## TITLE

# CONTRIBUTION OF REMOTE SENSING IN THE EVALUATION OF FOREST DYNAMICS ALONG THE SLOPES OF MOUNT CAMEROON


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## ABSTRACT

The lower altitudes of the Mount Cameroon Region undergo radical changes in forest cover. These changes are linked to the creation of vast plantations of the Cameroon Development Corporation (CDC), the opening of new crop farms and other cash crops such as cocoa and the extension of settlements. Besides these, volcanic eruptions which have a frequency of at least 1 time for every 11 years also induce major changes mostly on the forest cover. These changes thus constitute a preoccupation of the Cameroonian Government to interrogate on the factors and the rate of these modifications.

The rate of deforestation is analysed in terms biodiversity destruction and the danger that lava flow poses during volcanic eruptions. This study of an evolution between 1986 and 2000, done through Remote Sensing which depended on satellite images is under the auspices of the National Advanced School of Engineering (ENSP) Yaoundé. The results realised throw more light on the quantitative change of surface phenomena mentioned above. The work demonstrates the extent of forest degradation which is in an irrational manner and which, given the demographic growth, risks becoming irreversible if conservative measure are not reinforced.

## KEY WORDS

Mount Cameroon, Remote Sensing, Forest cover, Lava flow, National Advanced School of Engineering, satellite images.

## RESUME

Les basses altitudes de la région du Mont Cameroun subissent des changements radicaux du couvert forestier. Ces changements sont liés à la création de vastes plantations de la CDC, à l'ouverture de nouveaux champs vivriers et d'autres cultures de rentes tels que le cacao et à l'extension de l'habitat. En dehors de celles-ci, les éruptions volcaniques qui ont une fréquence d'au moins une fois tous les 11 ans induisent aussi des changements majeurs quoi que limités sur la couverture forestière. Ces changements ont donc suscités des préoccupations du Gouvernement camerounais sur les facteurs et le rythme de ces modifications.

Le taux de déforestation s'analyse en termes de destruction de la biodiversité et du danger que pose les coulées de lave lors des éruptions volcaniques. Cette étude diachronique de 1986 et 2000 au moyen de la télédétection qui s'appuie sur les images de satellites est commanditée par l'Ecole Nationale Supérieure Polytechnique de Yaoundé. Cette justification tentera avec les données réalisées lors du déroulement de ces travaux, d'apporter un éclairage quantitatif à la situation susmentionné. Elle démontre l'amorce de la dégradation de forêt qui se fait de façon inéluctable et qui, grâce à l'accroissement démographique risque de devenir irréversible si des mesures conservatrices ne sont pas renforcées.

**MOTS CLES** :

Mont Cameroun, Télédétection, couvert forestier, coulée de lave, Ecole Nationale Supérieure Polytechnique

## MAIN TEXT

## 1. INTRODUCTION

Forests cover about 40% of the earth's surface. To this, the extent of tropical humid forest is about 60 million hectares. This forest stands out as the richest ecosystem of the planet (World Bank, 1989). It disposes 50 to 90% of animal and vegetal species of the earth's surface, with about 8000 species of plants which 80% are endemic. The hot and rainy climatic ambiance of the tropical regions, account for this great wealth of biodiversity.

Tropical humid forests stretch to about 60 countries of the world. They concentrate in Central and Southern America, Central and West Africa and in SE Asia. Among these, about 200 million hectares are concentrated in Central and West Africa. This renders the region the second in terms of surface area in humid tropical forest coming after the Amazon Basin. The humid tropical forest as it should be noted has a great socio economic and environmental importance at the regional, national and at local scales. It also plays a determinant role at the global scale. For almost 30 years now, about half of this forest has been lost due to irrational exploitation and demographic growth (WRI, 1994-95). Between 1981 and 1990, about 15 441 million hectares were destroyed (FAO, 1995; 1997). But most often, experts and researchers do not often agree on the methods and validity of statistical evaluation of the global rhythm of deforestation.

Cameroon, which is within the Central African Sub Region, (fig.1) has often relied on the global evaluation of deforestation carried out by international organisations. Thus following the FAO Report of 1995, her annual average deforestation stood at 0.6%. It is only of late that detailed studies of evaluating deforestation became adopted by the government. Cameroon government which works in collaboration with the FAO and Global Forest Watch (GFW) has adopted Remote Sensing as a technical means of evaluating forest change. This is illustrated by various measures taken at the national level to follow up forest evolution. In this light different studies have been carried out in different sections of the country to evaluate forest change. This study which points to this light focuses on the Mount Cameroon region.

**Fig.1: Location of the Mount Cameroon region.**

The Mount Cameroon region stands out of great interest for such a diachronic study for the following reasons:

- The massive projection of the relief provides the region with a unique climatic as well as biodiversity differentiation with altitude within the West and Central African Sub Region.
- The active volcanic nature of the mountain provides the surroundings with volcanic fertile soils that act as a pull factor to immigrant population and the creation of vast agro-industrial plantations.
- Agriculture practised by the resident population is largely detrimental to the rich humid forest though natural causes such as lava destruction resulting from eruptions (once every 11 years) cannot also be ignored.

The geography of this region makes it unique to the extent that evaluating the dynamism of forest cover is of prime importance as the loss of this forest will also imply a great loss in biodiversity and other natural resources.

This study falls within the context of donors' efforts such as the European Union, World Wide Fund for Nature (WWF), African Development Bank (ADB), and the French Cooperation to evaluate forest cover over time within the Central African Sub region. This study which is one of the first with the use of remote sensing focuses on fragile ecosystems such as the Mount Cameroon Region. It should be noted that azonal ecosystems (for example mountain regions) host about 1/10 of the world's population and the Mount Cameroon region in particular hosts more than 300 000 inhabitants. Further more, mountains within the tropical forest zone constitute rich biodiversities comparable to non in the world. Remote Sensing has already proven in other domains such as surface energy balance, evapotranspiration etc. It is a technique that enables us to obtain information about the earth's surface without direct or material contact with that surface. Remote Sensing consists of capturing and registering energy of electromagnetic waves emitted or reflected by the earth surface. It then treats and analyses the information registered before their application and use (Klein, 2002; Tommpo and Czaplewski, 2002).

Given that quantitative and qualitative changes of a surface can be evaluated through Remote Sensing, this study used Landsat images for two periods, 1986 and 2000 and radar image for 1999. After determining the coordinates of the region to be treated, the method of polynomial approximation of the first order was used and the region was extracted from Landsat scenes p187r57_861212 of 1986 and p187r057_20001210 of 2000. These images coupled with the radar image were treated using the following computer softwares – ENVI, ArcView, MapInfo and VOIR to come out with statistics of the evolution of surface phenomena between 1986 and 2000. This ended up with the realisation of spatio-maps for the Mount Cameroon region.

## 2. METHODS

In order to arrive at acceptable results, two major aspects constituted the methodology. The first was the acquisition of data to be treated in a laboratory and the second was going to the field to validate certain phenomena not well perceived on the images. The data treated was provided by the National advance School of Engineering (NASE) Yaounde- the structure that coordinated this research work. The data include amongst others: Landsat 7 ETM+ image of 2000, Landsat 5 TM image of 1986 (fig.2),

**Fig. 2**: **Extracted Landsat TM Images for 1986 and 2000 from scenes**

vegetation map of the south West Province of Cameroon produced through manual digitalisation from aerial photographs in 1977 and ERS1 radar image of 1999 (Tables 1 and 2).

**Table 1: The data used.**

**Table 2: The softwares used**

Preference to the Landsat images is that they are in base canals (RGB) and a good colour composition from the 7 bands can render all surface phenomena visible. In this case 753 and 543 band combinations were chosen which presented as seen on Fig.3. Each colour gives the first impression of reflection of the corresponding wave length. Most often, red corresponds to objects that are sensible to electromagnetic rays. The electromagnetic spectrum shows portions of wave lengths of different zones. These Landsat images are of the compressed BSQ format with a negligible rate of cloud cover since both were taken during the dry season. But radar image had to be used in order to validate the phenomena obscured by clouds on the Landsat images (Fig.4). The authority that provides these images to the public already geo-reference them in order to facilitate their interpretation.

**Fig. 3**: **Radar ERS1 Image**

Table 3 shows the characteristics of the images used.

