Evaluation of SPOT Imagery on Analytical Photogrammetric Instruments

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ABSTRACT: A rigorous method for the geometric processing of SPOT images has been developed and implemented on analytical photogrammetric instruments. Level 1A film products as delivered by SPOT IMAGE or other SPOT image distributors may be used on these instruments to produce Digital Elevation Models, orthophotos or linemaps. The method has been implemented and tested on the Zeiss Planicomp and Orthocomp hardware. A bundle adjustment program BINGO has been modified to handle CCD line scanner geometry for the restitution of the images. Results using a panchromatic SPOT stereo pair over the area of Marseille in the South of France are presented and discussed.

INTRODUCTION

SPOT has been successfully launched in February 1986 and since that time stereo image pairs are available on request. Because of the digital nature of the data digitale image processing techniques seem to be most adequate for most users. However, most digital image processing systems do not have the possibility of threedimensional processing and displaying of the data in terms of soft- and hardware and complicated processes, such as automatic image correlation are involved. For photogrammetric evaluations 3D processing is a prerequisite in order to produce precise maps or data sets.

Analytical instruments are available since nearly 20 years and in principle are capable of handling imagery with any geometry. Therefore, the processing of SPOT images with CCD line geometry consists only in the modification of existing software on these analytical instruments. Furthermore, photographic copies of SPOT images are cheaper than images on CCT.

Several attempts have been made in the past for the formulation of the geometrical model of CCD line scanner imagery (*Derenyi and Konecny 1966, Bähr 1976, Egels 1983, Toutin 1985, Wu 1986, Kruck and Lohmann 1986*). This paper shows a new possibility, which avoids high correlations between the unknowns and is based on the use of photo coordinates. The unknowns of the orientations are approximated by the use of orbit data and in the course of adjustment partly formulated as additional parameters.

MATHEMATICAL MODEL

An aerial photograph is a central perspective image of part of the earth surface with a common size of 23 x 23 cm. Within one strip a number of photos are taken at regular intervals. These overlap to a high degree. The exterior orientation of one photograph is given by the coordinates X_o, Y_o, Z_o and the angles φ, ω, $\varkappa$.

A CCD-Line Scanner commonly has one or more CCD-Line Sensors mounted in the focal plane of the optics. While the platform moves, the terrain is continuously projected onto the sensor. Within fixed time intervals (cycles) the measured intensities are read out of the single sensor elements of each line. In the case of a simultaneous read-out of all elements during each cycle the image of each line can be regarded as a central perspective.

The exterior orientation of each single line is given by six parameters, as in the case of aerial photography, but the parameters of neighbouring lines are highly correlated. This is especially true, if the scanner is mounted on a platform of a high altitude satellite with a geocentric orbit.

The sensor is moving uniformly, without acceleration during the period of acquisition from A to E (see *Fig. 1*).

Fig. 1

If the computation of the orientation parameters is performed in a coordinate system such as Gauss-Krueger or UTM, the flight path from A to E may be considered as straight. The center of projection moves linearly from A to E, which means:

$$X_{o,i} = X_{o,A} + S_i/S_{AE} \cdot (X_{o,E} - X_{o,A}) \qquad (1)$$

where

$X_{o,i}$: positional vector of the center of projection at time i

$X_{o,A}$: as above, but for the first line

$X_{o,E}$: as above, but for the last line

S_i : distance from $X_{o,A}$ to $X_{o,i}$

S_{AE} : distance from $X_{o,A}$ to $X_{o,E}$

The ratio of the distance in (1) may be replaced by

$$i/n = S_i / S_{AE} \tag{2}$$

where

i : number of actual line (time of exposure)

n : total number of lines

As first approximation the orientation angles φ, ω, and $\varkappa$ are regarded to be constant. The computation is performed using a tangential cartesian coordinate system located near the area of interest. For a discrete point of one line in the image its collinearity equation may be formulated according to

$$X - X_o = \lambda \cdot R \cdot x' \tag{3}$$

where

$$x' = (0, y', -c) \tag{4}$$

y' corresponds to the pixel number j within that particular line and is related to the center of the line, while c is the focal length of the instrument.

