Final Report

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Illicit Crop Monitoring in Colombia

Review of the Methodology

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Content

Summary of Recommendations

The overall impression obtained from the visit to the office of SIMCI is that very ambitious and dedicated work is performed by the staff members. In this report, several suggestions are made how to facilitate and the work. Furthermore, some improvements are proposed to increase the reliability of the results.

The following topics were discussed in this report:

- Sensors

Regarding the use of satellite imagery, there is not much scope for improvements. Although the SLC-gaps influence the result of the survey, Landsat 7 ETM imagery is still useful to get an overview of the area. For the acquisition of Landsat 5 TM imagery, the Landsat project manager should be contacted in order to get information about the availability of this kind of data for Colombia. ASTER currently is the best sensor. Therefore more influence on the acquisition of ASTER images is useful. Emphasis should be laid on acquiring images of the whole Colombian territory for a reasonable price. While SPOT should also be considered as an alternative to Landsat, negotiations will have to be carried out about the price of the scenes. Regarding the scene size, approximately 320 scenes would be needed to cover the territory of Colombia with ASTER or SPOT imagery.

In order to compare the quality of Landsat and ASTER scenes for coca monitoring, it would be interesting to interpret these images separately and analyze the quality of the boundary of the delineated fields.

The application of vertical aerial photography is recommended for field verification and the monitoring of opium poppy. For this purpose, a survey of photo flight companies in Colombia and their technical facilities has to be performed. In accordance with the objective and the concept of the illicit crop monitoring, the call for tenders and the contract with the flight companies must clearly include all requirements and specifications needed, such as digital imagery, stereoscopy etc.

- Image Preprocessing

Orthorectification, but also topographic-radiometric corrections are recommended for preprocessing satellite imagery. This is an improvement especially for mountainous areas.

- Classification and Interpretation

The compilation of a detailed interpretation key for coca and for opium poppy is necessary. Furthermore, a regular “calibration” of the interpreters is suggested. Research on the field of automating the classification process should be intensified as this is a valuable support for the visual interpretation.

- Verification flights

The application of tablet PCs instead of large format paper maps for direct visual inspection flights should be tested. Better than this, however, is the use of aerial photography, preferably with digital metric cameras and vertical image capture.

- Accuracy Assessment

The control of the quality of the results is an important process. For the assessment of the accuracy it will be necessary to work out a comprehensible schema how the samples are chosen with a minimum of bias.

- Opium Survey

The implementation of a method for surveying opium poppy cultivation is essential as no area-wide survey has been performed so far. Due to the limitations of satellite imagery for this purpose, aerial photography and a visual interpretation is recommended. Aerial photographs should be acquired on a statistical sample basis. Again, the use of a digital metric camera is suggested.

- Data Management

The application of a central data management system for storing all kind of geographical data should be taken into consideration. While such systems are expensive, they facilitate the data access. Apart from a central database, strict data documentation is strongly recommended. As soon as more users get access to the same data, information about the current status of the data at any time is a prerequisite for effective work.

1. Introduction

The detection of illicit crops based on the interpretation of remote sensing imagery is a complex and extensive task. The aim of this report is to support the internal review of the Illicit Crop Monitoring Activities in Colombia (SIMCI) carried out by the Illicit Crop Monitoring Programme (ICMP) of the United Nations Office on Drugs and Crime (UNODC). This advisory opinion should help in assessing the performance of the methodologies and techniques developed by SIMCI for coca cultivation identification. Suggestions are made for improving the monitoring of illicit crops in Colombia.

The report follows a visit to Colombia in August 2004, where a staff member of the Institute of Surveying, Remote Sensing and Land Information (IFVL) analyzed the methodologies applied by the team of SIMCI in situ.

The composition of this report follows the flow of work during the annual survey performed by SIMCI. In chapter 2, remote sensors suitable for the project are evaluated. Chapters 3 and 4 deal with the preprocessing of the images and the classification of coca fields. Chapter 5 describes the corrections applied to the initial classification. Chapter 6 discusses the aerial survey activities for training and verification purposes. Chapter 7 deals with accuracy assessment issues. As no methodology for the monitoring of opium poppy cultivation in the country has been established yet, suggestions are made for monitoring system this crop in chapter 8. General data management issues are addressed in chapter 9.

In these chapters suggestions for improvements in the described processing chain are given. Another goal of this report is to point out fields where further research is recommended. As developing and testing new methods is a time consuming process, this should be performed by research institutions.

2. Data Acquisition

The selection of the sensor is one of the most important steps in the process. The characteristics and the quality of the imagery strongly influence the result of the survey. In the 2003 census, mainly images of the LANDSAT 7 and ASTER sensors were used. In the following, the pros and cons of these satellite sensors are evaluated. Alternative sensors are considered. The use of airborne sensors for training purposes, verification flights and accuracy assessment is examined in a subchapter.

One of the major difficulties in data acquisition is the frequent cloud coverage over the Colombian territory. Therefore, satellites with a frequent revisit and a permanent recording of the area are to be favored.

2.1. Satellite Sensors Used by SIMCI

2.1.1 Landsat 7 ETM+

Landsat 7 ETM+ data are collected using a 30 m ground resolution cell. The satellite has a 16-day repeat cycle which enhances the chance for cloud free images. Data are collected in 7 spectral bands (the thermal band with a resolution of 60 m). In addition, a panchromatic band with a spatial resolution of 15m is recorded. Due to the swath width of 185 km this satellite is appropriate to regional landscape studies at a scale smaller than 1:100.000. However, the spatial resolution is not appropriate for large scale studies of small features. This scale limitation leading to mixed pixels at the edges of fields makes it difficult for the interpreter to delineate fields. Furthermore the effect of mixed pixels has an influence on the automatic classification. Especially for the monitoring of small coca plots this limits the usefulness of this sensor.

On May 31 2003, the Scan Line Corrector (SLC) on the Landsat 7 ETM+ instrument failed. The SLC compensates for the forward motion of the satellite. This malfunction is leading to gaps in the image (Fig. 1). Landsat 7 ETM+ is continuing to acquire image data in a "SLC-off" mode.

The SLC-off impacts are most pronounced along the edges of a scene and gradually diminish toward the center of a scene. The middle of a scene (approximately 20 kilometers) shows very little duplication or data loss. Only this region is similar in quality to previous Landsat 7 image data.

