THE PROCESSING OF SPOT IMAGERY IN BRAZIL

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ABSTRACT

The purpose of this paper is to show the present situation of the Brazilian SPOT Direct Receiving Station, involving both the SPOT Receiving and Recording Station and the SPOT Image Processing Center. One of the main functions of the Processing Center is to perform the radiometric and geometric treatments in order to eliminate system distortions inherent to the HRV-SPOT images generation process. Nowadays, the station is capable to process images in the 1A and 1B levels, in both digital and analogical domains. In addition, new developments are being carried for the generation of HRV-SPOT images in the levels 2A, 2 and 3, where extra information obtained from ground control points and digital terrain elevation models are used to refine the geometric system corrections.

1. INTRODUCTION

The Brazilian SPOT Direct Receiving Station (BSDRS), set up by INPE, begun its operational phase in December, 1987. It comprises the SPOT Receiving and Recording Station (SRRS), located at Cuiabá, Mato Grosso State, and the SPOT Image Processing Center (SIPC), situated at Cachoeira Paulista, São Paulo State.

The antenna of SRRS is shared with the Landsat Receiving and Recording Station (LRRS), and its location allows full coverage of Brazil and most of South America. SIPC makes use of hardware facilities of INPE's Image Generation Department (DGI) which were primarily configured in view of TM data processing, and are still used also to this end.

Figure 1 shows the present hardware configuration both for SRRS and SIPC, while Figure 2 presents the software already implemented. Together, they give an overview on the complete SPOT data manipulation cycle performed at BSDRS.