**Table 3**: **Characteristics of the images used.**

The polynomial approximation of the first order method was used in treating the Landsat images in the Laboratory of Electronics and the Treatment of Signals (LETS) of the National Advanced School of Engineering (NASE) Yaounde. By ignoring the edges of the image, pixels of 0 radiometric values were eliminated. Then we proceeded to the physical recognition of 4 points (A, B, C and D) on the 1986 image and (A1, B1, C1 and D1) on the 2000 image, given that the two images of this work were of the same spatial resolution (28.5m). Then the images were cut in the same dimensions (2922*2330) to extract the Mount Cameroon region and render them superimposable. These extracted images were then pre-treated as follows using the ENVI software: interactive stretching from 0 to 255 points in all the 3 bands (RGB) (Fig.7). We then proceeded with unsupervised classification and through this certain results were obtained which could not be validated. Our field work then constituted of taking photographs of objects not well perceived on the images in order to validate them for a supervised classification. These are shown on figures 4, 5 and 6. The treatment that followed the field work led to the validation of the results.

**Fig.4, 5 and 6: Validation of the objects in the field**

Following the validation of the objects in the field, the treatment of the images began by Photo Interpretation Assisted by Computer (PIAC). This exercise was done with the use of MapInfo software. Image iteration was done as seen on table 4. The results obtained here were later compared to those obtained after treating the images with the ENVI software.

**Table 4: Image iteration**

**Fig.7**: **Interactive stretching**

The “High Pass” filter was applied in order to render all the different plantation layers clearer as well as enhancing the savannah zones.

Other filters were also applied especially to differentiate similar phenomena on the surface such as settled areas and lava surfaces, young plantations and tea plantations or savannahs with tea plantations, dense forest and matured rubber plantations etc. Still with the ENVI software, sampling of different objects was realised with the ROI Tool and various colours were attributed to each sample. (Table 4).

**Table 5**: **Sampling of objects**

This operation proceeded to a classified classification-maximum likelihood (Fig.8) and then followed by post classification to give the following results (Fig.9). This did not still let to the validation of the results as different options in the ENVI software might lead to differing results. To that effect the images were segmented so as to obtain different colours with each colour representing a different object on the surface (Fig. 10). From this another supervised classification and post classification was done. The results obtained were then compared to those of the first two operations and the different results obtained were analysed.

**Fig.8**: **Supervised Classification maximum Likelihood**

**Fig.9 a) and b)**: **Statistics for the different classes of objects**

**Fig.10**: **Segmented 1986 and 2000 images**

The objective here was to define in multi spectral space new criteria that summarised the information contained in the image so as to compare the results with those obtained at the first operation. The classified images were then transformed to vector layers with the ArcView software for cartographic restitution. (Fig.15 and 16). Table 6 presents the procedure used in order to come out with the expected results.

**Table 6: Procedure of the methodology**

## 3. FOREST AND OTHER PHENOMENA DYNAMICS IN THE MOUNT CAMEROON REGION

### 3.1: Mount Cameroon Region within its Geographical context

According to this study, this region covers a surface area of 5695.5 km². Sections of the region are covered by forest which is subjected to change over time. The region stretches from latitudes 3°57' to 4°28' N and from longitudes 8°58'to 9°24'E of the Prime Meridian (Fometé and Tchouto,1998). Along the slopes of the mountain we find three forest reserves-prove of the necessity to conserve the forest of this region. They include;

- The Bambuko Forest Reserve (267 km²) on the NW flank. It was created in 1939 by the colonial administration;
- The Mokoko River Forest Reserve (91 km²) situated to the west of the Bambuko Forest Reserve. It was created in 1952;
- The South Bakundu Forest Reserve (19 km²) situated at the eastern flank of the mountain. Besides these reserves, there are many sites of national interest but which are ecologically fragile and need to be classified for rational management. Thus the

region is rich in biodiversity and it hosts more than 250 species of trees of multi uses, (Vivien and Faure, 1985), 49 are endemic while 52 are restricted to the Central African region (Fomete and Tchouto, 1998).

### 3.1.1 FLORA AND FAUNA

- FLORA

There is no doubt about the wealth in biodiversity of this region. With more than 250 species of trees of multi uses, (Vivien and Faure, 1985), 49 are endemic, 52 restricted to the Central African region (Fomete and Tchouto, 1998). The main vegetation types are;

- low altitude biafran forest (0 – 800 m)
- ever green forest of sterculiacae (800 – 900 m)
- sub mountainous forest (800 – 1800 m)
- mountainous forest (1600 – 2600 m)
- grass savannah of *impérata cylindrica* (2200 – 2800 m)
- steppe (2800 – 3000 m)
- sub-Alpine prairie (2800 – 4095 m). To these we can add bare surfaces of lava.

- FAUNA

Among the principal endemic mammals, two are threatened from extinction-the red guenon (C*ercopitecus erythrotis*) and the drill (*mandrillus leucophalus*).Their disappearance results from natural perturbations. There are about 12 species of mammals in the mount Cameroon region. The elephant is found along the slopes especially in the Bambuko Forest Reserve. Here we count about 20 species of birds that are endemic.

Given the floristic and faunistic wealth of the region, forest degradation leads to great loss in biodiversity.

### 3.1.2 GEOLOGICAL FORMATIONS AND SOILS

The formation of Mount Cameroon can be traced back to the superior Pleistocene or inferior Holocene eras (Fomete and Tchouto, 1998). This mountain is formed from a mosaic of lavas at different ages. The western flanks area formed from andosols that developed from quaternary basalt and which appear in the form of fluid lava or pyroclastic products. Above 2000m, the slopes comprise of ash and more or less ancient basaltic lavas. The region is exposed to natural hazards especially earth trembling, landslides and volcanic eruptions. Between 1815 and 1982, about 12 eruptions have occurred in the region (Zogning, 1994), and between 1999 and 2000, two other supplementary eruptions took place. The volcanic soils here are fertile, young with low capacity to retain water. This immense relief structure is influenced by a particular climate.

### 3.1.3: CLIMATE

The humid tropical climate generally reigns in the Mount Cameroon region. This climate is characterised by abundant rainfall that stretches through out the year. Precipitations are higher in June and October (4000mm/year) and lower between November and March (<2000mm/year). Debunscha is the highest rainy station along the Atlantic coast at the foot of Mount Cameroon. With 13 000mm per year, it is the 3rd highest rainy station in the world (Ayukegba, 2001). At the foot of the mountain and along the coast, annual rainfall varies from 3000 to 4000mm on the lower slopes of the windward side and on the leeward side it varies from 550 to 2000mm. Temperature at sea level varies between 27°C and 32°C in relation to season and decrease by 0.6°C for every 100m of accent. In order to better illustrate the data of the two stations (Debunscha along the west coast and Mabeta to the east of Limbe) were considered and which presented the following situation

**(Fig.11) Precipitations in Mount Cameroon region according to data from the Debunscha and Mabeta stations**

### 3.1.4: RELIEF AND HYDROGRAPHY

The Mount Cameroon region rises from sea level up to 4095m of altitude at the summit. This mountain is one of the active volcanoes in Africa and it is the highest in Central and West Africa. It comprises of many secondary cones among which are mount Etinde (1715m). The slopes are steep and abrupt.

There are limited number of rivers on the main massif but many springs and lakes at low altitude around Mabeta, Moliwe, Idenau, Bakingili, Mokoko, Onge and Bomana. The main rivers include Lokinge, Mokoko and Onge.

### 3.1.5: POPULATION AND SPACE UTILISATION

With a population density of about 120inhbts/km², the mount Cameroon region possesses a density that is higher than that of the national average of Cameroon (34inhbts/km²). This population is dominated by the youths who come from other parts of Cameroon, mostly the North West Province, West and neighbouring countries such as Nigeria. These immigrants either come to look for employment in the vast plantations of the CDC or to create new farms on the fertile soils. Further more commercial and industrial activities (petrol refinery in Limbe) and fishing attracts youths and workers. The creation of a naval base and cement factory in Limbe will certainly increase immigrants in the region.

The region is entire located in the South West Province of Cameroon. Administratively, it stretches to two Divisions;

- Fako Division which hosts about 75% of region’s population and more 90% of deforestation occurs here.
- Meme Division, where more than 70% of its surface area constitutes of forest reserves such as the Bambuko and the Mokoko River, thus with very low deforestation rate.

Our field work confirmed the different vegetation types which are in relation to the slope gradient as earlier recognised by Zogning (1989).

- From 0 to 1000 m low altitude biafran forest on a low gradient (0-15°). This forest is greatly disturbed by human activities (settlements, large plantations of the CDC, farms)
- From 1000 to 2000 m ; gradient accentuates (30°), farms become punctual and tropical mountain forest dominates.
- From 2000 to 3000 m escarpment (50° gradient) savannah dominates.
- From 3000m to the summit, the gradient reduces to 10 and 25°, there is prairie vegetation and steppe disappears with altitude to give way to lichens and mosses beyond 3800m.