As stated in a report on the Landsat homepage (http://landsat.usgs.gov/documents/SLC_off_Scientific_Usability.pdf), various tests have shown that approximately 80% of the scene are useable. I.e. while it is not possible to correct for this missing data, it is possible to modify the processing algorithms to produce imagery containing roughly 80% of the expected pixels. It must be annotated that the mentioned percentage is too high as the image near the gaps cannot be used completely, especially for a visual interpretation. Truncated parts limit the interpretation work as the surrounding pixel of an object might contain important information. For large area monitoring data of ETM is still adequate.

The following enhanced products are currently available:

- user selected interpolation
- gap filled product

In the first case, the user may select an alternate number of pixels to be interpolated across the scan-line boundary. For the latter all missing image pixels are replaced with estimated values derived from a co-registered, histogram-matched SLC-on scene. While these enhanced products will help for the orientation during a field verification, they can not be used for the image classification process, as the images used for filling the gaps are not of the same acquisition date.

Regarding the interpolation process, like any interpolation the method relies on the assumption that trends observed in the available signal are continued in the gaps to be interpolated. This assumption is problematic if small objects and structures are contained within the gaps. Therefore, a gap-filled product based on an interpolation is not recommended.

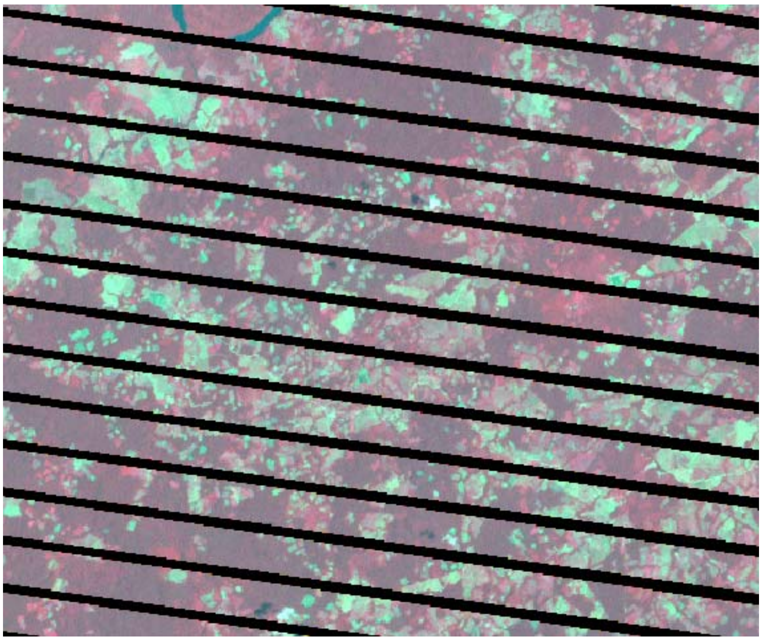

Fig. 1: SCL-off image

In addition to the enhanced products mentioned above, the US Geological Survey (USGS) will also release a series of other improvements in the near future. The „Phase II“ release, targeted for early 2005, will consist of a more advanced product that merges data from multiple SLC-off scenes acquired within weeks of each other. The usage of this improvement will depend on the practical implementation. In all cases, a binary bit mask will be provided so that the user can determine where the data for any given pixel originated. It will be worth monitoring the recent developments in this field. A successor mission for Landsat 7 has not been planned definitely yet.

2.1.2 ASTER

Due to the malfunction of the Landsat 7 ETM+ satellite, alternative sensors are of great interest. One of these systems is ASTER, which is mounted on board of the Terra satellite. ASTER comprises 16 spectral bands with a spatial resolution ranging from 15 to 90 m depending on the spectral band. For monitoring vegetation, especially the spectral bands 1-3 (visible to NIR) with a pixel size of 15 m are of interest. These characteristics are useful for detecting small coca plots (Fig. 2). The swath width comprises 60 km, which makes it necessary to collect more images than with Landsat in order to cover the same area.

The availability of ASTER images is the most problematic aspect of this sensor. ASTER is an on-demand instrument. Data of a certain location are acquired only if a request has been submitted to observe that area. Currently, SIMCI receives this kind of data via the Air Wing Section of the US State Department which is performing its own coca survey. However, this survey of the Air Wing Section only focuses on high density coca growing areas. Images are not covering the whole country. More influence on the selection of images by SIMCI would be beneficial.

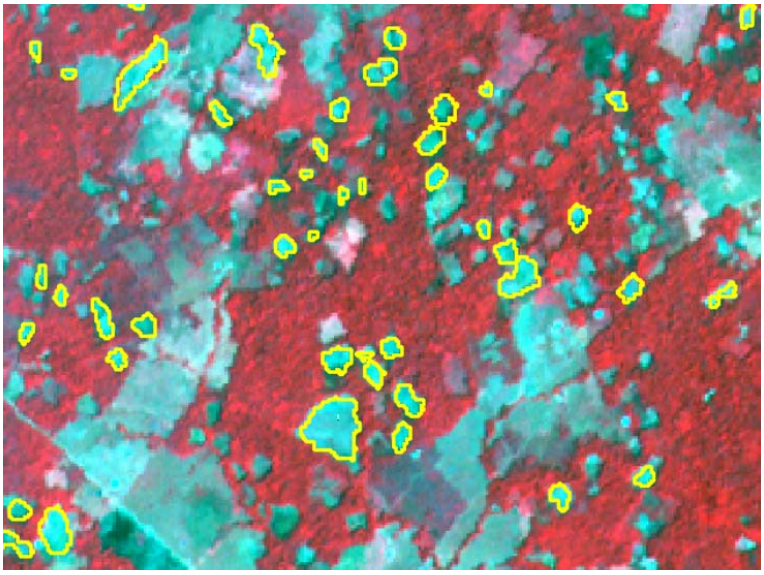

Fig. 2: ASTER scene and interpreted coca fields (yellow polygons)

2.1.3 SPOT

Similar to ASTER, the French satellite SPOT 5 also possesses very good characteristics for crop monitoring. In combination with the older satellite SPOT 4, the chances of image acquisition in cloudy areas are higher than with other sensors. In addition, due to an off-nadir viewing capability an area can be monitored more frequently. With a spectral sensitivity from the visible to the medium infrared and a spatial resolution from 2.5 m (panchromatic, 10 m with SPOT 4) to 10 m (multispectral, 20 m with SPOT 4) SPOT fulfills the requirements for vegetation monitoring at the required scale. One characteristic of the SPOT system is the ability to program the satellites according to the client's needs. Similar to ASTER, the swath width is 60 km. This again is a disadvantage in comparison to Landsat. The main disadvantage of this sensor is the price for archive products and for programmed products, which is currently too high to monitor large areas on a regular basis.
As for ASTER, more than 300 images would be needed to cover the whole Colombian territory.

