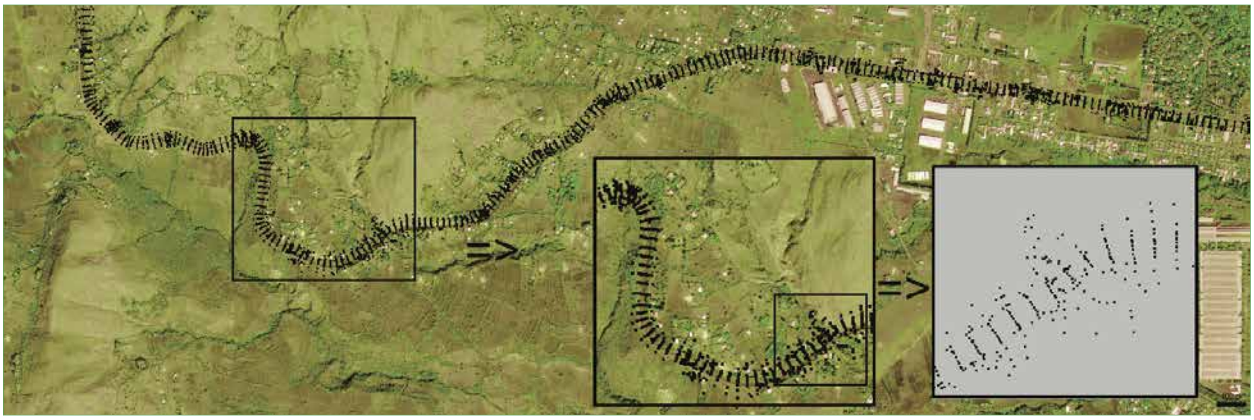


Quick Bird Satellite image (02/12/2007)

This method has certain similarities with that recommended on OpenStreetMap. We do however recommend merely marking intersections with a cross. Indeed, surveying the exact centres of intersections requires accurate field notes, and errors are frequent however carefully the notes are taken. In addition, we do not need to identify each intersection. Confrontation with the image will in fact identify them, as the distortions of the image from one vicinity to the next are never very marked.
It is however important to avoid having too few intersections along a track, often the case with GPS data obtained from bodies concerned with road development for example. The methods used in this case are not very useful for us despite the great precision of their data (often surveyed using differential methods). For example the Road Authority file (Ethiopian transport institute) comprising 15,000 GPS points plotting the main route through the town of Kombolcha to a precision of 10 cm yields a type of mapping that is not suited to our purpose.

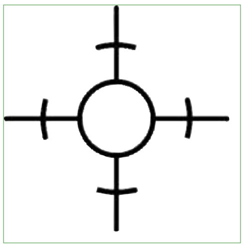
The Kombolcha Road Authority GPS survey points

Details from the map



Background image: Quick Bird 02/10/2007, 50 cm pixels

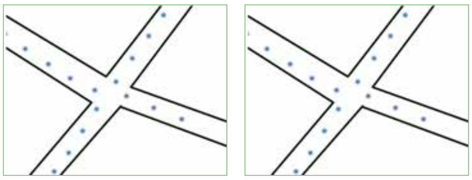
Reticule for sight used by Serge Bertorello on his telescope



When using a hair-cross we do not need the intersection of the vertical line with the horizontal line because the eye will accurately interpolate it.

GPS tracks

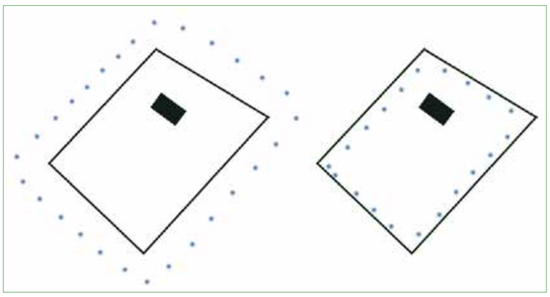
before repositioning | **after repositioning**



Continuous lines: edges of the roads
Dotted lines GPS tracks

Likewise, using two GPS tracks we can accurately reconstitute an intersection. It can be seen here that there is no need for previous accurate identification of the centre of the intersection. This avoids time being spent on determining it on the ground. If we use the principle of the hair-cross, there is no need to note the exact position of the centre of an intersection between two roads or streets This configuration generates a pair of control points.

Moving around a plot on the outside or the inside



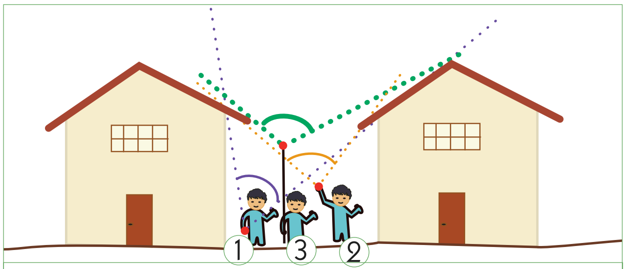
When there is no intersection but solely isolated objects, it is easy to create the equivalent of a hair-cross by moving round the isolated tree or building. It is sufficient to move around isolated objects, endeavouring to remain at the same distance from the walls or the fence (5 to 10 metres). Isolated trees should be circled maintaining a constant distance in relation to the canopy.

Two different but equivalent modes of surveying

It can be said that surveying the object according to the red outline, i.e. around the house or the tree, will be equivalent to surveying it according to the blue outline, around the hedge or fence.

It is important to work with an additional aerial. It is not heavy, and when fixed on a pole it enables you to work at a constant height of 2 metres without your arms becoming stiff and tired with reaching up. The difference in reception, and therefore in accuracy, will be apparent between a GPS on the belt and the same receiver making the measurement from an aerial situated at a certain height. The difference can be considerable, in particular in urban environments, because buildings cast shadows and reflections that can seriously hinder reception. A similar effect can be observed in streets lined with large trees.

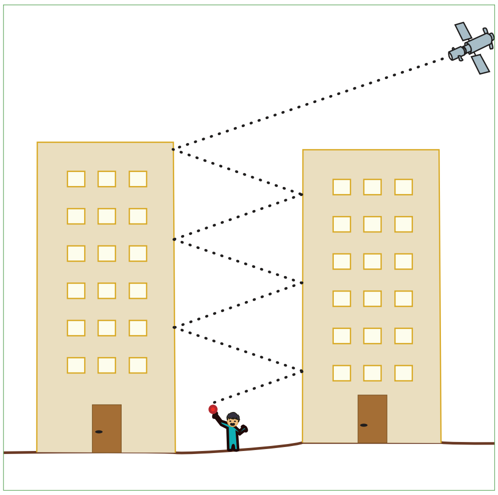
Diagram showing different GPS reception positions in urban areas



1 or 2 The position does not enable adequate reception, as the roofs interfere

3 Position and aerial reception enabling good detection of the satellite signal

Diagram of a situation in which the signal is repeatedly reflected



Some general rules for surveying

- Print the satellite image, even if it is not georeferenced, on a scale that enables streets and paths to be seen.
- Pencil-in an itinerary that will encounter numerous intersections, and also that is clearly different from the previous data captured. Make a note of the isolated objects that will need to be circled.
- Go on location to record the data. Take a rucksack and something to hold the aerial without too much difficulty. Travel on foot, on a bicycle or on a motorbike. You should avoid using a car, as some places will be inaccessible, and data will be less precise and less easy to handle.
- Check the geodesic system set for the GPS display; if it uses WGS84 it can, after calculation, display coordinates according to a different referentia.
- Set the GPS to "automatic tracking", either in seconds or in metres: Garmin 60 does not accept distances under 10 metres between stored points, which is the minimum that is acceptable.
- Turn on the receiver, remain in the same place on a fixed point with a clear horizon until the device has initialised, usually in 2 to 3 minutes. When you first use it, or after a long period out of use, the GPS may require 20 minutes to initialise correctly.
- Start out when the device indicates an estimated precision of around 6 m. In Europe, wait for 3 m.
- On non-asphalted roads or tracks, move down the centre.
- On asphalted roads, to avoid accidents, it is better to adopt the local convention of using the right or the left as appropriate. Since each GPS point is numbered it will subsequently be easy to know in which direction you were moving. The precision of the measure makes it easy to distinguish outward and return journeys.
- Move round isolated objects at a constant distance from the edges of the object, five or six metres from the walls of a house, from the spread of the canopy for a tree, or from the foot of a pylon.
- We advise you to start day after day with the same portion of road, serving as a known control. This is not very costly, because the receiver can store 100 km of track. It is also useful because it will validate the whole track for the day, and avoid having to cancel measures in case of doubt about the geodesic system used, or poor reception from the satellites. It also enables an estimation of the accuracy of data throughout the year.
- It is a good thing to turn off the GPS when you leave the planned track, because if reception is poor, it can record completely erroneous points. Remember to wait one minute after starting it up again to continue the route.

(Video sequence SavGIS)

Worksheet 15

Integrating GPS data into a GIS

The method for plotting GPS points set out in this manual serves to position a satellite image or an aerial photograph correctly. Once you have obtained this georeferencing, the image can be used to map the different urban elements.

Caution!

Iit is wise to test your procedure for reading data on your GPS before you embark on any exhaustive work. Test it around your own street block.

There is no real standard for exporting data obtained from a GPS receiver. Every GPS is accompanied by software that enables the data to be transferred to your computer in .csv format which can then be parameterised. In our method, it is important to retrieve at least the following data: identifier, longitude, latitude, altitude, date and time. Our reference GPS (Garmin 60) with its associated software (MapSource) can only read data expressed in WGS84. We consider it wise to check that values are exported in WGS84 with coordinates projected in metres rather than geographical coordinates in degrees.

The software sometimes has complicated formats.

Example of MapSource export files

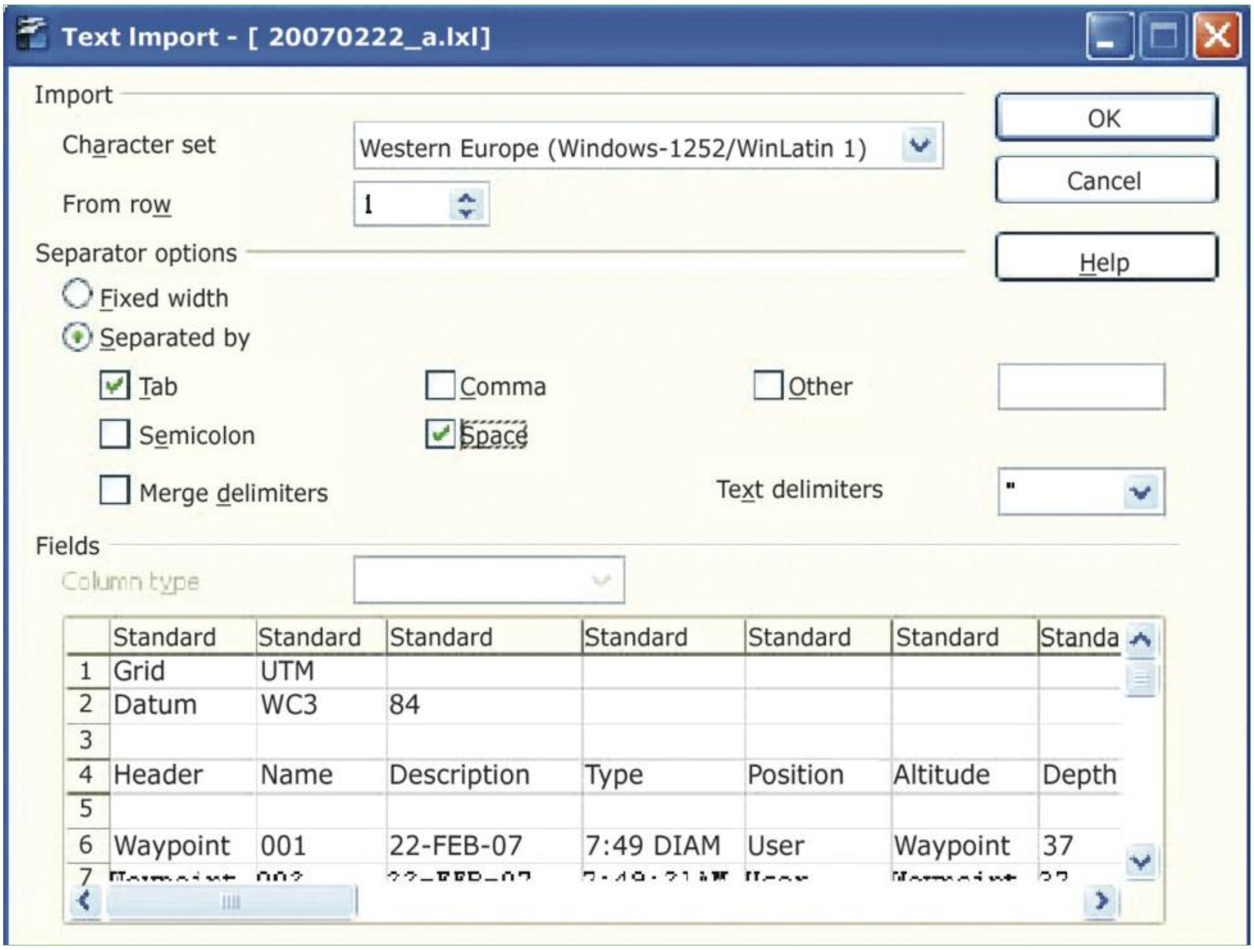
```
Grid   UTM
Datum  WGS 84

Header         Name   Description      Type    Position          Altitude       Depth Proximity        Temp
        Link   Categories
Waypoint       075    20-NOV-07   7:13:45 AM    User  Waypoint              37 P 480711   998173
Waypoint       076    20-NOV-07   7:13:47 AM    User  Waypoint              37 P 480711   998173
Waypoint       077    20-NOV-07   7:13:40 AM    User  Waypoint              37 P 480711   998173
Track ACTIVE LOG      13/10/2007  15:28:07      00:19:07          320 m 1.0   kph
Header         Position          Time    Altitude        Depth Leg Length      Leg Time       Leg Speed
Trackpoint     31  T  684791 4961027     13/10/2007 15:26:07      314 m
Trackpoint     31  T  684808 4960995     13/10/2007 15:26:25      369 m          38.8 m
Trackpoint     31  T  684791 4961027     13/10/2007 15:26:41      373 m          6.01 m
Trackpoint     31  T  684791 4961027     13/10/2007 15:26:57      376 m          7.12 m
Trackpoint     31  T  684791 4961027     13/10/2007 15:27:09      381 m          7.45 m
Trackpoint     31  T  684791 4961027     13/10/2007 15:27:20      385 m          4.75 m
Trackpoint     31  T  684791 4961027     13/10/2007 15:27:30      389 m          5.80 m
Trackpoint     31  T  684791 4961027     13/10/2007 15:27:50      391 m          3.17 m
Trackpoint     31  T  684791 4961027     13/10/2007 15:28:10      395 m          4.35
Trackpoint     31  T  684791 4961027     13/10/2007 15:28:26      397 m          8.66                 ...


...            Temperature Display Mode         Color Symbol      Facility      City State Country          Data Edified

               3                                Symbol & Name     Unknown       Flag.   Blue
               3                                Symbol & Name     Unknown       Flag.   Blue
               3                                Symbol & Name     Unknown       Flag.   Blue

               peed    Leg Course

               m       00-00-10     7.4  kph     153 ° true
               m       00-00-16     1.4  kph     205 ° true
               m       00-00-16     1.6  kph     211 ° true
               m       00-00-12     2.2  kph     213 ° true
               m       00-00-11     1.6  kph     212 ° true
               m       00-00-10     1.2  kph     192 ° true
               m       00-00-12     0.95 kph     213 ° true
               m       00-00-20     0.75 kph     205 ° true
               m       00-00-16     1.9  kph     203 ° true
```

It can be seen that the format of the "trackpoints", that is to say the automatic repeated readings reiterated every so many metres or seconds is not the same as that of the "waypoints" that serve to record precise, identified points.