The approximation used assumes a linear non-accelerated movement. In reality the elliptical form of the orbit and accelerations caused by manoeuvering actions together with movements due to the nonuniform gravity field of the earth cause the platform not to move in a defined orbit, and the angles φ, ω and κ do not remain constant. All six parameters of orientation are a function of time. Unfortunately the function itself is not known a priori and must be approximated by methods such as polynomials or time series (*Wu 1986).* It becomes clear, that the equations developed so far do not meet the reality, but in case of a satellite based CCD-sensor a very simple solution for the refinement of the approach may be given. A satellite compared to an aircraft moves very gently in its orbit. In addition the terrain heights are small compared with the flight altitude. Because of this the 6 orientation parameters of a perspective projection are highly correlated amongst each other, i.e. φ with X_o and ω with Y_o, assuming a flight in X-direction. In terms of ground coordinates it is therefore unimportant if φ or X_o is changed. Thus orbit refinements may exclude nonlinear changes of the orbital path if changes of φ, ω and κ are allowed.

These angular changes are a function of time i. In terms of mathematics they may be expressed as additional parameters, which change the image geometry. The question, which distortions are most likely, leads to a set of 8 parameters, which are shown in *Figure 2.* This set of parameters may be expanded if desired. Therefore the orientation angles are treated to be time invariant.

Fig. 2

Within the presented approach for each image the coordinates of the center point M *(Fig. 3)* and the orientation angles φ, ω and $\varkappa$ as well as the additional parameters are considered to be unknowns.

Fig. 3

By using satellite orbital data (ephemeris) approximations of the unknowns can be computed. Because of the rotation of the earth, the direction of flight h (heading) is not identical with the direction of the flight track t_{AE} on ground (Real TRACK HEADING).

The angle of difference r (rotation) is a function of the angular speed of the earth, the geographic latitude, the inclination and the time for one orbit period of the satellite:

$$h + r = t_{AE} \quad (7)$$

$$\text{and } \varkappa \approx h \quad (8)$$

In a similar way the direction of the flight track t, the distance S_{AE} and the height difference between A and E may be derived from orbital data. In case of missing orbital information these values may be obtained from existing maps or from measurements on the ground.

According to the empirical a priori standard deviation a weight is assigned to the unknowns φ, ω, $\varkappa$ in order to stabilize the block. The parameters t_{AE}, S_{AE} and H_{AE} are used to interpolate the centers of projection between A and E. In addition control points and tie points are included in the adjustment.

This approach is similar to standard bundle adjustments with central perspective projections and hence easy to implement into existing bundle adjustment programs. In the same way it becomes possible to adjust simultaneous photographs with central perspective and CCD-images. The utilization of all the other options of existing software is part of this approach. The presented algorithm has been integrated as an option to the Hannover bundleblock adjustment program BINGO (*Konecny et al. 1986, Kruck 1983).*

The above mentioned 8 additional parameters are a subset of 32 parameters, which may independently be selected for each image.

IMPLEMENTATION

The total restitution process is shown in the flow chart of *Fig. 4*. As input to the bundle adjustment program BINGO serve the image coordinates for all points as well as the ground control point coordinates. The header file data of SPOT image tapes are used by CSPOT to compute approximate orientations and sensor specific parameters.

Fig. 4

The adjustment with BINGO will result in the following:

- 6 parameters of exterior orientation X_M, φ, ω and $\varkappa$
- the values of the additional parameters representing the difference between the approximated uniform movement and the reality; redundant parameters are automatically removed
- the correlation of the additional parameters

- three-dimensional coordinates of object points
- variances and covariances of the unknowns
- the variance components of the observations to check the stochastic model.

These results are used by several programs to enable the production of orthophotos or other photogrammetric evaluations on analytical plotters.

The use of standard application software on analytical plotters requires central perspective images. In order to use SPOT data the differences between central perspective and SPOT geometry have to be considered. The necessary corrections depend on the terrrain heights, which at this stage of processing are not available. Therefore B 105 computes two correction grids with fixed terrain evaluations for each image. The real time program OLLI computes the actual stage corrections by bilinear interpolation as a function of the image coordinates and the actual point elevation. This is demonstrated in *Figure 5*.