2.2 Alternative Satellite Sensors

2.2.1 Landsat 5 TM

As an alternative to the Landsat 7 ETM+ sensor, Landsat 5, the older satellite of this series, is still operational (2 decades beyond its designed lifetime). For international locations, Landsat 5 TM scenes are not archived or distributed by the USGS, but only via other international ground receiving stations. As the nearest receiving station is located in Brazil, only the very eastern part of Colombia can currently be covered with Landsat 5 TM data. As mentioned on some web pages, the international ground station network is being expanded. It is worth checking in future if this applies to Colombia (http://landsat7.usgs.gov/grounds.html). The following information about this topic is to be found on the website mentioned above:

"… the Landsat Project is currently working with other ground stations to support the possible expansion of Landsat 5 TM direct reception in the future. Organizations interested in pursuing direct access to Landsat 5 data downlink should contact the Landsat Project Manager before making any form of commitment regarding implementation of a Landsat 5 ground receiving station"

2.2.2 Very High Spatial Resolution Satellites

This new generation of satellites comprises IKONOS, Quick Bird and OrbView-3 (?), three sensors operated by private US companies. While the high spatial resolution is an advancement for the detection of small coca or opium poppy fields, the acquisition of data is problematic. Due to the high percentage of clouds in Colombia the acquisition of images is difficult. Furthermore, prices are too high for the monitoring of large areas. Like ASTER, these systems record an area on demand. With a swath width of 11km (IKONOS) or 16.5 km (Quick Bird), these sensors are appropriate mainly for sample-based inventories.

2.2.3 IRS

The ground resolution (23.5 m multispectral, 5.7 m panchromatic) of the Indian Remote Sensing Satellite (IRS) is similar to SPOT 4 while the swath width (141 km) is larger. The sensor has a low radiometric quality compared to Landsat or SPOT as experienced by the authors in forest-related projects. Images of this sensor have not been taken into consideration due to the complicated distribution channels. It would be worth testing this imagery in regard to the quality on one area in order to evaluate its suitability for coca monitoring.

2.2.4 MODIS

The MODIS sensor (MODerate resolution Imaging Spectroradiometer) is mounted on the Terra satellite. MODIS is an instrument with high revisiting time and is mainly designed for global change research. The spatial resolution is 250m in two bands, 500m in five bands and 1 km in 29 bands. MODIS has a 2.330 km swath width and provides global coverage every one to two days. While the spatial resolution is too coarse for detecting illicit crops, MODIS can be considered for change detection analysis. MODIS comprises some aspects of a hyperspectral sensor because of its narrow spectral bands (see below).

2.2.5 Hyperspectral sensors

Hyperspectral remote sensing is a relatively new field. Hyperspectral sensors measure solar radiation reflected from the earth in many narrow spectral bands. This enables a better identification of objects at the surface and a better quantification of the object properties than can be achieved by traditional sensors such as Landsat TM or SPOT. Especially for crop monitoring, hyperspectral sensors lead to better results as it is easier to distinguish between different crops. Currently no satellite sensors with a high resolution are operated on a regular basis. In order to gain more experience on this field, it would be worth considering a research project on the usefulness of hyperspectral data for detecting illicit crops. Data of the experimental sensor HYPERION with 220 spectral bands could be used for this purpose.

2.3 Airborne Sensors

While it is unrealistic to cover the whole territory of Colombia with aerial photographs every year and to interpret these images, aerial photography may be important for training the interpreters and for accuracy assessment. Furthermore, the application of aerial photographs for an opium poppy monitoring system is promising and will be discussed below. In comparison to satellite imagery, airborne sensors offer a higher independence of weather and illumination conditions as airplanes can fly below clouds.

The usage of airborne sensors depends on various parameters like:

- camera: analogue or digital
- image scale
- flying altitude
- spectral range
- type and characteristics of the aircraft
- etc.

Cameras of various types are used to take aerial photographs. Aerial cameras can be classified into non-metric and metric cameras. Metric cameras offer the possibility to georeference the photos exactly with photogrammetric methods. In addition, the large format of metric cameras (23 x 23 cm^2 image size for analogue cameras) is of practical importance for covering large inventory areas.

Stereoscopic coverage is of advantage. For this purpose, a 60% endlap is necessary along a flight line. To prevent gaps in a complete coverage, a sidelap of 30% should be considered. The resulting images can be interpreted through a stereoscope, leading to a three-dimensional stereomodel. This improves the image interpretation.

A cheaper option is the use of small format cameras. Taking vertical aerial photographs along flight lines is recommended as locating the photograph on a satellite image is easier. However, mounting a small format camera for vertical view direction can be problematic.

With regard to the spectral range to be covered, multispectral image acquisition including the near infrared range is advisable for vegetation monitoring. Analogue color infrared film (CIR) fulfills these requirements. Processing of this type of film, however, is difficult and requires special facilities and experience of local companies. True color film which is easier to handle not only lacks the near infrared component, but also yields lower contrast images due to light scattering in the blue spectral range. In practice, therefore, black and white film often is to be preferred to true color film if CIR is not available.

Like in terrestrial photography, trends indicate that for airborne remote sensing digital recording systems will be more employed in the near future (GRAHAM & KOH 2002). The use of a digital camera is highly recommended as it offers a number of advantages: Panchromatic, true color and near infrared images can be acquired simultaneously. Complicated and expensive chemical development procedures are not necessary. A fully digital data flow from flight to the final product is possible.

Expert knowledge about the image scale required to identify illicit crops on aerial photos apparently is not available. The necessary scale depends on various factors such as the film type and the use of stereoscopy in interpretation. From experience with similar tasks of vegetation species identification (e.g. in forestry) it can be concluded that the image scale for illicit crop monitoring if possible should be around 1:5.000, certainly not below 1:10.000. In order to reduce slant effects at the edge of an image, a focal length of at least 210 mm should be chosen. These parameters lead to a flying height between 1.000 and 2.100m above ground.