In addition, the MapSource format mixes "tabulation" and "space" separators, which means we have to "translate" the files before integrating them into our database.

Reference :
http://upload.savgis.org/files/ Didacticiels/Didacticiel_4.zip

MapSource import window



Worksheet 16
Choosing your GPS device

With a differential GPS it is possible to achieve decimetre precision, but we do not recommend using this type of equipment because this degree of precision has a cost, and above all it is unnecessary. A precision of 10 cm is only meaningful if you are able to localise a place to ten centimetres. This means accurately completing a logbook and marking the spot on the ground with a stud or paint.
Our aim is to correctly georeference images with a resolution no finer than 50 cm^2 pixels. The aim is to geo-localise objects that can be seen both on the image and on the ground. We consider that a precision of 3 m (in Europe) or 5 m (in Africa) is adequate for our purposes. This precision is obtained with numerous quite basic GPS models. It is however important to ensure that they meet certain specific needs:

- portability and autonomy: the use of rechargeable batteries is advisable. In practice, the use of a small aerial is essential, as you can spend an hour with your arm in the air maintaining a constant height;
- an option for data collection in automatic mode (for instance a reading every 10 metres);
- adequate storage capacity: an itinerary of 100 km with a reading every 10 metres amounts to a total number of 10,000 readings;
- presence of a system of data storage and transfer to a computer.

We mostly use the Garmin 60 GPS, which possesses all these characteristics.

(Video sequence SavGIS *Georeferencing an image from GPS tracks*)

Worksheet 17

Georeferencing an image

What is a digital image?

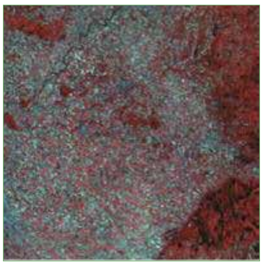
An aerial or satellite photograph is a matrix of values representing the sum of the light intensity reflected from a small terrestrial surface area, such as a square of 10 m by 10 m. These small areas, known as "pixels" (picture elements), are all the same size in the matrix. They can be 10 m pixels, 60 cm pixels, and so forth. The image is a matrix that is today always orthogonal. The image can be made up of several matrices that are linked, superimposed and possess values in each wave length used. It is a plane projection. Its localisation is perfectly defined if we know the size of the pixel, its position, and the projection system used.

Suppliers sell images with varying degrees or levels of geometric correction. For instance levels 1A and 1B in Spotimage* do not include any of the three localisation variables (pixel size and position, projection system used). Level 3 however, which is more elaborate, is supposed to be super-imposable on a map.

Level 1A (below) includes no geometric rectification. To obtain level 1B below, the position of each pixel is recalculated, line by line, in a new matrix to take account of the rotation of the earth. The new matrix has more columns, and certain pixels, shown in black, do not correspond to any pixel in image 1A. At the same time, another alteration takes account of the obliqueness of the viewpoint. The viewpoint is indeed often oblique, perpendicular to the satellite track, which leads to an elongation of the surface represented on the ground in an east/west direction Since the result is to be an orthogonal matrix, certain pixels will be repeated in the new image 1B, so that it will increase in width in proportion to the obliqueness. Spotimage specifies that neither of these two levels can provide geo-coded images (i.e. images that have been geometrically rectified).

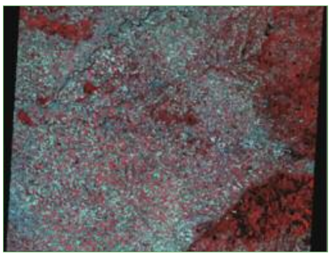
Level 1A

Radiometric correction of distortions resulting from different sensitivities of the satellite camera sensors. These images are intended for users wishing to perform the geometric processing of the images themselves.



Level 1B

Radiometric correction that is identical to that in level 1A. Geometric correction of systematic effects (panoramic effect, curvature and rotation of the earth). The distortions inside the image are corrected, which enables measures of distances, angles and surface areas. This is the best choice for photo-interpretation and thematic studies.



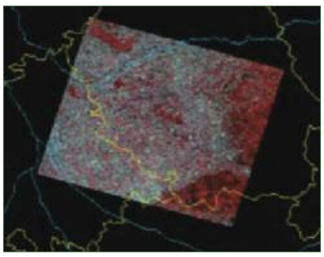
The algorithms in Spotimage use data that is said to be ancillary (also referred to today as meta-data*) from the satellite and its control system. The algorithms generating this data, known as level 3 data, also integrate reference points on the ground and a numerical altitude model. However these points and the model need to actually exist. Level 3 data is said to be "ortho-rectified".

Level 2B (precision)

Cartographic projection using reference points on maps or GPS-type measures on the ground. The image is corrected at an average altitude using standardised projection and map grid divisions. This level is used when the distortions due to relief are not prominent features (flat terrain).

Level 3 (ortho)

Map projection from reference points and from a DEM* derived from Reference 3D to remove distortions caused by the relief.

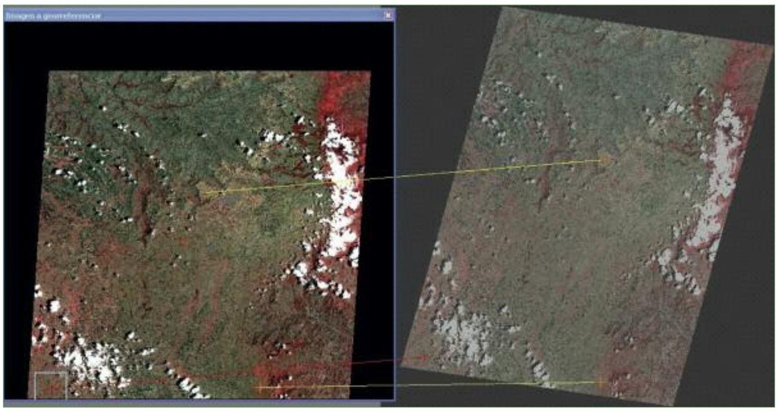


1 - http://www.spotimage.com/automne_modules_files/standard/public/p153

The algorithms implemented by Google Earth are often not known, and they also vary, certain portions of the Earth's surface taking account of altitude while others do not. More generally, the results of processing by image suppliers to which you will have access require some caution. There are two reasons for this: first the lack of sufficiently precise control points, and second the influence of the relief. It is generally better to perform the geometrical adjustment yourselves.
The processing techniques generally implemented in GIS tools use control points:

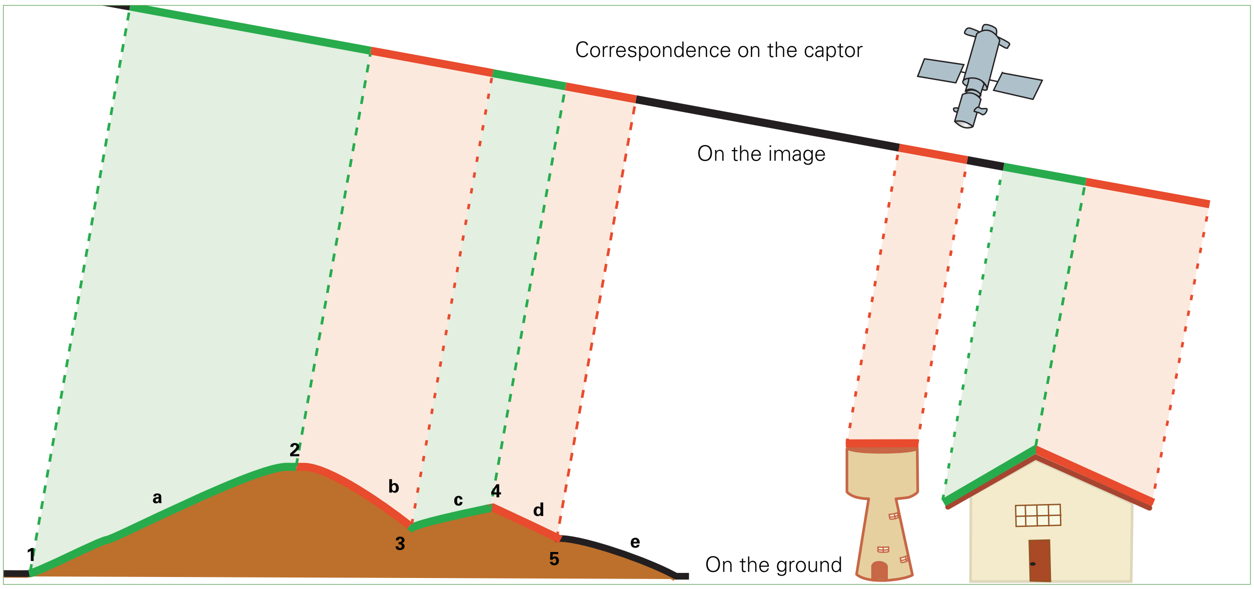
- with one point you can link the coordinates of the corresponding pixel to the image. A "transposition" is then performed;
- with two points it is possible to effect a rotation;
- with three points it will also be possible to alter the scale differently at x and y (latitude and longitude) by a first degree polynomial conversion. The algorithm starts by calculating the size of the matrix that is required to contain all the pixels, and then, to each pixel in the new matrix, it allocates the value corresponding to the pixel in the initial matrix that is closest to the point calculated. It is thus possible that certain pixels will be repeated, and others omitted. To overcome this problem, which occurs more often when there is a large change in scale, bi-linear or bi-cubic interpolations are used.

Image before and after rectification



In the image presented on the right, the algorithm has made the same conversion over the whole image. This may be sufficient for an image of flat terrain taken vertically, because in this case the distortion model may be uniform. But most of the time images are taken obliquely and there are slopes in the terrain. This means that locally the terrain will be distorted. The portions of terrain in which the slopes are facing the captor (shown in red) are elongated, while the others (shown in green) are reduced in size.

Diagram of the effects of relief on the photographic viewpoint

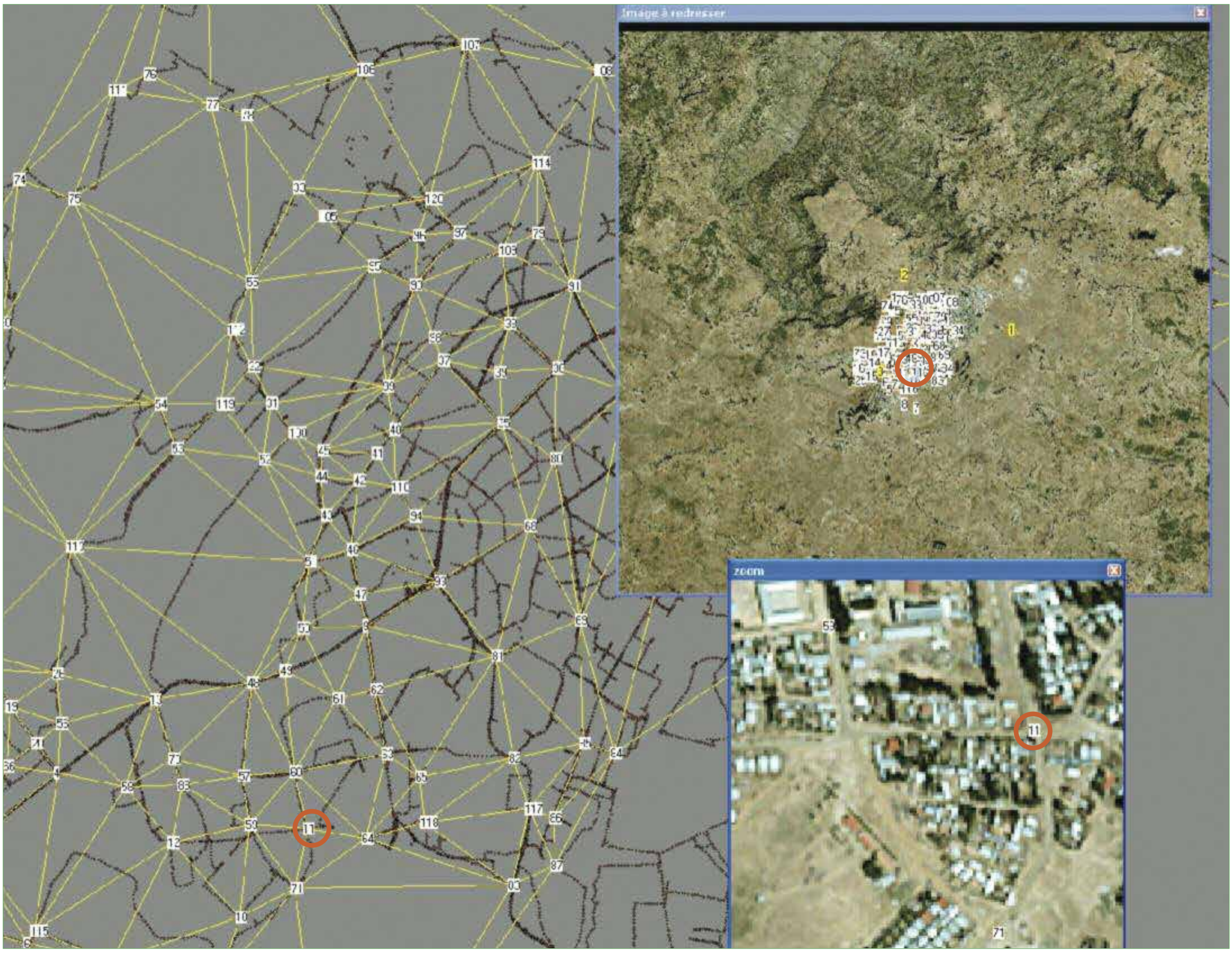


In this case we have not one distortion model but several. If we have control points (marked 1, 2, 3, 4 and 5 on the diagram) it is possible to construct triangles inside which a formula can be applied – specific to each triangle – the parameters of which are determined by the coordinates of the three vertices.

This repositioning method by tessellation requires as many control points as possible. In theory, they should be more numerous when the relief features are prominent, because these features will lead to considerable distortions. The control points can be provided by intersections of GPS tracks, or isolated objects that have been surveyed (*see Worksheet 14*). These points have a function that is analogous to the nails used to stretch a leather hide to dry it.

