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MANAGEMENT OF NATURAL RESOURCES THROUGH AUTOMATIC CARTOGRAPHIC INVENTORY

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for period August 1972 - January 1974
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15. Abstract :

Significant results of the ARNICA program (August 1972 - January 1974)

- Establishment of significant correspondence codes relating ERTS imagery to ground truth from vegetation and geology maps.
- Perfected use of color equidensity and color composite methods for selecting zones of equal densitometric value on ERTS imagery. Primary interest of TEMPORAL COLOR COMPOSITE shown.
- Development of a chain of transfer operations from ERTS imagery to the automatic mapping of natural resources.

N O T E

More details according to this TYPE III FINAL REPORT synthesis are given in the following reports, wrotten during the ERTS – ARNICA experiment with the NASA instructions.

November 1972

TYPE I PROGRESS REPORT N° 1
for Period August – September 1972

June 1973

TYPE I PROGRESS REPORT N° 2
for Period October 1972 – March 1973

January 1974

TYPE I PROGRESS REPORT N° 3
for Period April – December 1973

May 1973

TYPE II PROGRESS REPORT N° 1
for Period August 1972 – January 1973

December 1973

TYPE II PROGRESS REPORT N° 2
for Period February – December 1973

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PART I

PREFACE

- OBJECTIVES
- MEANS USED
- SCOPE OF ACTIVITY

OBJECTIVE OF THE PROJECT

The general objective of the ARNICA Project (Management of Natural Resources through Automatic Cartographic Inventory) has been geared to finding a method for applying satellite imagery to ground management.

Three complementary fields have thus been explored and coordinated :

1. The ERTS 1 MSS Imagery has been correlated with existing vegetation and geology maps of Southern FRANCE and Northern SPAIN, to develop correspondence codes between map units and space data.

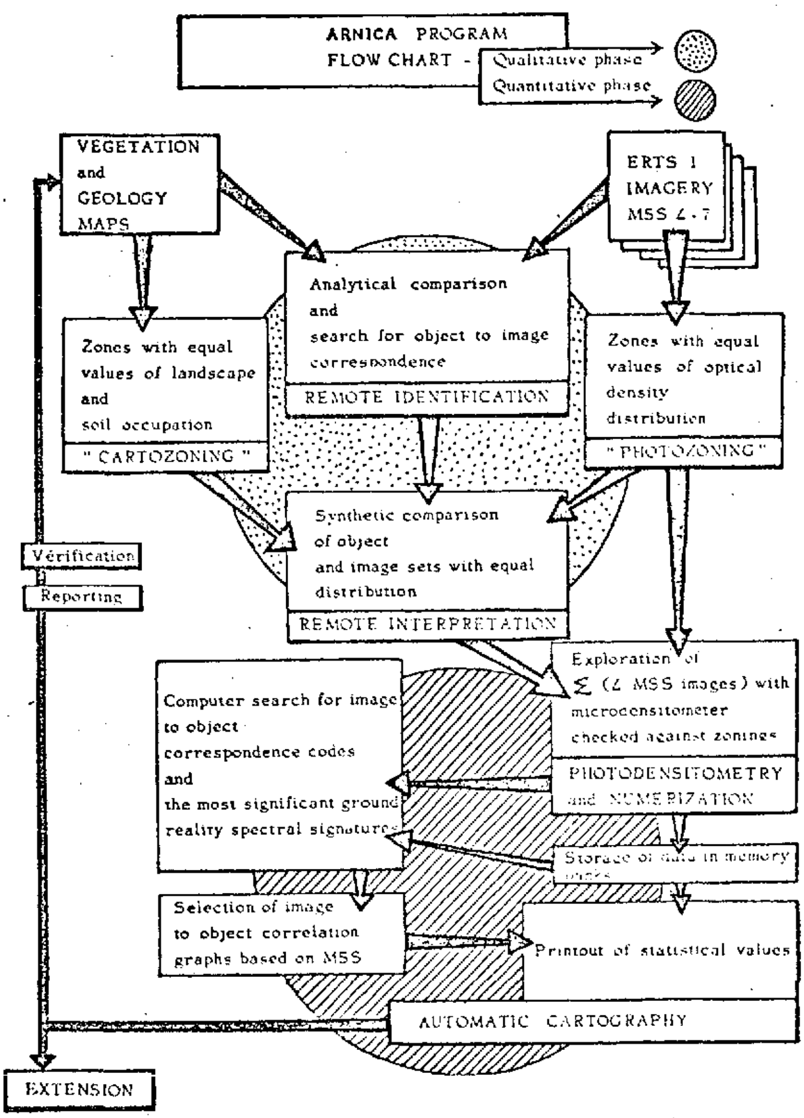
This search for correspondence depended on recognisance operations on the ground and on airborne radiometric measurements in the same spectral bands, MSS 4 - 7, simultaneous with the satellite's passing over the test site.

2. The ERTS Imagery has been put through a series of qualitative interpretation operations using various COLOR EQUIDENSITY and COLOR COMPOSITE methods, in order to establish general correspondences between the ground patterns and the equal density zones seen on the imagery.

(This interpretation includes an optical selection of the most useful spectral combinations for the various forms of ground thruth).

3. The above two groups of observations were to be used to develop an experimental chain of data transfer operations, from the ERTS imagery to the automatic mapping of natural resources.

(cf. figure 1)



C.N.R.S. - SCV/C.E.S.R./G.T.T.

Figure 1

MEANS USED

1. The ARNICA Program has been used by a coordinated group of scientific laboratories under the heading GROUPE TOULOUSAIN DE TELEDETECTION, which includes :

- The Service de la Carte de la Végétation, SCV
- The Centre d'Etudes Spatiales des Rayonnements, CESR
- The Paul-Sabatier University, UPS

(cf. figure 2)

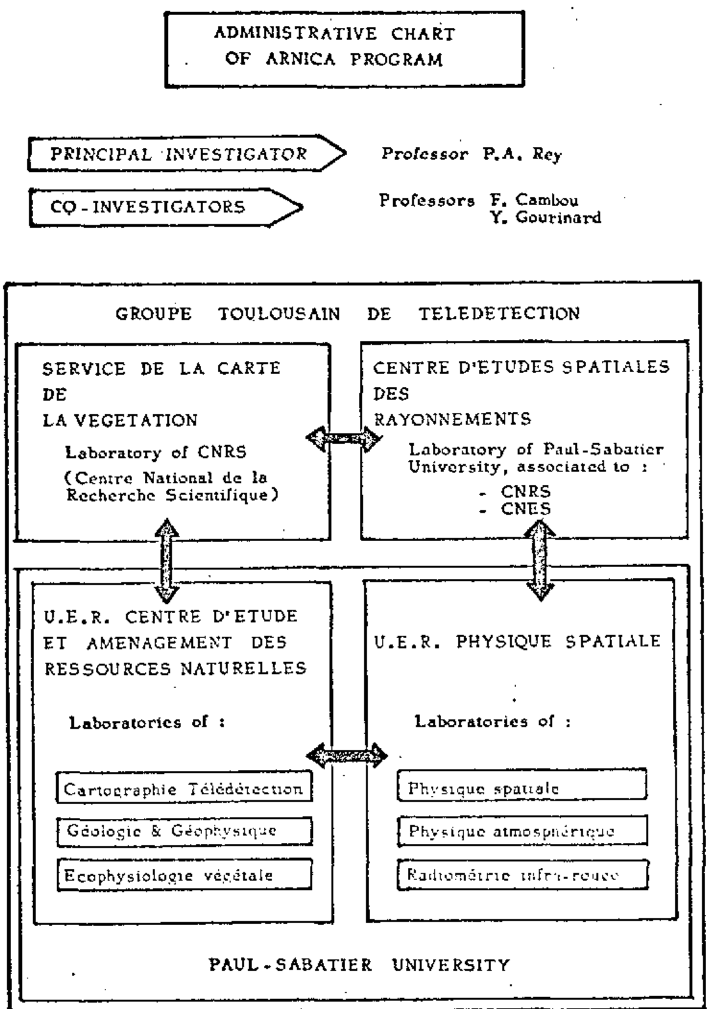
2. The work is divided as follows :

- The imagery-ground correspondence codes have been developed by the SCV and the Remote Sensing and Geology laboratories of the University.
- The radiometric operations have been prepared by the Atmospheric Physics and Vegetal-Ecophysiology laboratories of the University.
- The color equidensity and color composite research has been carried out by the SCV.
- The CESR, in conjunction with the SCV, has been in charge of the data processing.

3. The images requested from NASA for the program consisted of bulk products only (no precision products) and digital tapes.

It was important to have access as early as possible to the greatest number of images suitable for comparing with the immense amount of cartographic data available, rather than to receive a small number of unknown digital tapes of limited geographic significance.

However, after the ARNICA program's method has been developed, its eventual operational use will obviously require original magnetic tapes.


ADMINISTRATIVE CHART
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CENTRE D'ETUDES SPATIALES DES RAYONNEMENTS
Laboratory of Paul-Sabatier University, associated to :
- CNRS
- CNES
U.E.R. CENTRE D'ETUDE ET AMENAGEMENT DES RESSOURCES NATURELLES
Laboratories of :
Cartographie Télédétection
Géologie & Géophysique
Ecophysiologie végétale
U.E.R. PHYSIQUE SPATIALE
Laboratories of :
Physique spatiale
Physique atmosphérique
Radiométrie infra-rouge
PAUL-SABATIER UNIVERSITY

Figure 2

SCOPE OF ACTIVITY

Due to a large discrepancy between the images requested and those received (cf. figure 3 and annex 1) it was necessary to make a few major changes in certain aspects of the original program.

1. The ARNICA test site was never completely covered homogeneously. Repetitive coverage was only partially available and the nomber of land sections covered 2, 3, or 4 times over a period of 18 months is very small, and their geographical distribution is completely random, as well as being outside of the designated test site area.

No surface was covered more than 4 times, and the central part of the site (the Toulouse area) in which the experimental infra-structure on the ground was more sophisticated, provided no usable data at all.

2. Moreover, during the days when the satellite was passing over the test site and the meteorological conditions were favorable, increased ground truth work (ground-based experiments, recognisance of itineraries, etc ...) was carried out ; the corresponding imagery was not provided and this type of experimentation has to be abandoned.

3. The work actually carried out thus included the following :

- a search for imagery-object correspondence keys.

- the qualitative treatment of imagery on the repetitive parts of the test site.

- quantitative treatment of the images on very limited parts of the test site, sufficient nonetheless for the development of the methods sought.