Specifications of the aircraft include speed (minimum speed should be low), maximum flying distance without refueling, and possible flying altitude. The aircraft has to be adapted for camera operations (camera hole or external camera mount). Detailed flight planning according to the professional standards of photogrammetric image acquisition are essential.

3. Image Preprocessing

3.1 Georeferencing

Georeferencing is the process of adding "real world" coordinates to images. Ground control points (points with known coordinates in the national system) are required to georeference satellite images. In mountainous terrain the additional use of a Digital Elevation Model (DEM) can enhance the geometric accuracy by accounting for distortions as caused by elevation differences. At SIMCI, images are georeferenced on the basis of ground control points from maps and older images without using DEMs. Therefore, for Landsat images, positional deviations of the order of 1/10 of elevation differences can occur in the worst case.

It is recommended that orthorectification with the use of a DEM is applied, thereby increasing the geometric accuracy to below 1.5 pixels. This will facilitate the combination of image data with GIS layers. A free DEM from the Shuttle Radar Topography Mission (SRTM) with a 90 m raster cell can be used for this purpose.

3.2 Radiometric and topographic corrections

Topography has an effect on irradiation and reflected radiance of the earth’s surface particularly in mountainous areas. In general, these effects are caused by varying angles of incident solar radiation. Topographic effects lead to the phenomenon that within one image the same type of land cover shows different reflectance properties depending on slope and exposition of the terrain. It is obvious that this effect can cause a mix-up of spectrally close-by land cover classes and consequently reduce classification accuracy.

Topographic correction aims at recovering image pixel values that are not disturbed by topographic effects and that are reliable measures of surface reflectance characteristics. It requires detailed knowledge of topography (in the form of a DEM), time of acquisition (for deducing azimuth and zenith angle of incident sun radiation), atmospheric conditions (haze intensity – can also be estimated from the image itself) and, if possible, even rough information on land cover (to account for directional reflectance effects). The applied methods range from simple band ratio techniques to the use of complex procedures involving modelling atmospheric scattering.

It would be worth testing methods for radiometric and topographic correction on satellite scenes in different regions of Colombia.

4. Classification of Coca Fields

4.1 Visual Interpretation

The classification of coca fields mainly relies on the visual interpretation of satellite images. The detection is based on the spectral characteristics, the shape, the context and the surroundings of the fields. The class "coca" can be considered to be composed of bare soil and small rows of bushes (Fig. 3). No distinction is made between different phenological stages of coca bushes.

Furthermore small rivers, roads and urban areas are visually interpreted. This is important for the verification flights as these objects can be used for orientation in the field.

Fig. 3: Coca field detected during a verification flight

Coca fields are digitized on screen (Fig. 4). For this purpose a software tool called "pixel seeding" is used to delineate the fields. This means that pixels are grouped together automatically by the software if their spectral value is similar. The similarity threshold for grouping pixels is determined by the interpreter.

In addition, aerial photos taken by the Antinarcotics police (DIRAN), results of an aerial surveillance performed by DIRAN and the census of previous years are taken into account.

The interpretation process relies on the profound knowledge of the interpreters. The interpreters at SIMCI have an experience of many years. They receive training especially during the verification flights. The interpretation is carried out well organized.

Although the visual interpretation is performed with a high degree of commitment and correctness, the disadvantage is the subjectivity of this process. This means that different interpreters may come to different conclusions and produce different results. This is not a criticism of the dedicated work performed by the staff members of SIMCI, but a fair comment of the method of visual interpretation in general.

To improve the results of visual interpretation, on the one hand the compilation and regular use of an interpretation key, and on the other hand the "calibration" of the interpretation results are recommended.

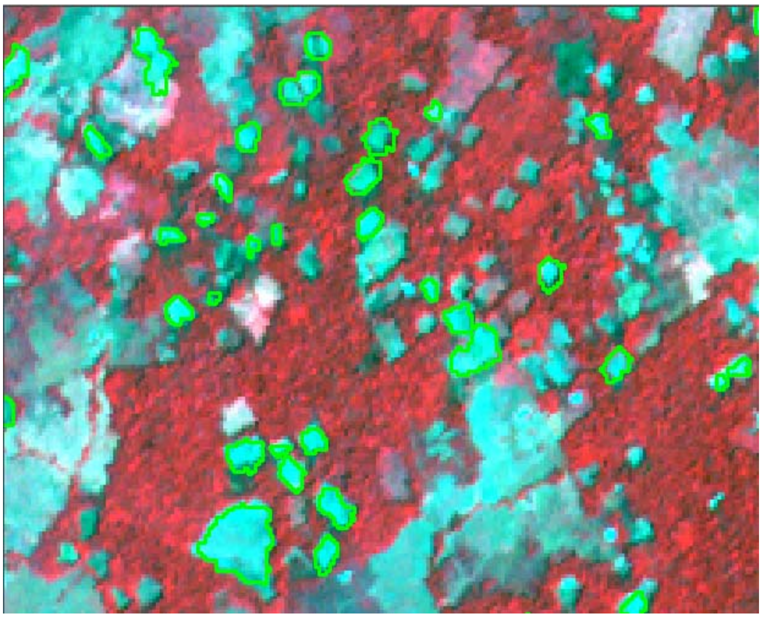

Fig. 4: Detected coca fields on an ASTER image

One of the major difficulties for interpreting coca fields is their size. As investigations have shown, 93% of the fields have less than 3 ha. The average size is about 1 ha. Based on the experience at the IVFL, a minimum of 10 pixel is reasonable for detecting small coca plots, unless it turns out that smaller plots are arranged in characteristic patterns. In this case a smaller number of pixel is acceptable.

In this context a comparison between interpretation results of different imagery (e.g. Landsat – ASTER) would be of interest (Fig. 5). For this purpose, a quantitative analysis of this problem could consist of the following steps:

1. Generation of a ground truth map for a test area based on verification flights and/or aerial photographs. Known coca fields of different sizes are delineated.

2. Different satellite imagery (ASTER, SPOT, Landsat) of the same area are to be analyzed.

3. The images of the same area are interpreted by different interpreters with the same experience (e.g. interpreters Nr. 1 and 2 – Landsat, interpreters Nr. 3 and 4 – ASTER).