Added to these,

Among the principal endemic mammals, two are threatened from extinction - the red guenon (C*ercopitecus erythrotis*) and the drill (*mandrillus leucophalus*). Generally there are 12 species of mammals notably the elephant and 20 species of birds which are endemic. The formation of this mountain which can be traced back to the superior Pleistocene or inferior hollocene eras (Fomete and Tchouto, 1998) is from a mosaic of lavas at different ages. The western flanks consist of andosols that developed from quaternary basalt and which appear in the form of fluid lava or pyroclastic products. The region is exposed to natural hazards especially earth trembling, landslides and volcanic eruptions. Between 1815 and 1982, about 12 eruptions have occurred in the region (Zogning, 1994), and between 1999 and 2000, two other supplementary eruptions took place. The volcanic soils here are fertile, young with low capacity to retain water.

With a humid tropical climate, rainfall is abundant (3000mm/year) though this differs between the windward and the leeward sides of the mountain. The windward side, where we also find a cone (Mount Etinde, 1715 m) attracts immigrants thus rendering the region with a high population density well above the national average (34 inhbts/km²).

### 3.2: STATISTICAL EVOLUTION OF PHENOMENA BETWEEN 1986 AND 2000

In 1986, dense forest covered a surface area of 1988.5 km². More than 50% of this surface area was found on the NW flank of the mountain. In this region, population density was so low and it is here that we find two of the three forest reserves. The savannah on its part mostly concentrated at more than 2000 m of altitude. (Fig.12)

**Figure 12: Savannah at more than 2000m of altitude**

At that height, entropic activities limit to hunting. Savannah in general covered a surface area of 777.56 km².

Lava which mostly concentrated on the summit of the mountain covered a surface area of 187 km². Away from the summit one could not easily identify lava surfaces as they have covered by vegetation. This is the case of the lava that resulted from the 1922 eruption in the SW flank of the mountain.

Farms which generally did not extend to more than 3 km from settled areas towards the mountain, occupied a surface area of 680km². (Fig. 13).

**Figure 13: Farms at more than 1000m on the mountain**

The CDC plantations occupied the lowest altitudes besides the mangroves. They then occupied a surface area of 493.2 km².

The situation in 2000 saw some phenomena increase while others reduced. Since this study laid more emphasis on forest, dense forest by the year 2000 had degraded by 269.7 km² that is, passing from 1988.5 km² in 1986 to 1718.8 km² in 2000. After the 1999 and 2000 eruptions, the Limbe-Idenau road was blocked as well as 92.2 km² of forest was destroyed by lava (Fig.14)

**Fig.14 Lava flow at Bakingili which blocked a road**

The spatio-maps from which these results were obtained are as seen on figures 15 and 16.

**Figures 15 and 16: Spatio-maps for the Mount Cameroon region 1986 and 2000**

**Tableau 7: Rate of change of phenomena**

**Figure 17: Histogram for the evolution of surface occupation**

## 4. DEFORESTATION AND ITS IMPACT ON THE MOUNT CAMEROON REGION

By deforestation we refer to the physical destruction of the forest cover either by natural factors or human factors. The reductions of forest cover in this region by 269.7 km² between 1986 and 2000 points to the gravity of the problem. This mostly affects the South, SW and SE flanks of the mountain. This part of the mountain which administratively is within Fako Division, is a save haven of the larger part of the population in the area. This population which to the most part constitutes immigrants- attracted by the fertile volcanic soils largely practice subsistence and commercial or plantation agriculture. Therefore the high rate of deforestation results from the great increase plantation surfaces within the determined period (1986 and 2000). Apart from the CDC plantations, new banana corporations came to the area (DELMONTE) in 1987 and took up large expands of land. This led to an increase of plantation surfaces by 294 km², thus with an annual increase of 21 km² per year. The farmlands that hitherto occupied certain areas were taken up for plantations and the continuous influx of immigrants also saw the opening of new farms in the forest (Table 8)

**Table 8**: **Evolution of surface occupation**

It is difficult to control the forest destruction that result from natural causes especially lava flow during an eruption. This situation which is further compounded by entropic activities renders forest destruction by lava more devastating. For example during the 1999 and 2000 eruptions, lava flow had to get to the village of Bakingili and cut through the Limbe-Idenau main road. Certainly had it been dense forest occupied all this area, such a situation couldn't have occurred. Such extension of lava is also a threat to some fauna species especially the red guenon already threatened from extinction. Others feeling threatened migrate to other regions.

## 5. DISCUSSION

With the advent of the computer, the manipulation and management of certain aspects of life have been facilitated. This has been mostly through the development of computer softwares that are assigned to particular aspects. To that effect Remote Sensing (RS) and Geographical

Information Systems (GIS) have received much attention. The computer softwares so far developed for RS include ENVI, ERDAS, ARCGIS, ILWIS, etc and for GIS – MapInfo, ArcView, Power AMC etc. Using Remote Sensing therefore to evaluate surface dynamism is recommendable and results got are often considered to be the most acceptable compared to any other technique (Bauer et al, 2003). Given the structured nature of plantations, one can easily differentiate them from non plantation surfaces on satellite images even at higher resolutions. Pre-treating the images and going to the field add to the authenticity of the expected results as colour composition is not enough to render the clarity of surface phenomena.

From the results obtained, one cannot conclude that the Mount Cameroon region witnesses the fastest forest degradation in the Central African Sub Region. The imposing nature of the outstanding relief equally acts as a barrier to forest destruction. The sections of rapid degradation in the region (South, South West, South East) are to a larger extent flat surfaces. The high fertility of the volcanic soils here actually attracts the creation of vast agro-industrial plantations whose crops are mostly destined for exports. It should therefore be noted that this region highly contributes to the Cameroon economy in terms of export crops. Thus thousands of immigrants have settled in the region to fortify the plantations with the necessary man power.

On the opposite flanks of the mountain i.e. in the North, North West, North East, much of the virgin forest still exist and they have been designed into forest reserves, some sections worshipped as sacred forests. Such sections are believed to host important shrines of the Bakundu and Bakweri tribes. Hunters and other trespassers must duly be authorised by the traditional authorities. Such reverence coupled with the low population density in this part of the mountain help maintain the forest integrity which certainly can sustain in the next 50 years and even beyond.

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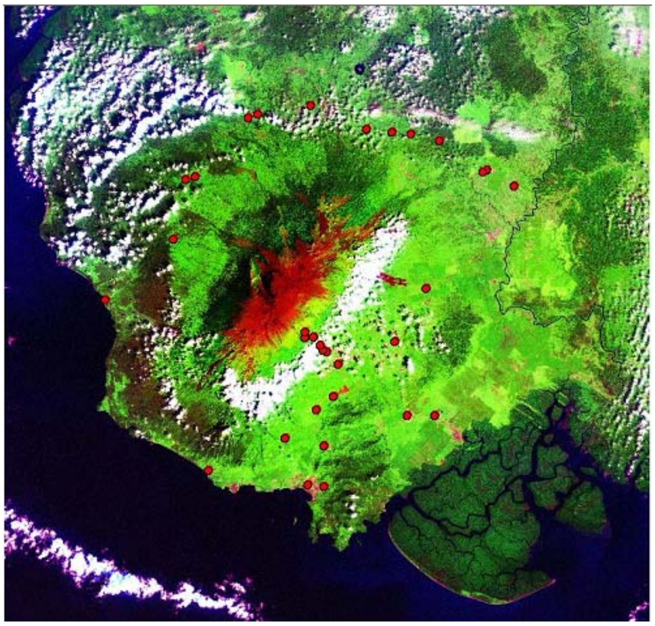
## APPENCICE