ARNICA PROGRAM

IMAGES RECEIVED

August 1972 - October 1973

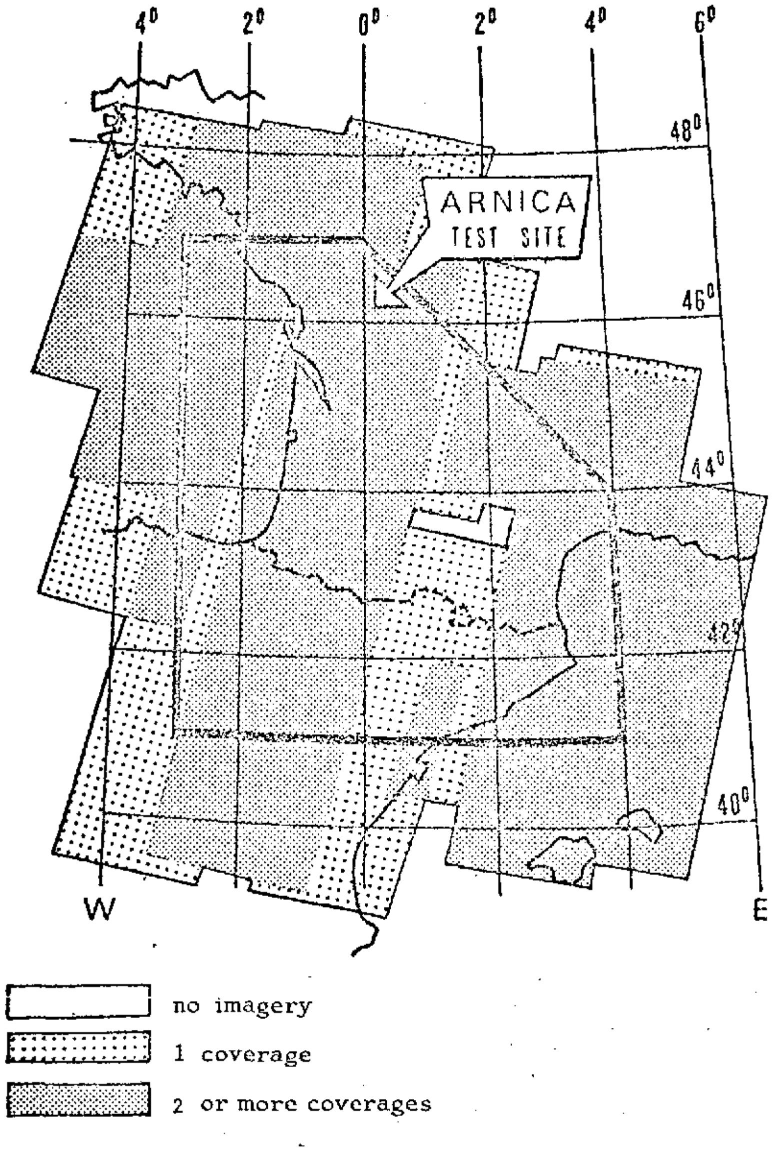


Figure 3

PART II

RESULTS

Chapter 1.

- Search for and interpretation of elementary spectral signatures.

Chapter 2.

- Qualitative use of imagery and analogic correspondence codes.

Chapter 3.

- Quantitative processing of data and automatic mapping.

Chapter 1

SEARCH FOR AND INTERPRETATION OF ELEMENTARY SIGNATURES

Within the scope of the ARNICA program, the search for elementary signatures depended primarily on the systematic referencing on the vegetation and geology maps already available prior to receiving the satellite imagery.

Thus, this early phase consists of the reading and identification of the imagery, a necessary step for further investigation.

Signatures

Three forms are used here for detection. The probabilities are given in the tables below.

- Biological signatures, relating to various soil use types reflecting the progression of development of a natural area, which includes :
  - . natural vegetation (structure, flora, phenology)
  - . agriculture (stable cultures, rotation crops, phenology)
  - . urbanization (housing developments, roads, industrialization).
- Geographical and geological signatures, relating to the organization of the landscapes and the study of their substrata :
  - . hydrography (marine, fluvial, lacustral)
  - . geography (altitudes, forms, structures)
  - . geology (land types, tectonics, lineaments).
- Historical signatures, doubtless the most unusual, pertaining to temporal situations for which satellite imagery is particularly valuable:
  - . meteorology : periods showing the evolution of cloud masses
  - . hydrology : watersheds, water turbidity, floods
  - . snow conditions : conditions and changes in snowfall patterns.

ARNICA PROGRAM	MAIN SIGNATURES DETECTION GRADIENT			
+++++ Very clear detect. ++++ Clear detection +++ Medium detection	++ Fair detection + Difficult detection . No detection			
	MSS			
SIGNATURES	4	5	6	7
Biological signatures				
NATURAL VEGETATION				
Deciduous forest summer	++++	+++++	+	+
Deciduous forest winter	++++	+++++	++++	+++++
Deciduous forest arcade	.	.	+++++	+++++
Coniferous forest	++++	++++	++++	++++
Moorland	+++	++++	++	++
Garigue	+++	+++++	+	.
High moorland	+++++	++++	+++	+++
Marsh summer	++++	++++	+	+
Marsh winter	++++	++++	+++++	+++++
AGRICULTURE				
Salt-marsh	++++	+	+++++	++++
Drained marsh	+++	++++	+	+
Swampy grassland	+++	++++	+	++
Salt-land	.	.	++++	++++
Crop	+++++	+++++	++++	++++
Irrigated crop	++++	+++++	++	+
Plough-land	.	.	++	+++
Coppice summer	.	++	.	.
Coppice winter	.	+++++	+++	++++

URBAN AND INDUSTRY				
Large city	.	+++	++++	+++++
Little city	.	.	+	++++
Roads	+++	++++	+	+
Aerodrome	.	.	+++	+++
Break-fire	++++	+++++	+++	+++
Harbour	++++	++++	++++	+++
Geomorphological signatures				
Sea	+++++	+++++	+++++	+++++
System of streams	+	+++	+++++	+++++
Pond	++	++++	+++++	+++++
Range	++++	++++	++++	++++
Regional features	++++	++++	++++	++++
Stratigraphy	++	++	+++	++
Tectonic	++	+++	+++	+++
Lineaments	+	++++	+++	+++
Signatures linked with event				
Meteorology	+++	+++++	+	++
Hydrology : flood	++	+++	+++++	+++++
turbidity	++++	++++	++	.
Oceanography :				
. surface observation	++	++	+++	+++
. sub surface observ.	+++	+	.	.
Snow study	+++++	++++	++++	++++

Interpretation of the signatures

- Guidelines

Any reasonable use of a remote sensing image, with the exception of a few particular cases, necessarily involves an interpretation of the real vegetation conditions, no matter what the purpose : by its presence, variations, and often even by its absence, the vegetation is always significant, directly in the case of an analysis of vegetation cover, either natural or artificial, indirectly in research connected with geological, pedological, geographical, or archeological substrata, for example. In the field of oceanography even the changes in signature of plancton seem to be of great interest.

The spectral signature of any actual vegetation conditions is the result of the combined action of 3 components :

. the morphological or structural component, linked to the shape, size, texture, and structure of the element observed ;

. the phenological component, related to its stage of development according to the biological cycle : germination, leaf formation, blossoming, maturation, leaf fall ;

. the ecophysiological component, reflecting relations between station (climate, soil, topography) and behavior (variations in photosynthesis, transpiration, moisture level, ventilation, etc).

The exact value of the relative influence of these three components on the image is all the more difficult to determine, because each result is space and time dependent. The term "ground truth", applied to vegetation, must therefore be used judiciously.

In this light, it is fitting to bring up the question of scale and image resolution : the systematic procedure for ERTS 1 imagery, carried out over a period of 18 months, leads to very fine distinctions compared to theoretical evaluations based on the physical parameters and techniques of the experiment, since contrast must always be coupled with resolution. For example, there are situations where forests several hundreds of hectares wide cannot be distinguished from the surroundings ; there are other cases where a small bridge made of white stone is visible, while a freeway overpass next to it is not.

- Geographical organization of signatures

Whatever the thresholds of analytical identification of the imagery, a very favorable interpretation situation results from the clustering of significant groups of varied densitometric combinations, which reflect an equal number of combinations of landscape elements.
These groupings, which are favored by a small scale, thus lead to the identification of isophenic zones, according to a process of interpretation very much like that currently practised in photo-interpretation.

Taking into account the advance availability of thematic maps (phytogeographical, geological, ecological, etc) which are read for the same purpose, this isophenic zoning of the images can serve as a relay between the cartographic zoning which is explanatory in nature (zonings of equal meaning) and the densitometric zonings necessary to the final data processing (equal treatment value zones).

The procedure on which the whole exploration of the images depends will thus begin with a comparison of the two ordered sets of equal value zones, taken from two complementary sources of information :

"cartozoning" and "photozoning", each clarifying and correcting the other, for a more effective organization of the operations to follow.

- Diachronic variation of the signatures

The phenological component of the imagery, which here determines the spectral response pattern of an object, is of primary significance, first because the scale of the imagery makes it possible with each ERTS document to take in wide geographical and ecological variation, and also because the repetitivity conditions of flights over the test site make it possible to follow the time pattern of the situations observed.

A complete understanding of the phenology, which brings indispensible ecological qualifying factors into play, is thus imperative for the interpretor if he is to avoid serious error. It is also one of the two essential reasons (the other being geological) for interest in a stereoscopic coverage, at least partially, of satellite images, not for the purpose of photogrametric restitution, which is weak here, but in view of relative interpretations of station conditions (orientation, exposure, slope, relations with topography) whose action determines the phenological behavior of the vegetation.

The main difficulty with, but also doubtless the key to, an integrated use of the ERTS imagery is thus to evaluate the timespace pattern of the vegetation signatures.

Related Experiments

In its qualitative phase, the ARNICA program planned a set of ground truth experiments which were to be conducted in close connection with flight periods (ecophysiological experimentation) or in particularly favorable geographical sections, either because they were already equipped with an experimental infrastructure (hydrobiological experimentation) or because there was very complete information (geological experimentation).

Some were disappointed with this aspect. In fact, in the fields of ecophysiology and hydrobiology, it was imperative to carry out the experiments at the exact moment that the satellite passed over. Some of the experiments planned were indeed carried out, but the corresponding ERTS imagery was not delivered.

In the field of geology, not one image was available on the sections chosen for study.

In spite of such unfavorable circumstances, the research has been carried out in these fields anyway, and some significant results have veen obtained. (Cf. Type II Progress Report No. 2).

Chapter 2

QUALITATIVE USE OF IMAGERY AND ANALOGIC CORRESPONDENCE CODES

Since the basic reference is cartographic, the first step in a logical analysis leads to using methods appropriate to an analogic treatment of the imagery, for the purpose of elaborating original selective imagery likely to be compared profitably with the various maps available.
If satisfactory optical correlations can thus be shown up, the corresponding "filterings" will be a useful guide to further data processing.

The methods used within the scope of the ARNICA experiment must not be confused :

- one uses the technique of color equidensities or pseudocolor, and consists of transfering coded colors for variations in density from a single original black and white image ;

- the other uses color composite techniques obtained by superimposing three images of a single situation, treated in three basic tones : cyan, magenta, and yellow, respectively.

