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Using sequential aerial photographs to detect land-use changes in the Austro Ecuatoriano / *Utilisation de photographies aériennes séquentielles pour détecter les changements d'utilisation du sol dans l'Austro Equateur*

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Résumé

Resume : Utilisation de photographies aériennes séquentielles pour détecter les changements d'utilisation du sol dans l'Austro Equateur. Durant les dernières décennies, il y a eu un accroissement de l'utilisation des photographies aériennes et de l'imagerie satellitaire pour récolter rapidement de l'information digitale dans un certain nombre de régions. Du fait d'une accessibilité plus grande des photographies aériennes et d'une décroissance significative de leur coût, aussi bien pour les logiciels de traitement d'image et de l'information géographique, ces techniques ont connu une popularité croissante. Cet article présente une méthodologie pour utiliser des Systèmes d'Information Géographiques pour quantifier les changements d'usages du sol passés à partir de photographies aériennes. Une application de cette technique à l'Austro Equateur a montré qu'une telle méthodologie nécessitait une compatibilité des données à la fois spatiales et temporelles. Pour obtenir des données spatialement compatibles, les photographies aériennes sont géoréférencées sur la base de l'utilisation d'une série de points de contrôle de base. Notre analyse montre que, si certaines conditions sont satisfaites, ces points de contrôle obtenus à partir de cartes topographiques sont suffisants en qualité pour exécuter une procédure de géoréférencement avec une très bonne précision. D'autre part, la compatibilité temporelle apparaît plus difficile à mettre en œuvre : l'échelle (et probablement la qualité) des photographies aériennes a un effet significatif sur la classification de l'utilisation du sol qui en découle. Par conséquent, un étalonnage des différentes sources de données est nécessaire de façon à éviter des erreurs dans les résultats.

Abstract

Abstract : During the last decades, there is a boom of the use of aerial photographs and remote sensing images to collect quickly accurate digital information in remote areas. Due to an easier accessibility of aerial photographs and a significant decrease of their price as well as that of the image analysis and GIS software, these techniques are becoming increasingly popular. This article presents a methodology to use Geographic Information Systems for quantifying past land use changes from aerial photographs. An application of this technique to the Austro Ecuatoriano has demonstrated that such a methodology requires that the data are both spatially and temporally compatible. In order to obtain spatially compatible data, the air photos are geo-referenced using a set of ground control points (GCP's). Our analysis shows that, if certain conditions are satisfied, GCP's obtained from topographical maps are of sufficient quality to carry out the geo-referencing procedure with a very good precision. On the other hand, temporal compatibility appears more difficult to achieve : the scale (and probably the quality) of the air photos has a significant effect on the resulting land use classification. Consequently, a calibration of the various datasources is necessary in order to avoid bias in the final results.

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Using sequential aerial photographs to detect land-use changes in the Austro Ecuatoriano