4. Comparison of the results.

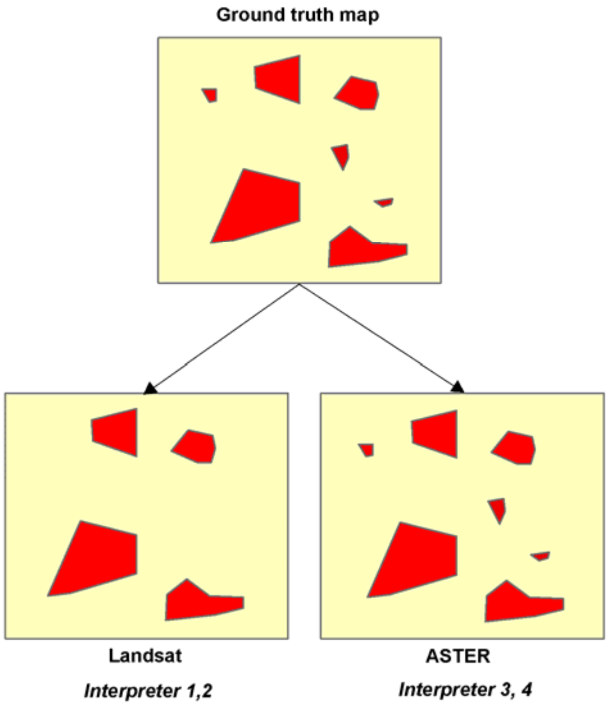

Fig. 5: Analysis of interpretation results

This analysis should help to determine the adequate sensor for detecting coca fields. In addition, the result of this interpretation can be used as a “calibration” of the interpreters, which will be described below.

4.1.1 Interpretation key

The process of interpreting images can be supported through the use of interpretation keys. Keys can be valuable training aids for novice interpreters and provide useful reference or refresher materials for more experienced interpreters (LILLESAND & KIEFER 2000). They help the interpreter to evaluate the information presented on images in an organized and consistent manner. The use of interpretation keys, which, for the entire range of applications, are identically structured, is meant to ensure that the results of inventories are comparable (EUROPEAN COMMUNITIES 2000).

Two general types of interpretation keys exist: A selective key contains image examples of objects of the different categories to be identified, in the present case coca and non-coca fields in various settings, together with supporting text. The interpreter selects the example that most closely resembles the feature found on the image. An elimination key, on the other hand, has the form of a decision tree, guiding the interpreter to the result with a series of decision based of attributes of the object to be interpreted. Typical attributes are size, shape, color, texture, pattern, neighboring objects (context). Combinations of selective keys and elimination keys can also be useful.

The different phenological stages, but also the different geographic growing areas of coca have to be described and accounted for in an interpretation key. Keys are normally developed on region-by-region basis in that the appearance of vegetation can vary widely with location. More information about different types of coca plants and information about different phenological stages with regard to the appearance on satellite images is needed. As ground access is limited, the only possibility to acquire this information is through aerial reconnaissance. Difficulties are to be expected from time differences between aerial reconnaissance and satellite image acquisition.

The interpretation key should be developed by the interpreters or in close cooperation with them, as they have the highest experience on this field.

4.1.2 Calibration of the interpretations

Measures should be taken to ensure that the subjective factor of visual interpretations is minimized and that each of the interpreters adheres to a common standard (EUROPEAN COMMUNITIES 2000). Regular discussion meetings are recommended. Furthermore, there are various possibilities for controlling the quality of interpretations. The most common method is the assessment of the accuracy of interpretations of test areas with given “ground truth” in the form of error matrices as described below. Depending on these error matrices, special training measures for interpreters producing deviating results may be introduced. Depending on the theme of the interpretation, it may also be possible to compensate an interpretation bias of an interpreter (to “calibrate” an interpretation) on the basis of the test area error matrix. It remains to be analyzed whether such a calibration method is feasible for illicit crop interpretations.

These calibrations would have to be carried out on a regular basis, e.g. every two months.

4.2 Automated classification

Another possibility to overcome the problem of subjectivity in the interpretation process is automation of the land cover classification. This is a difficult task as several factors influence the process. The main problem in order to classify crops is the nonexistence of a crop calendar as coca but also other crops are grown throughout the entire year. This makes it difficult to separate coca from other crops based on phenological differences. A land cover classification produced by SIMCI is currently contributed to the planning of activities of other institutions but not explicitly used for the coca or opium survey.

Two different approaches of automated classification can be distinguished: the so-called “per-pixel classification”, and the object-oriented approach.

4.2.1 Per-pixel Classification

An automated per-pixel land cover classification is performed by SIMCI. A supervised classification technique is applied (maximum-likelihood classification). An example is shown in figure 5. 13 classes are distinguished. Coca fields are not classified automatically, but are interpreted visually. The final map is a combination of the visual interpretation (coca fields, roads, rivers and urban areas) and the supervised classification. No accuracy assessment is performed. This would be important and will be discussed in chapter 7.

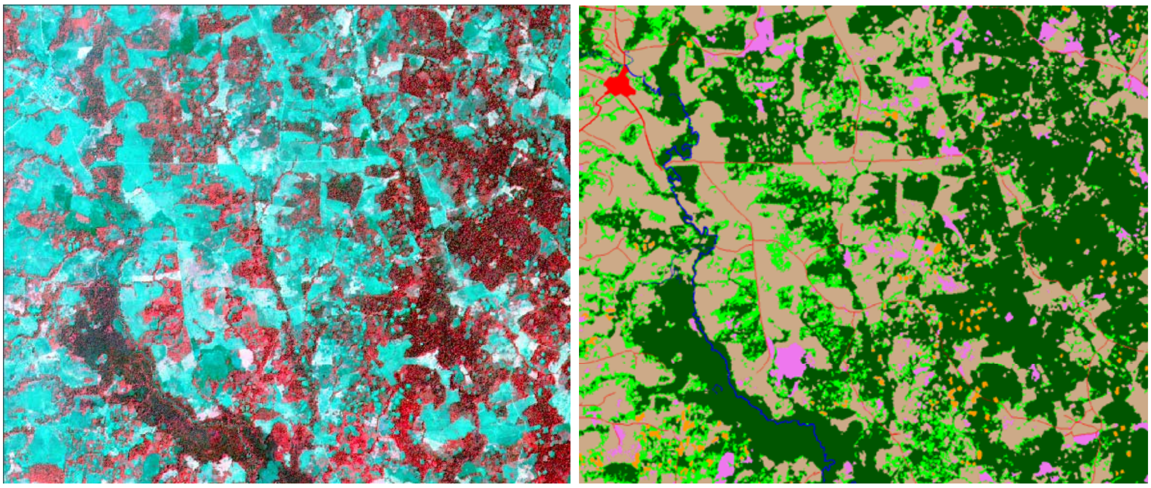

Fig. 6: Satellite image (ASTER) and corresponding land cover classification

Beside the applied maximum-likelihood classification, other methods should be taken into consideration (e.g. decision tree classification, kNN classification, or neural net classification, which do not require normally distributed signatures). It is recommended that these questions are treated in a research project.

