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THE FRENCH ATLANTIC LITTORAL
AND THE MASSIF ARMORICAIN

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| 15. Abstract : | | |
| <p>This final report gives results on Landsat - 2 data received and evaluated 5 scenes have been received in CCT Format and 65 scenes in film Format. These have been chosen to complete or extend time-series covering significant test areas.</p> <p>Data processing was mostly digital and different classification techniques were developed and comparatively evaluated with other available techniques.</p> <p>Output was in the form of colour or B/W maps using one or more scenes concurrently.</p> <p>Significant results were obtained in the following areas of investigation :-</p> <ul style="list-style-type: none"> - coastal geomorphology, with possible applications in shullfish aquaculture or recreation development ; - sedimentary transport, with identification of numerous sedimentary plumes (Loire estuary, Gironde estuary, Gulf of St-Malo, etc...) - methodological aspects of classification techniques. | | |

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1 - INTRODUCTION

This report covers the whole of the FRALIT-B investigation period. A number of data processing techniques were developed and applied to LANDSAT-2 CCTS.

On arrival, magnetic tapes were reformatted to our data bank standards (4 strips reassembled as a single scene file) and stored on direct access units.

Classification of pixels in various spectral categories was followed by mapping and interpretation using ground truth. Spectral signatures were gathered on site using an EXOTECH radiometer and used in the training phase of the classification process. Emphasis was put on the mapping of coastal areas, extending seaward out to the limit of coastal sediment transports, and landward into salt marshes, dunes and polder environments.

Comparisons were conducted in various test areas between LANDSAT data and other remotely sensed information (airplanes or other satellites). Ground resolution as well as spectral band variations were assessed.

Applications of remote sensing in coastal geomorphology were identified with particular reference to shell fish aquaculture and recreation development.

2 - TECHNIQUES

2. 1 - COMPARATIVE ASSESSMENT OF DIGITAL TECHNIQUES

The different classification methods used in the FRALIT program were applied to data from a test site on the French Atlantic coast. For critical evaluation of performance, this data was also processed by non-FRALIT methods (LARSYS, LARS JSC, IMAGE-100). Before describing some of the results from this comparison, and the test site itself, we will define some terms we shall use to characterize different techniques.

2. 1.1 - Definitions

Many different data processing techniques have been used in order to classify the spectral signature of remotely sensed data, into a given number of categories showing different terrain units or taxons (categories).

In a classification process, operator participation (in the broadest sense) can occur at different phases and in various fields of competence. Therefore, we propose to use the following terminology :

- assistance : participation of the operator in data processing. This can take place at different phases.
- pre-assistance : assistance occurring before the actual classification process.
- post-assistance : assistance occurring after classification.
- co-assistance : assistance carried out during the classification process. Practice shows that the level of co-assistance is likely to increase with the speed and efficiency of man-machine interaction.

The experience required for operator assistance can be drawn from different fields of competence. Therefore operator assistance can be termed spectral, taxonomic or geographical.

- spectral assistance is based on the knowledge of the statistical characteristics of spectral signatures. The decision to subdivide a class having a bimodal spectral signature histogram is a case of spectral assistance.
- taxonomic assistance requires prior knowledge of the physiographic units or taxons in a scene. An example is the decision to subdivide a forest class into coniferous and deciduous.

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- geographical assistance uses prior knowledge of the area covered by a given type of landscape or of the limit between two terrain units. Geographical assistance, for example, is the decision to group into one class all the pixels belonging to a given ground area.

Taxonomic and geographical assistance are linked when they are based on the unambiguous association of a taxon and a clearly defined geographical area.

Assistance is internal when it is based on the knowledge of the intrinsic characteristics of the data. The operator then participates by assessing these characteristics in order to make decisions.

Conversely, assistance is external when data from other sources are used. This is the case when ground truth data is available and taken into account.

The following table identifies the different processing techniques tried by FRALIT using the types of assistance as a classification criterion.

2. 1.2 - Test zone description

All the processing techniques used were tried out on the Fromentine test zone for the following reasons (Fig 2.1.A) :

- 1/ This area was imaged a number of times both by LANDSAT 1 and LANDSAT 2. Indeed, it had the lowest cloud cover of all the area studied in the FRALIT program.
- 2/ It has a variety of coastal terrain units whose study is the subject the FRALIT program. Each of these units is large enough to be compatible with the spatial resolution of the remote sensors used.
- 3/ It had been extensively studied by the FRALIT team.

The Fromentine test site lies in the Vendée area and is defined by the following quadrangle :

Lat 46° 47' N to 46° 57' N
and Long 2° 0' W to 2° 20' W

It includes the following terrain-types : (Fig. 2.1.B)

- Landward : Southern part of the island of Noirmoutier
: Breton Marsh
- Seaward : Southern part of the bay of Bourgneuf
: Atlantic Ocean (Bay of Biscay)

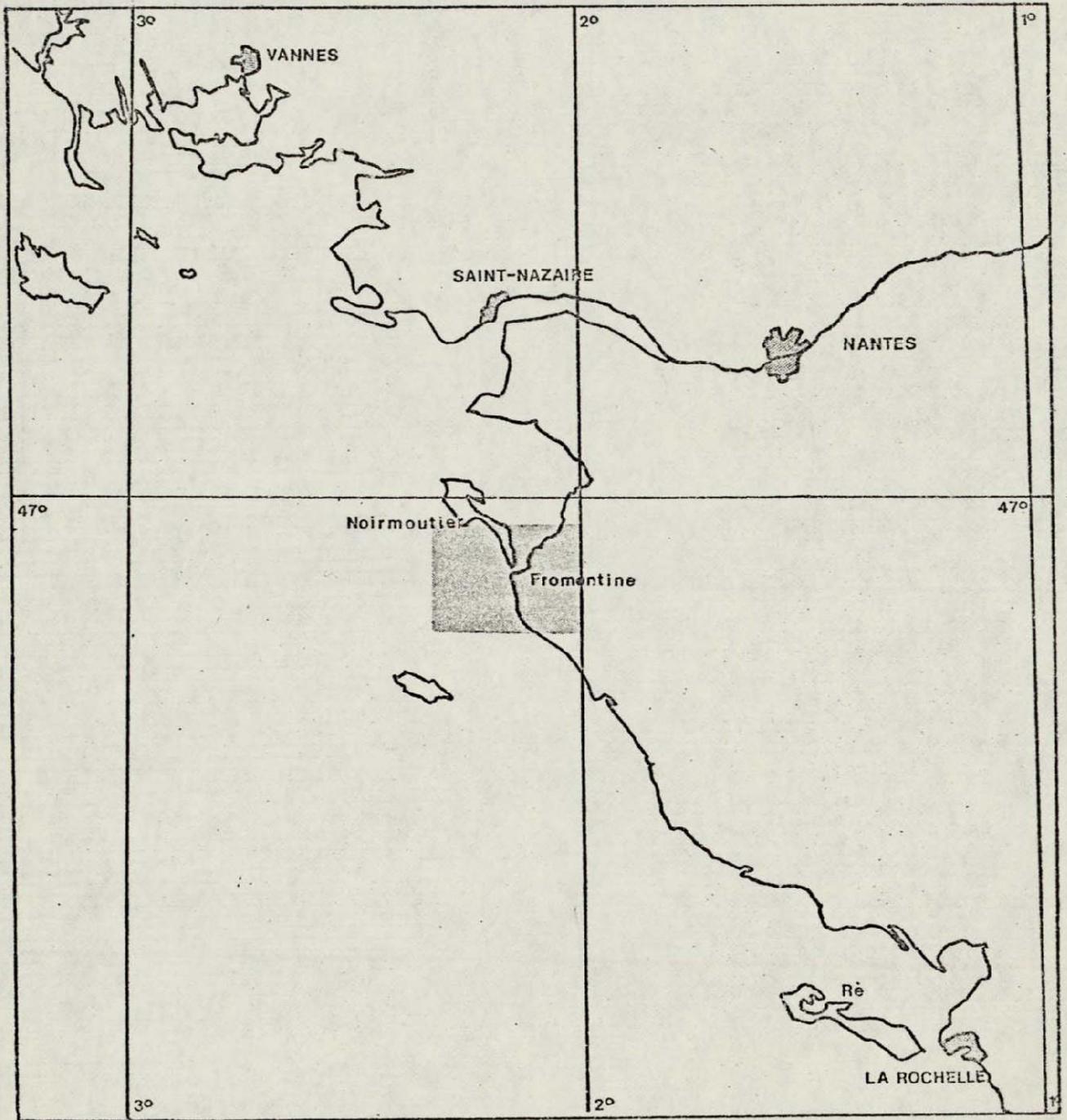


Fig. 2.1.A - Geographical location of the Fromentine test site

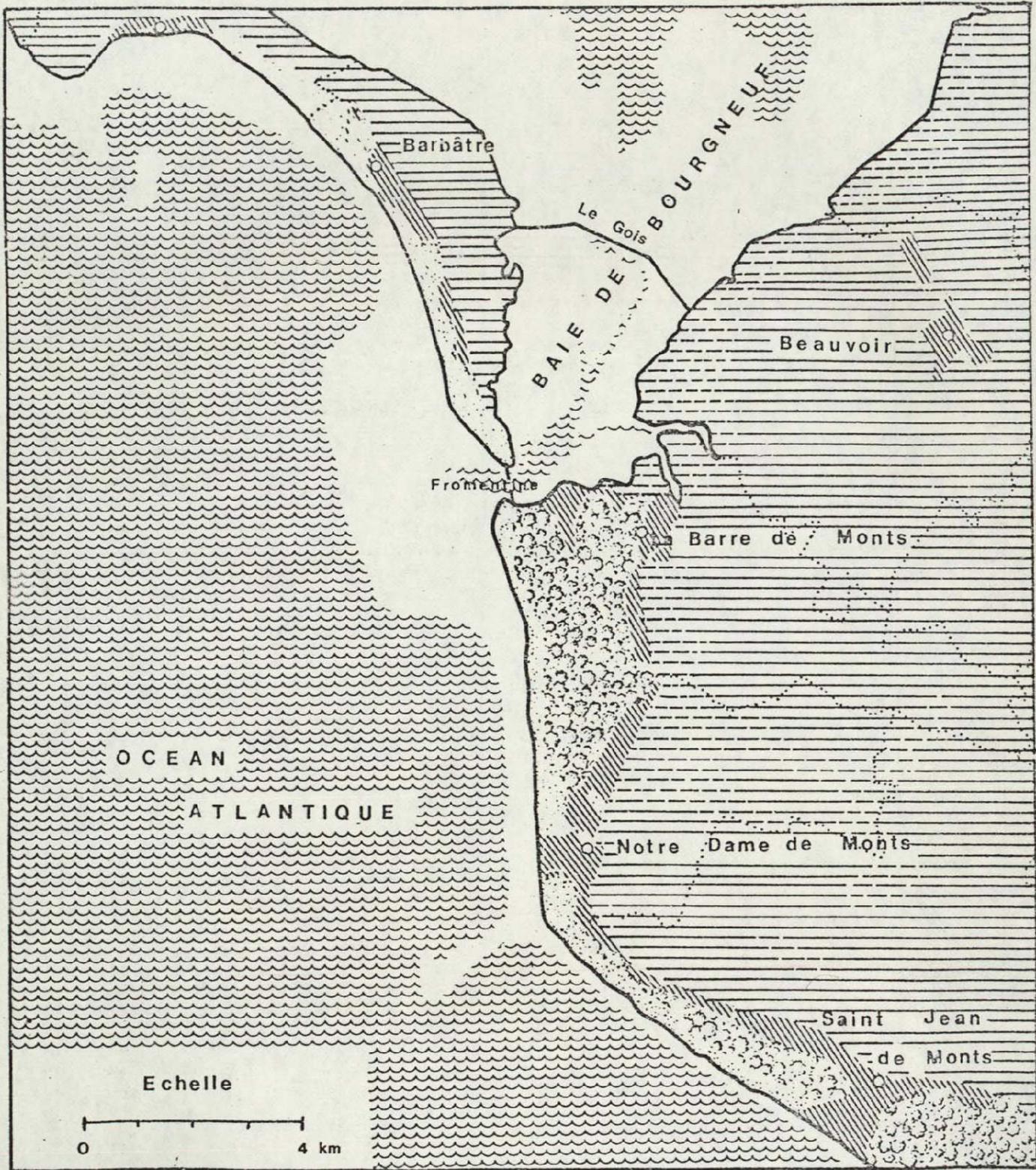
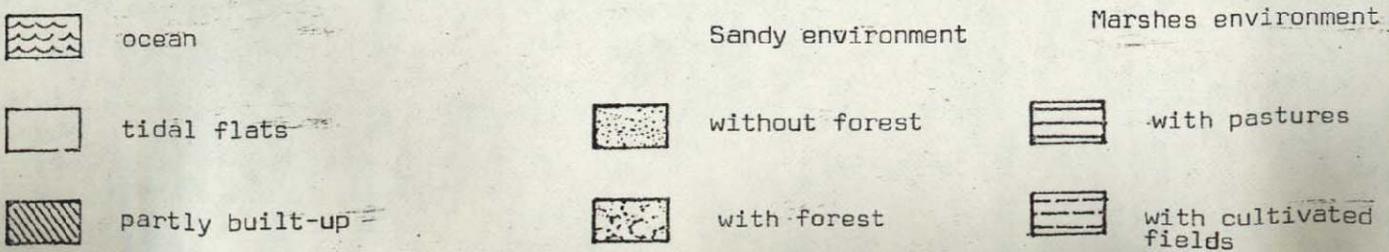


Fig. 2.1.B. - Ground truth map of the Fromentine test zone



a - Land environments

a-1- Southern part of the Island of Noirmoutier

This is basically a sand spit built against tertiary limestone out-crops. This spit includes coastal dunes with psammophyte cover locally mixed with maritime pine or Lambert's cypress.

East of dunes, a sandy marsh is divided up into small, variously cultivated strips. This marsh zone was extended by reclamation from the middle ages to the 19th century. The latest dyke lies north of the Gois ford : the Barbâtre polder holds nearly 300 acres and was hollowed out by the flood. The dyke was patched round the outside of this dip so that a stagnant pond remains : the "Trou de Sebastopol".

a-2- Breton Marsh

The Breton Marsh is a marine alluvial accumulation (mostly clay), protected by the dune covered bar of La Côte de Monts. The dunes are mostly built up along the sand bar to the West. Eastward, they lie across the bar and locally reach 20 metres height. They were planted with trees, mostly maritime pine, in the nineteenth century.

Housing is mostly developed where the dunes meet the marsh. Villages such as Fromentine and Notre Dame de Monts have fanned inland from the coast, with well-spaced houses and numerous gardens.

Land use in the marsh itself is very diversified : pastures in the east, with salt marshes (active or abandoned), sand or clay cultivated areas (Barre de Monts and La Crosniere) and occasional oyster beds (Bouin). Ancient polders have been invaded by the sea and partly reclaimed on the bay of Bourgneuf coast.

The area is abundantly drained by narrow and winding canals, often linked to drainage ditches.

Winding roads also run through the marsh. A four-lane highway crosses the south of the island of Noirmoutier, in line with the bridge linking the island to the continent near the narrowest point of the straits.

b - Marine environment

The marine parts of the test site are under the influence of a semi-diurnal tide. The tide drives a complex system of coastal currents which can reach 5 knots in the Goulet de Fromentine. Tidal variations lead to the drying out of parts of the foreshore both in the southern bay of Bourgneuf and on the Atlantic coast. The Noirmoutier bridge marks the limit between these two environments.

b-1- Southern Bay of Bourgneuf

From high to low tide marks, the foreshore can be subdivided into :

- . A polder, flooded by the sea in 1940 and never reclaimed since : the Grande Prise de Fromentine. It has been largely silted up and the highest parts are covered by halophiles, mostly Suaeda Fruticosa. It is partly used as submersible oyster-beds.

The Pointe aux Herbes de la Crosniere tidal marsh includes the following species from top to bottom : Suaeda Fruticosa on and near the dyke ; Puccinella maritima and Salicornia radicans, Obione portulacoides Suaeda maritima and Aster Tripolium ; Salicornia herbacea and Spartina Stricta.

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- . Flooded polders with little or no halophile vegetation. Beauvoir polder reclaimed in 1862 then enlarged in 1868 and abandoned in the twentieth century.
- . Sandy mudflats behind the nineteenth century dykes. Geomorphologically active sand bars such as the Piau t
- . Mixed sand and mud areas on either side of the Gois sedimentary ridge and its causeway. North of the Gois these areas include oyster beds.
- . Tidal channels of varying depths above L.A.T. levels, running towards the straits in the southern part of the bay. To the North, the test-zone reaches the deep Fain French.

b-2- Atlantic Ocean

On the shores of the Atlantic Ocean, the following tidal areas can be distinguished :

- . Sand beaches on the Island of Noirmoutier, on the Mont coast and the shores of the strait.
- . Calcareo-siliceous limestone outcrops : the la Fosse rocks.
- . Sand banks (submarine delta at Fromentine) for up to two miles seaward. These banks often include low frequency crosswise ridges with a changing morphology

The water itself changes considerably with the tide and also with the weather. Three main types can be observed muddy waters in rough weather on a lowering tide in the Goulet de Fromentine ; sand-laden waters over the submarine delta on a rising tide ; clear water off-shore near the Côte de Monts beaches.

Sea state is variable : waves and swell are frequent in the Atlantic ocean, whereas the formation of foam takes place in the south part of the Bay of Bourgneuf where waves are weak.

2. 2 - CLASSIFICATION BY TAXONOMIC PRE-ASSISTANCE (FRACARTE)

2. 2.1 - Introduction

The results presented here were obtained at the École Normale Supérieure (Montrouge) using the batch system FRACARTE tailored to the needs of the FRALIT team.

Computation is done in batch processing on an IBM 370/168. The test area is the Fromentine area as surveyed by LANDSAT2 on July 1975.

Computing time can be separated into two parts :

- 12 seconds of CPU for legend construction during the pre-assistance phase which was conducted by selection of training samples drawn from the entire population of 40 800 pixels.
- 9.6 seconds of CPU for the actual plotting file generation of a category map covering the 16 800 pixels test area. Off-line plotting was done in 45 minutes on a BENSON 122 ink-plotter.

2. 2.2 - Software organization

The system includes in two programs : FRALISIM and FRACARTE.

FRALISIM is used to identify the spectral signatures of the known taxons located in the area of interest. This category determination is drawn from the selection of sufficiently homogeneous training areas in the image to be processed. When the geographical area to be categorized is too small, it is necessary to select training samples outside it in order to draw conclusions from homogeneous taxons covering a statistically significant number of pixels. The spectral signature determination is done on gray scale prints or plain listing outputs. These listings help in the determination in each spectral band of the radiance intervals which bound the multispectral signatures of each taxon.

Once this determination is complete the spectral characteristics of each category are input on punched cards to the FRACARTE program. This module generates a magnetic tape plotting file which is used to drive the off-line BENSON plotter. Any projection and scales can be selected. In the example presented the operator selected a Lambert2 projection and 1:50 000 scale.

2. 2.3 - Theoretical background

All the philosophy of this system relies on a high level of pre-assistance used for the determination of radiance intervals bounding the spectral characteristics of each recognized category (taxon).

This determination can be guided using two types of approaches :

- a - Assuming the taxons belong to spectrally well defined and homogeneous categories. Their geographical boundaries as well as their spectral limits are clearly defined because the spectral gradients at their boundaries are strong. In LANDSAT data this type of signature is more frequent on land than at sea and is very often associated with man-made environments rather than natural ones. However it is possible to find moderate gradients at sea (Fig. 2.2.A) especially in estuarine or coastal areas.

In this case, the taxonomic pre-assistance will produce unambiguous spectral bounds for each category. It is seldom necessary with LANDSAT to use the entire set of spectral bands, 2 spectral bands are sufficient in most cases.

- b - The taxons cover continuously varying environments which are really obtained by mixing in various proportions a limited number of categories. The limits are in this case rather fuzzy and variations of signatures do not generate significant gradients.

We propose to call them spectral continuums. They can be found

- in coastal waters, especially in the inside of bays
- in the intertidal environments

In this case, the taxonomic pre-assistance can usefully be followed by a spectral pre-assistance working on the statistics of data. For example, types of waters defined by spectral intervals can be mapped by increasing turbidity as this parameter is correlated with spectral bands MSS4 and MSS5.

The weak points of this approach are :

- its dependance on careful choice of training areas in which categories are known for their homogeneity by collecting appropriate ground truth.
- its reliance on the "a priori" knowledge and skills of the operator.

But, it is also very useful because of :

- its simplicity of use
- its small computing times
- and its results in the case of spectral continuums classification because the produced maps are equivalent to photographic isodensity slicing.

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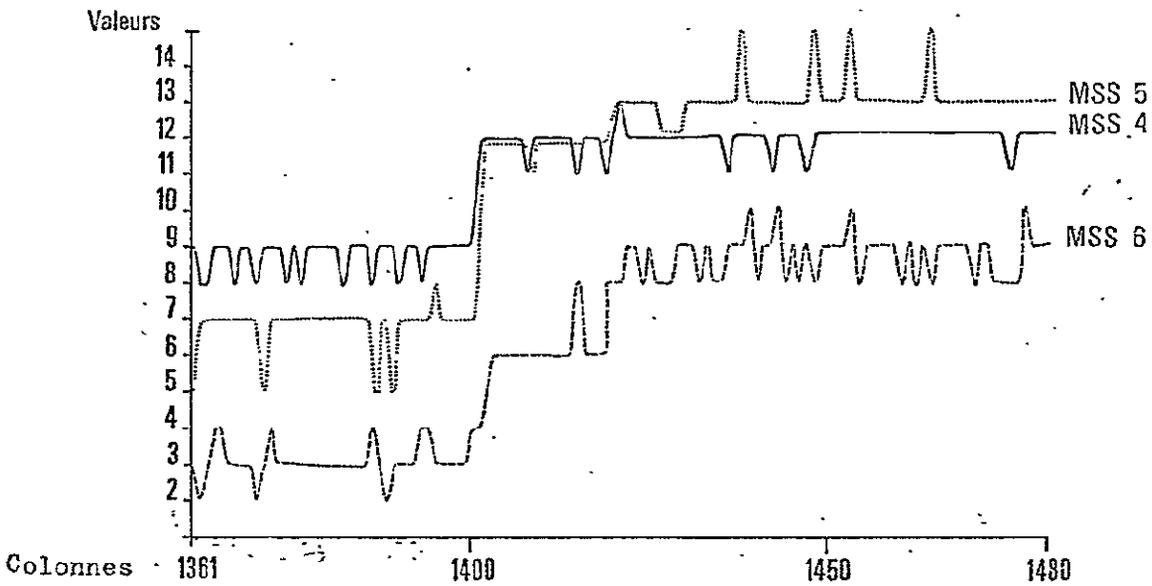


Fig. 2.2.A - Example of coastal water color gradient
At ebb tide, the plume of turbid waters
coming out the Maumusson strait expands
over clear ocean waters (E.2331 - 10110,
19 Dec 75, line 1566)
Values in MSS7 were not drawn because always
equal to zero or one.

2. 2.4 - An example of processing

The first step of the processing of the Fromentine area leads to the determination of class spectral intervals drawn from homogeneous training samples. The listing output of FRASILIM gives a list of values for the four MSS spectral bands. Each individual symbol is assigned to a specific radiance value (Fig. 2.2.B).

From this listing the spectral signatures of 6 categories were identified :

- water
- tidal flats
- sand and built-up areas
- dense forest
- cultures, meadows, vegetated sand dunes and open forest
- dispersed cultures and settlements with gardens

These definitions are assigned to each signature by taxonomic assistance. Two categories from this set can be interpreted as spectral continuums : the water and tidal flat environments. Theoretical considerations on spectral signatures or ground-truth radiometric measurements done with an EXOTECH radiometer lead to the subdivision of the first environment into 5 sub-categories of water ranked by their radiance values in spectral band MSS5 :

- MSS5 : 23 - class 1
- MSS5 : 24-27 - class 2
- MSS5 : 28-31 - class 3
- MSS5 : 32-35 - class 4
- MSS5 : 36 - class 5

These waters are ranked by increasing turbidity level. The tidal flat category extends its signature in MSS7 from radiance value 6 to 12. It is divided into two sub-classes using the intervals [6,9] and [10,12]. This gives us a separation between humid slikkes and tidal flats with lower water content.

The previous taxonomic pre-assistance has been refined by spectral interpretation of the spectral continua. The subsequent intervals are input to FRACARTE which outputs a 1:50 000 scale map. (Fig. 2.2.B). The legend of this document can be described as follows.

- 1 = Clear marine waters. They extend off the Monts coast (lower left part of map).
- 2 = Slightly turbid marine waters in Bourgneuf bay and North of the Gois ford (upper left part of map) as well as of the outer edge of the Fromentine submarine delta.

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- 3 = Average turbid marine waters.
- 4 = Highly turbid marine waters.
- 5 = Marine waters with very high sediment content in suspension often mixed with slightly covered tidal flats.
- 6 = Very humid slikkes.
- 7 = Tidal flats with low water content.
- 8 = Maritime pine forest and salt marshes (Monts forest and salt marshes on the rim of the Bourgneuf-bay coast).
- 9 = Cultures, open forest, meadow and vegetated sand dunes.
- 10 = Dispersed cultures and garden settlements.
- 11 = Sand and built-up areas.

Objects of different natures such as the maritime pine forest of Monts and the salt marshes of the abandoned Grande Prise polders may have the same spectral signature. In fact, three pixels belonging to these areas display identical quadruplet signatures : 23, 24, 37 and 16 respectively in spectral bands MSS4, 5, 6 and 7 (cf. quadruplets NM-G in Fig. 2.2.C). Resolving such ambiguities may involve the use of time varying signatures (diachronic) or spatial signatures (texture).

Results can be further refined on land but misclassification may increase due the complexity of the agricultural pattern of the Marais de Monts and Noirmoutier island. We decided to keep this level of category division because it is well correlated with physiographic units and broad categories of land use.

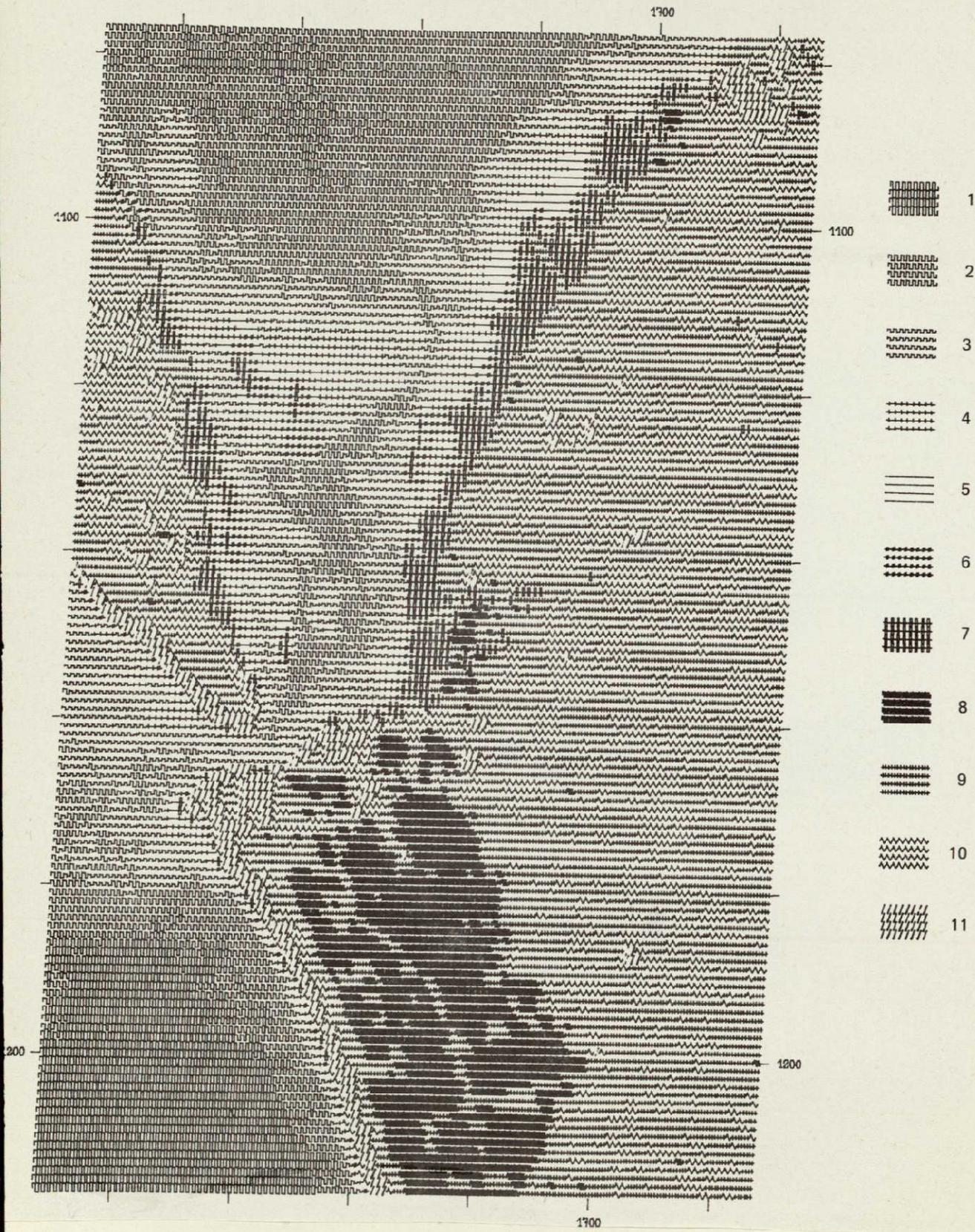


Fig. 2.2.B - An example of classification by taxonomic pre-assistance
Map of the Fromentine area at 1/50 000 scale generated
from LANDSAT2 data (E2188-10181 - 29 July 1975)

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UTL4 UTN6 SUP6 UXR7 UXUA SXSA SQS7 PPJC NP=F NM=G
VXK7 VXVA SXTA SVVA SVXA VXVA STR9 OOTD RU=F MM=F
UYVA UYVA UYVA UVUB UYYB UVVB OPSA NMYE OO=F OU=G
VYXA EYVA TWXB TYXC VYZC RSTA PPVB OPZE PP=G OM=G
UUW9 UWWB UWWB SWYB SWYB UWWB UW-C QR-E NN=G PRYC
TYVA SVVB TYYB TVYC SYYC SVYB ST=C PO+G OM+H PSVC
RTU9 RUWA SUZB JUZC SX=D PQ=E PQ=E PQ=F PP=G NP+H
SXVA STTA RTRA SVVA SV-E KS=F MO=G OO+H OO+H OO-E
SVVA SYUB UVUA UVVB UYZF RS=F OOZG OOZJ OPZH OP.G
TWT9 TTV9 TWT9 VYZC VYZC RSXB PP.I OPBL OSBI PQBK
UWT8 SWT9 SWT9 UZ-C SA.E SSW9 SS-D SS.G SW.F PR.G
K+D W+Z F W.O J Y7MO W.O K WZK WZE O W+Z O SVZM PT7O
S+7J UZGN U+EO XZGN XZEO X4GN S+9O UZEO SXGN S+9N
V.O BL W4DM S2BL OS4J MOZK RVBK V.O BM V.O BM S+BM S-8M
OT8N S-8N S-8L NM.I LL=H LMYG NO=H OSZJ RYBM KY8M
MLBK USBM RYAM UQZJ JK-I ML-I ML-I MK.I OQZL RYAM
NLZK NR7L PS7K ML.J KJ-G ML-H MK.H ML.H ML.H SZ9M
S-EM T+BP S-9M ML.H MO.H SY9L PS4J MJ.H OM.H PS7K
RTBL S.O O RX7M LK=I LM=I UZBL RT.I NL+I PQ.I NMZL
MOZH MPZJ MPBL LLZJ MO+I SX4J S+8K SX5J SVBK SX8M
LK=H LL=H OPZH OSZH OSZI RTBI NPZH NO=H NP.H OSBJ
RWBJ OM=G JK.G JJ-I JJZG JLZG JKZG JLZG OQZK RW8M
ML-G KJ-G MK-G MLYF MK-G MK-G MK-F MK.G MK.H NR7M
JJ+G MLYG ML-H JL+H ML-G JL-G JJ+H ML+G ML.H ML.H
JK=G JK=G LL=G LL=G LM=H LL=H JK=H LK=H LL=G LLZG
LLZI JK+H JK-H JK-H LL-G LM+H LL+I LI-I LK-I LL+H
NMZK LI.I LLYH LL=F LL=G LL=H NL=G JK=G LK.H LKYG
PWEO RT8N OM3K MKZF JLZG NL-I OL.I JMZF MK-G JG-J
QZSO XZOU SWEO MK-G KLYF NL-G MK.H KJ-G KJ-G KJ.H
OP4J PV8P OP4L JJ+H JLYG MK=H JM+G MO-H MO+H MM+H
NP+H LL+I NL=H LKZH LM=H NP=I NP=H JMZG LLZG LL+H
LM+I LO+J LLZI LL+H LL-H JL-H LM+I LH+I LM=F LL-H
LK.H LL.H LM=H LL=G LK=H LK=G LL.I NOZL LOZI LL=G
JK.I JK-J MM.I MM.I JMZG MM-I ML.J MMZK JLZJ JL.I
MJ.H MK-G KN.G NN-H KL.H MK.J NK.J NL.K NN.G ML.F
ML=G JL+H OO+H OO+H MJ+H MJ+I ML.I ML+H ML=G JJZI
LL=H LM=G LL=G NM=H LL=H LK=H JM=H LLZG LL=G JK=I
LM=G LL=G LL-H LL+I LL+I MM+I LM+H JM-G LKXH JK=H
NM=G NM=G LL.G LK=G LM.H LM.H LM=G JIYG JI.G NI.H

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Fig. 2.2.C - Part of a FRALISIM output listing for the Fromentine area (29 Juillet 1975). Each quadruplet gives the value taken by one pixel in the four spectral bands MSS4 to MSS7. The coding of individual values is hexadecimal. The determination of category (taxon) signature is taken from such a document during taxonomic pre-assistance. The quadruplets NM=G (values 23, 24, 37, 16) have been circled out. They are associated to the Monts forest (last line of display) or the Grande prise salt marshes (first line of display)

2. 3 - CLASSIFICATION BY SPECTRAL PRE-ASSISTANCE (AGREG)

2.3.1 - Introduction

Data processing results discussed here, were obtained using the AGREG program which is part of the CLAMS classification system. This system was developed by Ecole des Mines under contract with the Centre National d'Etudes Spatiales (CNES). It is implemented in batch processing at the CNES computing center in Toulouse, using a CDC 7600. Overall CPU computing time for treatment of the Fromentine area was about 1 minute and 20 seconds.

Graphic output related to the classification results is generated as printed lists and graphs drawn on black and white microfilm using a CALCOMP 1670 COM system.

2. 3.2 - Software organization

The use of the AGREG algorithm causes the execution of several modules integrated in the CLAMS system. They perform the following actions :

- supervised clustering per se (AGREG)
- image display of classification results
- spectral statistics

"A priori" knowledge by the operator of the number of classes and of their spectral statistics (average and RMS) is needed in order to run AGREG. These characteristics can be acquired using various means of information :

- a spectral data bank built by collecting typical spectral signatures. In this case the statistics are estimated by the variability expected from natural environments.
- a previous classification applied to a sample of the original image using a limited number of pixels. The reduction in the number of objects to be classified would in this case be linked to the use of more sophisticated methods than AGREG thus more costly in computing time.
- a previous classification carried out on a different area or even on data acquired for the area of interest but at a different date. The philosophy is in this last case to extend in time and in space the results obtained on an intensive test site where ground truth was thoroughly collected.

Once clustering has been performed around cluster centers initialized by spectral pre-assistance, category display and spectral statistics help in assessing the quality of the subsequent mapping.

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2. 3.3 - Theoretical background

The supervised clustering performed by AGREG belongs to the general family of algorithms in which spectral radiances are assigned to classes which are "a priori" defined by their statistical characteristics.

Several practical approaches are found in order to solve this type of problem. They are generally of three types :

- assignment by computation of the conditional probability that a spectral signature belongs to a specific class
- assignment by reference to a decision table
- assignment by computation of the distance separating a spectral signature and a specific class.

a - Assignment by conditional probability

The first type of approach relies on the theory of probability. The basic information used in this case is the joint radiance histogram computed for the entire set of spectral bands.

This basic set of data can be information compressed at various degrees depending on the available computing time and core memory space. This compression usually involves the use of probability distribution modelling of the spectral radiance values repartition of pixels known to belong to specific classes. This training is done by "a priori" gathering of ground truth.

The model may use a limited number of parameters. This is for example the case of Gaussian hypothesis used in the LARSYS system. Illustration of this type of parametric approach can be found in Fig 2.3.A in the case where two spectral bands are used. A more precise but more complex solution can be found by the use of general types of distributions as in the general class of non parametric methods.

b - Assignment using a decision table

The basic information used is the same as in the preceding method, namely the joint radiance histogram.

But in this case no effort is done to model this distribution. Data compression is only performed in the storing phase in order to build a multidimensional decision table (Fig 2.3.A).

The assignment is in this case very quick but core memory used is often in the order of several tens of thousands of bytes. Memory reduction is in this case entirely dependent on computing skills developed by trained personnel.

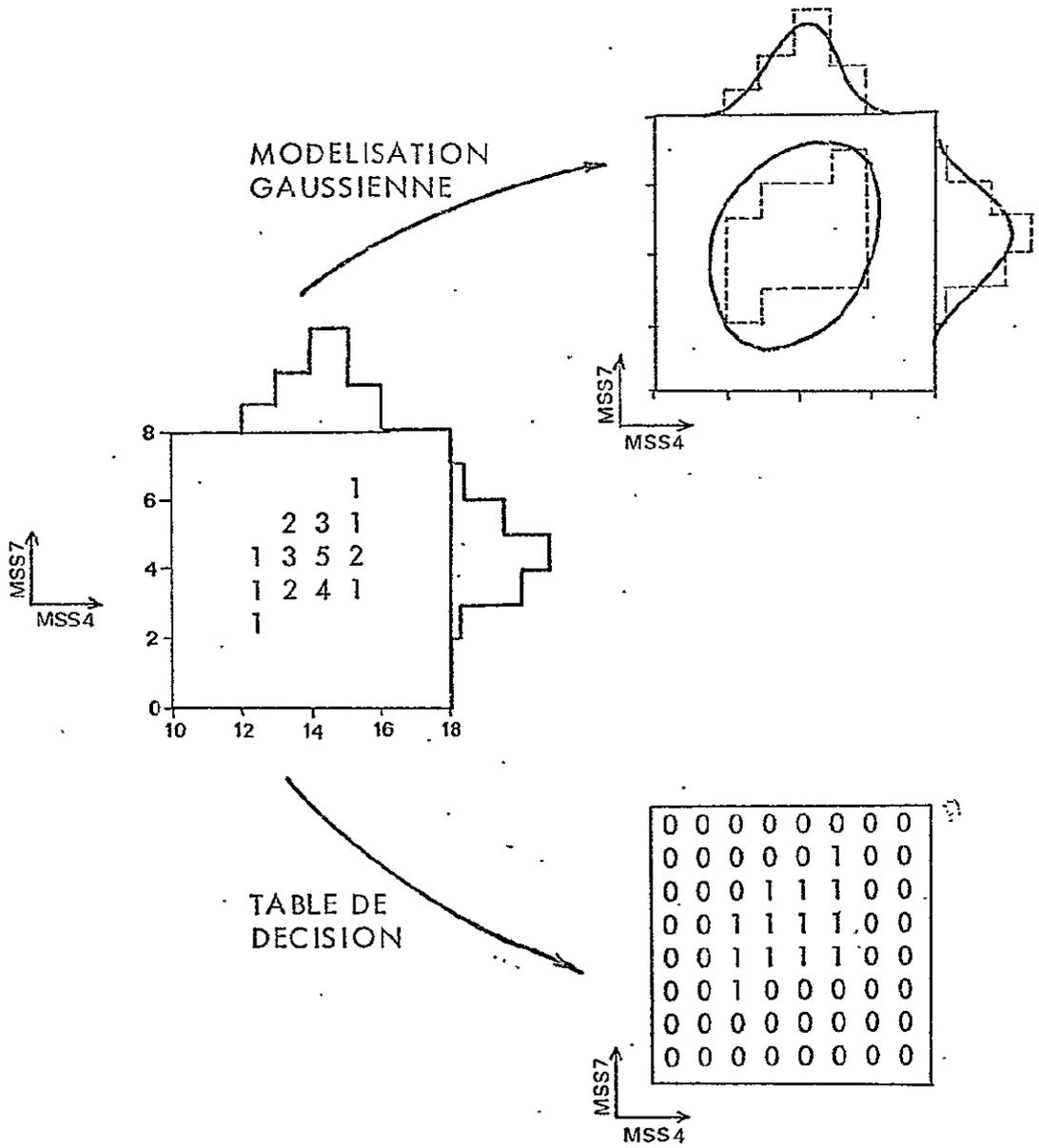


Fig. 2.3.A - Two types of assignment methods using the joint radiance histogram of spectral signatures

c - Assignment using a distance criterion

The degree of similarity between a spectrum and a class is computed in this case in place of the conditional probability of a spectrum to belong to a class. The solution used in general is to compute the Mahalanobis distance which uses for each class C_i , its average signature m_i and the associated variance-covariance matrix Σ_i .

$$D_M(z, C_i) = (z - m_i)' \Sigma_i^{-1} (z - m_i)$$

where : Σ_i^{-1} = inverse of matrix Σ_i

This formula defines a quadratic form associated to the Mahalanobis metric.

The AGREG program designers prefer a distance which uses the average signature m_i and the vector σ_i which set of components σ_{ik} are the spectral variances class C_i for the spectral band k . It is defined as follows :

$$D(z, C_i) = \sum_{k=1}^n |x_k - m_{ik}| / \sigma_{ik}$$

The use of this distance gives classification results which are equivalent in quality to the use of D_M . However it is more simple to compute than the last distance, leading to a saving in computer time.

A reject class (unclassified points) is built using a criterion equivalent to the mean divergence.

Methods of assignment using similarity indexes do save the computing time used in fitting specific models to the radiance joint distribution histogram but this saving is often lost when the assignment phase involves a large number of pixels.

2. 3.4 - Data processing example

a - "A priori" class statistics

Decision was made to categorize the Fromentine area into six "a priori" classes (Fig 2.3.B) whose statistical characteristics were drawn from a detailed classification computed on a regular sampling of the studied area.

The six classes are related to land use themes and do not cover sea water or tidal flats.

b - Classification performance evaluation

A solution to the "a posteriori" evaluation of the supervised clustering performance may be found in the comparison of the position of means and variances of "a priori" classes in relation to the "a posteriori" spectral signature histograms computed in each spectral band.