It is therefore possible to integrate and rectify local distortions. However the method does require a good deal of caution. Any point that seems doubtful should be removed. To do this, refer to the image of the distortion produced. It should not exhibit excessive or peak distortions, and it should globally reflect the image of the slopes (*see video*)

Method for repositioning by tessellation



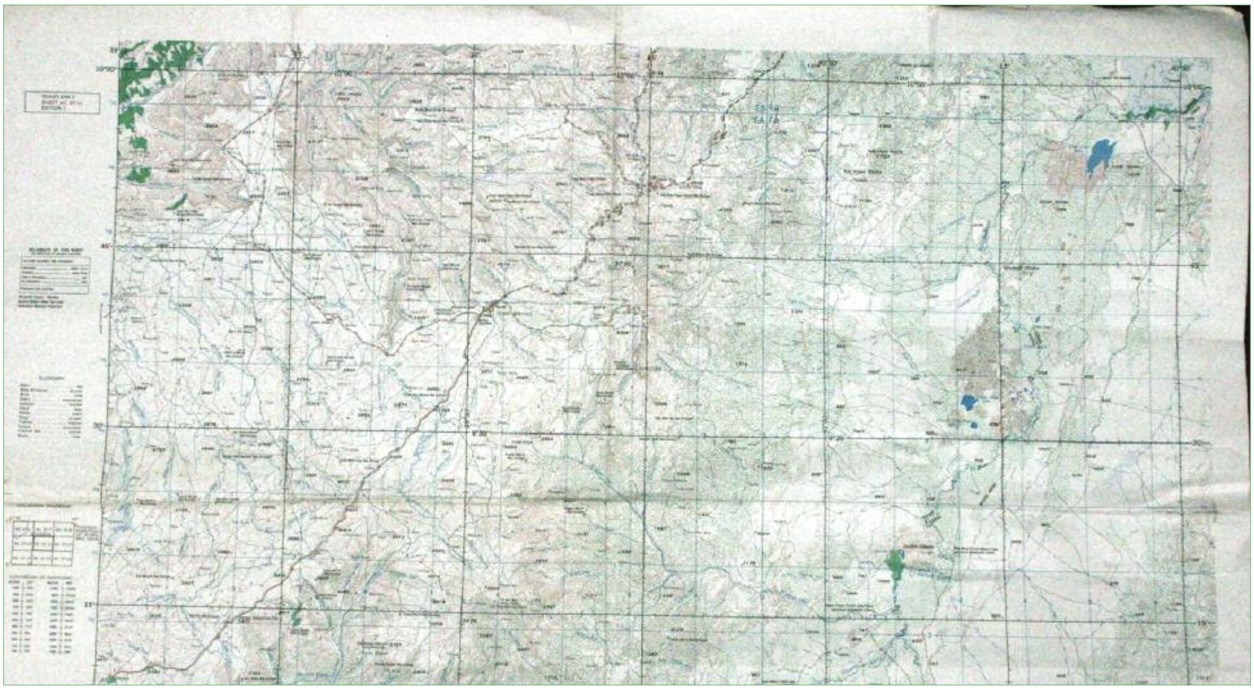
Adjustment point located: on the right on the georeferenced map of GPS tracks
on the left in the lower part of the image

(Video sequence SavGIS)

Worksheet 18
Georeferencing a map

Below you will find a raster image of the topographic map on the scale 1:50,000 of the region of Debre Birhan (Ethiopia). It is a photograph taken with an amateur digital camera. It therefore shows numerous distortions (folds, warping of the paper, obliqueness of the shot). We nevertheless have numerous control points, formed by all the nodes in the grid (or graticule *) printed on the map. On this map there are two grids.

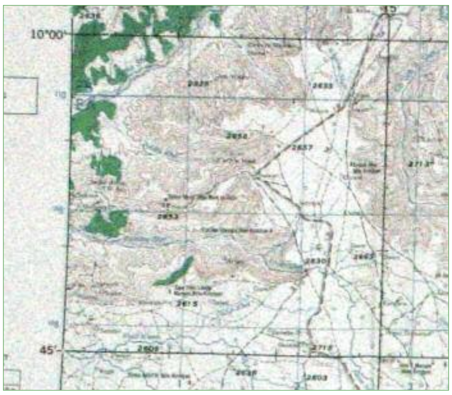
Example of a raster image derived from a digital photograph of a topographic map on the scale 1:50,000 (Debre Birhan, Ethiopia)



Using georeferencing information available on a map

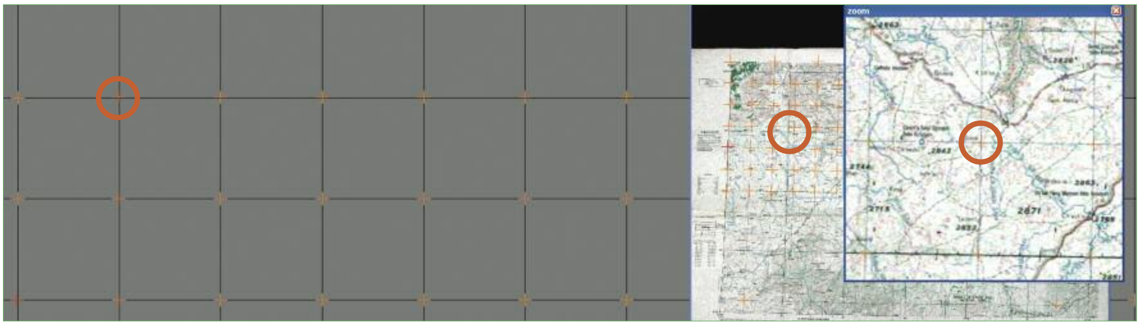
The first grid, marked in black, is expressed in degrees and minutes (Adindan Ethiopia datum). The second, shown in blue, is a smaller grid, and it is expressed in coordinates projected in kilometres (UTM zone 37) on this type of map (it should be noted that the coordinates are in many cases missing on the right, so that only the kilometric value is available). We therefore have ample scope for listing control points.
For each of the intersections or nodes in the blue grid an item will be created in the control points table: ID, image column n°, image line n°, longitude and latitude.

Extract from the above map



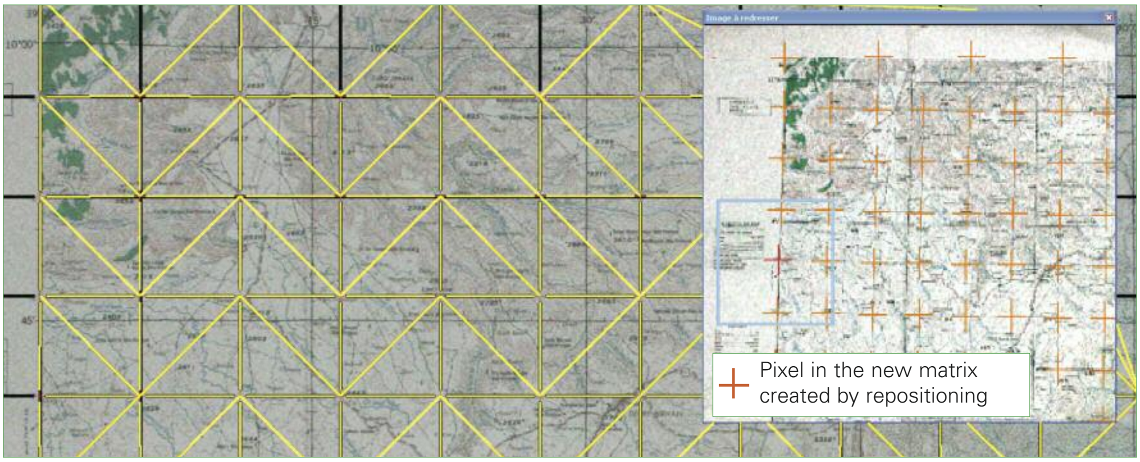
With this method, the error at each point is of the order of the size of the pixel in the image (here 40 m). The error that occurs in each triangle (shown in yellow on the image below) is of similar magnitude. It is thus possible to create the list by clicking on the blue grid nodes in the map to the right, and on the nodes in the display of the metric coordinates in the projection used to the left.

Display of the graticule matrix georeferenced in the projection used, and its correspondences on the photograph of the map

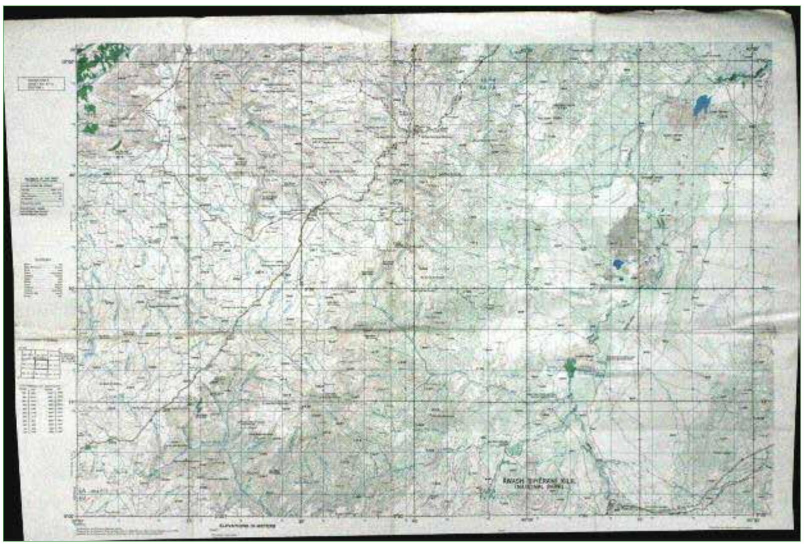


For each square in the blue grid, the tessellation process will create two triangles, which are shown in yellow on the map below.

Triangles created by the tessellation overlaying the topographical map



Raster image of the photographed map once it has been repositioned and georeferenced



This repositioning procedure produces a new matrix of pixels. Each place will have new coordinates in the target matrix. It can be seen that geographical lines are now very correctly positioned. If the processing does not include the correction of the shadows created by the folds in the paper, the geometrical distortion caused by these fold will be rectified.

(Video sequence SawGIS)

Worksheet 19

Photo-interpreting an image

Creating a map from satellite images or aerial photographs is still presented today as a rather difficult and complex operation. "*Photo-interpretation consists in generating vectorial data from aerial photographs or satellite images. This procedure is used for various purposes - flora or fauna inventories, geological or hydrological surveys, land use surveys. These different types of inventory, which can be implemented for a single town or village or for a whole country, are based on a very work-intensive process of data-crossing, digitising, and determination of a suitable set of symbols...*" remarks one company (IGE, Information géographique et environnement). It concludes: "*If you have aerial photographs or satellite images available, and you wish to extract new data from them, IGE can do the photo-interpretation work for you*".

In fact, technological innovations enable us to obtain satisfactory results using a very simple procedure of visual interpretation of images, available in large numbers today.

A georeferenced image is basically a photograph. Just as we can identify objects on the photograph visually, we can also use it to extract the modelled objects described earlier (*Worksheet 4*). You should work in "natural" manner, although of course it is not really natural to view landscape from above and from a considerable height – there is nevertheless not much difference between an image taken at an altitude of 500 m and one taken at an altitude of 800 km. The image remains fairly easy to apprehend: any farmer can readily recognise his land on an aerial photograph, pupils will recognise their school, and people in general can identify objects on a satellite image without having to resort to mathematical processing of any sort. It is a process of recognition and identification. The more familiar you are with the object, the more likely you are to recognise it on the image.

Using natural visual identification of geographical objects

We will follow a sensible approach and we will use very little radiometric classifications that we practice on images with large pixels. Color is an important element in the identification process. When the vegetation appears clearly by its green color, the reading of the image is easier. Similarly, for the urban landscape, a multi-spectral image with 10 m pixels size is easier to visually interpret than a panchromatic image with 5 m pixels size.

Historically, photo-interpreters have worked a lot with false color images, integrating infrared wavelengths and translating the vegetation in red. Currently, the work is done more with a color translation that approaches the natural color. But we are working very little on the object reflectance; thus the operator who would draw only buildings with clear roofs, under the pretext that it is "globally" a common standard answer would be subject to considerable oversights.

To interpret properly, it is necessary take into account the forms and volumes; identify an object, which is to say very often understand the function; For this we will use mainly the interpretation of the shadows.

Using the functional identification of urban objects

In the following photograph, how can we interpret what appears as a space with no buildings situated in the midst of the Addis Abeba built-up area? We need to call on our general knowledge. Why would there be a large, clear space with no buildings in a city where building land is in short supply? What urban function or facility does this suggest?

The former airport, Addis Abeba (Ethiopia). Extract from a multi-spectrum Quick Bird satellite image, 60 cm pixels, 2008

The general appearance of this object is similar to the one in the photograph below, a clearly recognisable image of an airport. The preceding photograph also shows an airport, but it is older, and above all disused, but it has been thus far preserved. There are no aircraft on the ground, and no marks on the runways. The image below shows an airport in activity: you can see aircraft and identification is immediate.

The new airport in Addis Abeba (Ethiopia). Extract from a multi-spectrum Quick Bird satellite image, 60 cm pixels, 2008

It can be useful to improve the different image parameters (contrast, colour, definition, etc.) to enable more accurate identification, as can be seen from the series of images opposite.

The town of Kombolcha (Ethiopia)

Quick Bird image, 60 cm pixels, 2005

The same image on Google Earth

Improvements in colours and contrast

Details from the above images

Consider rotating the image in relation to the original viewpoin

Volcanic cone in the Auvergne, a mountain of the Ballon d'Alsace type, or a crater?

This image looks very much like a rather curious dome-shaped pustule: if taken in France it could be one of the many "puys" (former volcanoes) in Auvergne.

The same image, once it has been rotated, is interpreted as a crater with a central knoll.

The first interpretation arises from the fact that the relief tends to appear reversed when the sun's rays originate from the bottom of the picture. This reversal is a reflex adjustment, as we are not used to the sun's rays coming from below: they naturally come from above. For us the sun is always in the sky and never beneath our feet. That is why the shading performed by IGN on its topographical maps always simulates the positioning of the sun to the north, although this never occurs in France.

The Vatican, Rome (Italy): a monumental building of a central square?

For the same reason, in the image on the left we will tend to interpret the large grey circle as a single, large monumental building.

If the same image is reversed, we can distinguish the shadows of the buildings surrounding what is in fact a vast square.

Using graphic capture software integrated into a GIS Savedit in SavGIS

Using Savedit to capture the values of an attribute

When the identification of objects is well advanced and you have established a fairly exhaustive description of the different forms in a collection of objects, you can start digitising, that is to say tracing each object on the screen.
For instance in the illustration opposite there are three objects in a collection of "buildings". Each object has a single key or identifier (*see Worksheet 24*).
The object outlined in green has the identifier 0045, and a "function" attribute value which is "residential".
The object outlined in blue has the identifier 0044 and its function attribute is "industrial".
The object outlined in yellow has the identifier 0046 and the function attribute is "leisure/swimming pool".

Two fundamental topological requirements should be complied with:

- **no line should cut across itself;**
- **no two zones should be superimposed.**

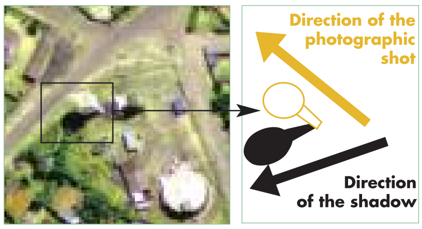
The system will help you to manage and check for these two rules in semi-automatic fashion.

(Video sequence SavGIS *Digitising "point" objects*)

Worksheet 20
Capturing points

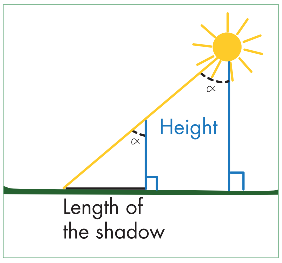
We will start by "translating" geographical objects of the "point" type. For instance, in the case of Debre Birhan (Ethiopia) we decided to model electric power lines as linear sets of pylons linked one to the other. To capture these power lines, we will therefore capture the pylons as points accompanied by descriptive attributes.