Fig. 5

The image coordinates of a point P_k having an elevation Z_k are corrected by dx'_k, dy'_k according to:

$$\Delta x'_k = (x'_k - x'_{(i,j)}) \,/\, g$$
$$\Delta y'_k = (y'_k - y'_{(i,j)}) \,/\, g \qquad (9)$$

$$dx'_I = dx'_{(i,j)} + \Delta x'_k(dx'_{(i+1,j)} - dx'_{(i,j)}) + \Delta y'_k(dx'_{(i,j+1)} - dx'_{(i,j)}) +$$
$$\Delta x'_k \Delta y'_k(dx'_{(i,j)} - dx'_{(i+1,j)} - dx'_{(i,j+1)} + dx'_{(i+1,j+1)}) \qquad (10)$$

$$dx'_k = (dx'_{II} - dx'_I) \cdot (Z_k/(Z_2 - Z_1)) + dx'_I$$
$$dy'_k = (dy'_{II} - dy'_I) \cdot (Z_k/(Z_2 - Z_1)) + dy'_I \qquad (11)$$

I represents Z-level 1 for each image

II represents Z-level 2 for each image.

In case of the generation of orthophotos the output of BINGO and an existing DTM are used by the program SIREC to generate a file of anchor points, containing profiles in the ground and the image coordinate system. This file may be used by the software of orthophoto printers or digital image processing systems to generate the desired output.

PRACTICAL RESULTS

The approach discussed was tested using a panchromatic stereo pair in the South of France. *Figure 6* and *Table 1* show one image with control and describe the acquisition data. This stereo pair was the only one available at the time of evaluation.

Fig. 6

The results of the bundle adjustment with BINGO are shown in *Table 2.* As mentioned earlier the program automatically selects the additional parameters out of a set of 32 and removes redundant parameters. In any case the parameters 8 and 7 (see *Fig. 2)* have been selected and are of major importance.

The gain in accuracy by increasing the number of control points is not proportional to the effort for the determination of these control points. However, 18 control points were necessary to stabilize the geometry in this case, considering that over 50 % of the model is covered by water, and the ground control has been taken from existing 1:25 000 maps.

The results prove that SPOT stereoscopic data may be used for the purpose of topographic mapping up to a scale of 1:25 000.

Using the data obtained by aerial triangulation a DTM was generated on the ZEISS Planicomp C100 for part of the image. It is shown in *Fig. 7*.

Fig. 7

The DTM was sampled with a spacing of 500 m and an accuracy of 7.5 m rms. This DTM could then be used to print an orthophoto as shown in *Fig. 8*. *Figure 9* shows as an example a line map obtained by digital plotting on the analytical plotter, which in combination with the orthophoto and a thematic overlay produced by digital image processing completes the needed information for topographic mapping.

Fig. 8

Fig. 9

SUMMARY

The presented approach of evaluating SPOT images on analytical instruments allows the use of existing hard- and software and promises good results for topographic mapping up to a scale of 1:25 000.The modification of the existing software is easy to implement and is hardware independent. However, because of the digital nature of the data, a pure digital processing is desirable. Presently the digital image processing system GOP 300 from CONTEXT VISION at the University of Hanover is being reprogrammed and redesigned to combine the advantages of digital image processing techniques and photogrammetry.

ACKNOWLEDGEMENTS

The practical implementation of this method consisted of a joint effort of the authors and their colleagues, *G. Picht, R. Priebbenow, M. Michaelis.*

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Table 1: Acquisition Data

	CCT ST006038	CCT ST005353
Instrument	HRV1	HRV1
Mean orbit altitude	830 km	830 km
Focal length	2087,4 mm	2087,4 mm
Photo scale	1:400 000	1:400 000
Format	15 x 15 cm	15 x 15 cm
Area	~ 60 x 60 km	~ 60 x 60 km
View angle	25°02' left	26°11' right
b/h	1:1,05	
Date	11-5-86	18-5-86

Table 2: Results of Bundle Adjustment

Number of adjusted points	Number of control points	Add.Par. left/right	Internal accuracy				
			σ_o	σ_{xy} max	σ_{xy} mean	σ_z max	σ_z mean
86	18	4/3	8.4	8.7	5.2	10.9	8.5
86	34	3/3	7.9	6.1	4.5	8.8	7.1
89	83	4/5	6.1	4.5	3.0	5.6	5.0

Number of independ. check points	Number of control points	Mean Differences			Mean Square Differences		
		x	y	z	x	y	z
68	18	7.9	10.4	4.8	10.9	13.7	6.5
52	34	8.3	10.5	4.5	11.3	13.8	6.2