An important variation can be introduced into this second method when the three images are from flights on different dates ; diachronic color compositions can be made, more unusual and effective than the instantaneous color compositions commonly used.

Color Equidensities

The principle of such a method, which can be carried out in several different ways, depending on the choice of photographic support used and the technical means available to the operator, is known.

In all cases it involves substituting a series of density levels arbitrarily chosen each of which is assigned a color transcription, also arbitrary for a densitometric gradient which is insensitive and difficult for the human eye to perceive. The image is finally made into a print or a transparency.

Such a treatment makes it easier to examine possible analogic correspondences revealed by each of the levels. A disadvantage is that it can over-emphasize meaningless thresholds, thereby covering up significant ones.

It is therefore obvious that such methods can only be effective if the aforementioned equal densitometric zoning is very strictly monitored, since the same density level, on a single image, can have very different meanings depending on the zone of geographical organization of the signatures in which it is located.

In any case, the correspondence between the documents obtained and the thematic reference maps constitutes here the most reliable test of the validity of the process.

Figure 4 illustrates the succession of the experiments actually carried out on the ERTS imagery in the ARNICA program.

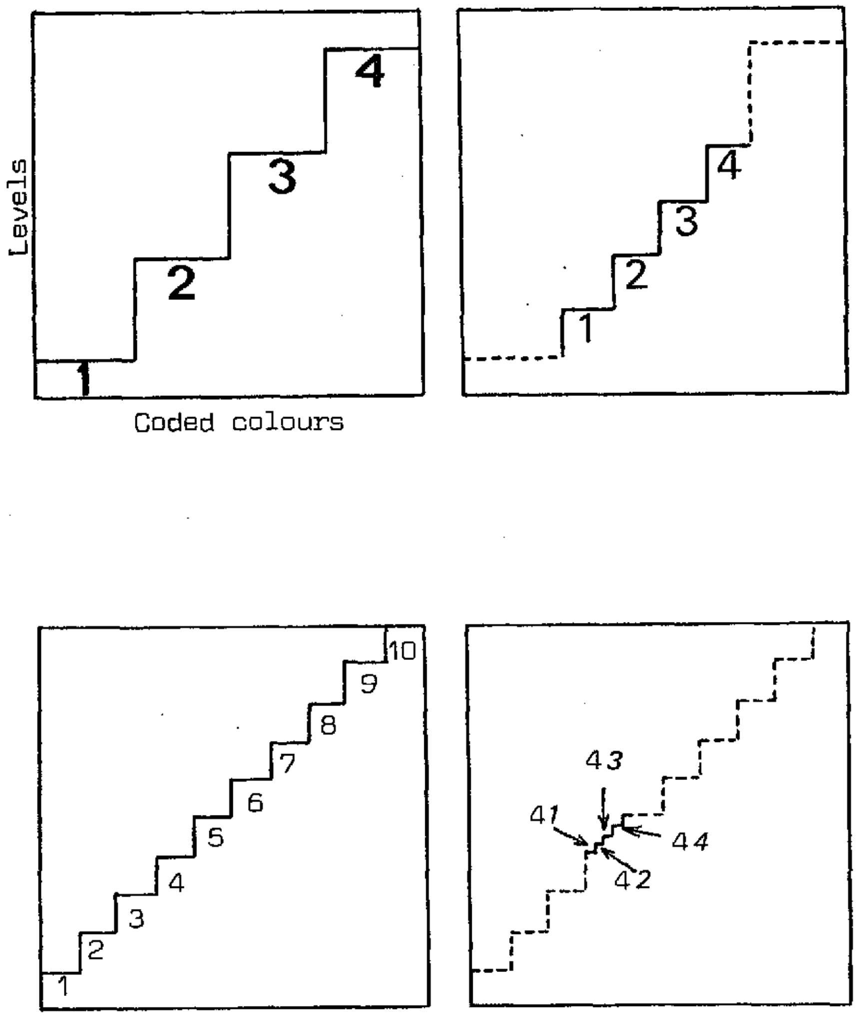


Figure 4

COLOR EQUIDENSITIES

Refining levels

The first graph shows a rough approach to treatment : only 4 densitometric levels are retained. An examination of the result shows that the two intermediary levels noticeably integrate the densitometric variation of the section studied here (the Landes Forest, a major physiographical unit of the Aquitaine Basin).

A following treatment further analyses both levels, breakingthem down into 4 sub-levels, thereby further narrowing the densitometric variation : this will thus bring out thresholds corresponding to the vegetation types present in the area.

The third graph shows the possibility of adapting the method to the traditional densitometric levels of the ERTS imagery as seen on the scale on each frame. A printout colored for the levels of the initially supplied image is obtained, at the expense of 48 elementary shots and a suitable set of marks and counter-masks : obvious correlations appear which were difficult to distinguish on the original document (Board I).

A final refinement of the method lies in further analying the preceding levels and translating a more precise phenomenon. Thus a mixed type of display can be conceived of, in which this privileged level will be the object of a detailed densitometric selection.

From this point on, it is easier to make fine distinctions in the densitometric correspondence code between the actual situation and the spectral response. This is one possible method for selecting the best signatures for a single object. It has the advantage of strict filtering, and the disadvantage of being very technically complex, since it is applicable to a single image, and its broader use can only be more difficult.

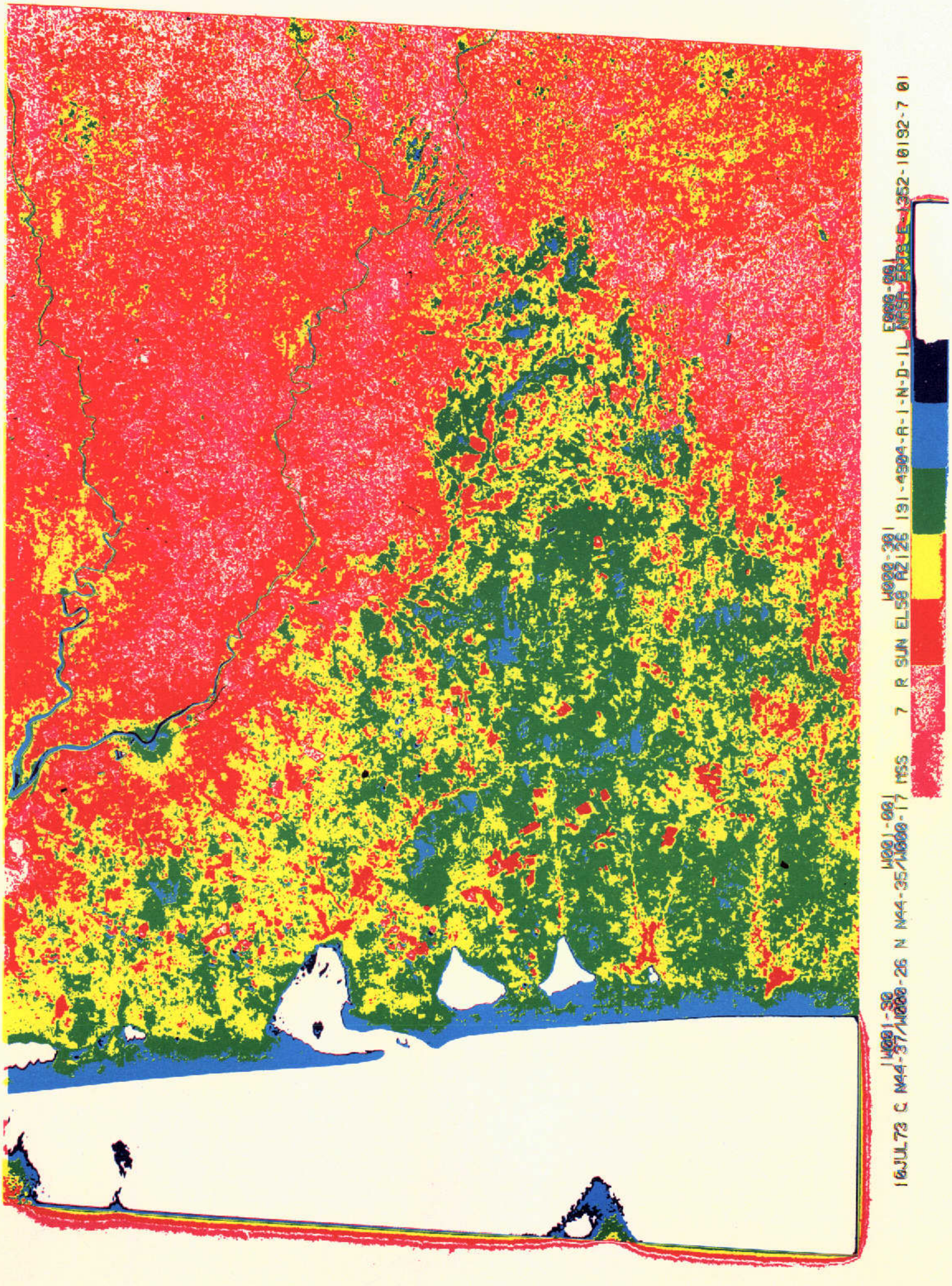
BOARD I

PSEUDO - COLOR

(EQUIDENSITY)

" LANDES de GASCOGNE "

20(a)



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Color Composites

The color composites method is incontestably more elegant : it is also traditional at the level of satellite imagery treatment programs. The ARNICA program was therefore able to benefit from it, for two types of methods : instantaneous compositions and diachronic compositions.

- Instantaneous color composites

In its most frequently used form, the color composition method consists of associating 3 simultaneous images from 3 multispectral scanner bands. In the present case of the ERTS imagery, the combination is generally valuable for superimposing MSS bands 4, 5, and 7, reproduced respectively in yellow, magenta, and cyan.

Richly chromatic documents are this obtained, which can be processed at two levels : at the synthetic level for isophenic zones, and at the analytical level for certain elementary signatures which are better revealed by the combination retained for a specific time.

The agreement with the zoning suggested by the phytogeographical maps is, in general, very satisfactory, especially for mid-season imagery (spring and autumn), whose details seem clearer than the too violent contrasts of winter and summer imagery, where many basic signatures are obscured.

Finally, the essential interest of this method lies in comparing several situations separated in time. From this, a less involved method may be found which would integrate diachronic variation more satisfactorily.

– Diachronic color composites

The accuracy of the ERTS satellite's successive trajectories and flights over the same territory under amazing conditions of repetitivity, requires an original application of the color composition method, which traditional shots on conventional vectors (planes and balloons) could not allow unless very strictly controlled.