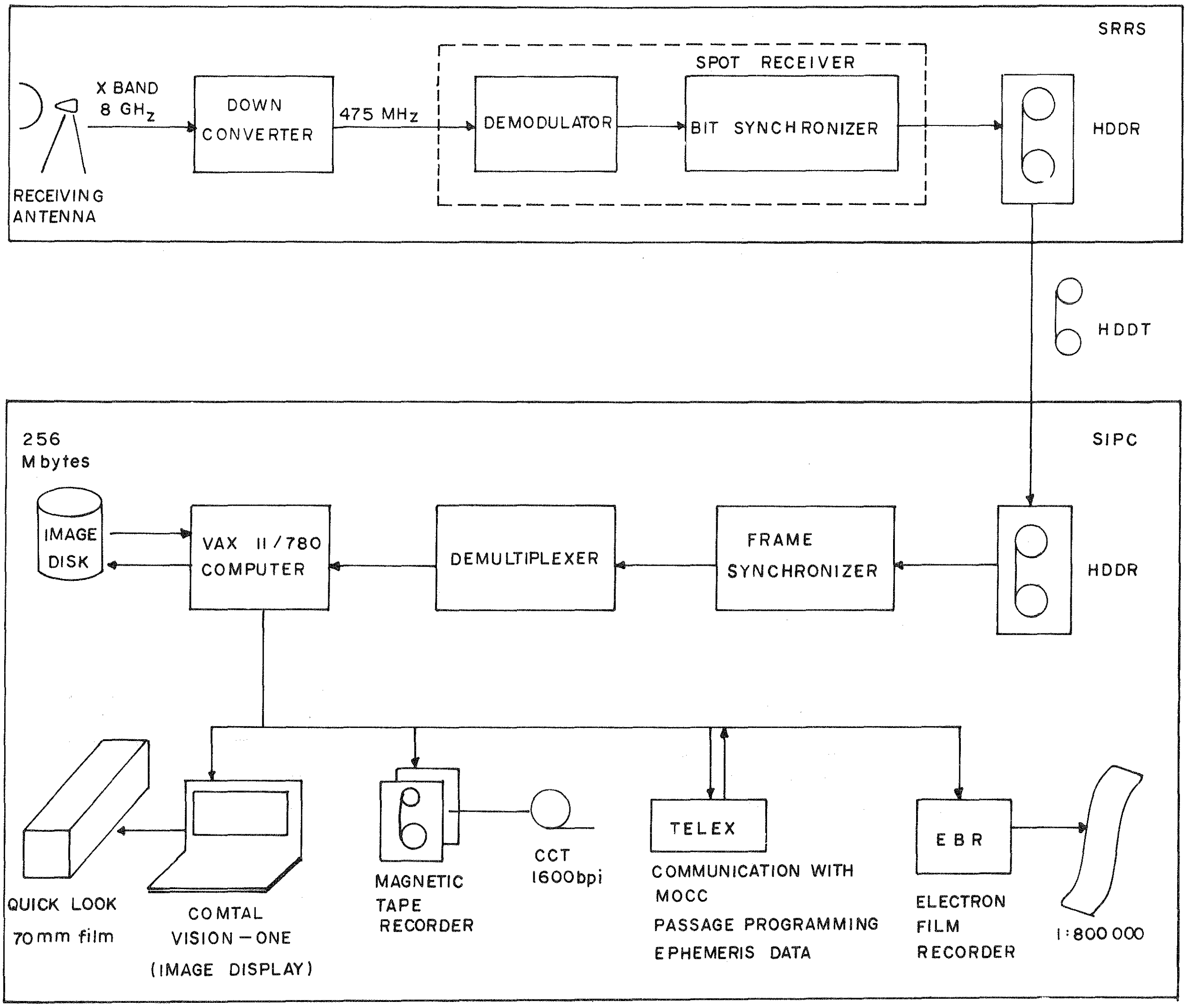

figure 1 — BSDRS HARDWARE CHAIN

Nowadays, the station is capable of producing images in the 1A and 1B preprocessing levels, and new effors are being carried by INPE in order to enable the processing at higher levels. These efforts are oriented into two directions:

— Development Project SPOT2, whose objective is to implement a processing subsystem corresponding to levels 2A and 2 before the end of 1988,

— Research Project SPOT3, where experiments with Digital Terrain Elevation Models are being made with the aim of giving subsidies to a future development project.

The differences between the various levels are concentrated on software functions GEO and COR, and so the following sections are dedicated to describe the different mathematical models associated with them.