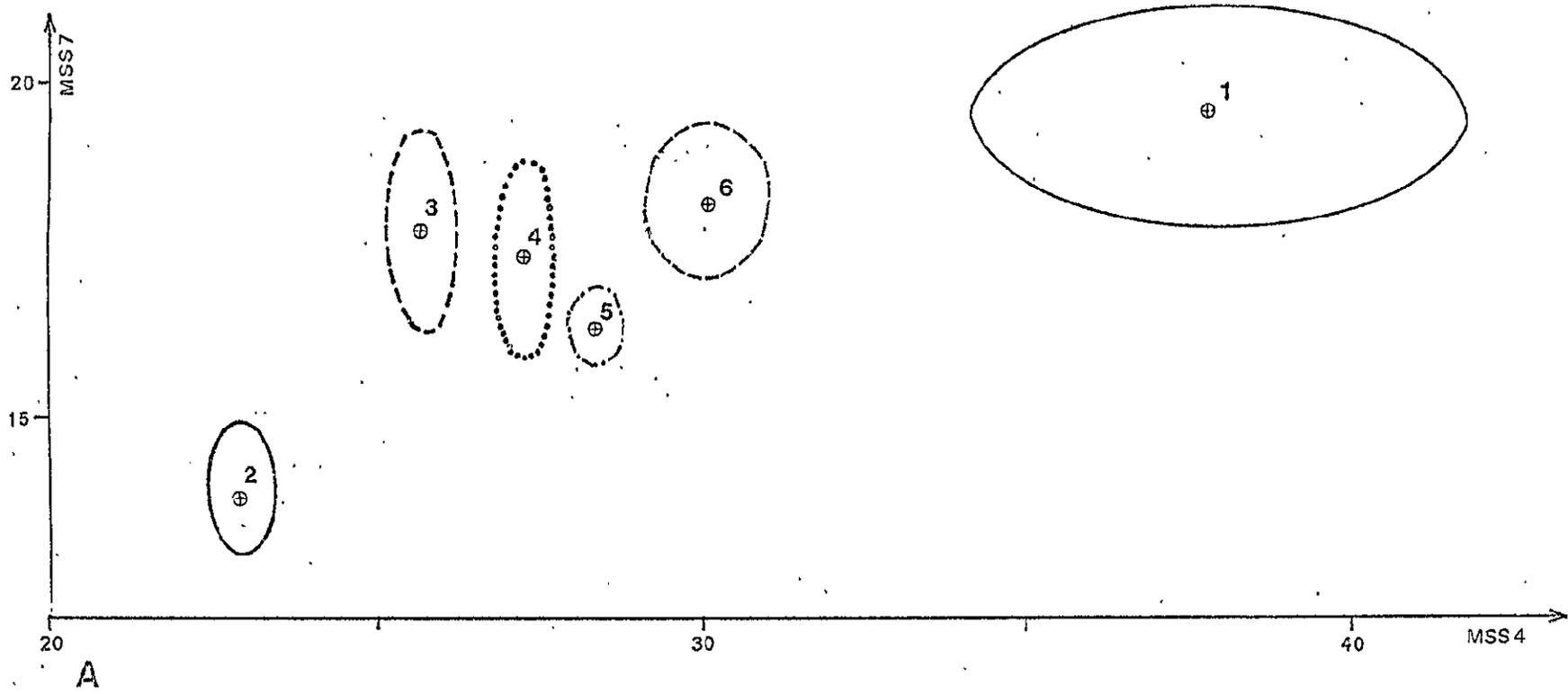
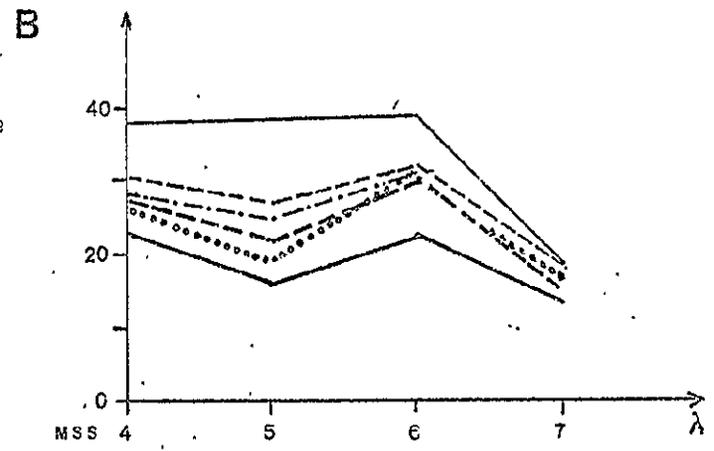


Fig. 2.3.B - Spectral characteristics of the classes involved in the supervised clustering phase

A - Spectral means and variances for each group for spectral bands MSS4 and MSS7

B - Average spectral signatures

1
 2
 3
 4
 5
 6



This test was performed on Fig 2.3.C comparing the MSS4 histograms of groups 1 and 2. The hatched part in each histogram is related to the radiance interval $[m-\sigma, m+\sigma]$ computed from the "a priori" spectral characteristics of the associated class.

A good fit is noticeable for group 2 between "a posteriori" histogram and "a priori" spectral characteristics.

This is not the case for group 1 for which the histogram has a trend toward bimodality. This property was not taken into account in the similarity distance formula used in AGREG because it is only computed from spectral mean and variance. A probability assignment method, using a non-parametric approach, might have given a better result to the expense of more computing time.

c - Results display

The cartography presented on Fig 2.3.D is an enlargement of a display generated on microfilm.

The reject class is represented in white. It contains the pixels which spectral radiances were found to be too different from those of the "a priori" classes.

The taxonomic significance of the classes was found to be in good relationship with existing land use patterns.

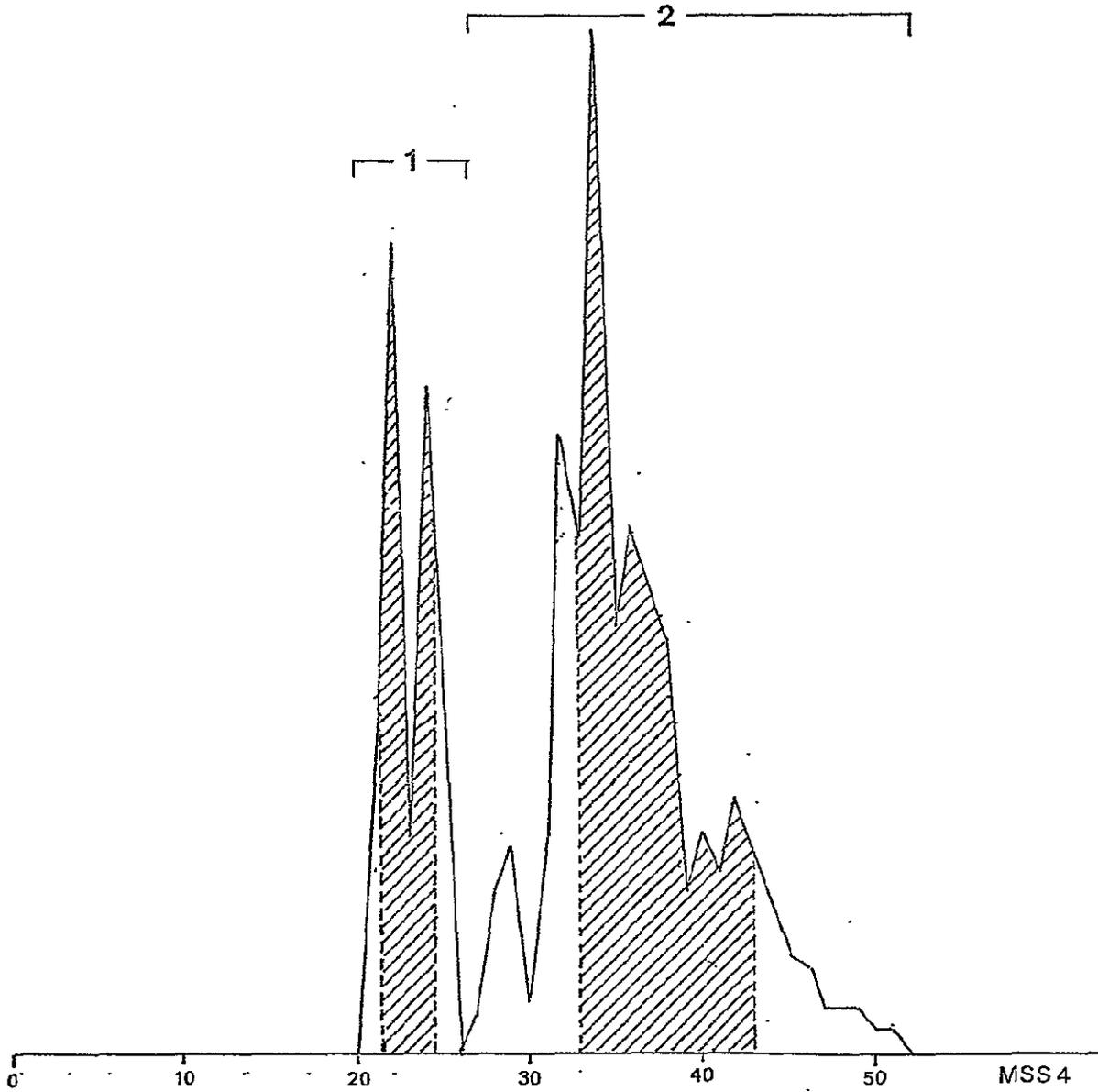


Fig. 2.3.C - Comparison of "a posteriori" spectral characteristics of groups 1 and 2 with the "a priori" parameters used in the clustering phase

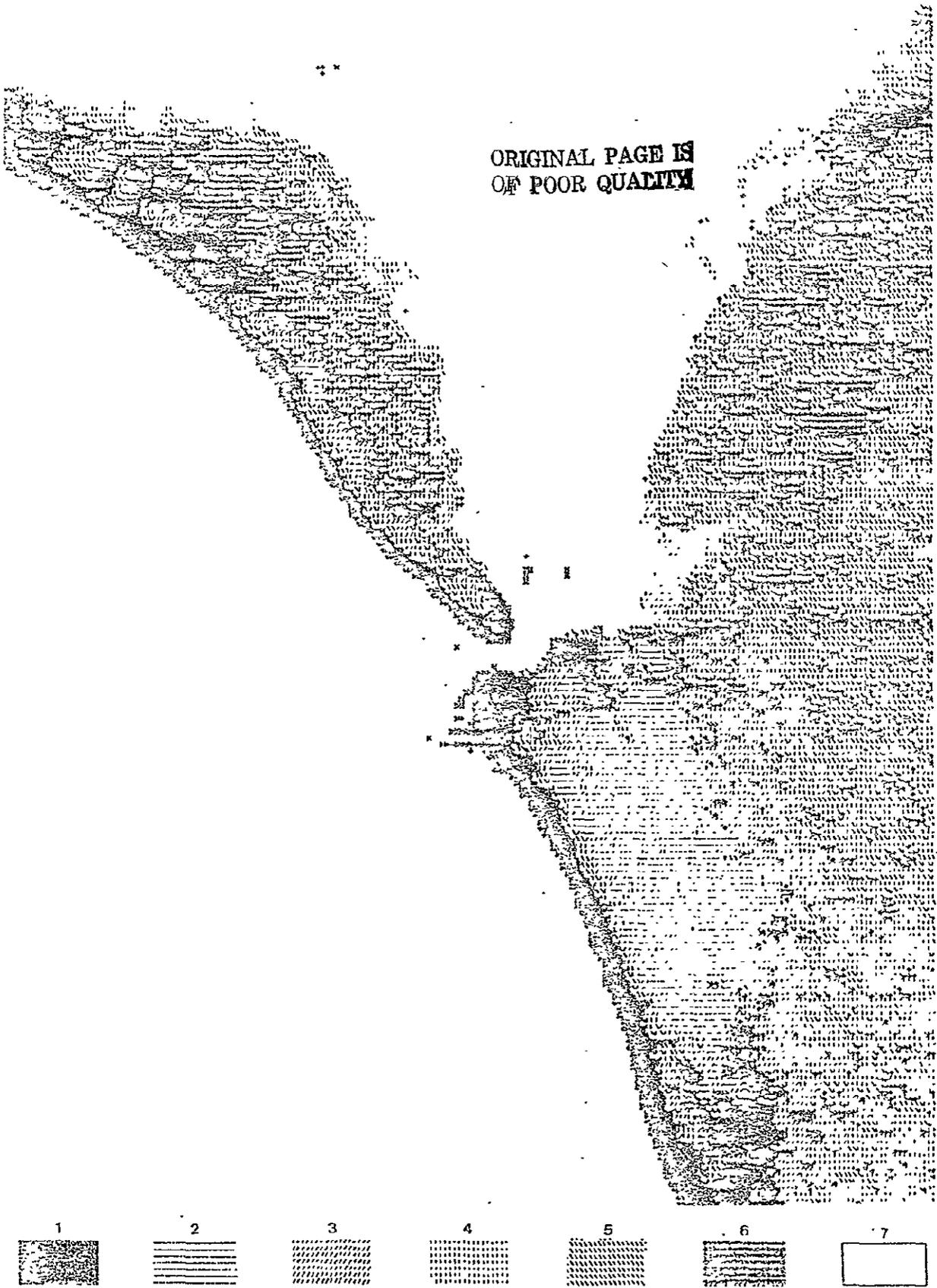


Fig. 2.3.D - Enlargement of AGREG classification display
generated on a COM microfilm device

2. 4 - CLASSIFICATION BY SPECTRAL COASSISTANCE AND TAXONOMIC POSTASSISTANCE (FRACAM)

2. 4.1 - Introduction

The data analysis results presented here are taken from the Fromentine area, overpassed by LANDSAT1 on July 11, 1973 (Ref. number: 1353-10244). The equipment used is a CII IRIS-80 computer linked in the time-sharing mode to a Tektronix graphic display terminal. The graphs and maps produced on this interactive console can be hard-copied on paper using a Versatec printer-plotter.

The overall computing time for a classification involving 40 000 pixels is about 20 minutes.

2. 4.2 - Software organization

The FRACAM system has been developed at the Ecole des Mines (Paris). It is organized in four separate modules, whose functions are :

- data display and spectral statistics (FRAC1),
- correspondence analysis (FRAC2),
- ascending hierarchical classification (FRAC3),
- adaptative clustering (FRAC4).

The FRAC1 program has various display capabilities whereby images can be presented as :

- black and white binary maps related to a specific interval of radiance values in a given spectral band or to a spectral class produced by a previous analysis.
- gray-scale images, with a limited number of gray scales (4 levels at maximum), by modulating the intensity of the electron beam impinging on the storage tube.
- as an infographic map using the same logic as the FRACART program.

This program produces graphs related to the following statistical results :

- radiance values histogram, in a specific spectral band, computed on the entire image or restricted to a spectral class produced by a previous analysis.
- average and RMS signatures of pixels associated to a spectral class or to an interval of radiance values in a given spectral band.
- bidimensional histograms obtained by the comparison of two spectral bands (MSS4 and MSS7, for example). These can be computed for a complete image or can be restricted to spectral class.

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- a display of spectral class signatures in the plane of two spectral bands.

The maps produced by FRAC1 are geometrically corrected using LANDSAT orbit parameters and scanning geometry specifications. The hard-copies generated on the printer-plotter match the Lambert 2 projection system at any scale between 1:1000 000 and 1:10 000.

Another function of the FRAC1 program is to prepare the coding of data, either by slicing the histograms in isopopulation intervals, or by adapting these intervals to the spectral contrasts the operator is able to assess in the image before any classification (opposition between water and soil, for example). The first step in any pattern recognition problem is to select an appropriate feature space by data coding and also, in most cases data compression. This is done in the FRAC2 program. Feature space selection uses a two step procedure where data coding is followed by data compression. A binary coding of the radiance values using the previously determined histogram intervals is followed by correspondence analysis. This multidimensional statistical method similar to factor analysis enables the operator to select a sub-space of limited dimensions (5 typically) in which hierarchical classification and clustering will be performed. This analysis can be carried out for the entire image or can be restricted to a spectral class produced by a previous analysis.

The FRAC3 program helps in initiating the clustering of radiance spectra in groups of similar shapes. The number of groups that one would expect to find in the data set is objectively determined as a result of an ascending hierarchical classification of the spectral intervals used in the data coding performed in FRAC2.

Dialogue between the computer and the operator is required in this phase, because the determination of the expected number of groups involves the interactive "pruning" of a dendrogram resulting from the hierarchical classification. Along with the number of groups the position of their centers of mass in the feature space is estimated as well.

FRAC3 output is used in order to initialize the adaptive clustering performed by FRAC4. It uses an iterative procedure of the same principle as the ISODATA clustering algorithm. Within each iteration every radiance spectrum is assigned to a specific group whose center of mass is updated at the end of the assignment phase. Various convergence criteria are used such as an upper bound on overall center displacements or total number of class assignments changes between each iteration. Operator action is limited to the choice of the maximum number of iterations in the case where convergence does not occur using built in criteria.

The FRACAM system is organized so as to enable the operator to perform a layered classification by sequentially refining the spectral groups (spectral co-assistance) in relation to their taxonomic significance (taxonomic post-assistance).

2. 4.3 - Theoretical background

a - Methodology

The relationship existing between an object located on the surface of the earth and the shape of its radiance spectrum as measured by LANDSAT is the basic principle of remote sensing. It lends itself to automatic cartography through the use of numerical procedures which by mathematical nature belong to pattern recognition techniques.

The recognition of spectral shapes is solved by two types of methods. Segmentation of the set of spectral radiances is based, in the supervised approach, on the "a priori" knowledge of the nature and location of typical objects existing in a given test area. In the unsupervised approach, clustering using objective criteria.

The classification method used in FRACAM belongs to the latter type. It is built around an adaptative clustering algorithm : similar to the ISODATA method.

As the number of objects to be recognized can be rather large (8×10^6 for a complete LANDSAT image), special care has been taken to reduce computing time. For an ISODATA type algorithm this mainly requires the minimization of the number of iterations necessary to reach convergence. This problem is equivalent in some respects to the search for initial centers of mass as close as possible to their final positions after convergence.

Correspondence analysis of J.P. BENZECRI as a multidimensional method for data structure analysis provides an answer to the search for reliable centers of mass. It results in the selection of a sub-space of limited dimensionality (feature space) in which it is possible to undertake a detailed study of the similarities existing between the spectral bands or their coded equivalents. The groupings thus determined are used in the initialization phase of the clustering algorithm. Initial centers of mass are computed using the simultaneous representative formula of correspondence analysis which builds a straightforward link between the factor space of the spectral bands and the factor space of the spectral signatures.

Using this general framework, the FRACAM system is logically organized in three steps :

- use of correspondence analysis in an objective study of the data set structure followed by the selection of a factor sub-space which is retained as feature space. This data compression very often filters instrument noise
- determination on the filtered data of an ascending hierarchical classification of the spectral bands or their coded equivalents. This similarity study leads to the recognition of associations between spectral bands and spectral shapes
- construction of spectrally homogeneous groups by adaptative clustering where the initial positions of the centers of mass in the feature space are calculated from the results of the previous phase.

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b - Data coding

In order to have more flexibility in the determination of spectral band groups, it is preferable to transform the originally measured spectral radiances. This transformation is called complete disjunctive coding or isopopulation coding.

Such a code is generated by the following steps : computation of the radiance histogram of each spectral band j for the area of study, determination of n_j isopopulation radiance intervals for each spectral band j and replacement in the original data set of each measured radiance spectrum by its complete disjunctive code.

Each n dimensional spectrum (n = 4 for LANDSAT) is thus replaced by a K-dimensional vector, with :

$$K = \sum \{n_j \mid j = 1, n\}$$

Each component of this vector associated to a given radiance interval takes a binary value 1 or 0 depending whether the corresponding spectrum radiance value in the spectral band j belongs to the given radiance interval or not.

The principle of this coding is illustrated in Fig 2.4.A when the four spectral bands of LANDSAT are split into four isopopulation intervals.

The use of this procedure was justified by an increase in overall classification performance, specifically regarding the number and spectral definition of classes.

c - Correspondence analysis

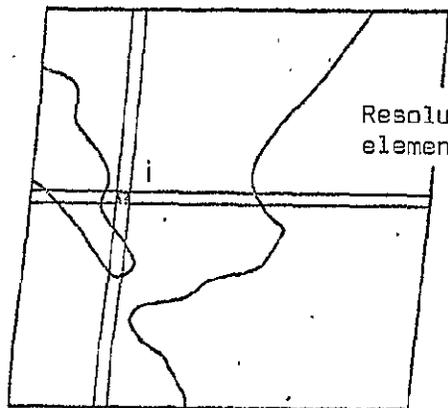
After transforming the data set, it is interesting to study its structure with particular reference to the similarity existing between the K coded equivalents to the n initial spectral bands.

We will call transformed band $c_{j\alpha}$, the binary instrument whose output is 1 or 0, whether the observed object radiance in band j falls or not in the isopopulation radiance interval of rank α .

In the example of Fig. 2.4.B the transformed band C_{42} is a very simple incremental instrument with an output of 1 when the measured radiance in band 4 (MSS7) falls between intensities 4 and 16 or 0 for any radiance value outside this interval.

The total number of transformed bands is K (K=16 in Fig. 2.4.) they will be indexed by k in our formulas as long as the explicit identification of the relationship between spectral bands and transformed bands is not required.

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| | | | |
|----|----|----|---|
| 37 | 27 | 15 | 7 |
|----|----|----|---|

Measured radiances in 'i'

| | | | |
|------|------|------|------|
| 0010 | 0010 | 0100 | 0100 |
|------|------|------|------|

Coded spectrum

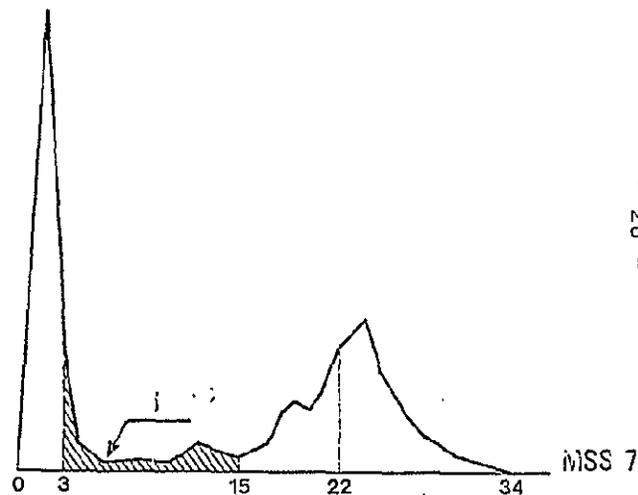
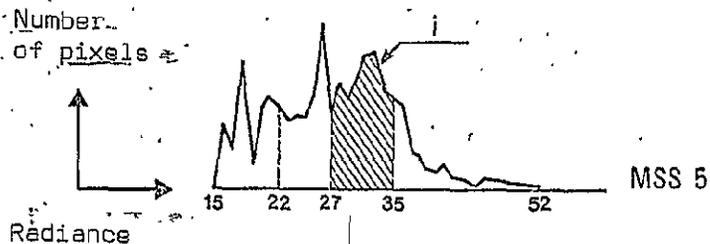
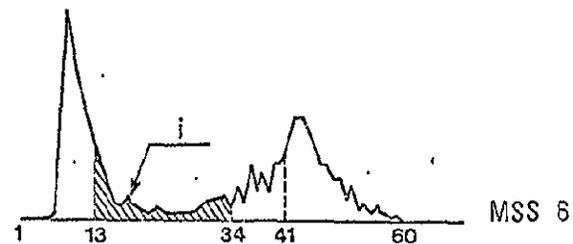
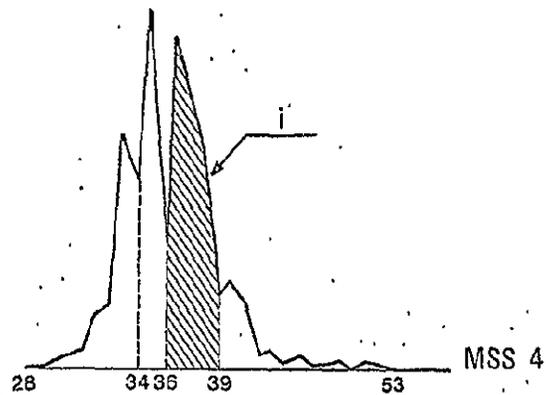
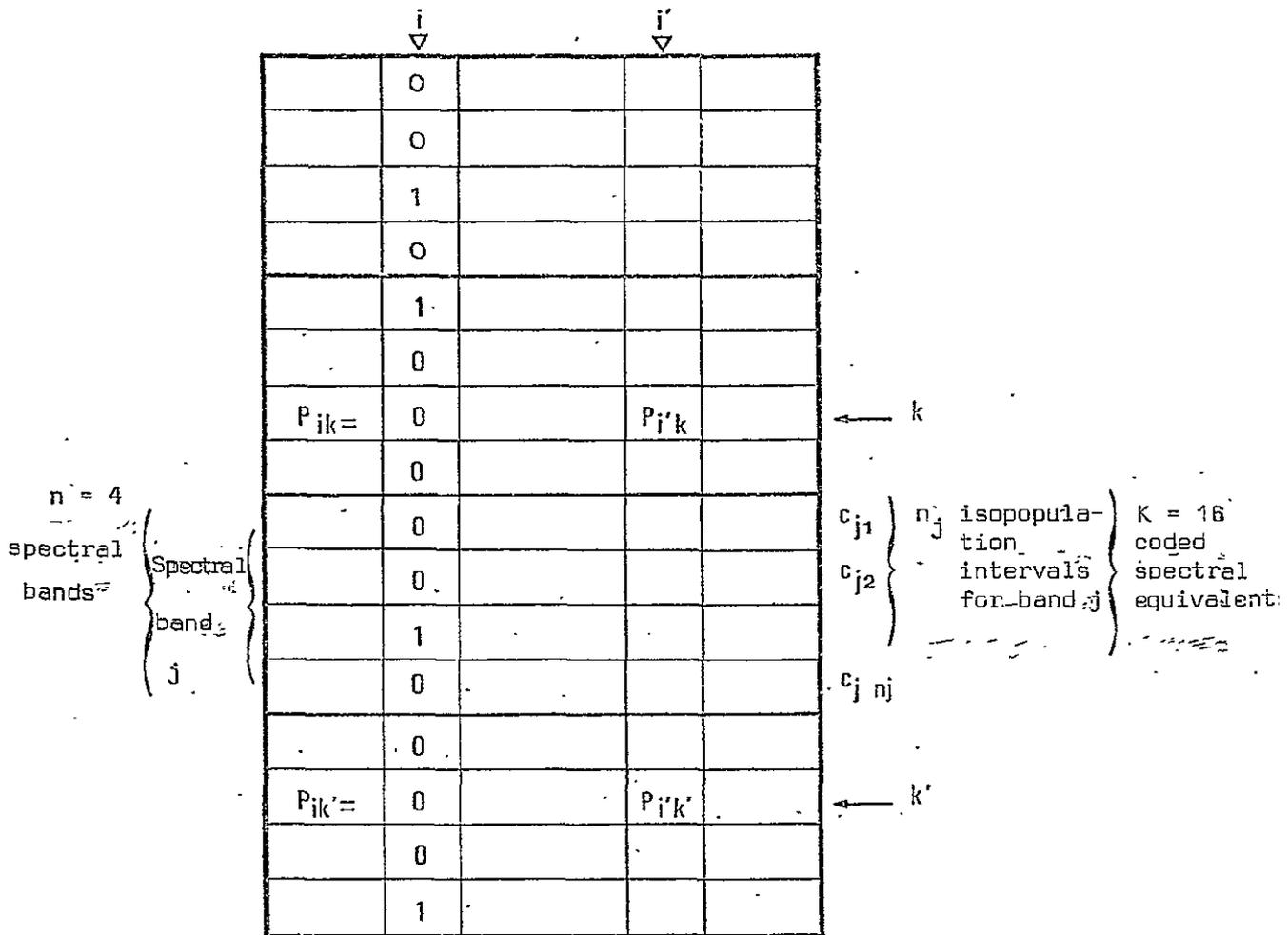


Fig. 2.4.A - Principles of complete disjunctive coding in isopopulation intervals



I pixels

Coded spectral radiance: $S_i = \{ p_{ik} / k = 1, K \}$

Global energy equivalent sensed in coded spectral band k $= p_k = \sum \{ p_{ik} / i = 1, I \}$

Equivalent image C_k sensed in coded spectral band k $= \{ p_{ik} / i = 1, I \}$

Fig. 2.4.B - Matrix structure of complete disjunctive coded LANDSAT data

The study of the similarity between two transformed bands k and k' is done by using the following algebraic structure. The transformed bands are considered as points of an I dimensional vector space E_I , in which I is the number of pixels to be classified. The origin of this vector space is the average radiance computed in each spectral band for the entire set of pixels.

Fig. 2.4.B gives an example of the data table associated to the situation shown in Fig. 2.4.A. If one seeks a mechanical equivalent to this data set, it can be thought of as a "cloud" of K transformed bands scattered in the vector space E_I .

Each point k belonging to this "cloud" in E_I is given a weight p_k which is the global energy received by the incremental band k . The metric of E_I is defined by a similarity distance called χ^2 distance (Chi square distance) defined as follows :

$$d_{kk'}^2 = 1/m \sum \left\{ (p_k^i - p_{k'}^i)^2 \mid i = 1, I \right\}$$

with :

$$- p_k^i = p_{ik} / p_k$$

- n = number of actual spectral bands ($n=4$ for LANDSAT)

This distance is equal to zero when the binary images associated with k and k' are identical. Theoretically the computation of the distance existing between each couple (k, k') is sufficient for the study of their similarity.

Unfortunately the computation of $d_{kk'}^2$ in E_I is long and tedious because of the very large number of dimensions of this vector space. Typically several billions for a LANDSAT image.

Fortunately, correspondence analysis enables us to select a feature space F of limited dimensionality ($m=5$ for example). F is a sub-space ^{m} of E_I which is chosen so that in F the distance between the projections of the transformed bands k and k' is a good approximation of the true distance $d_{kk'}$ between the two points E_I . The base vectors of F are the eigenvectors of the "cloud" N_k built with the K transformed bands weighted by the p_k . The associated eigenvalues λ_α are ranked by decreasing order :

$$\lambda_1 > \lambda_2 > \dots > \lambda_m$$

Each of them can be interpreted as representing the percentage of information (or inertia) born by the associated eigenvector Φ . These eigenvectors are the coordinate axes of F which is often called factor space. It is in F that the other steps of FRACAM take place.

d - Typology of transformed bands

In order to find reliable initial conditions for the adaptative clustering of spectra in F_m , it is necessary to have an estimation both of the number m of groups they form and of the positions of the corresponding centers of mass.

Our philosophy is to consider that groups of similar transformed bands are most likely to characterize specific types of spectral shapes (or signatures); This is why groupings of transformed bands are sought for in F_m .

Using the simultaneous representation formula of correspondence analysis we will then be able to associate to the center of mass of each group of transformed bands a point in the spectral space which is a good approximation of the "true" center of mass of the corresponding group of similar spectra.

Before performing this spectral band to spectral signature transition, a detailed study of the geometric structure of the "cloud" built by the projections of the transformed bands is undertaken. This is done by using an ascending hierarchical classification algorithm in F_m .

The construction of a hierarchy on the set on K projections is done by gradually building a series of mutually inclusive classes fitted one into another. A dendogram representation is given to this series (Fig. 2.4.C) in which each node is indexed by a number proportional to the diameter in F_m of the corresponding class. The ascending character of the selected algorithm comes from upward construction of the dendogram (tree), the classes being formed by sequentially grouping points or groups of points which are close to one another.

The determination of the characteristic groupings between similar bands is done by "cutting" the dendogram at a given diameter by the operator thus defining an upper bound to the diameter of the classes being constructed.

In the case of Fig. 2.4.C three groups of similar transformed bands are selected as :

- group 1 : $C_{44}, C_{42}, C_{14}, C_{24}$,
- group 2 : C_{11}, C_{33} .
- group 3 : $C_{13}, C_{22}, C_{32}, C_{21}, C_{31}, C_{41},$
 $C_{12}, C_{34}, C_{43}, C_{23}$.

A center of mass (center of gravity) is associated to each of those groups as a points in F_m . The spatial distribution of the groups of transformed band m "points" corresponding to the previous determination is presented in Fig. 2.4.D. We have limited ourselves to a plane representation restricted to the first and second factors ($m=2$).

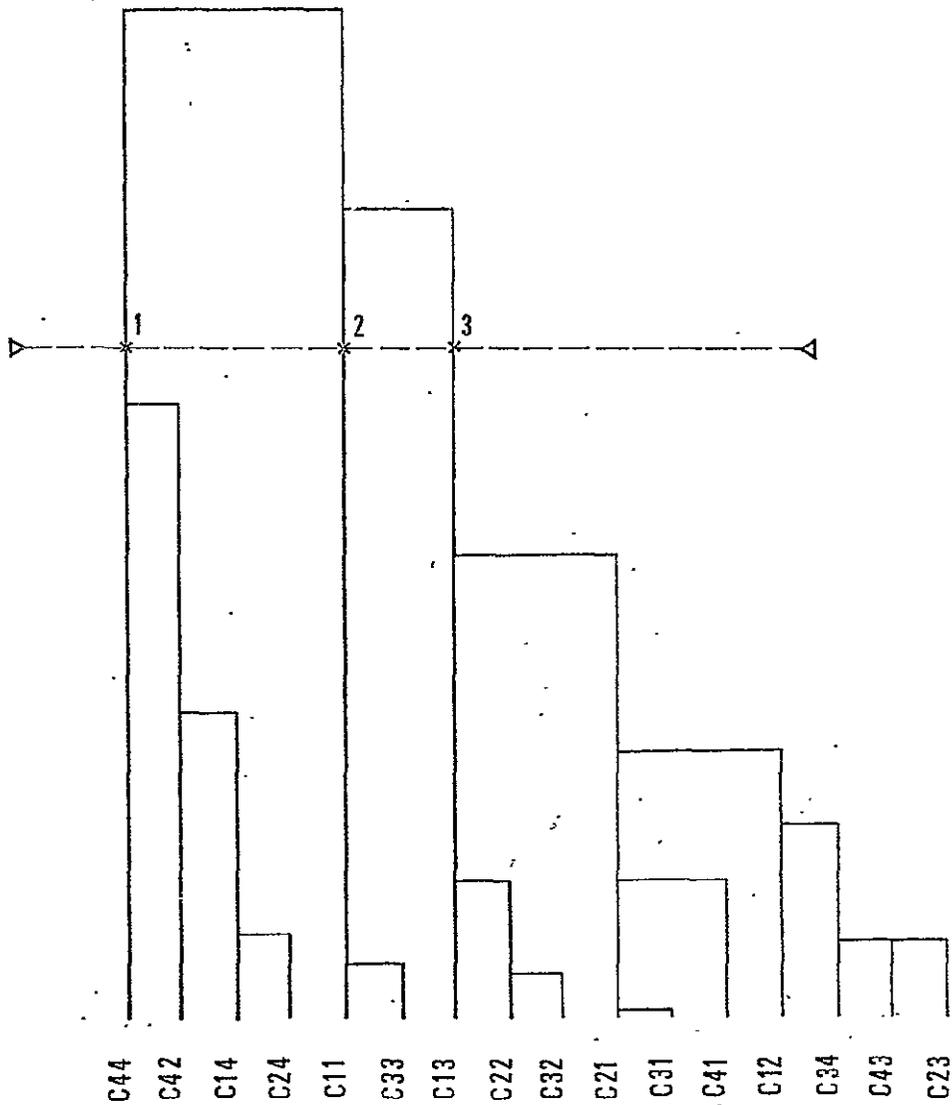


Fig. 2.4.C - Tree representation of similarities existing between coded equivalent spectral bands in the sub-space of the five first factor axes.
"Cutting" of the tree at constant diameter along the dotted line defines three groups of coded bands

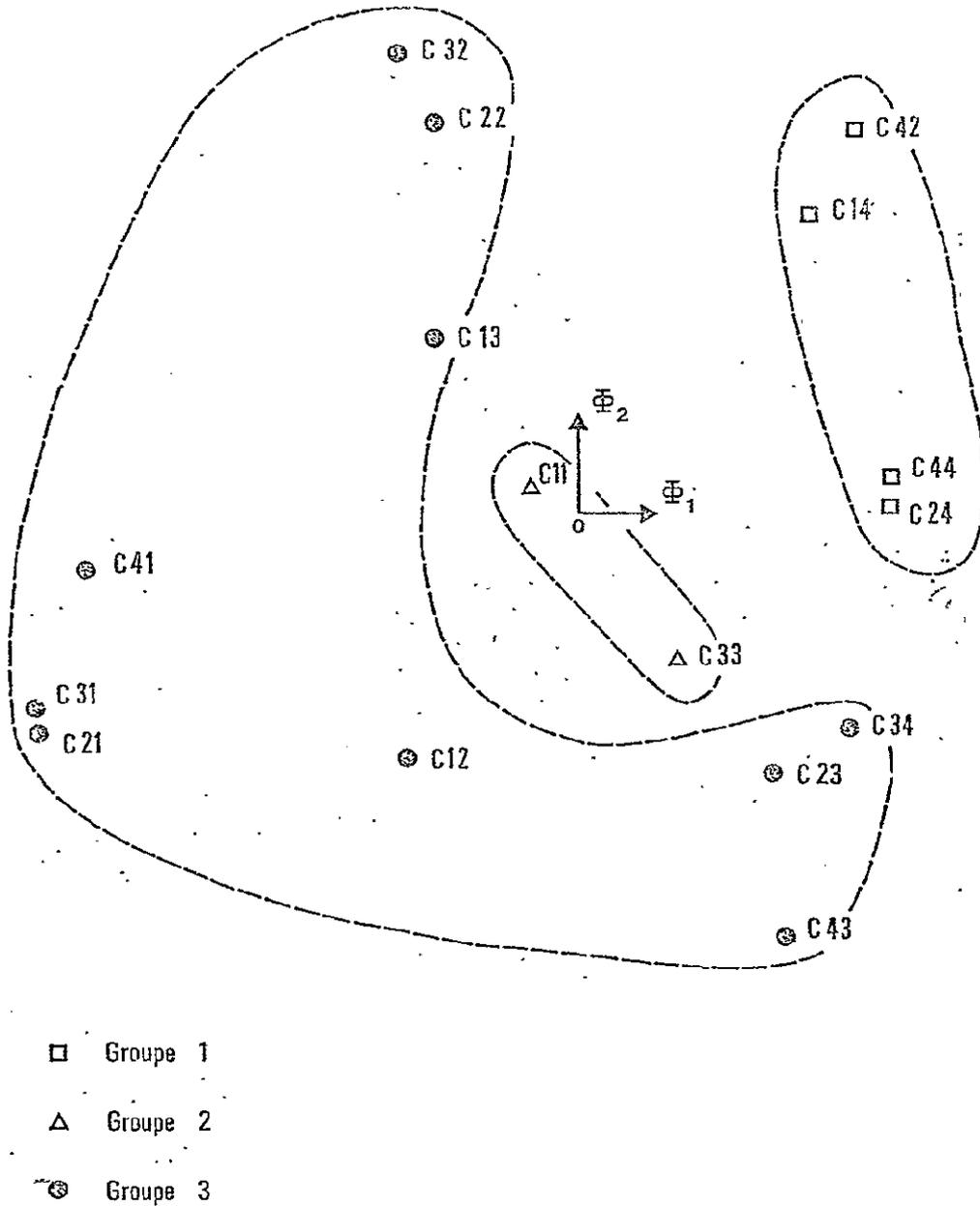


Fig. 2.4.D - Display of a hierarchy of coded spectral bands generated from the results of Fig. 2.4.C. The representation is done in the plane of factors 1 and 2.

e - Clustering of spectra

One of the more important properties of correspondence analysis is to solve at the same time the twin problem of structure analysis of similarities both between spectral bands and between spectral signatures. In fact, the set of eigenvalues $\{\lambda_\alpha \mid \alpha = 1, m\}$ which is used in order to build F_m can also be used to build a feature space G_m of the measured spectra with the same number of dimension as F_m . This sub-space G_m is constructed from F_m by simple multiplication of the base vectors components by the square roots of the associated eigenvalues λ_α .

Clustering takes place in G_m using an adaptative centers of mass algorithm which borrows some of its properties from the K-means and the ISODATA algorithms. Initialization takes place by specification of the number of groups and initial positions of the cluster centers.

In the present case the number of spectral groups is equal to the number of groups of similar bands as determined by the previous phase. The initial cluster centers are the projections in G_m of the centers of mass of the groups of similar bands determined in F_m . Projection is easily done by multiplying each of the m components of the centers of mass by the corresponding eigenvalue λ_α .

The clustering algorithm is stopped, and radiance spectra are assigned to a class by using a minimal distance criterion in G_m . Namely, each spectra is assigned to the closest cluster center. After each iteration, the cluster centers are updated with regard to the effective population of each class.

The philosophy of this approach is that after a certain number of iterations, cluster centers and cluster cardinals are sufficiently stable to give a reliable classification. Various stability criteria are computed at the end of each iteration in order to assess the quality of the classification. The criteria are : the ratio between intra-class variance and inter-class variance, the overall displacement of cluster centers between their previous and updated positions and the number of class assignment changes from one iteration to the next.

At the end of previous algorithm, various results are available. First, a cartography in which each pixel is given a symbol uniquely associated to the class to which the associated radiance spectrum belongs. Statistical results are also produced for each class in the form of average and R.M.S. radiance values for each spectral band.

Experience has shown that the initial cluster centers, as determined from the transformed bands typology are very reliable. This has enabled us to reduce the number of iterations to 2 or 3 thus obtaining a considerable saving in overall computing time.

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f - An adaptative descending classification

In the practical use of unsupervised clustering algorithms, two approaches are possible.

In the first case, a large number of clusters is determined, with the risk of having to follow up the clustering phase by a similarity study of the groups in order to reduce their number. In the second case, the clustering algorithm proceeds by successive dichotomy until the desired number of classes is reached.

The first type of heuristics is used in the LARSYS system, in which the first step leads to the determination of a large number of potential classes taken from the training area. The study of the similarities existing between those groups of limited cardinals, enables to regroup them following a typical phase of taxonomic pre-assistance. This method uses an ascending approach whereby the complexity of a weak data compression (large number of groups) is reduced by the relative simplicity of a taxonomy often guided by typical application themes (oceanography, agriculture, geology ...).

The algorithm used in ISOCLS belongs to the second type of approach, it proceeds by successive dichotomy between each iteration. This is a descending approach going from the general to the particular.

The structure of the FRACAM system looks well suited to the second type of heuristics. The "cutting" phase of the hierarchical dendogram enables the operator to control the number of groups while performing a polytomy which is more complex than ISOCLS. This descending classification process is also made adaptative because at each downward move, correspondence analysis and hierarchical classification are computed again in order to adapt their results to the statistical properties of the group which the operator wants to refine.

Several criteria for assessing the need to pursue the subdivision of a group can be used. We propose to rely on the shape of the radiance histogram in MSS7. The subdivision is pursued if the group histogram is multimodal or does not fit a simple probability distribution model (Gauss, uniform or lognormal distributions): For example, we have reproduced in Fig. 2.4.E the spectral distributions of the class of pixels obtained after a first classification of the Fromentine area on July 11, 1973. Six groups were determined, the use of above criterion leads us to the following conclusions :

- groups 4, 5 and 6 do not need to be subdivided
- groups 1, 2 and 3 are on the contrary eligible for further processing

Going from divisions to subdivisions, the FRACAM system is able to perform an adaptative descending classification guided by a spectral coassistance tailored to the group spectral statistics.