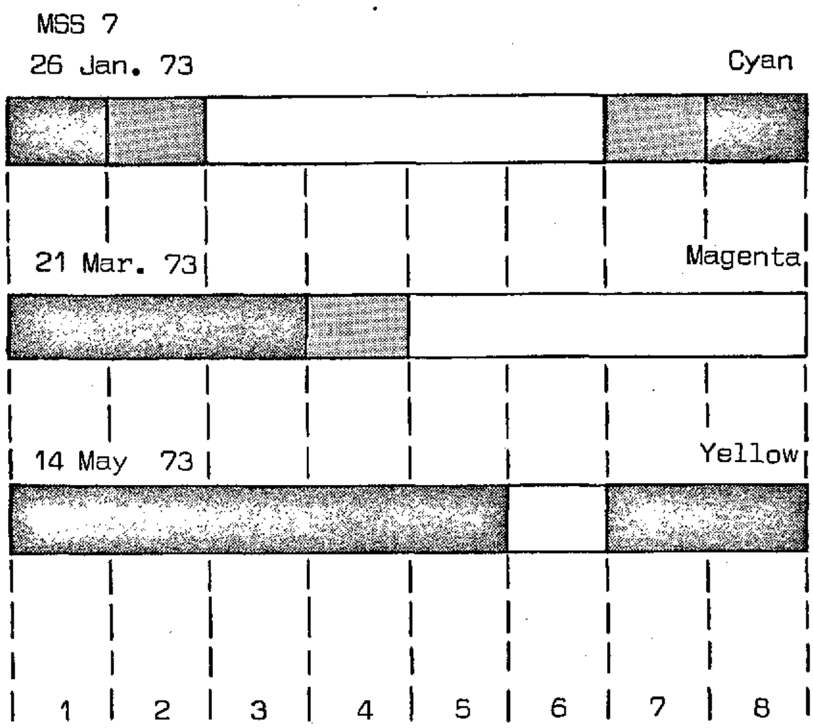
In fact, what is involved is making the color composite by superimposing 3 situations separated in time, treated with the 3 traditional basic colors, cyan, magenta, and yellow ; the operation is only possible if the 3 images have accurate, strictly identical geometric boundaries.

The experiment has shown that this was indeed the case ; this indispensable conditions was respected.

At an early experimental stage, the method was tested on a particularly revealing, yet simple, case : that of variations in snowfall levels for a mountain range whose MSS band 7 imagery was particularly revealing.

The experiment pertains to the eastern side of the French Central Mountain range (Massif Central) where 3 successive images (January 26, March 21, and May 14) were used.

The result of superimposing (Board II) shows up 8 significant chromatic combinations for various snowfall patterns (Cf. figure 5).
The ecological interpretation can be very precise for such a document, and provides information of utmost importance about a basic nature phenomenon, whose pattern of development is normally difficult to see, both as a whole and in fine detail.



1.	BLACK	Snowless
2.	BLUEISH	Melting winter snow
3.	ORANGE	Early
4.	PALE ORANGE	Spring melting winter snow
5.	YELLOW	Lately melting winter snow
6.	WHITE	Summer melting winter snow
7.	PALE GREEN	Spring snow spreading on former snow
8.	GREEN	Spring snow

SNOW CONDITION EVOLUTION
(Temporal color composite)
Figure 5

BOARD II

TEMPORAL COLOR COMPOSITE

SNOW CONDITION EVOLUTION

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Since the validity of this method can be easily shown, it is fitting to apply it to the more complex problem of the whole of the major biological signatures of a region.

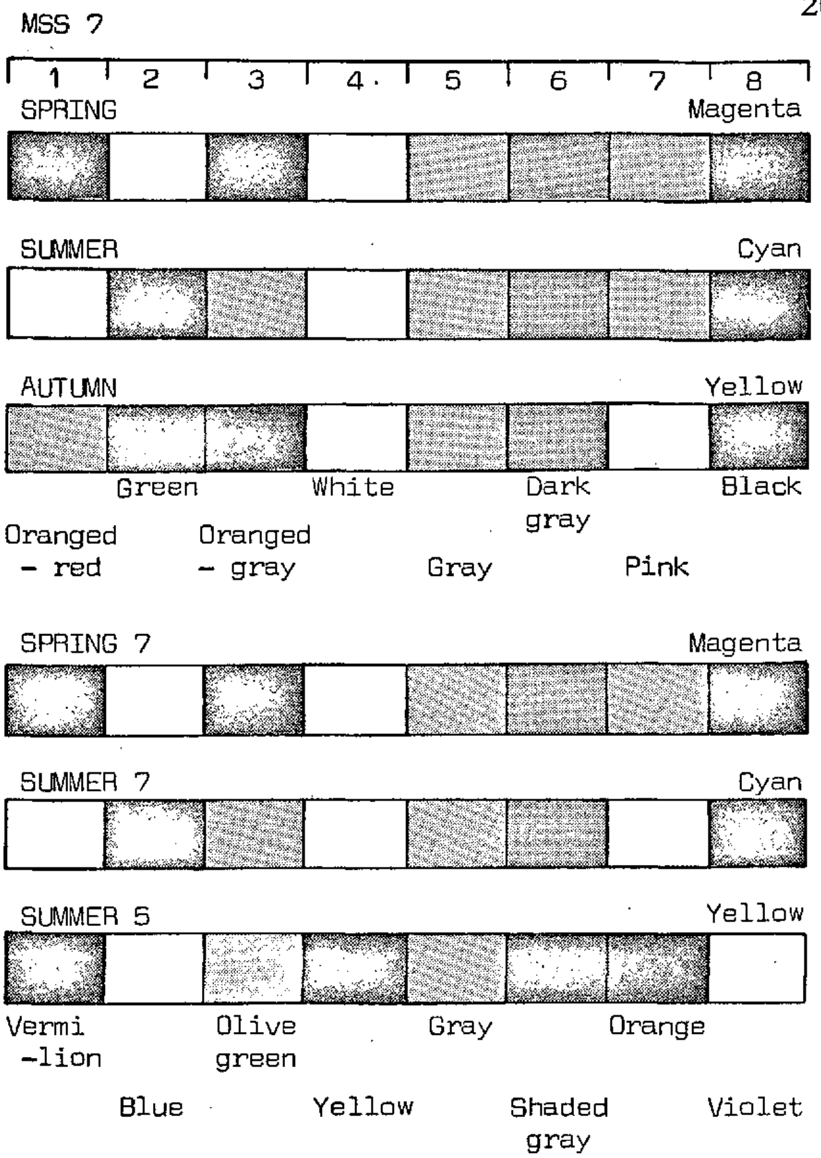
The section under study concerns the whole Aquitaine Basin, essentially characterized by a wide variety of soil occupation types and numerous land divisions, i.e., conditions which are as inconvenient as possible, given the scale of the imagery and the variety of the responses.

Tests were based on theoretical procedures such as those illustrated in figure 6 :

. In an early case, 3 successive MSS band 7 images, showing the synthesis of responses at 3 significant phenological times : spring, summer, fall (the real difficulty was in actually using these images in the desired order, since the series autumn-spring-summer was not suited to the experiment).
The graph shows that an ambiguity exists, at least theoretically, at the level of two types of signatures.

. In a later case, it was possible to save one flight by superimposing not only the MSS band 7 but also the MSS band 5, both for the summer, onto an MSS band 7 for spring. The preceeding ambiguity is here removed and the chromatic range thus obtained becomes meanningful (Board III).

Systematic tests are now in progress on sections where the ARNICA experiments have access to suitable imagery. In essence, they confirm the hopes raised by the theoretical procedures, whose efficiency can be improved by seeking more meaningful diachronic and spectral combinations.



1. Corn
2. Winter wheat
3. Spring wheat
4. Grasslands
5. Vineyards
6. Coniferous forests
7. Deciduous forests
8. Urban

LAND USE TYPES IN AQUITAINE REGION

(Temporal color composite)

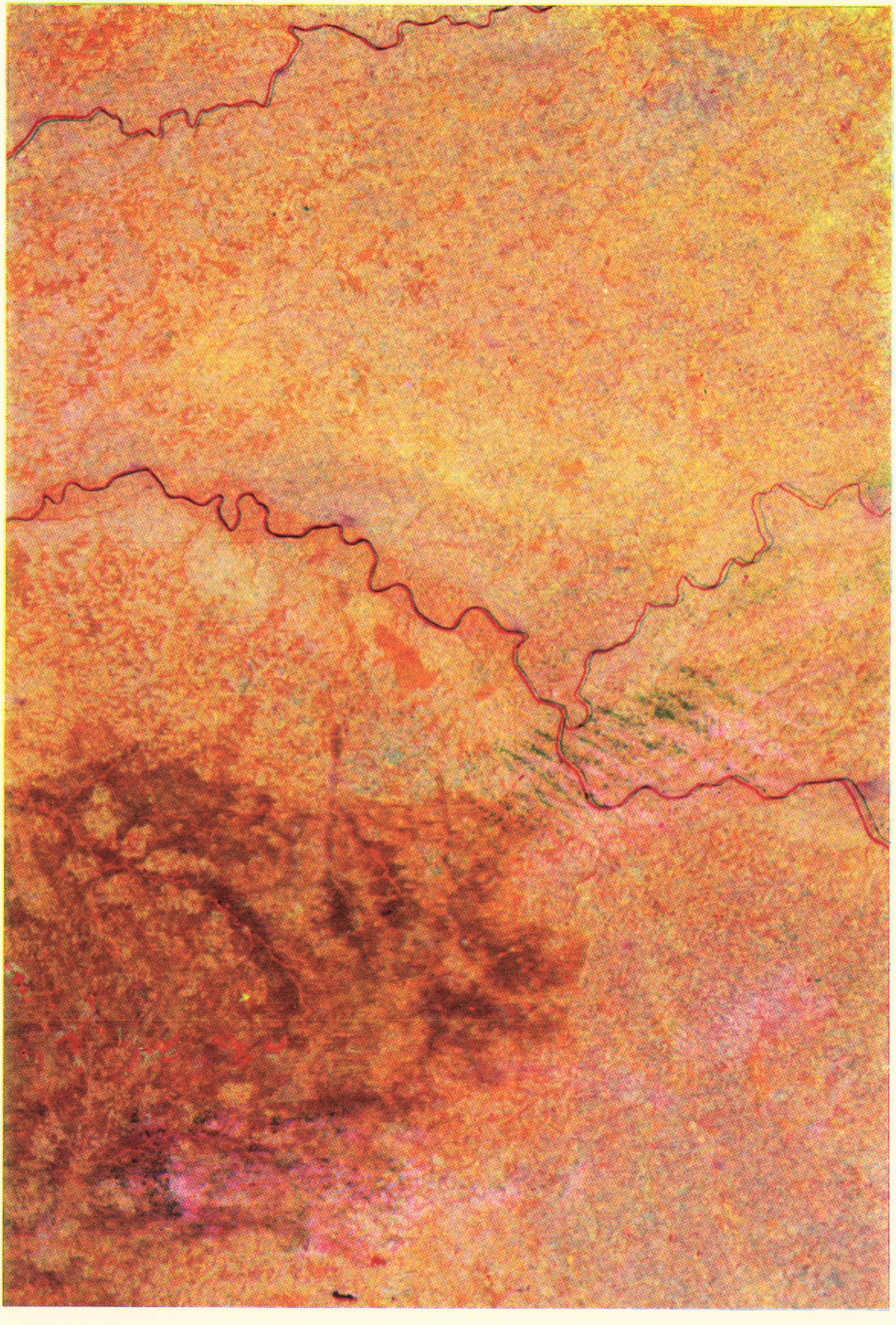
Figure 6

BOARD III

TEMPORAL COLOR COMPOSITE

LAND USE TYPES

IN AQUITAINE REGION



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Chapter 3

QUANTITATIVE TREATMENT OF DATA AND AUTOMATIC MAPPING

The purpose of all the reading operations and analogic treatment of imagery is to determine the object-image correspondence and to find the most characteristic signatures for the various land - scape elements and their time-space variations.