CAPTIONS

Figure 1: CCD Line Scanner Imaging with Non-accelerated Uniform Movement

Figure 2: Additional Parameters to account for the non-uniform Movement and Earth Rotation (1 & 2 periodic change of φ; 3 & 4 periodic change of ω; 5 periodic change of χ; 6 correction of earth curvature for $\varphi = 0$; 7 affinity; 8 earth rotation)

Figure 3: Definition of Heading h, Real Track Heading t and Earth Rotation r

Figure 4: Flow chart of the Restitution Process

Figure 5: Determination of Stage Corrections (Left: Bilinear Interpolation using 2 Elevation Levels; Right: Computet Correction Vectors at one Elevation Level)

Figure 6: SPOT Level 1a Panchromatic Image No ST00 6038 (left) purchased from Spot Image. Land Control-/Check Point Distribution

Figure 7: Digital Terrain Model derived from SPOT Stereoscopic Data using an Analytical Plotter

Figure 8: Orthophoto Print (original scale 1:100 000)

Figure 9: Example of linemap covering the same area as the orthophoto as obtained by digital plotting on the analytical plotter (original scale 1:100 000)

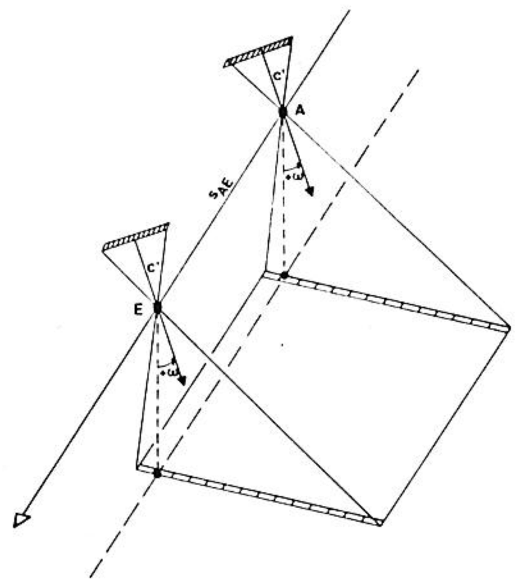


FIG. 1

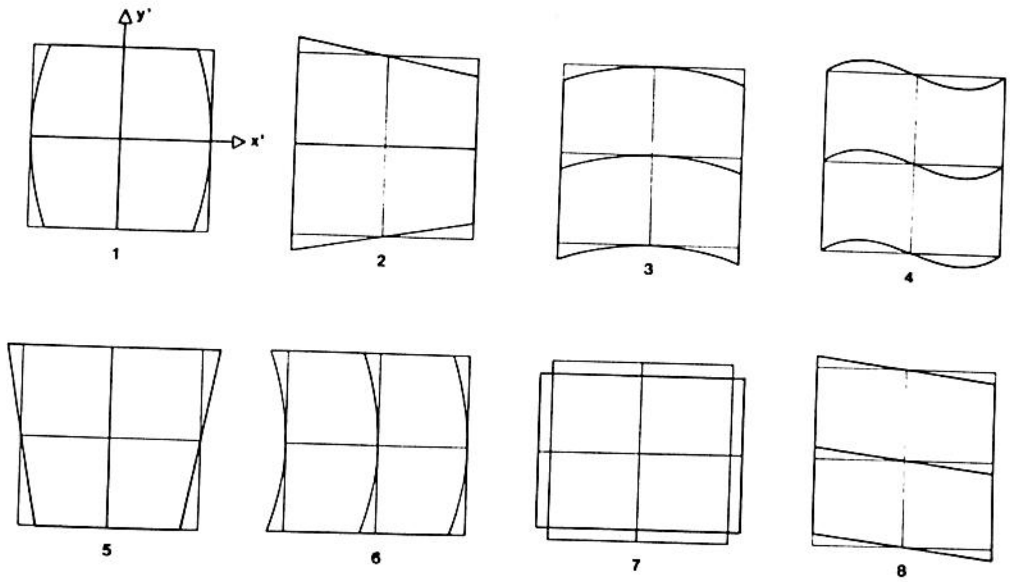


FIG. 2

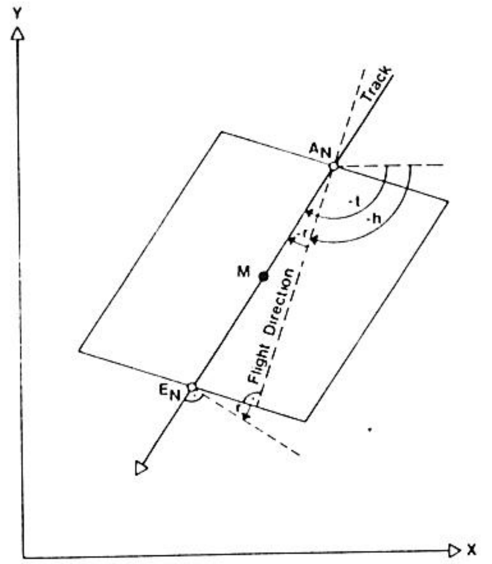

Y
Track
A_N
-t
-h
-r
M
Flight Direction
E_N
r
X

FIG. 3

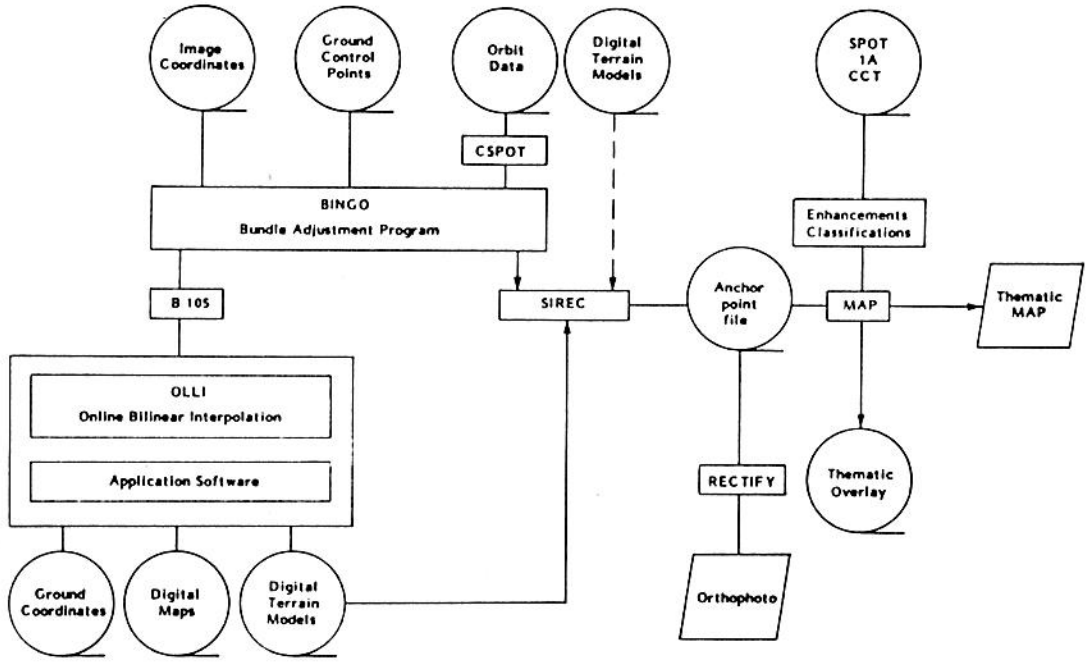
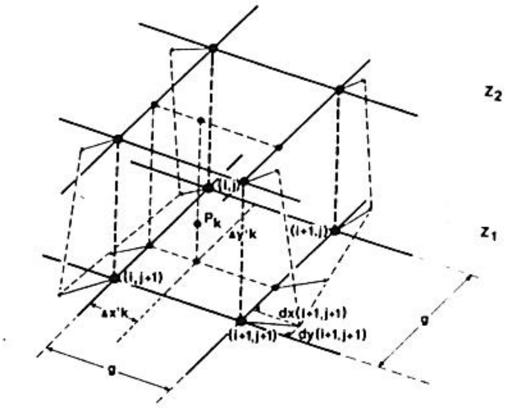
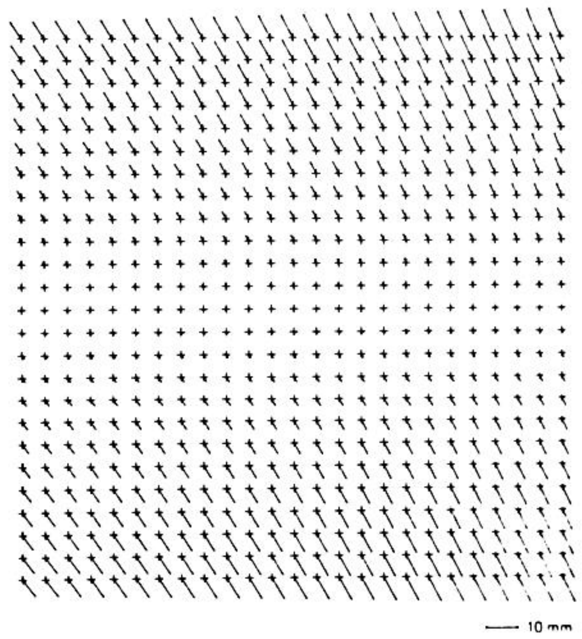