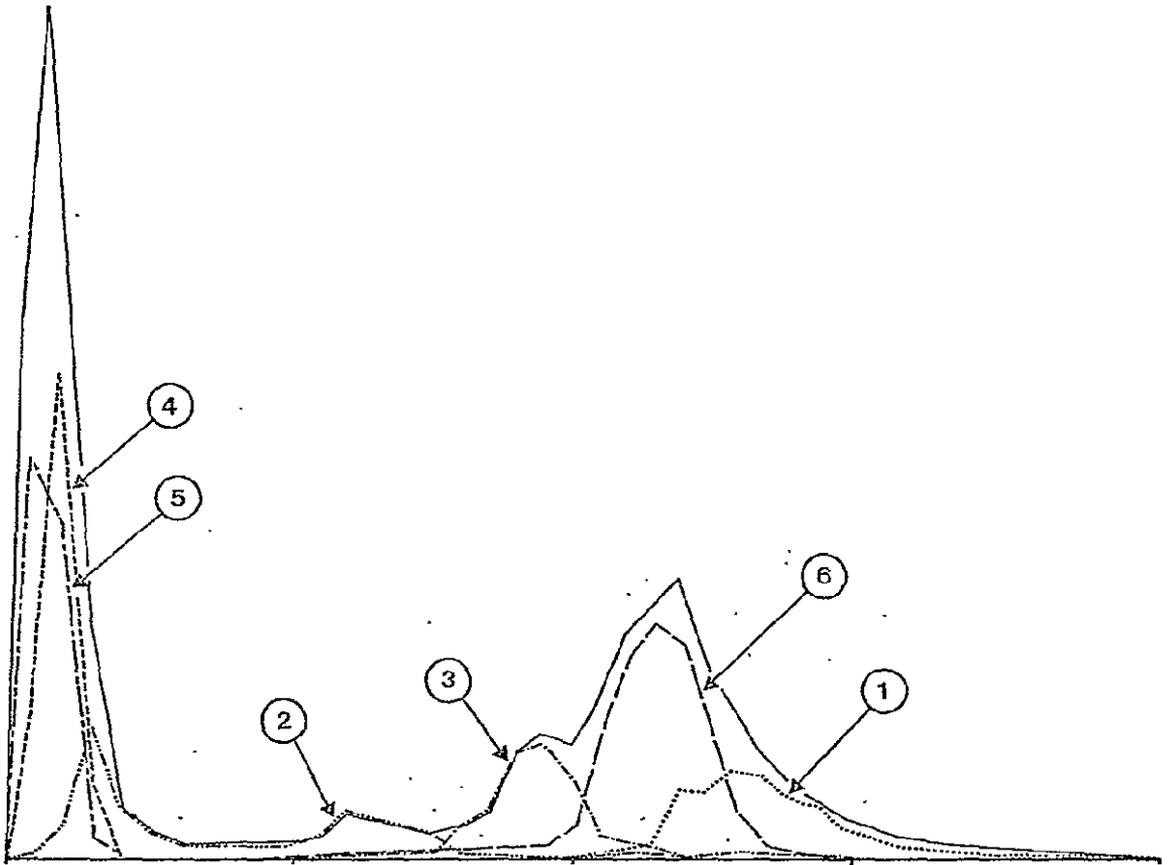


Fig. 2.4.E - MSS7 spectral band histograms for the six groups obtained after the first phase of treatment preceding spectral co-assistance. The unnumbered plain line is the MSS7 histogram for the entire image.

2. 4.4 - An example of processing

The processing of the Fromentine area surveyed on July 11, 1973 was done in two steps. In the first step, complete disjunctive coding of MSS4 to MSS6 in eight intervals and MSS7 in seven intervals led to the determination of six groups. Spectral coassistance was performed on the band MSS7- histograms (Fig.2.4.E) thus resulting in the further subdivision of groups 1, 2 and 3. The adaptative descending classification was pursued for these groups, by first generating a new complete disjunctive code with four intervals in each spectral band. This code was adapted to each group's statistics separately. Finally, eleven groups were determined by the classification and submitted to interpretation in the taxonomic post-assistance phase.

a - The results of the first phase

Regarding correspondence analysis we present on Fig. 2.4.F the projections of the transformed bands in the plane of the first and second factors. In this representation, each spectral band (MSS4 to MSS7) was assigned a letter (A to D) and a number corresponding to a complete disjunctive interval. For example B7 is the the transformed band related to the seventh spectral interval determined from the MSS5 histogram.

Each factor can be interpreted as follows :

- on the first axis, the general structure corresponds to a transition from low radiance values to high radiance values in spectral bands MSS5, MSS6 and MSS7.
- on the second axis, spectral band MSS4 is organised from low to high values except for the near center position of A1 (radiances from 26 to 32 in MSS4).

The two dimensional plane representation enables us to refine this interpretation. A strong correlation is observed between MSS6 and MSS7. The parallel structures drawn by these spectral bands are organised in two arcs of opposite curvature:

- a first arc spreads over factor 1 going from C₁, D₁ to C₄, D₃
- a second arc spreads over factor 2 going from C₅, D₄ to C₈, D₇

This general organization is due to a broad dichotomy in the data set between two types of spectral signatures corresponding, in the surveyed area, to the opposition between water themes (sea, channels, tidal flats) and land themes (cultures, forest, marshes).

The ascending hierarchical classification has led to the determination of six groups of transformed bands which are outlined in Fig. 2.4.F. The resulting spectral clusters were displayed one groupe at a time as binary maps. One can find an example of a such a map in Fig. 2.4.G.

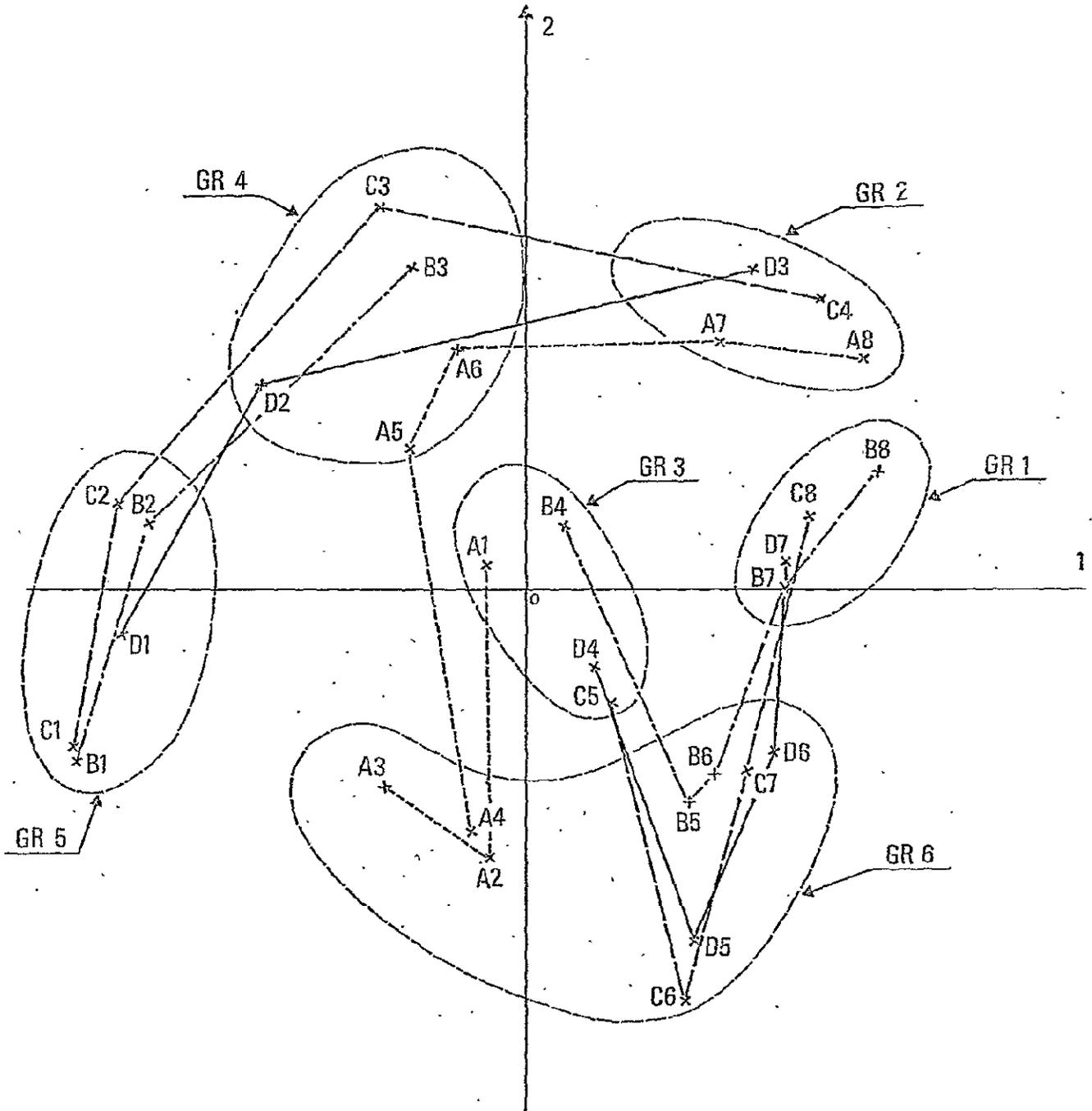


Fig. 2.4.F - Display of first phase results in factor plane 1-2. Groups of coded equivalent spectral bands were determined by hierarchical ascending classification.

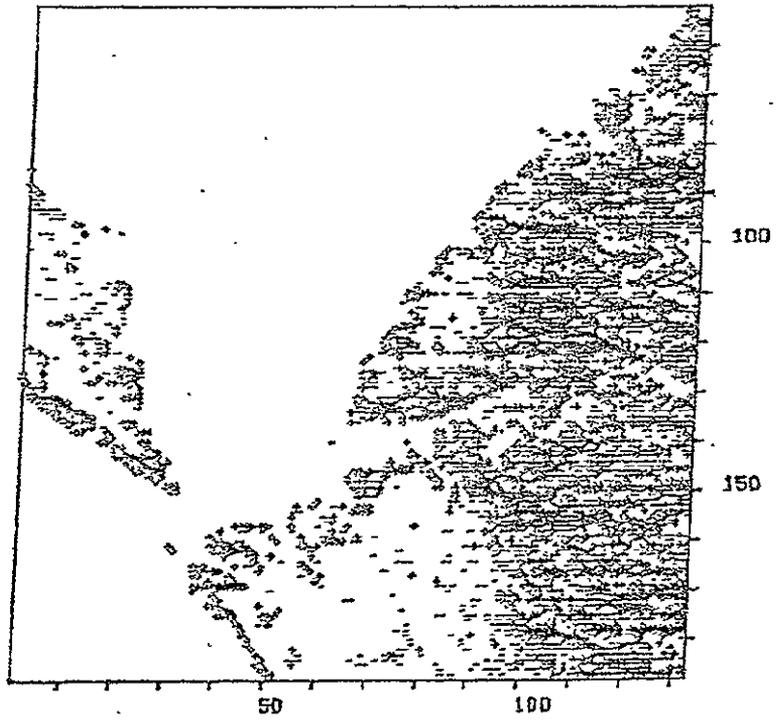


Fig. 2.4.G - Display of pixels belonging to group 6
as determined in the first treatment phase.

This display of group 6 was obtained as a Versatec printer-plotter hardcopy of a Tektronix graphic display.

The spectral coassistance phase involves the active participation of the operator in assessing the spectral individual of each group. This is done using spectral signature statis for each group : radiance values histogram, average spectra signature or even bidimensional histogram crossing two spec bands. An MSS4/MSS7 bidimensional histogram is shown on Fig. 2.4.H in which each pair of radiance values is assigne to a group when a one to one relationship exists. A bispect representation being unable to take into account the divers of spectral signatures (in four spectral bands) there are some pairs of radiance values which are assigned to several groups at the same time. Such ambiguities are pin-pointed o the display by a vertical bar symbol.

Taking account of these results, it was decided to pursue t subdivision of groups 1, 2 and 3.

b - Results of the subdivision phase

The histograms of class 1, 2 and 3 were divided into 5 equipopulation intervals. The entire process was started ag seperately for each group. Hereafter, we restrict our repre sentation to the subdivision of group 3.

Correspondence analysis of the spectral signature of the pi of group 3 was followed by an ascending hierarchical classifi cation whose dendogram is presented in Fig. 2.4.I. The simi larities between transformed bands lead to the determinator of three spectral sub-groups.

After clustering, the individuality of each sub-group can be assessed by the unimodality of its spectral histogram in MSS (Fig 2.4.J). Separability between sub-groups is however bet understood using the whole set of spectral bands. The averag spectral signatures (Fig. 2.4.K) can be used for this purpose. One could note that for these objets, separability is maximu in MSS4 and MSS5 but very low in MSS7. This can be noticed b the overlapping of MSS7 histograms (Fig 2.4.J).

In the display generation (FRAC1) composite maps can be produced in which pixels assigned to each sub-group are represented by different symbols. Those maps were interacti vely generated on the display console of the FRACAM system. Fig.2.4.L to Fig.2.4.N are illustration to the subdivision of groups 1, 2 and 3.

c - Interpretation phase

Each class now remains to be interpreted by taxonomic post-assistance and the objects it represents must be identified.

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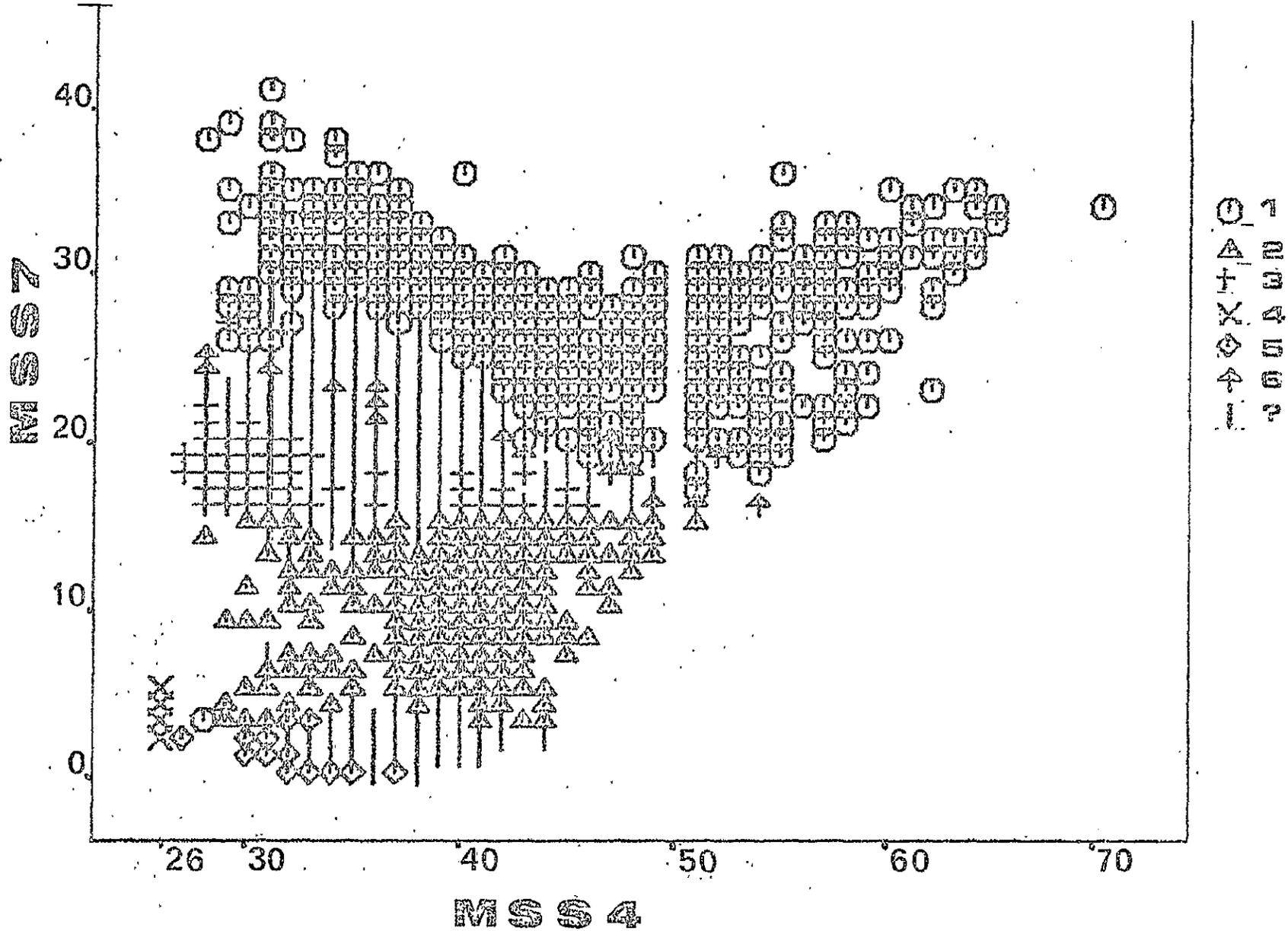


Fig. 2.4.H - Joint MSS4/MSS7 histogram. Symbols are assigned to pair of radiance values which were associated to specific groups in the first phase of treatment

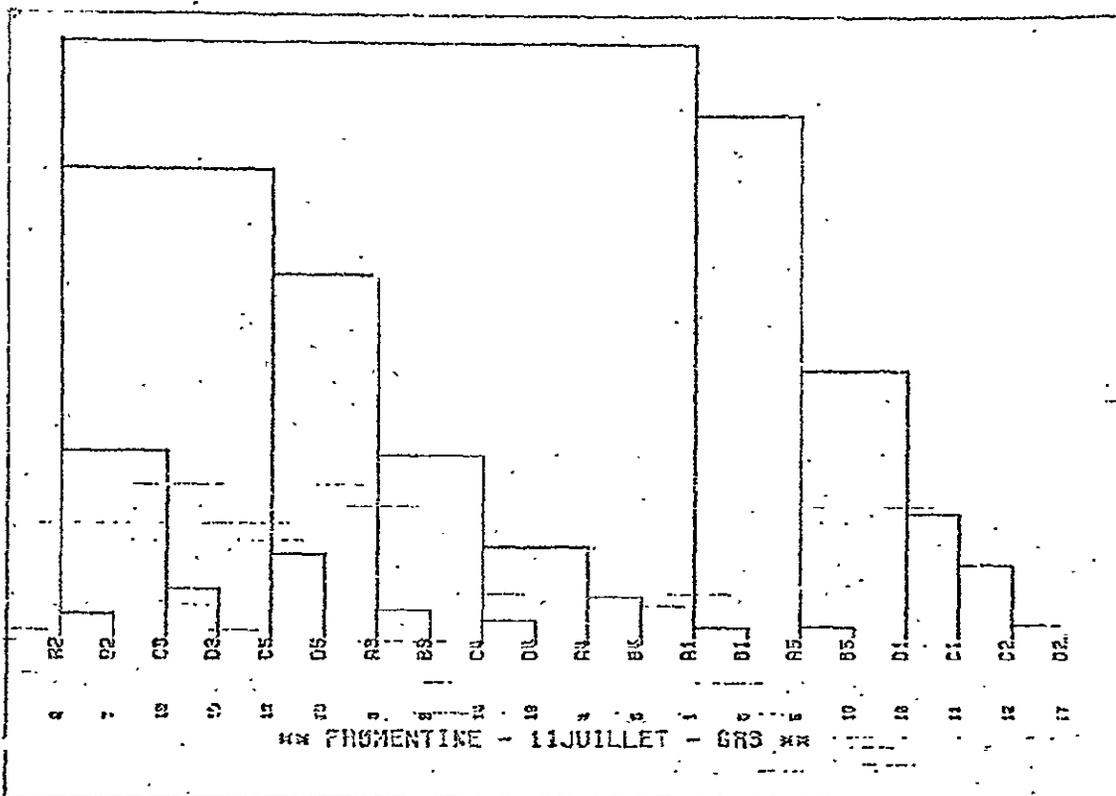


Fig. 2.4.I - Ascending hierarchical tree representation of coded equivalent spectral bands determined by the subdivision of class 3 histograms

Number of pixels

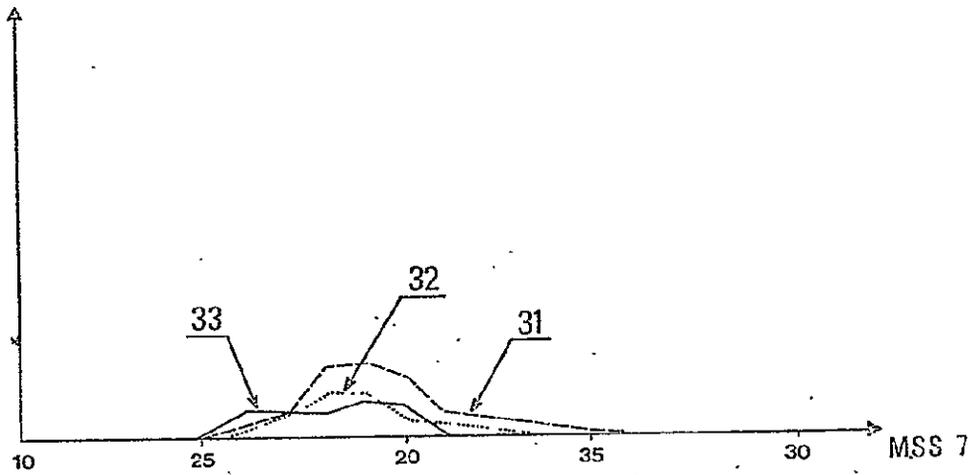


Fig. 2.4.J - MSS7 histograms of groups 31, 32 and 33 subdivided from group 3

Radiance

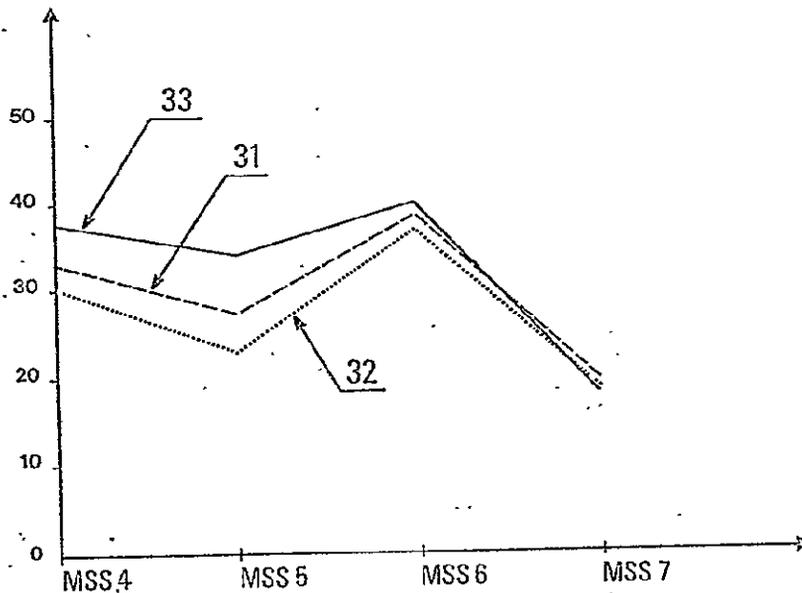


Fig. 2.4.K - Average spectral signatures of subdivided groups from group 3

Class 5 shows areas of clear water as indicated both by its spectral signature and its location. These waters are found to the North of the studied area ; satellite overpass took place at mid-flow. The southward tidal current through the Fosse du Fain carries relatively clear water across the Gois ford. Clear water also occurs :

- extensively :

. in the South part of Bourgneuf Bay where pools between emerged banks hold relatively calm water which is low in sediment content.

. in the open sea off the Fromentine channel where waters are clear at mid-flow.

- locally : (as isolated pixels)

. in the Trou de Sebastopol (line 94, column 19), a pool in a dip formed by marine erosion during a storm which breached the main dyke. The breach was repaired by rebuilding the dyke round this dip, outside the polder.

. on the continent, in the pond of the new polder at Bouin (line 57, column 133). This pond formed in the lower part of this polder between the old seadyke which was destroyed by a storm in 1940 and the new dyke rebuilt in 1965.

In these last two cases, the pools are so small that only one pixel was correctly identified as clear, stagnant water. Surroundings pixels were only partly covered in water and the classification process misplaced them in another class.

Class 4 is sediment laden sea-water

Class 22 is associated to very turbid or shallow water. In this case, the reflectance spectrum is influenced by the sea-bottom : this occurs, along Notre-Dame de Monts point, in the outer tidal delta at Fromentine. This class also outlines the border between two environments. Thus, the bridge linking the island of Noirmoutier to the continent at Fromentine shows up as a row of class 22 and is mixed with pixels of intermediate spectral signature overlaying two different environments.

Class 21 maps the emerged tidal flats at the time of overpass. These tidal flats line the western coast of the island of Noirmoutier as well as the continent. They also cover the top of sandbanks in the South of Bourgneuf Bay. Class 21 is also found in ploughed land or salt marsh areas physiographically similar to tidal flats although they fall into a different land use category. Finally, this class marks the border between classes 22 and 11 with pixels of intermediate spectral signature overlaying two different environments.

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Class 11 shows dry area of a dominantly mineral nature : dry sandy beaches of Noirmoutier and the Monts coast ; sand or shell banks in resses parts of the Bourgneuf Bay coast ; sandy soils in the marsh and the island of Noirmoutier ; sand and stone embankment of the Bec de l'Epoids pit ; and several slighty urban areas : Fromentine, parts of La Barre de Monts, l'Epoids, la Fosse etc ...

Class 31 identifies vegetated areas such as the western part of Monts forest (maritime pines), marsh channel flats etc ...

Class 32 is similar in content and located nearby class 31 : Monts forest (maritime pines, holm oaks) etc ...

Classes 12 and 13

show cultivated fields, but the crops in class 13 are partly bare (sandy plots on Noirmoutier Island) whereas the crops in class 12 have more coverage : on the Monts coast (near La Barre de Monts) or at Crosniere.

Class 6 Shows grassy areas : pastures in marshes, coastal dunes with psammophyte cover.

Class 33 shows marshes and damp border areas.

Its by combining a specific ground truth experience with a general knowledge of spectral signatures that the operator can give a meaning to the classes previously defined. For this final step, which takes place after classification, we shall use the term of taxonomic post-assistance.

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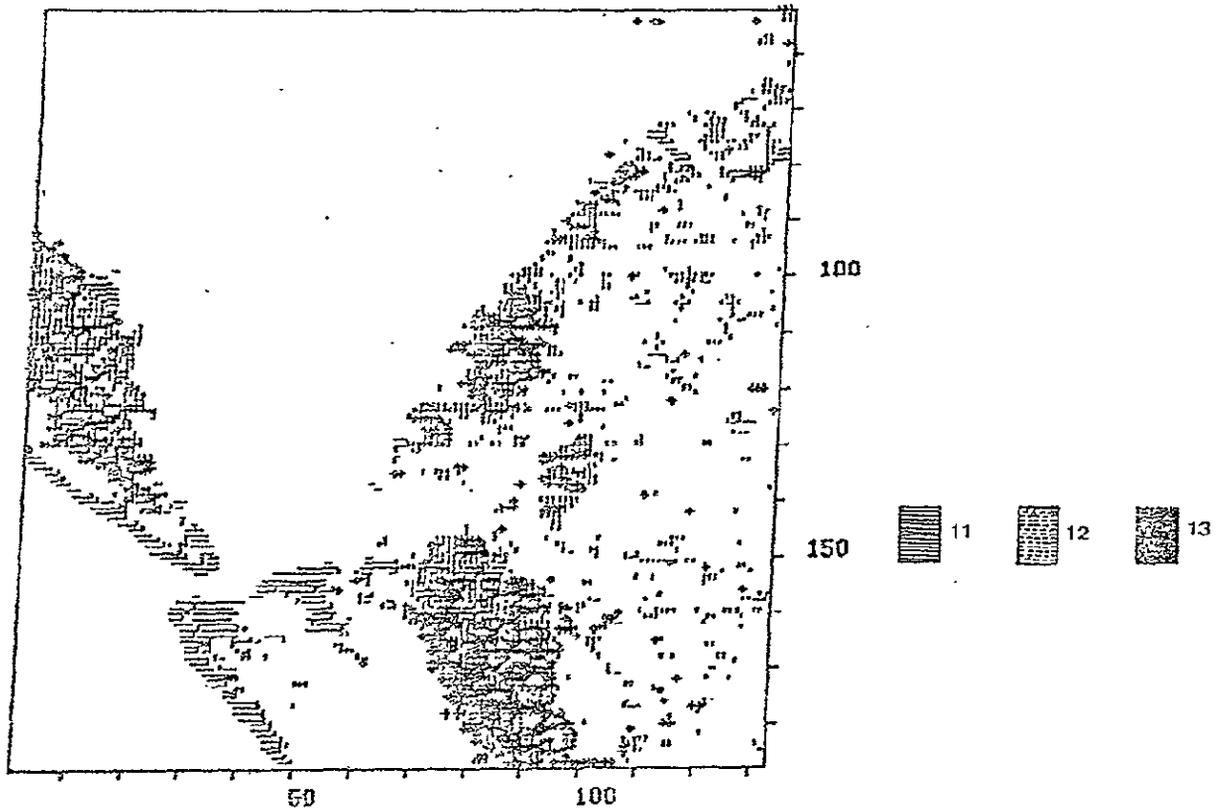


Fig. 2.4.L - Cartography of subgroups 11, 12 and 13 obtained by subdivision of group 1.
Taxonomic interpretation follows :
11 - Built up areas, beach, dry sand
12 - Farming on calcareous, sandy soil (Noirmoutier island, Crosnière)
13 - Farming along the Barre de Monts

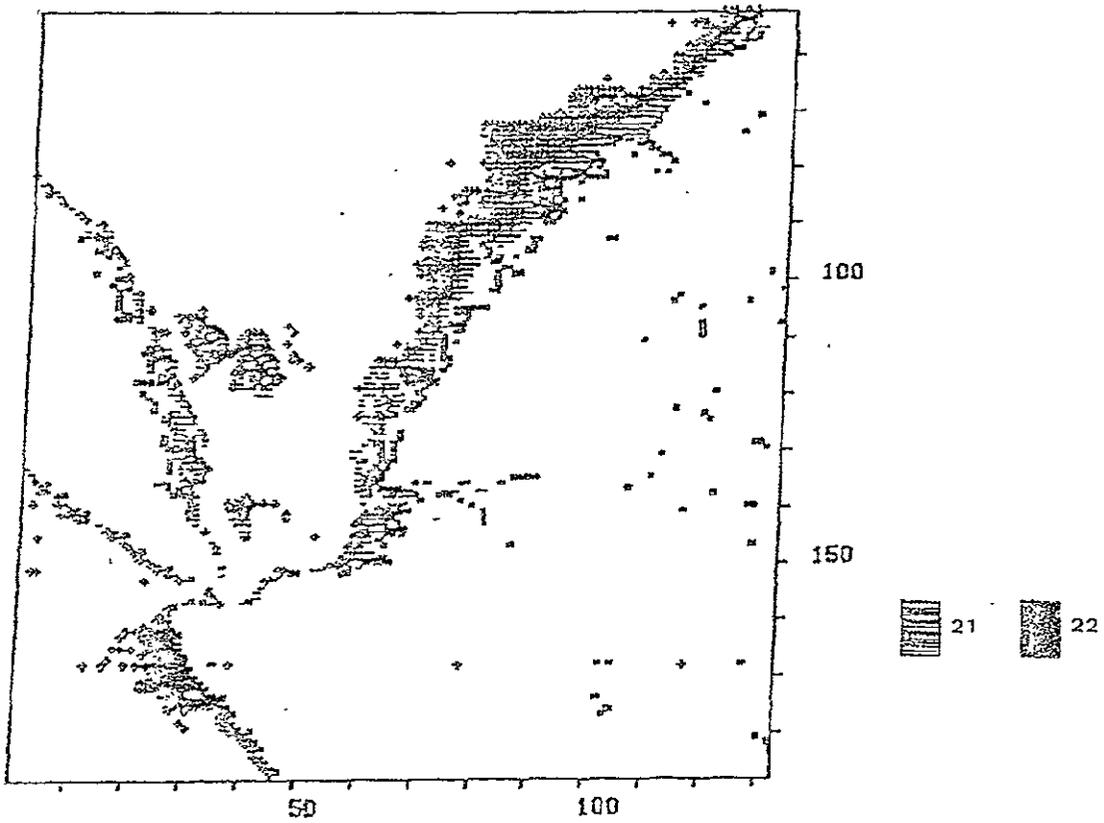


Fig. 2.4.M - Cartography of subgroups 21, 22 obtained by subdivision of group 2. Taxonomic interpretation is :

21 - Tidal flats

22 - Very turbid water

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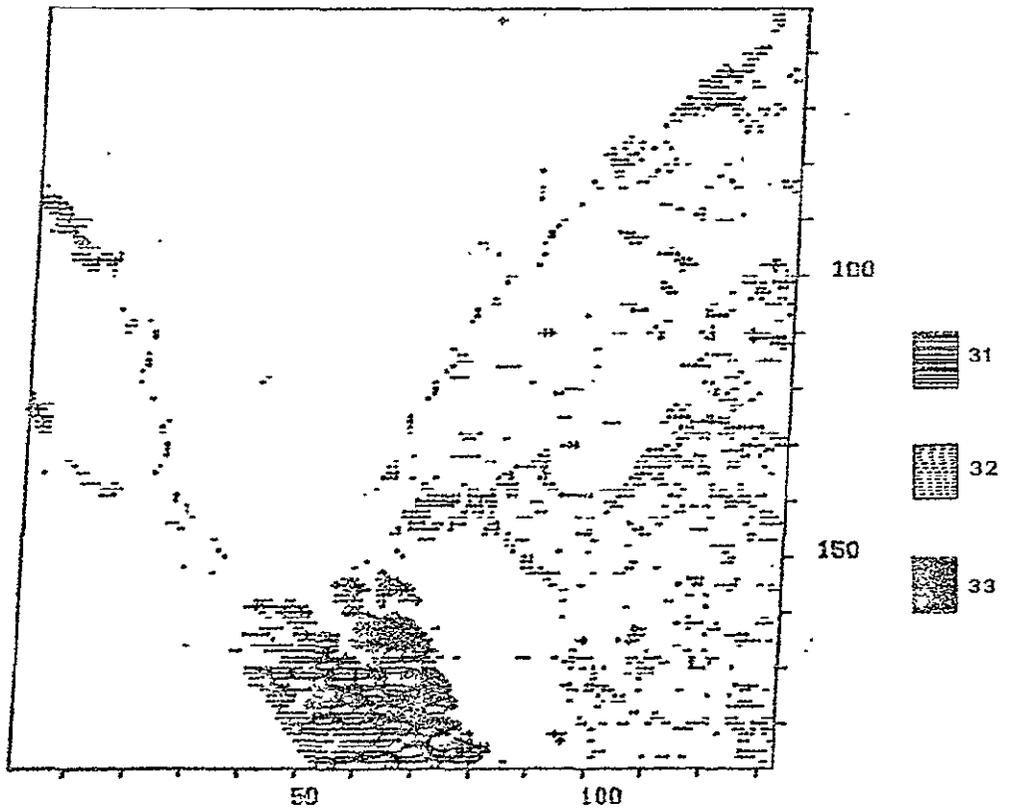


Fig. 2.4.N - Cartography of subgroups 31, 32 and 33
obtained by subdivision of group 3.
Taxonomic interpretation is :

- 31 - Fallow marshes, west of the Barre de Monts forest
- 32 - Damp border areas
- 33 - East of Barre de Monts forest

2. 5 - AUTOMATIC CARTOGRAPHY

The results from all the classification techniques developed in the FRALIT experience can be output as colour maps on an ink plotter, by using the programs described here.

2. 5.1 - The FRACARTO program (Fig. 2.5.A)

This program basically maps a pre-assisted classification of multispectral data using spectral parameters selected and input by the user. It replaces the FRACARTE program with increased possibilities. It can also be used to map classifications resulting from other programs such as FRACAM (c.f. 2.4).

The main possibilities offered are :

- Simultaneous processing of data from two (or more) different images using all 8 (or more) spectral bands for LANDSAT.
- Raw or smoothed data output, using a majority vote type decision in the matrix surrounding each pixel ; this process can be iterated, and/or used conditionally.
- Mapping of each pixel by a given colour and symbol or contouring of areas with identical taxonomic content.
- Attainment of the best possible drafting speed according to the type of output, with automatic and permanent control of ink levels in each pen.

The user first selects the digital image, or images, to be processed, and defines the scale and boundaries of his area of interest.

If the proposed map exceeds the dimensions of the plotter, a sampling procedure is provided, enabling one in n lines (and one in n columns) to be mapped.

This possibility can also be used to avoid the sixth-line banding often found in LANDSAT data. The map border is annotated with line and column tick-marks. In order to save time and lower costs, it is possible to leave blank an area of little interest within the map boundaries by specifying the appropriate lines and columns.

This program is currently implemented on the CNRS IBM 370/178, computer using a three-pen BENSON plotter in the offline mode. Pen selection is programmable and maps use up to 6 colours.

For offset printing purposes, an option in the program enables a separation to be made of each colour overlay. These are drawn in black on a stable base (Mylar) to conserve maximum accuracy in the preparation of the offset plate.

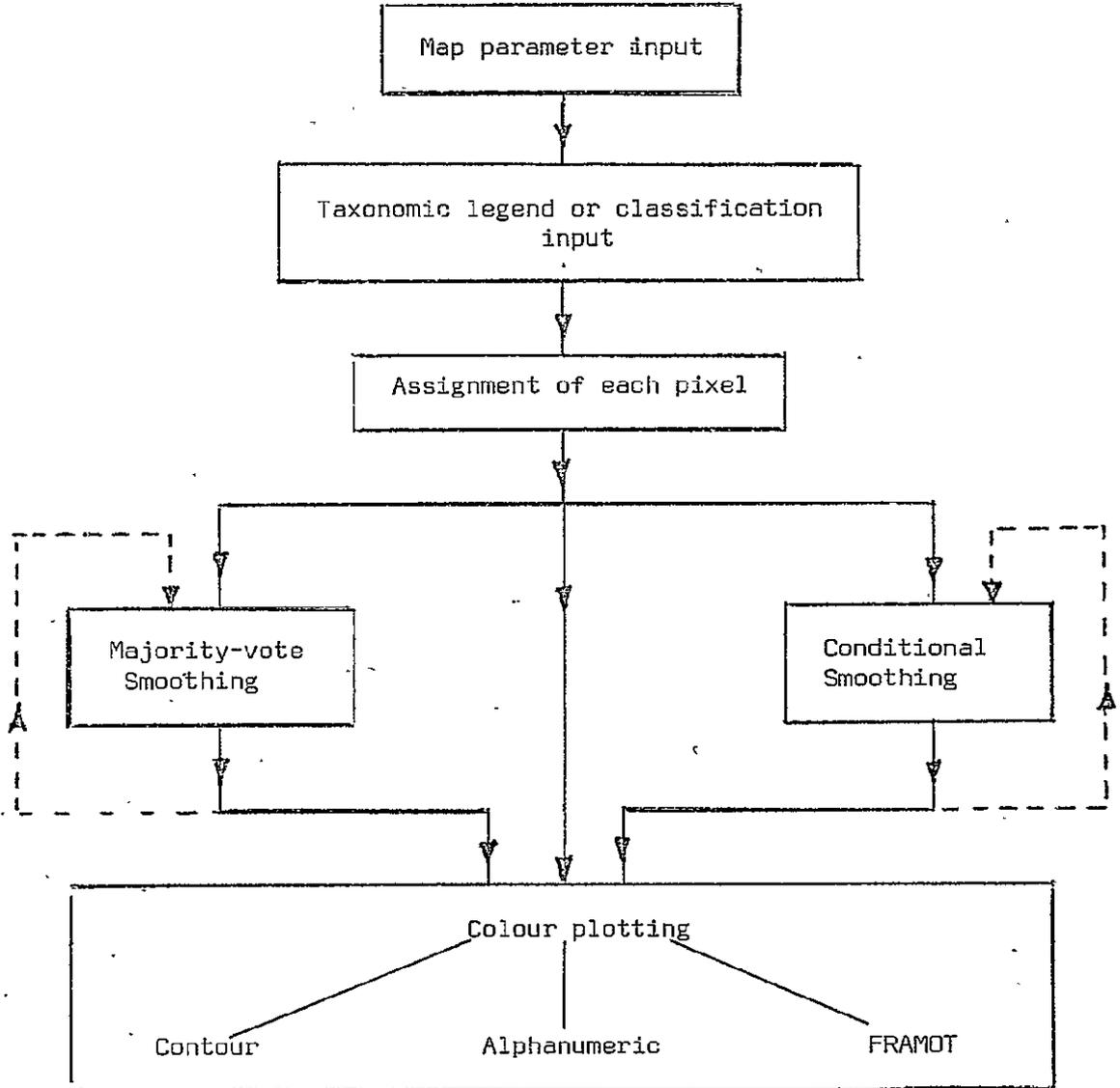


Fig. 2.5.A - Main functions of the FRACARTO program.

Dotted paths indicate possible iterations of the smoothing process.

When used for a pre-assisted classification, FRACARTO annotates the map with a key giving spectral characteristics of each class and the corresponding symbol. In every case, each symbol is followed by the number of pixels, the area covered in km², and two parallel caption lines (which can be bilingual).

Raw data mapping often shows up striping, wrong data values or immediate pixels with spectral signatures mixing the values of contrasted terrain units. The latter is a major cause of misclassification, but all three effects can be avoided to some extent by smoothing the data before map edition.

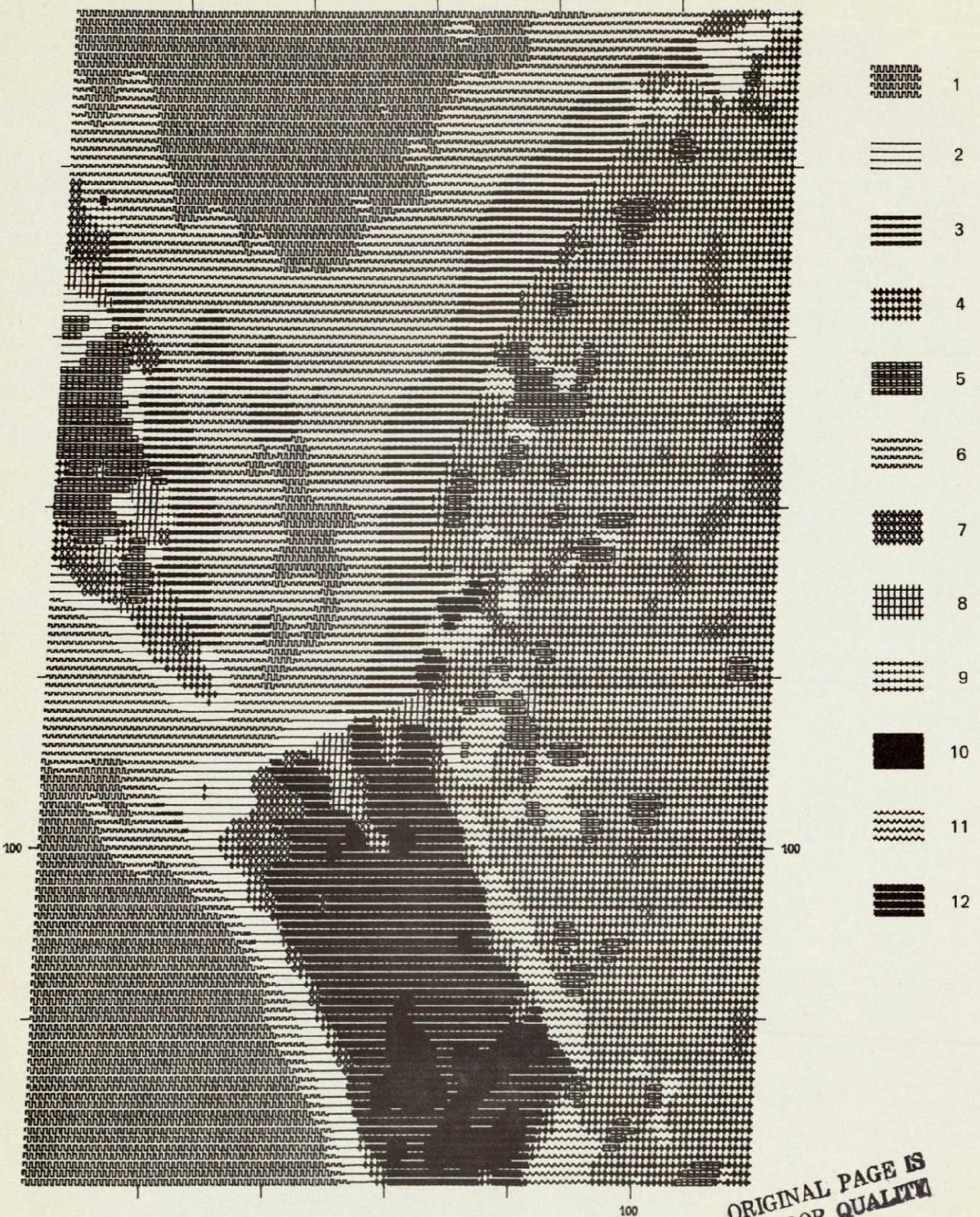
As the bad pixels can be differentiated from the surrounding ones, smoothing requires a form of neighbourhood analysis. Optionnally, two types of smoothing are available :

- majority-vote : here a pixel is replaced by the most frequent one in the surrounding neighbourhood matrix. The user selects the size of the neighbourhood matrix (3x3 or 5x5) and, if required, the number of iterations. This techniques is fairly efficient, but eliminates much of the fine detail in an image (Fig. 2.5.B and 2.5.C).
- conditional : this was developed to eliminate intermediate values. MSS7 spectral signatures are compared for the eight pixels surrounding the one being smoothed. Striping is detected by comparing the current line with the ones immediatly before and after it. If these are identical and the current pixel slightly different, its value is replaced by majority vote. The resulting map is more accurate than simple majority vote (Fig. 2.5.D)

The results of classification smoothing can be compared to the corresponding unprocessed classification (Fig. 2.5.E).