These signatures are expressed in terms of the optical density, a quantifiable feature which lends itself to computer processing.

Figure 1 gives the general ARNICA program flowchart in which the qualitative phase serves as a basis for the quantitative phase.

The quantitative data processing procedures developed by the Centre National d'Etudes Spatiales can be divided into 5 main parts :

- data management
- reconstruction of imagery
- sampling
- pretreatment of information
- classification

according to the sketch in figure 7.

I. Data management

The data comes from the numerization of the ERTS imagery on the Joyce-Loebl Scandig 25 microdensitometer.

Each image is scanned by the microdensitometer row by row with a step of 25 μ, which gives a numerical value between 0 and 256 per byte for each point analyzed.

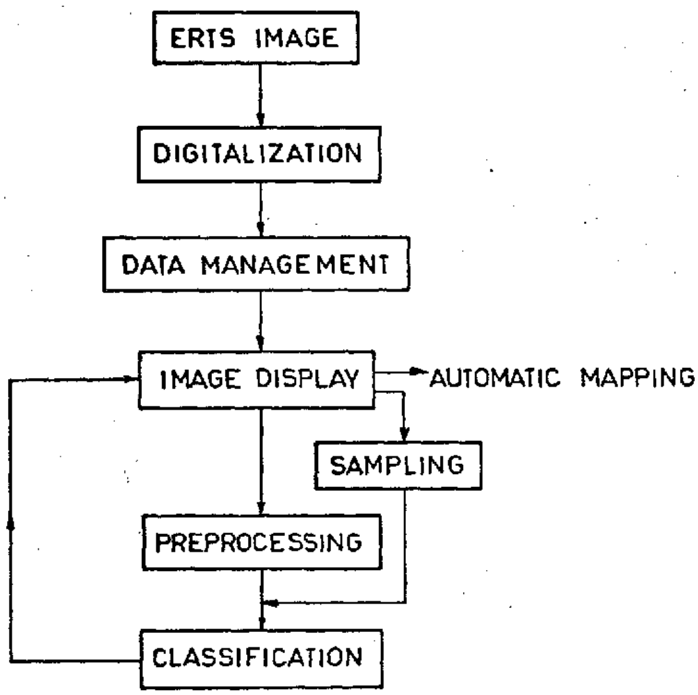


Figure 7

IMAGE PROCESSING SCHEME

The 4 ERTS images (MSS bands 4 to 7) correspond to 4 files of 2500 x 2500 bytes contained on 2 magnetic tapes.

Many problems result from the vast amount of data :

1. <u>Numerization problems</u>

In order to have access to a geographical point on an image taken in the 4 channels one must theoretically read the recordings which precede that of the point 4 times.

The access to information time can be reduced by a factor 4 by regrouping the 4 numerical values, n_1, n_2 , n_3 , n_4 , corresponding to the same point.

The process is further improved by dividing the image into elementary zones. The access to any given point on the image then involves only locating the elementary zone in which it is situated and reading the preceding recordings in the zone.

Obviously all of this implied a perfect coincidence between the elementary zones on the ERTS imagery, and therefore between the numerization axes (coordinates) on the 4 images.

When the images are digitized by the microdensitometer, it is impossible to have the scan lines perfectly aligned with the reference coordinates of the image, defined by a set of 4 crosses.

For each point on the image, it is necessary to carry out a translation and a rotation procedure in order to transpose the ERTS imagery x-y reference coordinates into the numerized coordinates.

The automization of the operation is done by a program which at an early stage determines the coordinates formed by 4 crosses with 4 pinholes for easier location. Figure 8 shows a display of a pinhole at the center of the crosses. Figure 9 represents the "location" chain.

To avoid repeating the procedure of transporting coordinates for all points on the image, the image is divided into sub-zones and the transposition is carried out on the 4 images ; the 4 axes matrices thus determined are stored together.

The size of the elementary zone is limited both by the maximum rotation angle between the 2 coordinate systems, numerized and photo, and by the type of computer (CDC 6600).

2. Computer problems

A CDC 6600 computer is being used ; the smallest piece of information to be handled is related to the structure of the machine word, which is 60 bits. it is therefore necessary to store several 8-bit (1 byte) pieces of information in 1 machine word : 7.5 bytes in 1 word or 15 bytes in 2 words.

However, in order to have access to a piece of information, it is necessary to use an extraction software.

Taking into account the structure of the machine word, each dimension of the elementary zone is chosen as a multiple of 15.

In our case, the zones are made up of 60 x 60 point squares.

The next step is to combine the information contained in each of the 4 elementary images (MSS bands 4-7) point by point and then to compress the resulting information (15 bytes in 2 words).

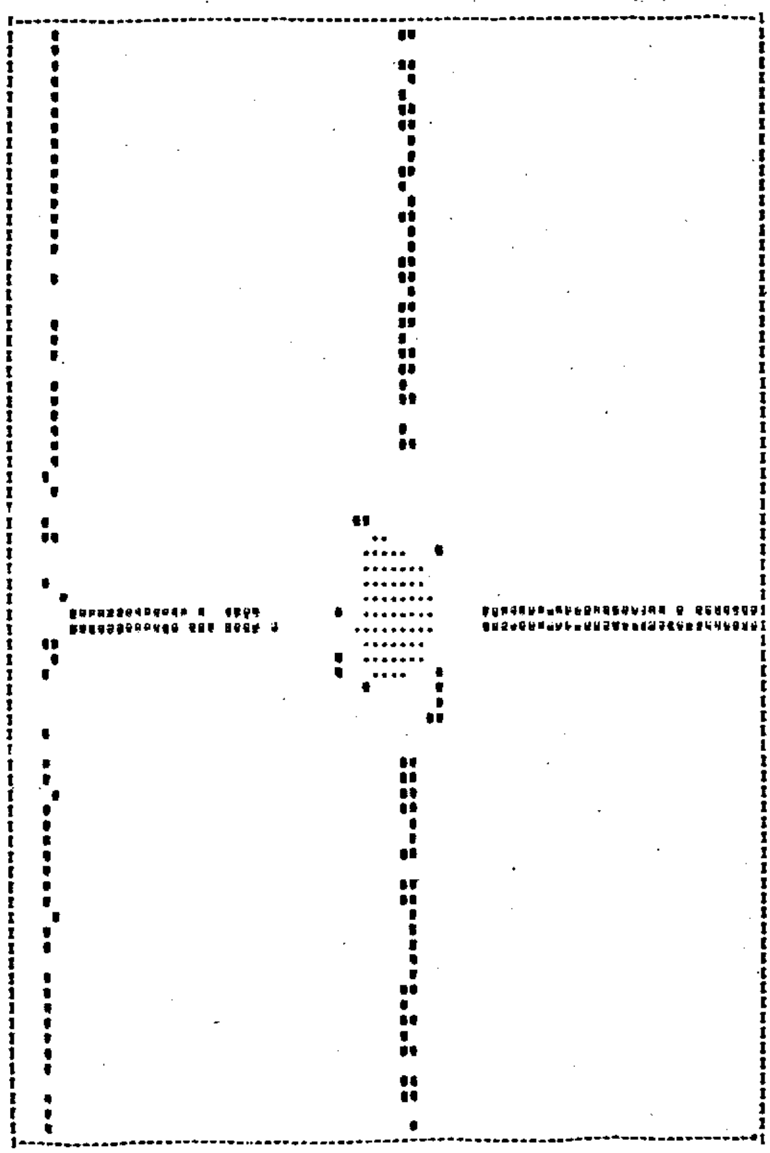


Figure 8

Printout of a pinhole
at the center of a cross.

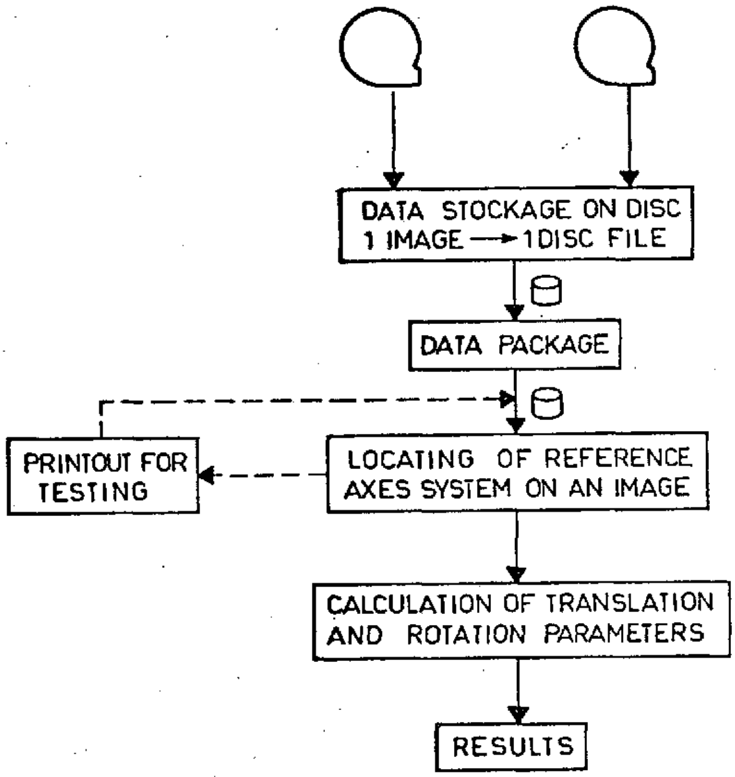


Figure 9

LOCATING CHAIN

The information to be handled is in the form of blocks made up of elementary zones where each point includes the responses in the 4 wavelength bands. (Data management procedure : figure 10).

II. Image reconstruction

(See the ARNICA Report : Progress Report, December, 1973).

The reconstruction of the image consists of assigning a graphic symbol to each point or surface element in the printout.

The data can come from optical density level values resulting from the numerization of the image or from the results of classification starting from these optical density levels.

- In the first case, the choice of symbols to be assigned to each range of optical density levels is derived from a breakdown of the optical density histogram of the numerized image.

The histogram obtained is in fact the sum of several elementary distribution curves depending on the response of the ground object and the transfer function of the microdensitometer (Figure 11 a).