**1: Landsat Image with integrated GPS points**



**2: Downloaded GPS Points**

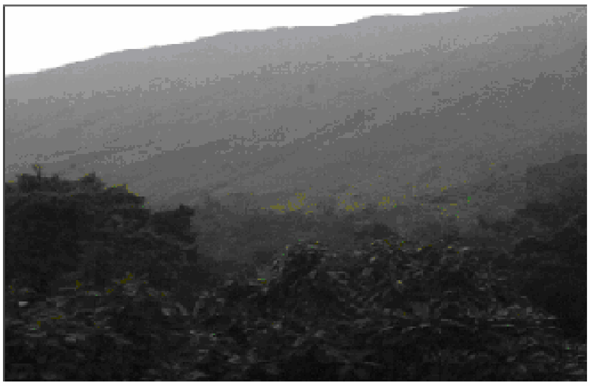
| Shape | Recnum | Name | Altitude | Longname | X_coord | Y_coord |
|---|---|---|---|---|---|---|
| Point | 1 | BATOKE | 0 | 23-SEP-06 08:05 | 510978.12389 | 445500.18499 |
| Point | 2 | BOJOGO | 0 | 23-SEP-06 11:36 | 520218.20038 | 449418.88524 |
| Point | 3 | BOKO14 | 0 | 22-SEP-06 14:55 | 515816.17760 | 488082.20538 |
| Point | 4 | BOM15 | 0 | 22-SEP-06 15:52 | 509344.53560 | 481014.26473 |
| Point | 5 | BOMANA | 0 | 22-SEP-06 16:38 | 506761.90060 | 473468.55647 |
| Point | 6 | BOVA12 | 0 | 22-SEP-06 13:58 | 523408.29913 | 489630.47152 |
| Point | 7 | EKO3 | 0 | 22-SEP-06 09:17 | 537290.71612 | 467482.69084 |
| Point | 8 | HUT1 | 0 | 24-SEP-06 08:31 | 522658.16317 | 461575.82157 |
| Point | 9 | HUT2 | 0 | 24-SEP-06 09:22 | 522700.25042 | 462279.08875 |
| Point | 10 | IBIE13 | 0 | 22-SEP-06 14:42 | 516945.70482 | 488571.03414 |
| Point | 11 | IDENAU | 0 | 23-SEP-06 06:51 | 498479.78985 | 466107.86299 |
| Point | 12 | KADEF6 | 0 | 22-SEP-06 10:41 | 544656.27490 | 481779.91338 |
| Point | 13 | KAFAC7 | 0 | 22-SEP-06 10:49 | 544244.47639 | 481595.87131 |
| Point | 14 | KOTO17 | 0 | 22-SEP-06 16:03 | 508276.15714 | 480658.37390 |
| Point | 15 | LIKO9 | 0 | 22-SEP-06 12:21 | 535526.08368 | 486136.85679 |
| Point | 16 | LIMBE | 0 | 23-SEP-06 08:29 | 523049.14530 | 443816.66203 |
| Point | 17 | LIMBE1 | 0 | 23-SEP-06 08:28 | 523049.74062 | 443817.25515 |
| Point | 18 | LIMBE2 | 0 | 23-SEP-06 09:31 | 524987.47167 | 443607.26563 |
| Point | 19 | MALEN5 | 0 | 22-SEP-06 10:20 | 547966.83826 | 479850.40839 |
| Point | 20 | MILE4 | 0 | 23-SEP-06 11:02 | 524934.32866 | 448451.76238 |
| Point | 21 | MUEA2 | 0 | 22-SEP-06 08:52 | 533565.86606 | 461149.43042 |
| Point | 22 | MUT1 | 0 | 22-SEP-06 08:19 | 535056.65502 | 452154.07768 |
| Point | 23 | MUVE11 | 0 | 22-SEP-06 12:54 | 530141.18729 | 486785.80623 |
| Point | 24 | SASSE | 0 | 23-SEP-06 12:11 | 526110.35446 | 454480.17453 |
| Point | 25 | SAXPHO | 0 | 23-SEP-06 11:58 | 524032.25036 | 452812.76491 |
| Point | 26 | SOPO | 0 | 23-SEP-06 12:32 | 526668.26269 | 458376.12383 |
| Point | 27 | TIKO | 0 | 24-SEP-06 14:55 | 538379.68891 | 452228.97470 |
| Point | 28 | UPFAM | 0 | 23-SEP-06 14:55 | 525308.00204 | 459823.74317 |
| Point | 29 | UPFAM2 | 0 | 23-SEP-06 15:08 | 524859.02307 | 460076.21790 |
| Point | 30 | UPLIKO | 0 | 22-SEP-06 12:36 | 533240.46930 | 486365.98212 |
| Point | 31 | UPMT | 0 | 23-SEP-06 15:37 | 524539.15651 | 460629.36428 |
| Point | 32 | UPMT2 | 0 | 24-SEP-06 06:40 | 523685.70761 | 461718.40586 |
| Point | 33 | VOKUP8 | 0 | 22-SEP-06 11:36 | 538985.07741 | 485399.56381 |

**3: Photographs of the Mount Cameroon region**

Plantains cultivated along the slopes of Mount Cameroon

Hut 1:st resting point during Mount Cameroon races

Former PM's Lodge on the slopes of Mount Cameroon



Limit between forest and savannah on Mt Cameroon(2355m)

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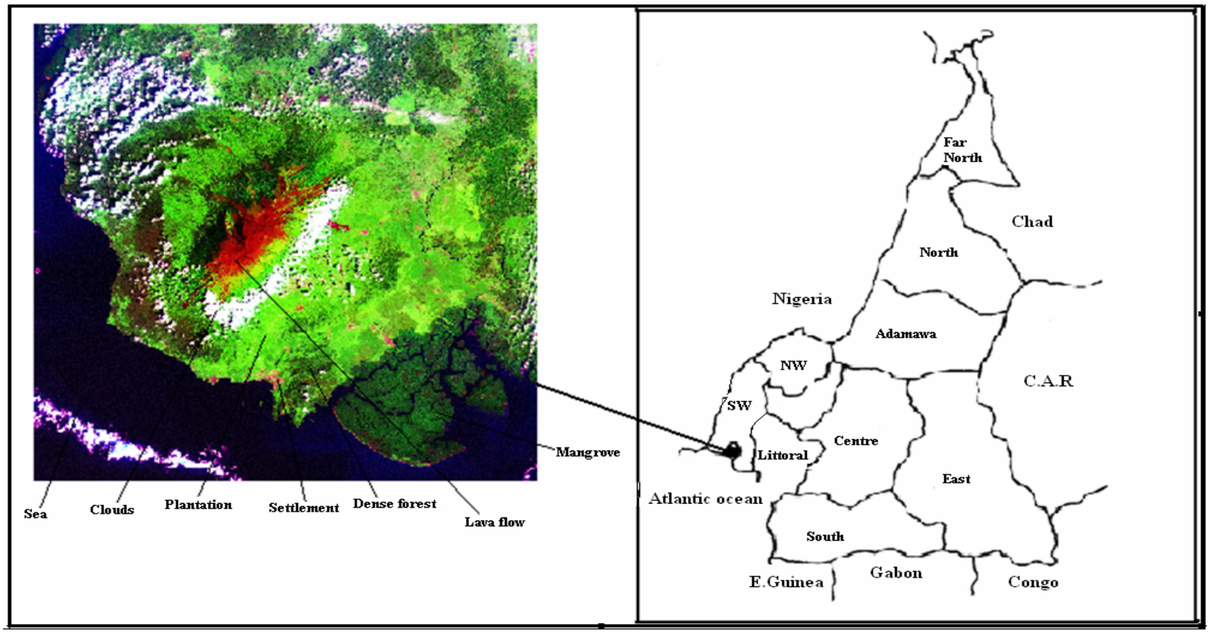