So as to clearly visualise the town, we have "rotated" the image through 90° clockwise. This places the shadows on the left hand side or below the object, which is the position that makes it easier to interpret by eye. Indeed we are used to viewing landscapes from ground level, which always places the sun above us, at the top of the image, so that we never have to "read" a shadow "above" an object.
It is quite easy to locate the water tower, inclined slightly to the left, and its fairly long shadow also falls to the left.



This same image, in its standard configuration (north orientated towards the top) is less easy to perceive, but it is easier to find the parameters provided by DigitalGlobe, the suppliers of the image.

It is possible to estimate the height of the water tower from the length of its shadow.



Example of an estimation of the height of a building

Height of the sun (given by DigitalGlobe) = 56.06°
Tan α) = height/length
Height of the water tower = tan 56°* length of the shadow (measured on the screen, since the image is georeferenced, 17.2 m)
Tan(56°)= 1.4825609685127403
Estimated height of the building = 25.5 m
Actual height of the building = 27 m.

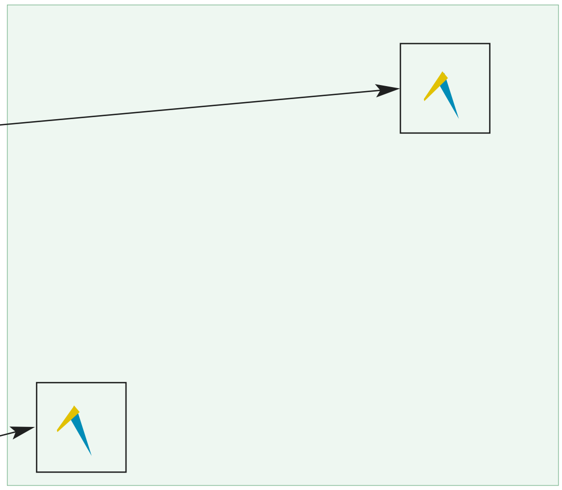
Example of the parameters provided by DigitalGlobe for three selected images
Highlighted in yellow: the parameters for the image of Debre Birhan

3 images meet your filter criteria

Select	Browse Image	Catalog Id	Sensor Vehicle	Acquisition Date	Total Max Off Nadir Angle	Area Max Off Nadir Angle	Area Min Sun Elevation	Total Cloud Cover Pct	Area Cloud Cover Pct	Imaging Bands
☐	☐ View	☐ 10100100076AD900	GB02	2007/12/02	22.88°	22.50°	56.06°	0%	0%	Pan_MS1
☐	☐ View	☐ 1020010001D69200	W01	2007/12/14	9.27°	7.27°	50.57°	0%	0%	Pan
☐	☐ View	☐ 1020010002674600	W01	2006/03/14	14.93°	14.36°	62.36°	0%	0%	Pan

We can see that the detection of the pylons is essentially based on the shadows they cast, since the pylons themselves are far less visible. With the digitising tool displayed on the screen, you point the base of the pylon and allocate a single identifier to each point. The estimated height can be added. This collection of points will then give us the line followed. This can be used to locate certain pylons that are not very easy to see, even if they are not evenly spaced.

Identification of pylons on Quick Bird image, 60 cm pixels, 2007, Debre Birhan (Ethiopia)

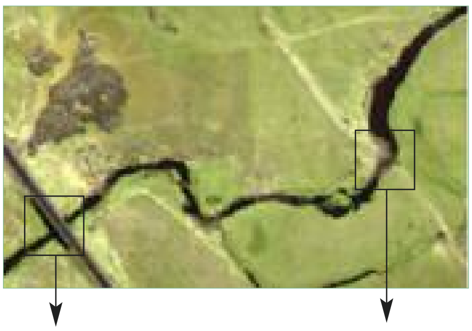


Pylon shown in yellow, shadow in blue

This pylon is not easy to see, but its shadow is clearly visible.

The pylon points captured are represented here by blue crosses on the Quick Bird background image, 60 cm pixels, 2007, Debre Birhan (Ethiopia)

The particular instance of bridges and fords



Bridge Ford

The detection of bridges is performed in similar manner, from the shadow they form when they cross the river. A river is often obvious even if it is a dry gulley. It is also possible to single out inverts or fords. We think it is preferable to capture these objects as points and not as lines, because the length of the construction is not easy to determine from the images. It is possible to design the collection to include inverts and fording-places, either as attributes, or as specific collections.

(Video sequence SavGIS *Digitising "line" objects*)

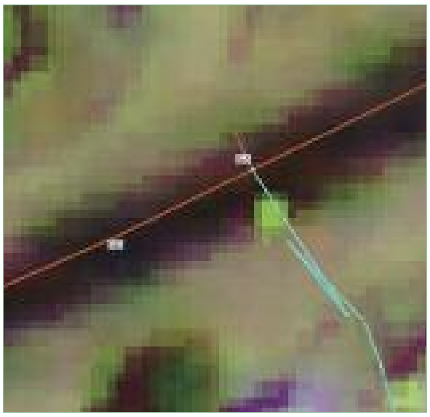
Worksheet 21
Drawing the road network

We propose to model the road system (including roads, streets, paths, dirt tracks, railways, waterways, etc.) as a collection of lines of flow. Numerous attributes can be associated with it, such as one-way or two-way traffic, estimated width, type of surface, presence of different service networks, and so forth. Thus is seems more relevant to capture the road system not in the form of zones, but in segments.
A road or street is liable to have a regulatory width, so that demolition orders may be issued on buildings that are out of alignment. This width can be included in the representation of the road system. On images of the Quick Bird type, we have to interpret and guess at the function of what appears as a roadway, path or track. For instance, in the image to the right, a tree and its shadow form a break in the visible continuity of the road. This can be remedied by drawing in the missing section. It is probably preferable to capture and draw in all the portions that appear to connect – footpaths or mule tracks, flights of steps etc. The task is to (re)construct the system, and describe a network. It is therefore essential to make a good note of the links and connections. The trace should follow the middle line of roadway objects as far as possible. It is their attributes that will enable the differentiation of the different types of "road" (asphalted, earth track, steps, etc.).
In practice, it is important to clearly mark out the road intersections. The best way is to use a tool dividing up the segments at the intersections that have been created so as to check they have been created, and then to remove the residual segments that are of no use. This is much more efficient than "aiming" at the line to be intersected, and running the risk of not correctly "cutting across" the road that has already been traced The extra segment can then easily be erased. It is also important to avoid creating a "loop" on an arc*. In the illustration at least one point should be removed.

Example of the procedure
- Start by tracing the roads in "spaghetti" mode, with a generous representation of intersections on the roads that connect (step 1);
- Then divide up the arcs according to the intersections (step 2);

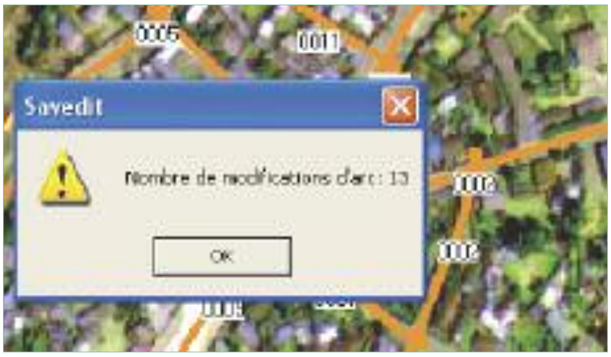
Road network capture on a Quick Bird image, 60 cm pixels, 2007, Debre Birhan (Ethiopia)

Example of an unwanted loop on an arc that should be deleted

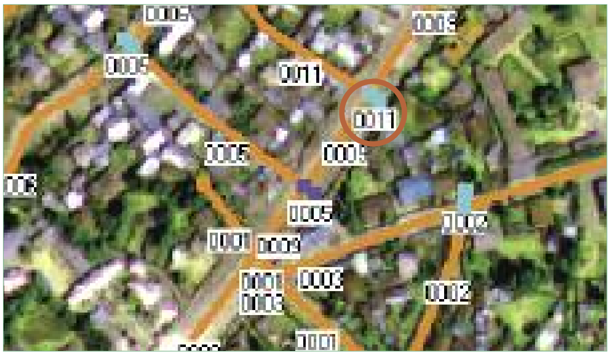


Step 1: trace the roads in spaghetti mode

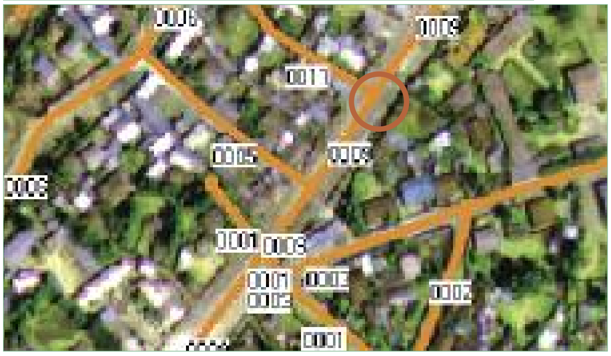
Step 2: divide up the arcs at the intersections



Step 3: identification and removal of superfluous segments



Example of a superfluous segment later removed



- Finally, prune out the superfluous segments (step3).

When you have finished this tracing procedure, each segment can be re-allocated an identifier.

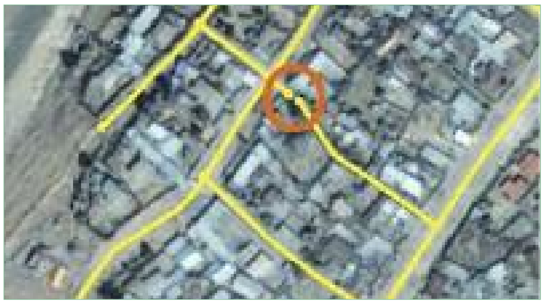
A few difficulties occurring with intersections in urban areas

In the case shown opposite, the two segments of street have not been linked because between them there is a flight of steps that cannot be negotiated by a vehicle. In this case our "road" or "thoroughfare" model (in the basic meaning of the way from one place to another rather than a main route through a town) does not integrate flights of steps. They will have to be placed in another collection of objects, which could for instance be labelled "pedestrian passages".

But if we choose to gather the roads and all other thoroughfares and similar objects into a single collection, "thoroughfares", the flight of steps should be included as a specific segment, accompanied by a specific attribute enabling its pedestrian nature to be identified. It should in all events be clearly differentiated from the two streets that are accessible to vehicles.

The street or road system is probably the first element to map and capture. It is indeed possible to capture this data before any repositioning: this is because its linear patterns enable you to plan subsequent GPS surveying. When you go into the field to do the surveying, you will also be able to detect and

The particular instance of flights of steps linking two traffic thoroughfares



correct connection errors that you might have made when capturing the road network. The network will in fact serve as a sort of skeleton enabling you to fill in other urban elements.

So that a particular thoroughfare can be identified, a new identical attribute will be created (for instance the name of the street) characterising all the segments making up a stretch of street going under that name. Once the network is completely traced and corrected, it is technically quite easy to establish a system of addresses. The remaining difficulty at this stage can be solely political, as it is always a sensitive issue to create a system of identification involving land use and layout.

(Video sequence SavGIS ***Digitising "zone" objects, blocks***)

Worksheet 22
Capturing blocks of houses

The block or "ilôt" (meaning islet) is the basic territorial unit used in France by INSEE for its general censuses. It is the smallest surface area delineated by streets and thoroughfares (public or private), natural or artificial obstacles (river, railway etc) or by a non-visible boundary between two municipalities (or other officially distinct administrative entities).
Two methods can be used to capture the zones corresponding to "blocks".

Method for capturing blocks of houses by exhaustive manual outlining

The first method consists in drawing the zones by hand, following the outline of the fences, walls etc, forming the boundaries with the thoroughfares. This defines blocks of housing through which there is no passage or crossing cutting them into two. You can refer to worksheet 23 (capturing buildings) for the capture of zones.

Extract from Quick Bird image, 60 cm pixels, 2007, Debre Birhan (Ethiopia)

Contours of the zones drawn in by hand

Method for capturing blocks of houses by semi-automatic outlining

The second method consists in using the close interdependence between the boundaries of the blocks and the street layout so as to partly automatise the outlining process. To do this we use information on the street system that already exists in the database. This is also why we recommend starting with the capture of the urban road and street network in any quick cartography procedure, before any attempt to capture the blocks.
In most GIS software, we will have a function which, starting from the "skeleton" layout of the street system, enables the representation of the system according to its attribute or variable, "width" (see image above left). We can create zones that form the "negative" of the street system, i.e. everything in the urban fabric that is not the street network. This corresponds fairly well to the definition of our bocks. We then need to allocate a single identifier to each block (*see worksheet 24*).

Representation of main and secondary thoroughfares, showing widths

Tracing the layout of the street network using different standard widths for main and secondary thoroughfares provides a "negative" of the contours of the blocks. It is then sufficient to reverse the shading to obtain their shape.

Road network
Block of houses

Reversal of the shading gives us the shape of the blocks

It can be seen on the one hand that the result depends on the quality of the earlier estimate concerning the width of the streets, and on the other that the boundaries of the blocks that are not streets (a river bank for instance) will have to be added manually. This method however enables subsequent work to be done by adjustment rather than by exhaustive capture. The method is less meticulous to perform, less demanding and less time-consuming.

(Video sequence SavGIS *Digitising "zones " objects, buildings*)

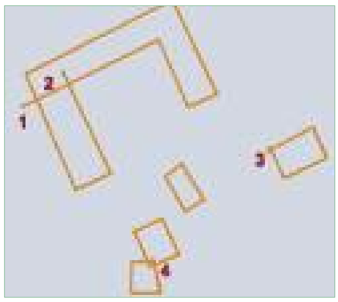
Worksheet 23
Capturing buildings

What is a "building"? Many different definitions are possible. The first step is therefore to define the collection. Should we include all man-made objects? Swimming pools, boundary walls, concrete car parks and so forth? The use to be made of the data, and the scope for identification on the image also contribute to the way in which a building is to be defined. It is in fact more useful to create and define a collection of objects from their function. It can be considered that electric pylons are "buildings" or constructions, but that their function and hence the relevant descriptive attributes of these objects are unlike the attributes that characterise buildings housing people. It is clear that a choice must be made between a large collection comprising a large number of attributes, and a set of smaller collections in which each object is described by attributes that are more specific to its group. For instance, we suggest you create a collection of "buildings" grouping all constructions with one or several floors, whatever their use, and different collections for the other types of construction (car parks, asphalt road, wall, pylon, play area, etc).
It would also be possible to capture dwellings (houses, blocks of flats) as point objects. The disadvantage would be that you would then have to create a descriptive attribute introducing the surface area as a characteristic of each object, but this is nevertheless a possibility. However, with the images we have available today (satellite or aerial photographs) it is possible to capture and draw the object as a zone. Thus we will automatically obtain the surface area. It is then possible to calculate built-up densities, and subsequently densities of human occupation per square metre.