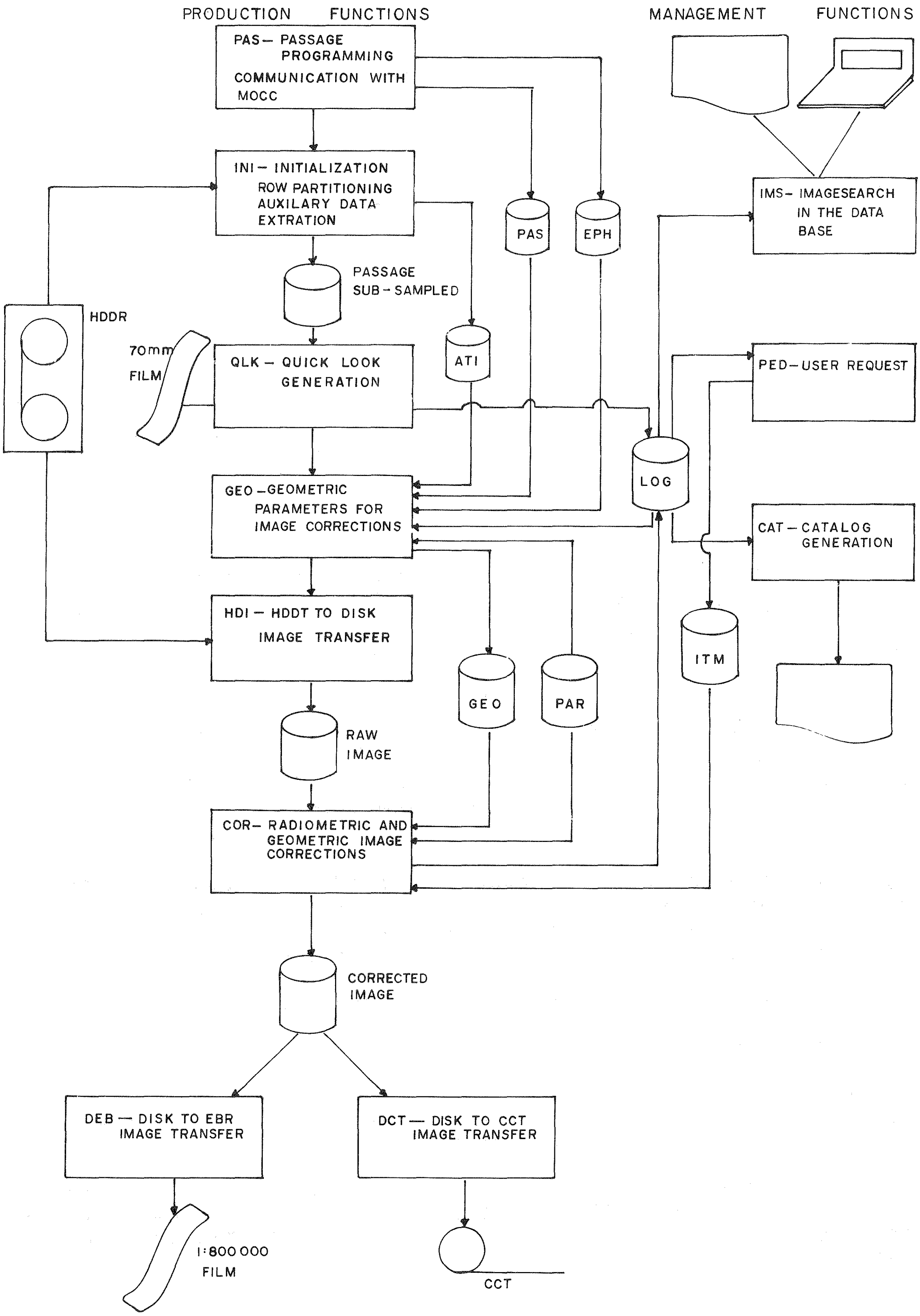

figure 2 — SIPC SOFTWARE CHAIN

2. PREPROCESSING LEVELS 1A AND 1B

As stated earlier, these are the levels at which SPIC is presently capable to generate SPOT images. Thus, in the scope of the software package already implemented, the aim of GEO is to determine the geometric correction parameters for the image generation at level 1B; for all scenes recorded during one pass of the satellite. COR is applied for the generation of each scene, both on level 1A and 1B; if the level is 1A only radiometric corrections are done, while if it is 1B the geometric corrections are also taken into account, based on the parameters computed by GEO.

2.1 — GEO FUNCTION

On level 1B, one-dimensional geometric corrections are used, which allows one to write the inverse mapping equations as follows:

$$L = f\ (I) \qquad (1)$$
$$C = g\ (J) \qquad (2)$$
$$\Delta J = h\ (I) \qquad (3)$$

where (L,C) and (I,J) correspond to (line, column) in raw and corrected images, respectively.

The applied geometric correction model, known as photogrammetric model, relates each point in a raw image to another one in a tangent plane to the reference ellipsoid, with the tangency point corresponding to the raw image center.

Due to the HRV-SPOT sensor characteristics, all the pixels belonging to a given raw line are acquired at the same time. Because of this, the sight directions relative to these pixels determine a plane, and thus the intersection of this plane with the projection plane defines a straight line, which validates the hypothesis related to equation 1. Nevertheless, it is important to observe that the direction of this line will be variable if the heading velocity and the yaw are not constant.

Otherwise, the pixels belonging to a given raw column are sampled at different times, being submitted to different effects coming from attitude and heading velocity changes and, above all, from Earth's rotation. These effects give rise to displacements between consecutive lines, causing discontinuities in the columns; these displacements are taken into account by equation 3.

Functions f, g and h were specified as third order polynoimials, being left to GEO the determination of their coefficients $\{fi\}$,$\{gi\}$ and $\{hi\}$, as well as the computation of geodetic coordinates (latitude ϕ and longitude λ) of the scene center and of its corners.

The polynomials coefficients are determined by applying the photogrammetric model to two sets of 61 breakpoints each, one regularly spaced along the center line ({gi}) and the other along the center column ({fi} and {hi}).

The photogrammetric model can be depicted by a two equations system, the first one corresponding to the straight line defined by the satellite position and some sight direction, and the other one corresponding to the reference surface.

Initially, the position of the satellite and the reference surface are entailed to the Greenwich geocentric system, and the sight angles are related to the HRV imager reference system as a function of operation mode, mirror position and detector number. Transformation from the latter to the former system is done in three steps, through boresight and attitude angles, and ephemeris data.

Attitude angles are determined by integrating attitude rate data broadcasted by the satellite. This integration is first carried out assuming a null attitude for the first received attitude rate record; later, when the geometric parameters for each scene are to be computed, the attitude at scene center time is subtracted from the integrated data corresponding to that scene, thus zeroing the scene center attitude. Ephemeris data obtained via telex link are interpolated through a seventh order Lagrangian polynomial.

The projection plane has its tangency point to the ellipsoid defined by the application of the photogrammetric model over the ellipsoid for the scene center. The photogrammetric model is then applied over this plane for every breakpoint, leading to a set of points with coordinates referred to the Greenwich geocentric system.

Afterwards, a projection system is defined with origin in the tangency point to the ellipsoid, Y axis corresponding to the center line on the projection plane, eastward oriented, and X axis orthogonal to Y, southward oriented. Using the origin coordinates and the unitary vectors X and Y, both related to the Greenwich geocentric system, it is possible to perform the transformation from this system to the projection system for all the breakpoints.