4.2.2 Object-oriented Classification

In this case objects (sets of pixels, segments) are classified. The objects are delineated in a preceding step with a segmentation algorithm. The main advantage of this approach is that information on the shape of the objects and context information can be used in the classification process. The overall goal is to imitate and formalize the process of a visual interpretation. The main difficulty is to build up a rule base (i.e. interpretation key) general enough to be used on several images. All types of land cover classes to be distinguished have to be described in detail. An interpretation key used for a visual interpretation could be adapted. With such a description, a rule base can be established. Various existing GIS layers (e.g. elevation, previous surveys, spraying lines, …) can be included into the image classification process. The advantage of such a rule based approach is that the rules can be applied for the following surveys.

This approach was already tested by students of the university in Bogotá (ARDILA & ESPEJO 2004). The first results are promising. The method should be followed and could be part of future research projects together with SIMCI.

5. Corrections

Following the interpretation process, a number of corrections are applied on the result of the survey by SIMCI, to account for the effects of spraying activities before or after image acquisition, for missing image information due to clouds or gaps (SLC off), and for differences in acquisition date of the images. Corrections are a necessary step for improving the final statistics.

- Corrections for spraying

As part of the illicit crop eradication program, coca fields are sprayed from aircraft. The spraying lines are automatically recorded. After transforming the coordinates into the coordinate system of the satellite images, a buffer is calculated depending on the type of the plane and the characteristics of the spraying equipment. The buffer is placed over the coca interpretation (Fig. 6). Corrections are then performed depending on the date of image acquisition and on the date of spraying. Coca areas are ignored if they have been identified and delineated in images acquired before spraying but have been eradicated afterwards.

Corrections for spraying are important, as only those fields are taken into account which can be harvested. The parameters used in the spraying correction procedure are partly unsure and rely on experience. Under circumstances further investigations about the effect of spraying on the coca plants are necessary. In view of the small effect of this correction on the result, however this procedure is reasonable.

Attention has to be paid on the transformation of the coordinate systems. While the WGS 1984 system is used for recording the spraying lines with GPS, the coordinate system of the national survey (a Gauss-Krueger system), based on a different ellipsoid, is used for the coca survey. There can be various reasons for errors in the transformation from one system to the other, leading to incorrect results and to a shift between the different layers (Fig. 6). It is therefore highly recommended that independent checks are made for every transformation, based on unambiguous structures to be identified in the different input data sets. A possible shift between data sets (layers) may also depend on the accuracy of the georeferencing process. Accurately georeferencing the layer with the spraying line information is particularly important if it is to be used in an automated correction procedure in a GIS.

- Corrections for cloud cover and gaps in Landsat 7 images (SLC off)

Clouds and cloud shadow are automatically delineated during the land cover classification process. In a first step, buffers of one kilometer width around the clouds are calculated. The coca cultivation area within this buffer is measured. By comparison with the previous survey, trends for coca cultivation are calculated for the buffer area. This trend is used to estimate recent coca area under the clouds from the corresponding area in the previous survey.

In the 2003 survey, the corrections for the gaps of the Landsat 7 scenes (SLC failure) were treated like clouds. The only difference is the buffer (300 m). The definition of the buffer width is based on experience in both cases. Again in view of the small percentage of clouds and gaps, this procedure can be committed as advisable.

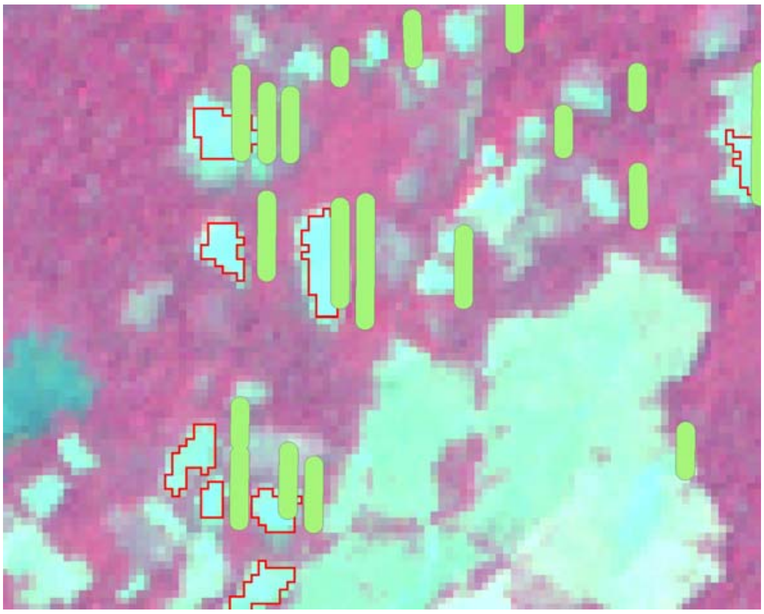

Fig. 7: Interpreted coca fields and buffer of spraying lines with a shift

- Correction for differences in acquisition dates of images

The initial results of the survey are updated to the cut-off date of December 31. Thereby, the influence of different acquisition dates of the satellite images on the result of the inventory is eliminated. For this purpose, a monthly coca increment is calculated from the difference in coca cultivation between images acquired over the same area at different dates, divided by the number of months separating the two images.

This is a useful way for correcting the overall statistics. While the image is a snapshot of one point in time, calculating a trend in this way is recommendable.

6. Verification flights

Verification flights are required for training the interpreters and for correcting the results of the survey. At present, training and verification are based on direct visual inspection of the ground. The main difficulty in this activity is quick orientation during the flight. Paper maps are used for orientation and as data base for verification. The handling of the large format map printouts causes additional problems.

Fig. 8: Field verification with paper maps

In addition to visual inspection from the aircraft, a new digital camera combined with GPS is used for documentation (Fig. 8) by SIMCI. Tests have shown that the localization of the photographs on satellite images is difficult. Distinct points in nature (rivers, roads, junctions) are often not available or cannot be identified on the medium resolution satellite images.