The first stage of breakdown consists of establishing the characteristics of the operation of the apparatus, i.e., to calculate a dispersion law giving the standard deviation of the distribution of a range of levels centered at level N. (Fig. 12). This scaling is done from a non continuous grid of 24 levels.

The extraction of the elementary distribution curves is done by a program based on the above dispersion law. A graphic symbol is assigned to each elementary distribution for the printout.

DATA MANAGEMENT

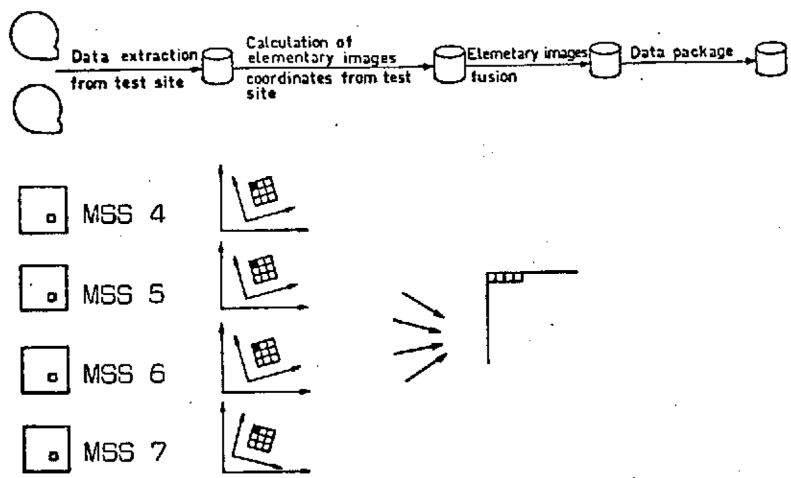
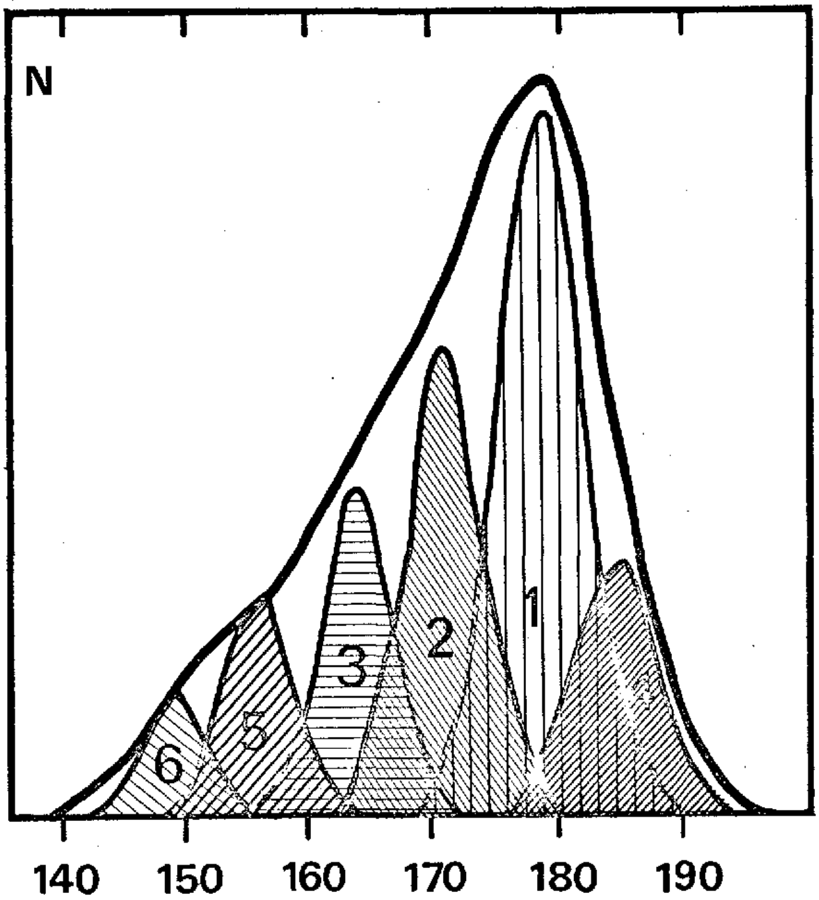


Figure 10

Figure 11a

Principle of levels separation



Printout of the coded levels

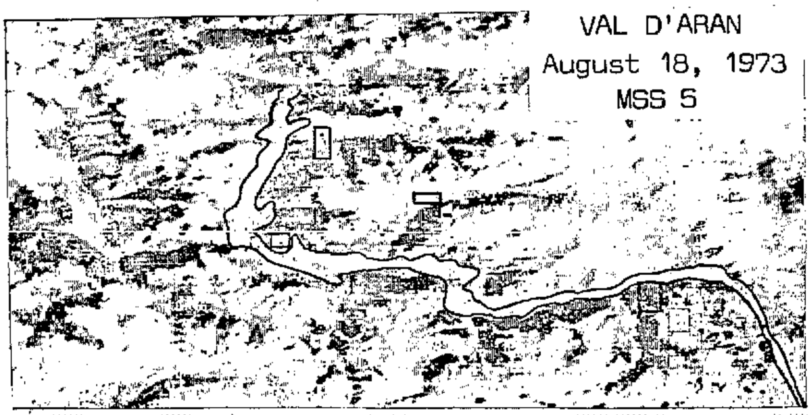


Figure 11b

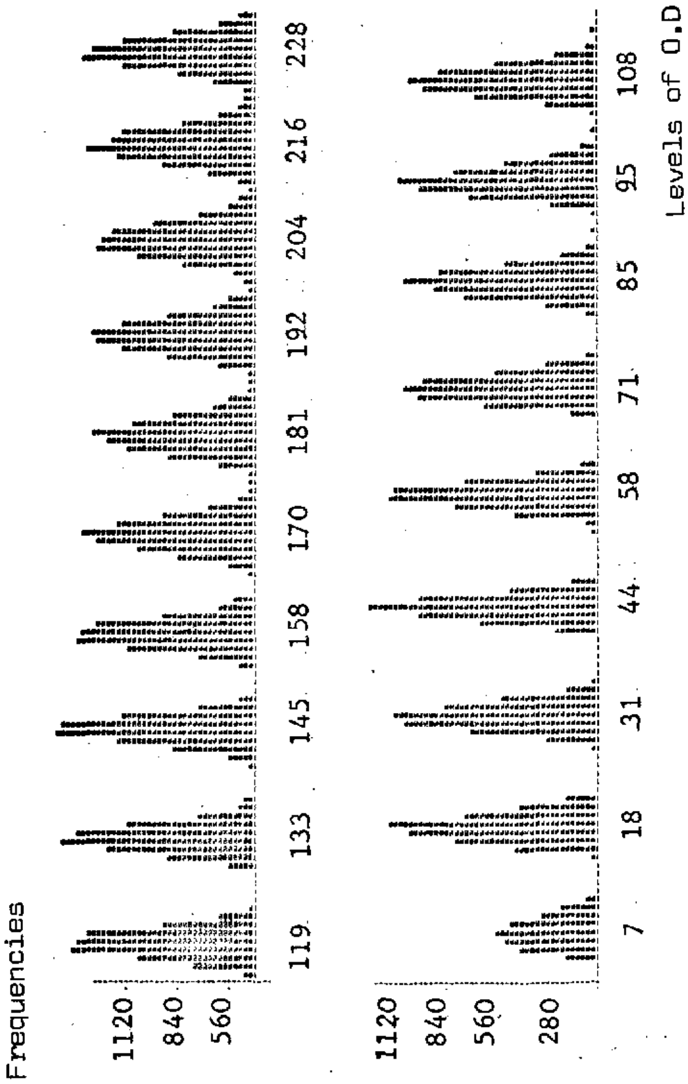


Figure 12

PRINTOUT OF A 21 LEVELS STEP-WEDGE

- In the second case, the use of a graphic symbol is not made directly from the optical density levels, but from the result of classification algorithms : a graphic symbol for each class is used so that a comparison with ground truth, classes or vegetation series, and thus a check of the existing information (the Vegetation Map, for example) or an estimate of the surfaces covered in an unsupervised zone can be made.

When 1 point can be assigned to 2 or more distributions (zones of repeated coverage), a further test is made using the responses of 8 points in the geographical vicinity. The distribution which corresponds to the majority of these points is assigned to it.

III. Selection of samples

The results of the supervised classification depend essentially on the homogeneity of the selected samples. Then a display of the main levels to be compared with vegetation classes on the ground is obtained by studying the zone's histogram and breaking down the elementary distributions.

The selection of homogeneous surfaces in then made by the Vegetation Map Service depending on the classes thus located. The process is further refined in order to improve the homogeneity of the samples, defined by the variance of their histogram.(Figures 13, 14, 15).

The final samples in each multispectral scanner band are then processed statistically (computation of the average and standard deviation)(Figure 16), so that correspondence graphs of the type shown in Figure 17 can be made.