Image Coordinates
Ground Control Points
Orbit Data
Digital Terrain Models
SPOT 1A CCT
CSPOT
BINGO
Bundle Adjustment Program
Enhancements Classifications
B 105
SIREC
Anchor point file
MAP
Thematic MAP
OLLI
Online Bilinear Interpolation
Application Software
RECTIFY
Thematic Overlay
Ground Coordinates
Digital Maps
Digital Terrain Models
Orthophoto

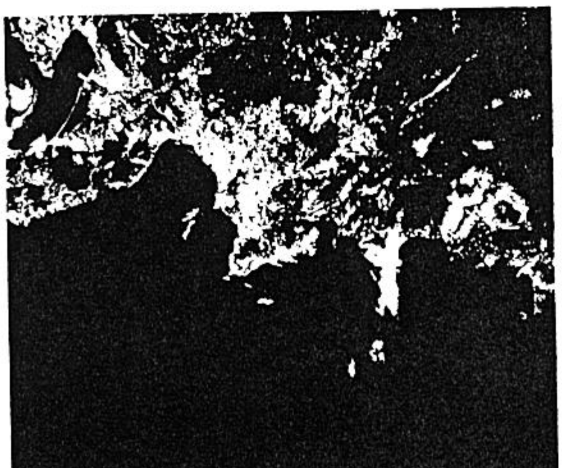
FIG. 4





SPOT IMAGE NO 6038 HEIGHT -87.000

FIG. 5



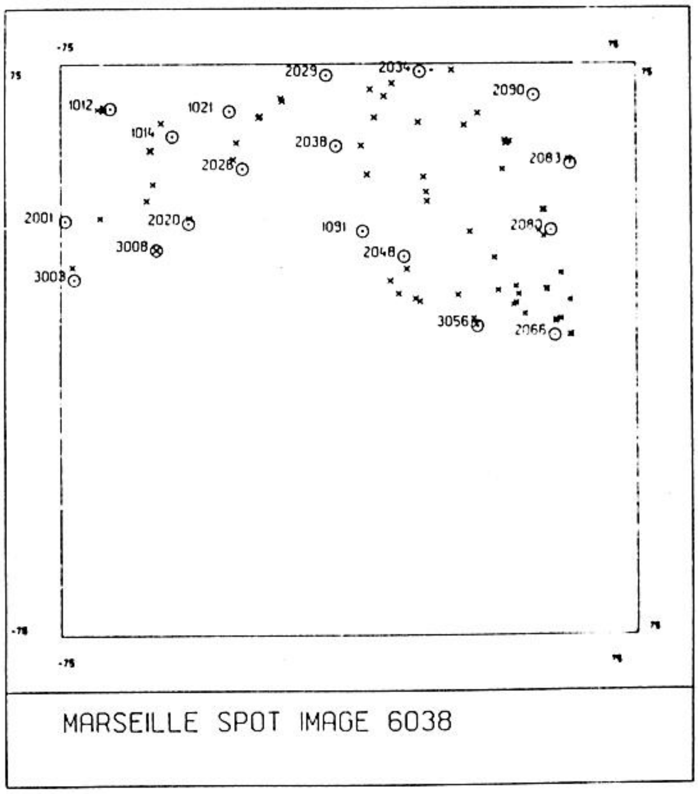


FIG. 6

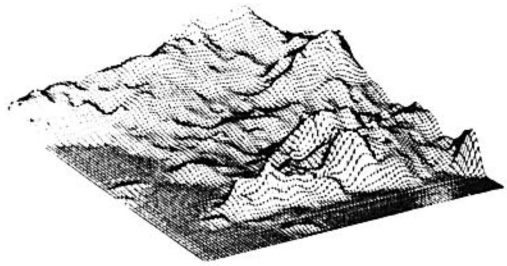
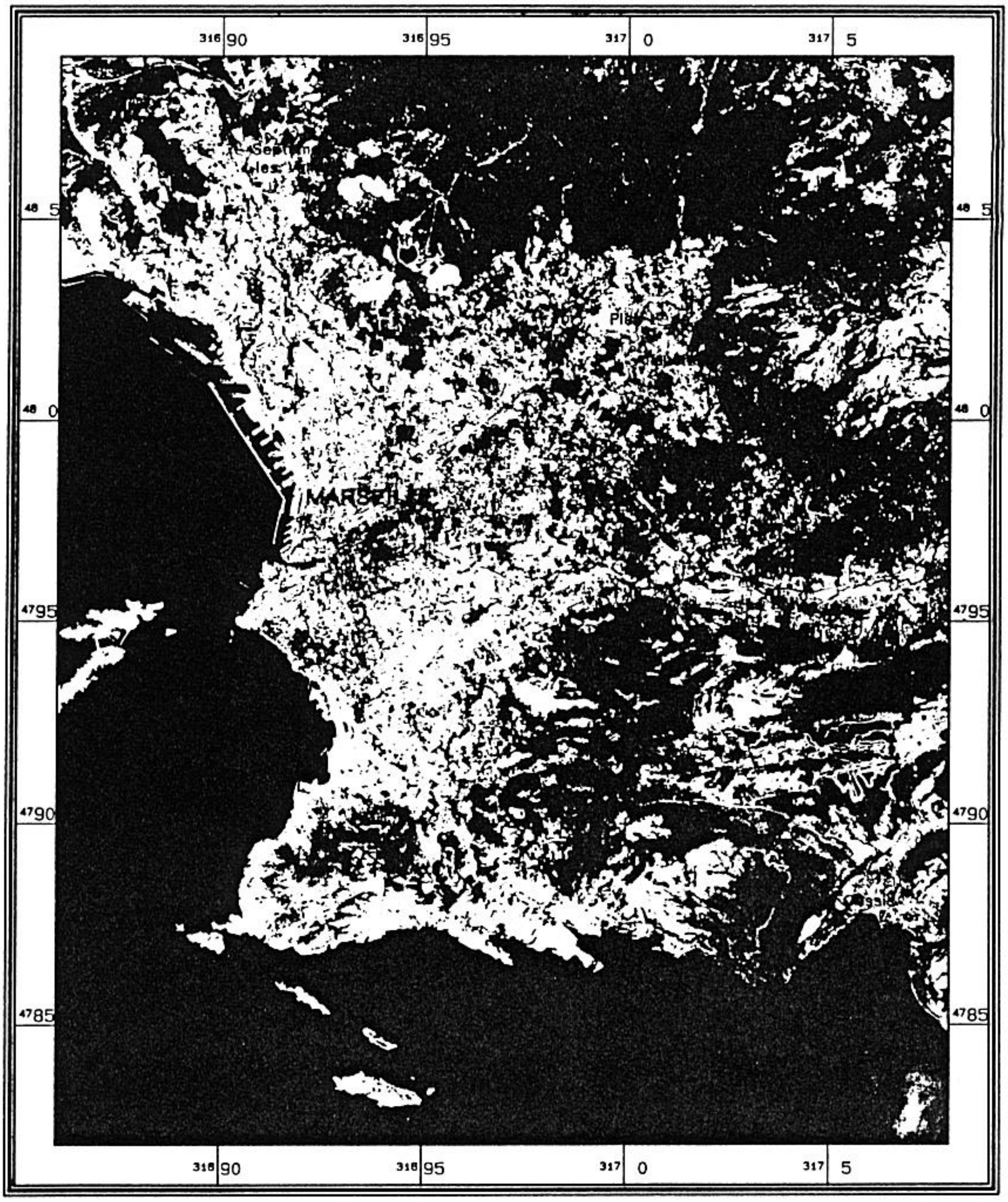