After the optimal smoothing phase, mapping is carried out colour by colour, in one of three modes :

- Alphanumeric : each pixel is individually identified by an alphanumeric symbol. This is costly in plotting time as each symbol requires one or more pen up-down calls.
- FRAMOT : a set of symbols has been selected to give varied tonal values and speed of execution (Fig. 2.5.F). This has been found most useful both for variety and efficiency of use.
- Contour : identically classified pixels are outlined in groups. This gives the quickest results but the maps are only satisfactory if the classification is previously smoothed to eliminate isolated pixels.



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Fig. 2.5.C - Example of majority vote smoothing with two iterations
Map of Fromentine area at a 1/50 000 scale generated from
LANDSAT2 data acquired on 29 July 1975 (E2188-10181)

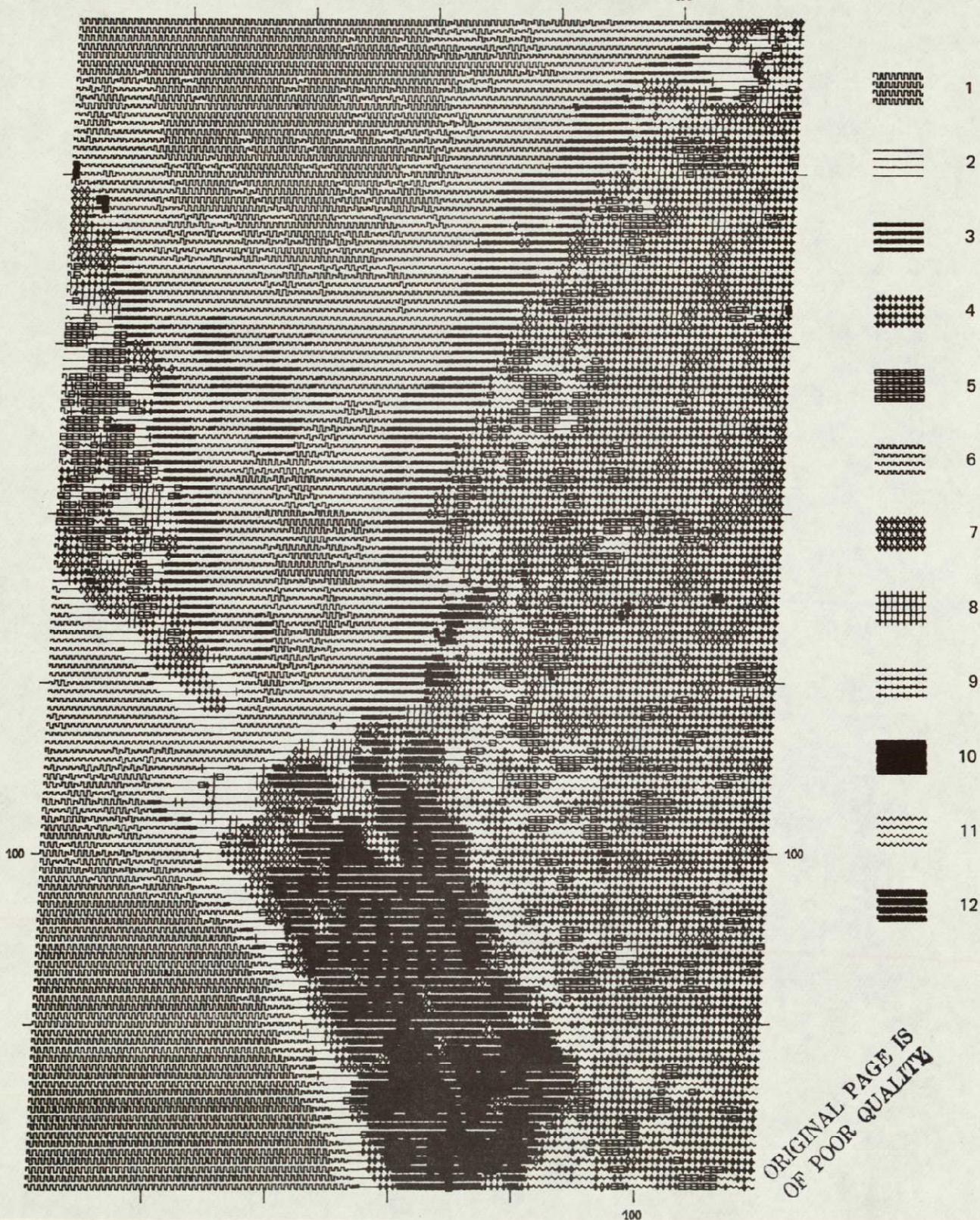


Fig. 2.5.D - Example of conditional smoothing with two iterations map of Fromentine area at a 1/50 000 scale generated From LANDSAT2 data required on July 1975 (E2188-10181)

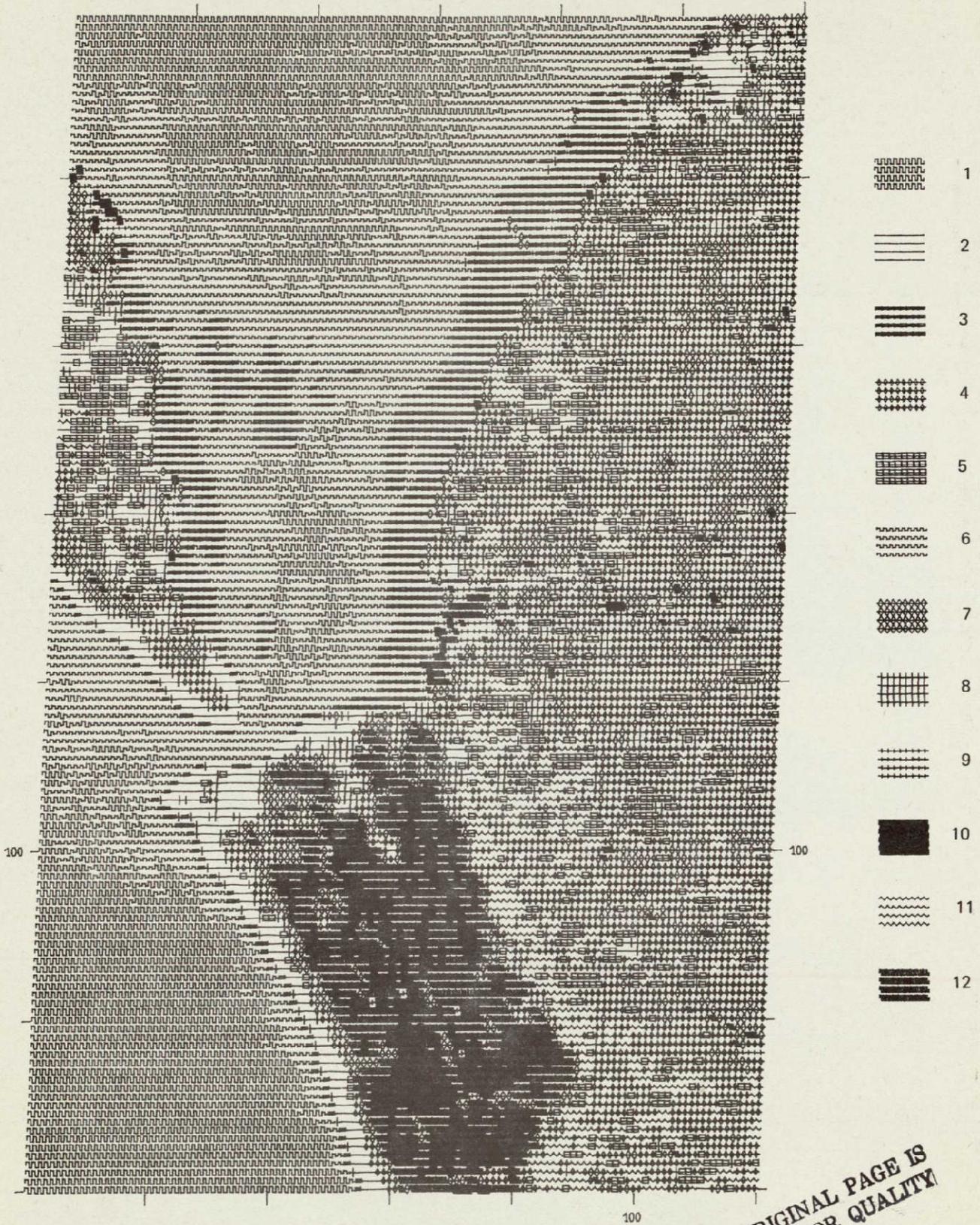


Fig. 2.5.E - Example of classification results before smoothing

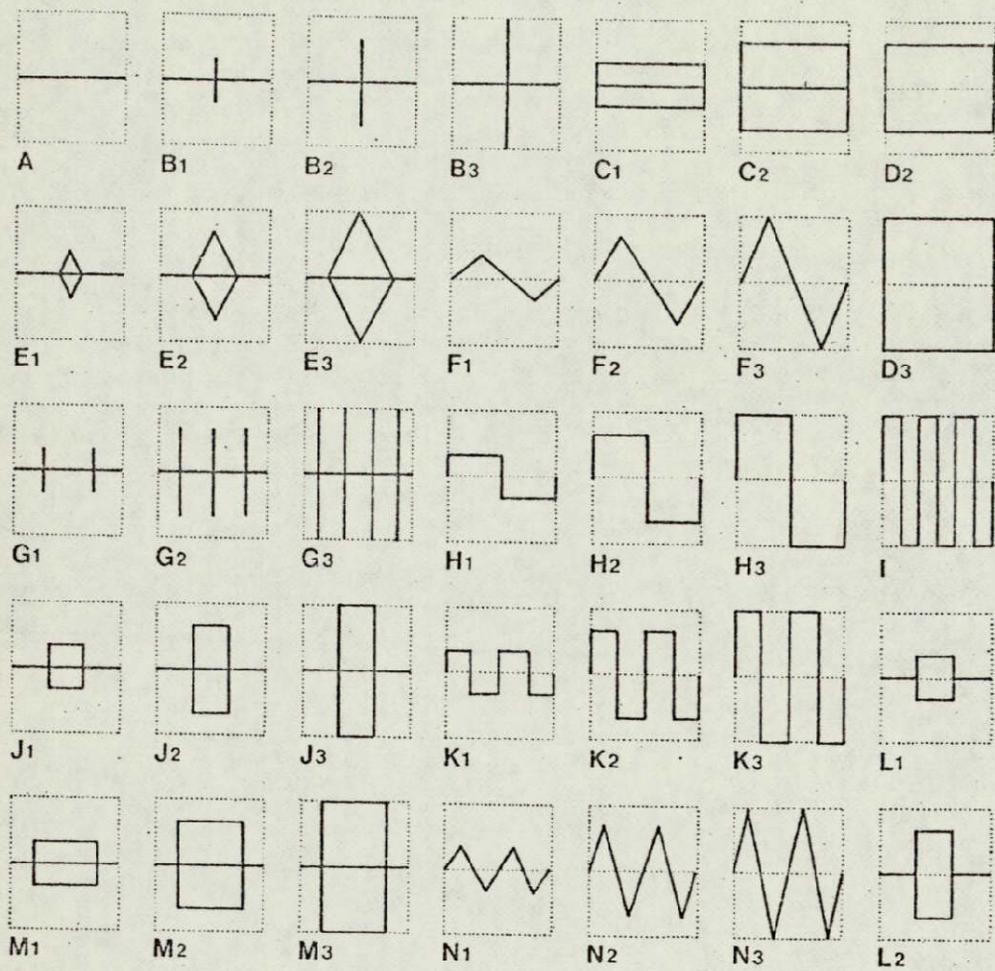


Fig. 2.5.F - FRAMOT symbol set

Some symbols are height parameterized with simple (1), double (2) and triple (3) height. All symbols are bounded by the same rectangular grid.

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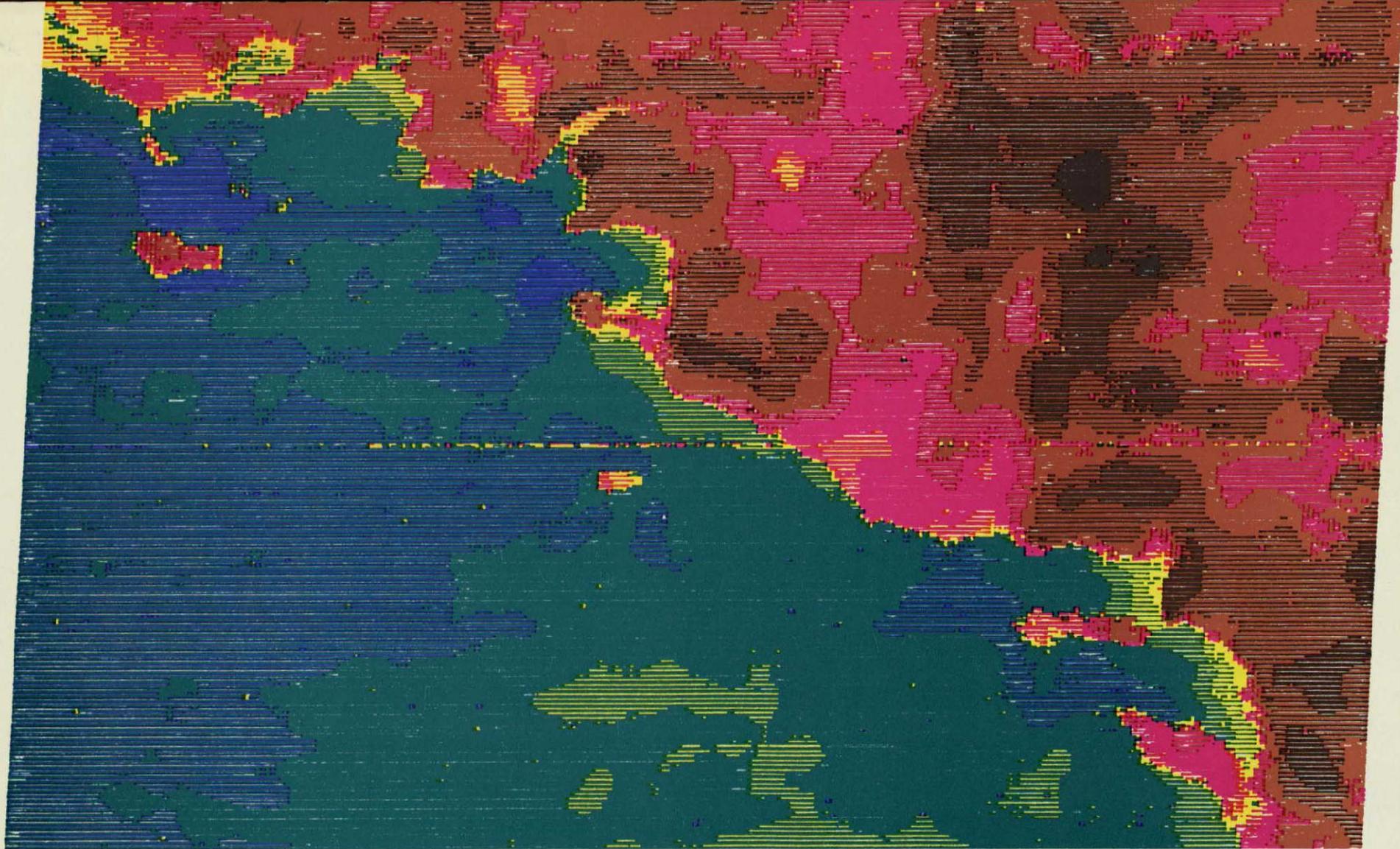
2. 5.2 - The FRATHERM program

FRATHERM is a version of FRACARTO adapted for mapping visible and infra red data from the NOAA VHRR. Two versions are presently in use :

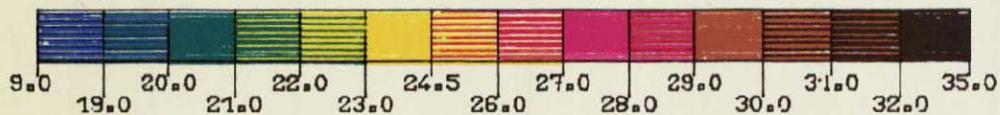
The first one is a FRACARTO adapted to the output from the TSS (Sea Surface Temperature) programme. The two channels available can be combined and the graphic options available with FRACARTO are available.

The second one has been perfected to make the best possible choice of colour or B/W scales for single-channel mapping. I/O transfers and computer time are reduced to a minimum (Fig. 2.5.G).

Well designed, legible map output is the standard format for FRALIT results. Experience shows that other types of output (line printer cartography, tabular data, etc ...) are basically unattractive to potential users. On the contrary, a properly designed map, scaled for compatibility with standard topographic map overlays has high user value both for research (geography, biology, sedimentology, oceanography) and applications (urban or country planning). For these reasons a great deal of effort has been put into the development of sophisticated automatic mapping procedures.



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TEMPERATURE EN DEG. CELSIUS

FRATHERM - VERSION 2.2
LIGNES 21 A 200 /1
COLONNES 51 A 320 /1
ECHELLE: 1:1000000
JANVIER 1977

Fig. 2.5.6 - NOAA thermography generated by the fratherm program
Satellite overpass was on 06/08/75 at 9H 30 MN TU.

2. 6 - GROUND TRUTH RADIOMETRIC MEASUREMENTS

Object reflectances measured by each of the four spectral bands of the MSS system build the LANDSAT spectral signature of this object.

The use of an EXOTECH radiometer (model 100-A) helps in undertaking ground truth operations as well as the necessary measurement of atmospheric parameters. It can be used for :

- the prediction of object LANDSAT signatures by "in situ" measurements
- the transformation of measured radiance by the MSS system of the LANDSAT satellite into a ground albedo which is independent of sun angle as well as atmosphere parameters.

2. 6.1 - The EXOTECH radiometer and its control equipment

The EXOTECH radiometer, model 100-A, acquired by Ecole Normale Supérieure (contrat CNES 222/75) is a multichannel ground truth radiometer suitable for point by point measurement. In its present configuration the EXOTECH radiometer is made of a measurement optical head made by EXOTECH and a power source as well as a monitoring console built by Ecole Normale Supérieure.

a - The EXOTECH radiometer

It is a four channel radiometer with separate sensor optics, filter, detector and analog amplifier for each channel. It is capable of giving four simultaneous measurements in a non-sequential fashion. Simultaneous measurement in the four channels is a compulsory feature when sensing is to be done from a plane or from a ship.

The spectral characteristics of each of the four channels match the MSS spectral bands of the LANDSAT satellites :

- channel 1 = band NDPF4 = 0.5 to 0.6 μm ,
- channel 2 = band NDPF5 = 0.6 to 0.7 μm ,
- channel 3 = band NDPF6 = 0.7 to 0.8 μm ,
- channel 4 = band NDPF7 = 0.8 to 1.1 μm .

The equipment is sold with 3 switchable types of sensor optics with the following fields of view :

| Field of view | Aperture shape | Sensor optics |
|-------------------|----------------|-----------------|
| 1° | square | lens |
| 15° | circular | diaphragm |
| 2 π steradian | hemispheric | diffuse surface |

The hemispheric sensor with a 2π steradian aperture enables the measurement of half-space illumination (in watts/cm²) and is suitable for the measurement of down-welling solar illumination. The 15° circular aperture sensor enables the measurement of object radiance (in watts/cm².sr) and is suitable for ground truth collection. The 1° square aperture sensor measures the radiance of a target 260 feet wide (260 ft = 79.2 m) when mounted in a plane flying at an altitude of 2300 meters. This target is identical in geometry to a LANDSAT pixel.

The output signal of each of the four channels is a continuous voltage bounded by 0 and 5 volts. For each channel, four different gain factors can be selected. They are respectively of : 1, 5, 25 and 125.

The transformation of output volts into radiometric units is done by the use of a calibration factor which can take one of twelve values corresponding to a specific association between a channel and a type of sensor. Let us point out that the calibration of this type of radiometer sensing in the visible part of the electromagnetic spectrum is a difficult task. It is highly dependent on the precision of the reference source used during the calibration phase.

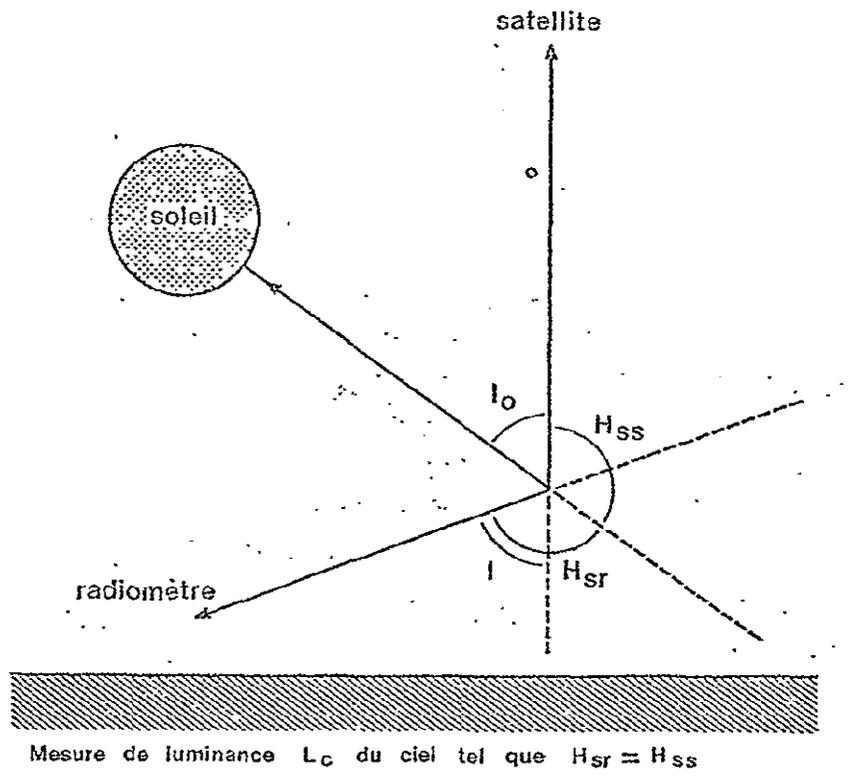
Consequently the precision uncertainty of the radiometer is no better than $\pm 5\%$. The long term variations in detector characteristics must also be taken care of by frequent recalibration.

b - Power source and monitoring console

This console is made of a separate equipment box which holds : four micro-voltmeters allowing the simultaneous display of the four channels output, a Cadmium. Nickel accumulator power source and a built-in charger. A fifth commutator on the monitoring panel can be used in order to check on the accumulator charge.

2. 6.2 - Atmospheric parameters measurement

The EXOTECH radiometer (model 100 A) is suitable for the measurement of atmospheric parameters such as : atmospheric turbidity, water concentration as well as other absorbant materials. These measurements are necessary in order to transform the satellite measured radiances into ground albedo independent of solar angle and atmospheric parameters. This method has been introduced by R.H.Rogers and K. Peacock : A Machine Processing of ERTS and Ground Truth Data ; Conference proceedings of Machine Processing of Remotely Sensed data [LARS]. October 16-18th 1973 at Purdue University - IEEE Catalog n° 73 CHO 834-2GE, pp 4A14-4A27.



Measurement of sky radiance L_c such that $H_{sr} = H_{ss}$

Fig. 2.6.A - Diffusion toward radiometer and satellite

If ground reflection is perfectly diffuse, satellite measured radiance at nadir angle can be expressed as :

$$L = \frac{R_T}{\pi} E T_A + L_A \quad (1)$$

where :

L = measured satellite radiance

R_T = ground albedo

E = irradiance of a perfectly horizontal ground target

T_A = atmospheric transmittance from the target to the sensor per unit of air mass

L_A = atmospheric path radiance

The radiance can be decomposed into two terms :

$$E = E_0 T_A^m \cos I_0 + E_D \quad (2)$$

where :

E_0 = solar irradiance outside atmosphere

E_D = diffuse sky irradiance

I_0 = sun zenith angle

$m = \frac{1}{\cos I_0}$ is the air mass along I_0 direction

Thus, the relationship between L and R_T is expressed by the following formula :

$$R_T = \frac{(L - L_A) \pi}{T_A (E_0 T_A^m \cos I_0 + E_D)} \quad (3)$$

The different terms of relation (3) can be estimated by radiometric measurements at the time of satellite overpass. Solar angle I_0 and air mass m are easy to determine. Diffuse irradiance E_D from the sky is measured by solar occultation. As E and E_D are measured and F_0 is known from standard models, T_A can be determined by equation (2).

The diffuse air radiance L_A is estimated from the measurement of sky radiance L_C so that the angle between viewing direction and solar path H_{SR} is equal to the angle between the viewing of sun and satellite H_{SS} .

Diffusions towards radiometer and satellite are proportional in such a system geometry, the corresponding ratio being a function of the difference in optical path for the two directions (Fig. 2.6.A) :

$$L_P = L_C \frac{1 - T_A}{1 - T_A^m}$$

This method is only applicable for zenith angles I_0 smaller than 45° . When the sun zenithal angle is larger than 45° , viewing of the sun has to be done for I_0 smaller than 45° and subsequently corrected.

The main interest in such an approach is to reduce all satellite measurements to physical albedo values. But it is also a fact that in such radiometric schemes, good calibration is a critical factor.

2. 6.3 - Ground truth measurements

The EXOTECH radiometer is also suitable to ground-truth measurements which aim at comparing satellite measured radiances and ground measured albedo.

This method has been introduced by H.W. Smedes, R.L. Hulstrom and K.J. Ranson : The mixture problem in computer mapping of terrain : improved technique for establishing spectral signatures, atmospheric path radiance and transmittance. Houston, NASA Earth Resources Survey Symposium, June 1975. First comprehensive symposium on practical application of earth resources survey data, volume 1-B, pp 1099-1159.

If ground reflection is perfectly diffuse, a satellite viewing at nadir angle would measure the following radiance (equation 2) :

$$L = \frac{R_T}{\pi} \cdot E \cdot T_A + L_A$$

and the target reflectance is expressed as :

$$K_T = (L - L_A) \times \frac{\pi}{H \cdot T_A} \quad (5)$$

If reflectance of a set of targets is measured at ground level or at a small altitude, the comparison of the values of R_T and L shows a linear relationship :

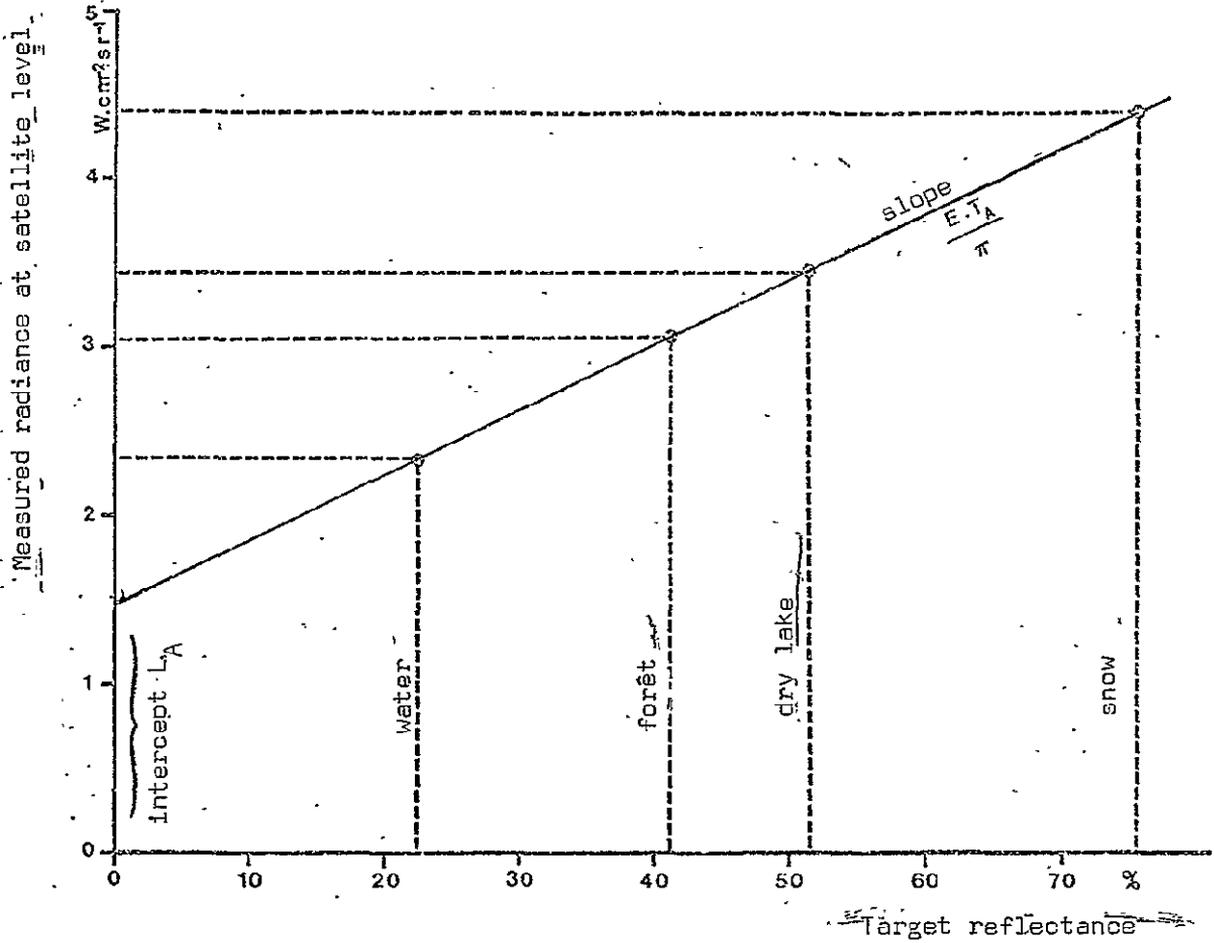
$$L = a \times R_T + b \quad (6)$$

The intercept is equal to the atmospheric diffusion : $b = L_A$ and the slope of this line is related to the downwelling irradiance and the atmospheric transmittance $a = \frac{E \cdot T_A}{\pi}$ are presented on Fig. 2.6.B.

Consequently the spectral signature of an object in albedo related to the four spectral bands of the LANDSAT MSS system can be determined as follows :

$$\left\{ R_i = (L_i - L_{Ai}) \times \frac{\pi}{H_i \cdot T_{Ai}} \mid i \in I \right\}$$

where I is the set of the four MSS sensors



< <-from>> H. W. SMEDES et al.

Fig. 2.6.B - Relationship between measured reflectance at ground level and nadir radiance measured by satellite

This method has several positive aspects :

- the value of the measured atmospheric radiance is a direct contribution to the signal sensed by the satellite radiometer,
- measurement of atmospheric effects is done in a global way (downwelling solar irradiance and atmospheric transmission effects are integrated in the same term),
- no specific ground equipment set-up is necessary.

However two type of constraints are present :

- position of ground targets has to be known with a high degree of geometric precision,
- measurements usefulness is related to the quality of ground measured reflectances which implies a good knowledge of temporal variations of object signatures.

2. 6.4 - Typical ground measurements

Several "in situ" radiometric measurements were conducted in various-environments :

- on the tidal flats and marine marshes of the Mont St-Michel bay,
- in harbour waters, on beaches and coastal ponds along the coast of Golfe du Lion,
- in the Fromentine test area,
- on the lawn of the Scientific campus of University of Villeneuve d'Ascq , near Lille,
- on snow cover at the Ecole Normale Supérieure in Montrouge,
- on several samples taken from the beaches and littoral sand dunes of the coasts of France (measurements were made in natural sun light).

These measurements were performed in spectral bands matching those of the LANDSAT MSS system, using two types of radiometers

- 820 - 10 A ERTS radiometer head manufactured by Gamma Scientific,
- EXOTECH 100 - A ERTS radiometer manufactured by EXOTECH

Each measurement sequence is made of :

- reflectance R_i

$$\left\{ R_i = (L_{ci} \cdot G_{ci}) \times 100 / (L_{vi} \cdot G_{vi}) \mid i \in I \right\}$$

- normalized reflectance R_{Ni}

$$\left\{ R_{Ni} = R_i / R_1 \mid i \in I \right\}$$

with :

L_c = voltmeter output when measuring the target radiance

G_c = gain set when viewing the target

L_v = voltmeter output when measuring the downwelling irradiance

G_v = gain set when viewing the sky

i = channel index

Measurements are presented on the following tables (Tab. 2.6.C)

Tab. 2. 6.C - Examples of spectral signatures

e = Laboratory sample studied in daylight

d = depth of Secchi disk (in meters)

E = EXOTECH radiometer, model 100-A

G = Gamma Scientific radiometer, model 820-10 A

| Sample | Material | Site | reflectance (in %) | | | |
|--------|------------------------|--------------------|--------------------|------------|------------|------------|
| | | | MSS4 | MSS5 | MSS6 | MSS7 |
| 01 E | beach sand | Mont St-Michel Bay | 31 1 | 34 1.10 | 42 1.35 | 41 1.32 |
| 02 E | beach sand with shells | Mont St-Michel Bay | 52 1 | 55 1.06 | 65 1.25 | 68 1.31 |
| 03 E | shell bar | Mont St-Michel Bay | 67 1 | 69 1.03 | 84 1.25 | 82 1.22 |
| 04 E | very dry tidal clay | Mont St-Michel Bay | 32 1 | 30 0.94 | 37 1.16 | 36 1.13 |
| 05 E | dry tidal clay | Mont St-Michel Bay | 28 1 | 29 1.4 | 34 1.21 | 30 1.07 |
| 06 E | humid tidal clay | Mont St-Michel Bay | 24 1 | 22 0.92 | 27 1.13 | 26 1.08 |
| 07 E | Salicorne field | Mont St-Michel Bay | 11 1 | 10 0.91 | 53 4.82 | 69 6.27 |
| 08 E | Obione field | Mont St-Michel Bay | 12 1 | 10 0.83 | 63 5.25 | 86 7.17 |

Tab. 2.6.C (Suite)

| Sample | Material | Site | Reflectance (in %) | | | |
|--------|---------------------------|------------------|--------------------|------------|------------|------------|
| | | | MSS4 | MSS5 | MSS6 | MSS7 |
| 09 E | beach sand with shells | Saint Enogat | 63 1 | 65 1.03 | 79 1.25 | 81 1.29 |
| 10 eE | beach sand | Deauduc point | 42 2 | 42 1 | 54 1.29 | 54 1.29 |
| 11 eE | beach sand | Soulac | 64 1 | 70 1.09 | 88 1.38 | 88 1.38 |
| 12 eE | damped beach sand | Soulac | 38 1 | 38 1 | 50 1.32 | 50 1.32 |
| 13 eE | dune sand | Arcay spit | 58 1 | 67 1.16 | 89 1.53 | 92 1.59 |
| 14 eE | beach sand | Arcay spit | 49 1 | 56 1.14 | 76 1.55 | 77 1.57 |
| 15 eE | dry pasture | Dól marsh | 14 1 | 15 1.07 | 39 2.79 | 50 3.57 |
| 16 eE | dune sand | Kersidan | 69 1 | 76 1.10 | 93 1.35 | 93 1.35 |
| 17 eE | dune sand | Trevignon | 49 1 | 61 1.24 | 90 1.84 | 93 1.90 |
| 18 eE | dune sand | Rospico | 45 1 | 54 1.20 | 82 1.82 | 89 1.98 |
| 19 eE | dune sand | Kerboven | 53 1 | 61 1.15 | 90 1.70 | 96 1.61 |

Tab. 2. 6.C (Suite)

| Sample | Material | Site | reflectance (in %) | | | |
|--------|-------------------|---------------------|--------------------|------------|------------|------------|
| | | | MSS4 | MSS5 | MSS6 | MSS7 |
| 20 eE | beach sand | Guimorais | 55 1 | 66 1.20 | 82 1.49 | 81 1.47 |
| 21 eE | beach sand | Keloidan | 66 1 | 66 1.1 | 81 1.23 | 81 1.23 |
| 22 G | snow | Montrouge | 70 1 | 78 1.11 | 68 0.97 | 62 0.89 |
| 23 G | snow | Montrouge | 58 1 | 66 1.14 | 64 1.10 | 60 1.03 |
| 24 G | snow | Montrouge | 60 1 | 70 1.17 | 68 1.13 | 65 1.08 |
| 25 G | thawed lawn | Lille | 22 1 | 23 1.05 | 68 3.09 | 90 4.09 |
| 26 G | lawn | Lille | 9 1 | 10 1.11 | 42 4.67 | 57 6.33 |
| 27 G | beach pebbles | Collioure | 14 1 | 17 1.24 | 25 1.79 | 21 1.53 |
| 28 G | beach pebbles | Sete | 18 1 | 15 0.83 | 32 1.75 | 36 1.98 |
| 29 G | dry beach sand | Collioure | 18 1 | 21 1.19 | 20 1.14 | 20 1.13 |
| 30 G | dry beach sand | Port la Nouvelle | 22 1 | 28 1.30 | 30 1.37 | 33 1.52 |

Tab. 2. 6.C (Suite)

| Sample | Material | Site | reflectance (in %) | | | |
|--------|--------------------------------|------------------|--------------------|------------|------------|------------|
| | | | MSS4 | MSS5 | MSS6 | MSS7 |
| 31 G | dry beach sand | Fontignan | 15 1 | 23 1.56 | 24 1.58 | 26 1.71 |
| 32 G | dry beach sand | Fontignan | 10 1 | 13 1.32 | 14 1.41 | 16 1.58 |
| 33 G | rippled dry beach sand | Port la Nouvelle | 24 1 | 31 1.32 | 29 1.21 | 36 1.50 |
| 34 G | beach sand under film of water | Port la Nouvelle | 8 1 | 11 1.40 | 11 1.44 | 17 2.13 |
| 35 G | beach sand under film of water | Sete | 16 1 | 24 1.51 | 26 1.62 | 27 1.67 |
| 36 G | beach sand under film of water | Sete | 17 1 | 25 1.46 | 28 1.61 | 31 1.79 |
| 37 G | rippled damp beach sand | Port la Nouvelle | 11 1 | 12 1.05 | 16 1.39 | 26 2.29 |
| 38 G | damp beach sand | Port la Nouvelle | 16 1 | 21 1.33 | 21 1.38 | 25 1.63 |
| 39 G | damp beach sand | Sete | 25 1 | 34 1.32 | 37 1.46 | 38 1.50 |
| 40 G | damp beach sand | Fontignan | 19 1 | 25 1.33 | 25 1.33 | 30 1.61 |
| 41 G | shell sand | Sete | 27 1 | 37 1.39 | 42 1.57 | 50 1.87 |
| 42 G | shells and pebbles | Sete | 36 1 | 45 1.26 | 47 1.32 | 66 1.86 |

Tab. 2. 6.C (Suite)

| Sample | Material | Site | reflectance (in %) | | | |
|--------|-------------------------------|------------|--------------------|------------|------------|------------|
| | | | MSS4 | MSS5 | MSS6 | MSS7 |
| 43 G | shells | Sete | 24 1 | 39 1.64 | 45 1.89 | 52 2.19 |
| 44 G | shells | Frontignan | 14 1 | 20 1.40 | 24 1.67 | 27 1.89 |
| 45 G | muddy sand | Sete | 10 1 | 14 1.34 | 17 1.67 | 21 1.99 |
| 46 G | muddy sand | Sete | 12 1 | 18 1.43 | 19 1.57 | 21 1.73 |
| 47 G | muddy sand | Sete | 13 1 | 18 1.39 | 19 1.48 | 24 1.63 |
| 48 G | muddy sand | Sete | 15 1 | 21 1.44 | 21 1.45 | 24 1.59 |
| 49 G | muddy sand with film of water | Sete | 18 1 | 23 1.27 | 26 1.47 | 31 1.72 |
| 50 G | red soil | Frontignan | 10 1 | 30 2.94 | 43 4.18 | 47 4.60 |
| 51 G | muddy sand with film of water | Sete | 7 1 | 10 1.33 | 14 1.94 | 10 1.45 |
| 52 G | muddy sand with film of water | Sete | 7 1 | 10 1.25 | 14 1.86 | 10 1.35 |
| 53 G | muddy sand with film of water | Sete | 8 1 | 10 1.36 | 15 2.01 | 12 1.54 |

Tab. 2. 6.C (Suite)

| Sample | Material | Site | reflectance (in %) | | | |
|--------|--------------------|--------------|--------------------|------|------|------|
| | | | MSS4 | MSS5 | MSS6 | MSS7 |
| 54 G | obione field | Sete | 8 | 12 | 41 | 59 |
| | | | 1 | 1.50 | 5.31 | 7.53 |
| 55 G | obione field | Sete | 7 | 12 | 42 | 60 |
| | | | 1 | 1.72 | 5.84 | 8.38 |
| 56 G | salicorne field | Sete | 4 | 5 | 12 | 20 |
| | | | 1 | 1.16 | 2.86 | 4.93 |
| 57 G | ocean d = 3.0 m | Port Vendres | 1.86 | 0.81 | 0.41 | 0.27 |
| | | | 1 | 0.44 | 0.22 | 0.15 |
| 58 G | ocean d = 3.0 m | Port Vendres | 1.90 | 1.04 | 0.45 | 0.30 |
| | | | 1 | 0.55 | 0.24 | 0.16 |
| 59 G | ocean d = 3.5 m | Port Vendres | 1.70 | 0.81 | 0.30 | 0.21 |
| | | | 1 | 0.48 | 0.18 | 0.12 |
| 60 G | ocean d = 3.5 m | Port Vendres | 2.15 | 1.13 | 0.45 | 0.65 |
| | | | 1 | 0.53 | 0.21 | 0.30 |
| 61 G | ocean d = 4.0 m | Port Vendres | 1.98 | 0.80 | 0.38 | 0.21 |
| | | | 1 | 0.45 | 0.19 | 0.11 |
| 62 G | ocean d = 4.5 m | Port Vendres | 1.92 | 0.99 | 0.44 | 0.22 |
| | | | 1 | 0.52 | 0.23 | 0.11 |
| 63 G | ocean d = 4.5 m | Port Vendres | 2.13 | 1.25 | 0.75 | 0.85 |
| | | | 1 | 0.59 | 0.35 | 0.40 |
| 64 G | ocean d = 3.5 m | Port Vendres | 1.87 | 0.77 | 0.28 | 0.18 |
| | | | 1 | 0.41 | 0.15 | 0.10 |
| 65 G | ocean d = 4.5 m | Port Vendres | 2.00 | 1.29 | 1.09 | 1.11 |
| | | | 1 | 0.65 | 0.55 | 0.56 |

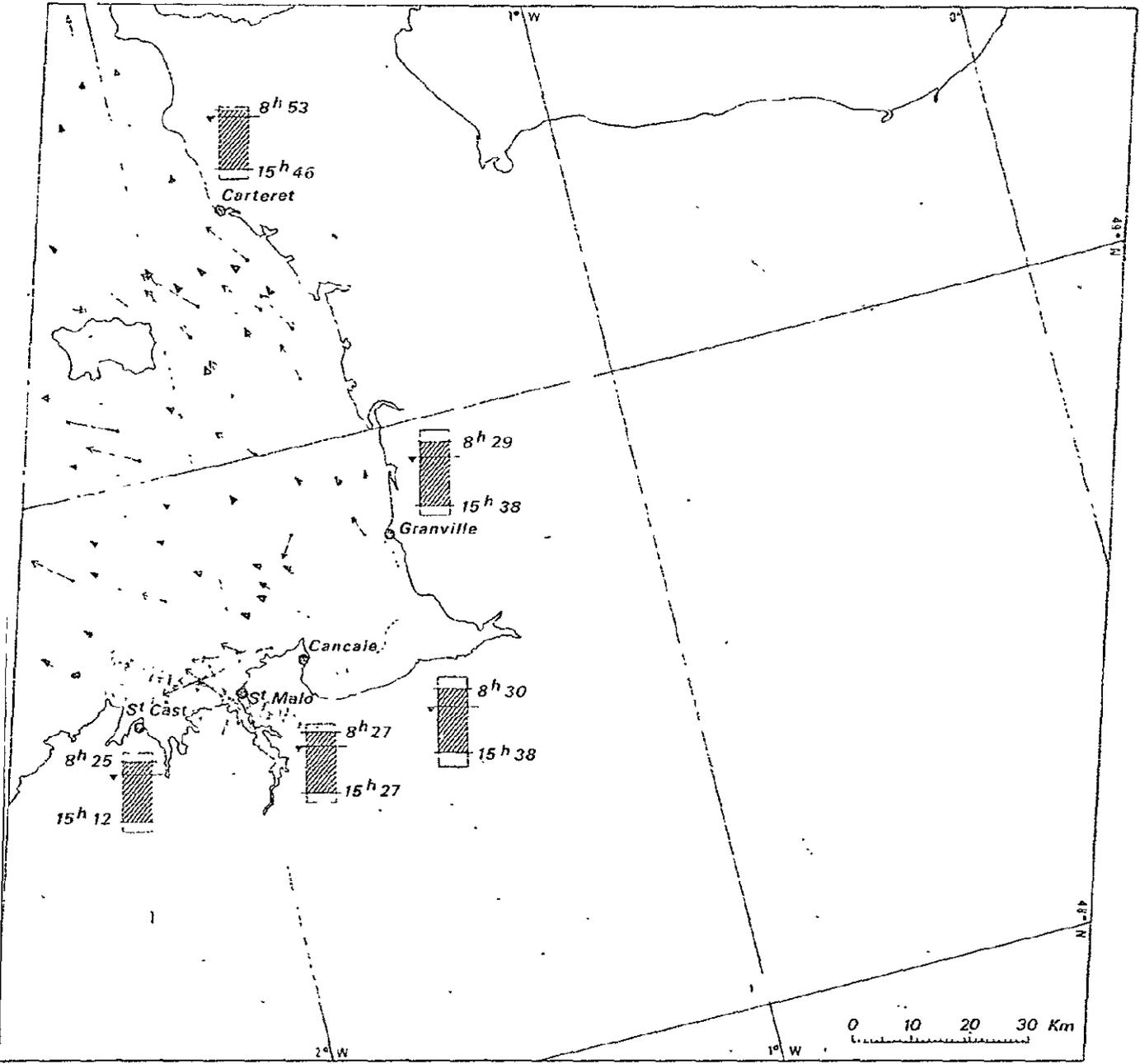
2. 7 - DETERMINATION OF TIDAL CURRENTS AND TIDAL HEIGHTS

Since a large part of the works of the FRALIT team are related to the tidal coast of France, it was necessary to compute the tidal heights as well as the speed and heading of the tidal currents at satellite overpass. Those determinations were drawn from data collected by the Service Hydrographique and Oceanographique de la Marine and sometimes from other data sources (E.D.F., direct observations, ...).