**Fig.2:** Landsat extracted Images of 1986 and 2000

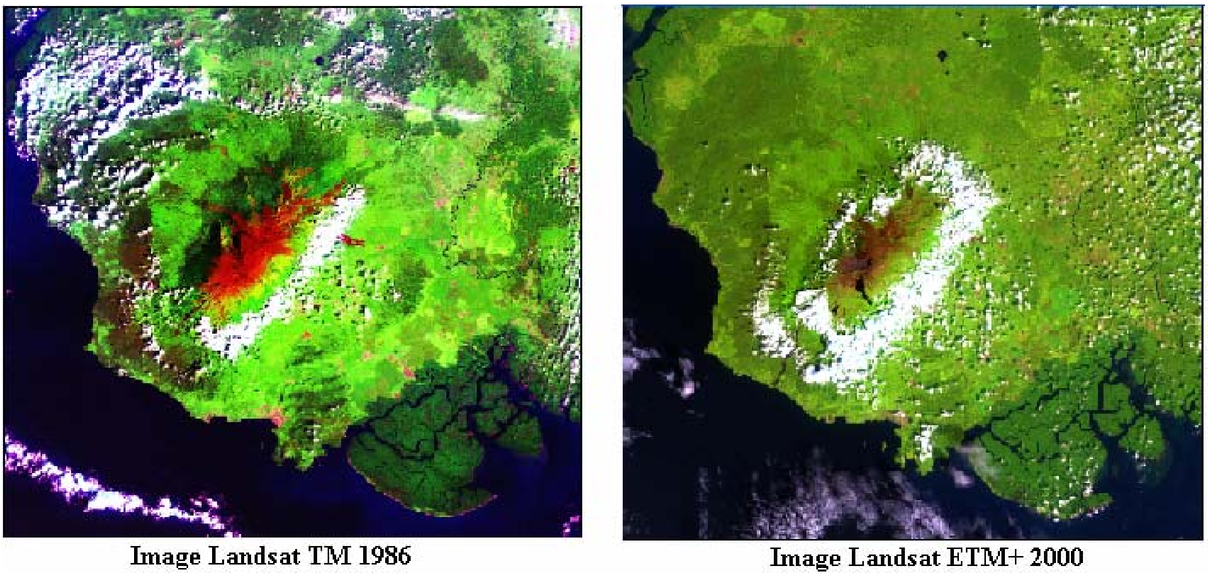



**Fig. 3**: ERS1 Radar Image

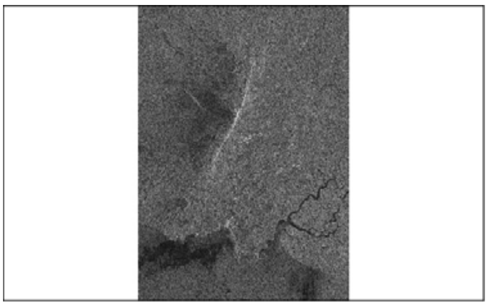
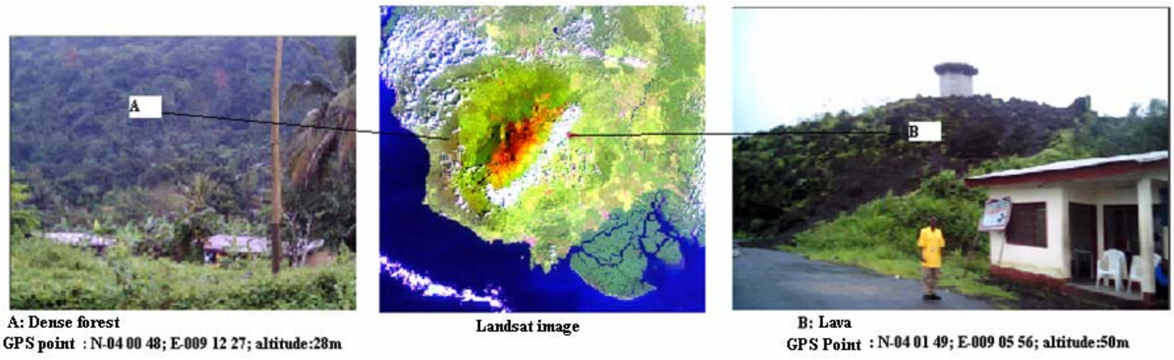
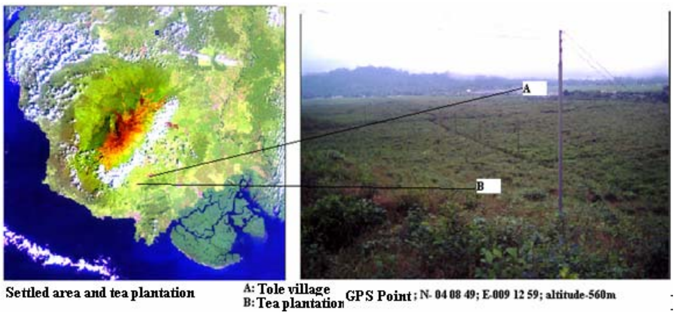


**Fig.4**: Validation of objects a), b) and c)

a)




b)




c)

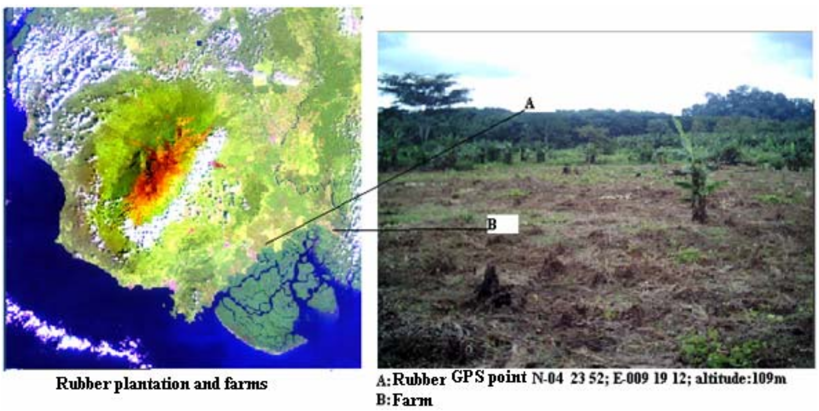



**Fig 5**: Integration of farms in the CDC plantations at Idenau.
(GPS Point **N** : 04 13 01 ; **E** : 008 59 10 ; **altitude** 12 m) (Photo Kah Elvis)


**Fig.6:** The different types of plantations

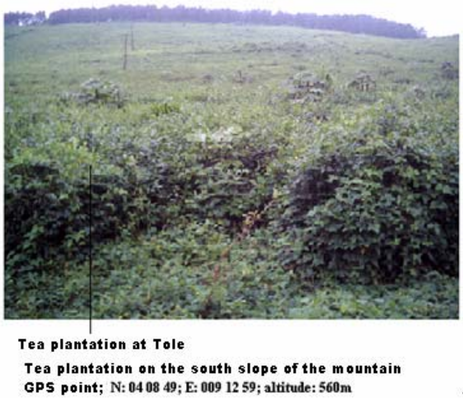




**Fig.7**: Interactive stretching

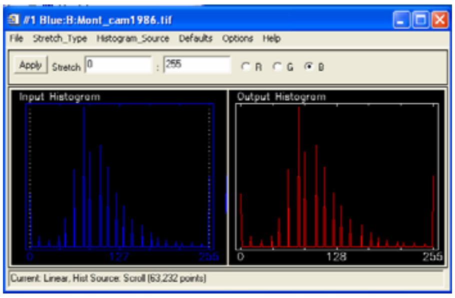



**Fig.8**: Supervised Classification maximum Likelihood

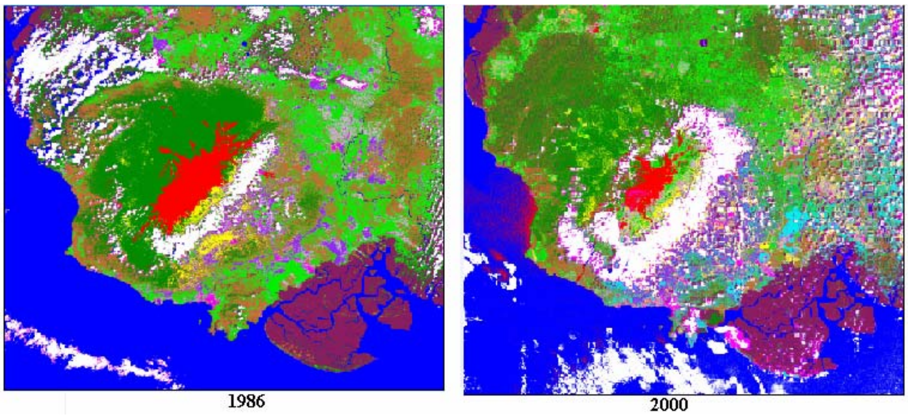
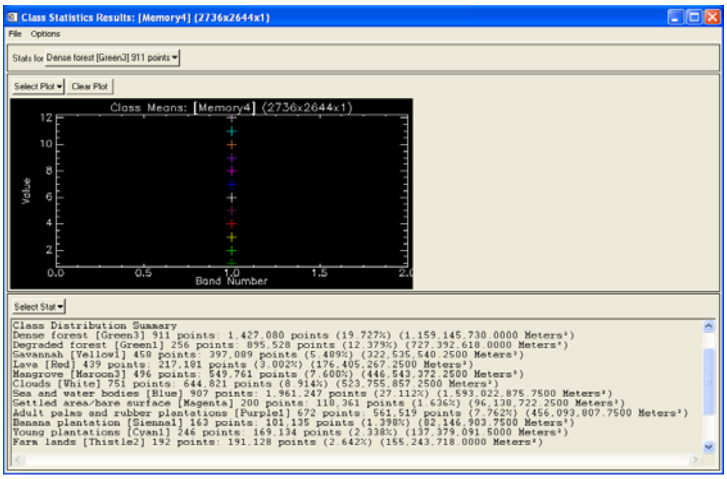
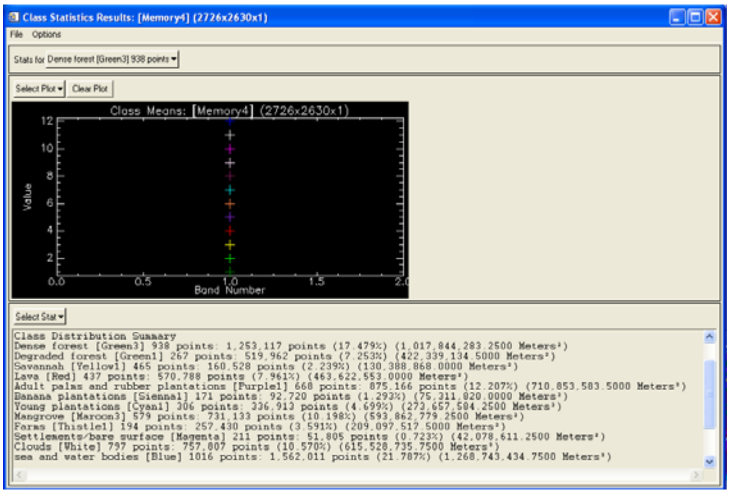