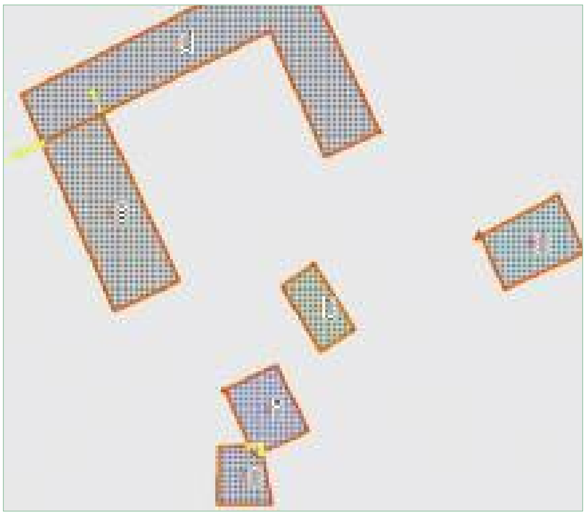
Capture of zones on Quick Bird image, 60 cm pixels, 2007, Debre Birhan (Ethiopia)

On this image, clearly rectangular zones are visible. They are not buildings, however, since they do not have a shadow. The absence of any shadow indicates the absence of any elevation of the constructed object.
We will also need to discuss and predetermine the minimum size for a "building" to be taken into account.
Thus a building is a "zone" made up of a list of the arcs required for its topological construction. Let us see how to differentiate between two houses that are very close to one another, but isolated or "detached", and two adjacent or "semi-detached" (party-wall) houses. For the first two, the different arcs will belong to only one zone. In the second instance, there will be at least one partitioning arc in common. The arcs in common are not duplicated. One of the topological rules is that while an arc can belong to two zones at the same time, it can never belong to three zones.

Method enabling correct closure of zones



As was the case for streets, arcs should be amply intersected (case n° 1 opposite). An example of a single arc separating two buildings is shown (case n° 2). Topological rules relating to the singleness of the arcs should be complied with (case n° 3), and to the non-superimposition of two objects (case n° 4). These adjustments should be made as soon as the tracing is complete, because while corrections are always possible later, they are always lengthy and tedious to perform because for a town a very large number of objects will be captured. This makes even the simplest procedures much more complex.



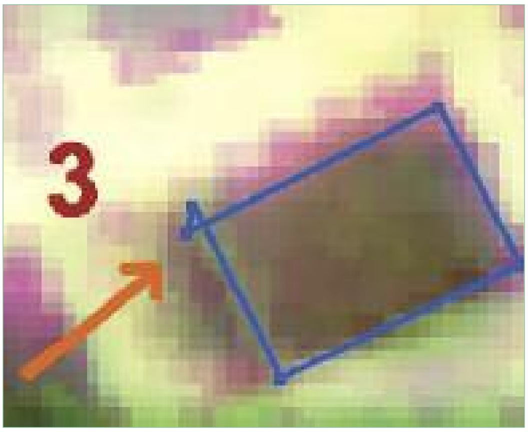
Zone captured before deletion of superfluous arcs

Once the zones have been created, i.e. once each one has been allocated the list of arcs that make it up, and is clearly associated with a single zone identifier, we can proceed as follows:

1 - Deletion

This is done using an automatic command; for example, you can automatically remove all the arcs that are no use (shown in yellow on the image).

First type of capture error: formation of a loop on an arc



2 - Check for and correct topographic errors that the system cannot correct without affecting accuracy.

These errors are of three main types:

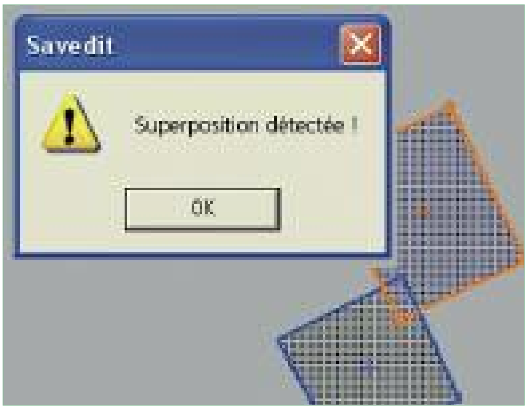
- non-simple arcs

The example shows a non-simple arc looping back to itself (*see arrow*). The system will not be able to decide what to do, so that manual correction is required.

Second type of capture error: contradiction in the crossing of two arcs

- non extra-simple arcs

The example opposite shows two arcs that are contradictory. If the tracing was left as such, the arc would define two partly overlapping zones. Again the system will not be able to decide, and manual correction is required.



Third type of error capture: partial overlap of two zones that creates a third

- Zone superimposition

The example opposite shows two zones that partly overlap. The system shows one of the zones by colouring it orange, but it cannot decide on its own and manual correction is required.

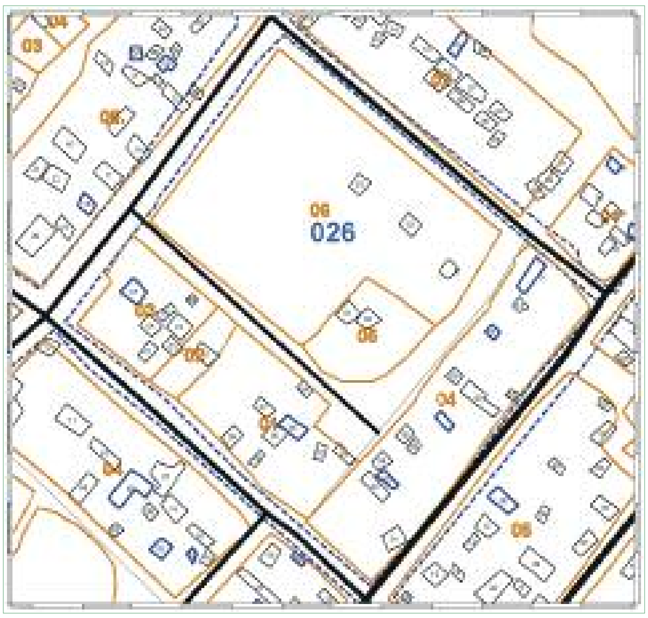
(Video sequence SavGIS)

Worksheet 24
Hierarchical coding

Let us imagine that we wish to capture all the building in the Ethiopian town of Awash. There are 21,469 known buildings in Awash, and we require a single identifier for each. These objects can very well be coded from 00001 to 21469 for instance. The capture is often achieved in batches or portions of space, so that there is a degree of correspondence between continuous series of codes and their localisation in adjacent geographical zones. However in this case, if a building is omitted at the start of the work, or if it has been built since the last census, it is liable to be allocated a code of 21470 or more, although it may be geographically located in the midst of buildings coded earlier in the 00001 to 00021 range. This means that a parallel list should be kept giving all the new codes already attributed to all the newly-constructed buildings, which will be scattered across the whole area and not easy to identify. They will for a very large part not exhibit the correlation between continuous series of codes and close geographical location on the map. In this case avoiding duplicates involves a fairly complex re-coding system.
The French INSEE and DGI* use two similar methods for this type of coding, solving the problem and greatly simplifying the addition of new elements or plots. It is a hierarchised geographical coding system.
For instance in France the code number of building 02614102003324 would refer to building 24 in plot 0033, section 02 municipality 141 (Gigors), *département* 26 (Drôme). It should nevertheless be noted that in France, on the finer scale of urban objects, there are several types of coding. For instance, DGI and INSEE do not have exactly the same code for a given building. Each uses the hierarchy that is most useful for its purposes.
It can be noted a French town of 50,000 inhabitants comprises on average 20,000 dwellings, while an Ethiopian town with the same population will have around 10,000 dwellings. This makes it difficult to simplify and unify coding systems, and to organise data capture. However, whatever the country or the size of the town or city, the number of dwellings per plot is necessarily restricted, as is the number of plots in a block, or the number of blocks in an urban district or section. Of course, this method assumes that the different nested levels of urban subdivision have already been delineated. If possible, these levels should be close or identical to those used by the national cartographic system. It is a good thing to obtain this information, since there is liable to be a system in every country, even if it has not been implemented right across the national territory. It is never very constructive to add extra coding systems, and much better to use those already in existence.

Example of zone data, Awash database (Ethiopia), IRD ECSC, 2008

In this example concerning the Ethiopian town of Awash, we have shown three coding systems nested one within the other. A code marked in blue corresponds to blocks whose boundaries are marked by a blue dotted line. It can be seen that the delineation of the bocks uses the streets surrounding them, which we have marked in black. Inside block 026 there are six plots (marked in orange). Inside each plot there are buildings (outlines in black). In plot 04 (marked in orange) at the time when the image was taken there were thirteen buildings.



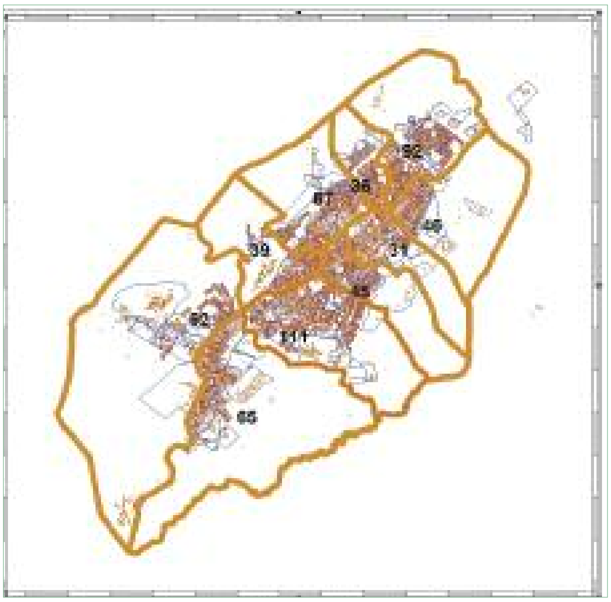
In practice, to perform this coding procedure the hierarchical subdivision should be settled before capturing any codes, that is to say there should be a clear geographical definition of each level and an exhaustive inventory of the objects, starting from a stable threshold for the next level up.
Here it is easy to see the advantage of a GIS tool that enables the rapid capture of the cartographic data for the different nested levels (district, block, plot) and a superimposed visualisation of these different levels. This greatly facilitates the identification of the different zones and their identifiers.

Let us now see how this is done in practice.
Let us look at the example of the town of Debre Birhan, where it is difficult to correctly delineate the "plot" level.
We first of all outline objects on three levels, from largest to smallest – *kebele* (district), block, and building. The identifiers have been automatically allocated in sequential manner by the system.

Detail of the three zone levels (*kebele*, block, building), Debre Birhan database (Ethiopia), 2008

Kebele — *Background image Quick Bird, pixel size 50 cm , 2007*
Block
GPS trail

The three levels of subdivision (*kebele*, block, building)



For the town as a whole we outlined 587 blocks and 13,571 buildings. The town is divided into 10 *kebeles* or districts. Inside kebele 04, we have outlined 111 blocks. The maximum number of buildings inside one of these blocks is 191. On the basis of this work we can therefore say that we need:

- 2 characters to code the *kebeles*,
- 3 characters to code blocks,
- 3 characters to code buildings.

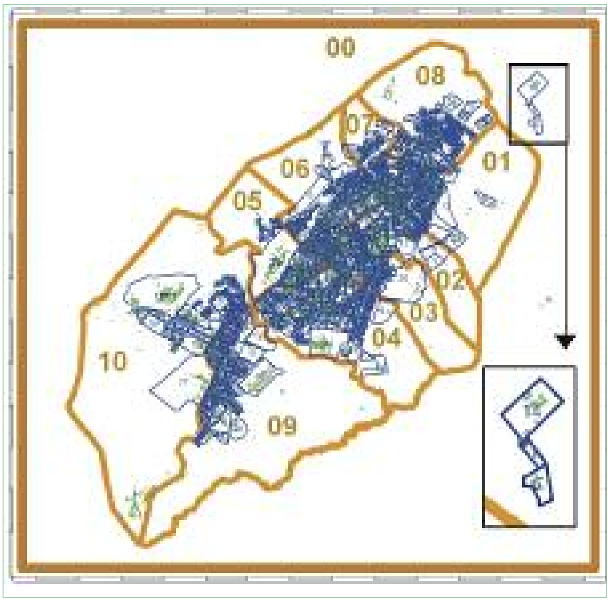
In this instance, the single, compete identifier that results for each building in the town of Debre Birhan will comprise 8 characters.

Source: Debre Birhan database (Ethiopia), 2008, IRD ECSC

The result obtained from this process of hierarchical coding is shown opposite. It can be seen that:

- there are buildings that are not within the administrative boundary of the *woreda* (municipality) of Debre Birhan. If we want to deal with them, we will have to add a zone "outside *kebele*", which could for instance be coded 00;
- the boundaries of the *kebeles* are imposed by political delineations, they are not derived from the image, even if these boundaries sometimes use elements of landscape;
- it is however possible to alter the boundaries of the blocks, since they have no legal existence and are merely defined by the ground layout. They can be created from the image;

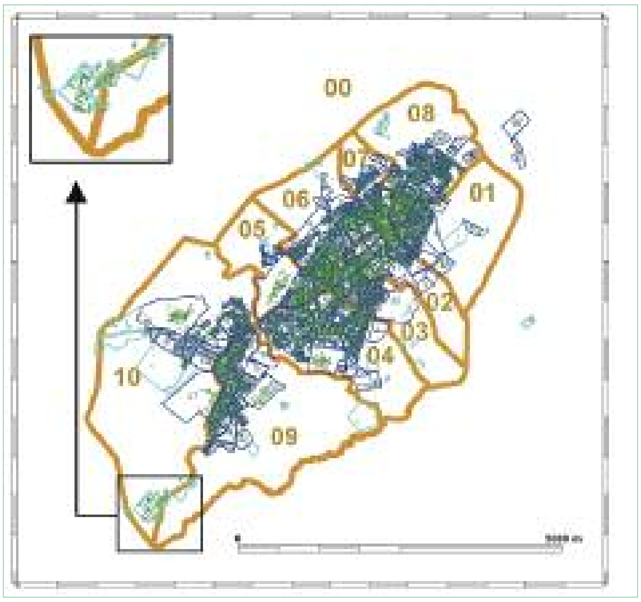
Coding of blocks in the "outside *kebele*" zone



Source: Debre Birhan database (Ethiopia), 2008, IRD ECSC

- certain buildings are inside the *woreda* administrative boundaries, but not inside a block. To deal with these, blocks will have to be added (shown here outlined in pale blue);

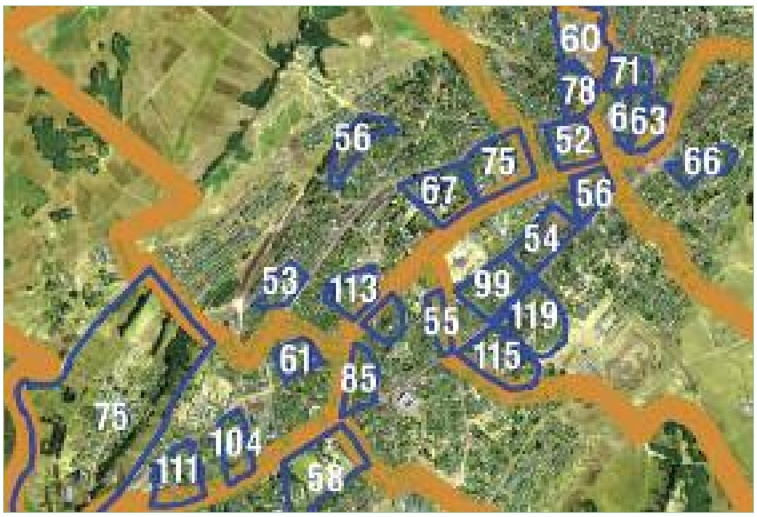
Creation of blocks that have been omitted



Source: Debre Birhan database (Ethiopia), 2008, IRD ECSC

Building
Block
Kebele

Display of blocks containing more than 50 buildings



- certain blocks turn out to contain more than 50 buildings (see opposite). This large number of objects can generate a large number of errors at the coding stage. We therefore consider it useful to subdivide these blocks so as to facilitate the coding procedure. Indeed, reducing the number of buildings that need to be coded inside a block is a very simple way of avoiding omissions and duplicates;

Source: Debre Birhan database (Ethiopia), 2008, IRD ECSC
Background image Quick Bird, 50 cm pixels, 2007

Buildings and blocks in Debre Birhan (Ethiopia)

Source: Debre Birhan database (Ethiopia), 2008, IRD ECSC
Background image Quick Bird, 50 cm pixels, 2007

- we have subdivided certain blocks, so that the maximum number of buildings per block is now 50;
- we have shown the boundaries of the different blocks (in red);
- we can now start the hierarchical coding by coding buildings using only two characters, and starting from 01 inside each new block;
- we do not need to know the identifier of the block because it will not be captured;
- however we do need to clearly identify the boundaries of each block so as to determine the set of buildings that belongs to each, the codes for which will form the new series, starting with the code 01 and finishing at most with 50;
- the block at the bottom right of the image only contains one building. Its identifier will be 01, and not 1;
- the block to the top left comprises 16 buildings. Codes 02 and 09 do not exist. There is nevertheless a code 16 because there is no need for the coding to be continuous;
- we have used a numerical coding system, but we could very well have used letters as identifiers – AA AB, AC, AD...BA, BB, BC etc.;
- the buildings in the block to the top right have not yet been recoded, and they carry the automatic default coding, and therefore need to be altered;
- if after the new coding of the buildings is complete it proves necessary to split the block in two, the code does not necessarily have to be altered for the buildings corresponding to the two new blocks.