Figures 2.7.1 through 2.7.18 provide this type of information for 15 images of the French Atlantic littoral which were computer processed by the FRALIT team ; those images are ordered by geographical area and for each geographical area by chronological order.

| Latitude axes | Orbit axes | Date | Tidal coefficient |
|---------------|------------|--------------------|-------------------|
| 26 | 217 | September 27, 1972 | 92 |
| " | " | March 8, 1973 | 100 |
| " | 218 | June 6, 1975 | 55 |
| " | " | July 30, 1975 | 56 |
| " | " | October 28, 1975 | 47 |
| 27 | 217 | September 27, 1972 | 92 |
| " | " | March 8, 1973 | 100 |
| " | " | July 29, 1975 | 65 |
| " | " | March 28, 1976 | 70 |
| " | " | June 8, 1976 | 65 |
| " | " | June 26, 1976 | 68 |
| " | 218 | October 28, 1975 | 47 |
| 28 | 216 | July 11, 1973 | 44 |
| " | " | June 4, 1975 | 45 |
| " | " | December 19, 1975 | 84 |
| " | 217 | March 8, 1973 | 100 |
| " | " | July 29, 1975 | 65 |
| 29 | 216 | June 4, 1975 | 64 |

Note : Tidal coefficients are locally determined for satellite overpass with high water in Brest.



Tidal currents (1cm = 1m/s)

Tidal range and water level (1mm = 1m)

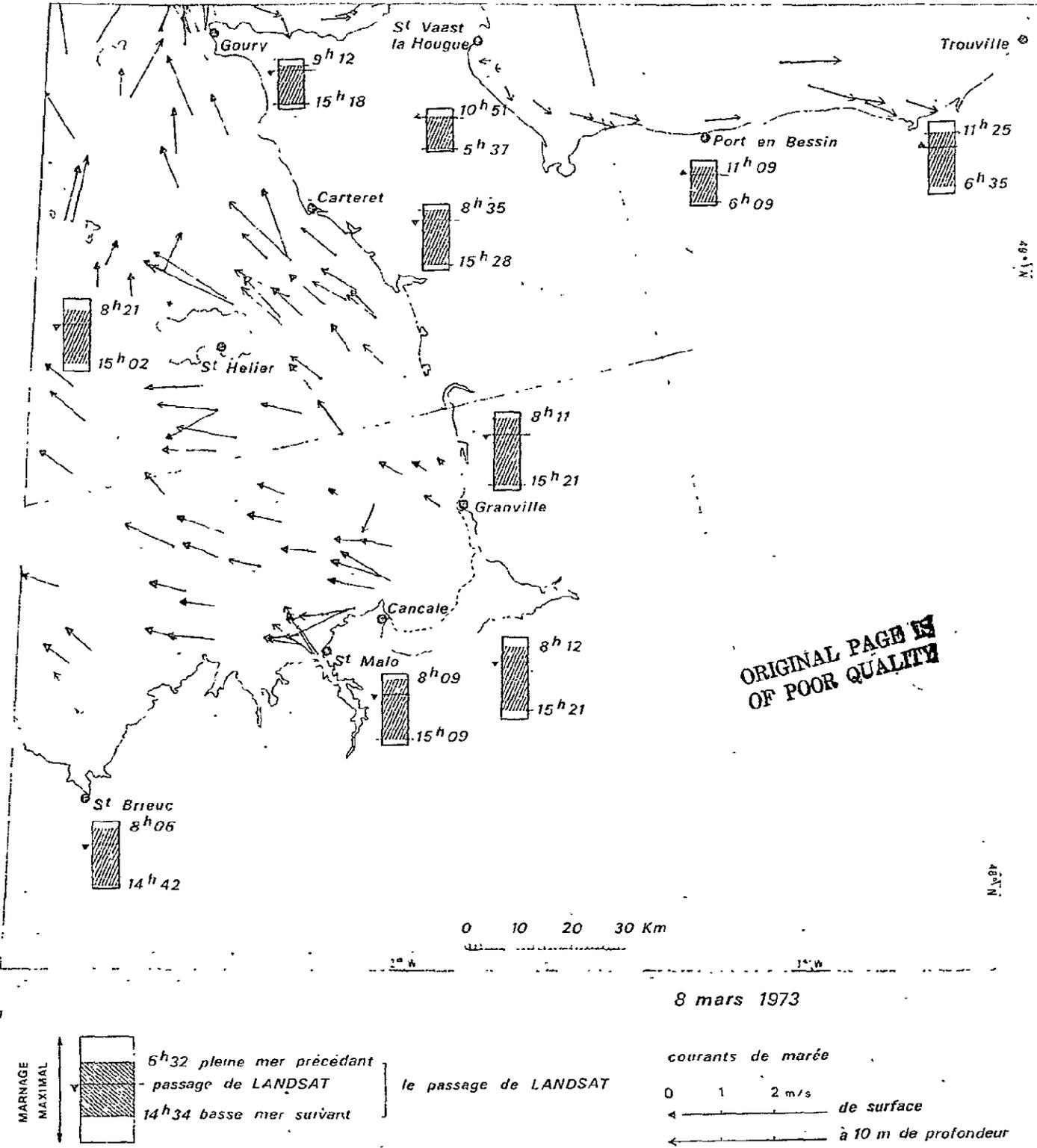
Data issued from :

- Laboratoire National d'Hydraulique
- S H O M

Maximum high water springs September 27, 1972

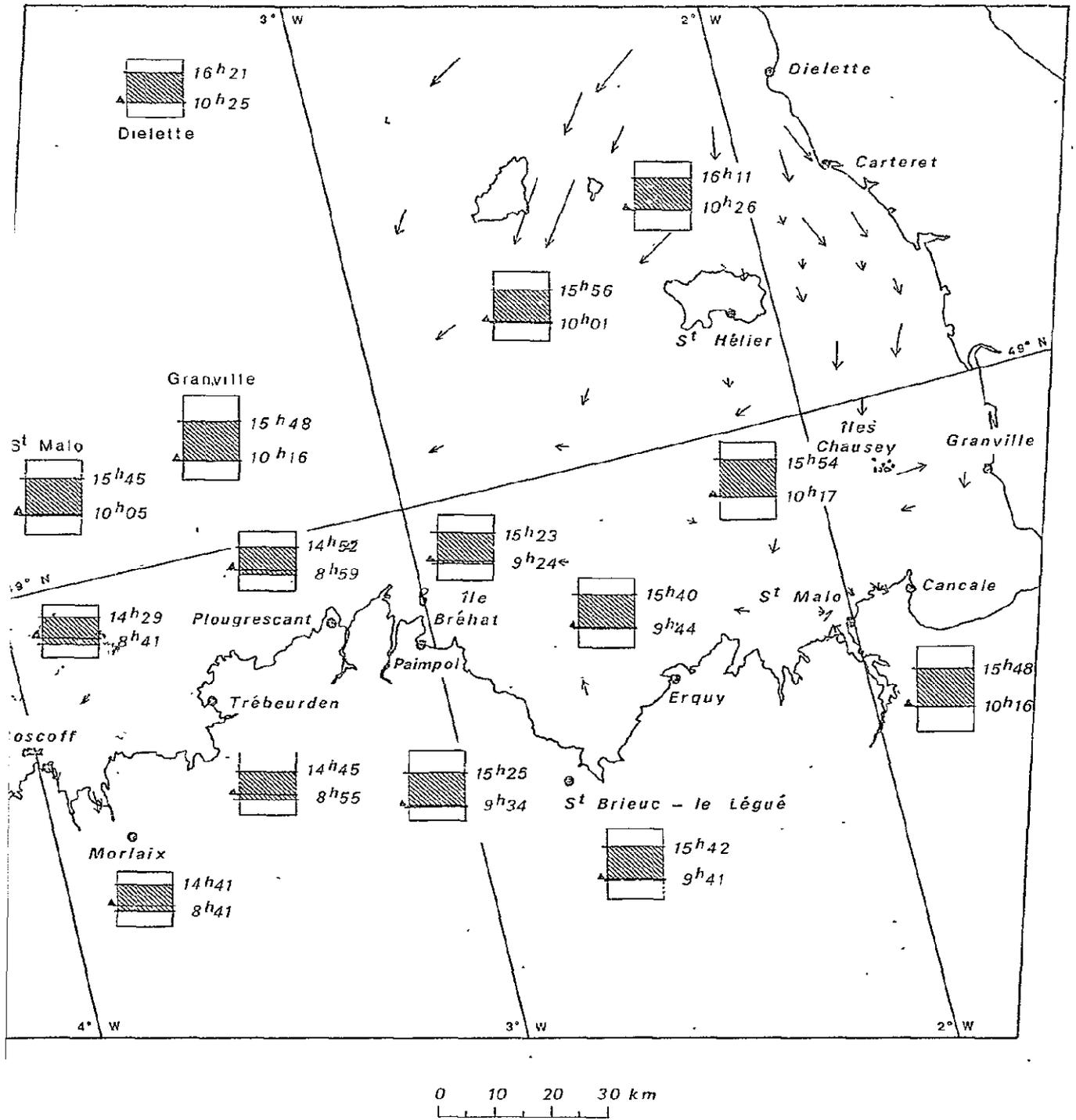
▾ falling tide
 ▲ rising tide
 Chart datum 0

Fig. 2.7.1 - Hydrological ground truth data



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Fig. 2.7.2 - Hydrological ground truth data



dal currents (1 cm = 1 m/s)

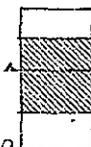
Tidal range and water level (1 mm = 1 m)

June 6, 1975

Maximum high water springs

falling tide
 rising tide

Chart datum 0

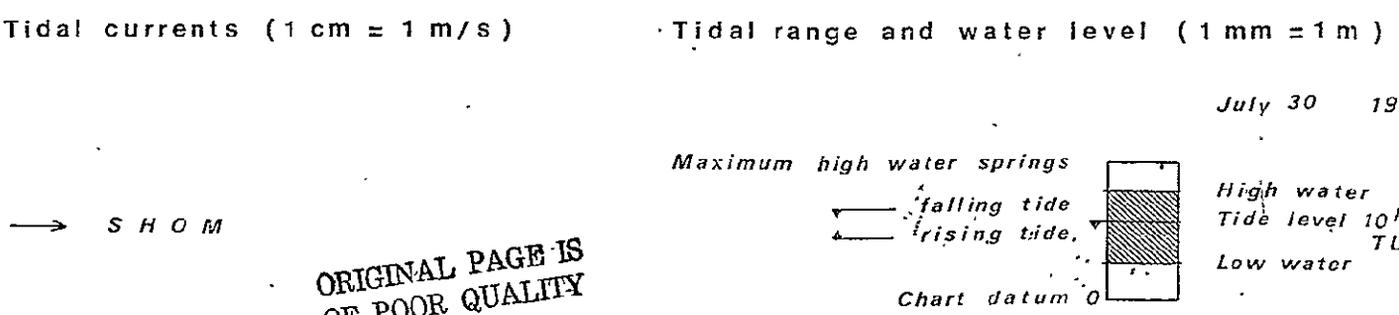
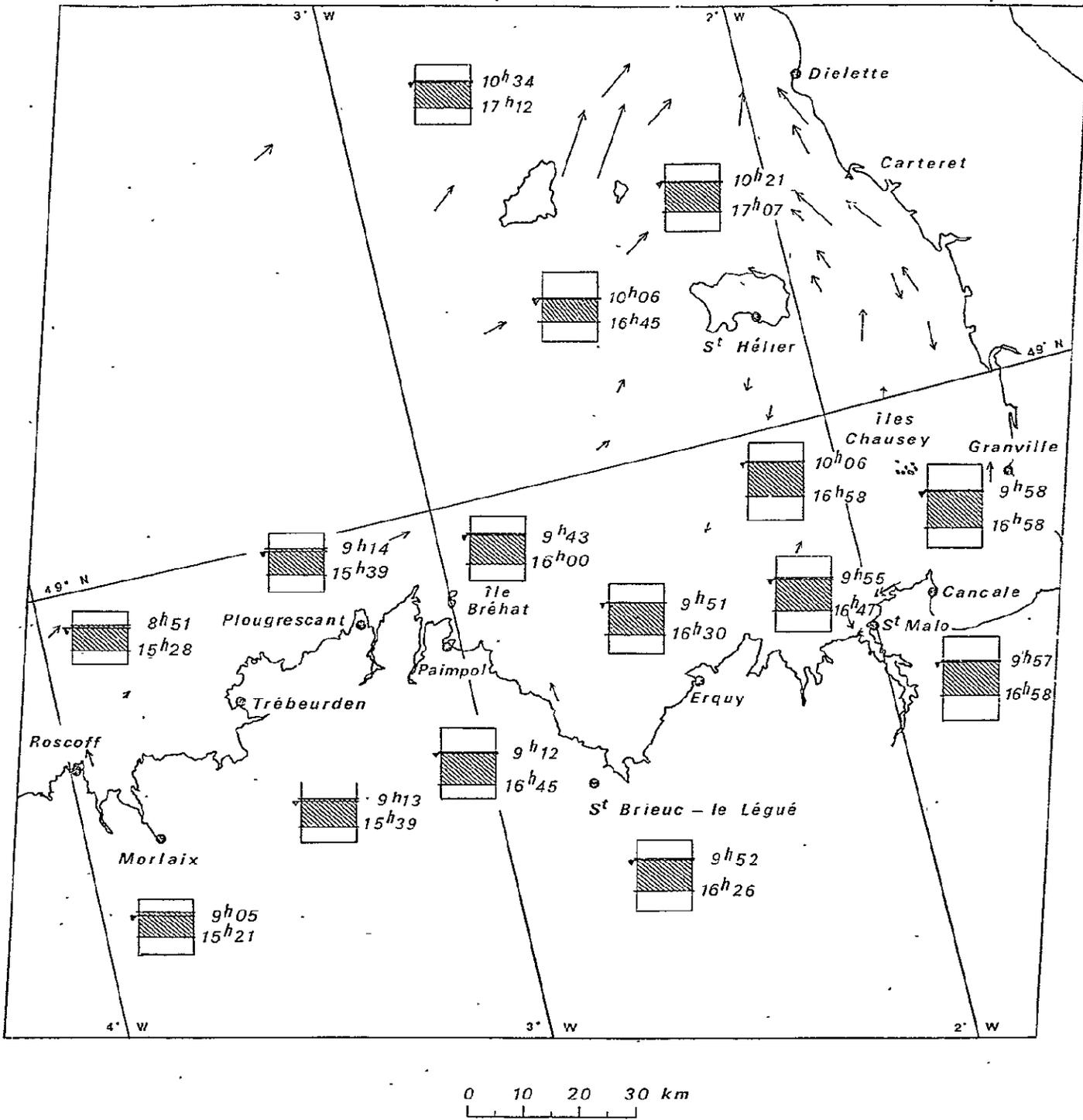


High water
 Tide level 10h23 TU
 Low water

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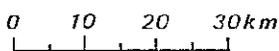
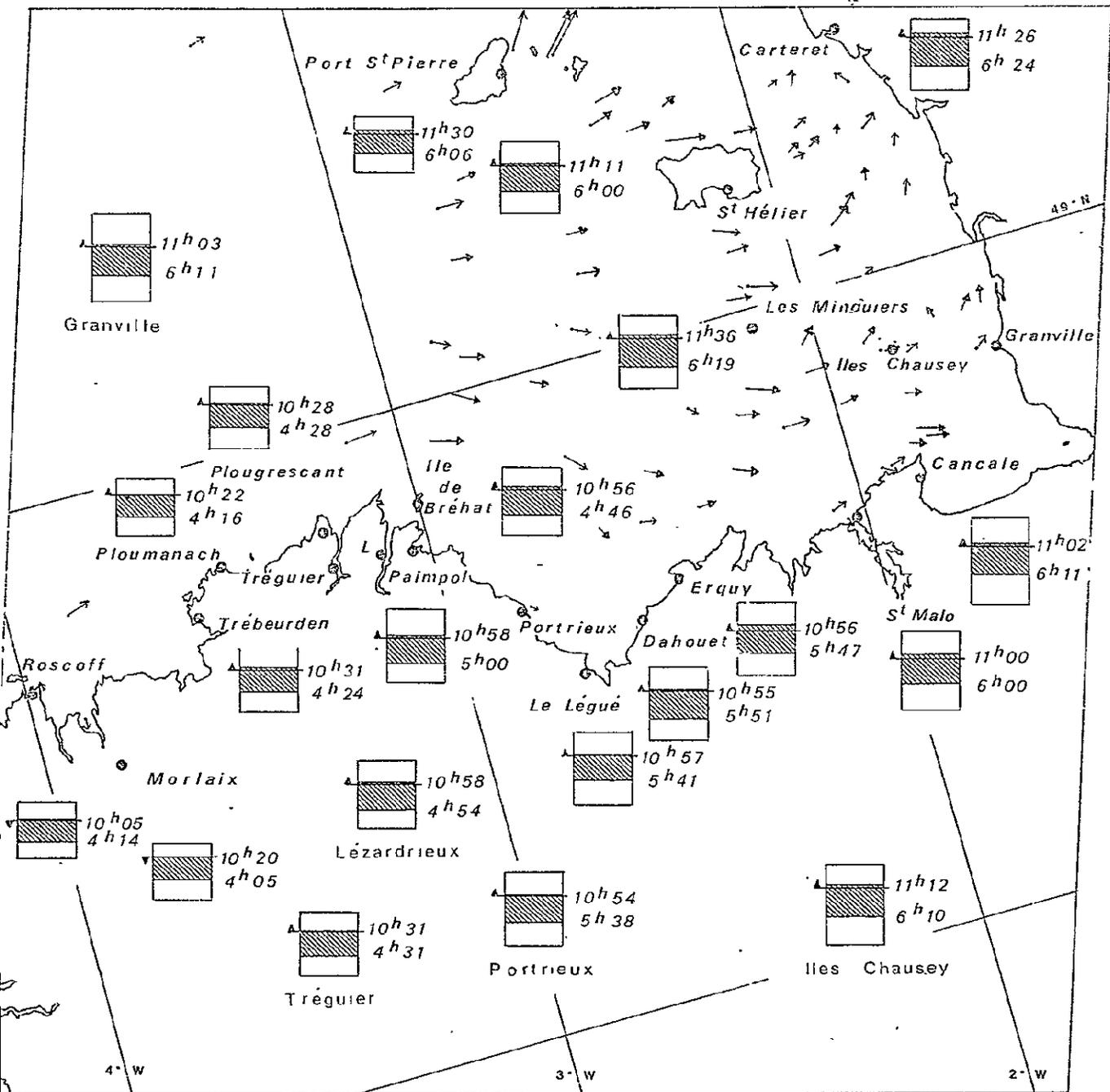
Fig. 2.7.3 - Hydrogological ground truth data

S H O M



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Fig. 2.7.4 - Hydrological ground - truth data.



dal currents (1cm = 1m / s)

Tidal range and water level (1mm = 1m)

October 28, 1975

S H O M

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Maximum high water springs

— falling tide
 ▲ rising tide

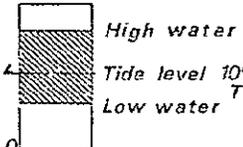
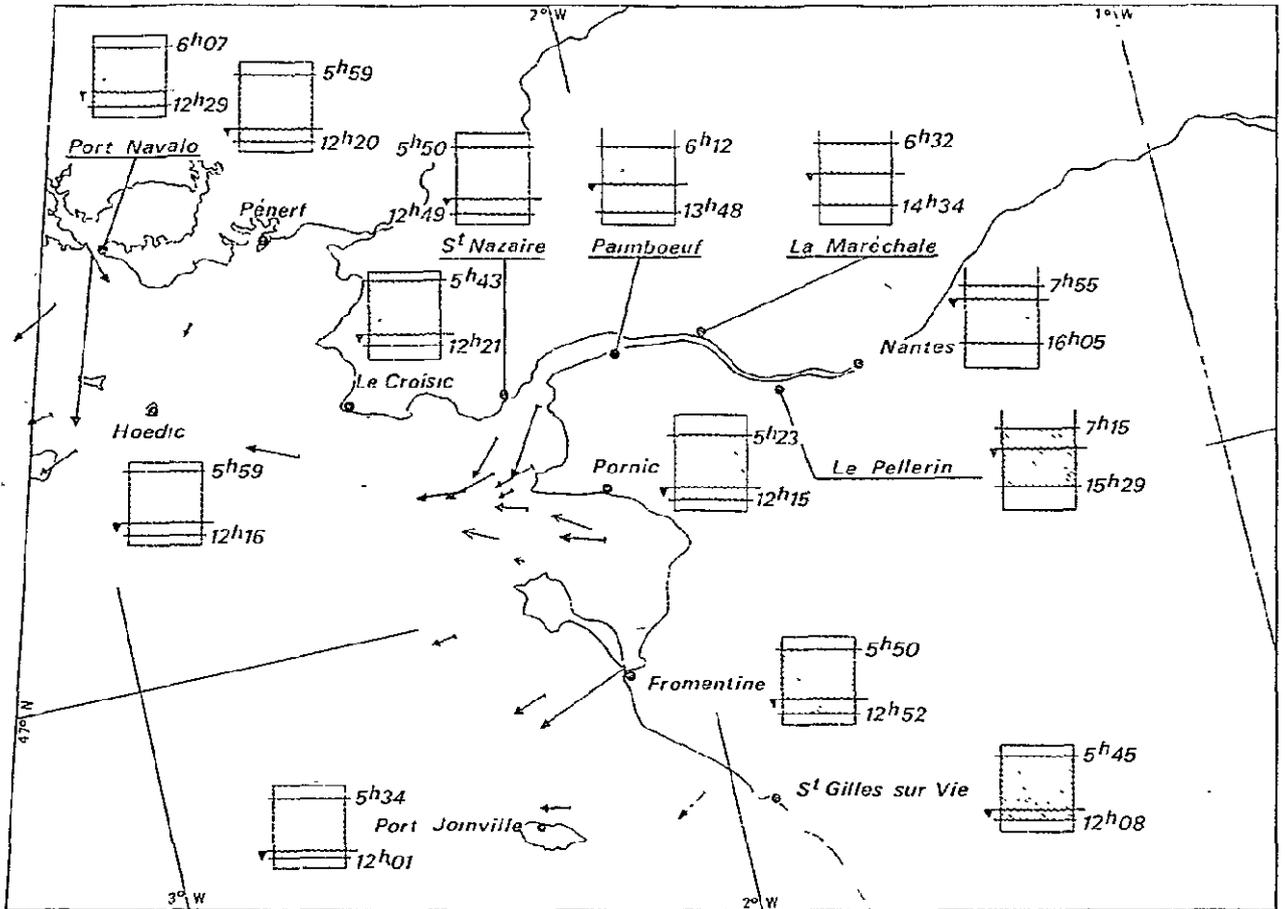


Chart datum 0

Laboratoire National d'Hydraulique

Fig. 2.7.5 - Hydrological ground truth data



ERTS 1 FRALIT 27 SEPT. 1972 E 1066 10 294

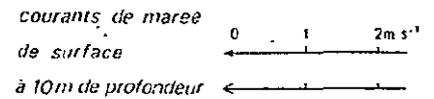
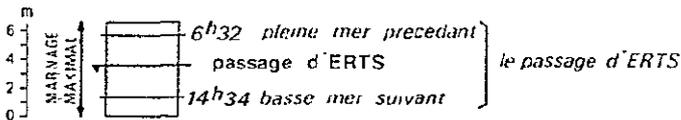
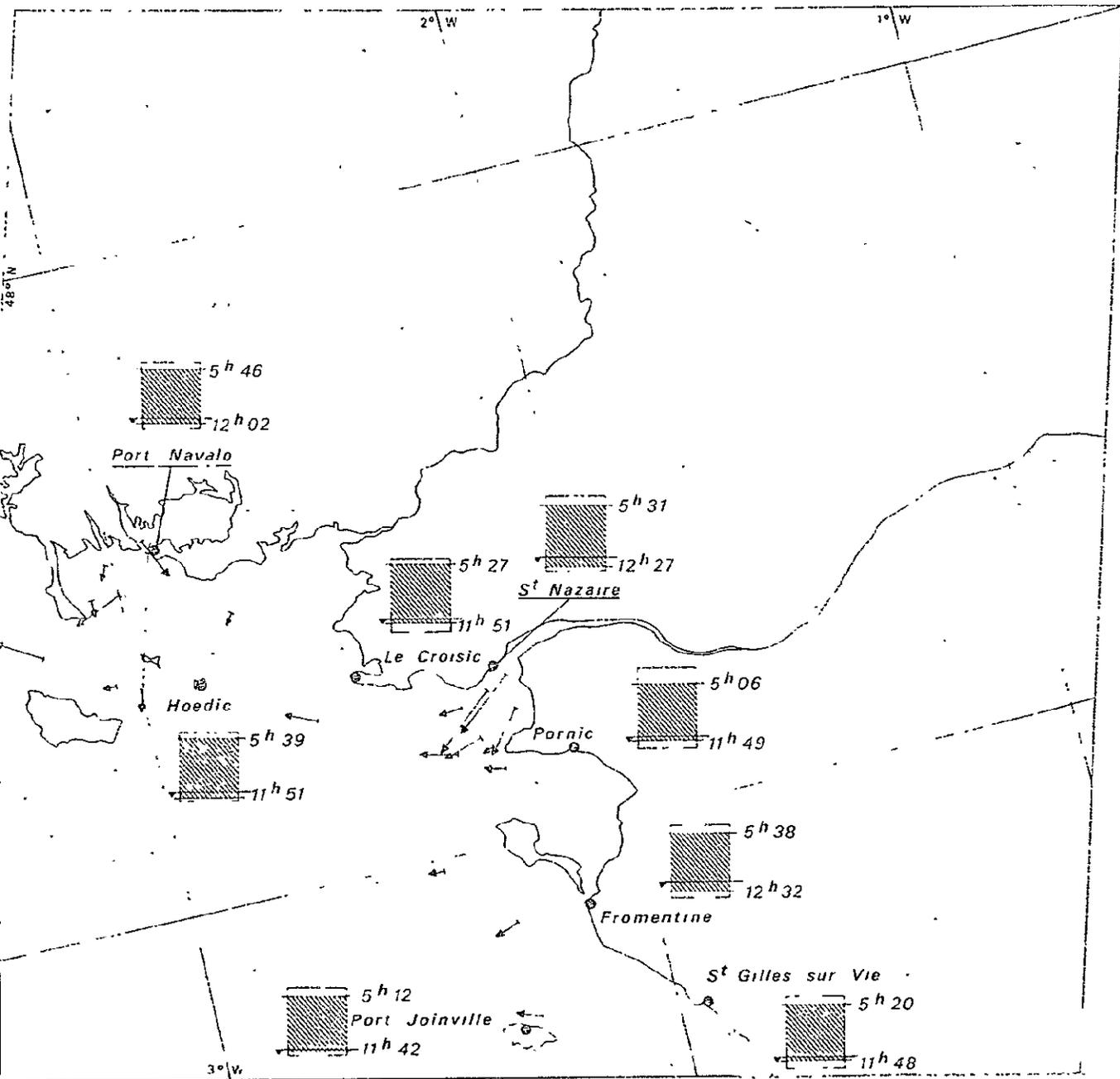
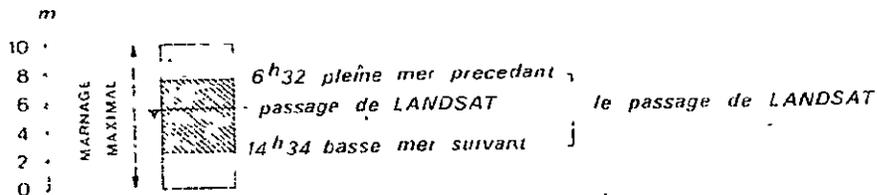


Fig. 2.7.6 - Hydrological ground truth data



8 mars 1973

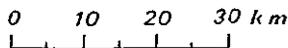
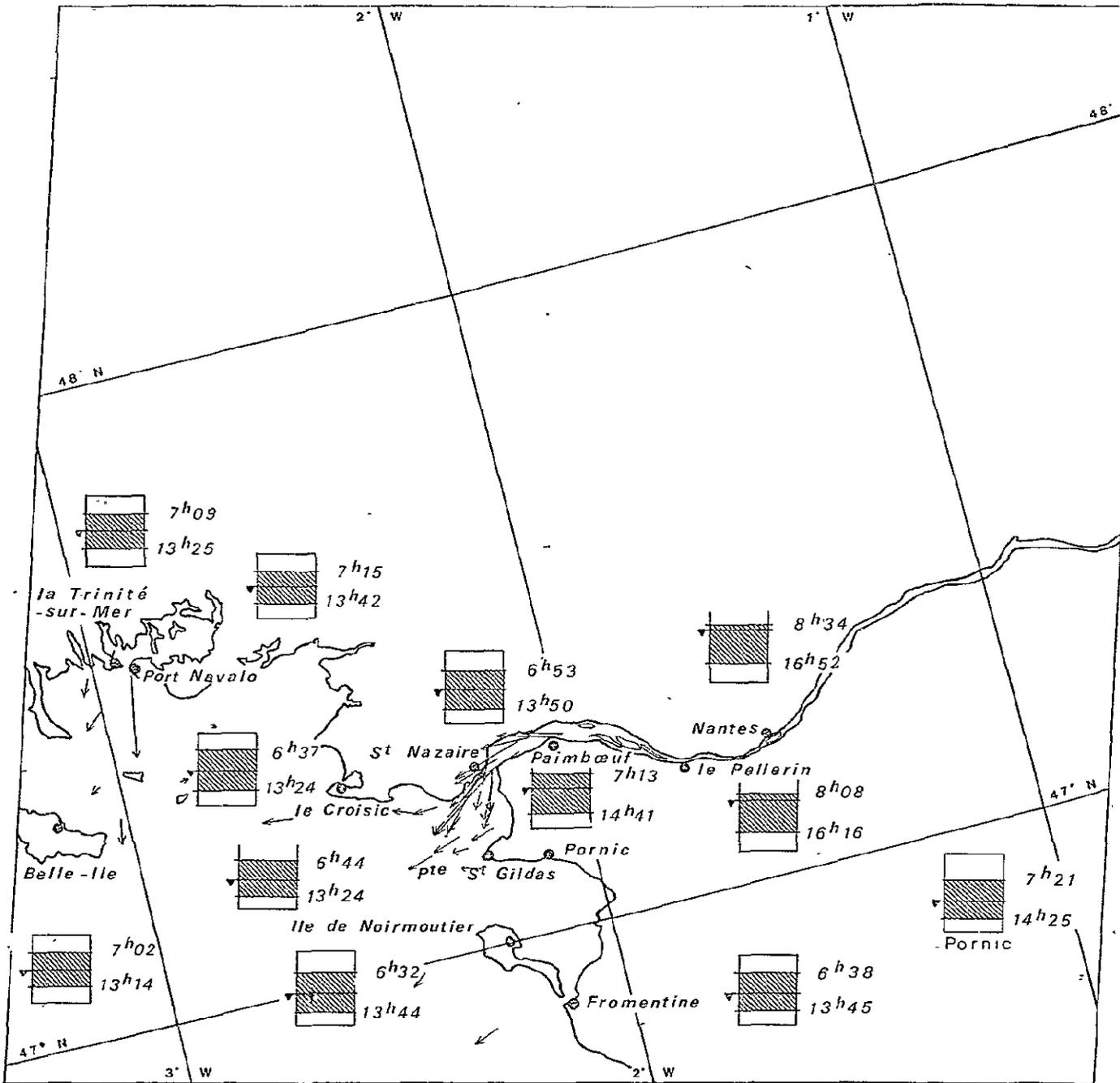


courants de marée

0 1 2 m/s

Fig. 2.7.7 - Hydrological ground truth data

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Tidal currents (1 cm = 1 m/s)

Tidal range and water level (2 mm = 1 m)

July 2, 1973

→ S H O M

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Maximum high water springs

— falling tide
— rising tide

Chart datum 0



High water
Tide level
Low water

Fig. 2.7.8 - Hydrological ground - truth data.

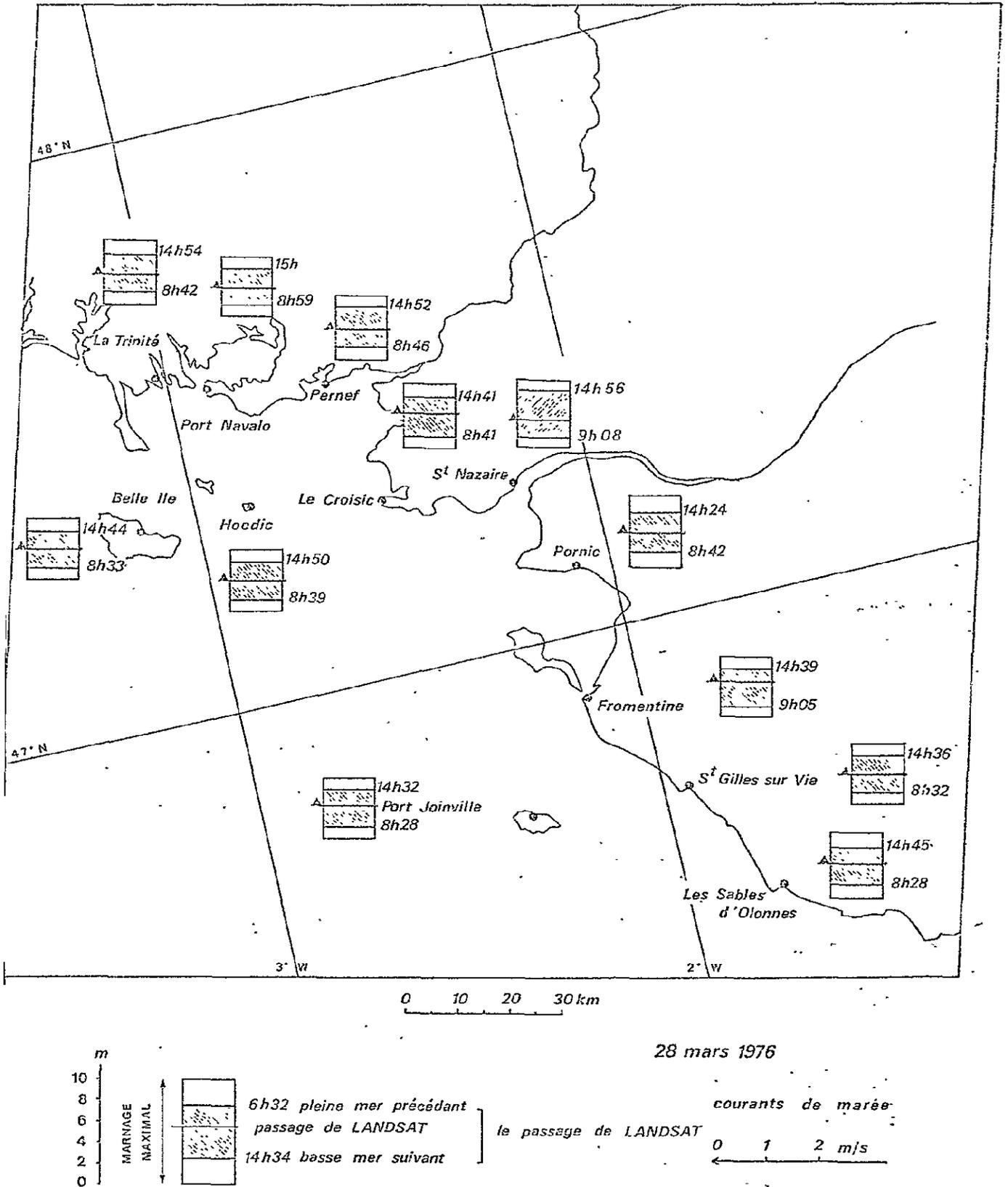


Fig. 2.7.9 - Hydrological ground truth data

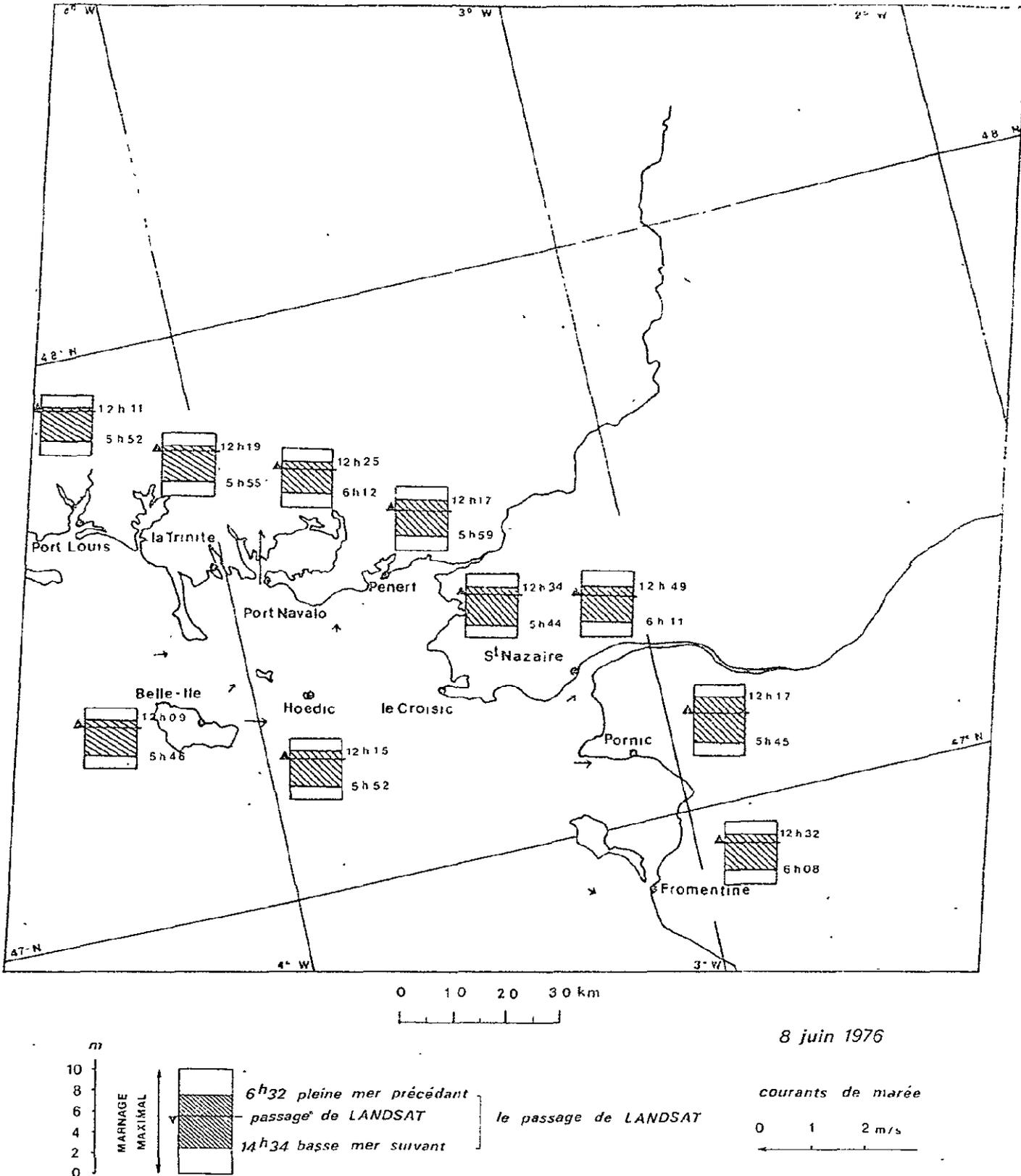
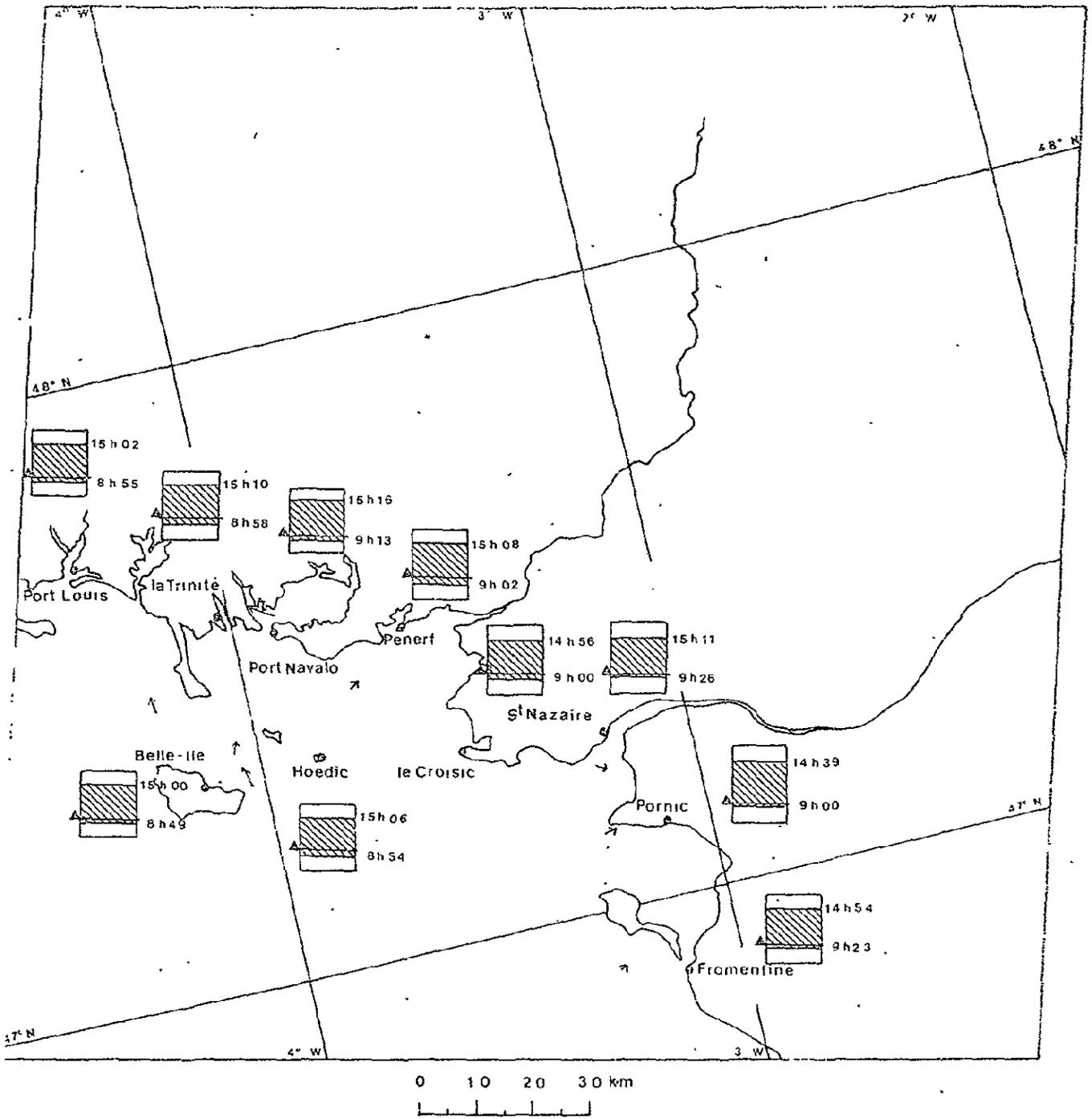