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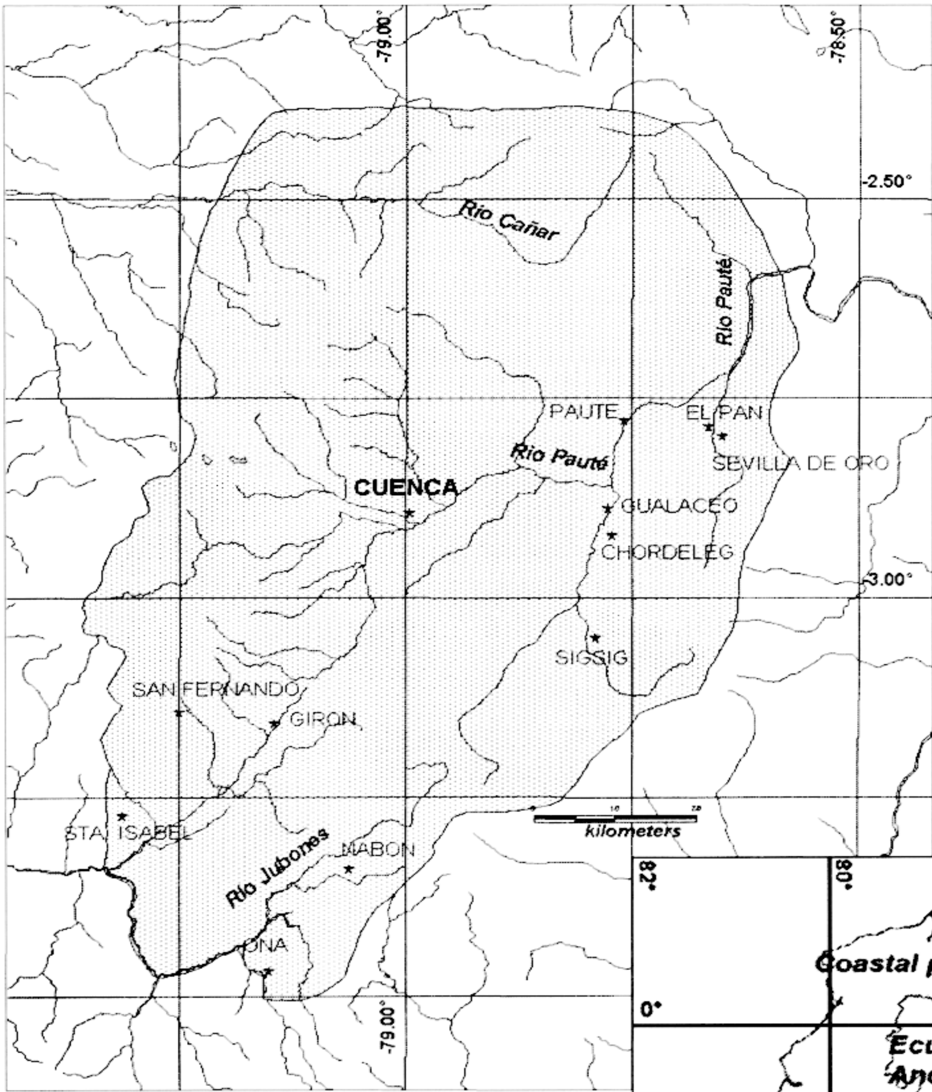
Introduction

During the last decades, land use and land cover have changed drastically in the tropics due to a growing population and a changing economy (Allen *et al.*, 1985 ; Meyer *et al.*, 1992 ; Walker, 1987). This has caused important adverse effects on physical and ecological processes, on soil and water resources, on local and global climate systems and on the diversity and abundance of terrestrial species. These changes also affect the prospects for economic development and they can have a large number of social and cultural impacts (Dale *et al.*, 1998 ; Lambin, 1994, Ojima *et al.*, 1994 ; Turner II, 1994). This problem is getting more and more attention in international research. The Land Use and Land Cover Change Project (LUCC project) forms an important part of the International Geosphere-Biosphere Program (IGBP Program) on Global Change for the sake of the complexity of the possible consequences of land use changes to the terrestrial ecosystem, both on local as on global scale (Turner II *et al.*, 1995). Important improvements were made with relation to the analysis and the modelling of land use changes (Kaimowitz *et al.*, 1998 ; Lambin, 1994 ; Riebsame *et al.*, 1994 ; Sklar *et al.*, 1991).

In Ecuador, land use changed dramatically during the last century (De Koning *et al.*, 1998 ; De Noni *et al.*, 1993 ; Gondard, 1988 ; Southgate *et al.*, 1991). In the past, the arable lands were concentrated in the more densely populated inter-Andean basins. The land property structure was not egalitarian whereby the population was concentrated within the haciendas. Crops were produced on the fertile soils in the inter-Andean basins while extensive cattle breeding extended to the steeper slopes. This feudalistic agrarian structure disappeared almost entirely from the 1960s onwards (Commander *et al.*, 1986). The urban industry and manufacturing became increasingly important and the current agrarian structure was an obstacle to this development since it was incapable of producing sufficient wage goods for a growing urban population. A second factor that stimulated the agrarian change was the oil boom of the 1970s. The Land Reform Programs of the 1960s and 1970s together with the demographic boom resulted in a more capital-intensive production on the large and middle-sized farms in the sub-sectors of agro-industry and cattle-breeding due to an expanding market for commercial crops and wage goods in particular (Vos, 1988). But it also led to a spatial redistribution of the small farms towards steep slopes and the highlands. The intensification of the agricultural