The main advantage of working with a GIS is that we do not need to capture the whole code giving the geographical hierarchy for each building – two characters are sufficient instead of 8. Thus numerous risks of error are avoided.

In addition, this coding system can be used as a zone address system. It is indeed the system used in Ethiopia. An address comprises: n° of *woreda*, n° of *kebele*, n° of building.

(Video sequences Extracting the vegetation Using macro-commands)

Worksheet 25
Extracting the vegetation

Certain issues that you aim to approach using your cartographic data may require information concerning the vegetation. It is anyway a good thing to distinguish herbaceous or grassy zones from forest zones in your modelling procedure. Likewise, design your model so that it meets your needs in terms of land use, for instance see that built-up areas, public parks and greens, horticultural zones, arable land, orchards etc. are well differentiated.

Vegetation on the Quick Bird image

For instance in Debre Birhan, two main concerns on the part of the municipality can justify information on the vegetation being included in our mapping process: management of arboreal zones, and listing and managing individual trees.

- The first solution is to **model each tree as a dot**, to which we can then allocate attributes – species, diameter of trunk, height etc. This solution could prove rather tedious because the trees are numerous. In addition, it can be seen that in hedges or clumps of trees it is difficult to distinguish individual objects..

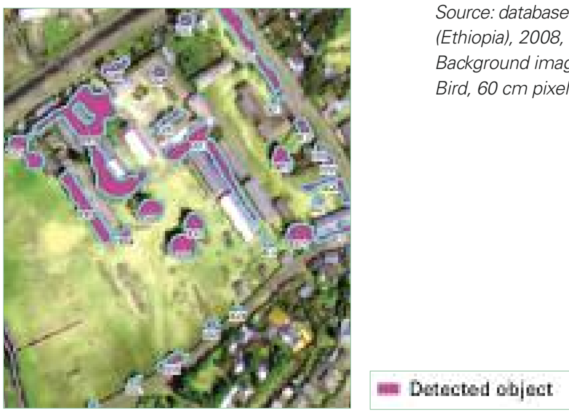
Capture of trees in point mode

- The second solution is to capture **arborescent vegetation in the form of zones.**

In this case you do not point the centre of the canopy, you draw the outline. The objects, with their identifiers, and are formed on the basis of continuous wooded portions.

In the example opposite we have not completed the outline of the hedge situated in the south-west portion of the image.

Capture of the canopy in zone mode



Source: database Debre Birhan (Ethiopia), 2008, IRD ECSC Background image Quick Bird, 60 cm pixels, 2007

Extraction of the canopy in pixel mode

- A third solution, which is attractive because in a few seconds the processing will be applied to the whole image, is to extract all the trees using radiometric threshold values on the Quick Bird image. A macro-command triggers these operations:

– separation of colours,

– determination of threshold values, in the present instance: value of the green component > 40 AND value of the red component > 25.

However, this type of processing gives results that are not easy to master without considerable skill and practice. It is quite difficult to distinguish between shade and foliage, or shrubs and arborescent formations.

(Video sequences SavGIS *Digitising relief contours*
from a map on the scale 1:50,000
from a map on the scale 1:2,000
Interpolating relief contours and survey points)

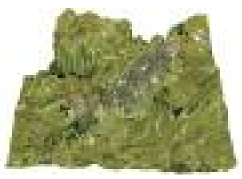
Worksheet 26
Extracting altitudes

Data concerning altitude is useful and necessary when mapping a town or city. It enables the following:

- visualisation of the relief across the space concerned,
- better understanding and planning of water supply networks, sewage and water treatment systems,
- fcalculations of visibility – what can be seen from a given point,
- calculation of local slopes, and zone typology according to scope for urban development,
- mapping of flood zones,

and so forth.

Examples of visualisations and cartographic representations provided by the processing of altitude data


View towards the north, Quick Bird image in perspective


View towards the north-east, Quick Bird image in perspective

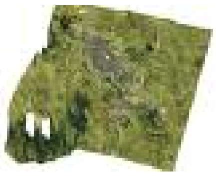
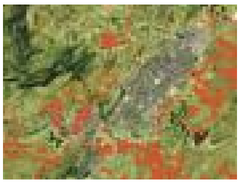

View to the east, hill shading in perspective


Image of the slopes in Debre Birhan – increasing values from black to white


Shown in red: null slope values situated over low-lying areas

Source: Quick Bird image, 60 cm pixels , 2007, town of Debre Birhan (Ethiopia)

The altitude data can be apprehended by way of four types of geographical indication:

- dots: these correspond to points that have been surveyed and are shown on regular topographical maps, but they can also be provided by the altitude value given for each GPS reading,
- lines: these are the relief contours that link places at the same altitude and marked out in topographical maps,
- zones: this is more infrequent, since these zones are merely a rough reflection of the two previous types of indication,
- pixel matrices (rasters) where each pixel has its own altitude value (SRTM-GDEM).

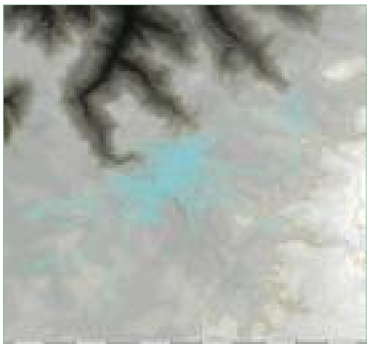
The three 2-dimension mapping techniques showing altitudes


Dots and lines

Relief contour
survey point


Zones

Altitude zone 1
Altitude zone 2
Altitude zone 3


Raster

Progressive altitude zones according to SRTM
Debre Birhan road network

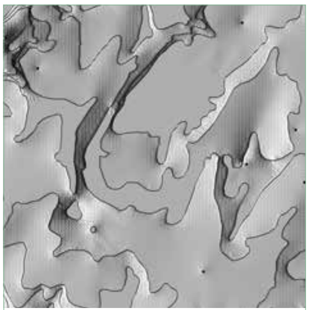
Background: EMA map on the scale 1:2,000, Debre Birhan (Ethiopia)

Source: Quick Bird image, 50 cm pixels, 2007, town of Debre Birhan (Ethiopia)

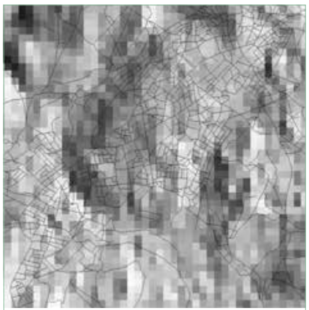
Making the map, extracting the data

The data in the form of a raster matrix (SRTM or GDEM) are data that are already interpolated: the altitudes are known for all the pixels in the matrix. Interpolating consists in calculating the means of all the known altitude points and/or the contours present on the map using GIS software (such as SavGIS). Precision will vary. SRTM presents the values in 90 m pixels. GDEM gives 30 m pixels, which is roughly equivalent to what can be obtained from relief contours on a map on the scale 1:50,000. Survey points or GPS points cannot really be used, except to provide checks, because they would have to be extremely numerous for the interpolation to be valid.

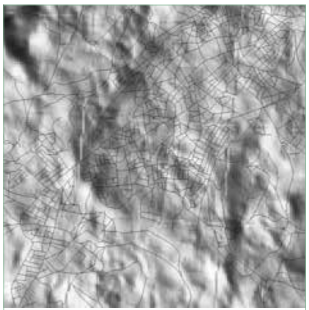
Visualisation of altitudes by shading. Simulated position of the sun: north-east



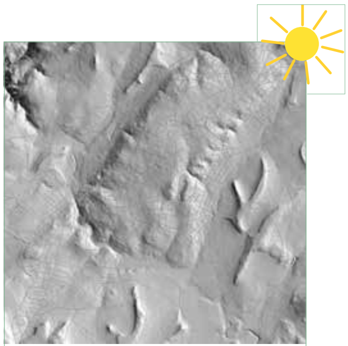
Altitudes using relief contours from the map on the scale 1:50,000



SRTM altitudes, 90 m pixel

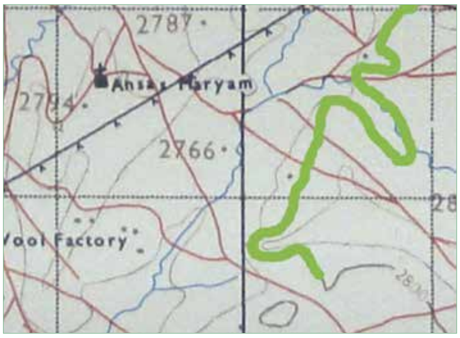


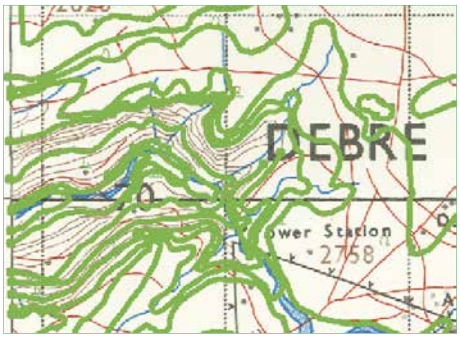
GDEM altitudes, 90 m pixels



Altitudes from relief contours on the EMA map on the scale 1:2,000, 2 m pixels

Capture of relief contours from a topographical map





Digitised relief contours
Roads
Rivers

Background EMA topographical map on the scale 1:50,000

The raster image of the repositioned and georeferenced topographical map is displayed.

- Start by tracing (in line mode) the master contours (in green). This will enable a reduction in errors when shifting from one contour to the next.
- It can be noted that there is a discrepancy in latitude between the "contour" layer and the "river" layer, which is due to printing inaccuracy.
- When the contours run parallel and are very close, it is not essential to digitise them because the result of the interpolation will not be any better.
- The shaded view is used to detect errors. For this shading it is preferable to simulate the sun from the north-east, because that is what gives the best view of the relief.

A few precautions are required before using altitudes derived from different sources in conjoint manner. Indeed, not all of them will indicate the 0 altitude reference

Here are a few altitude values (in metres) for the example of Debre Birhan:

	SRTM V1	SRTM V4	GDEM	Carte 1 : 2 000
Point 1	2,753	2,754	2,758	2,772
Point 2	2,827	2,825	2,823	2,846
High point	2,829	2,852	2,847	2,882
Low point	2,596	2,539	2,533	2,543

(Video sequence SavGIS *Presentation of the Debre Birhan database dictionary*)

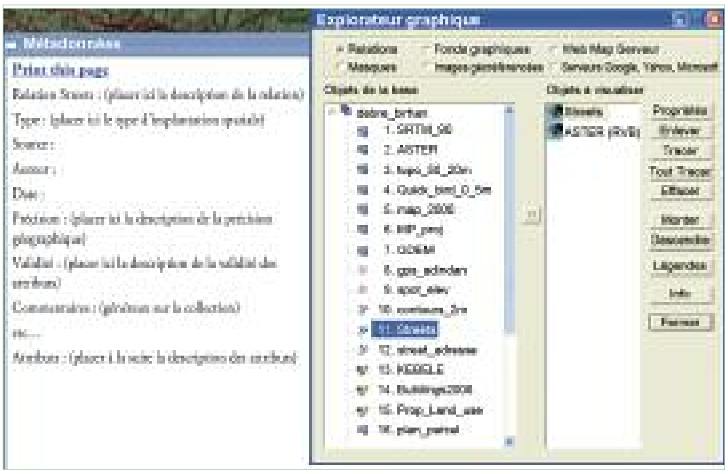
Worksheet 27

The legend or the data catalogue

This worksheet, arriving at the end of the manual, nevertheless describes an important task that needs to be performed from start to finish of the enterprise. Just as a thematic map should always comprise a presentation, our database should comprise a precise **description** of each of its elements, i.e. a **catalogue**. This is often referred to as "metadata", a term that we think is not wholly appropriate because the prefix "meta-" could suggest something that is above, beyond or beside, tending to minimise the importance of this primary description which needs to be set out at the start. It is in fact a precise description of the data: the description of the different attributes attached to the collections, and also the source, the date of creation, the methodology etc.
Yet it is often a task that is eluded, as it is difficult and tedious. Describing all the parameters and all the decisions reached is not very easy, because a number of them are implicit. They do indeed seem obvious at the moment when the decision is made. But as remarked by Marc Leobet* (a member of CNIG, Conseil national de l'information géographique* ; http://georezo.net/ blog/inspire/), "*any questions that are not asked at the time of the capture or the production will cause problems when the time comes for the catalogue*".
Fortunately most software provides facilities for providing information on data. Even so, the description does have to be entered by the operator.

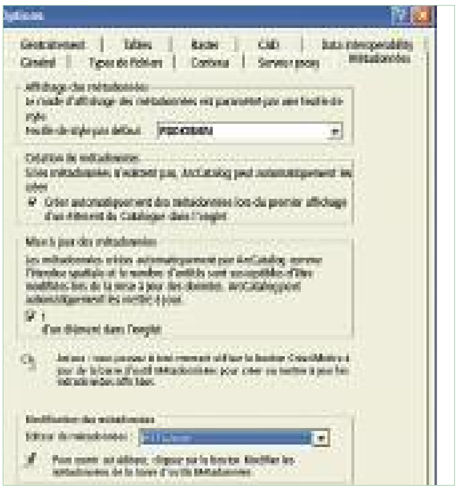
The window opposite is provided in SavGIS in HTML format. SavGIS creates two types of file: one briefly describing all the layers in the database, and another individual file for each of the layers. These files are stored in standardised manner in a folder that is created automatically, and which is an integral part of the database. The description is accessed via a right-hand click on the title of a particular layer in the cartographic explorer for each of the modules. Completing each sheet displayed is easy using a tool such as the free software OpenOffice.