The lines and columns of the corrected image are oriented along the Y and X axis, respectively; for this reason, the conversion from metric projection coordinates to discrete coordinates (I,J) is easy and conditioned only to the nominal spatial resolution and the corrected image dimensions.

The coordinates L_k, I_k and J_k ($J_k = J_k - J_{61}$) of the center column points are then related, and the coefficients {fi} and {hi} determined. In the same way, Ck and Jk of the center line points are related, and the coefficients {gi} computed.

The geodetic coordinates of the scene corners are obtained by applying the photogrammetric model over the reference ellipsoid for the four raw image corners.

2.2 — COR FUNCTION

This function is applied when an HRV—SPOT scene is to be generated, both on level 1A and 1B. In the first situation, only a radiometric calibration is executed, corresponding to a normalization of detector responses in each spectral band. On level 1B, besides the calibration, also radiometric deconvolutions along lines and columns and geometric corrections are applied.

The gray level interpolation associated to the geometric corrections may be performed in two different ways: nearest neighbour for lines and columns, or nearest neighbour for lines and cubic convolution for columns. In the former option, polynomials f and g are used to determine respectively the lines and columns to be supressed or repeated. In the latter, polynomial f is used in the same way as in the former option, and polynomial g defines, within a given line, the four neighbours to be considered in the convolution. In both options, polynomial h is used to compute the number of black pixels corresponding to the corrected image left skew.

All operations executed by COR require the raw image to be read only once.

3. PREPROCESSING LEVELS 2A AND 2

The HRV—SPOT imagery generation sybsystem for levels 2A and 2 uses a geometric correction model which is applied in three steps.

In the first one, a direct mapping is determined through the photogrammetric model over the ellipsoid for a grid of 61 x 61 breakpoints regularly distributed over the raw image. A set $(L, C, \phi, \lambda)_{ij}$ is obtained for each breakpoint, and the geodetic coordinates are transformed into projection coordinates (UTM, SOM, etc.), which are then converted into discrete image coordinates (I, J). As a consequence, a direct relation (L, C)—(I, J) is set up.

The second step begins with the direct mapping inversion, by using a grid of breakpoints regularly distributed over the corrected image. For this purpose, it is current to use from third up to fifth order polynomials, which are defined by the resulting grid in the first step. This model has some disadvantages, as polynomials cannot represent high frequency distortions. Moreover, they are not reliable when applied to points located outside of the original grid. INPE is now searching into the determination of the inverse grid breakpoints from the four direct grid nearest ones.

The last step refers to the resampling process, where a gray level is determined for every point on the corrected image. The resampling includes a rotation over the images in order to orientate them northwards. Every line on the corrected image is related to 950 lines on the raw image in the P mode or 475 lines in the XS mode, so increasing the necessary computer