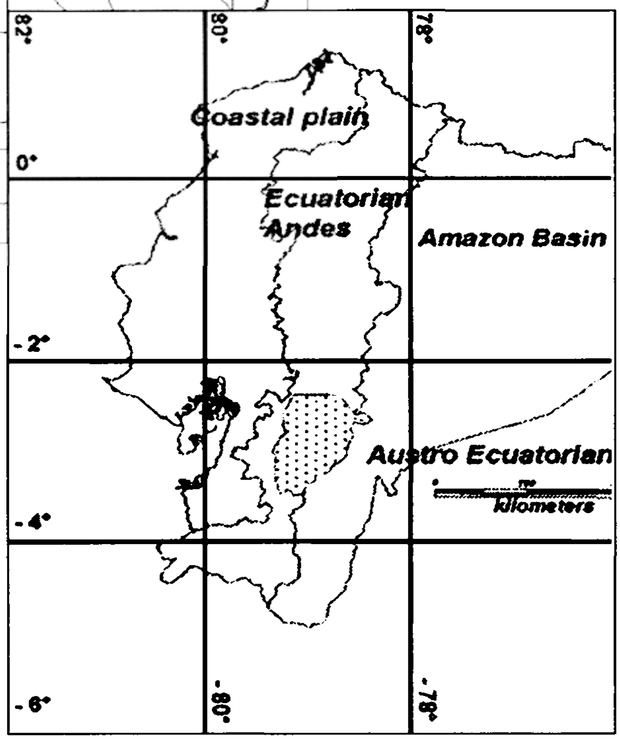


Figure 1 :
Location of the Austro Ecuatoriano

land use and the cultivation of non-adapted areas have caused serious modifications of the natural ecosystem and an acceleration of the degradation processes (De Noni *et al.*, 1990).

It is obvious that an extensive and accurate database with relation to the evolution of the land use is of primary importance to get a clear insight in the subject. The availability of such information already allows making preliminary evaluations of past and actual land use changes. Good predictions of future land use changes and their impacts are only possible if the controlling factors can be identified and incorporated in a land use change model. It allows the early identification of possible negative evolutions in land use and the proposition of remedial or attending measures.

The lack of knowledge of land use dynamics is especially important for tropical areas : many areas in the tropics undergo very quick changes at present due to an important increase in population and dramatic changes in agricultural practices. This is not only an important scientific gap, but it also has practical implications : the geomorphologic activity in these areas is particularly high, leading to increased soil degradation, mass wasting, reservoir sedimentation etc. Recently, there is a boom of the use of aerial photographs and remote sensing techniques to monitor land use changes in the tropics. However, these powerful techniques are often used as such without considering their real accuracy or the errors generated by combining images of different types. This paper concentrates on some methodological aspects of the study of land use change using aerial photos. The first objective is to present a general method to use Geographic Information Systems for quantifying past land use changes by means of aerial photographs. In addition, some comments are given about the limitations and precision of aerial photogrammetry.

Study area

The study area selected for this research is the Austro Ecuatoriano, located in the southern part of the Ecuadorean Andes. It has a surface area of ca. 8100 km^2 and consists of three main catchments (River Cañar, River Pauté and River Jubones) (Dercon *et al.*, 1998). The northern and southern parts drain to the Pacific Ocean by respectively the River Cañar and River Jubones. The central catchment drains to the Amazon by way of the River Pauté. Altitude varies between 600 and 4300m. The region has a mountainous tropical climate and precipitation varies between ca. 700 and 3500mm yr-1. There is an intensive agricultural land use in the middle and higher parts of the catchments, whereby the most important crops are maize, corn, potatoes, vegetables and fruits (Bossuyt *et al.*, 1997). The lower parts are more forested, but disturbance is increasing. Intensive cultivation of steep parcels and the lack of adequate cultivation techniques brought about a very high geomorphologic activity including water erosion (sheet, rill and gully erosion), tillage erosion, mass wasting and fluvial activity, leading to a very high annual sediment export of ca. 9,5 ton $ha^{-1}yr^{-1}$ (Harden, 1993). These severe erosion problems do not only affect the agricultural production, but they also have big implications for other human activities : for example, the siltation of the reservoir of the Pauté hydro-electric project that generates half of Ecuador's electricity may severely hamper future electric power production.