Fig. 2.7.10 - Hydrological ground truth data



26 JUNE 1976

Tidal currents (1cm = 1m/s)

Tidal range and water level (2mm = 1m)

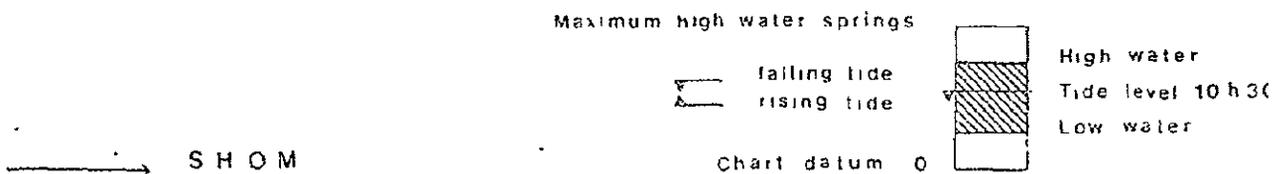
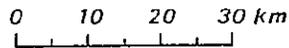
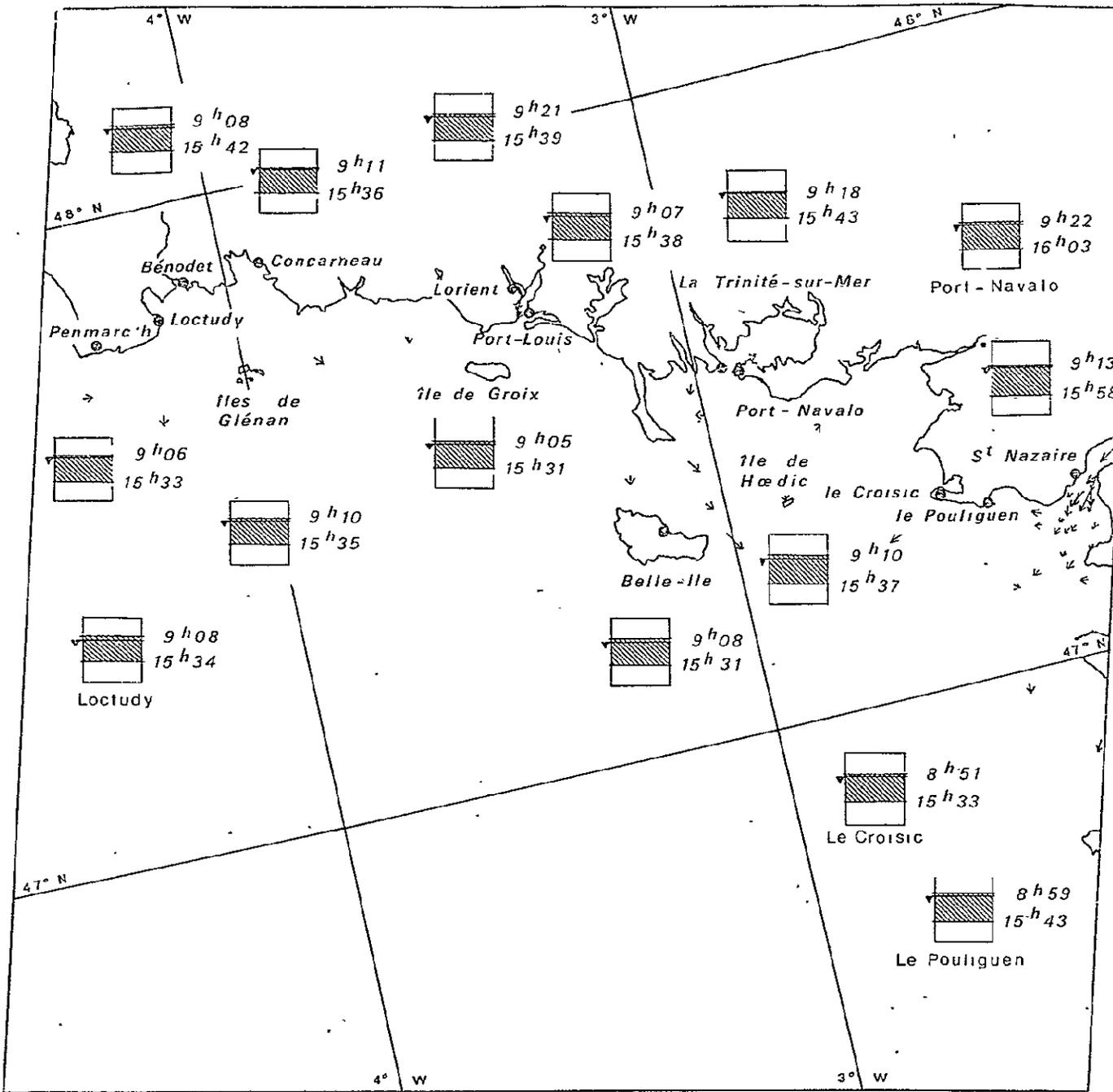


Fig. 2.7.11 - Hydrological ground truth data



Tidal currents (1 cm. = 1 m/s)

Tidal range and water level (2 mm = 1 m)

October 28, 19

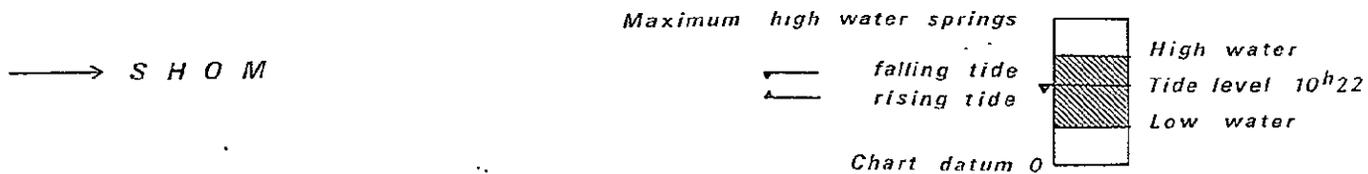
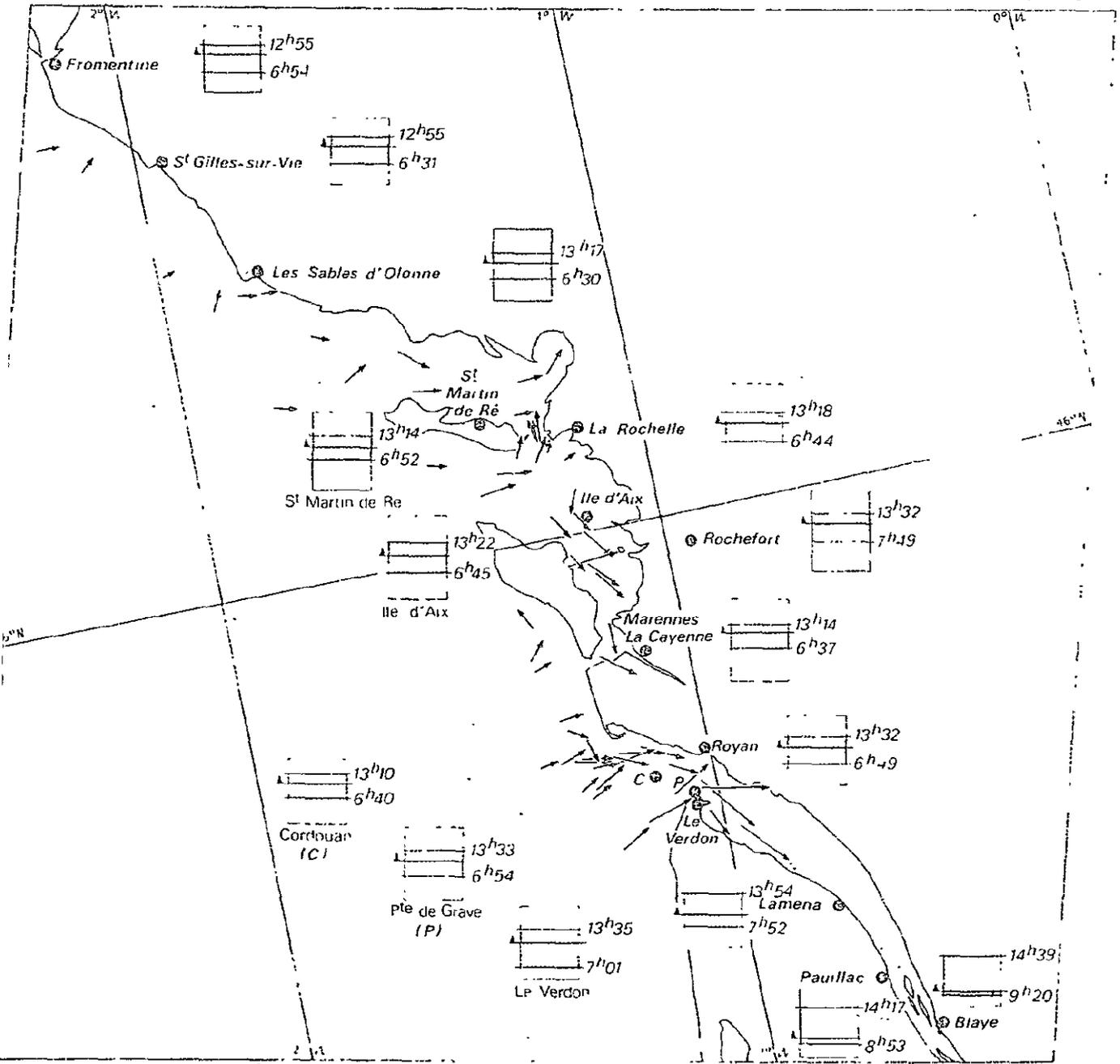


Fig. 2.7.12 - Hydrological ground truth data



11 juillet 1973

MAXIMUM
MINIMUM

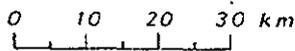
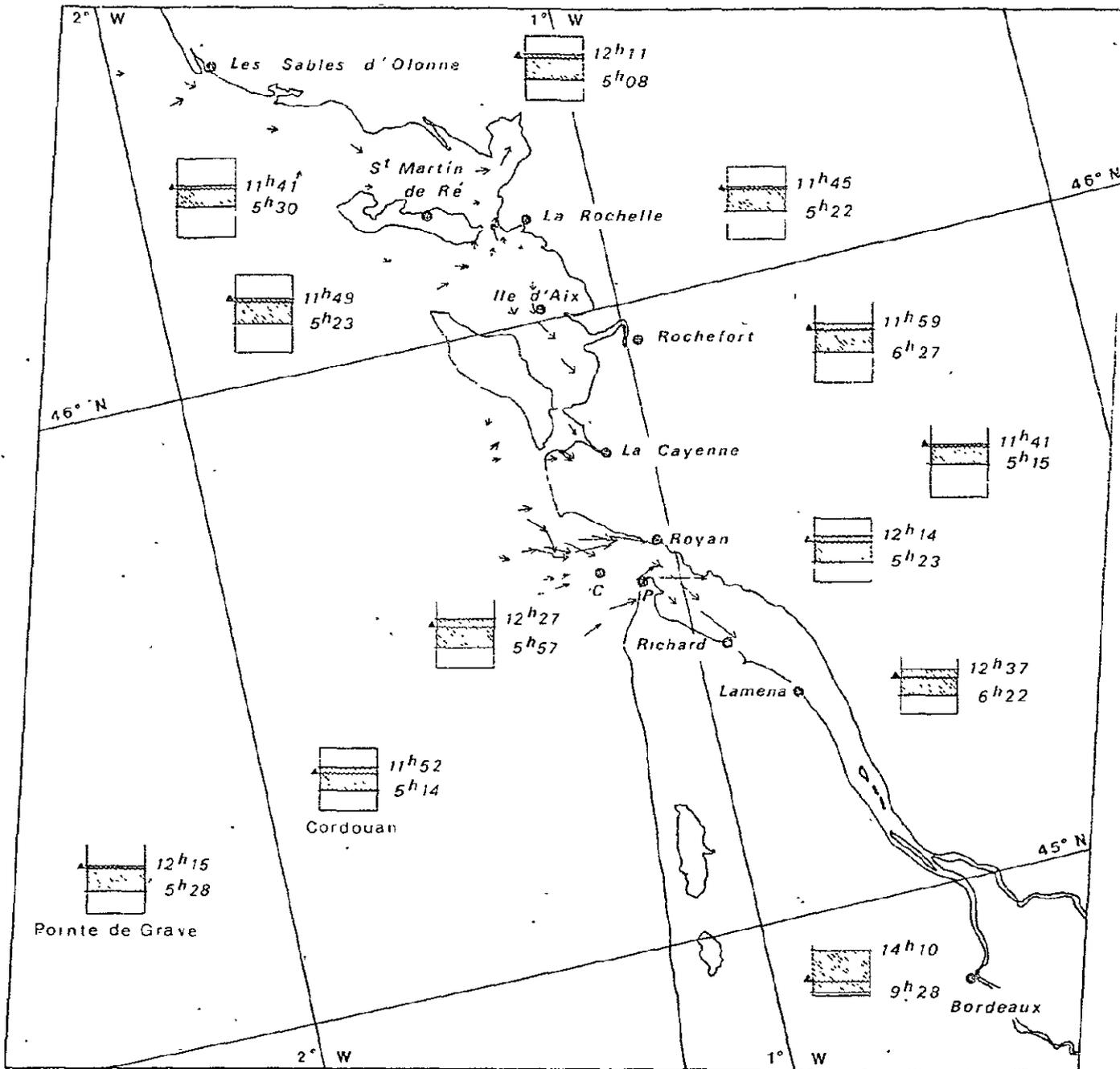
——— 6^h32 pleine mer precedant
 le passage de LANDSAT
 - - - - 14^h34 basse mer suivant

le passage de LANDSAT

courants de marée

Fig. 2.7.13 - Hydrological ground truth data

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Tidal currents (1 cm = 1 m/s)

Tidal range and water level (2 mm = 1 m)

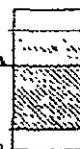
June 4, 1977

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---> S H O M

Maximum high water springs

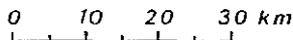
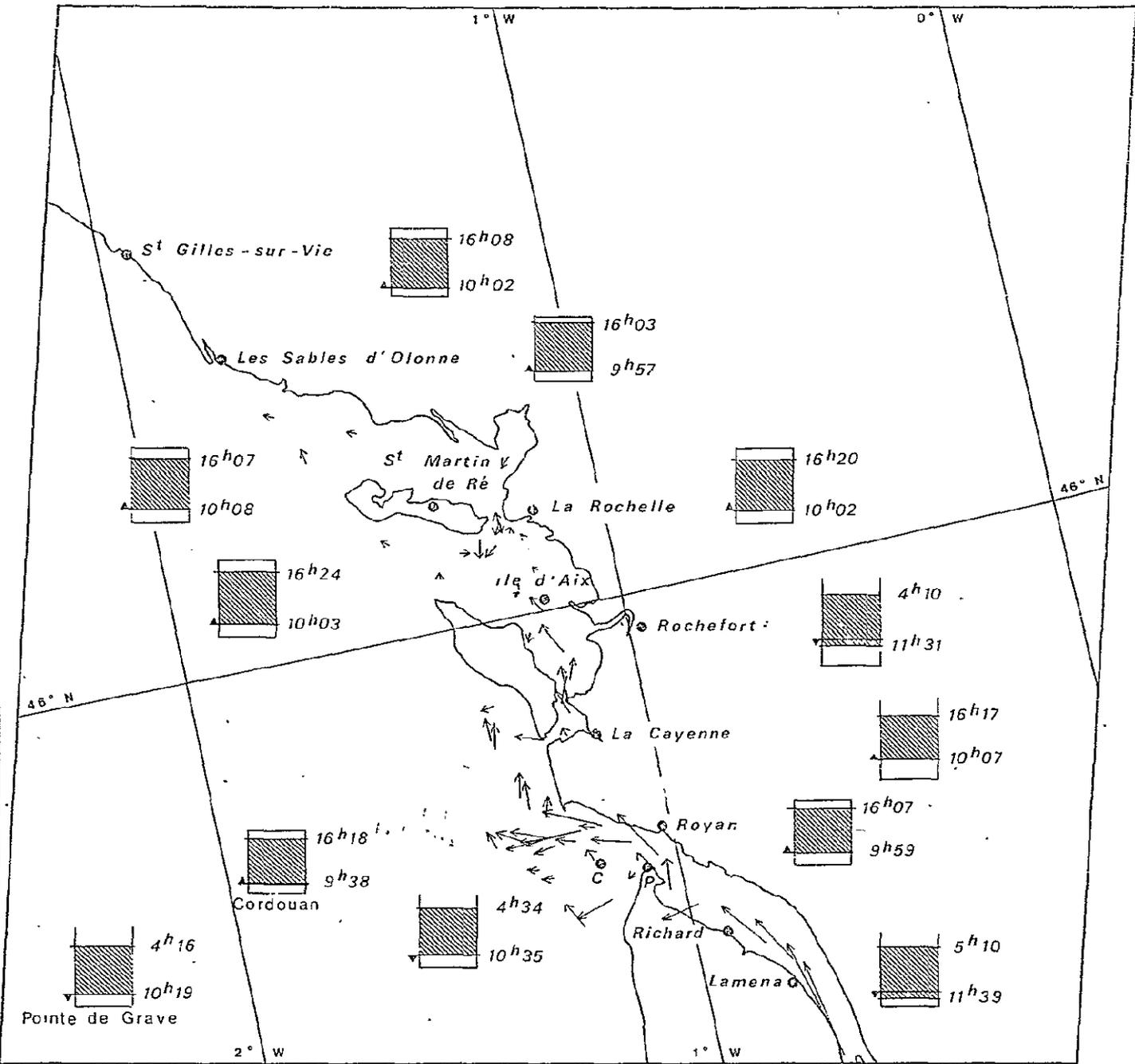
--- falling tide
- - - rising tide



High water
Tide water 10h13
Low water

Chart datum 0

Fig. 2.7.A4 - Hydrological ground truth data



Tidal currents (1 cm = 1 m/s)

Tidal range and water level (2 mm = 1 m)

December 19, 1975

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→ S H O M

Maximum high water springs

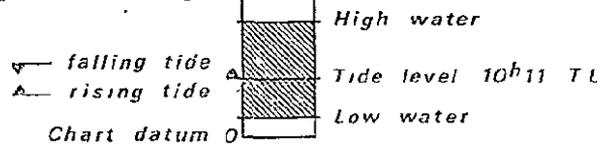
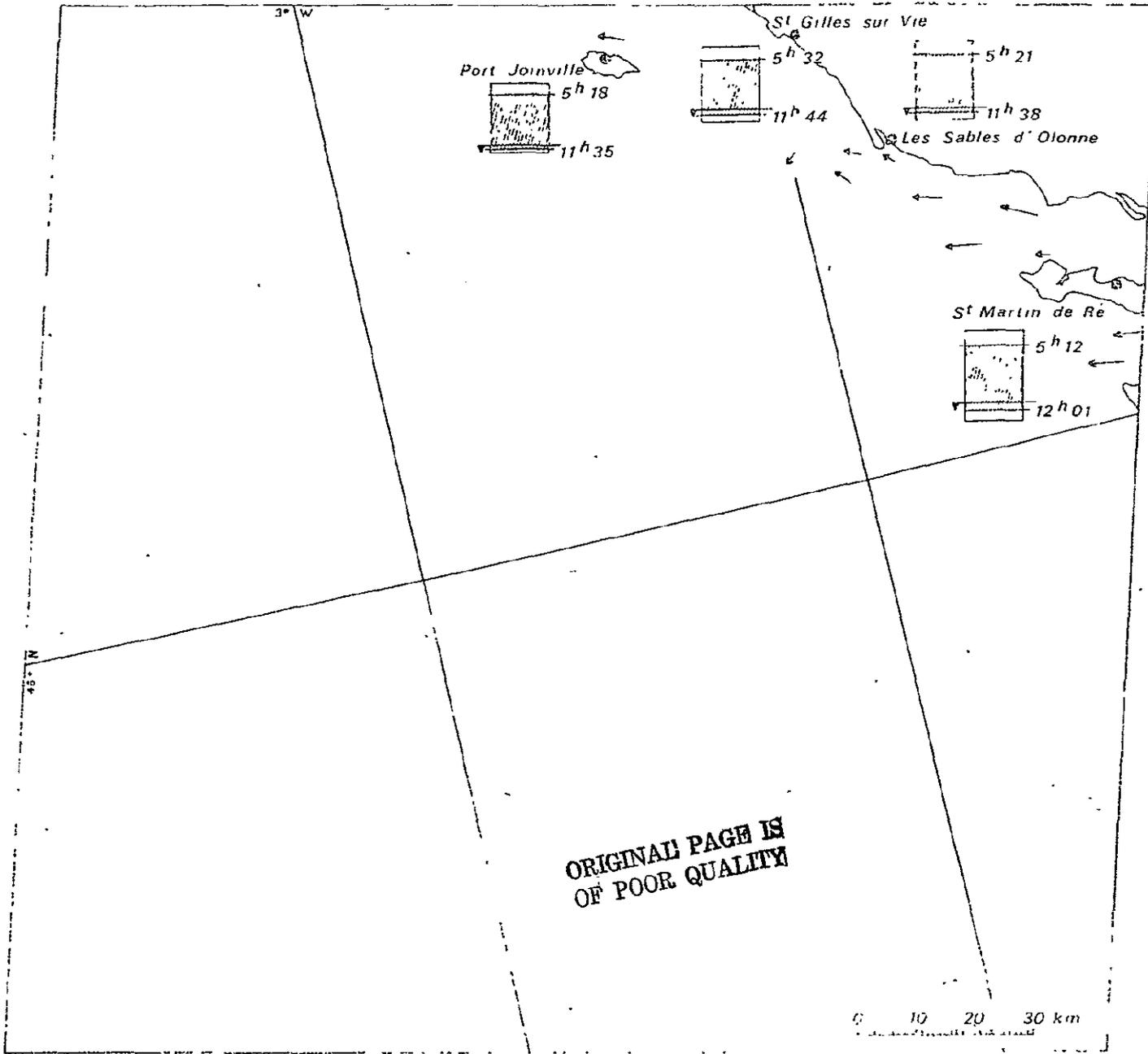


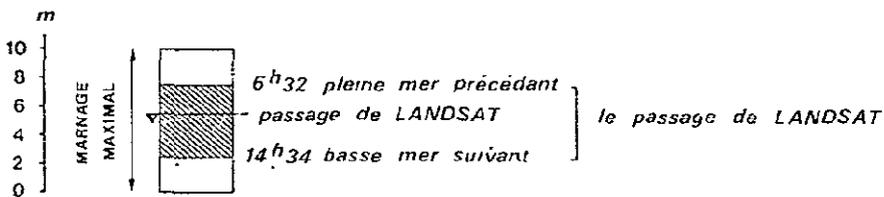
Fig. 2.7.15 - Hydrological ground truth data



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0 10 20 30 km

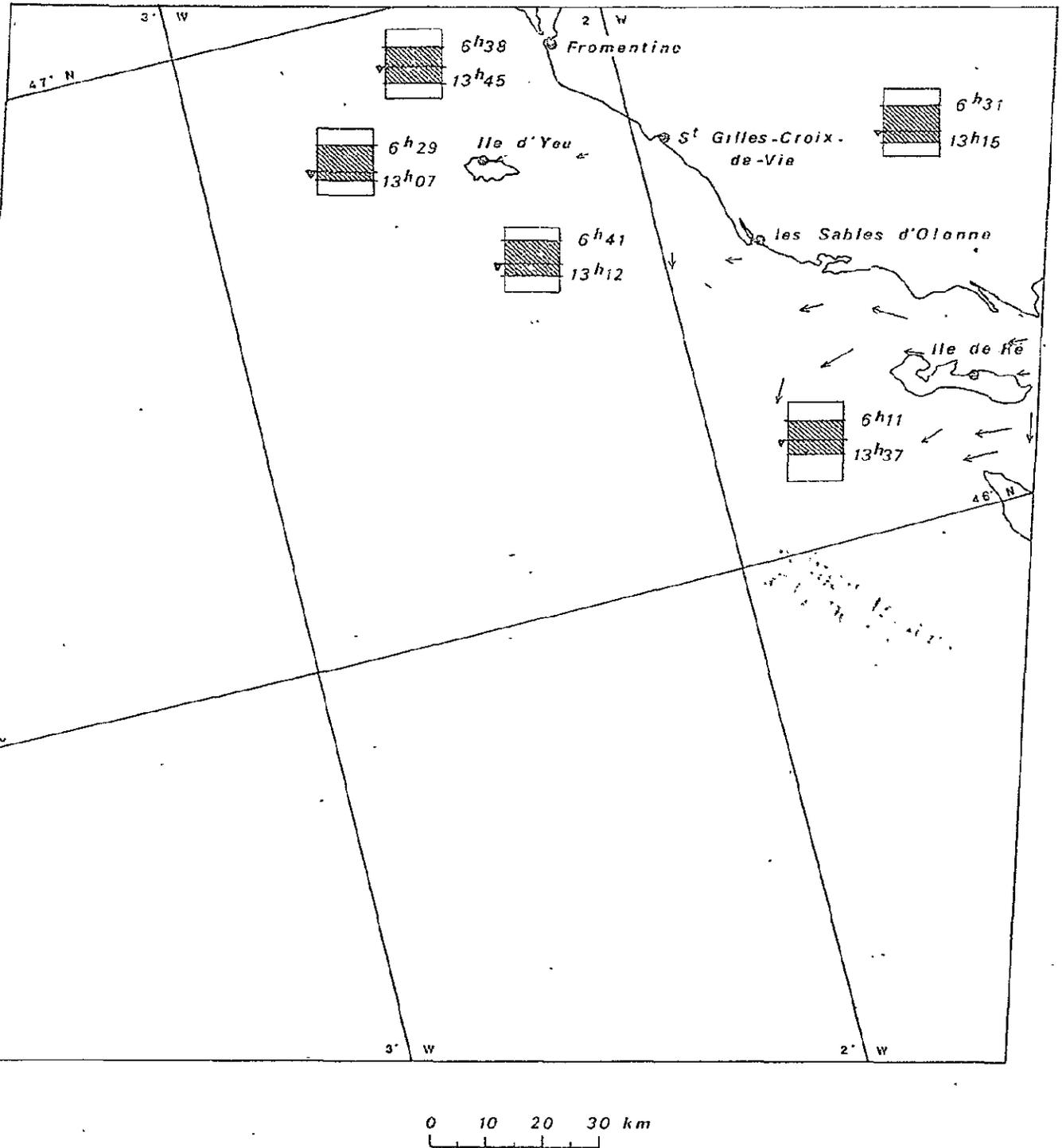
8 mars 1973



courants de marée

0 1 2 m/s

Fig. 2.7.16 - Hydrological ground truth data



Tidal currents (1 cm = 1 m/s)

Tidal range and water level (2 mm = 1m)

July 29 1975

Maximum high water springs

→ S H O M

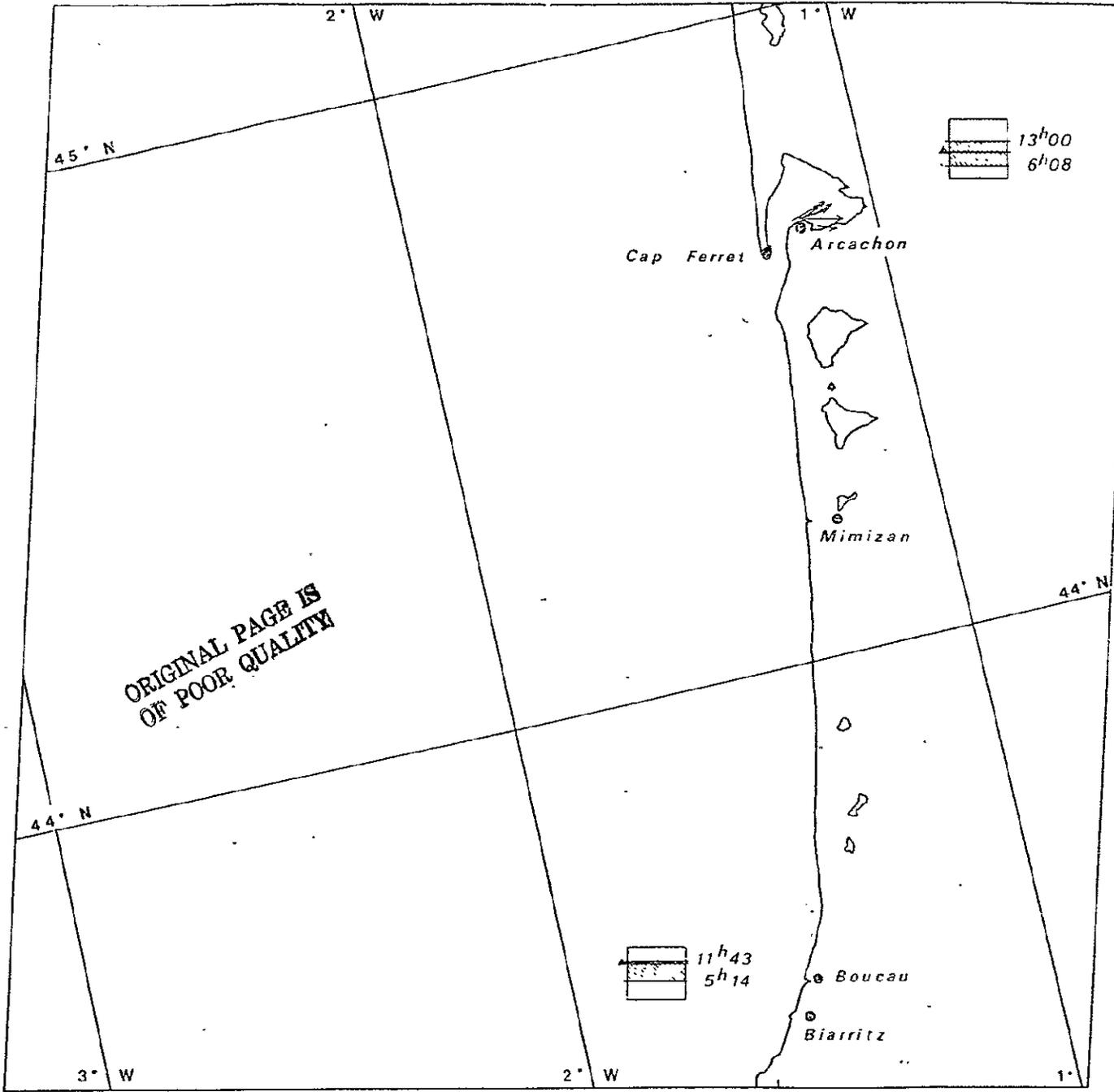
 falling tide
 rising tide



High water
 Tide level 10^h18 TL
 Low water

Chart datum 0

Fig. 2.7.17 - Hydrological ground - truth data.



Tidal currents (1 cm = 1 m/s)

Tidal range and water level (2 mm = 1 m)

June 4, 1975

→ S H O M

Maximum high water springs

∨ falling tide
∧ rising tide



High water

Tide water 10h

Low water

Chart datum 0

Fig. 2.7.18 - Hydrological ground truth data

3 - SIGNIFICANT RESULTS AND ACCOMPLISHMENTS

3. 1 - AN AUTOMATIC CLASSIFICATION OF LANDSAT-2 DIACHRONIC DATA ON THE
FORESHORE OF THE ISLAND OF JERSEY

3. 1.1 - Data description

Landsat-2 data from June 8th 1975 and July 30th 1975 were used to draw up a diachronic (multitemporal) map of the island of Jersey. These two dates were chosen for the differences in tide levels between them. In the first case, satellite overpass took place 20 minutes after low water at St-Helier, and twenty minutes after high water in the second case.

3. 1.2 - Data processing

Diachronic processing requires the overlaying of the two digital images, using significant landmarks identified on single channel imagery as tiepoints. At the end of this step, a single data file is available, where each pixel is characterized by eight different spectral bands (4 bands for each date).

Preliminary to data analysis, radiance histograms in each of the 8 spectral bands are divided into radiance intervals. This subdivision is used in order to generate a binary coding of the original data. When the radiance histogram of a spectral band is unimodal it is divided in isopopulation intervals. However if this distribution is bi or multimodal, a rapid interpretation of the main spectral contrasts allows to interactively adapt the radiance intervals to this situation. This second situation was the case for the MSS7 bands at the two different dates analysed here. The emphasis was put on the contrast existing between sea and land signatures.

After correspondence analysis of coded data using the FRACAM system, a hierarchical classification reveals the similarities existing between spectral bands. The groups of spectral bands thus determined are displayed as nodes of a hierarchical tree structure (dendogram) in Fig. 3.1.A.

The length of each branch of this tree is proportional to the distance between the groups it links. Operator interaction is required for the determination of the maximum group diameter as well as the number of desired groups. This step is followed by an adaptative clustering of radiance spectra leading to a spectral classification.

It is possible to control the results of this classification by displaying the class spectral histograms and spectral statistics. The analysis can then be refined in a layered fashion by reprocessing each class for further subdivision. The present study being mainly related to the tidal flats dynamics, classes 3 and 7 were subdivided in 3 subgroups each.

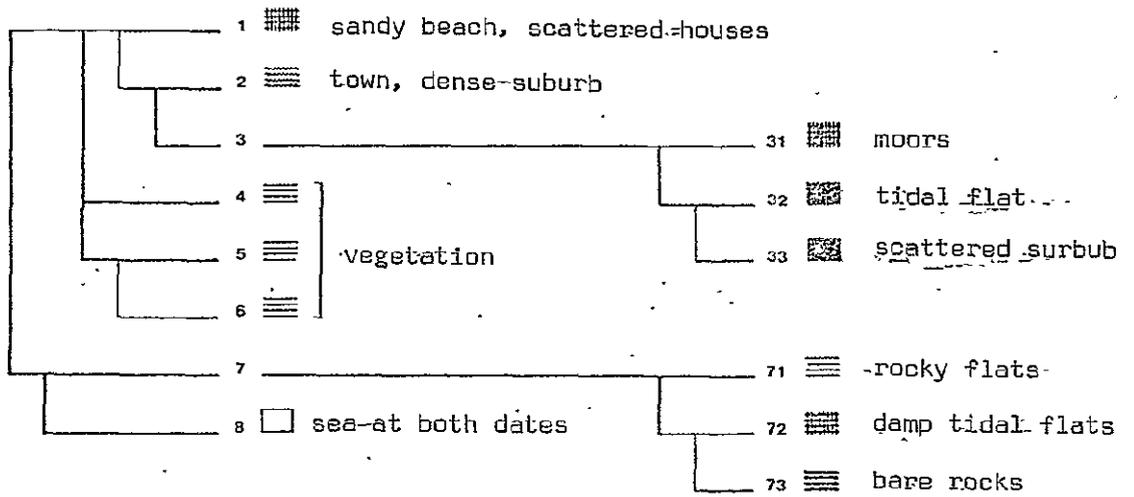


Fig. 3.1.A - Spectral similarity tree between mapped categories

3. 1.3 - Interpretation of classification results

The map legend (Fig. 3.1.B) shows each taxon in its relative position within the hierarchy defined by the classification.

For interpretation purposes, two types of taxons have been defined according to their variability in time. On the whole, taxons with a similar spectral signature at both dates can be opposed to those with strongly varying spectral signature.

a - Categories with low diachronic variation

- . Class 1 shows the upper part of beaches (South and south-east coast) which was not covered by the neap tide of July 30 th. It also borders class 2 and occurs inland, generally, where it shows low-density built-up areas.
- . Class 2 covers the town of St-Helier and the discontinuous urban areas along the South and East coasts.
- . Class 31 occurs along the North coast in moorland. This subset of the vegetation class was individualized during the second stage of classification.
- . Class 33 shows low density built-up areas.
- . Class 4, 5 and 6 are different types of vegetation. The same symbol has been used to map them because of the lack of appropriate ground-truth data for accurate interpretation.
- . Class 71 represents bare rock, in the cliffs to the North East of the island, and in the new harbour area under construction southward of St-Helier.
- . Finally class 8 is an example of "false stability" in time since it shows areas which were covered by the sea at both dates.

b - Categories with strong diachronic variation

These are mostly foreshore areas, with a land-type spectral signature at low tide and a sea-type signature at high tide. At the first level of classification, the foreshore was defined by class 3 and 7, but some of their subclasses are in fact land area as mentioned above.

Class 31 and 72 show different moisture levels ideally illustrated in St-Aubin's bay where class 1, 31 and 72 occur in sequence between the high and low tide marks.

Class 71 covers the emerged parts of the rocky shoals south-east of the island.

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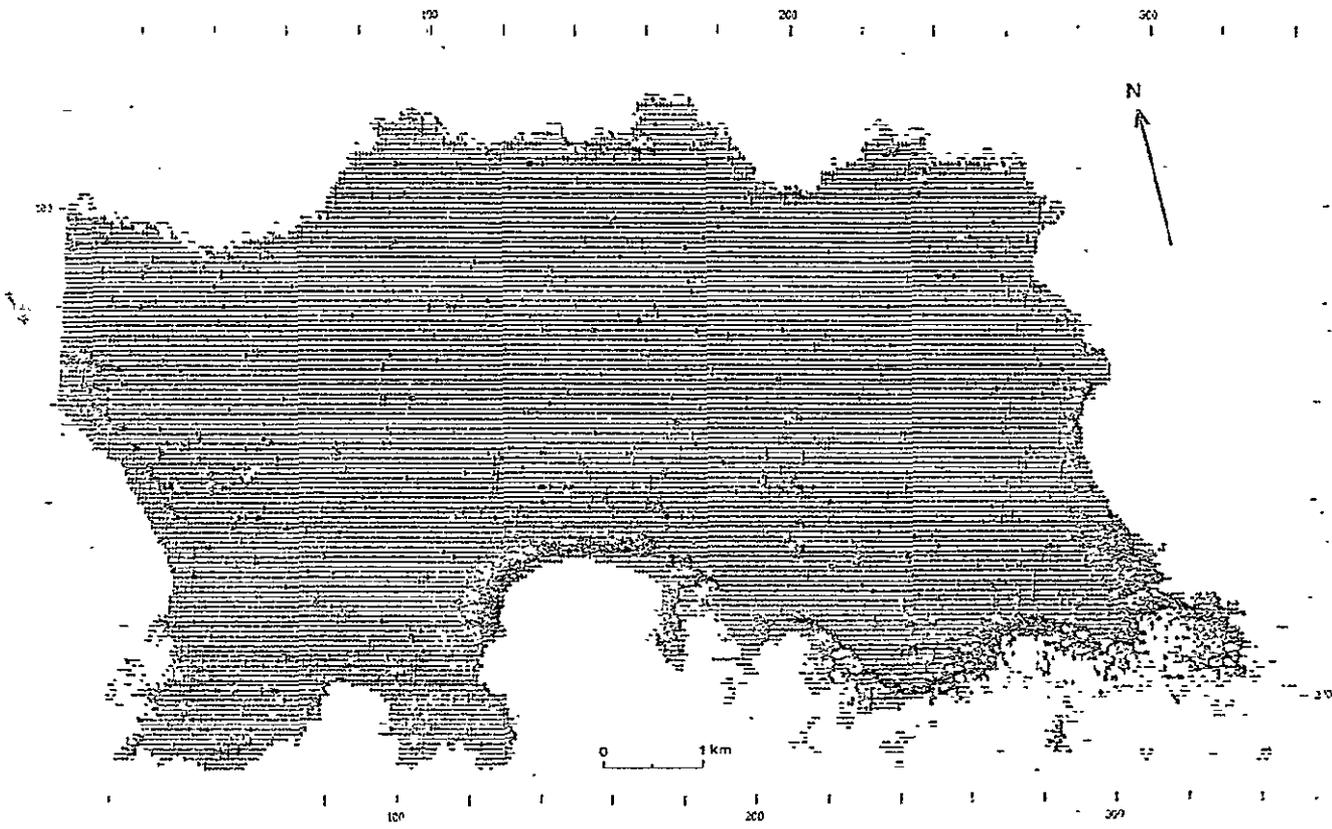


Fig. 3.1.B - Automatic diachronic classification of Jersey island using LANDSAT-2

3. 1.4 - Critics

The diachronic classification used for this study has both the simplicity and rapidity of implementation of post assisted automatic classification, and the good identification obtained by diachronic techniques. For observation of rapidly changing terrain types such as the foreshore, diachronic techniques make the best possible use of the repetitivity and fairly good geometric repeatability of satellite remotely sensed data.