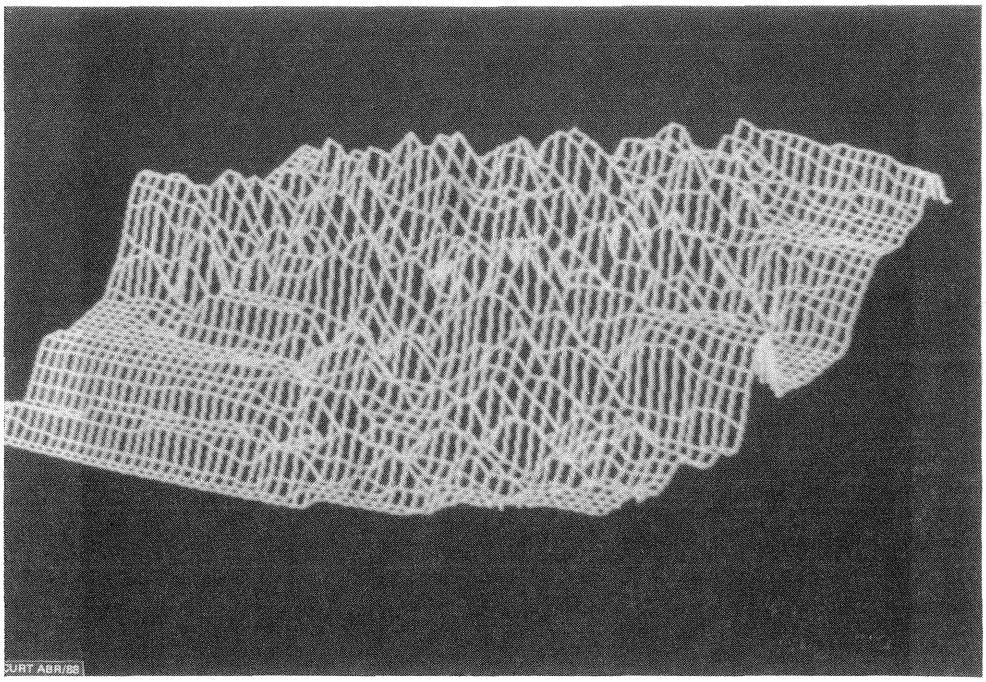

Fig. 3 - Digital Elevation Model of the test area. Observer position: elevation 30 degrees, azimuth 150 degrees. Vertical scale exaggerated for clarity.

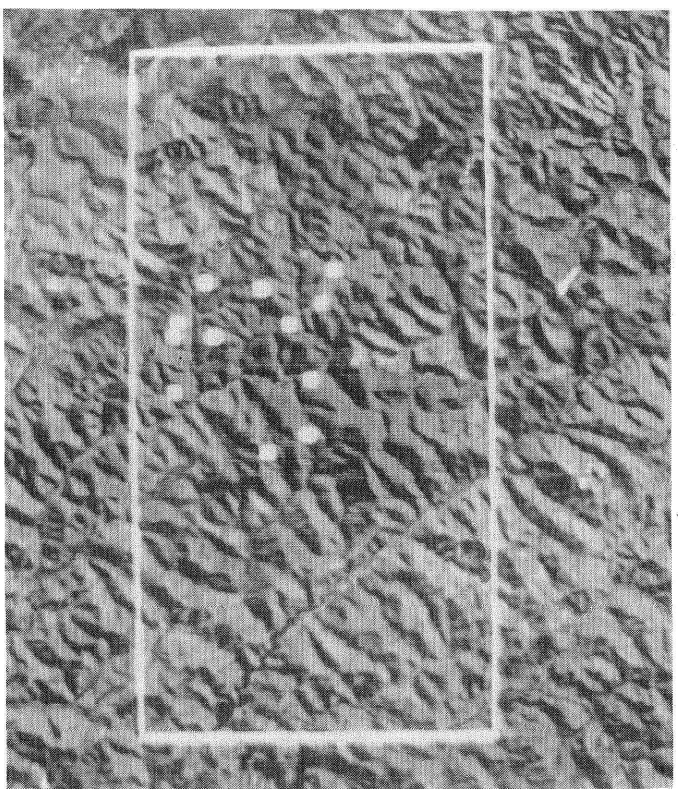

Fig. 4 - False color TM image with a cursor indicating the region where the correction was performed and the sample points for the maximum likelihood classification (3 classes, 4 samples for each class).

position of the sensor with respect to the terrain normal (exitance angle). In this study the satellite images were acquired under the supposition of nadir looking sensors, in spite of the fact that for illumination correction the exitance angle was not used.

Another distortion produced by the topography is the geometric distortion, described by Guindon, Goodenough, and Teillet (1982), and expressed as:

$$\Delta g = h \tan\theta$$

where θ is the sensor looking angle,
h is the elevation above the ground reference, and
Δg is the ground range error.

For the present test area θ is smaller than 4 degrees and $h<1000$ m, rendering the ground range error to the subpixel level.

RESULTS AND CONCLUSIONS

In order to assess the relief effect correction on the image classification, the maximum likelihood classifications were compared before and after the correction. Figure 4 shows the sample positions used on both classifications, as well as the interest region adopted (inside the cursor area). The classification on the original scene identified three classes, mainly on the forest limits, as seen from Figure 5. It was painted blue the darkest class (class 1), pink the medium shaded class (class 2), and white the clearest class (class 3), on the reforested area, seen in red in Figure 2.

The corrected image is presented channel by channel on Figure 6, and as a color composition on Figure 7. Note the difference between this last Figure, and Figure 1. The image degradation is supposed to be due to the linear interpolation on the DEM, and the Lambertian illumination model.

The classification of the corrected scene (channels 3, 4 and 5) is presented on Figure 8. Table 1 shows the areas of each class. The same sample positions were used, taken from the corrected image after being registered to the original image, and the same class names were given. The classified image is painted with the same colors as the original image.

TABLE 1

AREAS FOR EACH CLASS

CLASSES	ORIGINAL	CORRECTED
1 (BLUE)	3.953 km	4.568 km
2 (PINK)	8.397 km	7.252 km
3 (WHITE)	4.548 km	19.349 km