Methodology

Considering the extent of the Austro Ecuatoriano, it is impossible to make an inventory of land use changes based on aerial photographs for the area as a whole. Therefore, a few catchments of a limited size were selected within the Austro. These data are considered to be representative for the whole region. For each catchment, the evolution of the land use was thoroughly documented using archived aerial photographs. Considering the fact that the effects of change over a time scale of decades were evaluated, no detailed information on different crops etc. was collected. Rather, it was attempted to make a distinction between a limited number of land use categories (e.g. arable land, pasture, forest, built-up areas). Because of the differences in quality and scale of the aerial photographs, it was not possible to automate the classification process. Therefore, the photo-interpretation was done manually using a stereoscope. Afterwards, this information was transferred into a digital form, whereby each aerial photograph was georeferenced. Once the land use data were incorporated in a GIS-environment, it became possible to analyse quantitatively the land use changes.

Photo-Interpretation

For each catchment, a set of archived aerial photographs from the 1960s onwards was available to analyse the evolution in land use during the last decades. It was tried to obtain a good quality database of land use data by using aerial photographs taken on dates more or less regularly spread in time (e.g. catchment of Sta. Ana, see table 1). The scale of the photos varied considerably : from 1 / 30 000 to 1 / 60 000.

Illustration non autorisée à la diffusion

Table 1 : Main characteristics of the aerial photographs (Willems, 1999)

Each couple of stereo-pairs was analysed manually using a WILD stereoscope and transparent overlays to mark the different types of land use. It was beyond the scope of this research to automate the classification procedures. Due to significant differences in quality and scale between and within the aerial photographs, it was not possible to automate the classification process without an unreasonable investment of time.

Land use was classified using only three categories : forested areas, arable lands - pasture and wastelands. Because of gradual transitions in three cover in the forested areas, areas were delineated arbitrary as forested if tree density was more then 100 threes per hectare ground area. According to the scale of the aerial photographs, areas with adapted three densities have to be identified on the photos. (e.g. : when the scale of the photographs is 1 / 40 000 ; an area will be classified as forest if the number of threes on a randomly selected line of 1 cm length is more then 20). Due to the low quality and the small scale of the aerial photographs, it was impossible to make a distinction between a larger number of land use classes. Furthermore, the land use classification was to some extent arbitrary because of the gradual transitions that exist between different land use classes (e.g. agro-forestry, extensive cropping combined with grazing, silvo-pastoral production etc.). Therefore, the whole process of photo – interpretation and – classification was done by one photo-interpreter to obtain a uniform and consistent land use database.

GEO-REFERENCING OF AERIAL PHOTOGRAPHS

After the manual photo-interpretation, each photo stereo-pair was imported in a GIS-environment. The purpose of this computerisation was (i) to analyse the land use database quantitatively and (ii) to combine the land use change data with extra information, such as pedology, topography, geology, population density, migration, etc as to reveal the controlling factors of the concluded land use changes. The creation of orthophotos[1] was done in ILWIS 2.2 (International Institute for Aerospace Survey & Earth Sciences, 1999). An orthophoto is obtained by resampling a scanned photograph. This procedure requires a scanned photogrammetric aerial photograph on which at least two fiducial marks can be distinguished, knowledge of the principal distance of the photogrammetric camera, a Digital Elevation Model of the area and a set of Ground Control Points[2].

Various methods exist to collect Ground Control Points (GCP). Here, GCP's were collected using two different procedures, so that their effect on the accuracy of the georeferencing could be assessed. A first set was collected by measuring the geographic position of some reference points by GPS (Trimble Geo-Explorer) in the field, a second set by collecting geographic co-ordinates of recognisable points on topographic maps on a scale of 1/10 000. Each dataset consists of at least nine points, which were sampled systemically regarding both their geographic positions as their elevations.