A metadata sheet completed using SavGIS



Source: database Debre Birhan

A module comprising 3 sheets of metadata using ArcGis (1 tab = 1 sheet)



ArcGis offers a wide range of style sheetsin different formats.

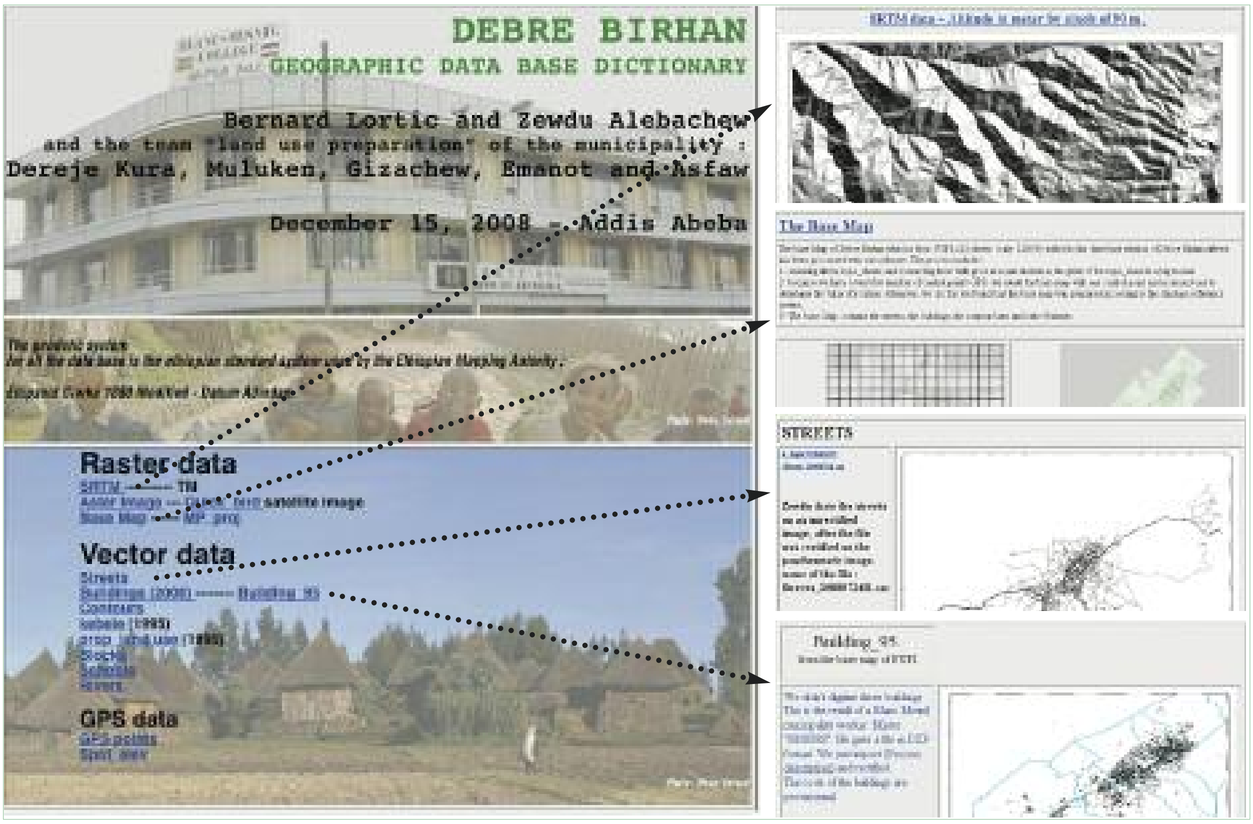
Map legend, updating data

These sheets are essential for use of the database by anyone who has not taken part in the elaboration of the data, and also for any subsequent use, including further use by the developer. Six months after completing the work, it is not easy to remember exactly the decisions reached at the outset, since many will have been implicit. For instance the minimum size for buildings to be recognised as buildings.

All these sheets can be published on the Web, because they are not the data itself, merely its description. This publication is a simple matter, even if there are legal problems concerning the actual data. The owner or owners of the data should be indicated precisely in each sheet.

If the descriptive sheets are presented with one page of introduction, this will give a rapid although incomplete overview of the contents of the database. It should provide information on the conditions in which the database was created, and also on the important general data. For instance, the geodesic system used should be specified. This information is essential, particularly because to date no software enables you to switch rapidly from one geodesic system to another. The legal passage of the French NTF* system (*Nouvelle triangulation de la France*) to the RGF93* system (the French geodesic network adopted from January 1st 1993 at 0 hours) took more than ten years to fully take effect.

The home page of the Debre Birhan database dictionary



It is on this catalogue that the legends of the resulting paper maps will be based. The legends should be an easily comprehensible summary of the geographical content, but they are not required to explain every detail.

Should we embark on the creation of conceptual data model (CDM*) by way of the Merise* method?

It seems to us that this is not necessary. The definition of a model of this sort aims to accelerate access to data in a set and standardised manner, and for the purpose of a particular application. As our manual aims more simply to create data, it seems to us that the most important task is to accurately describe the conditions in which each piece of data was created.

(Video sequence SavGIS)

Worksheet 28
Updating a map

Updating after completion is better than wasting time waiting for a recent piece of data.

This manual recommends that you always start by using the information that is available in existing cartographic or vertical photographic documents. They will therefore often be obsolete. Firstly, the urban reality under observation can evolve very fast. Thus in Ethiopia an image of a town dating three years back will describe a largely outdated situation, and will not give the main part of recent urban extension, so fast have been the changes in urban areas since 2000. Second, recent technological and economic developments have led to the appearance of new sources of data, and this suggests that access to increasingly up-to-date information will be more and more common. Today it is possible to find recent sets of aerial or satellite photographs in which buildings can be correctly distinguished for almost any town. However it is still unusual to find sets of data for a given town at different dates.

For the moment, it is difficult to plan your mapping procedures on the basis of the most recently issued documents, because issue dates may not be reliable.

However it is wise to plan from the outset for the updating of your map as soon as the data does become available, and to remember to return to these sources once your first mapping enterprise is complete.

We therefore suggest you always use the older documents first to create your map, when they exist and if their level of precision suits your purpose. In the choice of the documents to use, availability and precision should take precedence over the accuracy of the data or its date:

- accurate geographical localisation can be introduced from another source (for instance by adjustment on GPS readings in the field;
- updating of the data can be performed at a later stage. Once your map exists, it is easy to update, since the older part of the urban space is already digitised, and it merely needs completing.

Example: map updating for the town of Debre Birhan (Ethiopia)

a) Accessing the images

Our quick cartography procedure was applied to Debre Birhan using the Ikonos image dated November 14th 2007. More recent images found for this town were Quickbird for August 1st 2010 and Ikonos for March 22nd 2008, and nothing further in the Spotimage catalogue.

For the demonstration, we have used the QuickBird image dated December 2nd 2007. It might be thought that with a time lapse of under one month nothing will have changed. But this is not so: numerous new buildings can be seen, which is coherent with the present phenomenon of very rapid urban extension in secondary towns and cities in Ethiopia.

Debre Birhan (Ethiopia)

Source: Ikonos image, 14-11-2007, 1 m pixels

Debre Birhan (Ethiopia)

Source: QuickBird image 2-12-2007, 60 cm pixels

Partial cover of Debre Birhan

Source: Ikonons image, 22-03-2008, 1 m pixels *b) Geometric rectification*

The difference in obliqueness of the views needs to be taken into account.

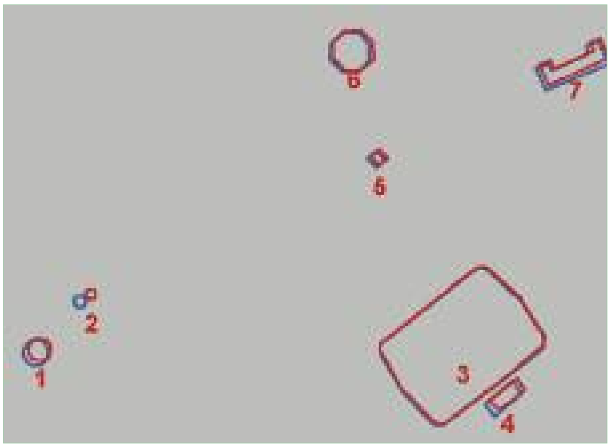
There are no very high buildings in Debre Birhan. For instance building 7, the Blanc-Mesnil school, has only three storeys (15 metres in all). Nevertheless the water tower is 27 m high (building 2). The rectification of the images was performed on objects at ground level. Thus we traced the visible boundary of a sports ground on the two images. It can be seen that the apparent displacement of the roofs between the two images is proportionally greater for the taller objects:

- no displacement for the outline of building 3,
- more marked displacement for the hexagonal church (6) and the school (7),
- for the water tower (2) the two outlines are distinct.

Extract from Ikonos image dated 14-11-2007 used for the quick cartography procedure

6 The numbered objects are represented in the vector file opposite

Traces of objects corresponding to the images for the two dates



Object traced from the Ikonos image opposite
Object traced from the Quick Bird image dated 02-12-2007

c) Photo-interpretation

Below you will find two examples of new buildings appearing between November and December 2007.

We have stored the outline of these new buildings in a specific vector file named "bati_nouveau_dec_2007".

Tracing on the extract from the Ikonos image dated 14-11-2007

Outline of building present in the first Ikonos image dated 14-11-2007, and hence present on the map that we developed. At the time, we traced buildings under construction, only one of which had a roof

Tracing on the extract from the Quick Birds image dated 02-12-2007

Outline of new buildings detected on this image and assigned to a new collection

The example presented on the next page explains how to deal with the appearance of a new building (outlined in red), a private house standing on its own in a planned individual construction zone.

Extract from Ikonos image dated 14-11-2007

Outline of the buildings present on the first Ikonos image dated 14-11-2007 and hence present in the map developed

Outline of the new house

New private house

d) Addition of a territorial subdivision

The south-west part of *kebele* 04 is not at present a built-up area. However, there are major urbanisation projects underway, comprising condominium zones and individual construction zones. It is highly likely that the municipality will in the end decide to split the *kebele* into two. The simulation below shows that it will be easy to update the map in accordance with the decisions reached by the municipality. We have split *kebele* 04 into two parts, and the resulting *kebeles* are labelled *kebele* 04 and *kebele* AA.

Extract from Ikonos image dated 14-11-2007 used for the quick cartography procedure

Present outline of *kebele* 04

Extract from the QuickBird image dated 02-12-2007

Outline of the theoretical new *kebele* AA and the new boundary of *kebele* 04

e) The organisation of the database

When there are different image chronologies for a collection of objects, there are at least two solutions for storing the "date" information:

- for instance in the case of the *kebeles*, it is simpler to create a new complete collection of objects for the second date.
  Thus in the database we will have a collection of objects named "Kebeles2000" and another labelled "Kebeles2012";
- in the case of buildings, it is wiser to create a collection of objects containing solely the new buildings appearing at the new date. In addition, certain buildings that existed in the earlier collection will have disappeared or been demolished. It is possible to create a new attribute "demolition date", and to integrate this extra information for the few buildings involved.

Other collections of individually-captured objects such as trees or pylons can be processed in the same manner.

Bibliography

Humanitarian and charity websites (NGOs)

These should be consulted because they often offer a quick cartography approach.

AGTER (an association seeking to improve management of land, water and natural resources)

45 bis, av. de la Belle Gabrielle, 94736 Nogent-sur-Marne cedex, France, web : http://www.agter.asso.fr/

CartOng, cartography for humanitarian action

CartOng is an NGO offering mapping and GIS services to small associations, NGOs, UN bodies, and funding agencies involved in humanitarian work.
Bureau 116, Parc d'activités de Cote Rousse, 180, rue du Gennevois, 73000 Chambéry, France, web : http://www.cartong.org/

Humanitarian OpenStreetMap

http://hot.openstreetmap.org/weblog/

Mapaction,maps for emergency settings, http://www.mapaction.org/

Mapaction supplies maps created from information collected in disaster settings to facilitate swift humanitarian action in the field.

Free-access cartography

CETE-Méditerranée - technical exchange website

http://www.cete-mediterranee.fr/tt13/www/imgarea/DemoOSM-Manuel_Utilisation.pdf (application of OpenStreeMap data to geographical analyses of road and public transport networks, version 27.11.09)
http://www.cete-mediterranee.fr/tt13/www/imgarea/DemoSIG-vptc-manuel.pdf (free demonstration- geographical analysis of road and public transport networks, version 19.10.09)

OpenStreetMap

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Glossary

′
symbol used to represent minutes in an angle, 60th of a degree outside the International unit system.

°
Symbol for the degree, angle unit outside the International system.

API – Application Programming Interface
This is a programming interface provided by a computing programme. It enables programmes to interact with one another, rather like a man-machine interface making interactions possible between man and machine. From the technical point of view, an API is a set of functions, procedures or classes made available in a programme catalogue, an operating system or a service. Familiarity with the relevant API is essential for software components interoperablitity.

Arc
A portion of line that may have several segments.

ASTER Global Digital Elevation Model or GDEM (Global Digital Elevation Model)
A digital elevation model (including ground-standing elements, i.e. buildings) calculated from stereoscopic pairs in the panchromatic images captured by ASTER. It has been available on Internet since June 29th 2009 from NASA and the Japanese ministry for the economy, trade and industry. It offers better geographical cover than SRTM (99% vs 80%), the resolution is 30 m, including Europe and Canada.

CGIAR-CSI – Consortium for Spatial Information of Consultative Group on International Agricultural Research (http://www.cgiar-csi.org)
CGIAR is an international body aiming to coordinate international programmes to alleviate poverty and ensure food security in developing countries by way of agricultural research. It was founded by the World Bank on May 19th 1971 under the joint sponsorship of FAO, the International Agricultural Development Fund, and UNDP. CGIAR has 64 member organisations – international organisations, foundations (Rockfeller, Gates, Monsanto), governments and NGOs. It at present supports fifteen research centres grouped in the CGIAR Alliance of international centres. In May 1999 this Alliance created the Consortium for Spatial Information (CGIAR-CIS, which associates GIS/RS laboratories, researchers, and different institutions worldwide.

cm
Symbol used to represent the centimetre.

CNIG – Conseil national de l'information géographique (http://www.cnig.gouv.fr)
This national French body has the job of advising the French government on all questions relating to geographical information. It also contributes to promoting its development.

Conceptual data model
Also Semantic Data Model: its purpose is to set out in formal manner the data that will be used by the information system. It is thus a representation of the data, derived from a modelling process, that should be easily understood. It enables a description of the information system in the form of entities or objects possessing characteristics or attributes, and of the associations or relationships grouping these entities.

Convers
This is a free access programme for converting geographical coordinates (http://vtopo.free.fr:convers.htm). It enables the conversion of coordinates expressed in latitude and longitude into different geodesic systems or into X/Y in different projections. It also enables the calculation the convergence angle of meridians at a given point (the angle between the geographical north and the north in the projection considered). Series of coordinates can be converted from a file. Convers can be used as a command line.