The following measures could improve the efficiency of the verification flights:

- For visual inspection, the application of tablet-PCs in combination with GPS and GIS could improve the field verification procedure. With a “moving map” on a tablet PC, the interpreter could concentrate on the detection of illicit crops on the ground rather than on the handling of the large-format paper maps. Sketches and notes can be drawn digitally with a pen on the map and tied to a geographic location. The technical specifications of tablet-PCs and the usability for this kind field work have to be reviewed (e.g. screen layout).
- Aerial photography and subsequent interpretation of the photos in the lab is to be given preference over direct visual inspection. Color infrared photography offers great advantages in crop identification as compared to visual inspection. Vertical aerial photos are particularly useful for implementing statistical sampling schemes for accuracy assessment as discussed below.

Fig. 9: Digital camera in combination with a GPS

In figure 9, the problem of relating an aerial photograph to a satellite image is illustrated. To facilitate localization of the photos, a vertical view direction should be considered: This produces photos of roughly constant image scale, thereby facilitating the correlation of photos and satellite images. A camera hole in the aircraft or an external camera mount is necessary for this, but is not available at the moment. The use of a large format metric camera as described in chapter 2.3 is recommended.

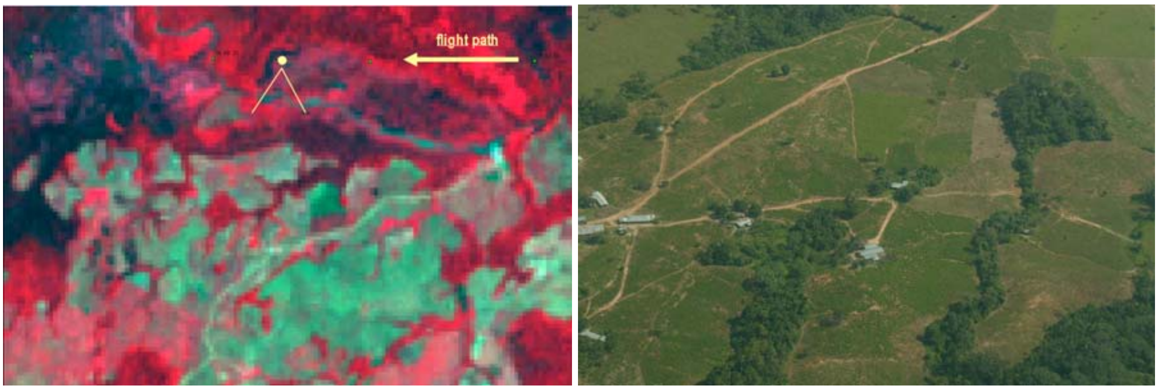

Fig. 10: Satellite image and corresponding photograph taken during verification flight

7. Accuracy Assessment

The assessment of the accuracy of the interpretation result is part of quality control. Accuracy has two aspects: a geometric one (accuracy of the boundaries of land cover units, in particular of coca fields), and a thematic one (reliability of identification of land cover classes, in particular of coca plantations). In this report, geometric accuracy is discussed in chapter 3.1. Here, the thematic accuracy is addressed. It is to be applied on the coca survey, but also on the automated land cover classification.

Thematic accuracy parameters serve a twofold purpose: They are used for refining the methods (by indicating weak points – in particular they are required in the process of calibrating interpretations, chapter 4.1.2), and they provide figures for the reliability of the result for the public.

Thematic accuracy is usually specified in terms of an error matrix, giving the frequency (probability) of misclassifications between the different classes. Various statistical accuracy parameters can be deduced from the error matrix to describe thematic accuracy in a more compact form, like the overall accuracy (providing the mean (average over all classes) percentage of correctly classified area), the class-specific producer's accuracy (providing, for every class, the probability that an area which in reality belongs to the class is correctly identified on the map), the class-specific user's accuracy (providing, for every class, the probability that an area which on the map is assigned to the class is correctly identified), and the so-called Kappa value, which is the overall accuracy adjusted for (reduced by) the fraction correctly classified by chance.

The compilation of the error matrix must be based on a representative, unbiased sample of reference data. The collection of reference data is difficult as access to the ground is not possible due to security reasons. Aerial photographs have to be used as reference data. The way how to collect the data is addressed in chapter 6. Additional problems may occur, as reference data are collected not at the same time as the image capture.

The selection of the sample of reference data is a crucial step in the process, as the design will determine the cost and the statistical rigor of the assessment. The selection of a representative sample strongly depends on the spatial distribution of the classes (CONGALTON & GREEN 1999). A minimum of 50 independent sample elements for each land cover category in the error matrix is recommended. This number should be increased for large areas or the classification of a large number of vegetation or land cover categories to 75 or 100 sample elements per category. It is also important to mention that the accuracy assessment should not be conducted using the same data that are used to train the automated classifier.

A systematic sampling grid is recommended. This can for instance be realized by placing a certain number of flight strips over every satellite image area (e.g. at a distance of 20 km from each other) and taking pairs of aerial photos of a large image scale (e.g. 1:6.000) with 60% overlap at regular intervals or according to a certain distance pattern along the flight lines. These photos are then to be interpreted stereoscopically with regard to land cover categories to provide "ground truth". Error matrices are to be compiled from the comparison of this result and the combination of visual and automatic satellite image analysis. It is felt that this procedure can be implemented with realistic expenditures, if proper sampling parameters are chosen.

Optimization of the procedure (highest reliability at lowest costs) may be possible be using stratified systematic sampling. This question could be treated in a small research project.

8. Opium Survey

Opium poppy estimates are up to now based on aerial reconnaissance flights by the DIRAN. No area-wide survey has been performed yet. A monitoring system has to be developed for this purpose.

Opium poppy is grown all the year round and therefore no crop calendar is available. There are no phenology-induced spectral characteristics. The identification of the crops therefore has to be based on spatial structure to a large extent.

The usefulness of satellite imagery for opium poppy monitoring is limited mainly due to geometric resolution limitations. First tests have shown that, as to be expected, medium-resolution Landsat and SPOT images cannot be used for an area-wide survey. Spatial characteristics of opium poppy plantations are not resolved. In addition, the fields are small, causing mixed pixel problems. However, this kind of sensors can be used for screening the area and the detection of agricultural land with a high potential for opium cultivation.