C-2

3. 2 - INTERPRETATION OF LANDSAT DATA ON THE LANDWARD PART OF THE FROMENTINE TEST AREA

3. 2.1 - Data description

Data analysed on the Fromentine test area are related to the following dates of overpass :

| | | | |
|-------------------|------|-----------|-----------|
| 27 September 1972 | - | LANDSAT 1 | - |
| 11 July | 1973 | - | LANDSAT 1 |
| 29 July | 1975 | - | LANDSAT 2 |

3. 2.2 - Data processing

The Fromentine test area has been analysed using various analysis techniques described in part 2 (Cf 2-2 to 2-5). The results presented were respectively related to the following dates : 27 September 1972 (cf. 2-3), 11 July 1973 (cf 2-4) and 29 July 1975 (cf 2-2 and 2-5).

3. 2.3 - Interpretation of results before classification smoothing

The interpretation is restricted to the landward part of the Fromentine area including the sand beaches which are often difficult to spectrally separate from the barren coastal dunes in the southern part of Noirmoutier island as well as along the Breton marsh.

Comparisons are made between results more than between processing methods because they usually depend upon the quality of operator assistance. This parameter has obviously improved in time with the knowledge acquired by the FRALIT team on the test area.

A certain number of conclusions can be drawn :

- a - All methods of classification easily separate water from land categories
- b - All methods of classification map relatively abundant sand formations which present high radiances for the whole set of MSS spectral bands. Their spectral separation is usually the best (cf. 2-3, AGREG). This category is associated to barren sands, sandy bars and various open spaces with varying proportion of buildings and sands.
- c - The various classification techniques are usually successful in the separation of the maritime pine forest (Monts forest)
 - . The FRACARTE classification (Fig. 2.2.C, 29 July 1975) maps in category 8 the well outlined forest area as well as polders which were taken over by the sea.
 - . The AGREG classification (Fig. 2.3.D, 27 September 1972) displays a restricted and homogeneous forested area (category 8). Certain parts of the forest under peculiar stress condition have been omitted but on the average the recognition of the Monts forest by this classification is excellent.

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. The FRACAM classification (Fig. 2.4.N, 11 July 1975) splits the forest into two parts ;

31 to which are associated the low parts of the old Grande Prise polder and a part of the Monts forest ;

and 33 where an other part of the Monts forest is displayed

A FRACAM classification of another date (29 July 1975) is presented in Fig. 3.2.A. It also points out a division of the Monts forest into two parts. The first symbol is related to a dense stand of maritime pines which comprises numerous young trees along the Monts coastline or older patches of wealthy trees. It is this denser part of the forest which is associated to the old Grande Prise polder taken over by the sea. This confusion is due to the fact that the spectral signatures of those two types of objects are quasi identical (cf. 2.2.B).

Could it be that the use of a multitemporal approach would eliminate this ambiguity which is present for the LANDSAT scenes of 11 July 1973 and 29 July 1975 ? This similarity between spectral signatures of otherwise distinct types of objects makes their possible separation a difficult task, in particular when this confusion can be repeated in the data of distinct dates (11 July 1973 and 25 July 1975). The use of diachronic data could save this problem if for instance one of the survey dates would correspond to the flood of a very high tide (which is impossible due to the time periodicity of LANDSAT coverage) or the period following the uncovering of old polder by the sea. In this second type of situation the presence of water in one of the environments (old polder) associated to its absence in the other one (forest) would help in order to perform a successful separation.

d. - The other types of land use are mapped with a varying amount of success by the various classifications. We will only compare the results obtained for the 29 July 1975 by FRACARTE (cf 2.2.C) and FRACAM (Fig 3.2.A).

One remark has to be done before any interpretation. The mapping of agriculture areas was not undertaken in full detail during preassistance of FRACARTE. Motivations of the operator were biased by a coastal mapping approach so that more details were sought in tidal flats or ocean waters than in the vegetated marshes. On the contrary the operator while performing the FRACAM coassistance phase is taking into account the spectral statistics of the data more than the "a priori" nature of the environments to be mapped.

For the FRACARTE classification two symbols only are associated to the marsh land use type.

- symbol 9 is related to psammophyte dune cover, most of the marsh pastures as well as some of the cultivated fields of Noirmoutier island and the Breton marsh ;

- symbol 10 represents essentially cultivated areas as well as some grass pastures.

On the contrary, the FRACAM classification results propose six different categories on the marsh :

- symbol 3 : cultivated areas (mostly on the rim of the Monts forest) ;
- symbol 4 : partially built open spaces (Fromentine, the Barre de Monts pier, La Fosse) ;
- symbol 6 : psammophyte covered dunes, marsh pastures ;
- symbol 7 : cultures with small plant canopy cover most on sandy soils ;
- symbol 8 : vegetation along drainage ditches and canal
- symbol 9 : lower parts of polders taken over by the sea

3. 2.4 - Interpretation of results after classification smoothing

We will compare the mapping results of the raw and smoothed FRACAM classification of the 29 July 1975 data set. Cartograph improvements due to classification smoothing will be assessed (Table - 3.2.B).

a - Common properties to the two types of smoothing

It is noticeable that conditional and majority vote smoothing algorithms have the common property to suppress artificial categories generated by the classification processes at the boundary between two types of well contrasted objects. Symbol 5, for example, is mostly representative of muddy tidal flats but it has been introduced as an artefact along the seaward part of the Monts forest sandy coast (Fig 3.2). This misclassification can be eliminated by each of the smoothing algorithms working on "clean" categories such as the sandy beach (12) and the turbid part of the sea water

In the Noirmoutier island, the Trou de Sebastopol (lines 24 to 25, columns 5 to 6 in Fig 3.2.A) is partially stable under a two iterations conditional smoothing. The pixels of this water pool take very low values in MSS7 which are very different from those taken by the surrounding pixels. This spectral discontinuity insures the stability of the Trou de Sebastopol pixels through conditional smoothing because the process is more influenced by spectral contrasts than by the relative geographic position of the pixels (Fig 2.2.E). The pool can still be outlined after a simple majority vote smoothing (Fig 2.2.C) but if this type of algorithm is iterated, the Trou de Sebastopol can no longer be identified because it is merged with the nearby ocean surface (Fig 2.2.D). This confusion is due to the suppression of the polder ditch which separates the pool from the Bourgneuf Bay. Majority vote rule does in fact drastically alter linear shaped objects like ditches, canals, piers, bridges ...

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Cultivated plots represented by two symbol 3 (ligne 99 and columns 111 to 112, for example) are surrounded by symbol 4 pixels in Fig 3.2.A (unsmoothed classification).

Those plots are left untouched by a two iterations conditional smoothing due to the fact that their spectral individuality is good and their shape is not too similar to horizontal striping artefacts (Fig 2.2.E). On the contrary, the presence of category 6 on the lines 98 and 100 causes the removal of those isolated plots at the first iteration of the majority vote smoothing process (Fig 2.2.C).

b - Differences between properties of the two smoothing algorithms

Conditional smoothing results are usually different from those of the majority-vote algorithm, even if both of them succeed in suppressing most of the "artificial" category assignments.

The numerous isolated singularities which are present in our landscapes, often influenced by human activities, are usually unaltered by conditional smoothing. This is the case of small entities such as : the Trou de Sebastopol pool, the small clear cuts of the Monts forest, the cultivated plots scattered in the pastured marsh and associated to farm buildings, pastures intermixed with the fields along the rim of the Monts forest, small pools of the active or abandoned salt mills.

The majority vote smoothing, on the contrary, has a trend towards strong generalizations. It is more suited to the enhancement of global contrast such as the one which separate the forest into two parts. The specific land use pattern along the forest rim, mixing cultivated fields and houses, is also well outlined by majority vote (Fig 2.2.D).

Each of the two smoothing algorithms has particular advantages and drawbacks, they should be selected in relation to the type of geographical theme to be studied.

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CLASSIFICATION AUTOMATIQUE A CO-ASSISTANCE SPECTRALE ET POST-ASSISTANCE TAXONOMIQUE

100

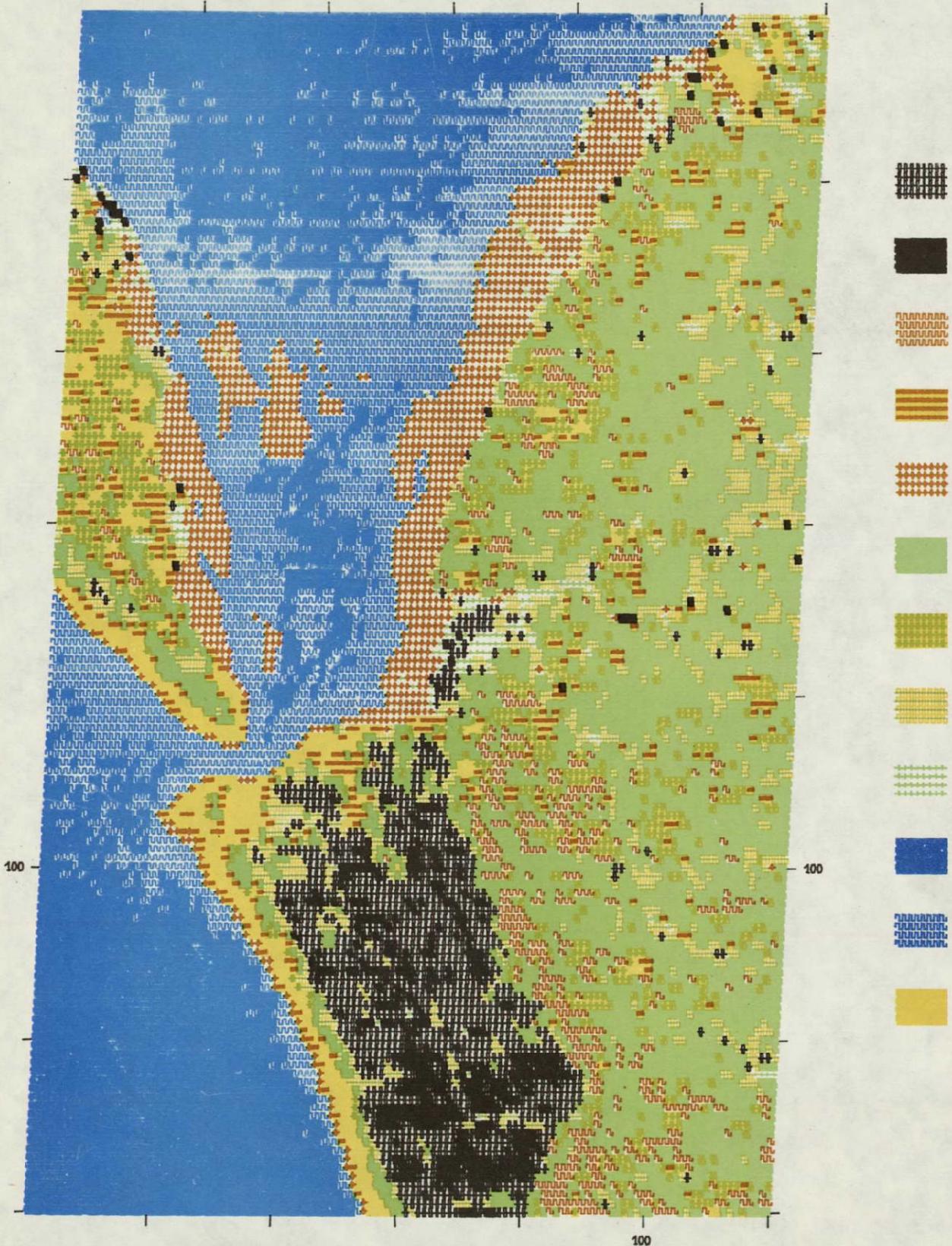


Fig. 3.2.A. - FRACAM Classification display of the Fromentine area for the 29 July 1975

FRACAM classification (29 July 1975)

| symbol n° | no Smoothing | With FRACARTO smoothing | | |
|--------------|--------------------------------|-------------------------|------------|-------------|
| | FRACARTO mapping program | Majority vote | | Conditional |
| | | simple | itérated | |
| | Fig. 3.2.A | Fig. 2.2.C | Fig. 2.2.D | Fig. 2.2.E |
| 1 | 1 095 | 1 236 | 1 303 | 1 124 |
| 2 | 433 | 298 | 258 | 390 |
| 3 | 614 | 472 | 446 | 541 |
| 4 | 472 | 205 | 146 | 330 |
| 5 | 1 251 | 1 260 | 1 264 | 1 247 |
| 6 | 3 928 | 4 612 | 4 864 | 4 068 |
| 7 | 967 | 733 | 665 | 879 |
| 8 | 1 038 | 651 | 501 | 875 |
| 9 | 236 | 163 | 145 | 165 |
| 10 | 3 330 | 3 180 | 3 200 | 3 170 |
| 11 | 2 939 | 2 920 | 2 923 | 2 941 |
| 12 | 497 | 554 | 569 | 554 |
| Total | 16 800 | 16 284 | 16 284 | 16 284 |

Table 3.2.B - Number of pixels pertaining to each category

When smoothing data, a rim of pixels is lost
along each sides of the processed area

3.3 - INTERPRETATION OF LANDSAT DATA COVERING THE LOIRE ESTUARY

An accurate knowledge of the position of sandbanks in the Loire estuary (Fig. 3.3.A) is essential for navigation up to the major harbour at Nantes - St Nazaire and the new docks at Donges (10 km upriver). Navigable channels are frequently dredged to maintain a constant depth. Outside these channels the shallows silt up continuously. This is most apparent off Paimboeuf where low tides uncover numerous sandbanks, visible on charts and survey maps. Extension and location of these banks varies considerably according to map type and date. There are three main causes for these variations :

- The banks have very weak slopes and a 10 cm error in soundings or levelling can lead to tens of meters in planimetric error.
- The nature of these banks (mud or sand) makes accurate bathymetric or topographic measurement practically impossible.
- The combined action of currents, waves and estuaire sediment transport is constantly modifying the size and shape of each bank. These actions can be very rapid, especially during a storm.

The long and costly depth-sounding missions are not very frequent. Surveys were carried out by the Port of Nantes - St Nazaire harbour authority in 1969 (resulting in a 1/25 000 scale map) and in 1976-77.

Aerial surveys are also fairly infrequent, and are merely used for updating terrestrial topographical maps.

Knowledge of sandbank movements is thus very inaccurate and is mostly based on word-of-mouth reports from local fishermen who describe the difficulties encountered in their navigation and the new channels they occasionally find.

3.3.1 - Landsat imagery used in this study

Technical conditions seemed to be ideally suited for an application of satellite imagery to see if this was adapted to sandbank monitoring.

The following table shows the images used and the corresponding tidal height.

| Figure number | Date | Source | Tide height (meters) | Cycle |
|---------------|---------------|----------|----------------------|-------|
| Fig. 3.3.D | Sept. 27 1972 | NASA | 2.37 | EBB |
| E | March 8 1973 | " | 1.44 | EBB |
| F | July 29 1975 | " | 3.18 | EBB |
| G | March 28 1976 | Telespa- | 1.46 | FLOW |
| H | June 26 1976 | zio " | 1.55 | FLOW |

Two other images were available covering this area but were not used because of their high tide level (over 4 meters).

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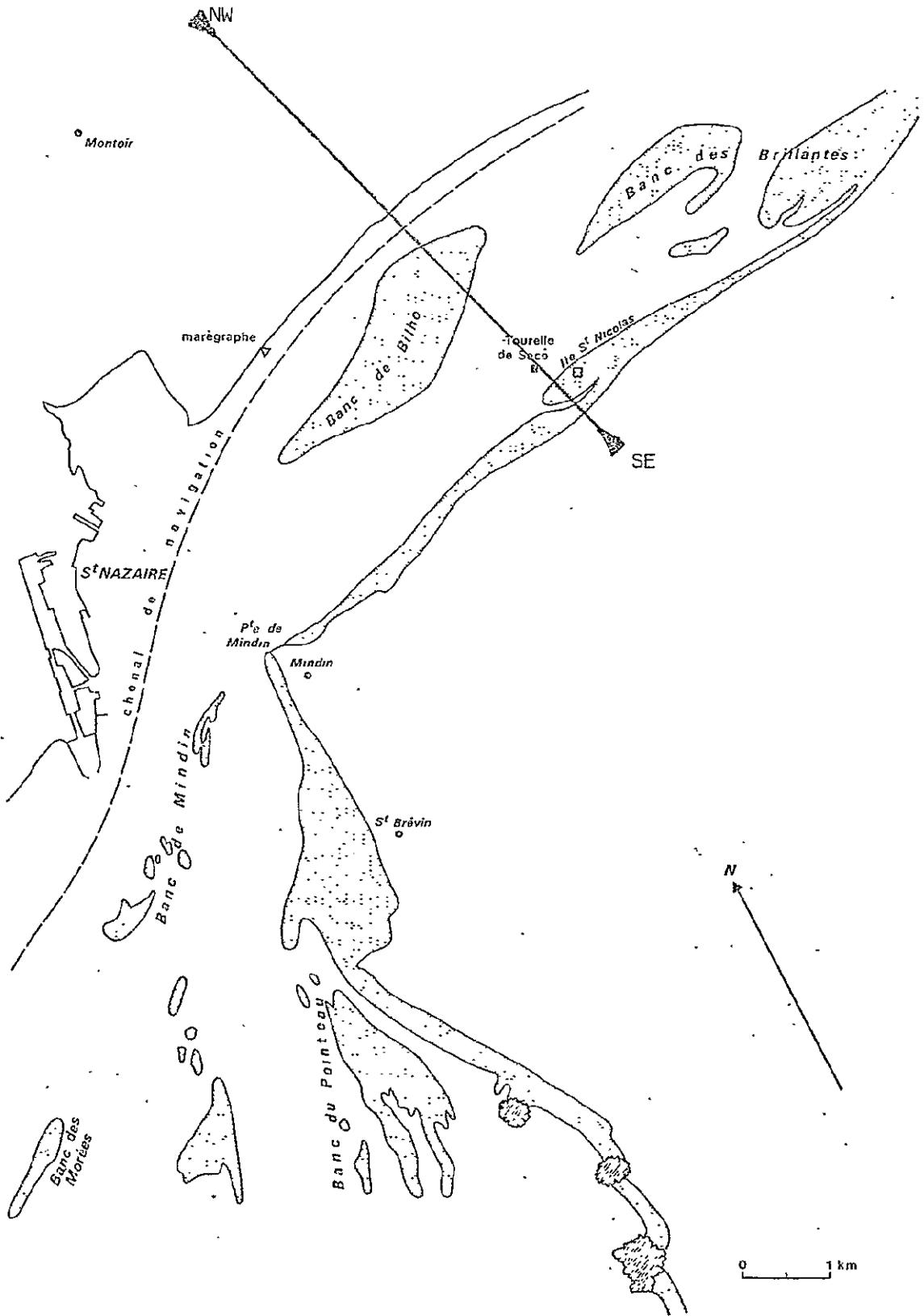


Fig. 3.3.A - The Loire estuary. Location of transect cutting through The Banc de Bilho is indicated

3. 3.2 - Data processing in relation to local conditions of interpretation

Interpretation of the maps shown here is not straightforward

- a - Three of the images show an ebb tide. This situation is characterized by powerful seaward currents with a heavy sediment load which is largely carried out to sea. These currents sweep the shallows and raise most of their fine sediment cover. It is therefore fairly difficult to distinguish the actual sandbanks from turbid water.

The flow tide which predominates on the remaining two images brings clear oceanic water into the estuary and the banks are then clearly distinguishable.

Four transects (Fig. 3.3.B and 3.3.C) have been drawn up near the Banc de Bilho : two show ebb tides with Nasa-type digital values (5 to 8 in MSS7 for emerged banks) and two flow tides with Telespazio digital values (20 to 40 MSS7 for emerged banks). In both situations, the distinction between banks and water is easiest when the river outflow is lowest. During the low discharge periods, the estuarine turbidity area does not extend this far down channel whereas in flood periods this turbid area extends further seaward.

- b - The part of the river between the port of St Nazaire and the new docks at Donges is heavily industrialised. Aerial pollution is occasionally blown over the study area (cf Fig. 3.3.F) and has a similar spectral signature to sandbanks. This can lead to certain misclassification. Urban areas are also misclassified but their known position does not hinder interpretation.
- c - Finally, the most difficult element of misclassification is the quasi-identical signature of turbid water and sandbanks. Fig. 3.3.E shows a long turbidity plume near Mindin Point, developed in the same direction as the current. This is probably connected with the drilling operations in progress then for the construction of a bridge across the estuary at St Nazaire. There is a second, lighter, plume to the north, where drilling was less advanced. The muddy waters move alternately up and downstream with the tides.

3. 3.3 - Significant results on the evolution of the sandbanks

Observed variations cannot be accurately measured due to the differences in sea level between satellite overpass (1.74 to 0.0 meters) : pixel size is not compatible with this type of scene variation.

- a - Overall evolution from 1972 to 1976 : Throughout this period at similar tide levels, the banks reduce in area. The two high river discharge images (3.3.E and 3.3.G) show over a two year period an identical outline for the Bilho bank to seaward whereas upstream the bank has receded in same time to a line joining Paimboeuf to Montoir. The Brillantes bank has receded at both ends, partly because of dredging operations in the access channel to Donges harbour.

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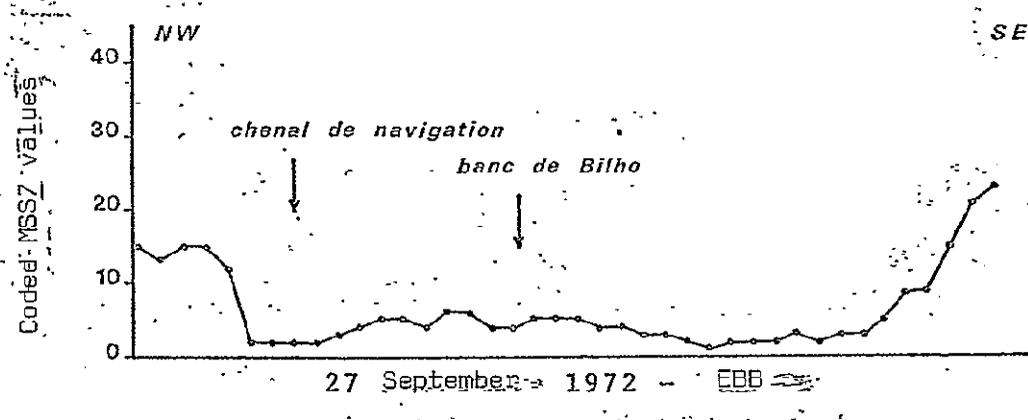
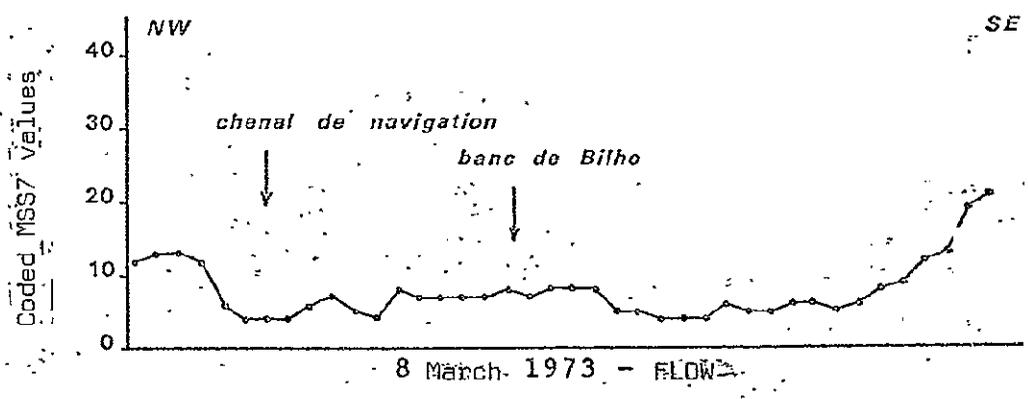


Fig. 3.3.B - Radiometric transects cutting through the Banc de Bilho. LANDSAT-1 data received from NASA

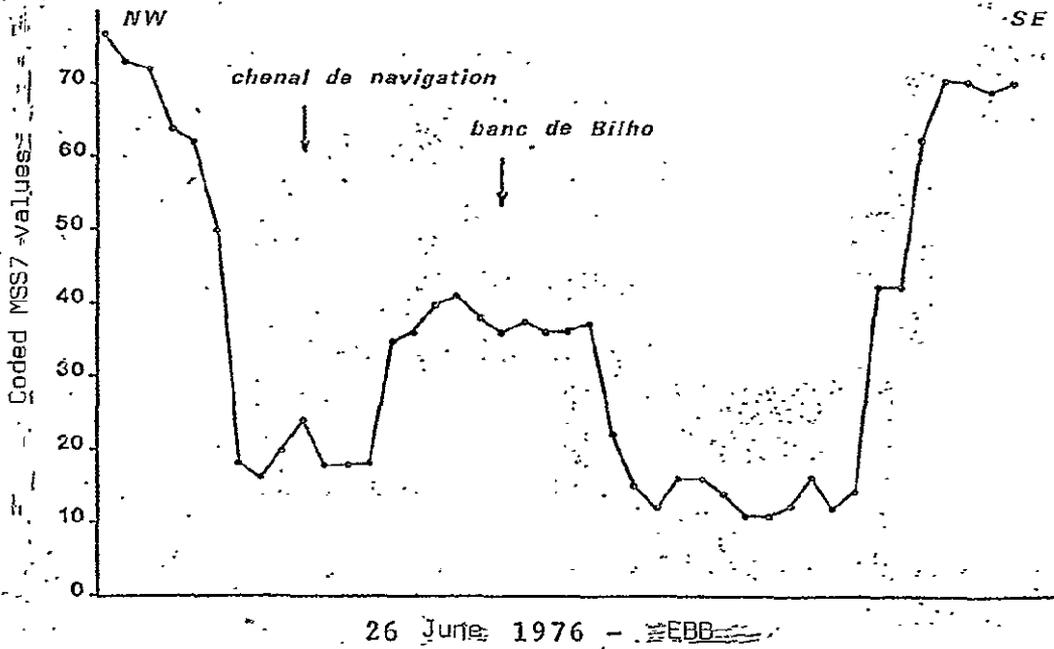
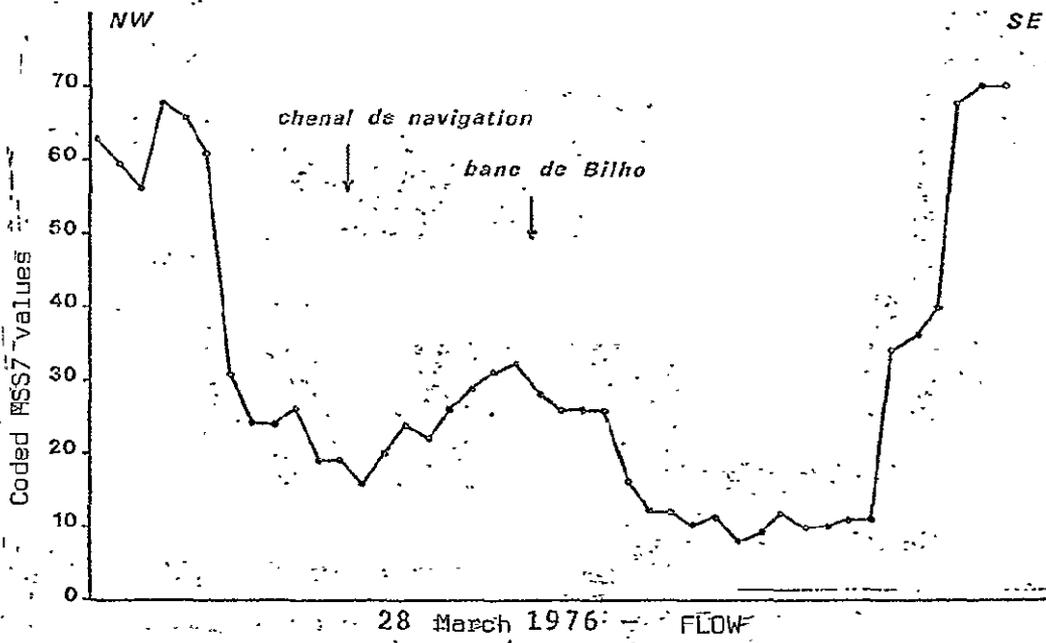


Fig. 3.3.C - Radiometric transects cutting through the Banc de Bilho. LANDSAT-1 data received from TELESPIAZIO

The Mindin bank, clearly visible in 1973, has almost disappeared in 1976 where it is obscured by smoke from the St Nazaire area. The St Brevin bank, extensive and separate from the coast in 1973, is not apparent in 1976. Finally the Pointeau bank with its typical y-shape is considerably reduced in 1976. Thus the overall picture is an erosion of all the banks between 1973 and 1976.

The three low river discharge images confirm this interpretation especially since the water level is lowest at the time of the most recent image : Bilho and Brillantes banks are truncated to the north, Pointeau bank is thinned out and St Brevin bank has disappeared.

b - Seasonal variations

A seasonal cycle can be distinguished between the March images on one hand and the June and July ones on the other.

- . The Bilho bank is seasonally stable, with little or no variation in its outline but the highest points of this bank (darkest tone on the maps) move fairly regularly upstream from March to September. Remarkably, one of the culminating points in the March imagery (Fig 3.3.E and 3.3.G), located farthest downstream, disappears completely in the other images.

The St Brevin bank is well separated from the coast in 1972 (Fig 3.3.D), and only linked to the coast at Mindin Point. During the winter, the whole bank moves nearer the shore and increases in height at both ends (Fig. 3.3.E). In March 1976 (Fig. 3.3.G) the remaining part of the bank is up against the coastline for most of its length. In June 1976 (Fig. 3.3.H) the bank is practically indistinguishable from the coastline. It appears, thus, that this bank is generally further offshore in the springtime than in the summer.

- . The Pointeau bank forks into branches in the spring (3 in 1973 : Fig 3.3.E, 2 in 1976 : Fig 3.3.G) beginning at the Pointeau point and apparently modelled by currents. In June these branches are assembled into a triangular shape and in September a single curved ridge remains, probably reworked by the swells which strike it head-on.

- c - Possible causes for these variations. For the three banks which show a seasonal evolution (Bilho, St Brevin, Pointeau) the spring state is conditioned by the geomorphological action of ebb-tide currents. The banks are stretched downstream into divergent branches in the outer estuary. In the inner estuary, the banks move downstream where they are built up to a peak. Conversely in the summertime, when river discharge is reduced, wave influence is predominant and the banks are moved inshore and their outline is simplified, occasionally concave seaward. The banks of the inner estuary move back upstream and their situation is stabilised until the next spring floods.

3. 3.4 - Conclusion

Long term evolution of the Loire river sandbanks has been evidenced despite the scarcity of available imagery. Possible explanations have been proposed for the evolution but they can only be confirmed by use of more frequent data covering other periods than spring or summertime.

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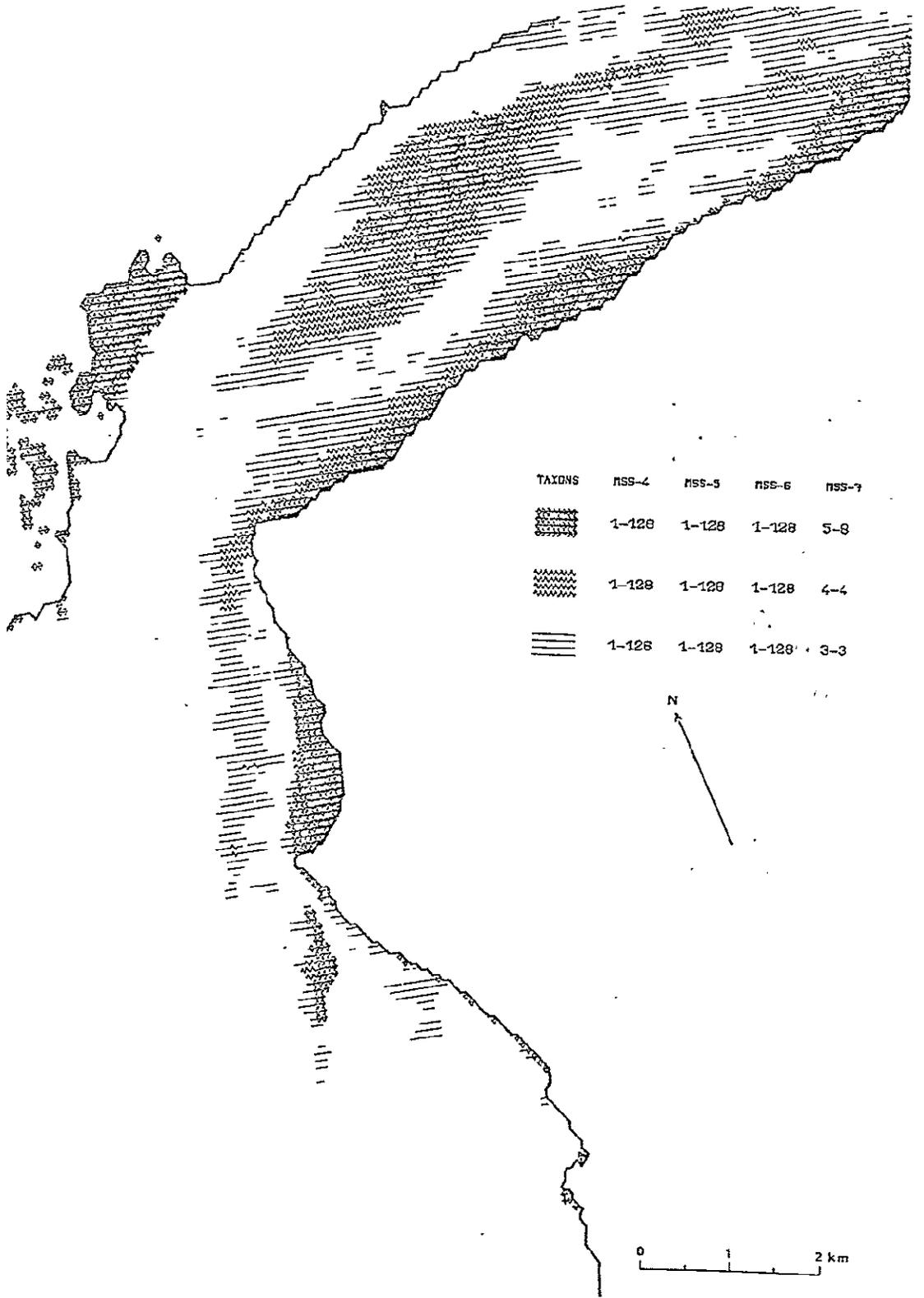


Fig. 3.3.D - Cartography of Sandbanks from LANDSAT
(Sept 27 1972)

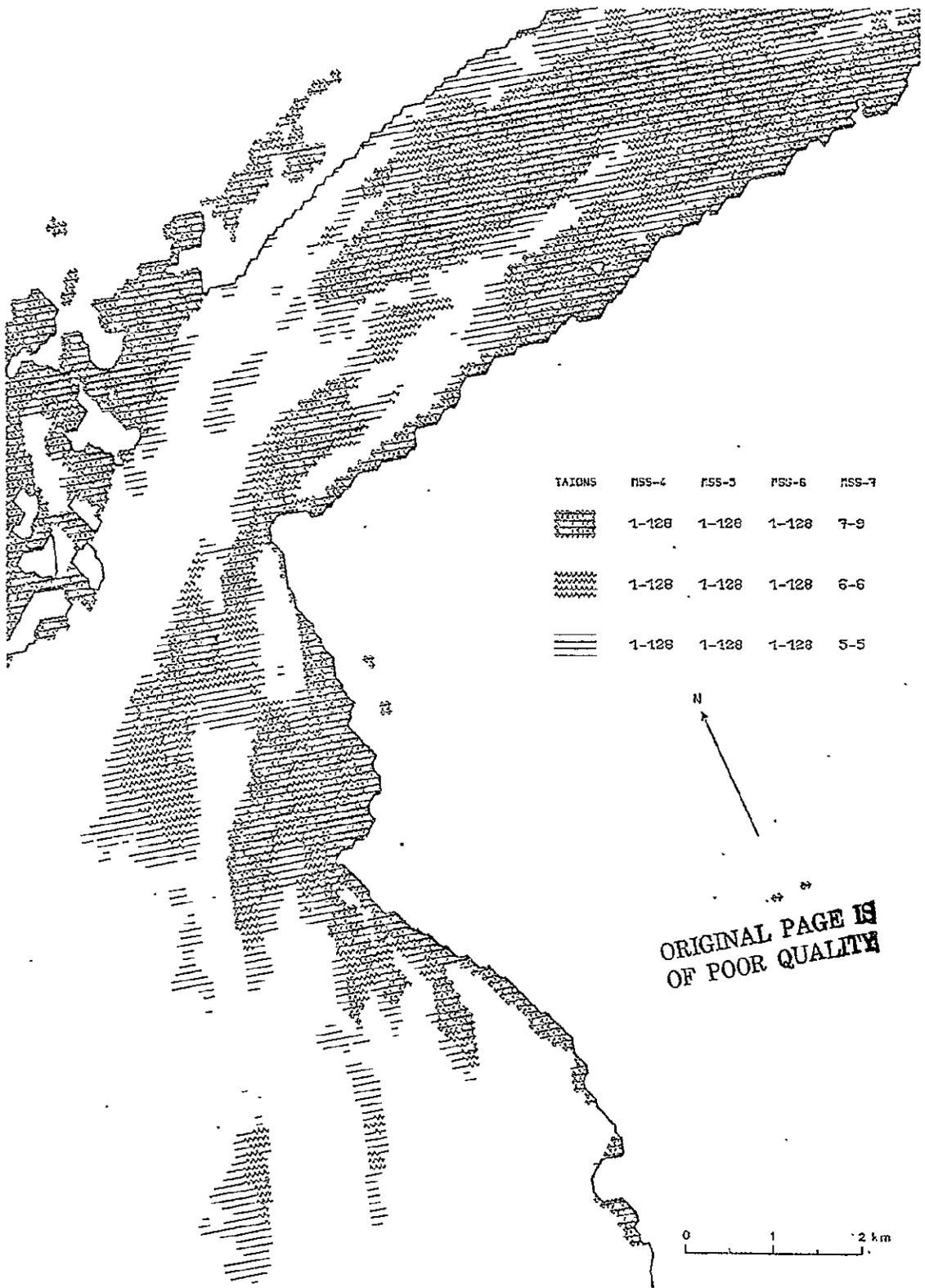


Fig. 3.3.E - Cartography of sandbanks from LANDSAT
(March 8 1973)

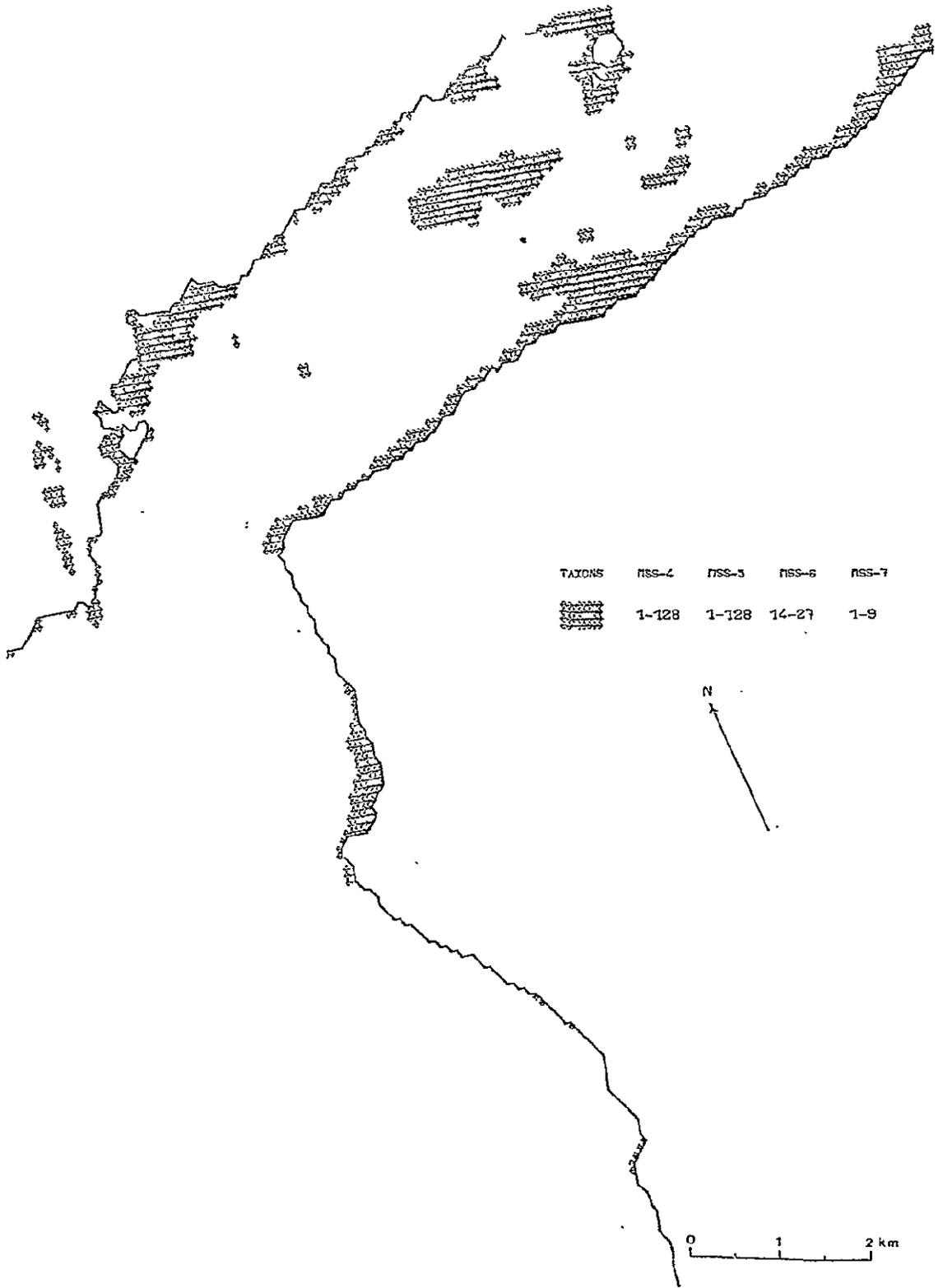


Fig. 3.3.F. - Cartography of sandbanks from LANDSAT
(July 29 1975)

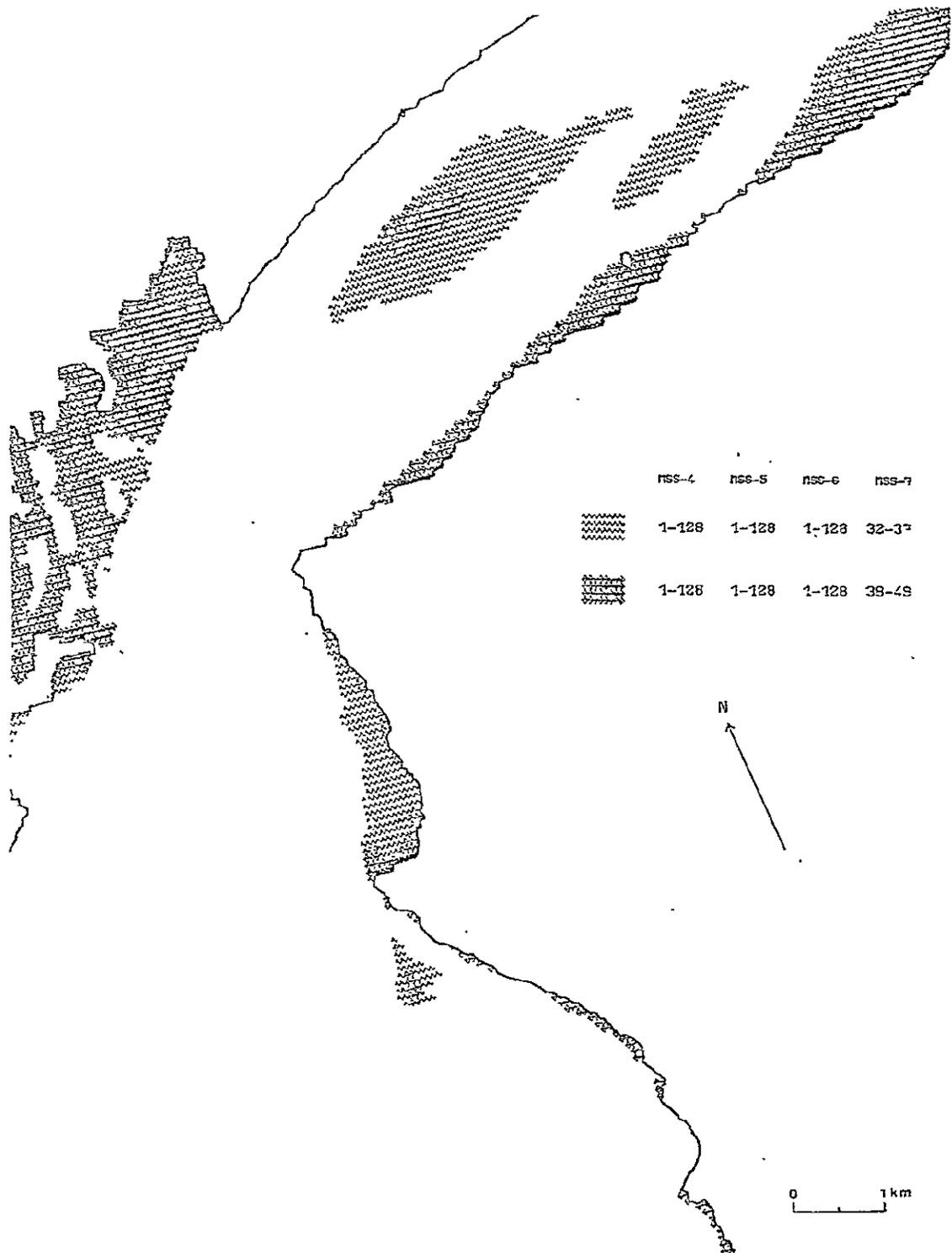


Fig. 3.3.6 - Cartography of sandbanks from LANDSAT
(March 18 1976)

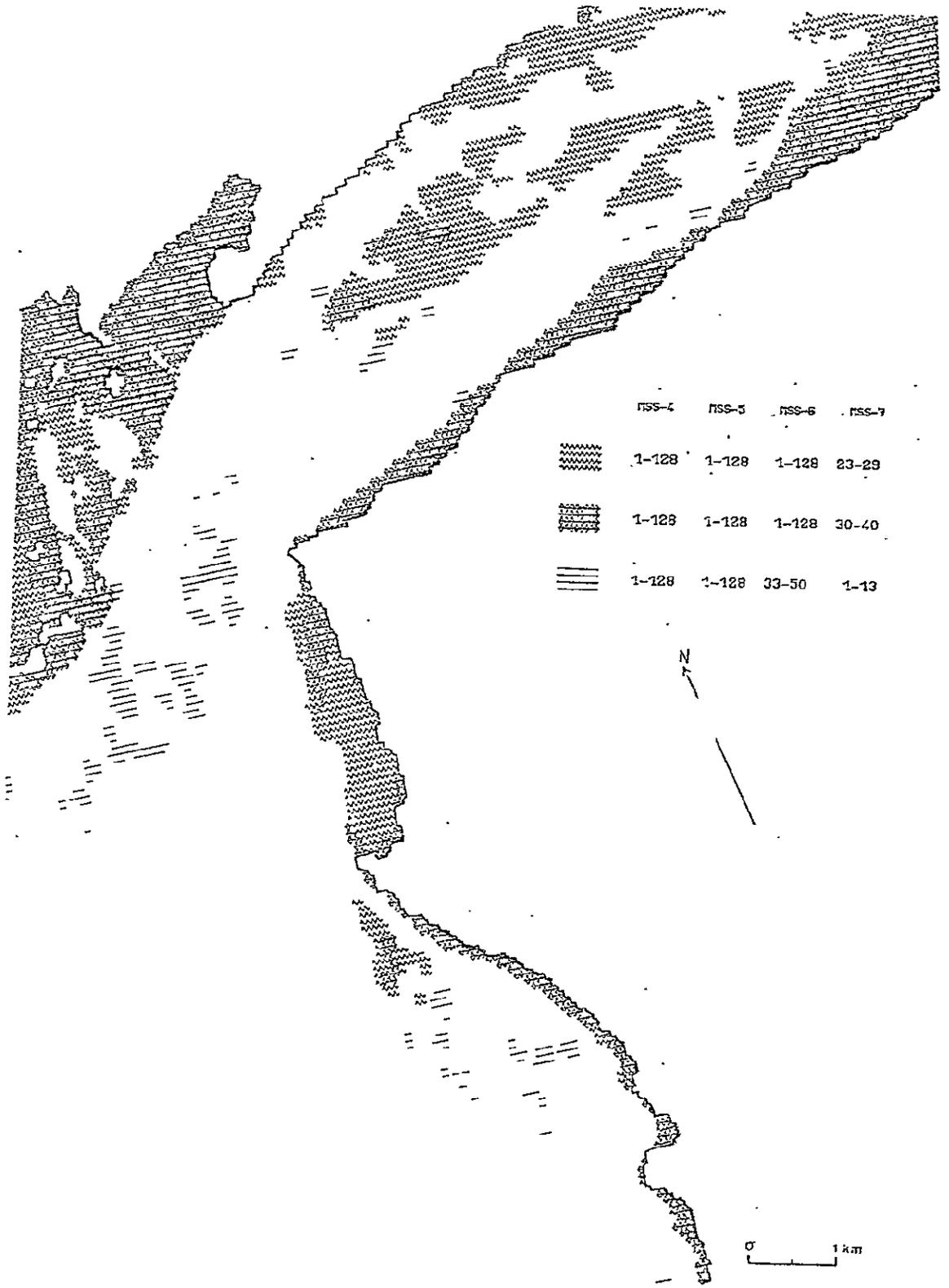


Fig. 3.3.H. - Cartography of sandbanks from LANDSAT
(June 26 1976)

3. 4 - INTERPRETATION OF GDTA SURVEYING OF MONT SAINT-MICHEL BAY

3. 4.1 - DATA SET SPECIFICATIONS

The aerial survey was carried out by the GDTA (Groupement pour le Développement de la Télédétection Aérospatiale) on 26 June 1975 using a plane of Institut Géographique National.

a - Description of radiometers

Two DAEDALUS multispectral scanners were used in the visible and the thermal infra-red part of the electromagnetic spectrum.