Before the GPS measures took place in the field, a dataset of possible reference points was composed. The first requirement was that the points were fixed and clearly identifiable like houses, intersections of paved roads, borders of parcels, isolated trees etc. An extra requirement was that the points had to be located in easily accessible areas. Geographic coordinates were obtained by measuring the geographic position in the field using a Trimble Geo-Explorer hand-held GPS (Trimble Navigation Ltd., 1994) and by applying a post-processed differential correction using Pathfinder Office (Trimble Navigation Ltd., 1997).

1. Rectified, North-oriented raster maps with square pixels, scanned photogrammetric aerial photographs with corrections for tilt and relief displacement.

2. A geographic feature of a known location that is recognisable on images and can be used to determine geometric corrections.

The horizontal accuracy ranges from submeter to 5 meters Circular Error Probable[3] (CEP) with differential correction. The horizontal co-ordinates are typically two to five times more accurate than the vertical co-ordinates for any given GPS position (Trimble Navigation Ltd., 1996). The second dataset consists of the reference points selected for the GPS measurements that were clearly identifiable on the topographic maps, complemented with extra reference points obtained from the topographic maps. In this case, geographic x and y co-ordinates were directly read from the topographic maps. Height values were obtained by linearly interpolating between contour lines.

The use of control points derived from topographic maps instead of GPS measurements has some advantages. The reference points can be selected more randomly in the area because the accessibility of the area has not to be considered. In this way, it becomes possible to select also intersections of rivers and streams as GCP's. These points are very well identifiable on aerial photographs and are stable in time.

Table 2 gives as an example the relative accuracies of the geo-referencing of the aerial photographs for the catchment of Sta. Ana using the two types of control points. The relative accuracy is very high and the root mean square error (RMS)[4] is always below 10 meters. This means that, with a chosen resolution of the images of 10m, the error on the location of the points is smaller than the pixel size. Consequently, the relative positional error of the orthophotos is negligible. Contrary to the expectations, a relationship between the scale of the aerial photographs and the relative accuracy of the geo-referencing could not be detected (table 2). The (subjective) visual quality of the aerial photographs neither affected the precision.

Year	1963	1979	1989a	1989b	1995a	1995b
Approximate scale	1:45 000	1 : 60 000	1:55 000	1:55 000	1:30 000	1:30 000
Relative accuracy of the geo-referentiations in ILWIS 2.2 (meter)						
Using GPS points	4.32	3.14	2.86	3.00	5.78	5.11
Using topographic maps	3.45	2.87	2.62		5.56	6.66

Table 2 : Relative accuracy of the geo-referentiation of the aerial photographs, e.g. the catchment of Sta. Ana

Thus, a similar accuracy was obtained with both types of GCP's. This is to some extent surprising as the GPS reference points are in principle of higher quality. This is not reflected in the end result as the locational accuracy that can be obtained by reading points from a

3. A statistical measure of horizontal precision. The CEP value is defined as a circle of a specific radius that encloses 50 % of the data points. Thus, half the data points are within a 2D CEP circle and half are outside the circle.

4. A measure of the variability of measurements about their true values, that is estimated by taking a sample of measurements and comparing them to their true values. These differences are squared and summed. The sum is then divided by the number of measurements to achieve a mean square deviation. The square root of the mean square deviation is taken to produce a characteristic error measure in the same units as the original measurements.

large-scale topographical map is still lower than the image resolution used in this project (10 m). This clearly demonstrates that, if a well-chosen set of GCP's is used, the same accuracy can be obtained using topographic maps as when working with GPS Ground Control Points. This conclusion is of great importance for poorly accessible regions because a lot of time and money can be gained when working with topographic maps. This conclusion is not generally valid as the results will be dependent on the quality of the topographic map. Furthermore, the final resolution is also important : while topographic maps may allow a sufficiently accurate location of GCP's for studies using a 10 m or lower resolution, this may not be the case if higher resolutions (e.g. 1 m) are to be used. Therefore, an accuracy evaluation should be carried out before GCP's from topographic maps are used.