High-spatial-resolution satellite images such as IKONOS in the multispectral bands still have too low spatial resolution to show spatial characteristics of plantations. Moreover, they are expensive.

In future, hyperspectral remote sensing from satellites may provide a solution for the opium poppy monitoring problem. The enhanced spectral information content of hyperspectral data may facilitate both the spectral recognition of poppy plants and the analysis of mixed pixels. These questions have to be treated in research projects.

While the usefulness of present-day satellite remote sensing for opium poppy monitoring is limited, the application of aerial photographs with metric cameras is advisable. As it is difficult to classify images on the basis of spatial and structural characteristics, the aerial photos have to be visually interpreted.

A monitoring system for the whole country or even for large areas is unrealistic as image interpretation is an extensive work. Hence, a method based on a sample basis should be used for this purpose.

Several points have to be considered:

- area to survey
- sample pattern
- sample size
- statistical analysis of the results
- parameters of aerial photography
- method of visual photo interpretation

Similar considerations apply as for the aerial reference data collection for coca monitoring (chapter 7).

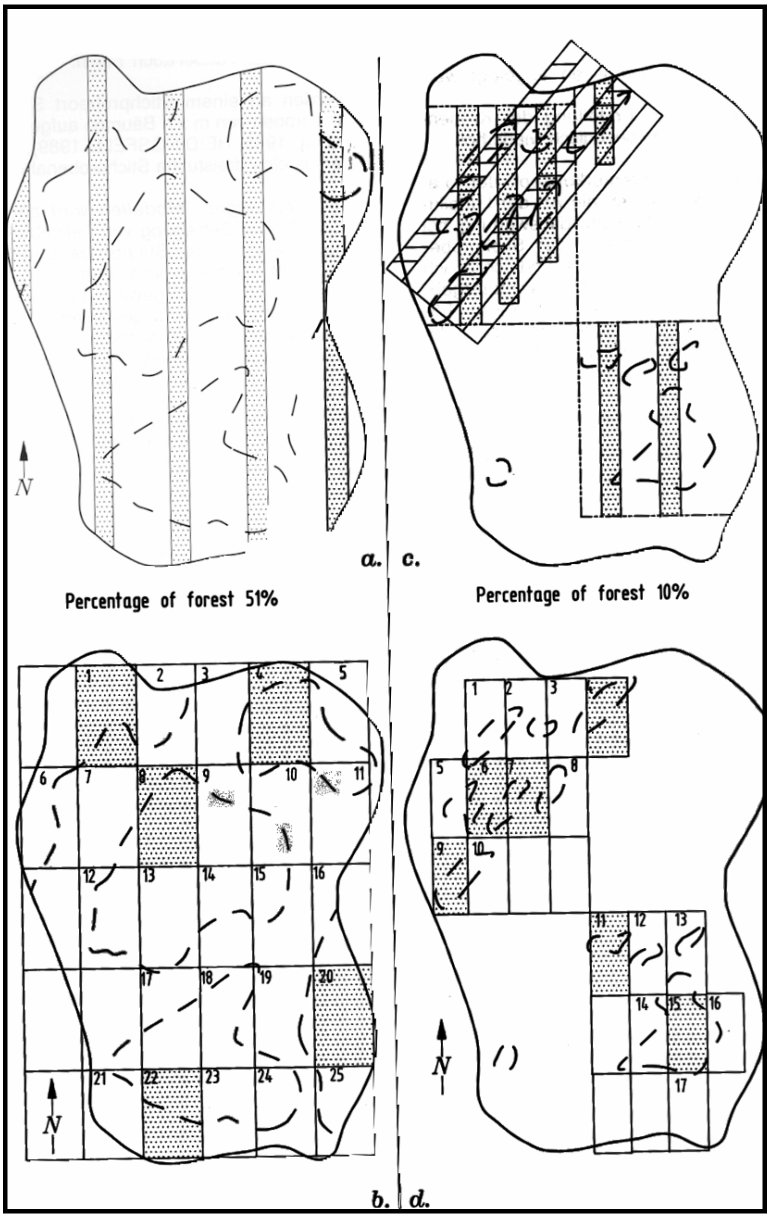

Fig. 11: Flight planning with strips or segments for forest areas (EUROPEAN COMMUNITIES 2000)

Various inventory concepts are available for a sample-based monitoring system on a regional or countrywide scale (EUROPEAN COMMUNITIES 2000). Multistage sampling is recommended. In a first stage aerial photography of sections are selected and for example in a second stage a specific number of photographs is selected. It has proved expedient to conduct the sampling in the form of systematically ordered sample strips (Fig. 10, a/c). For example, every n^{th} aerial photograph on the flight strip could then be taken as a sample. Statistics provides methods to calculate the optimum distance between strips.

As an alternative to this, complete aerial photography of randomly selected or restricted randomly-selected segments of the inventory area can be considered (Fig. 10, b/d). This will mainly depend on the distribution of opium poppy fields over the area.

Again, optimization of the procedure (highest reliability at lowest costs) should be performed in a small research project.

From a technical point of view, the use of a digital metric camera is highly recommended for the flight planning.

Similar to the procedure for coca, an interpretation key has to be developed for the visual interpretation, and interpreters have to be trained. Again, as for the coca monitoring, ground access is not possible for field verification. For this reason, accuracy assessment will again rely on aerial photographs (see chapter 7), may be of higher image scale.

9. GIS and Data Management

The combination of existing information available in the form of digital GIS layers with digital image processing can improve the accuracy and categorical detail of land cover classifications. For example a DEM, results of previous surveys, or information about spraying are already stored in a GIS database. These layers in combination with other data (e.g. information about soil, climate, etc.) can be used for spatial analysis during a post-classification process in order to improve the final statistics for the census. An analysis of coherences between several factors which might influence the growing of illicit crops would be necessary.

Effective data management within a large office is an important topic. The use of a GIS offers several ways for an effective geo-data management. A central database for storing all kind of geographical data in combination with metadata will simplify the usage of these data for all users. Data can easier be managed, accessed and updated.

In this context data documentation is important when more users got access to centrally stored data. Metadata are essentially "data about data." They are an integral part of the spatial data in that they describe the content, quality, status of processing and other characteristics of the spatial and attribute data. Even if not a central database is used, data documentation is recommended for a project like SIMCI. For the definition of metadata several standards already exist (e.g. ISO, FGDC), which can be used or adapted.

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