These electro optical sensors are equipped with a mirror rotating at 80 r.p.s. and the entire optical system has an instantaneous field of view of 2.5 milliradians.

In the visible spectrum the DAEDALUS radiometer is equipped with a set of ten detectors whose wavelength characteristics are listed in Tab. 3.4.A. In the thermal infra-red a second DAEDALUS radiometer was used with two spectral bands whose sensing windows are :

- 3 to 5 micrometers
- 8 to 14 micrometers

The analog output signals were recorded on a SANGAMO SABRE III 14-channel recorder along with a digital time base and continuous flight parameters such as : heading, roll and pitch.

b - Calibration schemes

The DAEDALUS radiometers are equipped with two internal calibration sources which are viewed at each mirror rotation before and after earth scan, they are called positive and negative reference values, respectively R^+ and R^- .

Transformation from output voltages to calibrated values is done on the basis of a running average of the R^+ and R^- time series with a time lag of 9 scans. Finally each of the 512 sample points of a scan line are transformed into calibrated values, using the following formula :

$$V_{ci} = (C_i \times V_{bi} - R_{ai}^-) / (R_{ai}^+ - R_{ai}^-)$$

where :

V_c = calibrated radiometric values of spectral band i

V_b = output voltage of spectral band i before transformation

C_i = amplitude coefficient of spectral band i used in order to generate an 8 bits (256 level) coding of V_c

R_{ai}^- = running average of negative reference values for spectral band i

R_{ai}^+ = running average of positive reference values for spectral band i

| Channel | Spectral band (in μm) | Ne De (I) |
|---------|-----------------------------------|-----------|
| 1 | 0,38 - 0,42 | 3,0 % |
| 2 | 0,42 - 0,45 | 1,3 % |
| 3 | 0,45 - 0,50 | 0,4 % |
| 4 | 0,50 - 0,55 | 0,3 % |
| 5 | 0,55 - 0,60 | 0,2 % |
| 6 | 0,60 - 0,65 | 0,2 % |
| 7 | 0,65 - 0,70 | 0,2 % |
| 8 | 0,70 - 0,80 | 0,2 % |
| 9 | 0,80 - 0,89 | 0,2 % |
| 10 | 0,92 - 1,10 | 0,3 % |

Table 3.4.A - Spectral bands of the visible DAEDALUS radiometer

(I) : Ne De is the minimum detectable reflectance increment

The amplitude coefficient C_i is determined for each visible spectral band i as :

$$C_i = L_i \times K_i \quad (\text{visible and near infra-red})$$

with

L_i = calibration coefficient equal to the equivalent radiance of the built-in reference source

K_i = conversion coefficient ensuring an 8 bit output code

It is worth noting that K_i is different from one spectral band to the next but is also dependent on the surveyed scene.

In the thermal infra-red, determination of C_i is slightly different :

$$C_i = (T_{i2} - T_{i1}) \times K_i \quad (\text{thermal infra-red})$$

with :

T_{i1} = equivalent black body temperature of the negative reference source

T_{i2} = equivalent black body temperature of the positive reference source

c - Survey planning

The surveyed area (Fig.3.4.B) is organized as a meridian transect going from the Dol marsh in the south to the Chausey islands in the north. It displays transitions between various environments such as : a precambrian formation, a cultivated marsh, some semidentary and rocky tidal flats and various gradations of water turbidity.

Data gathered on 26 June 1975 are organized in five different overpasses labeled α to ϵ (Tab.3.4.C). Results presented here are related to overpass α because it was the only one for which photographic documents, DAEDALUS analog displays and corresponding digital data were available. Furthermore at time of survey (15h 20 mn) hydraulic conditions were good because tidal flats were uncovered by a low tide of coefficient 0.79.

During the days preceeding the survey no rain precipitation was noticed and winds were measured at the Pointe du Grouin semaphore as N.W with a 3 to 4 m/s speed.

3 .4.2 - Data processing

Computer compatible tapes were generated by GDTA for overpass 1 and 3 which are labeled α and ϵ in our nomenclature. Data analysis was limited to a subset of overpass α which regrouped a representative sample of objects to be mapped.

Different data processing methods have been used regarding the thermal infra red temperature imagery and the measured radiances in the visible and near infra-red.

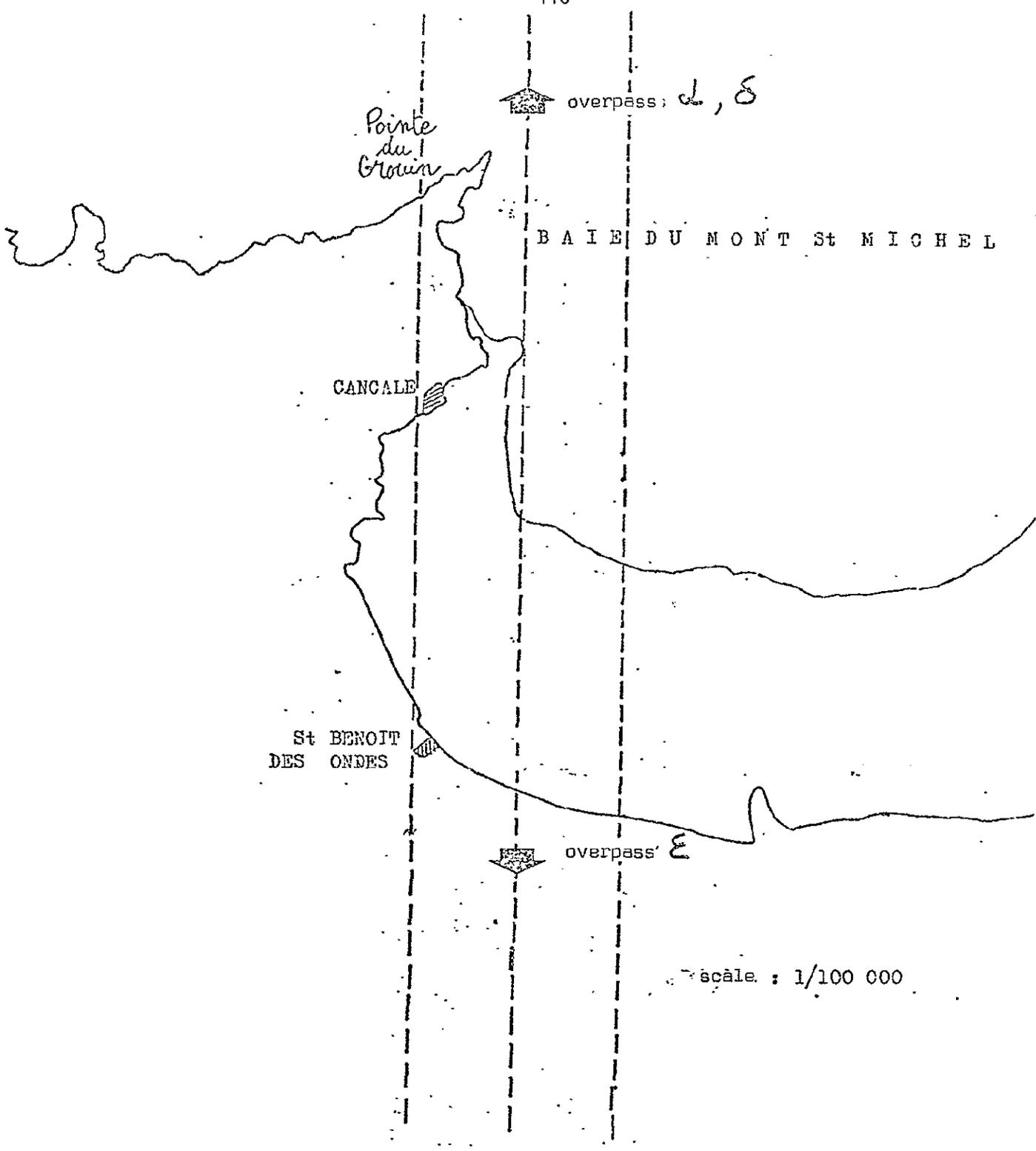


Fig. 3.41B - Survey plan of the GDTA mission on 26 June 1975

This transect is related to overpass α, δ and ϵ

| Overpass | Site | Heading | Altitude | Photography (1) | DAEDALUS analog imagery | DAEDALUS digital data |
|--------------|-------------------|---------|----------|--------------------|-------------------------------|-----------------------------|
| α | Cancale | 10° | 2510 m | Yes | Yes | Yes |
| β (4) | Cancale | 210° | 4875 m | — | — | — |
| γ (5) | Mont St-Michel | 35° | 5060 m | — | — | — |
| δ | Cancale | 10° | 2510 m | Yes | Yes | No |
| ϵ | Cancale | 190° | 2510 m | No | Yes | Yes |

Table 3.4.C - Missions characteristics of
Mont Saint-Michel GDTA survey

(1) : Infra-red photography taken with a WILD RC8 camera
of 152 mm focal length and 74° aperture

(2) : channels 3, 4, 5, 10 and thermal I.R.

(3) : channels 1 to 5,7, 9, 10 and thermal I.R.

(4) : documents not available

(5) : documents available at I.G.N.

a - Thermal infra-red processing

Data recorded for the 8-14 μm band are transformed into surface temperatures using calibration parameters stored in the first records of the magnetic tape. Output of this preprocessing phase is a file of pixel values in Celsius degrees uncorrected from atmospheric absorption. Format of this file has been made compatible with the input format of the NOAA VHRR thermography processing program (TSS system).

Following treatment done by TSS is in two phases :

- removing of striping effect noise by resetting the sequence of line histograms
- smoothing using a 7 x 7 boxcar filter conditioned to contrast enhance significant boundaries.

Results can be displayed on various peripheral equipments : line printer, electrostatic printer-plotter (VERSATEC) for intermediate maps and incremental color pen plotter (BENSON) for final edition.

b - Visible and near infra-red processing

Measurements recorded in the eight channels (C1 to C5, C7, C8 and C10) are preprocessed in order to estimate and subsequently correct for along scanlines systematic bias trend. This trend is due to the variation along the scan of the relative geometry of viewing angle versus solar angle.

After bias correction, the different types of ground objects are categorized using the FRACAM interactive classification system (cf 2.4.) Some groups can be subdivided after the initial classification phase using the adaptative descending classification approach.

Final results are displayed as color maps using the FRACARTO program (cf 2.5).

3. 4.3 - Significant results

a - Test area presentation

The test area presented here includes most of the infra-tidal and continental categories which can be characterized in the west part of Mont Saint-Michel bay.

Category and terrain description are drawn from observations which were made at airplane overpass time or a few hours after it.

a - 1 - Infra-tidal zone

The infra-tidal zone is characterized by flat expanses always carbonate rich with a N.W oriented slope ranging from 2.5 o/oo to 3 o/oo along tidal channels.

a - 2 - Infra-tidal zone

In front of Vildé - la - Marine village where ground-truth was collected, the tidal flats are wide (of the order of 3 km in width) and dip to the sea with a gentle slope (of the order of 3 o/oo). Sediments are made of "tange" which is granulometry and minerally defined as follows :

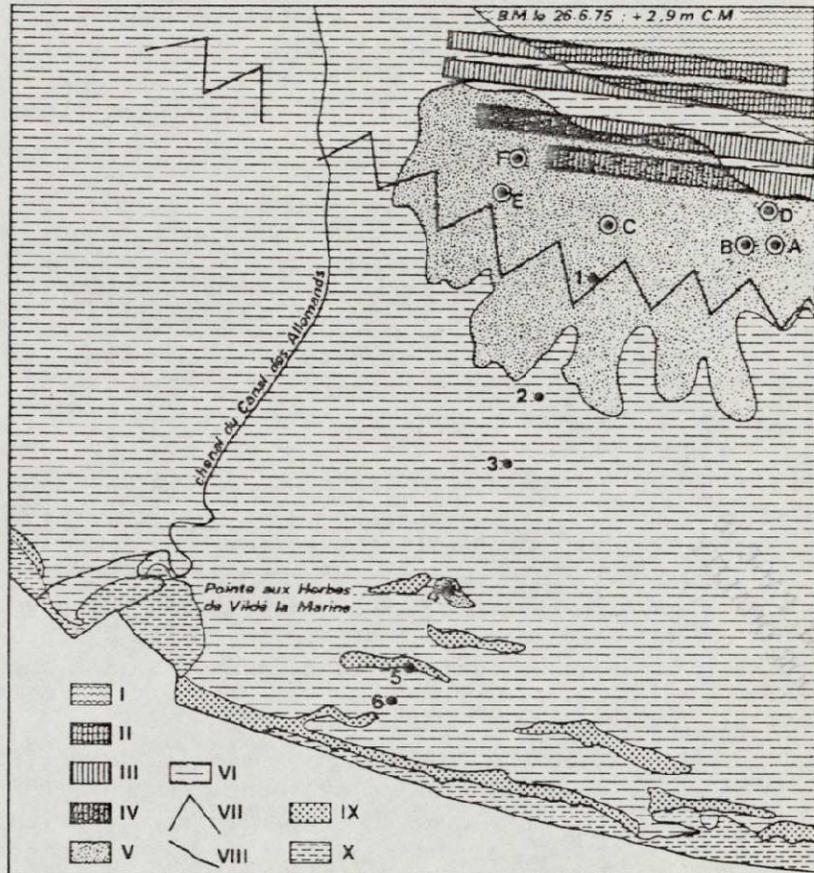


Fig 3.4.D - Localisation of categories (taxons) present on the infra and inter-tidal zones
A to F : diatomee samples ; 1 to 6 : sediment samples :

- I : turbid to non turbid water ;
- II : flooded mussel nurseries
- III : dry mussel nurseries ;
- IV : mussel nurseries on diatomee covered "tangué" ;
- V : diatomee covered "tangué" ;
- VI : bare "tangué" ;
- VII : fish traps ;
- VIII : channel ;
- IX : calcareous sand bar ;
- X : tidal flat (schorre)

- particle size median between 6 and 103 μ m ;
- percentage of the 2 to 200 μ m fraction ranging between 51 % and 84 %
- percentage in carbonates ranging from 28 % to 65 %

There is a trend to larger particle sizes and coarser sediments near the coast line (Fig. 3.4.D and Tab 3.4.E, samples 1 and 3).

During the survey, concentration in organic matter was found to be constant over the whole tidal flat surface with values ranging from 5 % to 7 %. On the contrary sediment water content was decreasing landward from the low tide line (36.5 %) to the salt marshes (18.5 %).

Finally, large expanses of the low flats were covered with a fine layer of diatoms (Tab 3.4.F).

In the upper part of the inter-tidal zone the monotony of "tangué" flats is disrupted by sandy levees. The shell-rich material of these levees is quite different from "tangué" granulometry as well as their concentrations in water, carbonates and organic matter (Tab 3.4.E, samples 4 and 5).

The only main tidal channel is the Canal des Allemands. It is deeply cut into the upper part of the flat resolving to a modest opening near the sea line.

It is also noticeable that the "tangué" flat bears a large number of human artefacts ; fish traps which are one to two meter high wooden constructions, mussel shells poles scattered seaward of the traps.

Near the upper part of the flat, the salt marsh (schorre) is gradually taking over the "tangué". The salt marsh is limited in the test area to a narrow triangular surface on the east bank of the Canal des Allemands. Its granulometry and mineralogy are similar to those of the "tangué" (Tab 3.4.E, sample 6). It is, however, different from the barren flat in its morphology and bears salt tolerant plant growth mostly composed of Puccinella maritima, Aster tripolium and a thin strip of Obione portulacoides along the channel banks.

a - 3 Continental zone

Behind the Duchesse Anne Lyke, the test area extends over the Dol marsh. This cultivated area has soil properties which are very close from "tangué".

b - Results interpretation

b - 1 Thermal infra-red

Interpretation of results obtained in the 8-14 μ m wavelengths has helped in outlining several interesting phenomena (Fig. 3.4). Going landward from coastal waters to the Dol marsh :

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| Samples : | 20-2 mm in % | 2-0,2 mm in % | 200-20 m in % | 20-2 m in % | inf. 2 m in % | Organic matter in % | Carbonate in % | Water content in % |
|-----------|-----------------|------------------|------------------|----------------|------------------|---------------------------|-------------------|--------------------------|
| 1 | - | 0,2 | 27,6 | 29,6 | 42,6 | 7,0 | 27,9 | 36,5 |
| 2 | - | 0,6 | 42,5 | 25,4 | 31,5 | 6,0 | 38,2 | 31,0 |
| 3 | 8,4 | 31,4 | 45,6 | 5,7 | 8,9 | 5,5 | 59,8 | 18,5 |
| 4 | 9,5 | 39,0 | 51,5 | - | - | 1,5 | 64,8 | 12,0 |
| 5 | 10,7 | 85,6 | 3,7 | - | - | 0,5 | 83,9 | 1,0 |
| 6 | - | 1,2 | 60,5 | 23,2 | 15,1 | 5,5 | 42,5 | 26,0 |

Table 3.4.E - Granulometry, organic matter content, carbonate and water contents for the various ground truth stations (cf. Fig. 3.4.D)

| Samples | Stations | | | | | |
|-------------------------------|----------|-----|-----|-----|-----|-----|
| | (A) | (B) | (C) | (D) | (E) | (F) |
| <i>Coscinodiscus lineatus</i> | + | + | + | + | + | + |
| <i>Navicula cancellata</i> | + | + | + | + | + | + |
| <i>Gyrosigma fasciola</i> | + | + | + | - | + | + |
| <i>Amphiprora</i> sp. | + | + | + | + | + | - |
| <i>Coscinodiscus nitidus</i> | + | + | + | - | + | - |
| <i>Pleurosigma angulatum</i> | + | + | + | - | + | - |
| <i>Biddulphia regia</i> | - | - | + | - | - | - |
| <i>Melosira dubia</i> | - | - | - | + | + | - |

Table 3.4.F - Distribution of most abundant (+) diatomee species at various stations (1) (cf. Fig 3.4.D)

(1) Measurements were made by Mr RICARD at the Laboratoire de Cryptogamie of Museum National d'Histoire Naturelle.

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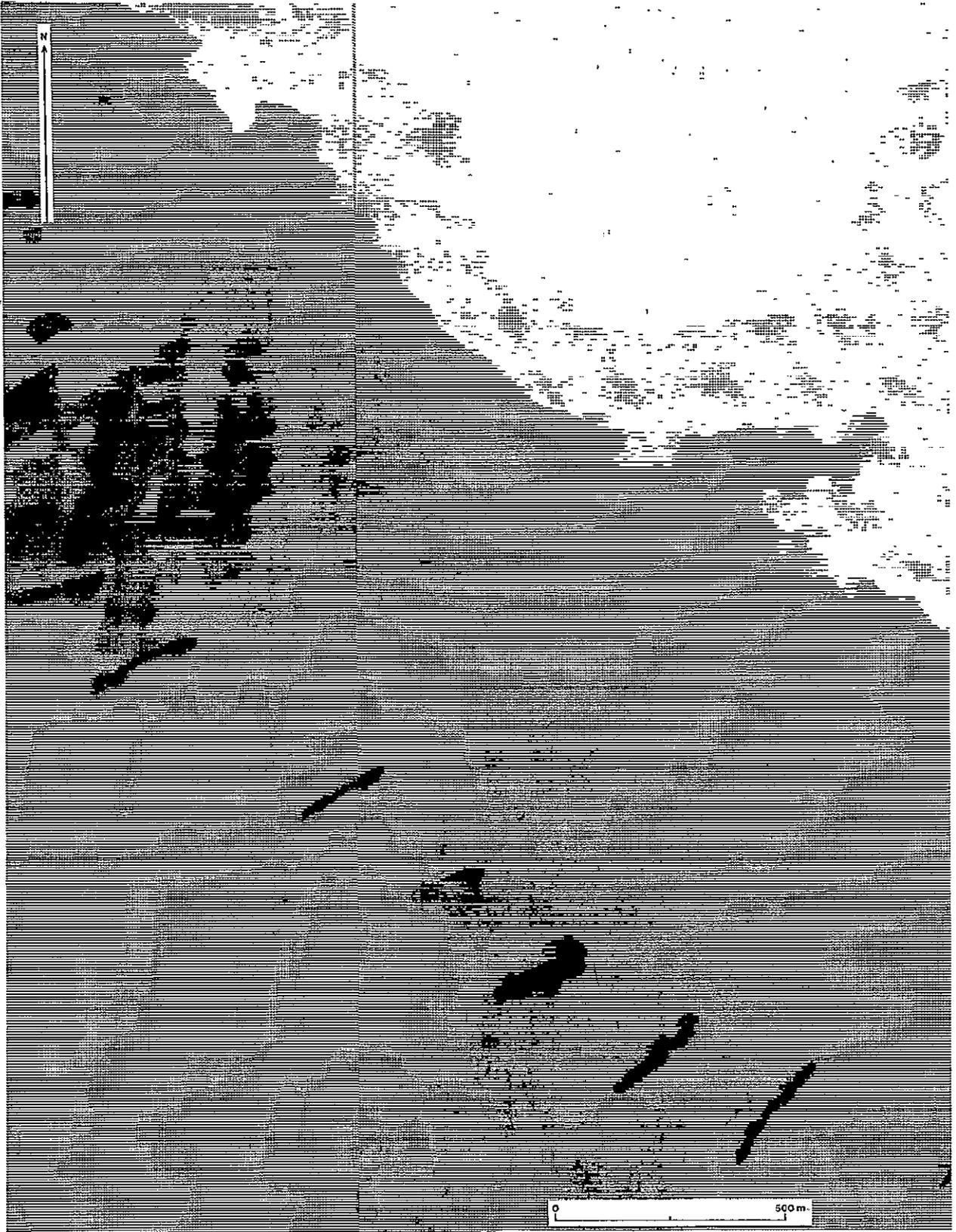


Fig. 3.4.G. - Thermal infra-red mapping of the inter-tidal zone of the Dol marsh (Fig. 3.4.D.)

- arrival at the beginning of flow tide of cold and clear waters in turbulent mixing with warmer bay waters which are heavily loaded with sediments. This contact takes place around the Châtelier and Rimains islands.
- digitations of warm water coming from the tidal flat are abundant at the limit between infra and inter-tidal zones. This flow takes its origin in the fish trap which is near the east bank of the Canal des Allemands channel. Orientation of this flow is easily explained by the fact that tidal currents were running N.W during the experience.
- a temperature difference between warm diatomée covered "tangué" and colder barren flat.
- a specific thermal signature for the mussel shells nurseries (bouchots) which are higher in temperature than the diatomée covered "tangué" on which they are settled
- a thermal assymetry between each side of the "V" shaped fish traps : the westward side being warmer than the east ward
- finally sand levees and barren fields of the Dol marsh are similar in surface temperature which is much higher than for the other targets.

b - 2 Visible and Near infra-red

The analysis of spectral signatures present in a test area of 350 scan lines of 180 sample points has led to the study of a complete disjunctive coded data set K_{IJ} (cf. 2.4) with $I = 63000$ sample points and $J = 64$ spectral coded equivalents. This matrix was analysed by the FRACAM automatic classification system.

Interpretation of a classification in nine categories lead us to the following conclusions :

- category limits are correct but some misclassifications subsist in detailed category assignments
- "tangué" is well discriminated by classification and subdivided in several classes depending on its water content
- sandy levees as well as locally sand rich "tangué" masses are correctly outlined
- diatomée covered areas are separated from barren ones but some misclassification occurs with cultivated fields of the Dol marsh
- finally salt marshes and other parts of cultivated fields fall into the some category.

4 - Criticism

In conclusion, two points must be emphasized :

- correction for systematic bias in the visible and near infra-red was estimated on the tidal flat zone. Unfortunately it appeared that forward scattering of solar light was function of target albedo and surface texture so that trend correction was not complete for sea water and continental zones. It is this phenomenon which is responsible for most of the misclassifications
- however results were sufficiently good to assess the feasibility of mapping tidal coasts by automatic classification of remotely sensed data. In the present study thermal infra-red was found to be best for knowledge of water movement and mixing in the west part of the Mont Saint-Michel bay while visible and near infra-red was better used for mapping tidal flats and associated organic films.

3. 5 - INVESTIGATION OF A COASTAL UPWELLING USING NOAA DATA

3. 5.1 - Data description

Since 1972 NASA has regularly launched on a yearly basis a series of meteorological satellites which are run under the supervision of the National Oceanic and Atmospheric Administration. The NOAA satellites (currently NOAA5) are equipped with various electro optical systems. Among them the two Very High Resolution Radiometers (VHRR) are of interest for oceanographic application.

Satellite orbit is sun synchronous with an inclination of 101° over the equator ; this allows any point on earth to be surveyed twice a day. Time of overpass is approximately 9 AM and 9 P M Universal Time for the coast of France. The geometry of this quasi-polar orbit tends to simplify the problem of geometric correction.

The two radiometers operate in different spectral bands :

- in the infra-red (IR) domain, from 10.5μ to 12μ for the VHRR1
- in the visible domain, from 0.6μ to 0.7μ for the VHRR2. The identical systems consists of a 12.7 cm aperture elliptical mirror with a surface of 100.4 cm². Rotation speed of the mirror is stabilized at 1 revolution per 150 milliseconds.

The relative flux is reflected by the mirror and focused on a detector thus leading to a 0.6 str instantaneous field of view (IFOV). With the satellite cruising at an altitude of about 1460 kms, the ground resolution is 0.88 km. Rotation speed of the mirror and trajectory velocity are synchronised so that no overlapping occurs in the relative geometry of consecutive scan lines.

The horizon to horizon scanning is done through a 70° rotation angle, and during the remaining part of the 360° complete revolution, the mirrors scan various internal calibration equipment such as two black bodies maintained at a fixed temperature and a point in space opposite the sun. About twenty different calibration signals are acquired during one revolution. This information is used to convert the voltage output of the system into black body radiance.

The signals transmitted by the satellite are acquired at the Meteorologie Nationale station (CEMS) in Lannion (Bretagne). It is then digitized and preprocessed for data cleaning and compression of the calibration information. The data is available in 8 bit coded digital form on magnetic tapes which are sent upon request to various users outside the meteorological community.

At Ecole des Mines the main point of interest is deriving sea-surface temperatures maps at scales ranging from 1/100 000 to 1/250 000 for various areas along the Atlantic and Mediterranean coasts of France.

A data file corresponding to an acquired image of the Earth includes one record for each scan line. Each record is physically built as follows ;

- 20 calibration values (16 bits)
- 2068 pixel values (8 bits) for the IR channel
- 2068 pixel values (8 bits) for the visible channel

Processing is currently done on 800 to 2400 scan lines files. The number of lines for a complete coverage of France is approximately 1200.

3. 5.2 - Data processing

In the production of surface temperature maps, the first step is to convert the 8 bit digital counts into black body radiances. This is done using a locally linear approximation of the Boltzmann formula based on the calibration information. From this step onwards, the data of interest, usually a subset of the entire scene, is handled in degree Celsius stored in binary floating points form.

The maps are produced as false-color displays or contour plots. The direct interpretation of these results has been very difficult due to the presence of spurious disturbances in the data. These problems were not experienced in other oceanographic applications such as the mapping and tracking of Gulf Stream meanders done by various NOAA experiment teams.

This is due to the fact that in Europe our scientific interests are more localized geographically and that we are looking at temperature gradients of a few degrees using the VHRR scanner which has a nominal performance between 1°C and 0.5°C .

Due to these differences in scientific approach, the oceanographic community in France is much more demanding on the refinement of the data processing necessary to bring out useful details in the sea-surface temperature structure.

Two types of disturbances have been identified

- a background noise caused by transmission or analog to digital conversion
- a striping effect due to sensor gain losses affecting the calibration signals.

The striping effect is similar in nature to the one currently experienced in LANDSAT imagery. However, in this case, one does not observe the six band repetitivity which is particular to the LANDSAT scanner technology. The jitter in average value from one line to the next displays on the contrary a random structure with characteristics varying in time during data acquisition. The variability can be as wide as it can be a purely random noise or a rather smooth modulation expanding over 10 to 20 scan lines. The lack of a typical frequency in this jitter led us to discard frequency domain filtering as used in various oceanographic applications of LANDSAT imagery.

Other methods were used such as smoothing averages or modes of the scan line histogram time-series. These approaches did not prove sufficient to eliminate the scan line noise in NOAA data. This is why a new method was developed which takes into account the complete structure of the marginal distribution of each scan line instead of only using a condensed information extracted from this distribution such as an average or a mode value.

The so called background noise is essentially isotropic in nature and evenly-distributed in the image plane. It is responsible for the "salt and pepper" aspect of the display. Its elimination involves a straightforward two-dimensional weighted smoothing algorithm.

The cleaning effect is satisfactory especially when the algorithm is iterated several times, leading to a contouring effect in the display which is rather useful for oceanographic applications. The drawback of this approach is that the contrast at the boundary between the earth and the sea is smeared at each iteration with a consequent degradation of the geographic location of the coastline.

This annoying effect is of particular importance for coastal applications where one would like to retain the original spatial definition of the coastline as produced by the ground resolution of the NOAA scanner data (approximately 1 km). In order to meet this goal the smoothing was conditioned to the local gradient in relation with average RMS of the background noise.

The unstriping and the iterative conditioned smoothing are sequentially applied to the data set of sea-surface temperatures: the final product is a smooth isocontour temperature field which can be easily interpreted by the oceanographers and have been found of great value when stored and compared for different satellite overpass dates.

3. 5.3 - Significant results

A - Interpretation of imagery

The data we have used for our interpretation is NOAA4 imagery acquired on 30 July 1975 at 9h 17 mn TU. The generated maps (Fig. 3.5.A and B) cover the oceanic waters surrounding the Finistère shoreline. In the visible band the gray scales are related to various radiance levels expressed in FT.L. In the thermal infra-red band the gray scales are associated to radiometric temperatures measured in Celsius degrees (°C).

The land features are characterized by radiances greater than 10 FT.L and temperatures greater than 21°C, they appear respectively in white (VIS) and black (IR) on the imagery. In the visible band, some confusion is possible between land and clouds and the coastline is rather fuzzy around the Crozon Cape.

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Fig. 3.5.1 - Display of the NOAA-VHRR visible band
Finistère coastal area.

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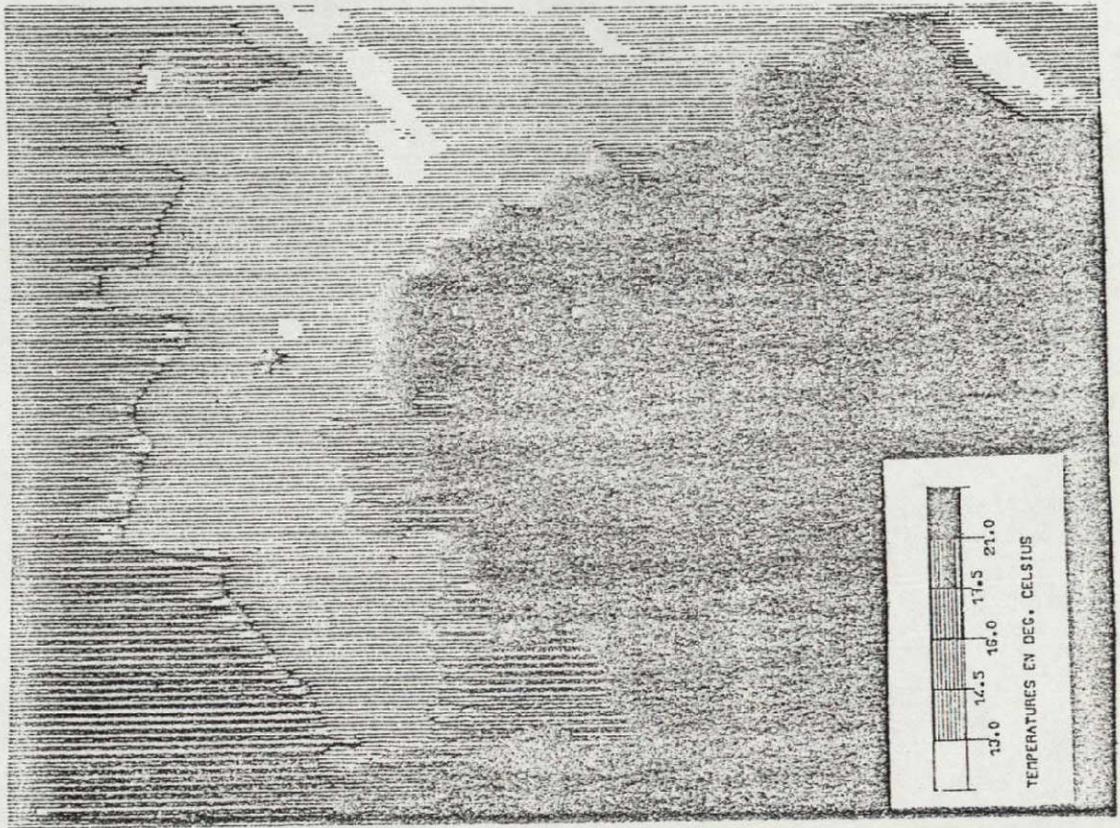


Fig. 3.5.B - Display of NOAA-VHRR infra-red band
Finistère coastal area.

The clouds with high radiance are easily outlined in the visible band North of Finistère, organized in North-West strips. The corresponding features in the infra-red have temperatures under 13°C. However they are generally broader masses than in the visible, this is due to the inertia of the infra-red sensor which is less capable of following instant contrasts. The resulting contamination has led us to eliminate from our oceanographic interpretation most of the English channel, North of Finistère.

Coastal fog is frequent along these coasts in summer, and their detection is more complex than that of the preceding features. For example, in the Saint-Brieuc bay they could be interpreted in the visible as patches of turbid water with rather high radiances. This confusion is easily avoided when using the I.R because their apparent temperature is much lower than the average seasonal temperature of the coastal waters of Brittany (typically 16°C). Probable presence of a small cloud of fog can be suspected North-West of Ouessant.

A cold surface front expands in the ocean waters West of Finistère. Organized in a crescent like shape, from the Raz point to the North of Ouessant it is characterized by surface temperatures between 13°C and 16°C. They are easily separated from the waters of the mouth of the English channel (> 16°C) and also from the coastal waters of South Brittany which are even warmer (above 17.5°C). Warm water pools are also locally trapped along the Finistère coast, South of the Raz point, in the Douarnenez bay and in the Brest sound.

b - Ground truth checking

Simultaneously with satellite overpass, a team of English oceanographers (1) was performing a detailed study of this cold front using classical surveying methods. The situation of the thermal gradients drawn from their maps is in excellent agreement with the NOAA4 observations. As far as the numerical values are concerned, the difference between in-situ measurements and satellite observations are no greater than 1°C. The radiometric temperatures are always lower than sea-truth which could be due to atmospheric losses.

Absolute temperature errors in the mapping of oceans thermal gradients using VHRR data are mainly due to the water content of the lower levels of the atmosphere and they can be corrected by the use of atmospheric models based for example on radio-sounding results. Large clouds are seldom an interpretation problem due to their straightforward separation in the visible

(1) R.D. Pingree, P.R. Pugh, P.M. Holligan and G.R. Forster

Summer phytoplankton blooms and red tides along tidal fronts in the approaches to the English Channel.

Nature - Vol 258 - PP 672-677

and in the infra-red but this is not the case for coastal fogs and scatters of small low clouds. The detection of these features is done by low clouds. The detection of these features is done by careful comparison between measured radiometric temperatures and seasonal average surface temperatures available for the surveyed area through classical physical oceanography observations.

In the strong thermal gradient area of the coast of Finistère, measurements had also detected a fair increase in chlorophyll A concentration due to phytoplankton activity. These concentrations should have modified the colour of the ocean by it is disappointing that the visible VHRR display does not show such a feature.

Several reasons can be conjectured :

- the visible VHRR band, identical to the LANDSAT MSS5, is not suited to chlorophyll mapping in water ;
- light penetration (≈ 2 m) could blurr the precise definition of the colour gradients ;
- the resolution (1 km) is too coarse regarding the detection of phytoplankton patches which follow the edge of the thermal front and are therefore of a width comparable in size with the VHRR resolution.

The results presented here show the utility of infra-red thermal imagery for oceanographic applications but they also suggest caution in the interpretation of rather coarse resolution future satellites such as NIMBUS-G.

3. 5.4 Conclusion

Although the processing techniques outlined in this work appear satisfactory for the available data some remarks can be made regarding the suitability of the resulting output for the user community's needs.

The accuracy of sea surface temperatures obtained from NOAA data, although useful, is not up to the standards currently applied by oceanographers who are able to measure sea temperature to 1/100th of a degree Celsius, using thermistors. The 1/10th of a degrees Celsius forecasted for future satellites will be closer to oceanographic needs.

Nonetheless thermal infra-red applications in general are more adapted to oceanographic applications than, for instance, Landsat data which provide ocean colour measurement at the surface or at a depth which is not always easily identified.

On the other hand, the spatial (1 km square) resolution of the NOAA VHRR is adequate for oceanographic applications, whilst Landsat data has the minimal resolution for coastal geomorphology applications.

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The density of observations is almost excessive in oceanography and provides a great deal of redundant information.

Finally, repetivity of coverage (twice daily for NOAA) provides time series which can be used for practical monitoring of fast-changing situations. At the present time we have mostly processed day-time coverage (9 a.m.) but we are planning to use both day-time and evening (9 p.m.) data in conjunction with HCMM data (12 a.m. - 12 p.m.) for an evaluation of high frequency coverage which should enable us to monitor most of the tidal cycle over a short period. In this last case, the low frequency of Landsat coverage makes it practically impossible to obtain a complete series since some tidal situations have not occurred concurrently with a Landsat overpass since we began to receive Landsat data.

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