Scale effects on air photo interpretation

When using time series of aerial photographs to detect land use changes, the scale is usually not the same for all the photographs. The degree of detail of the photo-interpretations is highly dependent on their scale. When using large-scale aerial photographs more detail can be seen (table 3). In this research, two independent land use classifications were done based on two different series of aerial photographs. These series were from the same time period (1976) but they had a different scale (1 / 20 000 and 1 / 60 000). A comparison of the two classifications revealed that (i) the detail of the land use classification on the small-scale aerial photographs decreases drastically as the limits of the land use polygons are inevitably generalised. This leads to a significant bias in the end results whereby smaller land units tend to be more biased because of a larger proportion of perimeter vs. surface area of the polygons. The research also showed that (ii) some types of land use that are predominantly associated with small or linear land units (e.g. sparsely deforested parcels, tree corridors along paths or deeply incised rivers) are no longer distinguishable on small-scale aerial photographs. Table 3 shows that when the scale of the photographs decreases from 1 / 20 000 to 1 / 60 000, the smallest observable polygons increase from 2 500 m^2 to 22 500 m^2 (table 3) and the smallest observable linear element increases from 1 to 3 meter. This also results in an extra bias towards the small land units.

Scale	1 / 20 000	1 / 60 000
Smallest observable polygon	(50 * 50) m	(150 * 150) m
Smallest observable linear element	1 m	3 m

Table 3 : The degree of detail of the photo-interpretations corresponding to different scale levels

As an example, two independent land use classifications based on aerial photographs of different scales (1 / 20 000 and 1 / 60 000) are summarised in table 4. The results in the table show clearly that land use data collected from different information sources can not be compared without calibration or correction. If this is done, erroneous conclusions about land use dynamics may be drawn. The calibrations of the land use

	Spatial distribution of the land use classes (%) in a study area collected from aerial photographs on different scales	
Land use categories	**1 / 20000**	**1 / 60000**
Arable land	27 %	15 %
Forested area	7 %	30 %
Wasteland with sheet and / or rill erosion	45 %	44 %
Wasteland with gully erosion	17 %	2 %
Other	4 %	9 %
Area (319 ha)	**100 %**	**100 %**

Table 4 : Comparison of land use data collected from aerial photographs on different scales (e.g. catchment of Santa Isabel, 1976)

classifications for different scale levels have to be repeated for each region in order to obtain comparable data, as the change in classification due to a change in scale will depend on the type of land use in the area as well as the geometry of the land units.

Conclusion

During the last decades, land use is changing dramatically in Ecuador. The increase of the urban industry and manufacture in the 1960s and the oil boom in the 1970s stimulated a more capital-intensive production in the sub-sectors of agro-industry and cattle-breeding, but led also to a spatial redistribution of the small farms towards steep slopes and highlands. An accurate and extensive database of land use information is of primary importance to get an insight in past and actual land use changes. Aerial photographs give new possibilities to obtain quickly digital information.

The use of aerial photographs to derive information on land use change requires various methodological steps. If the data are to be analysed in combination with other geographic information, it is necessary to import the analogue data into a GIS, for which a geo-referencing procedure is necessary. Our analysis shows that sufficiently accurate results may be obtained using GCP's derived from large-scale topographic maps. Indeed, no gain in accuracy could be obtained by using GCP's derived from GPS measurements in the field. So, if sufficiently accurate maps are available and the resolution used for the project is not too high, a time –consuming field campaign to obtain GCP– data is not necessary.

On the other hand, large errors may be generated when land use classifications obtained from aerial photographs of different scales are directly compared. The detail, represented on an aerial photo, decreases significantly with decreasing scale, which will lead to a relative over- or under-representation of certain land use types in the final classification. Thus, if photos of various scales are used in a temporal study, a calibration procedure is necessary to make the results comparable. Very often this may be difficult to achieve, as only rarely two series of air photos will be available that are taken at the same time but have different scales. If such material is absent, some information may obtained by studying the effect of artificially reducing the spatial resolution on land use classification.