FIG. 7

ORTHOPHOTO MAP MARSEILLE SCALE 1 : 100000



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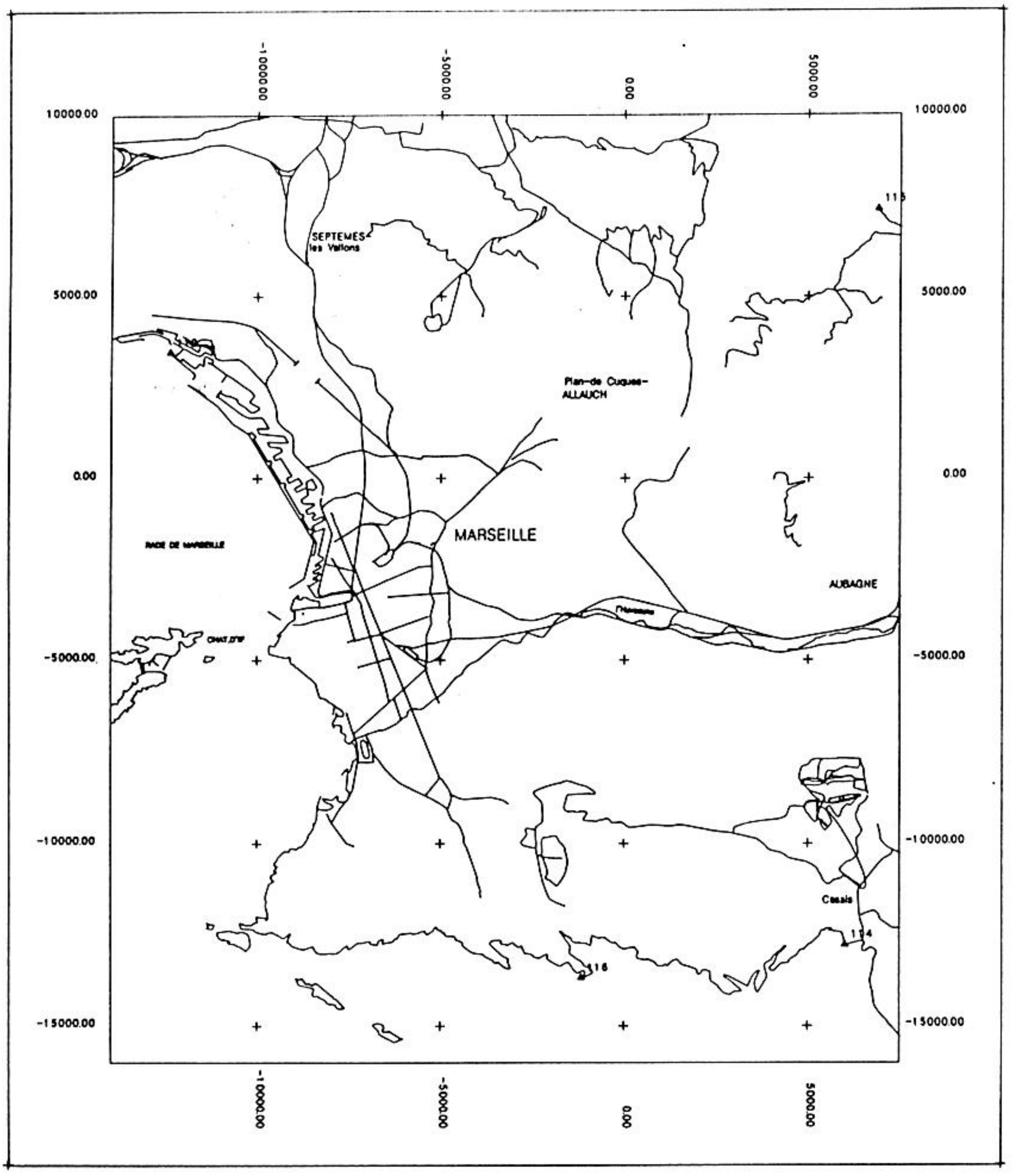
Source of Data:
SPOT Images ST006038 , ST005353
from 11 May 1986 , 18 May 1986
Level 1a

Universal Transvers Mercator Projection
Spheroid Clarke 1880
Differential Rectification with
ORTHOCOMP Z2 / ZEISS , West Germany

FIG. 8

MARSEILLE SCALE 1 : 100000



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Source of Data:
SPOT Images ST006036 , ST005353
from 11 May 1986 , 16 May 1986
Level 1a

Local Cartesian System
Origin: LAT 5° 28' 0.44" , LON 43° 19' 41.46"
Digital Plotting with
Planicomp C100 / ZEISS , West Germany

FIG. 9