**Fig.9**: Statistics of the different classes of objects



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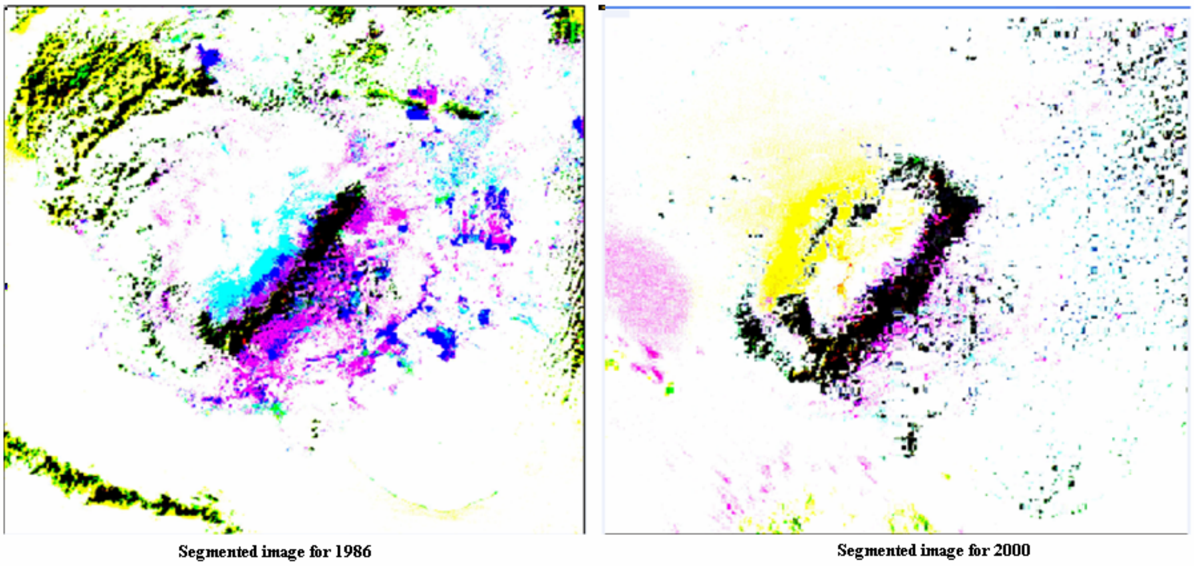



**Fig.11**: Precipitations in the Mount Cameroon region from Débunscha and Mabeta stations

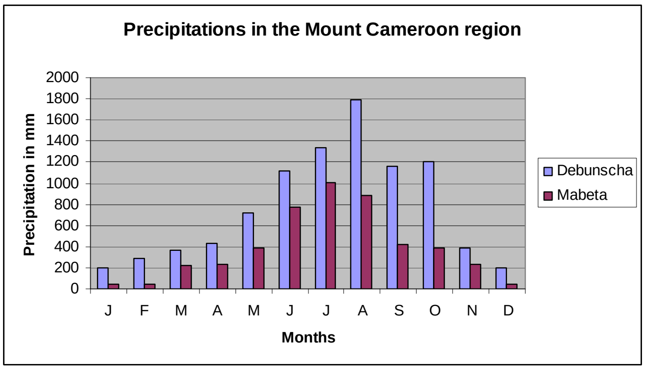



**Fig 12**: Savannah at more than 2000 m on Mount Cameroon

GPS Point **N** : 04 10 56 ; **E** : 009 12 16 ; **altitude** : 2355 m (Photo Kah Elvis)


**Fig 13**: Farms at more than 1000 m on Mount Cameroon.
GPS Point **N** : 04 10 22 ; **E** : 009 13 15 ; **altitude** 1329 m (Photo Kah Elvis)

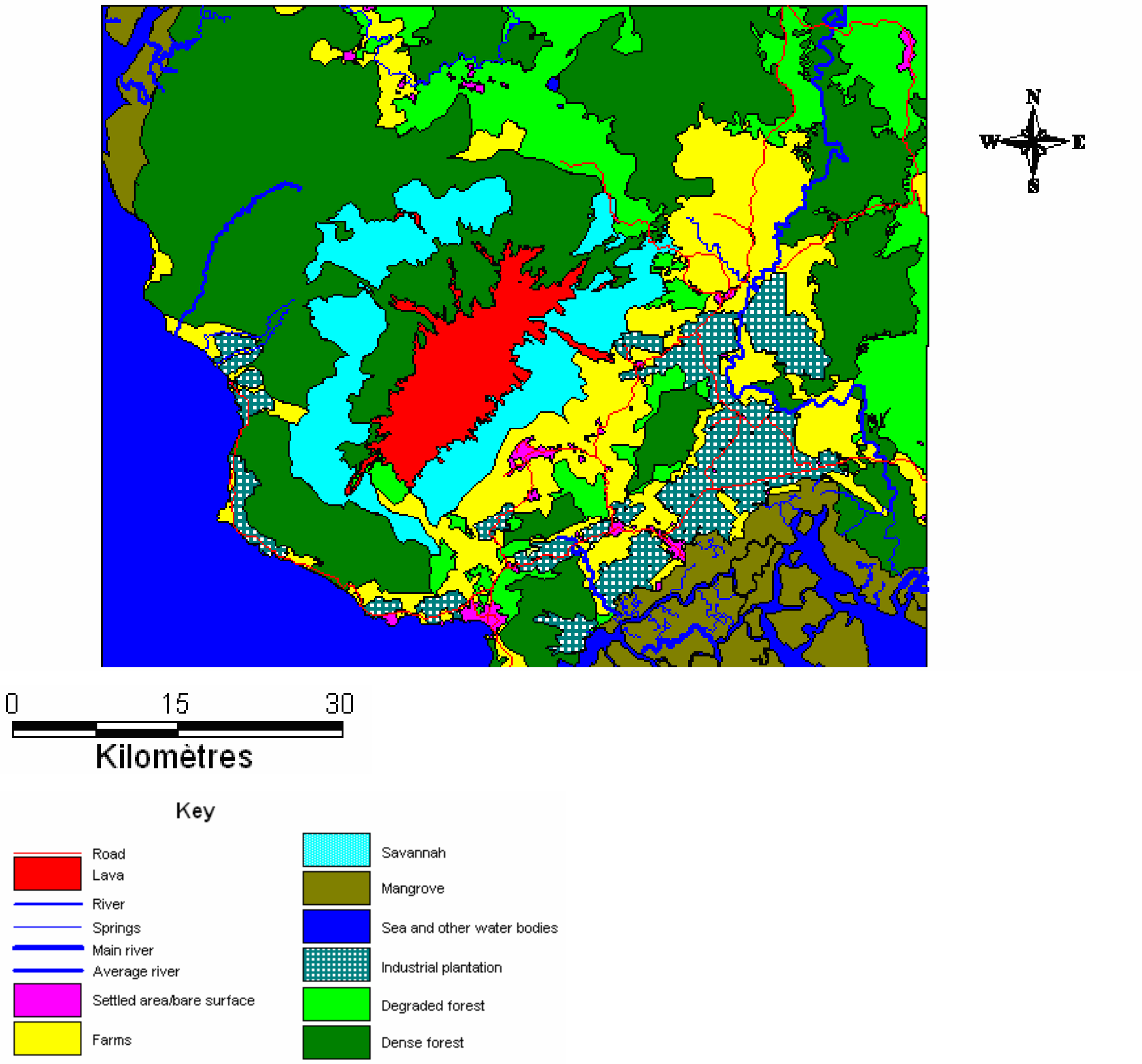

**Fig.14 Lava flow at Bakingili which blocked a road**

GPS Point **N**: 04 01 49; **E**: 009 05 56 (**altitude** 50 m) Photo Kah Elvis 2006