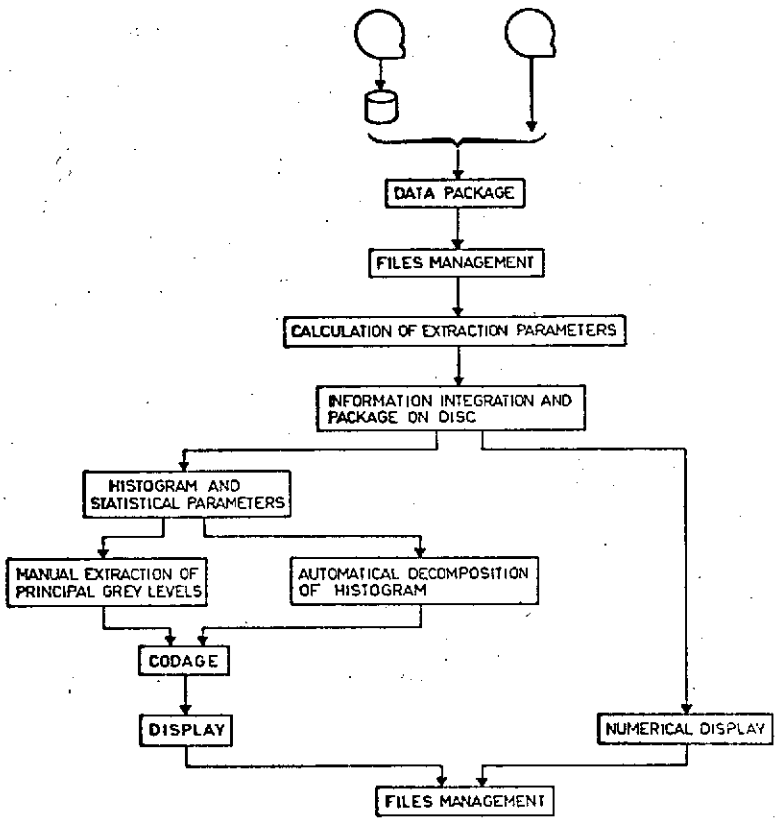


Figure 13

FILES PROCESSING CHAIN

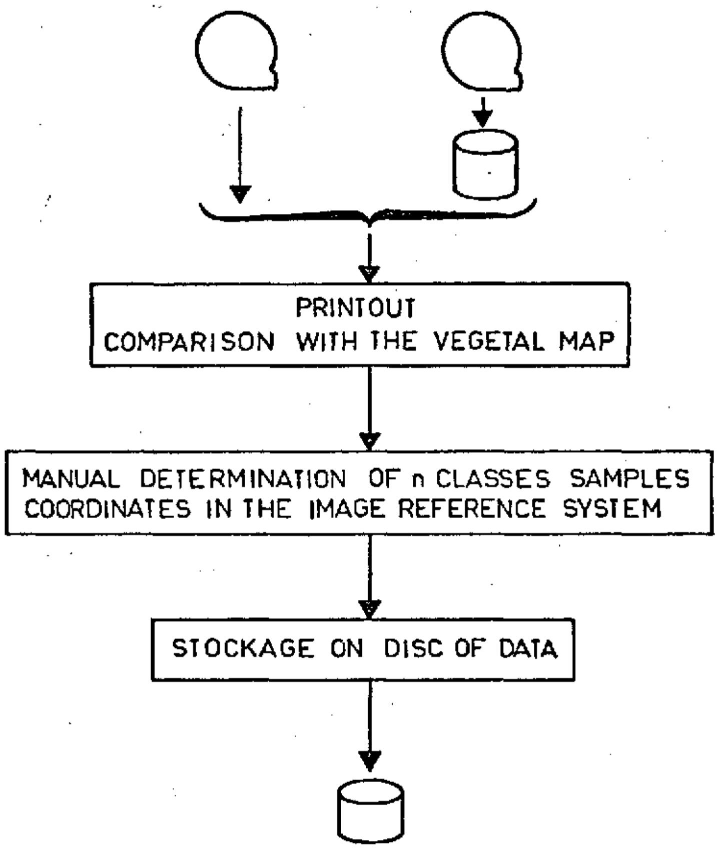
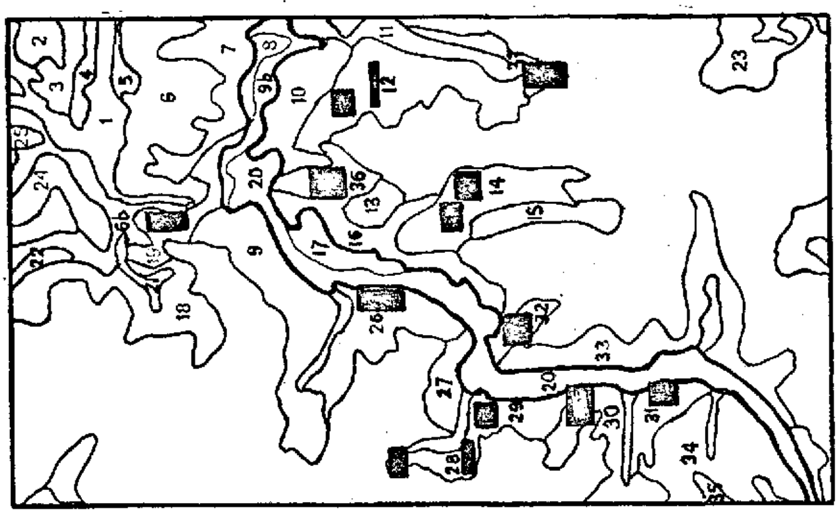


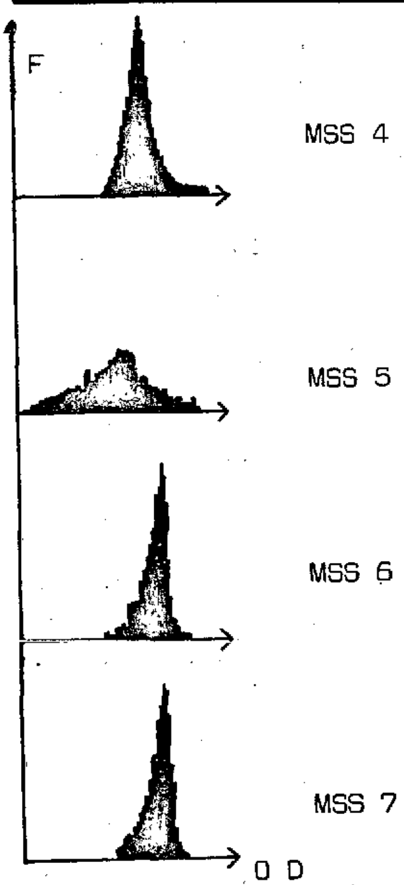
Figure 14

SAMPLES EXTRACTION CHAIN

SAMPLES LOCATION

Mapzoning





Histogram of optical density frequencies in the 4 channels of a sample.

Figure 15

Figure 16

Characteristics of samples in 4 MSS bands

TABLEAU MSS4 . MSS5 . MSS6 . MSS7 .

Echantillons		MSS4		MSS5		MSS6		MSS7	
		Moyenne	Ecart type	Moyenne	Ecart type	Moyenne	Ecart type	Moyenne	Ecart type
Sapin	2	177,43	3.25	152. 62	5.38	182.05	7,52	183.60	5.60
	3	179.5	3.35	156, 30	7,24	181.77	6.45	186.5	6.65
	4	177	3.32	153.98	5.99	184,09	4.38	188,7	4.64
	6	175,5	3.64	155.73	9,78	182,99	6.45	185.52	6.20
	7	176,63	3.30	151,54	5.29	181,29	5,74	186,31	5.09
	8	177.44	3.55	153.71	9.02	185.33	5,70	189.81	5.88
	10	177.3	4.00	155.62	7,66	185.02	3,70	187,29	4.09
	12	178,52	3,62	159.52	9,57	187,12	6.16	192,28	5.53
	13	175,78	4,08	154.45	5.33	181.27	5,49	186,20	5.21
Pins sylvestres	14	182.78	3.07	171.43	4.44	187,65	3.15	193,69	3,63
	16	182.53	3.42	170.85	7.41	190,29	3.98	195,09	3,00
	17	181,96	3.94	163,93	4.70	189.62	5.11	193,29	7.00
Pins à crochets	21	181,43	4.04	169,66	6.24	190.86	4.05	193,80	4.41
	22	181,99	3,11	174,21	5.21	191,04	3,24	195,32	3,32
Landes	24	184,07	2,35	178,49	3.93	192.73	2.89	197.80	5.50
	26	183,73	2,85	178,52	4.56	192.08	3.28	196,10	2.84
Prairies	28	184,72	3.57	176.31	3.80	—	—	195,28	2.60
	31	185.18	2.78	179.44	3,89	—	—	198,24	2,87
Pelouses	32	185.03	4,84	181.42	4,66	—	—	153,58	5,12

ARNICA III

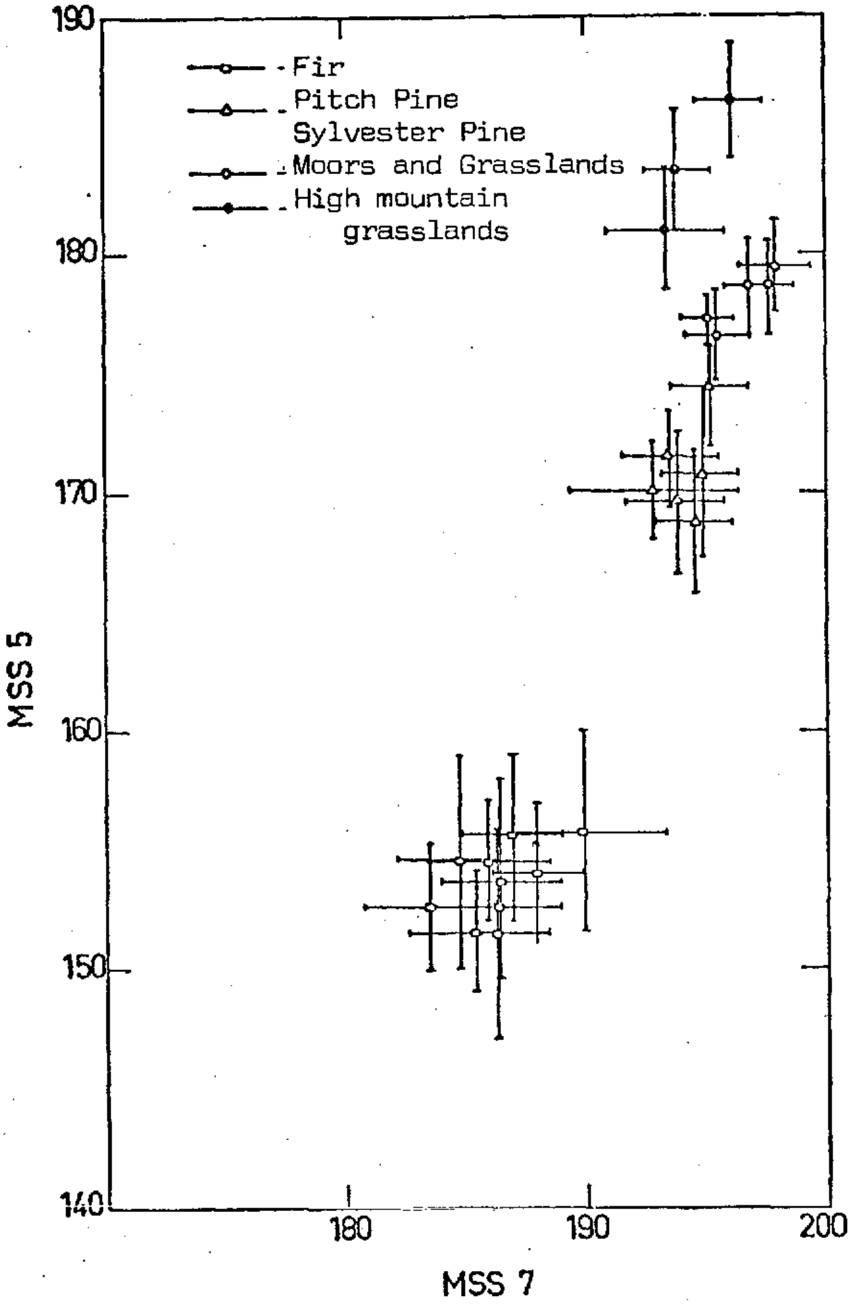


Figure 17

Responses of vegetation classes
in MSS 5, MSS 7 bands

Experience shows that it is useful to test the response correspondences between MSS bands 5 and 7 early and possibly then associate the correspondences between MSS bands 4 and 7 with them, in order to classify the vegetation series.