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Datum
To define a geodesic system, the ellipsoid alone is not sufficient. It needs to be positioned in relation to the actual surface of the earth. The information derived from the ellipsoid and the positioning parameters forms what is known as a geodesic datum. Thus a geodesic datum is defined by the ellipsoid data, the position of the centre of the ellipsoid and the orientation of the axes of the ellipsoid.

DEM or Digital Elevation Model
This is a matrix of altitude values for the ground level and ground-standing elements (i. e. it includes buildings).

DGI – Direction générale des impôts
The tax office in the French finance ministry.

Earth Remote Sensing Data Analysis Center (Ersdac)
(http://edac.unm.edu)
In 1964 the Earth Data Analysis Center (Edac) was created in New Mexico university for the transfer of NASA space technology to public and private sectors. Since then the centre has diversified its areas of transfer by including remote sensing (1973), image processing (1979), geographical information systems (1983), GPS (1990) and information technologies (1999).

EPSG – European Petroleum Survey Group
This group, created in 1985 by Jean-Patrick Girbig and the ELF company, defined a list of the georeferenced coordinate systems, and allocated codes to identify them. In 2005 the group became the Surveying and Positioning Committee of OGP (International Association of Oil and Gas Producers). These codes, still in existence under the label "EPSG Code", are used in particular in the Open Geospatial Consortium standards. APSG (Americas Petroleum Survey Group) was created ten years later in Houston (USA) by Jean-Patrick Girbig, with similar objectives. A geodesic system can have several EPSG codes, according to how it is used. Thus the geodesic system RGF93 (the official French geodesic network) which is valid in metropolitan France, carries the code EPSG 6171. It is a system of geocentric coordinates. The ellipsoid associated is IAG GRS 1980. When an EPSG Code is specified as [geographic 2D], it means that it integrates latitude, longitude and elevation on the ellipsoid.

Ethiopian Civil Service College – ECSC
This is a higher education establishment created in 1995 by the Ethiopian Ministry of education. It is intended to train territorial officers. It has integrated the former university urbanism department which was its precursor (http://www.ecsc.edu.et).

Etrex
A range of navigators produced by the Garmin company (ultra-compact portable GPS with highly sensitive aerial, waterproof casing, trajectory calculation that can be individualised, and memorisation of series of points.

ForumSIG – a French-language GIS portal
(http://www.portailsig.org)
One of the websites for exchange and information intended for the French-language GIS community.

GDEM
Global Digital Elevation Model, *see ASTER*

Géoportail
(http://www.geoportail.fr/5063351/index/accueil.htm)
This French-language website is designed for both ordinary citizens and state service departments, territorial collectives and companies. It is public service website, and a reference tool for online access to public-interest geographical information and its cartographic visualisation in 2D and 3D. The data – aerial photographs, maps, and IGN geographical data for France, its overseas territories (DOM/TOM) and territorial collectives – is provided by the different Geoportail partners that possess the data.

Georezo – French language geomatics portal
(http://georezo.net)
This websites invites you to "share", enrich and offer your skills in the numerous technical, organisational, legal and human domains relating to geographical information systems (GIS). This French-language website, run by a team of enthusiasts, is intended to provide assistance by way of thematic or technical forums. You will find a vast amount of information in four main sections: Community, Resources, Employment and Market.

GeoTif or Geotiff
Geotiff is a public specification enabling the addition of georeferencing information to a TIFF image (projection, coordinate system, date etc). The aim of Geotiff specifications is to enable the description of any "cartographic" information associated with a TIFF image and derived from satellite imagery, aerial photographs, or scanned maps, of an elevation model, or of a geographical analysis.

GIS
Geographical Information System.

Gon (also grad, grade, gradian)
This is the symbol for the gradian, which does not belong to the International System. Value in IS units (radian): p/200. The symbol *gr* is no longer allowed in France (decree n° 82203 dated 26th February 1982, JO publication 28th February 1982 and AFNOR standard NF X 02-006.

Google
Worldwide search engine which organises information across the globe for the purpose of making it accessible to all. This corporate company was started up in 1998 by Larry Page and Serge Brin, its head office is located 1600 Amphitheatre Parkway, Mountain View, CA 94043, USA. For further information:
http://www.google.ca/intl/fr/corporate/tenthings.html.

Google Earth
This visualisation and geographical localisation tool is available for consultation and downloading on the Google server. From satellite images, photographs on the ground, 2D cartography and 3D representations, it enables numerous applications, from the mere search for a place, the recording of a visit, to the import of GPS data.

GPS – Global Positioning System
GPS is an American satellite geo-localisation system that is operational worldwide. It is accessible to the

general public, as is its Russian counterpart, Glonass. Galileo is the European satellite positioning system planned to be operational in 2014.

Graticule

This is a grid or lattice of lines dividing a drawing into equal squares. The verb "to graticule" refers to the tracing of equal squares over a drawing so as to reproduce it, maintaining its proportions on the same or a different scale.

Ground swath

The word "swath" refers to the cutting width of a mower or a person scything grass by hand (around 1m50). By analogy, the term "ground swath" is used in remote sensing to refer to the band of terrain covered by the satellite cameras at a given moment, ranging from 10 to 600 km according to the satellite.

GRS80 – Geodetic Reference System 1980

This is the geodesic (or geodetic) reference system used by the American satellite geo-localisation system (Global Positioning System) adopted in 1979 by the General Assembly of the International Association of Geodesy (IAG).

IGN – Institut géographique national
(http://www.ign.fr)

The French National Geographical Institute. This body is in charge of the management and diffusion of geographical reference information in France. It has been involved in all cartographical operations across the French territory since 1940. Head office: 73 Avenue de Paris, 94165 Saint-Mandé cedex.

Insee – Institut national de la statistique et des études économiques français (http://www.insee.fr)

The French national institute for statistics and economic study. This body collects, produces, analyses and diffuses information on French society and the French economy, it coordinates the French public statistics department and compliance with the confidentiality of statistics.

IRD – Institut de recherche pour le développement
(http://www.ird.fr)

French research and development institute under the authority of the Ministries of research and foreign affairs. It is a public scientific and technological body that has been working for over 60 years in the countries of the South (known under the name of ORSTOM until 2000). Its activities involve research, expertise, valorisation and training aiming to foster development in these countries. Head office: 44 Boulevard de Dunkerque, CS 90009, F-13572 Marseille cedex 02.

IULIS – Integrated Urban Land Information Systems

These are planned geographical information systems devoted to the description of land use and urban cadastral (plot) layout.

JPL – Jet Propulsion Laboratory
(http://www.jpl.nasa.gov)

This NASA laboratory has been in charge of American satellites since the first American Satellite, Explorer 1, was put into orbit in 1958, in association with the California Institute of Technology. Head office: 4800 Oak Grove Drive, Pasadena, California 91109

km Symbol used to represent the kilometre.

Leobet, Marc

A member of the French national council for geographical information (CNIG – Conseil national de l'information géographique), appointed to the European directive 2007/2/CE dated 14th March 2007 and known as Inspire. This aims to establish a geographical information "infrastructure" in the European Community to foster environmental conservation. This is in fact a set of information services available on the Internet, spread across the websites of the different actors involved, enabling the diffusion and sharing of geographical data. (http://www.developpement-durable.gouv.fr/La-directive-europeenne-Inspire-de.html).

LIS – Local Information System

This term is used in the UK to refer to certain geographical information systems (GIS).

m Symbol used to represent the metre.

Merise Method

This is a method for designing an information system. The Merise method is based on the partitioning of data and processing procedures based on several different conceptual and physical models. This partitioning ensures the sustainability of the model. Indeed, the organisation of the data does not often need alteration, while the procedures are altered rather more often. The method dates back to 1978-9, and emerged in the wake of a national consultation launched in 1977 by the French Industry Ministry for the purpose of choosing advisory bureaus in the area of computing able to define a method for designing information systems. The two main companies that have developed this method are CTI (Centre technique d'informatique) in charge of managing the project, and CETE (Centre d'études techniques de l'équipement) located in Aix-en-Provence.

Metadata

The structured information serving to describe a resource.

Michelin

This multinational French company whose head office is in Clermont Ferrand (France) manufactures tyres. It was established in 1889 by the brothers André and Edouard Michelin, and it is known for the invention of the interchangeable bicycle tyre (1891) and the radial tyre (1946). From 1910 the company began to sell road maps and regional maps on the scale 1:200,000. In

France the phrase "Michelin map" became common language to refer to maps on the scales 1:200,000 or 1:100,000, and IGN maps or "*cartes d'état-major*" to refer to maps on the scales 1:50,000, 1:20,000, 1:10,000 or 1:5,000.

mille

This linear measure used to apply to a large number of units of length. Today the following are still in use: the British mile corresponds to 1,760 British yards, or 1,609.3426 metres, while the American mile, corresponding to 1,760 American yards amounts to 1,609.3472 metres; the international nautical mile is conventionally equivalent to 1,852 metres; the British nautical mile is equivalent to 1,853.1824 metres. The mile has been used, and is in some instances still used, in other languages, for instance the "*mille marin*" used in French to refer to the nautical mile.

Nasa – National Aeronautics and Space Administration

Best-known under its acronym, this is the American government agency in charge of the main part of the civilian space programme in the USA. It is also involved in aeronautical research. Since it was created at the start of the 1960s, NASA has been the world leader in the area of human space travel, the exploration of the solar system, and space research.

NGA – National Geospatial-Intelligence Agency

Formerly the National Imagery and Mapping Agency (NIMA). This is an agency in the USA defence department whose function is to collect, analyse and diffuse geospatial intelligence and satellite imagery.

NTF – Nouvelle triangulation de la France

This is sometimes referred to as the "Lambert system" (after the name of its associated projection). It is a geodesic system covering the French metropolitan territory. It is today giving way to the RFG93 system. The 70,000 geodesic sites (more than 80,000 if the 5th order or complementary triangulation points are also counted) are regularly distributed across the French territory, thus materialising the NTF system with a mean relative precision of the order of 10-6 (i.e. a few centimetres between neighbouring points).

OSM – OpenStreetMap

This is a programme intended to create free-access maps of the world using GPS and other free-access data, and to make them available via a portal. It was established in University College, London in July 2004 by Steve Coast, and it is based on a system of contributions from users.

RGF93 – Réseau géodésique français 1993

This system succeeded to NTF and has been the French geodesic system since January 2001 for all public works involving a surface area of more than one hectare, or where the greatest dimension is over 500 m (decree dated December 26th 2000, altered by decree n° 2006-272[1] dated March 3rd 2006). The planimetric coordinates of a point under RGF93 can be of two types: geographical, in longitude and latitude ($\lambda;\phi$); or Cartesian, east, north (E;N). RGF93 also provides information on the third dimension and ellipsoidal height, which should not be confused with NGF normal altitude. RGF93 precision: 2 cm in planimetry, 2-5 cm in altimetry.

Savane

This is the first name and version of the operating module for the GIS and remote sensing programme SavGIS, developed by IRD (Institut de recherche pour le développement) from 1884.

SavGIS (http://www.savgis.org)

This GIS and remote sensing software developed from 1884 by IRD aims to respond to the specific needs of the Institute's research teams and their partners. Developed for a large part by teams that have constructed geographical databases in Latin America, Africa and Asia, it has been used by numerous teams on a variety of themes: urban management, natural risk management, epidemiology, demographics, water management, health risks, coastal and lagoon management, cartography. SavGIS is compatible with other commercially available products (ArcGIS, MS Acess, AutoCad). It is freely accessible under MS Windows (98, 2000, XP, Vista 7) in three languages, French, English and Spanish.

Shuttle Radar Topography Mission (SRTM)

This refers to topographical matrix and vector files supplied by two American agencies, NASA and NGA (formerly NIMA). The altimetric data they provide was calculated from data collected during an 11-day mission in February 2000 by the Endeavour space shuttle (STS-99) at an altitude of 233 km, using radar interferometry. This observation campaign enabled the establishment of digital elevation models (DEM) for about 80% of the (emergent) land surfaces between 56° latitude South to 60° latitude North. Other data is also made available to the public: raw radar data, and general data derived from these DEM.

Spotimage

This is a limited company created in 1982 by the French Centre national d'études spatiales (CNES), IGN and the space industry (Matra, Alcatel, SSC, etc.). Today, alongside Infoterra, it forms the Geo-information division of EADS Astrium (European Aeronautic Defence and Space Company) which, under a mandate from CNES, operates the Terre SPOT observation satellites. The head office is in Toulouse (France).

Tessellation

The word is derived from the word tessera (tesserae) (originally Latin), meaning a small piece of stone, glass or pottery used in paving or decorative mosaics. In the setting of the cartographic repositioning or adjustment procedures described here, tessellation consists in

dividing an image into numerous sub-elements that are repositioned independently.
For further details on the mathematical meaning see http://recherche.ign.fr/labos/cogit/pdf/THESES/MONIER/These_Monier.pdf.

Thematic Mapper
This is the name of a captor carried by Landsat satellites since the issue of version 4, the main characteristics of which are that it acquires data over a wide range of wavelengths (8 values from violet to infrared), with a pixel resolution of 28.5 m and a ground swath of 185 km. Since 1972 the Landsat satellites have been put in orbit at an altitude if 700 km. They complete their orbits every 16 days, and are managed by the National Oceanic and Atmospheric Administration (NOAA) in the USA.

USGS – United States Geological Survey
This is the American geological study Institute's agency devoted to earth sciences, and created by decision of the American Congress on March 3rd 1879, attached to the department of the Interior, head office Reston (USA). It is the first civilian cartography agency in the USA, known in particular for its topographical maps on the scale 1:24,000. The recent programme named National Map is an attempt to digitise the topographic maps for the whole of the US territory. USGS is also in charge of the surveillance of seismic activity, and the detection of epicentres and magnitude of major earthquakes across the world from the National Earthquake Information Center, located in Golden, Colorado (USA).

WGS84 – World Geodetic System 1984
This derived from GRS80 used in the Global Positioning System. It is the 1984 version of the American satellite geo-localisation system and now used for GPS. It rapidly became a standard reference for cartography. A geodetic system should not be confused with the type of projection: it defines a representation of the terrestrial geoid.

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In 2005, on the terrain of Woldyia, a small Ethiopian town chosen as a fieldwork for a training course on urban planning, Bernard Lortic faces cartographic difficulties of students in urban planning school. The only available maps were blueprint copies quite unreadable and mostly obsolete since very old. The use of high accuracy readings made by the students from their careful handling of measuring tapes, is irremediably limited by the absence of associated georeferencing. Giving these students, the municipality and local territorial management, the way to control their geographical location; at the regional level as street furniture seems to Bernard a useful and possible work to do. From a pragmatic use of his experience in the field, the current availability of satellite images and facilities offered by modern geomatics tools, GIS and GPS mainly, he developed the method presented here. The principle is to first design a geographic database and then produce the desired georeferenced mapping. This manual makes available to everyone generic means of a rapid mapping applicable throughout the world and at all scales, from the region to that of urban furniture.

***Bernard Lortic**, engineer and geographer at the IRD, is known for his work in urban remote sensing and space analysis in researches on several cities of the South (Quito, Abidjan, Bogota, Mexico City, Lima, Addis Ababa...).*

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Keywords: mapping, georeferencing, GIS, GPS, geographical database.

DVD: MP4 video clips, demonstrations and exercises carried out with SavGIS software corresponding to the cards.

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