**Fig.15**: Surface occupation maps for 1986

15a) after manual digitalisation

**Fig.15a): Surface Occupation for the Mount Cameroon Region 1986**




15 b) after cartographic restitution on ENVI

Fig.15b): Surface occupation of the Mount Cameroon Region 1986

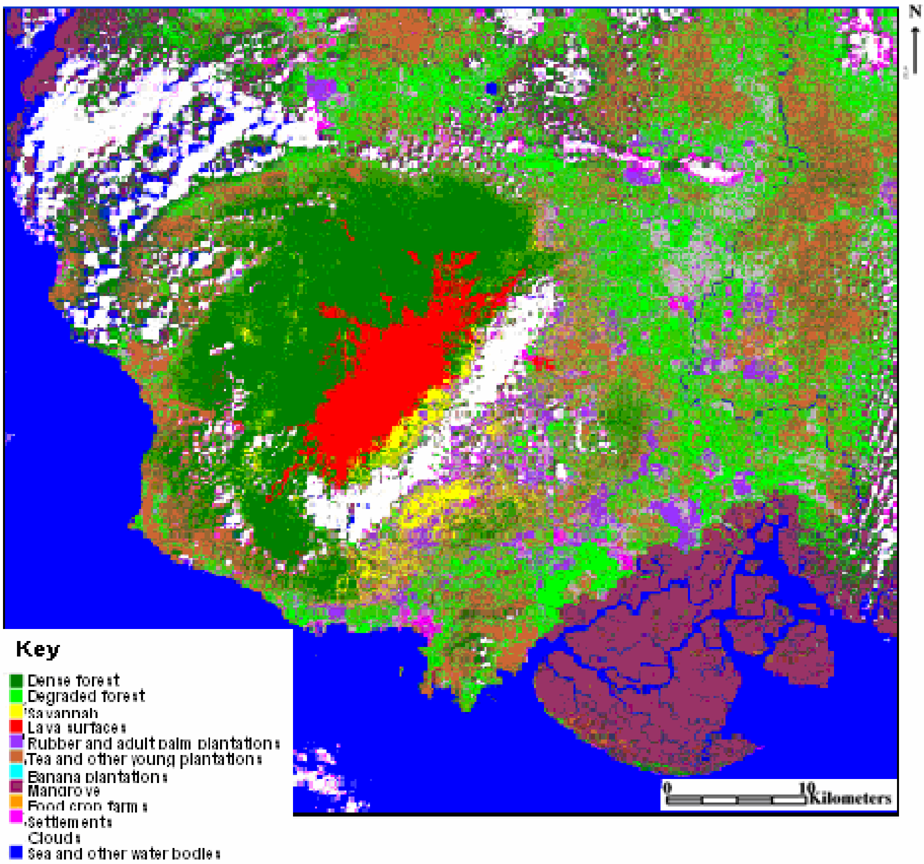
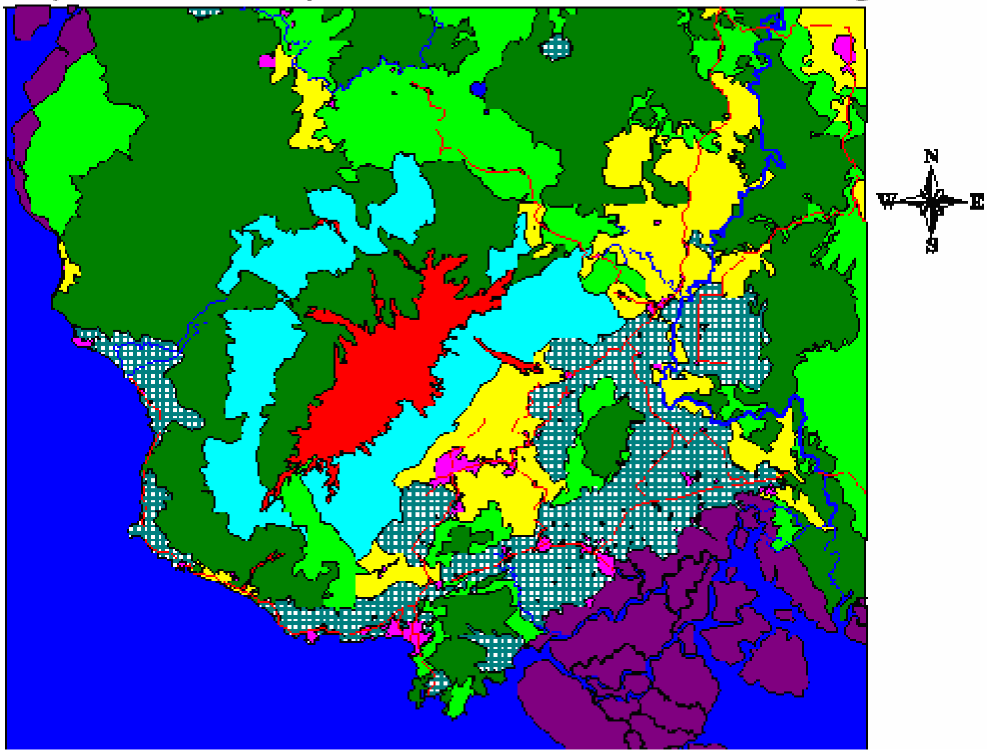
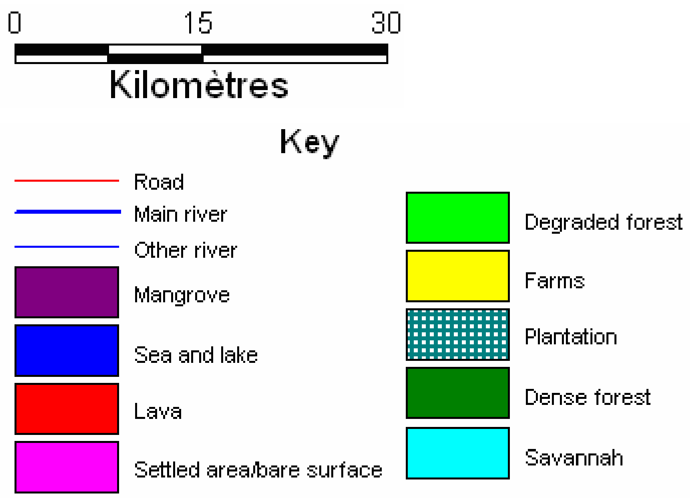