In this paper, a general methodology was presented to use aerial photographs to quantify past and actual land use changes. Firstly, four catchments were selected based on an agro-ecological zoning of the Austro Ecuatoriano. This selection process is crucial, as this information will be used to make inferences about the evolution in the Austro Ecuatoriano in general. For each catchment, a qualitatively good dataset of aerial photographs from the 1960s onwards was collected whereby the photos were regularly spread in time. Due to significant differences in quality and scale between and within the aerial photographs, each stereo-pair was analysed manually. Taking into account the small scale and the quality of the photographs, land use was classified using only three categories : forested areas, arable lands and pasture and wastelands. This information was computerised in ILWIS through a geo-referentiation procedure, whereby co-ordinates were given to the scanned aerial photos. The relative accuracy of the ortho-photos was generally very high and lower than 10m. Furthermore, it was proved that by well-considering the choice of the reference points on large-scale topographic maps, the same accuracies can be obtained as when working with GPS Ground Control Points. This conclusion has important practical implications : in poorly accessible areas a lot of time and money can be gained. The results also demonstrated that care should be given when working with time series of aerial photographs. If there is a difference in scale or quality of the photographs, a calibration should be done to make the land use data comparable.

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Résumé : *Utilisation de photographies aériennes séquentielles pour détecter les changements d'utilisation du sol dans l'Austro Équateur.* Durant les dernières décennies, il y a eu un accroissement de l'utilisation des photographies aériennes et de l'imagerie satellitaire pour récolter rapidement de l'information digitale dans un certain nombre de régions. Du fait d'une accessibilité plus grande des photographies aériennes et d'une décroissance significative de leur coût, aussi bien pour les logiciels de traitement d'image et de l'information géographique, ces techniques ont connu une popularité croissante. Cet article présente une méthodologie pour utiliser des Systèmes d'Information Géographiques pour quantifier les changements d'usages du sol passés à partir de photographies aériennes. Une application de cette technique à l'Austro Équateur a montré qu'une telle méthodologie nécessitait une compatibilité des données à la fois spatiales et temporelles. Pour obtenir des données spatialement compatibles, les photographies aériennes sont géoréférencées sur la base de l'utilisation d'une série de points de contrôle de base. Notre analyse montre que, si certaines conditions sont satisfaites, ces points de contrôle obtenus à partir de cartes topographiques sont suffisants en qualité pour exécuter une procédure de géoréférencement avec une très bonne précision. D'autre part, la compatibilité temporelle apparaît plus difficile à mettre en œuvre : l'échelle (et probablement la qualité) des photographies aériennes a un effet significatif sur la classification de l'utilisation du sol qui en découle. Par conséquent, un étalonnage des différentes sources de données est nécessaire de façon à éviter des erreurs dans les résultats.

Mots-clés : photographie aérienne, dynamique de l'utilisation du sol, ortho-rectification, Système d'Information Géographique, Équateur

Abstract : During the last decades, there is a boom of the use of aerial photographs and remote sensing images to collect quickly accurate digital information in remote areas. Due to an easier accessibility of aerial photographs and a significant decrease of their price as well as that of the image analysis and GIS software, these techniques are becoming increasingly popular. This article presents a methodology to use Geographic Information Systems for quantifying past land use changes from aerial photographs. An application of this technique to the Austro Ecuatoriano has demonstrated that such a methodology requires that the data are both spatially and temporally compatible. In order to obtain spatially compatible data, the air photos are geo-referenced using a set of ground control points (GCP's). Our analysis shows that, if certain conditions are satisfied, GCP's obtained from topographical maps are of sufficient quality to carry out the geo-referencing procedure with a very good precision. On the other hand, temporal compatibility appears more difficult to achieve : the scale (and probably the quality) of the air photos has a significant effect on the resulting land use classification. Consequently, a calibration of the various datasources is necessary in order to avoid bias in the final results.

Keywords : aerial photographs, landuse dynamics, orthorectification, Geographic Information Systems, Austro Ecuatoriano