Qualitative and quantitative methods of analyzing the imagery are involved in the selection of the samples : at an early point the samples zones are chosen by means of photo-interpretation, aided by the Vegetation Map.

IV. Preprocessing of data

The preprocessing of data is developed along two lines :

1. Data correction : noise removal and filtering, image enhancement, geometric corrections.

2. Data reduction : necessary in the case parameters redundancy, or where only certain parameters are specifically adapted to the type of classification chosen.

The CESR develops the data reduction procedures. Consider a set of p variables measured over a population of elements (in the case of ERTS imagery treatment, these are optical density levels of the points analyzed in the 4 spectral bands).

The object of the preprocessing is to extract the best n from the p variables which classify elements in k categories following a given criterion.

The discriminating criterion chosen depends on the samples characterizing the classes, in this case a minimum distance criterion where the distance is chosen as the Sebestien metric defined in R^p by :

$$Q = (\det.\Sigma)^{\frac{1}{p}} \quad \Sigma^{-1}$$

where Σ is the covariance matrix of p variables. The process used is the classification of elements from the samples following this criterion.

The test used for reducing variables is the criterion known as "well classed percentages" or the ratio of the number of elements from the sample classed in their original group to the total number of elements from the samples.

The percentage is calculated using one variable at a time, beginning with the one which maximizes this percentage and repeating the calculation each time adding another variable.

The process is stopped at n variables when the percentage decreases at n + 1, or when all the variables have been used.

V. Classification and automatic mapping

The purpose of classification is to associate a class with each analyzed point, so that the ground truths, can be reproduced as accurately as possible.

For each point, the optical density measurements of the ground patterns, that appear on MSS transparencies, form a feature measurement vector :

$$X = (X_1, X_2, X_3, X_4)$$

The classification model identifies a ground pattern resolution element represented by the feature measurement vector. Several models are used in the processing chain.

1) Minimum distance to the mean optical density measurement.

The classification rule for identification of a measurement vector X for m ground pattern categories may be formed as follows.

Classify the measurement vector X as belonging to pattern class ω_L if :

$$\sum_{j=1}^{N} (x(j) - \bar{x}_L(j))^2 < \sum_{j=1}^{N} (x(j) - \bar{x}_i(j))^2$$

for all $i \neq L$ where $\bar{X}_i$ are m-1 predicted measurement vectors calculated for X from m-1 pattern classes, excluding pattern class ω_L, and $\bar{X}_L$ is the Lth predicted vector calculated for X from pattern class ω_L

j (1 - N) represents the number of features.

In general, for pattern recognition investigations the total number of categories is unknown beforehand. Some feature measurement vectors may not belong to any of the m classes catalogued.
A rejection class for "every thing else" may be developed by employing standard deviations as threshold values.

2) Elliptical boundary criterion.

The mathematics used by this classification model evolves out of the elliptical law of essor. This law provides a method for describing the distribution of accidental errors for experimental measurements involving many variables with elliptical curves.

For every ground cover pattern class ω, an error hyper-ellipse in n dimensional space can be generated from the equation :

$$
\begin{aligned}
a_{11}(x_1-\overline{x_1})^2 + 2a_{12}(x_1-\overline{x_1})(x_2-\overline{x_2}) & + \ldots + 2a_{1n}(x_1-\overline{x_1})(x_n-\overline{x_n}) \\
& + \ldots + 2a_{2n}(x_2-\overline{x_2})(x_n-\overline{x_n}) \\
& + \ldots + a_{nn}(x_n-\overline{x_n})^2 \\
& - H = 0
\end{aligned}
$$

Classify candidate measurement vector X as belonging to pattern class ω_L if :

$$\sum_{i=1}^{n} \sum_{j=1}^{n} a_{ijL} (x_{iL} - \overline{x_{iL}})(x_{jL} - \overline{x_{jL}}) < \ldots\ldots$$

$$\sum_{i=1}^{n} \sum_{j=1}^{n} a_{ijK} (x_{iK} - \overline{x_{iK}})(x_{jK} - \overline{x_{jK}})$$

for all $K \neq L$ where the index K varies from 1 to L and excluded L where a_{ijL} is the term of the transposed variance - covariance matrix.

3) Maximum likelihood ratio.

The maximum likelihood ratio model assumes a multivariate normal distribution for each ground pattern category that is characterized by the measurement vector X.

The probability density of the measurement vector X from the ith category is :

$$P_i(X) = \frac{1}{(2\pi)^{N_i/2} \left|V_i\right|^{\frac{1}{2}}} \exp\left\{-\tfrac{1}{2}(X-M_i)^T V_i^{-1} (X-M_i)\right\}$$

where $\left|V_i\right|$ is the determinant and V_i^{-1} is the inverse matrix of the covariance matrix V_i. The superscript T denotes the transposition operation.

$$V_i = \frac{1}{N_i - 1} \sum_{j=1}^{N_i} (X_{ij} - M_i)(X_{ij} - M_i)^T$$

where N_i is the number of observations in the ith category.

The classification rule is given by the likelihood ratio test. A vector X is classified as from pattern class ω_L if the conditional probability of X from pattern class ω_L is maximal. Mathematically this rule is given by :

$$\text{Ratio}_L > \text{Ratio}_i$$

for all $i \neq L$ where the ratios are defined as :

$$\text{Ratio}_L = -(X-M_L)^T V_L^{-1} (X-M_L) - \text{Log}_e \left|V_L\right|$$

$$\text{Ratio}_i = -(X-M_i)^T V_i^{-1} (X-M_i) - \text{Log}_e \left|V_i\right|$$

4) <u>The dynamic clustering method</u> was also used (unsupervised classification model) in limited areas. In general, this method is reduced to finding a grouping of finite sets, such that the object is closer to objects within its own group than to those outside its group, following a previously chosen criterion.

In this way the technical conditions of the automatic mapping of ground truths having satisfactory signatures can be defined progressively. Figure 18 provides an example of such a treament on a favorable site : the Aran Valley region (Spanish Pyrenees). The automatic reconstruction of pine forests seems to demonstrate clearly the efficacity of the process.

The experiments now in progress within the scope of the ARNICA program involve testing the possibilities of extending the method, first in neighboring zones on the same ground objects, and then for other themes on the whole of the prospective site, but still in conjunction with the preparatory analogic treatment otherwise being pursued.

SIMULATION OF AN ANALYTIC CARTOGRAPHY
OF FIR WOODS

a ▮ covers 40 ha of fir woods

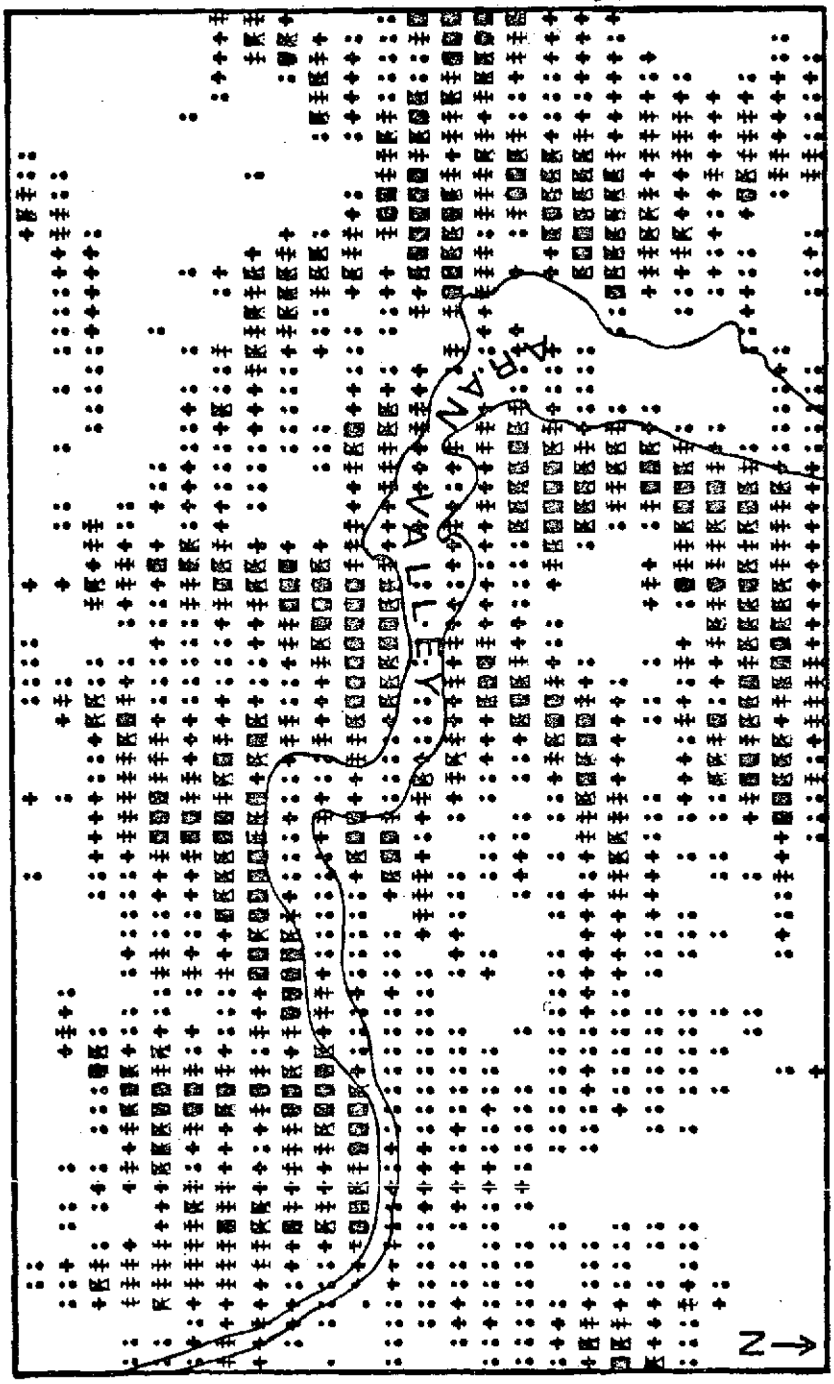


Figure 18

CONCLUSION

The ARNICA program has served to demonstrate the value of ERTS 1 data.

Work was done in 3 major areas :

- analogic treatment of imagery,
- digital treatment and automatic mapping,
- ground truth experiments and study of "atmospheric image transfer".

These are worth continuing in future programs in the light of our present experience.

Two proposals have been made for ERTS 2 which involve the Groupe Toulousain de Teledetection :

ARNICA 2, a continuation of ARNICA

AGRESTE, in an international context.

In order for this project to be carried out under the best conditions the following factors are absolutely indispensi ble :

1. Good conditions for repetitive coverage of the imagery (at least 3 times a year in general, with a more frequent periodicity in certain cases, such as for rice cultures).

2. Agreement between images and ground or air-borne observations.

Within this scope and in a multidiscipline and international joint effort, great strides can be made in remote sensing and the management of natural resources.

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