**Fig.16**: Surface occupation maps for 2000

Fig.16a): Surface occupation of the Mount cameroon Region 2000






16b) after cartographic restitution on ENVI

**Fig.16b): Surface occupation of the Mount Cameroon Region 2000**

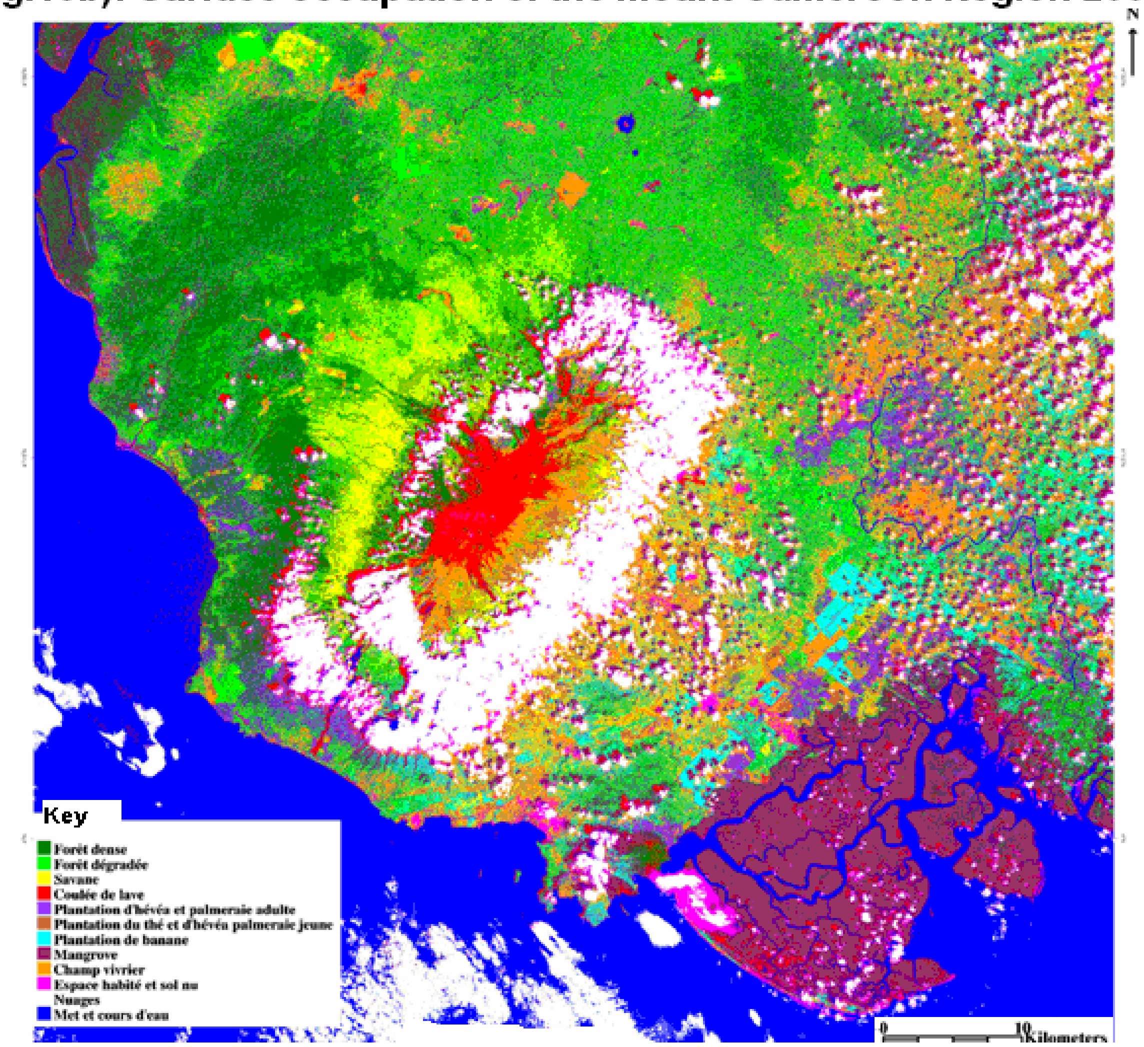



**Fig.17**: Histogram for the evolution of surface occupation

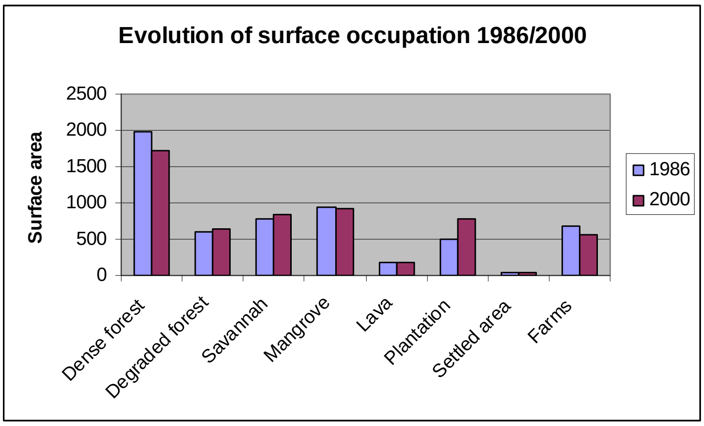



**Table 1:** The data used

| Data and Materials | Source | Use |
|---|---|---|
| Image Landsat ETM+ 2000 | LETS | Forest cover for 2000 |
| Landsat TM Image 1986 | LETS | Forest cover for 1986 |
| Radar ERS1 Image of 1999 | LETS | Validation of the zones covered by clouds |
| Vegetation map of the South West | NIC of Yaoundé | Forest cover for 1977 |
| Base map for South West | NIC of Yaoundé | To have a sense of direction |
| GPS | LETS | Taking of GPS points |
| Digital camera | EU | Taking of photographs |
| Computer with appropriate softwares | LETS | Treatment of images and cartographic restitution |

**Table 2**: The soft wares used

| Softwares | Use |
|---|---|
| Envi 4.1 | Treatment of images |
| MapInfo 7.5 | Realisation of PIAC and et cartographic restitution |
| Arcview | Cartographic restitution of the images treated |
| VOIR | Classification of the Radar image |
| Office softwares<br>Microsoft Word, Excel, Paint | For typing the final document, calculating data and modelling photographs and images to be integrated in the final document |

**Table 3**: Characteristics of the images used

| Criteria | 1986 Image | 2000 Image |
|---|---|---|
| Scene | P187R57_5T861212 | P187R057_7t20001210 |

| | | |
|---|---|---|
| Generation/Sensor | Landsat 5 TM | Landsat 7 ETM+ |
| Altitude of the orbit | 705 km | 705 km |
| Repetition | 16 days | 16 days |
| Band | 7 compressed bands | 3 bands registered under IMG format (Erdas 8.5) |
| Coverage | 185 km | 185 km |
| Spatial resolution | 28,5 M | 28,5M |
| Base format | Geotiff/BSQ | Geotiff/BSQ |
| Rate of cloud cover | Very low | low |
| Acquisition Date | 12/12/1986 | 12/10/2000 |
| Projection | UTM 32 N | UTM 32 N |
| Datum | WGS84 | WGS84 |
| Units of measurement | Metres | Metres |

**Table 4**: Sampling of objects

| Sample colour | Object determined | Number of pixels for 1986 image | Number of polygons for 1986 image | Number of pixels for 2000 image | Number of polygons for 2000 image |
|---|---|---|---|---|---|
| Deep green | Dense forest | 911 | 10 | 938 | 10 |
| Light green | Degraded forest | 256 | 5 | 267 | 5 |
| Light yellow | Savannah | 458 | 5 | 465 | 5 |
| Red | Lava | 439 | 15 | 437 | 15 |
| Light purple | Adult palms and rubber plantations | 672 | 8 | 668 | 8 |
| Light Sienna | Banana plantations | 163 | 3 | 171 | 3 |
| Light cyan | Young plantations | 246 | 4 | 306 | 4 |
| Light Maroon | Mangrove | 496 | 6 | 579 | 6 |
| Thistle | farm | 192 | 4 | 194 | 4 |
| Magenta | settlement/ bare surface | 200 | 5 | 211 | 5 |
| White | Clouds | 751 | 9 | 797 | 9 |
| Blue | Sea and water bodies | 907 | 7 | 1016 | 7 |

**Table 5**: image iteration

| Typology | texture | form | colour | orientation | size | value | Field observation |
|---|---|---|---|---|---|---|---|
| Dense forest | | | + | | | | + |
| Degraded forest | | | + | | | | + |
| Savannah | | | + | + | | | + |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Lava | | | + | + | | | + |
| Plantation | + | + | | | | | + |
| Mangrove | | | + | + | | | + |
| Farms | | | | | | + | + |
| Clouds | | + | + | | | | + |
| Sea and water bodies | | | + | + | + | | + |

**Table 6**: Procedure of the methodology

| Entry | Treatment | Exit | Objective |
|---|---|---|---|
| 1986 and 2000 scenes of images | - Visual Interpretation<br>- plotting the 2000 image in relation to the 1986 image | Superposable images | To realise a linkage. |
| 1986 and 2000 scenes of images | Extraction of the Mount Cameroon region | Image dimension 2922*2330 pixels | To have images of the same size |
| Extracted images of 1986 and 2000 | Realisation of PIAC through manual digitalisation | Layers of objects | To compare with the images treated on ENVI |
| Extracted images of 1986 and 2000 | Segmentation, classification, NDVI | NDVI of 1986 and 2000 | Compare with the images digitalise on MapInfo |
| Coloured composition<br>TM5 TM4 TM3<br>TM7 TM5 TM3 | Visual interpretation<br>Transect<br>Analyse des histograms | Identification of thematic groups | Understand the different thematic groups |
| TM5 TM4 TM3 | Linkage of images, ROI Tool and supervised classification | Classified images | Transformation |
| Field work | Taking of GPS points, photographs and observation | Down loaded GPS points and photographs | Integration of GPS points on the image using ArcView and photographs for the validation of objects |
| Classified images | ENVI restitution | Layers of the classes of objects | Cartographic restitution |
| Vector layers | Exportation to GIS software | Surface occupation maps | For analyses |
| Down loaded GPS points | Integration of GPS points on the image | Image with GPS points | Assure the results |

**Table 7:** Rate of changes of phenomena

| Theme | Surface area in 1986 (km²) | % of the region | Surface area en 2000 (km²) | % of the region | Variation in km² |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| Dense forest | 1988.5 | 35 | 1718.8 | 30.17 | 269.7 |
| Degraded forest | 597.9 | 10.5 | 645.86 | 11.33 | 47.6 |
| Savannah | 777.56 | 13.7 | 848.66 | 14.9 | 70.98 |
| Mangrove | 930.8 | 16.4 | 912.6 | 16.02 | 18.2 |
| Lava | 186.9 | 3.3 | 171.84 | 3.01 | 14.98 |
| Plantation | 493.2 | 8.7 | 787.3 | 13.82 | 294 |
| Settled area/bare surface | 40.6 | 0.7 | 47.8 | 0.83 | 7 |
| Farms | 680 | 12 | 562.66 | 9.87 | 117.6 |

**Table 8:** Evolution of surface occupation

| Theme | Variation 1986/2002 in km² | Annual change of surface area (km²) | Rate of annual variation | Observation |
|---|---|---|---|---|
| Dense forest | 269.7 | 19.25 | 1.12 % | Rapid reduction |
| Degraded forest | 47.6 | 3.42 | 0.53 % | Increase |
| Savannah | 70.98 | 5.07 | 0.59 % | Increase |
| Mangrove | 18.2 | 1.3 | 0.14 % | Reduction |
| Lava | 14.98 | 1.07 | 0.62 % | Reduction |
| Plantation | 294 | 21 | 2.6 % | Rapid reduction |
| Settled area/bare surface | 7 | 0.5 | 1.04 % | Increase |
| Farms | 117.6 | 8.4 | 1.49% | Reduction and compensation in the plantations |